



POWERING INNOVATION THAT DRIVES HUMAN ADVANCEMENT

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Twin Builder® Components: Basic Elements



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1 - Basic Elements Library

The Basic Elements library provides electric circuit components, blocks, states, measuring devices, signal characteristics (functions to evaluate characteristics Online during simulation), modeling tools (time functions, characteristics, equations), and components of physical domains.

- [Block](#)
- [Circuit](#)
- [Measurement](#)
- [Physical Domains](#)
- [Signal Characteristics](#)
- [State Graph](#)
- [Tools](#)

Modeling with Block Diagrams

Transfer Blocks in Twin Builder are defined by an internal identifier, the name and a set of parameters; Blocks have no conservative nodes. A block is a linear or nonlinear transfer element with a defined static or dynamic response characteristic. The block output signal does not influence the block input quantity (non-reacting).

The blocks are subdivided into continuous, discrete, and source blocks as well as signal processing and mathematical blocks.

Block diagrams with typical transfer behaviors can be modeled for control and cybernetic systems by means of the available blocks. The block output signal and the specific block dependent parameters can be used as outputs. The block output signal is represented by the «VAL» entry; the other parameters by their corresponding name.

The *Blocks* folder provides components in the following categories:

- [Continuous Blocks](#)
- [Discrete Blocks](#)
- [Source Blocks](#)
- [Signal Processing Blocks](#)
- [Math Blocks](#)

[Connecting Transfer Blocks](#)

[Signal Direction in Block Diagrams](#)

[Defining the Sample Time](#)

Connecting Transfer Blocks

Schematic checks the pins during the routing and will not allow invalid connections (e.g., between two inputs or two outputs). If an input or an output pin in the block diagram is not connected, a warning will be given. To avoid this warning, you can hide any unused pins of an element. Open the property dialog and clear the check box of the pin you want to hide. The pin is invisible on the sheet and the warning no longer occurs.

See also *Using Pins* in the main Twin Builder help.

Signal Direction in Block Diagrams

The sequence of block computation can significantly influence the simulation result. You can change the block sequence with the **Schematic>Sort Components** command which displays the **Determine Block Sequence** dialog box.

By Default the sequence of block computation is to sort automatically. In order to disable automatic block sorting, select **Design Settings** on the **Twin Builder Circuit** main menu. In the **Simulation Options** tab, uncheck the **Automatically sort block diagram before simulation** option.

Using Automatic Block Sorting

When the Automatic Block sorting mode in the Determine Block Sequence dialog box is selected, the blocks will be sorted according to their signal direction.

Using Manual Block Sorting

To sort blocks manually, in the Determine Block Sequence dialog box, select the block from the list. Select the up or down arrow to move the selected item up or down in the sorted list. The sequence digits on the sheet are changed accordingly.

Using Interactive Block Sorting

To sort blocks interactively, in the Determine Block Sequence dialog box, click the **Interactive** button and the current sequence is displayed in digits next to the blocks. Click on the blocks in the order you want them sorted. The sequence digits are initially displayed in the color specified in the dialog box as "Remains to Sort". When a block is selected, the color changes to the "Already Sorted" color as specified in the dialog box. Once all blocks have been selected, the sequence is saved and the sorting digits are removed.

The following functions are active in the interactive mode:

- Click the block: Defines next position in the sequence.
- Double-click beside the element: Exits the mode and applies the settings.
- <ESC>: Exits the mode without applying the changes.

Note: The block sequence in subsheets must be defined separately. Open the subsheet and choose **Schematic>Sort Components**. The sequence starts in each subsheet with '1'.

See also *Sorting Components* in the main Twin Builder help.

Defining the Sample Time

You can choose system sample time (set Sample Time to 0) or a specific value for each block. A proper sample time is recommended for giving a consistent behavior for the block diagrams during the simulation.

Note: The sampling time must be greater than the minimum time step (HMIN) and less than the simulation end time (TEND). If the sampling time is set to use the system sample time, the blocks are calculated with the time step determined by other modules (circuit, state graph, or equations), but at least by the maximum time step of integration.

Continuous Blocks

- [Dead-Time Element \(DEAD\)](#)
- [Derivative \(DIFF\)](#)
- [Gain \(GAIN\)](#)
- [S-Transfer Function \(GS\)](#)
- [Integrator \(INTG\)](#)
- [Memory \(MEMORY\)](#)

Dead-Time Element

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

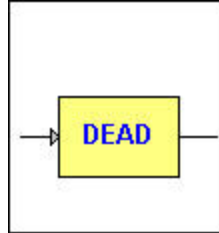


Figure 1. Component Symbol.

- [Description](#)
- [Assumptions and Limitations](#)
- [Mathematical Description](#)
- [Netlist Syntax](#)
- [Parameters](#)
- [Input/Output Quantities](#)
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Description

The block represents a delay of a number of simulation steps of the input signal with initial values. The delay is specified as a number of samples.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

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Mathematical Description

We can express the relation between the input and output signal as:

$$y(k) = x(k-NH) \text{ for } k > NH$$

$$y(k) = Y0(NH-k) \text{ for } k \leq NH$$

where Y_0 is the initial output value, $y(k)$ is the output signal at simulation time step k , NH is the number of samples, and $x(k-NH)$ is the input signal at the simulation time step $k-NH$.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
NH	Number of Samples (for separate initial values)	real	0
Y0[n]	Initial Values (for separate initial values)	real	0
FILE	File with Initial Values (for initial values defined in a file)	file	--
TS	Sample Time	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real
INPUT	Input Signal	Input	real

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Example

Figure 3 shows application of the Dead-Time model. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 4.



Figure 3. Application example of the Dead-Time model

Table 3

Component	Parameter	Value
Sine Function Sine_wave1	AMPL	1
	FREQ	2 [Hz]
	PHASE	0 [degree]
	OFF	0
	TDELAY	0
Derivative DEAD1	NH	10
	TS	1m [s]
Gain GAIN1	KP	1
	TS	0 [s]

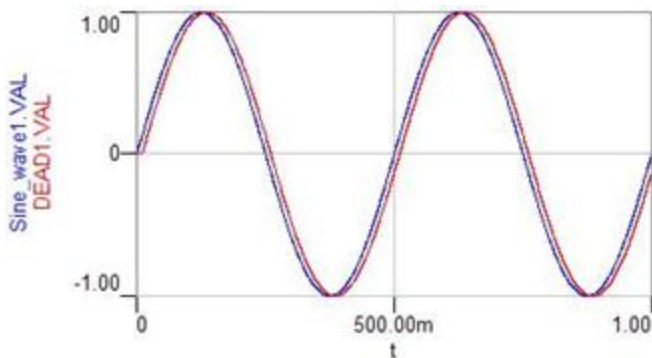


Figure 4. Simulation results-input and output signal of DEAD1

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References

Derivative

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

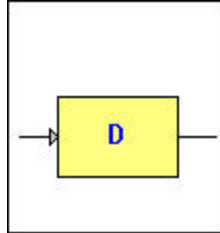


Figure 1. Component Symbol.

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Description

The block represents a differentiation block with limitation (Laplace-domain, Laplace-operator specified as **s**).

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

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Mathematical Description

The Laplace-domain transfer function of this component is:

$G(s) = KD * s$, where KD is the Derivative Gain specified by users.

or we can express the relation between the input and output signal as:

$y(k) = KD * Ts * [x(k) - x(k-1)]$, where $y(k)$ and $x(k)$ are the input and output signal at simulation time step k , respectively, and Ts is the sampling time.

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Netlist Syntax

INTERN DIFF ?InstanceName(@InstanceName):(@(Refbase)@(ID)) (INPUT:=@(INPUT),
KD:=@(KD), Y0:=@(Y0), UL:=@(UL), LL:=@(LL), TS:=@(TS)) ;

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
KD	Differential Gain	real	1
Y0	Initial Value for t=0	real	0
UL	Upper Limit	real	0
LL	Lower Limit	real	0
TS	Sample Time	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real
INPUT	Input Signal	Input	real

[Top](#)

Example

Figure 3 shows application of the Derivative model. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 4.



Figure 3. Application example of the Derivative model

Table 3

Component	Parameter	Value
Sine Function Sine_wave1	AMPL	1
	FREQ	2 [Hz]
	PHASE	0 [degree]
	OFF	0
	TDELAY	0
Derivative D_Anteil1	KD	1
	TS	0 [s]
	Y0	0
	UL	0
	LL	0

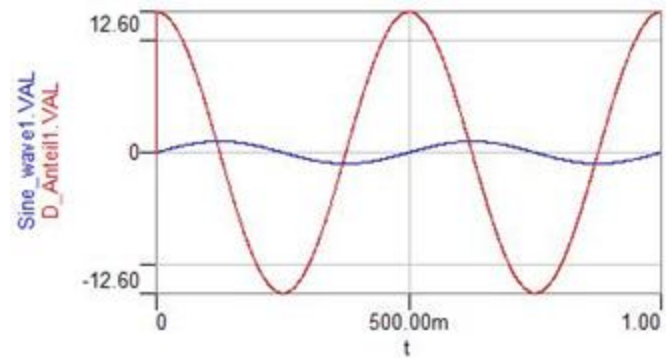


Figure 4. Simulation results-input and output signal of D_Anteil1

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References

Gain

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

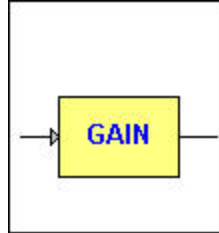


Figure 1. Component Symbol.

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Description

The block represents a proportional gain (Laplace-domain, Laplace-operator specified as **s**).

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

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Mathematical Description

The Laplace-domain transfer function of this component is:

$G(s) = K$, where K is the Proportional Gain specified by users.

or we can express the relation between the input and output signal as:

$y(k) = K * x(k)$, where $y(k)$ and $x(k)$ are the input and output signal at simulation time step k , respectively.

[Top](#)**Netlist Syntax**

```
INTERN GAIN ?InstanceName(@InstanceName):(@ (Refbase)@(ID)) (INPUT:=@(INPUT),
KP:=@(KP), TS:=@(TS)) ;
```

[Top](#)**Parameters****Table 1**

Name	Description	Data Type	Default Value [Unit]
K	Proportional Gain	real	1
TS	Sample Time	real	0 [s]

[Top](#)**Input/Output Quantities****Table 2**

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real
INPUT	Input Signal	Input	real

[Top](#)**Example**

Figure 3 shows application of the Gain model. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 4.

**Figure 3. Application example of the Gain model**

Table 3

Component	Parameter	Value
Step Function SPR1	AMPL	1
	TS	0 [s]
	T0	0.1n [s]
	Y0	1
Gain P_Anteil1	K	2
	TS	0 [s]

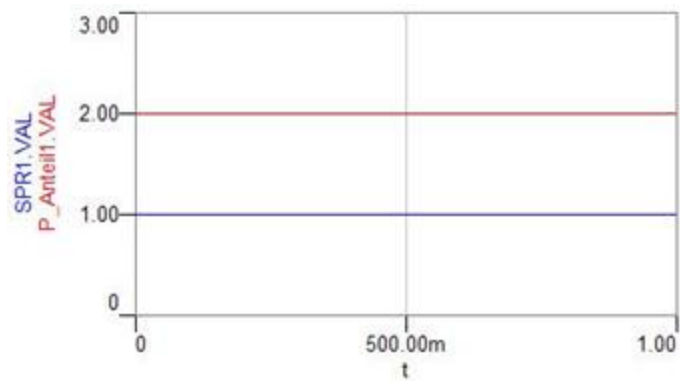


Figure 4. Simulation results-input and output value of P_Anteil1

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References

S-Transfer Function

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

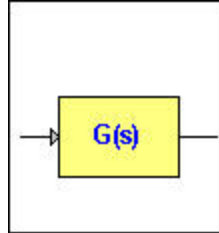


Figure 1. Component Symbol.

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Description

The Block represents a continuous transfer characteristic $G(s)$ (Laplace-domain, Laplace-operator specified as s). Within the dialog you can define numerator and denominator order and coefficients of the S-Transfer Function.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

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Mathematical Description

The Laplace-domain transfer function of this component can be expressed as:

$$G(s) = \frac{b_0 + b_1 s + b_2 s^2 + \dots + b_n s^n}{a_0 + a_1 s + a_2 s^2 + \dots + a_m s^m} \quad a_m \neq 0$$

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
N	Numerator Dimension	real	1
D	Denominator Dimension	real	2
B[n]	Numerator Coefficients	real	1
A[n]	Denominator Coefficients	real	1
SUM0	Sum of Initial Values (only SML)	real	0
TS	Sample Time	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real
INPUT	Input Signal	Input	real

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Example

Figure 3 shows application of the S-Transfer Function model. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 4.



Figure 3. Application example of the S-Transfer Function model

Table 3

Component	Parameter	Value
Step Function SPR1	AMPL	1
	TS	0 [s]
	T0	0.1n [s]
	Y0	1
S-Transfer Function GS1	N	0
	D	1
	TS	0 [s]
	B[0]	1
	A[0]	1
	A[1]	0.5

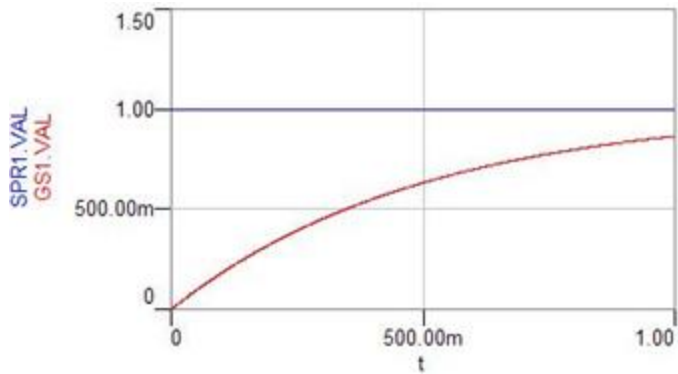


Figure 4. Simulation results-input and output value of GS1

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References

Integrator

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

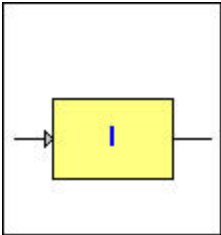


Figure 1. Component Symbol

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- [Mathematical Description](#)
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Description

The block represents an integration block with limitation and the possibility to reset the output signal (Laplace-domain, Laplace-operator specified as **s**). The table shows the different forms to reset the output signal of the integration block.

Table 1

TRIGSIG	CTRL	Description
0		Summation of input signal.
>0	0	Assign the TRIGVAL permanently to the output signal.
<0	0	Assign the TRIGVAL to the output signal and continue summation of input signal with this value.
>0	1	Hold the last output value of output signal.
<0	1	Continued summation of input signal but one step delay.

Note: The trigger signal is set once to '0' if the trigger event occurs; otherwise, the Integrator would be permanently reset.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

The Integration method used by the INTG block can be selected using the INTEG_FORMULA parameter as follows:

0 Forward Euler - default (behavior V7)

1 Backward Euler (behavior V6)

2 Trapezoid

3 Use Network solver settings

The Use Network Solver setting instructs the component to use the same integration formula used by the simulator to solve the overall network. See [Simulator Parameters](#)

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Mathematical Description

The Laplace-domain transfer function of this component is:

$G(s) = KI/s$, where KI is the Integral Gain specified by users.

or we can express the relation between the input and output signal as:

$y(k) = y(k-1) + KI * Ts * x(k)$, where $y(k)$ and $x(k)$ are the input and output signal at simulation time step k , respectively, and Ts is the sampling time.

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Netlist Syntax

```
INTERN INTG ?InstanceName(@InstanceName):(@Refbase)@(ID)) (INPUT:=@(INPUT),  
KI:=@(KI), Y0:=@(Y0), UL:=@(UL), LL:=@(LL), TRIGSIG:=@(TRIGSIG), TRIGVAL:=@  
(TRIGVAL), CTRL:=@(CTRL), TS:=@(TS), INTEG_FORMULA:=@(INTEG_FORMULA)) ;
```

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
KI	Integral Gain	real	1
Y0	Initial Value for t=0	real	0
UL	Upper Limit	real	0
LL	Lower Limit	real	0
TRIGSIG	Variable holding the Trigger Signal	real	0
TRIGVAL	Output Signal after Trigger Event	real	1
CTRL	Controls the behavior after trigger event	real	0
TS	Sample Time	real	0 [s]
INTEG_FORMULA	Method of Integration	real	0

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real
INPUT	Input Signal	Input	real

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Example

Figure 3 shows application of the Integrator model. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 4.



Figure 3. Application example of the Integrator model

Table 4

Component	Parameter	Value
Step Function SPR1	AMPL	1
	TS	0 [s]
	T0	0.1n [s]
	Y0	1
Integrator I_Anteil1	KI	1
	TS	0 [s]
	Y0	0
	UL	0
	LL	0

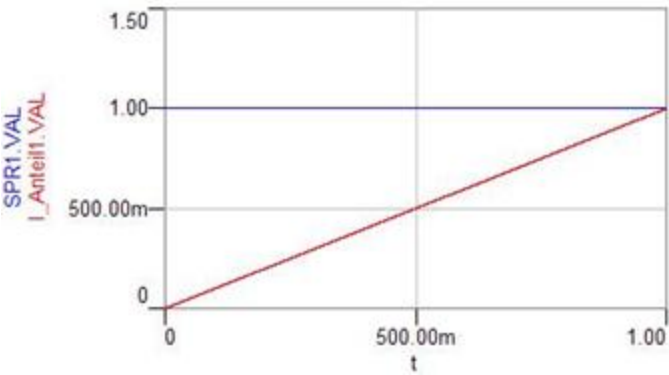


Figure 4. Simulation results-input and output value of I_Anteil1

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References

Memory

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

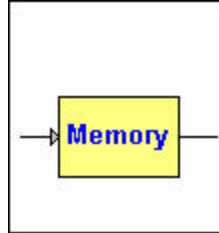


Figure 1. Component Symbol

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Description

The block represents a delay of one simulation step (H) of the input signal with initial value. The initial value represents the output value at t=0. You cannot define a special sampling time for the block.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

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Mathematical Description

We can express the relation between the input and output signal as:

$y(k) = x(k-1)$, where $y(k)$ is the output signal at simulation time step k , and $x(k-1)$ is the input signal at the previous simulation time step $k-1$.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
Y0[0]	Initial Value for t=0	real	0

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real
INPUT	Input Signal	Input	real

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Example

Figure 3 shows application of the Memory model. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 4 and 5, with Figure 5 being a zoomed-in version of Figure 4.

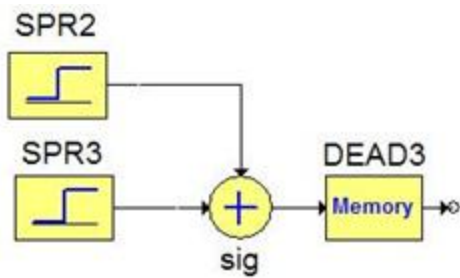


Figure 3. Application example of the Memory model

Table 3

Component	Parameter	Value

Step Function SPR2	AMPL	1
	TS	0 [s]
	T0	1m [s]
	Y0	0
Step Function SPR3	AMPL	-1
	TS	0 [s]
	T0	4m [s]
	Y0	0
Memory DEAD3	TS	0 [s]
	Y0	0

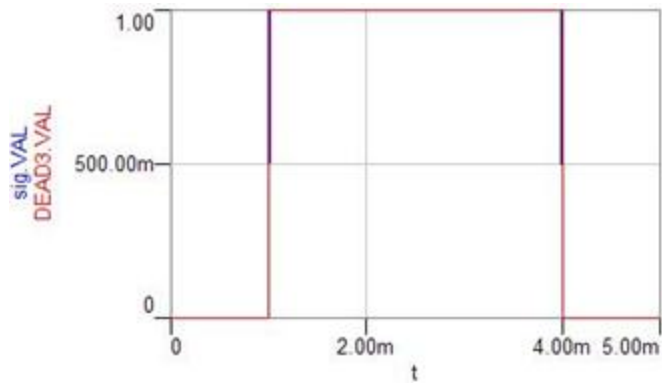


Figure 4. Simulation results-input and output signal of DEAD3

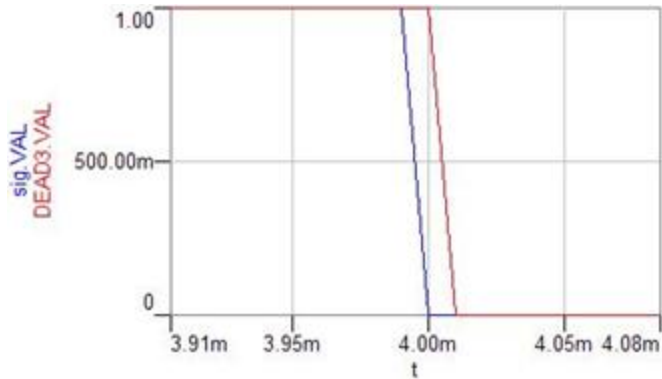


Figure 5. Simulation results-a section of the input and output signal of DEAD3

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References

Discrete Blocks

- Delay (DELAY)
- Digital Filter (FILTER)
- Z-Transfer Function (GZ)
- Discrete Integrator (INTG)
- Sample & Hold (SAH)
- Unit Delay (UNITDELAY)

Delay

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

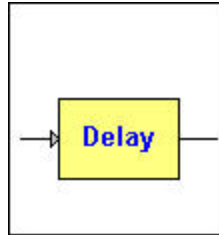


Figure 1. Component Symbol.

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Description

The block represents a delay time of the input signal with a defined number of samples. The delay is specified as simulation time.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

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Mathematical Description

We can express the relation between the input and output signal as:

$$y(t) = x(t-TD)$$

where $y(t)$ and $x(t)$ is the output and input simulation signal at simulation time t , respectively, and TD is the delay time. The sampling time of this model is calculated as:

$TS = TD / NH$, where NH is the number of samples.

Note: The value of Samples entered in the component dialog is added by 1 (shown as N, in the property manager window), because the first sample is coming from the initial value of the input signal.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
Q0[n]*	Initial Values	real	0
TD	Delay	real	0
Samples	20	real	0

* Q0 is a vector, and its size $n \in [1, \text{Samples}]$.

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real
INPUT	Input Signal	Input	real

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Example

Figure 2 shows application of the Delay model. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 3.

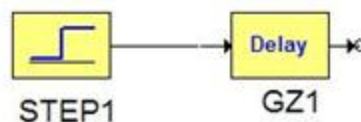


Figure 2. Application example of the Delay model

Table 3

Component	Parameter	Value
Step Function STEP1	AMPL	1
	T0	0.1 [s]
	TS*	0 [s]
	Y0	0
Delay GZ1	Q0[1~4]	0
	TD	2ms
	Samples	4
	TS*	0 [s]

* System simulation time is used as the sample time.

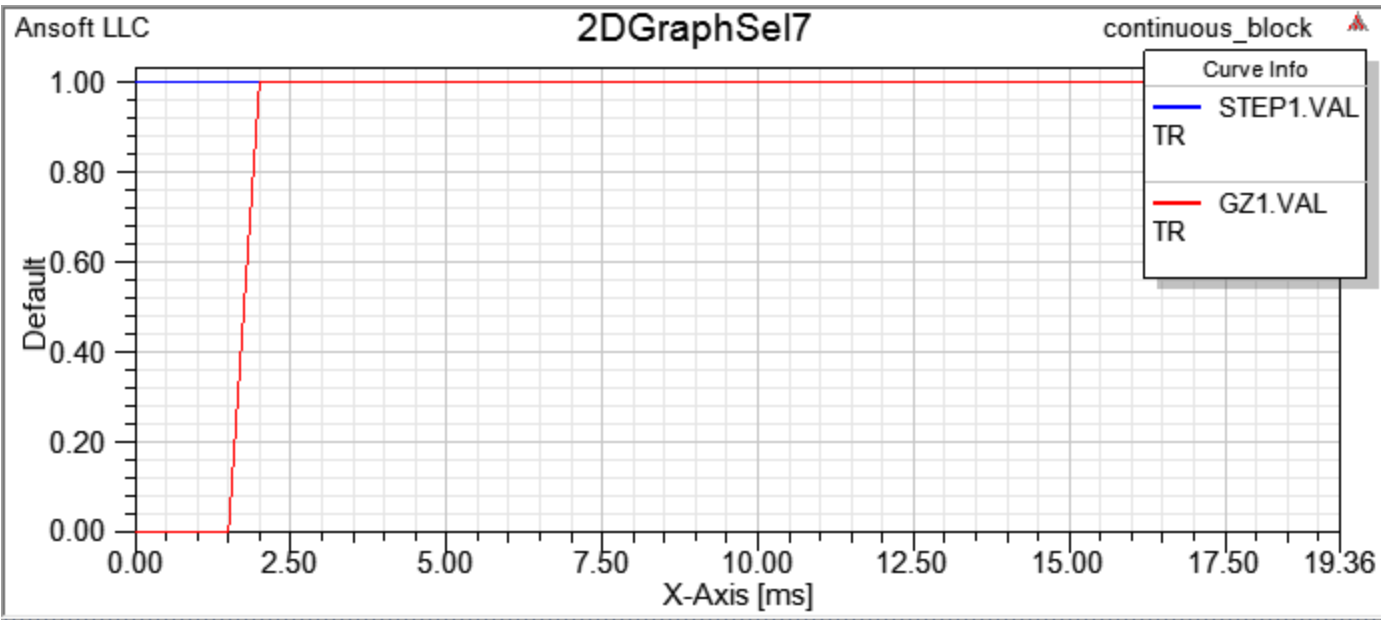


Figure 3. Simulation results – input and output signal of GZ1

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References

Digital Filter

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

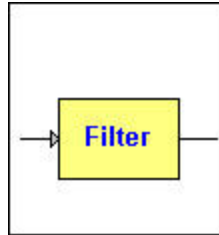


Figure 1. Component Symbol.

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Description

The block provides several filter types for the block diagram module. The filter models are implemented as a transfer function $G(z)$ which is parametrized with parameter sets in the property dialog box. See also Schröfer E.: Signalverarbeitung, C. Hanser, Verlag, 1992.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

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Mathematical Description

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
N	Dimension of Numerator	real	1
D	Dimension of Denominator	real	2
Q[n]	Numerator Coefficients	real	0
P[n]	Denominator Coefficients	real	0
TS	*Sample Time	real	0.001 [s]

***NOTE:** Users should be careful not to reduce the sample time too much as this can make the design unstable.

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real
INPUT	Input Signal	Input	real

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Example

Figure 2 shows application of the Digital Filter model. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 3 and 4.

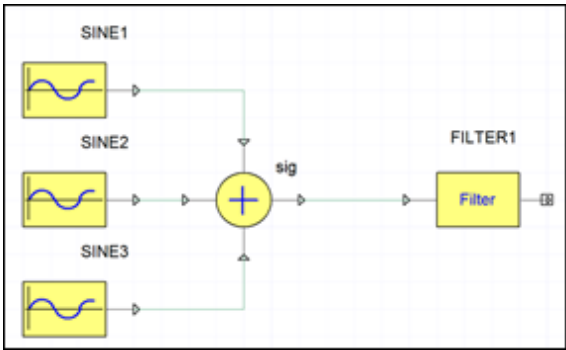


Figure 2. Application example of the Digital Filter model**Table 3**

Component	Parameter	Value
Sine Function SINE3	AMPL	1
	FREQ	5 [Hz]
	PHASE	0 [degree]
	TDELAY	0 [s]
	OFF	0
Sine Function SINE1	AMPL	0.2
	FREQ	100 [Hz]
	PHASE	0 [degree]
	TDELAY	0 [s]
	OFF	0
Sine Function SINE2	AMPL	0.1
	FREQ	200 [Hz]
	PHASE	0 [degree]
	TDELAY	0 [s]
	OFF	0
Digital Filter FILTER1	Filter	Butterworth
	Filter Type	Low Pass
	Filter Order	1
	Cut-off frequency	10 [Hz]
	Sample Time	0.001 [s]

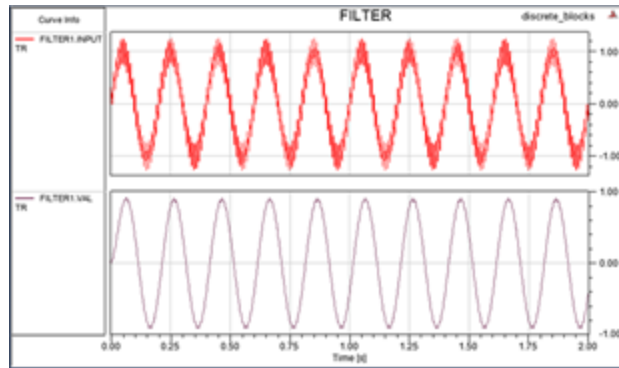


Figure 3. Simulation results – input signal vs. output signal of FILTER1

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References

Z-Transfer Function (Discrete)

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

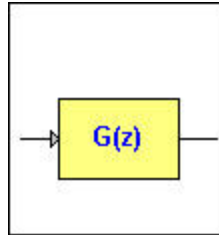


Figure 1. Component Symbol.

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Description

The Block represents time discrete transfer characteristic $G(z^{-1})$ by a difference equation. The block can be applied to model discontinuous controllers and processes. Within the dialog you can define the order and coefficients for the numerator and denominator of the Z-Transfer Function. In almost all cases of analyzing dynamic processes in controller systems, vanishing initial values (identical to zero) can be assumed. If this assumption is not fulfilled, initial values can be assigned to the variables x and y according to the implementation structure of $G(z^{-1})$.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

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Mathematical Description

The transfer function of this component is:

$$G(z^{-1}) = \frac{q_0 + q_1 z^{-1} + q_2 z^{-2} + \dots + q_n z^{-n}}{p_0 + p_1 z^{-1} + p_2 z^{-2} + \dots + p_m z^{-m}}$$

Note: p_0 cannot have a value of 0.

or we can express the relation between the input and output signal as:

$$p_0 y(k) = q_0 x(k) + q_1 x(k-1) + \dots + q_n x(k-n) - p_1 y(k-1) - p_2 y(k-2) - \dots - p_m y(k-m)$$

where $x(k)$ and $y(k)$ are the input and output signal at simulation time step k , respectively.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
N	Dimension of Numerator	real	2
D	Dimension of Denominator	real	1
Q[n]	Numerator Coefficients	real	1
P[n]	Denominator Coefficients	real	1
Q0[n]	Initial Values of X-Values	real	0
P0[n]	Initial Values of Y-Values	real	0
TS (must be greater than zero)	Sample Time	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real
INPUT	Input Signal	Input	real

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Example

Figure 3 shows application of the Z-Transfer Function model. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 4.



Figure 3. Application example of the Discrete Transfer Function model

Table 3

Component	Parameter	Value
Step Function STEP1	AMPL	1
	T0	0 [s]
	TS*	0 [s]
	Y0	0

Z-Transfer Function GZ1	N	2
	D	2
	P[0]	1
	P[1]	-0.999
	Q[0]	0
	Q[1]	0.9995m
	P0[1]	-2
	Q0[1]	5
	TS	1m [s]

* System simulation time is used as the sample time for STEP1

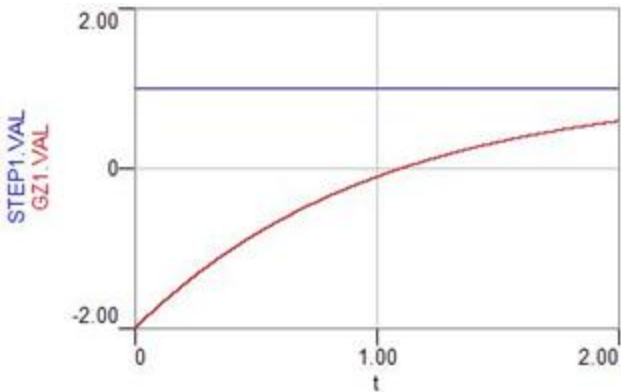


Figure 4. Simulation results-input and output signal of GZ1

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References

Discrete Integrator

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

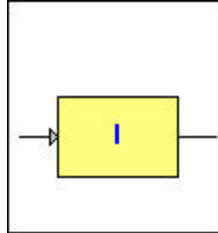


Figure 1. Component Symbol

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Description

The block represents an integration block in discrete-time domain. It has limitation and the possibility to reset the output signal. The table shows the different forms to reset the output signal of the integration block.

Table 1

TRIGSIG	CTRL	Description
0		Summation of input signal.
>0	0	Assign the output signal permanently to the trigger value.
<0	0	Assign the output signal to the trigger value and continue summation of input signal with this value.
>0	1	Hold the last output value of output signal.
<0	1	Continued summation of input signal but one step delay.

Note: The trigger signal is set once to '0' if the trigger event occurs; otherwise, the Integrator would be permanently reset.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

The Integration method used by the INTG block can be selected using the INTEG_FORMULA parameter as follows:

0 Forward Euler - default (behavior V7)

1 Backward Euler (behavior V6)

2 Trapezoid

3 Use Network solver settings

The Use Network Solver setting instructs the component to use the same integration formula used by the simulator to solve the overall network. See [Simulator Parameters](#)

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Mathematical Description

We can express the relation between the input and output signal as:

$$y(k) = y(k - 1) + KI \cdot TS \cdot x(k)$$

where $x(k)$ and $y(k)$ are the input and output signal at simulation time step k , respectively. KI is the Integral Gain, and TS is the Sample Time.

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Netlist Syntax

```
INTERN INTG ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) (INPUT:=@ (INPUT),  
KI:=@ (KI), Y0:=@ (Y0), UL:=@ (UL), LL:=@ (LL), TRIGSIG:=@ (TRIGSIG), TRIGVAL:=@  
(TRIGVAL), CTRL:=@ (CTRL), TS:=@ (TS));
```

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
KI	Integral Gain	real	1
Y0	Initial Value for t=0	real	0
UL	Upper Limit	real	0
LL	Lower Limit	real	0
TRIGSIG	Variable holding the Trigger Signal	real	0
TRIGVAL	Output Signal after Trigger Event	real	0
CTRL	Controls the behavior after trigger event	real	0
TS	Sample Time [s]	real	0 [s]
INTEG_FORMULA	Method of Integration	real	0

Note: when TS is set to 0s, system simulation time is uses as the sample time for the Discrete Integrator model.

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real
INPUT	Input Signal	Input	real

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Example

Figure 3 shows application of the Discrete Integrator model. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 4.

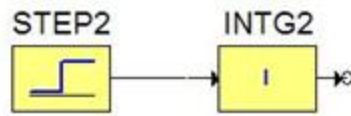


Figure 3. Application example of the Discrete Transfer Function model

Table 4

Component	Parameter	Value
Step Function STEP1	AMPL	1
	T0	0 [s]
	TS*	0 [s]
	Y0	0
Discrete Integrator INTG2	KI	1
	Y0	0
	UL**	
	LL**	
	TRIGSIG	0
	TRIGVAL	0
	CTRL	0
	TS	0 [s]

* System time is used as the sample time for STEP1 and INTG2.

** There are no integration limits.

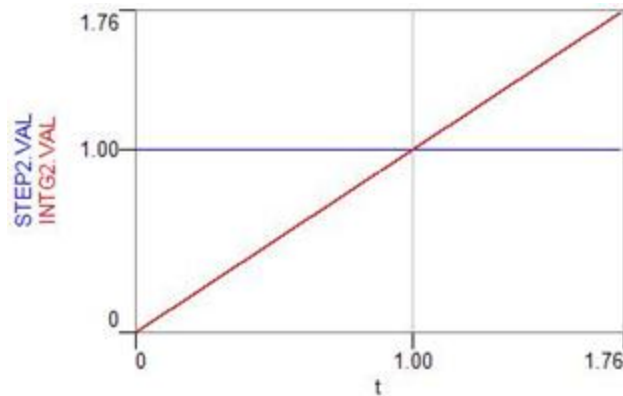


Figure 4. Simulation results - input and output signal of INTG2

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References

Sample and Hold Element

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

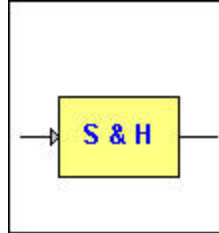


Figure 1. Component Symbol.

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Description

The Sample and Hold Element samples the input signal and holds this value constant up to the next sampling moment (discretization by time). The sampling period is specified as a number of samples.

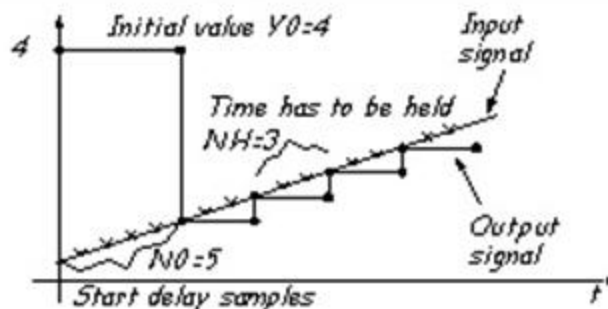


Figure 2. Input and Output waveforms showing effect of Sample and Hold

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)
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Mathematical Description

We can express the relation between the input and output signal as:

$$y(k) = x(n) \quad n = \text{INT}\left(\frac{k - N0}{NH}\right) + N0 \quad k > N0$$

where $y(k)$ is the input and output signal at simulation time step k , and $x(n)$ is the input signal at step n . $N0$ is the number of samples for initial delay, and NH is the number of samples that the Sample and Hold block holds the current sample value.

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Netlist Syntax

```
INTERN SAH ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) (INPUT:=@(INPUT),
NH:=@(NH), N0:=@(N0), Y0:=@(Y0), TS:=@(TS));
```

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
NH	Number of Samples	real	1
N0	Initial Samples	real	0
Y0	Initial Value	real	0
TS	Sample Time	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real
INPUT	Input Signal	Input	real

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Example

Figure 3 shows application of the Sample and Hold model. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 4.



Figure 3. Application example of the Sample and Hold model

Table 3

Component	Parameter	Value
Sine Function SINE4	AMPL	1
	FREQ	10 [Hz]
	PHASE	0 [degree]
	TDELAY	0 [s]
	OFF	0
Sample and Hold Element SAH2	NH	10
	N0	10
	Y0	0.5
	TS	1m [s]

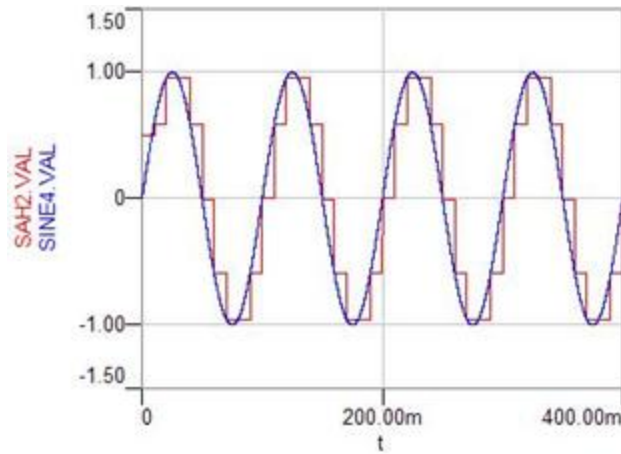


Figure 4. Simulation results-input and output signal of SAH2

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References

Unit Delay

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

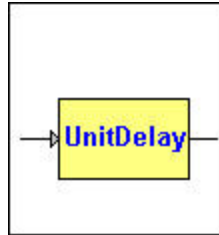


Figure 1. Component Symbol.

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- [Assumptions and Limitations](#)
- [Mathematical Description](#)
- [Netlist Syntax](#)
- [Parameters](#)
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Description

The block represents a delay of the of the input signal with the as sample time defined time. You can define an initial value for the output signal.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

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Mathematical Description

We can express the relation between the input and output signal as:

$$y(k) = x(k - 1)$$

where $y(k)$ is the input and output signal at simulation time step k , and $x(k-1)$ is the input signal at step $k-1$.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
Q0[1]	Initial Value for t=0	real	0
TS (must be greater than zero)	Sample Time	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real
INPUT	Input Signal	Input	real

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Example

Figure 2 shows application of the Unit Delay model. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 3.



Figure 2. Application example of the Unit Delay model

Table 3

Component	Parameter	Value
Step Function STEP1	AMPL	1
	T0	0 [s]
	TS*	0 [s]
	Y0	0
Unit Delay GZ2	Q0[1]	0
	TS	1m [s]

* Sample time of STEP1 is set to the system simulation time

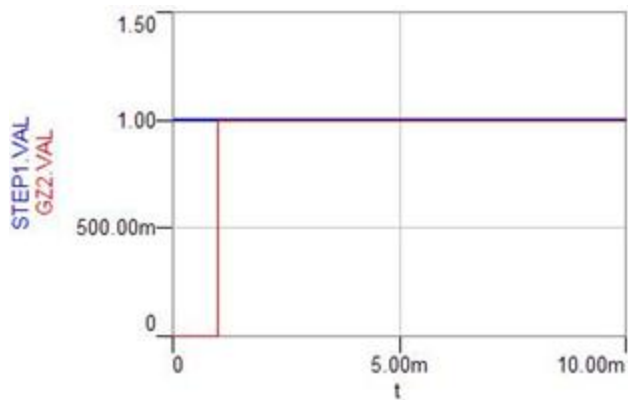


Figure 3. Simulation results-input and output signal of GZ2

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References

Math Blocks

The Math blocks allow the determination of the transfer characteristic according to certain analytical functions. Sine, Cosine, Tangent, Exponential function, Sine hyperbolic, Arc cosine, Natural Logarithm, Absolute value, Reciprocal value $1/x$.

- Absolute Value (FCT_ABS)
- Arc Cosine (FCT_ARCCOS)
- Cosine (FCT_COS)
- Exponential Function (FCT_EXP)
- Natural Logarithm (FCT_LN)
- Reciprocal Value (FCT_REC)
- Sine (FCT_SINE)
- Sine Hyperbolic (FCT_SINHYP)
- Tangent (FCT_TAN)
- Moving Average (MOV_AV)
- Power (POW)
- Root (ROOT)
- Sensitivity (SENSITIVITY)
- Sign (SIGN)

Absolute Value Function

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

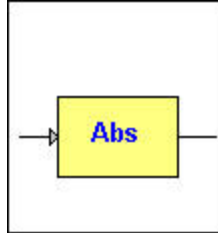


Figure 1. Component Symbol.

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Description

The output of the Natural Logarithm Function block is the absolute value of its input.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

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Mathematical Description

The output of the Absolute Value Function block can be expressed as following:

$$y(k) = \text{abs}(x(k))$$

where $y(k)$ and $x(k)$ are the output and input signal at the simulation time step k , respectively.

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Netlist Syntax

```
INTERN FCT ?InstanceName(@InstanceName):(@ (Refbase)@(ID)) (FCT:= 8, INPUT:=@
(INPUT), TS:=@(TS));
```

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
TS	Sample Time	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real
INPUT	Input Signal	Input	real

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Example

Figure 2 shows application of the Absolute Value Function model. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 3.



Figure 2. Application example of the Absolute Value Function model

Table 3

Component	Parameter	Value
Absolute Value Function FKTABS1	TS*	0 [s]

Triangular Wave TRIANG1	AMP	1
	FREQ	1 [Hz]
	TDELAY	0 [s]
	OFF	0
	PHASE	0 [degree]

* System simulation time step is used for the sample time of FK TABS1.

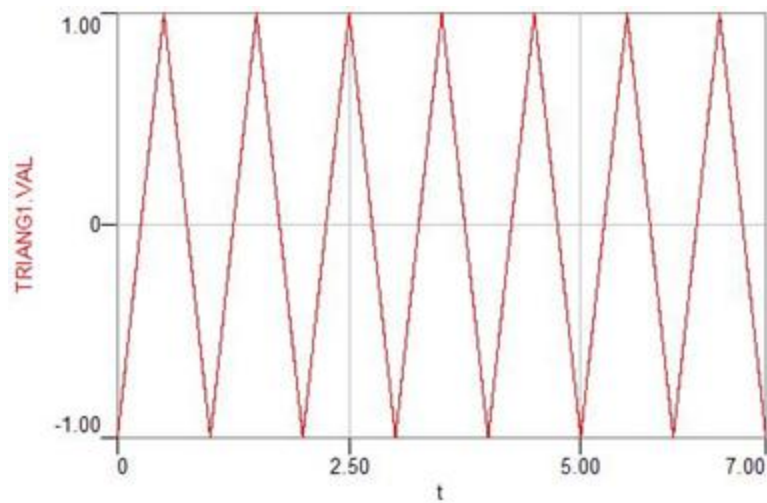


Figure 3. Simulation results-output of FK TABS1

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References

Arc Cosine Function

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

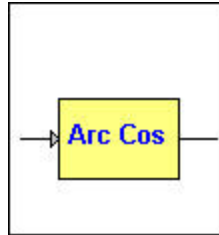


Figure 1. Component Symbol.

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Description

The Arc Cosine Function block defines the transfer characteristic of an arc cosine function.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

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Mathematical Description

The output of the Arc Cosine Function block can be expressed as following:

$$y(k) = \arccos(x(k))$$

where $y(k)$ and $x(k)$ are the output and input signal at the simulation time step k , respectively.

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Netlist Syntax

```
INTERN FCT ?InstanceName(@InstanceName):(@ (Refbase)@(ID)) (FCT:= 5, INPUT:=@
(INPUT), TS:=@(TS));
```

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
TS	Sample Time	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real
INPUT	Input Signal	Input	real

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Example

Figure 2 shows application of the Arc Cosine Function model. In this example, the input of the Gain block EXT2 is a function of the simulation time t , and the output of EXT2 (i.e. $1*(t-1)$) is sent to the Arc Cosine Function FKTARCCOS1 through a Limiter block LIMIT1. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 3 and 4.

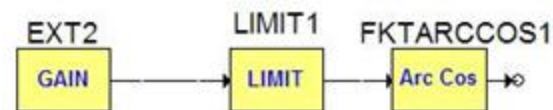


Figure 2. Application example of the Arc Cosine model

Table 3

Component	Parameter	Value

Gain EXT2	TS*	0 [s]
	INPUT	$(t-1)^{**}$
	KP	1
Limiter LIMIT1	UL	1
	LL	-1
	TS*	0 [s]
Sine Hyperbolic Function FKTARCCOS1	TS*	0 [s]

*System simulation time step is used for the sample time of EXT2 and FKTARCCOS1.

**t is the simulation time.

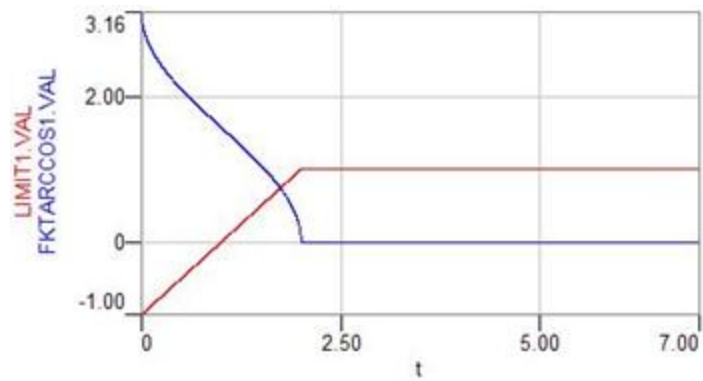


Figure 3. Simulation results-input and output of FKTARCCOS1

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References

Cosine Function

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

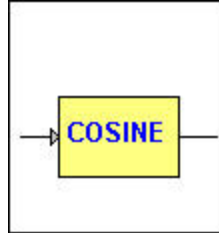


Figure 1. Component Symbol.

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Description

The Cosine Function block defines the transfer characteristic of a cosine function.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

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Mathematical Description

The output of the Cosine Function block can be expressed as following:

$$y(k)=\cos(x(k))$$

where $y(k)$ and $x(k)$ are the output and input signal at the simulation time step k , respectively.

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Netlist Syntax

```
INTERN FCT ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) (FCT:= 2, INPUT:=@
(INPUT), TS:=@ (TS));
```

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
TS	Sample Time	real	0 [s]

[Top](#)

Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Input	real
INPUT	Input Signal	Input	real

[Top](#)

Example

Figure 2 shows application of the Cosine Function model. In this example, the Gain block EXT1 takes the simulation time t as its input, and the output of EXT1 ($1 \cdot t$) is sent to the Cosine Function FKTCOS1. Hence the output of FKTCOS1 is a cosine wave over the simulation time. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 3.



Figure 2. Application example of the Cosine Function model

Table 3

Component	Parameter	Value

Gain EXT1	TS*	0 [s]
	INPUT	t**
	KP	1
Cosine Function FKTCOS1	TS*	0 [s]

*System simulation time step is used for the sample time of EXT1 and FKTCOS1.

**t is the simulation time.

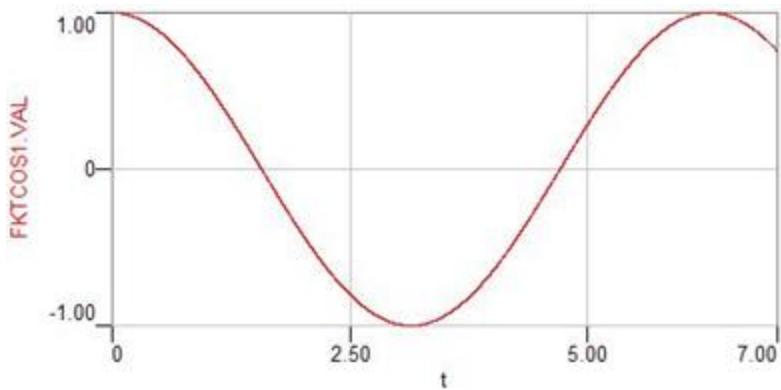


Figure 3. Simulation results-output of FKTCOS1

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References

Exponential Function

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

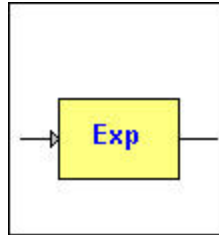


Figure 1. Component Symbol.

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Description

The Exponential Function block defines the transfer characteristic of an exponential function.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

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Mathematical Description

The output of the Exponential Function block can be expressed as following:

$$y(k) = \exp(x(k))$$

where $y(k)$ and $x(k)$ are the output and input signal at the simulation time step k , respectively.

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Netlist Syntax

INTERN FCT ?InstanceName(@InstanceName):(@ (Refbase)@(ID)) (FCT:= 6, INPUT:=@ (INPUT), TS:=@(TS));

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
TS	Sample Time	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real
INPUT	Input Signal	Input	real

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Example

Figure 2 shows application of the Exponential Function model. The nonlinear characteristic of the Nonlinear Transfer Function model NL1 is defined by the Exponential Function EXP1. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 3.

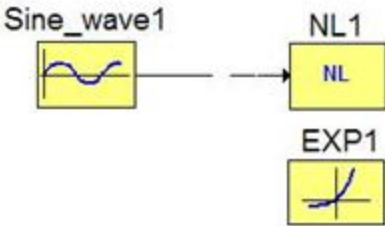


Figure 2. Application example of the Exponential Function model

Table 3

Component	Parameter	Value
Nonlinear Transfer Function NL1	TS*	0 [s]
	CH	EXP1
Sine Wave Sine_wave1	AMPL	1
	FREQ	2 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0
Exponential Function EXP1	VT	1 [V]
	ISAT	2 [A]
	RR	10 [Ohm]

* System simulation time step is used for the sample time of NL1.

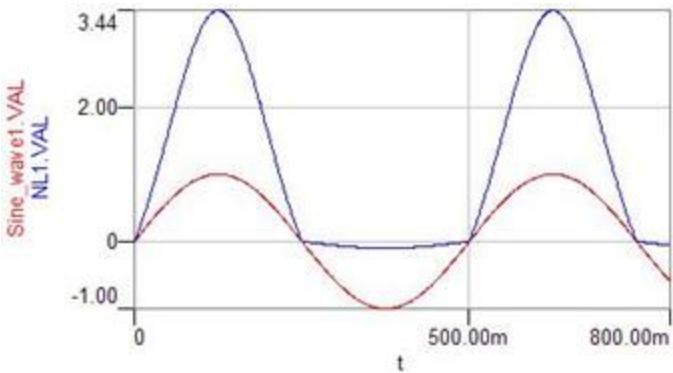


Figure 3. Simulation results-input and output of NL1

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References

Natural Logarithm Function

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

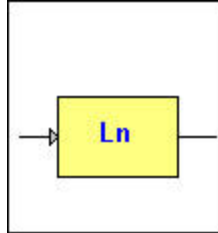


Figure 1. Component Symbol.

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Description

The Natural Logarithm Function block defines the transfer characteristic of a Natural Logarithm function.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

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Mathematical Description

The output of the Natural Logarithm Function block can be expressed as following:

$$y(k) = \ln(x(k))$$

where $y(k)$ and $x(k)$ are the output and input signal at the simulation time step k , respectively.

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Netlist Syntax

```
INTERN FCT ?InstanceName(@InstanceName):(@ (Refbase)@(ID)) (FCT:= 7, INPUT:=@
(INPUT), TS:=@(TS));
```

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
TS	Sample Time	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real
INPUT	Input Signal	Input	real

[Top](#)

Example

Figure 2 shows application of the Natural Logarithm Function model. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 3.



Figure 2. Application example of the Natural Logarithm Function model

Table 3

Component	Parameter	Value
Natural Logarithm Function FKTLN1	TS*	0 [s]

Gain EXT1	KP	1
	INPUT	$t^{**}+0.1$
	TS*	0 [s]

* System simulation time step is used for the sample time of FKTLN1 and EXT1.

** t is the simulation time.

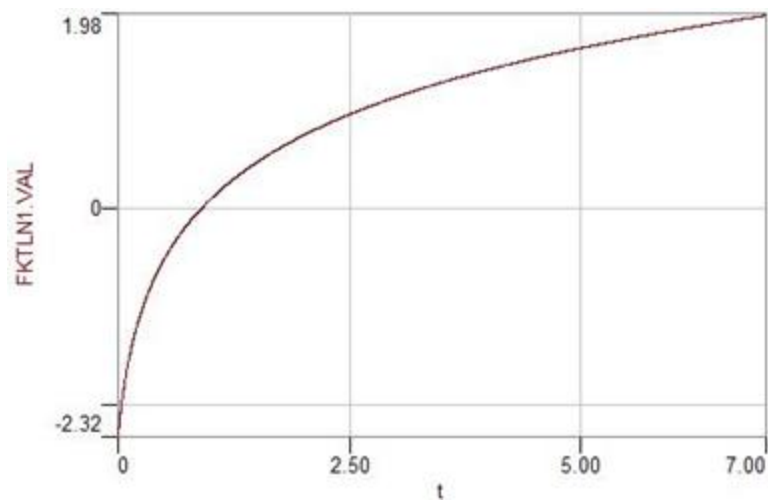


Figure 3. Simulation results-output of FKTLN1

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References

Reciprocal Function

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

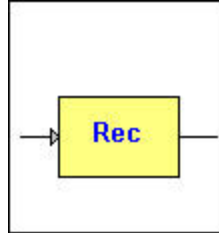


Figure 1. Component Symbol.

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Description

The output of this model is the reciprocal value of the input.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

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Mathematical Description

The output of the Reciprocal Function block can be expressed as following:

$$y(k) = 1 / (x(k))$$

where $y(k)$ and $x(k)$ are the output and input signal at the simulation time step k , respectively.

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Netlist Syntax

```
INTERN FCT ?InstanceName(@InstanceName):(@ (Refbase)@(ID)) (FCT:= 9, INPUT:=@
(INPUT), TS:=@(TS));
```

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
TS	Sample Time	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real
INPUT	Input Signal	Input	real

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Example

Figure 2 shows application of the Reciprocal Function model. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 3 and 4.

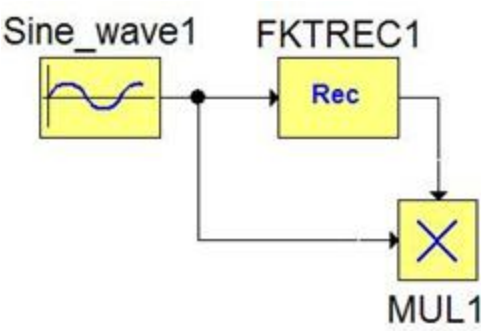


Figure 2. Application example of the Reciprocal Function model

Table 3

Component	Parameter	Value
Reciprocal Function FKTREC1	TS*	0 [s]
Sine Wave Sine_wave1	AMP	1
	FREQ	1 [Hz]
	TDELAY	0 [s]
	OFF	2
	PHASE	0 [degree]

* System simulation time step is used for the sample time of FKTREC1.

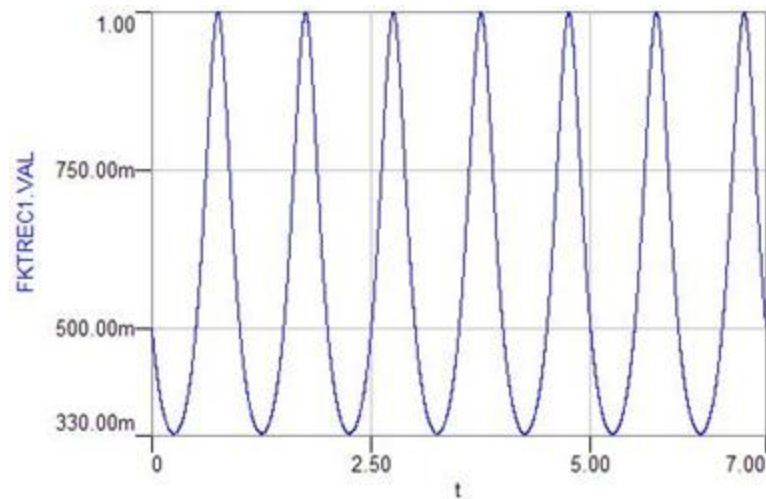
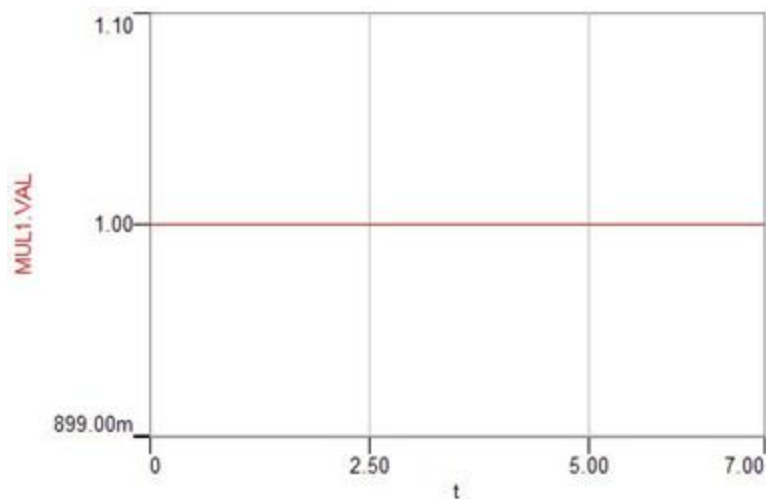
**Figure 3. Simulation results-output of FKTREC1**

Figure 4. Simulation results-output of MUL1

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References

Sine Function

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

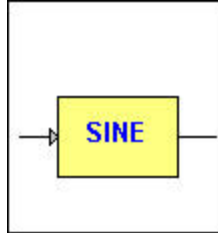


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Description

The Sine Function block defines the transfer characteristic of a Sinusoidal function.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

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Mathematical Description

The output of the Sine Function block can be expressed as following:

$$y(k) = \sin(x(k))$$

where $y(k)$ and $x(k)$ are the output and input signal at the simulation time step k , respectively.

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Netlist Syntax

INTERN FCT ?InstanceName(@InstanceName):(@ (Refbase)@(ID)) (FCT:= 1, INPUT:=@ (INPUT), TS:=@(TS));

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
TS	Sample Time	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real
INPUT	Input Signal	Input	real

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Example

Figure 2 shows application of the Sine Function model. In this example, the Gain block EXT1 takes the simulation time t as its input, and the output of EXT1 ($1 \cdot t$) is sent to the Sine Function FKTSIN1. Hence the output of FKTSIN1 is a sinusoidal waveform over the simulation time. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 3.



Figure 2. Application example of the Sine Function model

Table 3

Component	Parameter	Value
Gain EXT1	TS*	0 [s]
	INPUT	t^{**}
	KP	1
Sine Function FKTSIN1	TS*	0 [s]

*System simulation time step is used for the sample time of EXT1 and FKTCOS1.

**t is the simulation time.

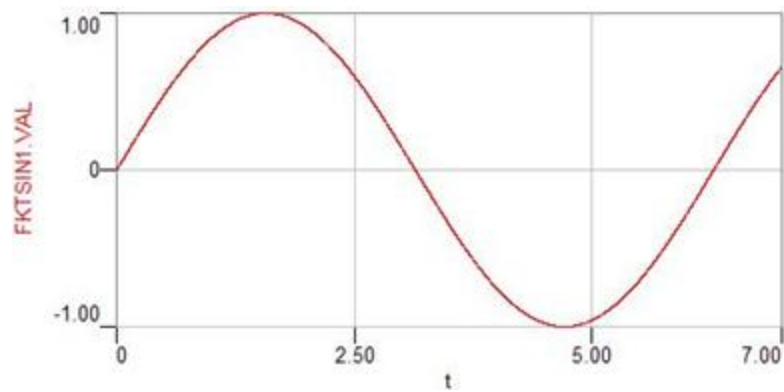


Figure 3. Simulation results-output of FKTSIN1

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References

Sine Hyperbolic Function

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

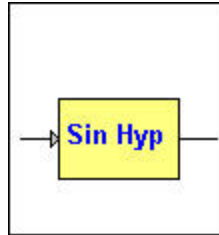


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Description

The Sine Hyperbolic Function block defines the transfer characteristic of a Sine Hyperbolic function.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

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Mathematical Description

The output of the Sine Hyperbolic Function block can be expressed as following:

$$y(k) = \sinh(x(k))$$

where $y(k)$ and $x(k)$ are the output and input signal at the simulation time step k , respectively.

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Netlist Syntax

```
INTERN FCT ?InstanceName(@InstanceName):(@ (Refbase)@(ID)) (FCT:= 4, INPUT:=@
(INPUT), TS:=@(TS));
```

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
TS	Sample Time	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real
INPUT	Input Signal	Input	real

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Example

Figure 2 shows application of the Sine Hyperbolic Function model. In this example, the input of the Gain block EXT2 is a function of the simulation time t , and the output of EXT2 (i.e. $1*(t-1)$) is sent to the Sine Hyperbolic Function FKTSINH1. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 3 and 4.

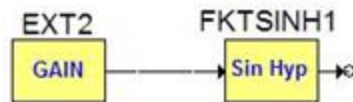


Figure 2. Application example of the Tangent Function model

Table 3

Component	Parameter	Value

Gain EXT2	TS*	0 [s]
	INPUT	(t-1)**
	KP	1
Sine Hyperbolic Function FKTSINH1	TS*	0 [s]

*System simulation time step is used for the sample time of EXT2 and FKTSINH1.

**t is the simulation time.

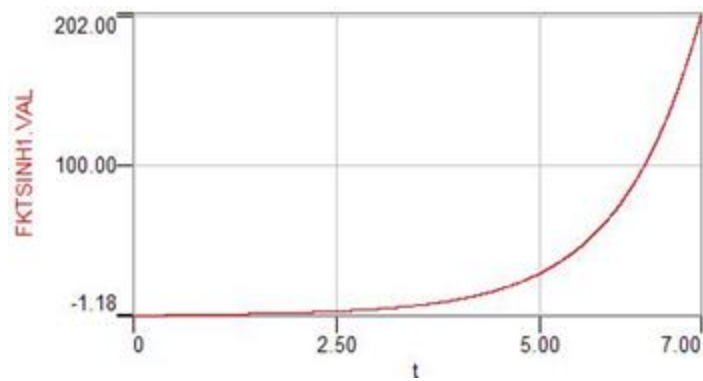


Figure 3. Simulation results-output of FKTSINH1

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References

Tangent Function

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

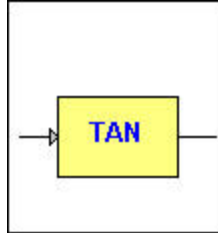


Figure 1. Component Symbol.

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Description

The Tangent Function block defines the transfer characteristic of a tangent function.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

[Top](#)

Mathematical Description

The output of the Tangent Function block can be expressed as following:

$$y(k)=\tan(x(k))$$

where $y(k)$ and $x(k)$ are the output and input signal at the simulation time step k , respectively.

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Netlist Syntax

```
INTERN FCT ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) (FCT:= 3, INPUT:=@ (INPUT), TS:=@ (TS));
```

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
TS	Sample Time	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real
INPUT	Input Signal	Input	real

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Example

Figure 2 shows application of the Sine Function model. In this example, the Gain block EXT1 takes the simulation time t as its input, and the output of EXT1 ($1 \cdot t$) is sent to the Sine Function FKTSIN1. Hence the output of FKTSIN1 is a sinusoidal waveform over the simulation time. This sine wave is then passed onto the Tangent Function block FKTTAN1. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 3 and 4.

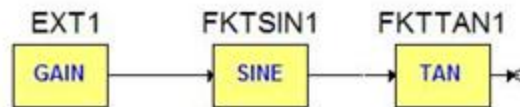


Figure 2. Application example of the Tangent Function model

Table 3

Component	Parameter	Value

Gain EXT1	TS*	0 [s]
	INPUT	t**
	KP	1
Sine Function FKTSIN1	TS*	0 [s]
Tangent Function FKTTAN1	TS*	0 [s]

*System simulation time step is used for the sample time of EXT1, FKTSIN1 and FKTTAN1.

**t is the simulation time.

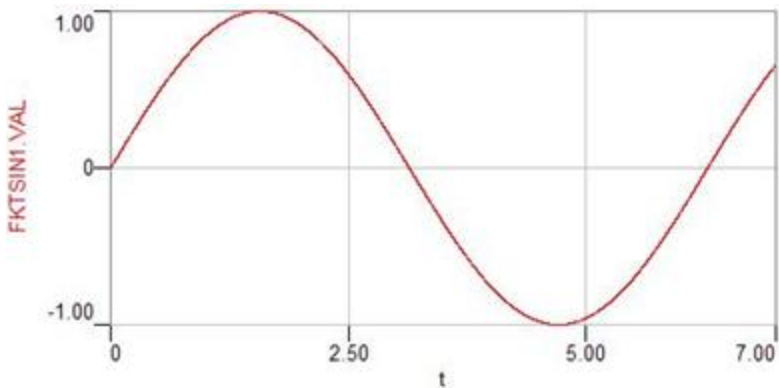


Figure 3. Simulation results-output of FKTSIN1

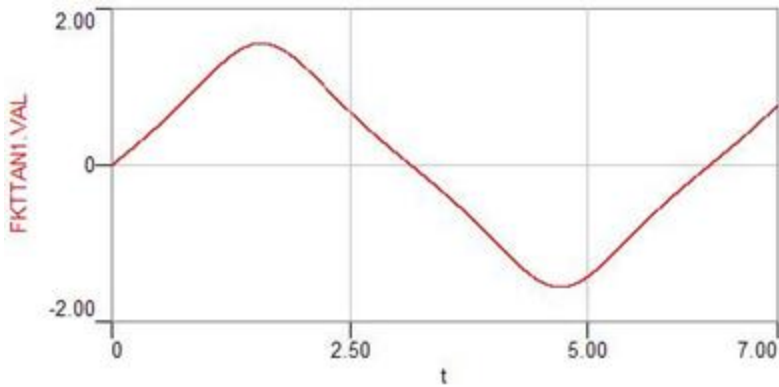


Figure 4. Simulation results-output of FKTTAN1

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References

Moving Average Math Block

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

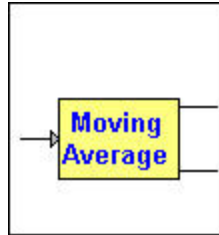


Figure 1. Component Symbol.

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Description

This block is for Transient analysis and is used to find the sliding mean and sliding RMS values via a moving average calculation. These outputs are updated continuously during simulation. During a DC analysis, both outputs are equal to the input value. For an AC analysis, both outputs are 0. The main application for this component is to mimic a physical measurement of the mean or RMS values.

Note: Both outputs begin as soon as two samples have been collected, even if a full period has not elapsed.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

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Mathematical Description

The output of the Moving Average Math block can be expressed as following:

$$MEAN = \frac{1}{period} \int_{t-period}^t x(t) dt$$

$$RMS = \sqrt{\frac{1}{period} \int_{t-period}^t x^2(t) dt}$$

where $x(t)$ is the input signal; MEAN and AVERAGE are the sliding mean and RMS value of the input signal; and PERIOD is the integration/averaging period.

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Netlist Syntax

```
UMODEL MOV_AV ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) ( INPUT:=
@INPUT, TSTART:= @TSTART, TSTOP:= @TSTOP, PERIOD:= @PERIOD) SRC: DB(Lib:-
:=@ModelLibraryName);
```

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
TSTART	Time to start monitoring.	real	0 [s]
TSTOP	Time to stop monitoring.	real	T_{end} [s]
PERIOD	Integration/averaging period.	real	1 [ms]

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Input/Output Quantities

Table 2

Name	Description	Direction	Data Type
MEAN	Sliding mean.	Output	real
RMS	Sliding RMS.	Output	real
INPUT	Input signal.	Input	real

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Example

Figure 2 shows application of the Moving Average Math model. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 3.

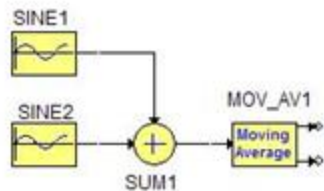


Figure 2. Application example of the Moving Average Math model

Table 3

Component	Parameter	Value
Summation SUM1	TS*	0 [s]
Sine Wave SINE1	AMP	1
	FREQ	2 [Hz]
	TDELAY	0 [s]
	OFF	2
	PHASE	0 [degree]
Sine Wave SINE2	AMP	2
	FREQ	3 [Hz]
	TDELAY	2 [s]
	OFF	0
	PHASE	0 [degree]
Moving Average Math Block MOV_AV1	TSTART	0 [s]
	TSTOP	Tend** [s]
	PERIOD	1 [s]

* System simulation time step is used for the sample time of Sign1.

** Tend is time when the simulation finishes.

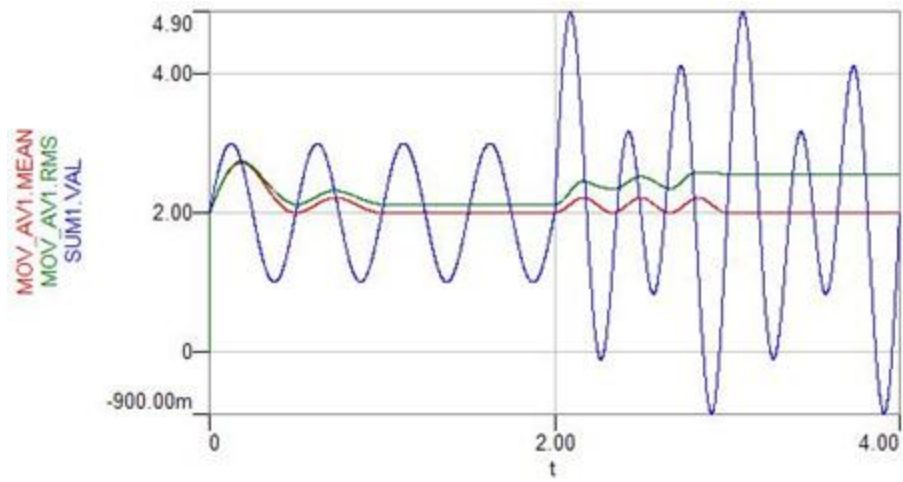


Figure 3. Simulation results-output of SUM1 and outputs of MOV_AV1

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References

Power

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

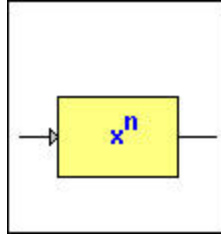


Figure 1. Component Symbol.

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Description

The block raises the block input signal to the n-th power (the value of n is given by EXP in this model). The Exponent n has to be a non-negative fractional number and must be entered in decimal style.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

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Mathematical Description

The output of the Power Function block can be expressed as following:

$$y(k) = x(k)^{\text{EXP}}$$

where $y(k)$ and $x(k)$ are the output and input signal at the simulation time step k , respectively; and EXP is the value of the exponent.

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Netlist Syntax

```
INTERN POW ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) (INPUT:=@(INPUT),
EXP:=@(EXP), TS:=@(TS));
```

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
EXP	Exponent	real	1
TS	Sample Time	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real
INPUT	Input Signal	Input	real

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Example

Figure 2 shows application of the Power model. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 3.



Figure 2. Application example of the Power Function model

Table 3

Component	Parameter	Value
Power Function Pow1	TS*	0 [s]
	EXP	2
Gain EXT4	KP	1
	INPUT	t*+0.1
	TS*	0 [s]

* System simulation time step is used for the sample time of Pow1 and EXT4.

** t is the simulation time.

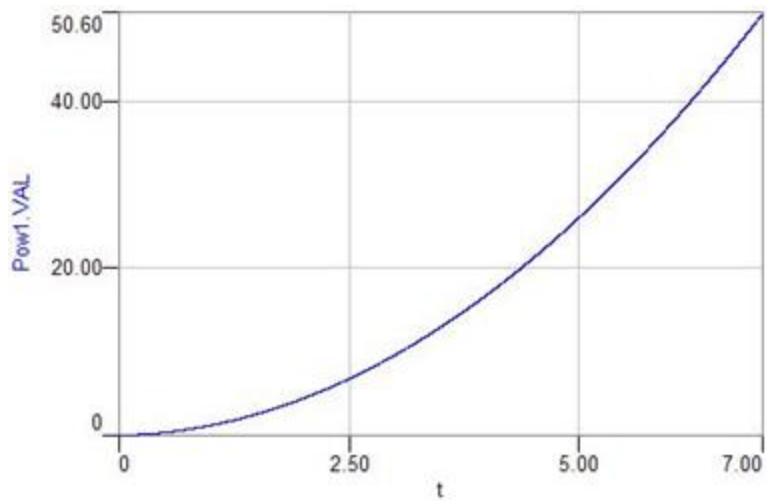


Figure 3. Simulation results-output of Pow1

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References

Root

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

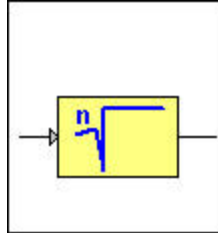


Figure 1. Component Symbol.

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Description

The block computes the n-th radical of the block input signal and provides the result at the block output. The radical exponent must be a positive natural number.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

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Mathematical Description

The output of the Root Function block can be expressed as following:

$$y(k) = \text{root} \sqrt[n]{x(k)}$$

where $y(k)$ and $x(k)$ are the output and input signal at the simulation time step k , respectively; and ROOT is the value of the radicand.

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Netlist Syntax

```
INTERN ROOT ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) (INPUT:=@(INPUT),
ROOT:=@(ROOT), TS:=@(TS));
```

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
ROOT	Radicand	real	2
TS	Sample Time	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real
INPUT	Input Signal	Input	real

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Example

Figure 2 shows application of the Root model. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 3.



Figure 2. Application example of the Root Function model

Table 3

Component	Parameter	Value

Root Function Rootn1	TS*	0 [s]
	ROOT	2
Gain EXT4	KP	1
	INPUT	$t^*+0.1$
	TS*	0 [s]

* System simulation time step is used for the sample time of Rootn1 and EXT4.

** t is the simulation time.

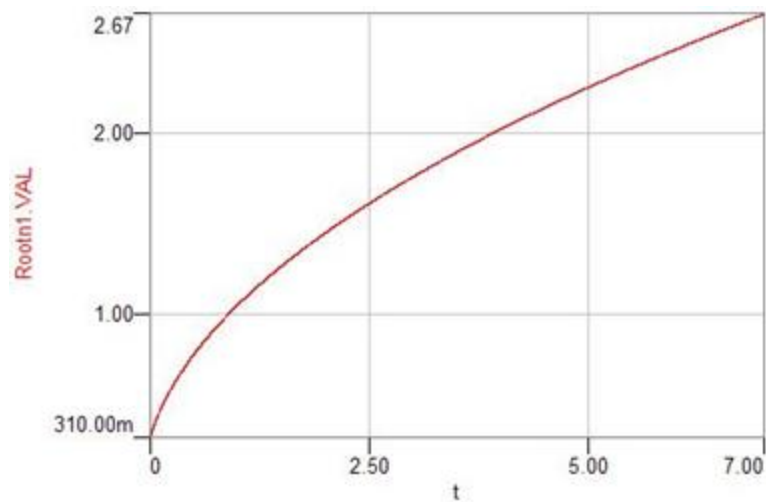


Figure 3. Simulation results-output of Rootn1

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References

Sensitivity

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

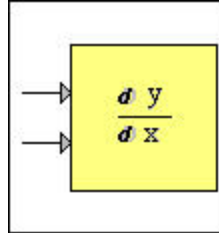


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Description

This model provides the partial derivation of two input signals $\text{DERIV} = \partial Y / \partial X$ with the active values of the input signals at each simulation step. Within the dialog you can define the X range of values and an initial delay.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

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Mathematical Description

The Derivative output of the Sensitivity Math block is calculated as following:

$$\text{DERIV} = \frac{\partial y}{\partial x} = \frac{y(k) - y(k-1)}{x(k) - x(k-1)}$$

The average of the derivatives of the Sensitivity Math block is calculated as following:

$$AVG = \frac{1}{N} \cdot \sum_{k=1}^N \frac{\partial y}{\partial x}$$

where x and y are the input and output signals, respectively; Deriv and AVG are the derivation and the average of the derivations.

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Netlist Syntax

Netlist Generated by special component dialog.

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
TDELAY	Delay	real	0 [s]
XMIN	X-Interval Lower Limit	real	0
XMAX	X-Interval Upper Limit	real	0
TS	Sample Time	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
DERIV	Derivative of Input Signal	Input/Output	real
AVG	Mean Value of Derivative	Input/Output	real
INPUTY	Input Signal Y for Derivation dy/dx	Input	real
INPUTX	Input Signal X for Derivation dy/dx	Input	real

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Example

Figure 2 shows application of the Sensitivity model. The Sensitivity block is used to take the derivative of the arctangent block output. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 3.



Figure 2. Application example of the Sensitivity model

Table 3

Component	Parameter	Value
ARCTAN Arc_tangent1	LIMY	1.578 [deg]
	FACTX	1
	OFFX	0
	OFFY	0
Sensitivity SENSITIVITY1	INPUTY	Arc_tangent1.VAL
	INPUTX	Time
	TDELAY	0 [s]
	XMIN	0
	XMAX	0
	TS	0 [s]

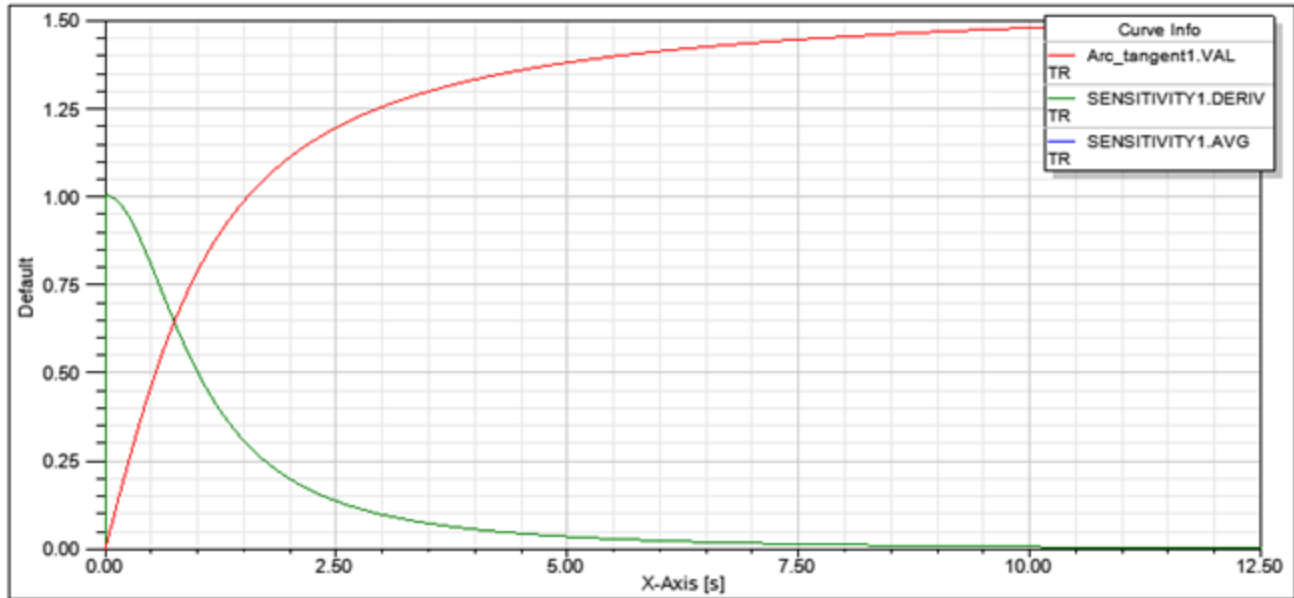


Figure 3. Simulation results-output of Arc_tangent1 and average and derivative outputs of SENSITIVITY1

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References

Sign

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

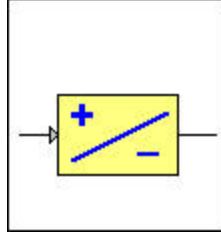


Figure 1. Component Symbol.

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Description

The block provides the discretized signal at the block output, depending on the sign of the block input signal and the adaption factor.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

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Mathematical Description

The output of the Sign Function block can be expressed as following:

$$\begin{aligned} y(k) &= \text{AMPL} & \text{if } x(k) \geq 0 \\ y(k) &= -\text{AMPL} & \text{if } x(k) < 0 \end{aligned}$$

where $y(k)$ and $x(k)$ are the output and input signal at the simulation time step k , respectively. AMPL is the amplitude of the output.

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Netlist Syntax

```
INTERN SIGN ?InstanceName(@InstanceName):(@Refbase)@(ID)) (INPUT:=@(INPUT),
AMPL:=@(AMPL), TS:=@(TS));
```

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
AMPL	Absolute Value of Output Amplitude	real	1
TS	Sample Time	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real
INPUT	Input Signal	Input	real

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Example

Figure 2 shows application of the Sign Function model. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 3.



Figure 2. Application example of the Sign Function model

Table 3

Component	Parameter	Value
Sign Function Sign1	TS*	0 [s]
	AMPL	2
Triangular Wave TRIANG1	AMP	1
	FREQ	1 [Hz]
	TDELAY	0 [s]
	OFF	0
	PHASE	0 [degree]

* System simulation time step is used for the sample time of Sign1.

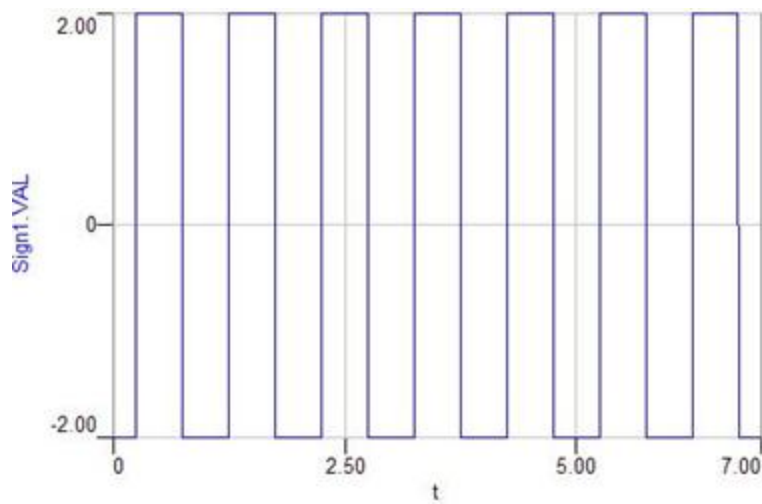


Figure 3. Simulation results-output of Sign1

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References

Signal Processing Blocks

- [Comparator \(COMP\)](#)
- [Discretization Element \(DIS\)](#)
- [Equation Block \(EQUBL\)](#)
- [Limiter \(LIMIT\)](#)
- [Maximum of Input Signals \(MAX\)](#)
- [Minimum of Input Signals \(MIN\)](#)
- [Maximum/Minimum Value at Time T \(MINMAXT\)](#)
- [Multiplier \(MUL\)](#)
- [Multidimensional Table Block \(NDNL\)](#)
- [Negator \(NEG\)](#)
- [Nonlinear Characteristic \(NL\)](#)
- [N-Point Element \(NP\)](#)
- [Summation \(SUM\)](#)
- [Two-Point Element with Hysteresis \(TPH\)](#)

Comparator

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

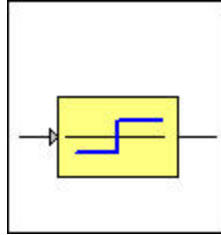


Figure 1. Component Symbol.

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Description

The block represents a two-point element **without** hysteresis.

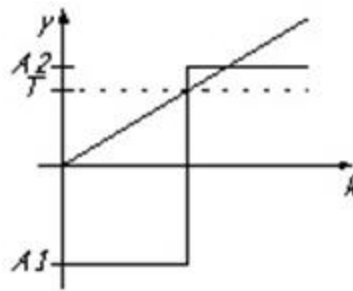


Figure 2. Input and Output waveforms as the input crosses the threshold T

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

[Top](#)**Mathematical Description**

The output of the Multiplier block can be expressed as following:

$$\begin{aligned} y(k) &= A1, \text{ if } x(k) < T \\ y(k) &= A2, \text{ if } x(k) \geq T \end{aligned}$$

where $y(k)$ and $x(k)$ are the output and input signal at the simulation time step k , respectively; T is the threshold.

[Top](#)**Netlist Syntax**

```
INTERN COMP ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) (INPUT:=@ (INPUT),
THRES:=@ (THRES), VAL1:=@ (VAL1), VAL2:=@ (VAL2), TS:=@ (TS));
```

[Top](#)**Parameters****Table 1**

Name	Description	Data Type	Default Value [Unit]
T	Threshold	real	0
VAL1	Value A1	real	1
VAL2	Value A2	real	-1
TS	Sample Time	real	0 [s]

[Top](#)**Input/Output Quantities****Table 2**

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real
INPUT	Input Signal	Input	real

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Example

Figure 2 shows application of the Comparator model. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 3.



Figure 2. Application example of the Comparator models

Table 3

Component	Parameter	Value
Comparator COMP1	TS*	0 [s]
	T	0.5
	VAL1	1.5
	VAL2	-0.8
Triangular Wave Triangular1	AMPL	1
	FREQ	2 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0

* System simulation time step is used for the sample time of COMP1.

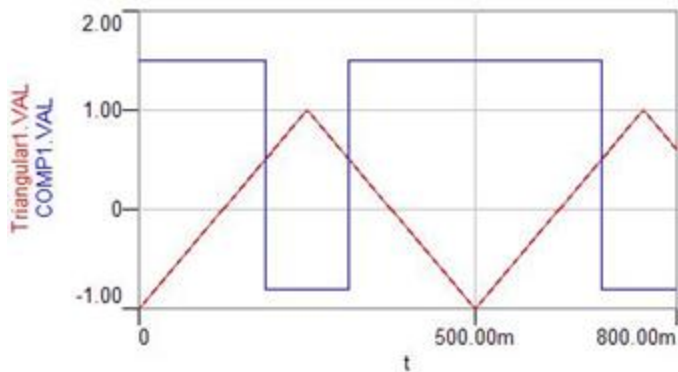


Figure 3. Simulation results-input and output of COMP1

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References

Discretization Element

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

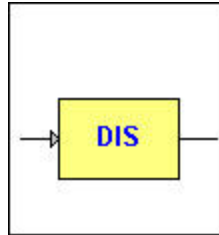


Figure 1. Component Symbol.

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Description

The input signal is discretized with respect to the specified coefficient (quantification of the signal amplitude). In other words, the minimum signal increment or decrement is always equal to K .

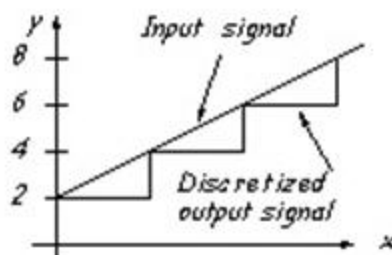


Figure 2. Input and Output waveforms illustrating discretization of the output.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)
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Mathematical Description

The output of the Discretization Element can be expressed as following:

$$y(k) = K \cdot \text{INT} \left(\frac{x(k)}{K} \right)$$

where $y(k)$ and $x(k)$ are the output and input signal at the simulation time step k , respectively; K is the Discretization Quantity.

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Netlist Syntax

```
INTERN DIS ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) (INPUT:=@ (INPUT),
K:=@ (K),TS:=@ (TS));
```

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
K	Discretization Quantity	real	2
TS	Sample Time	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real
INPUT	Input Signal	Input	real

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Example

Figure 2 shows application of the Discretization Element. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 3.

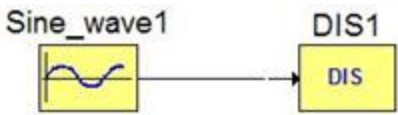


Figure 2. Application example of the Discretization Element

Table 3

Component	Parameter	Value
Discretization Element DIS1	TS*	0 [s]
	K	0.25
Sine Wave Sine_Wave1	AMPL	1
	FREQ	2 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0

* System simulation time step is used for the sample time of DIS1.

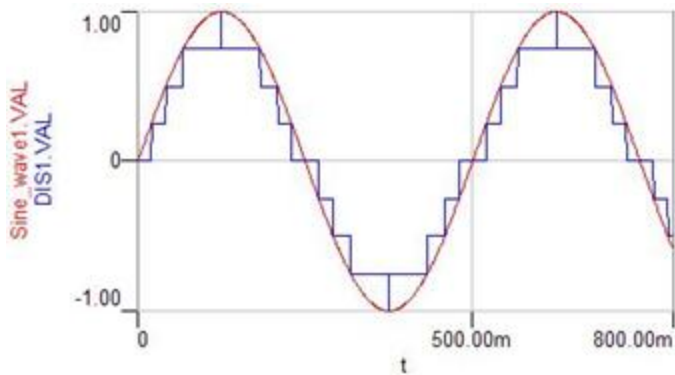


Figure 3. Simulation results-input and output of DIS1

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References

Equation Block

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

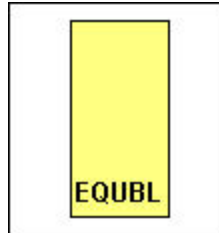


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Description

The block provides a numerical links between input signals and block intern variables at the block output.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

Note: All the variables used in the **Parameters>Equation** section of the EQUBL are limited to inputs from the **Parameters>Input** section, outputs from the **Parameters>Output** section, and internal variables. The internal variables are intermediate variables that can only be used in the equation: they cannot be used outside the Equation block for calculating/plotting purposes. Any quantities/variables from other parts of Twin Builder designs need to be passed through the **Parameters>Input** section.

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Mathematical Description

$$\begin{aligned} y(m) &= f(x(n), x(n-1), \dots, \text{var1}, \text{var2}, \dots) \\ y(m) &= \text{VAL}(m) \qquad x(n) = \text{INPUT}(n) \end{aligned}$$

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
TS	Sample Time	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
INPUT[n]	Input Signal [n]	Input	real
VAL[n]	Block output signal [n]	Output	real

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Example

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References

Limiter

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

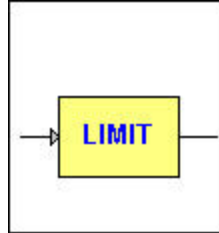


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Description

The block represents a limitation of the input signal within defined limits.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

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Mathematical Description

The output of the Multiplier block can be expressed as following:

$$\begin{aligned}
 y(k) &= \text{Lower Limit, if } x(k) \leq \text{Lower Limit} \\
 y(k) &= \text{Upper Limit, if } x(k) \geq \text{Upper Limit} \\
 y(k) &= x(k) \text{ else}
 \end{aligned}$$

where $y(k)$ and $x(k)$ are the output and input signal at the simulation time step k , respectively; UL and LL are the upper and lower limit, respectively.

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Netlist Syntax

```
INTERN LIMIT ?InstanceName(@InstanceName):(@ (Refbase)@(ID)) (INPUT:=@(INPUT),
UL:=@(UL), LL:=@(LL), TS:=@(TS)) ;
```

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
UL	Upper Limit of Output Signal	real	0
LL	Lower Limit of Output Signal	real	0
TS	Sample Time	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real
INPUT	Input Signal	Input	real

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Example

Figure 2 shows application of the Limiter model. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 3.



Figure 2. Application example of the Limiter models

Table 3

Component	Parameter	Value
Limiter LIMITER1	TS*	0 [s]
	UL	0.5
	LL	-0.3
Sine Wave Sine_wave2	AMPL	1
	FREQ	1 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0

* System simulation time step is used for the sample time of LIMITER1.

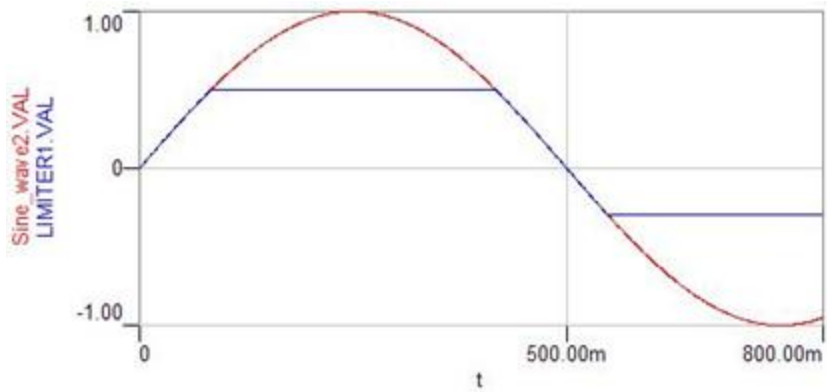


Figure 3. Simulation results-input and output of LIMITER1

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References

Maximum of Input Signals

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

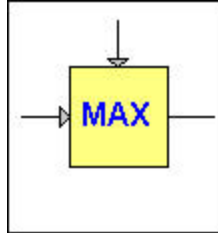


Figure 1. Component Symbol.

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- [Mathematical Description](#)
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Description

The block provides the maximum value from all input signals at each time step at the block output. The component cannot be used with AC and DC simulation.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

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Mathematical Description

The output of the Maximum of the Input Signal function can be expressed as following:

$$y(k) = \text{Max}(x_1(k), x_2(k), \dots, x_n(k))$$

where $y(k)$ is the output signal at the simulation time step k , and $x_i(k)$ is the i^{th} input signal at the simulation time step k .

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
TS	Sample Time	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real
INPUT[n]	Input Signal	Input	real

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Example

Figure 2 shows application of the Maximum and Minimum of Input Signals models. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 3-5.

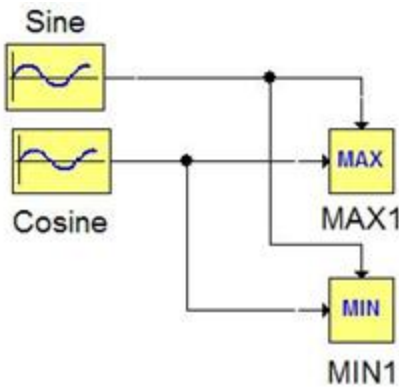


Figure 2. Application example of the Maximum and Minimum of Input Signals models**Table 3**

Component	Parameter	Value
Sine Wave Sine	AMPL	10
	PHASE	0 [degree]
	FREQ	10 [Hz]
	TDELAY	0 [s]
	OFF	0
Sine Wave Cosine	AMPL	5
	PHASE	90 [degree]
	FREQ	10 [Hz]
	TDELAY	0 [s]
	OFF	0

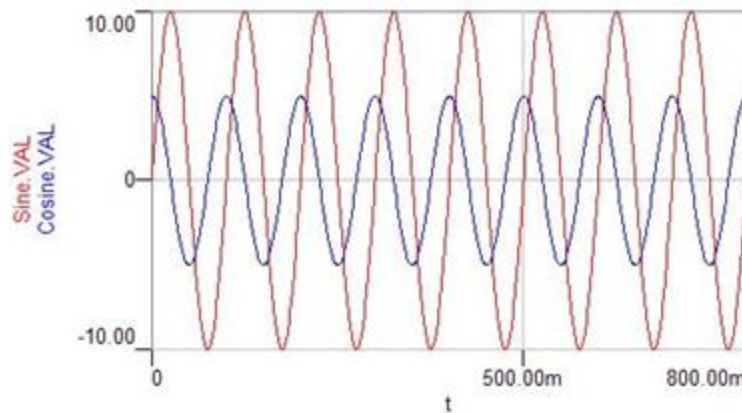
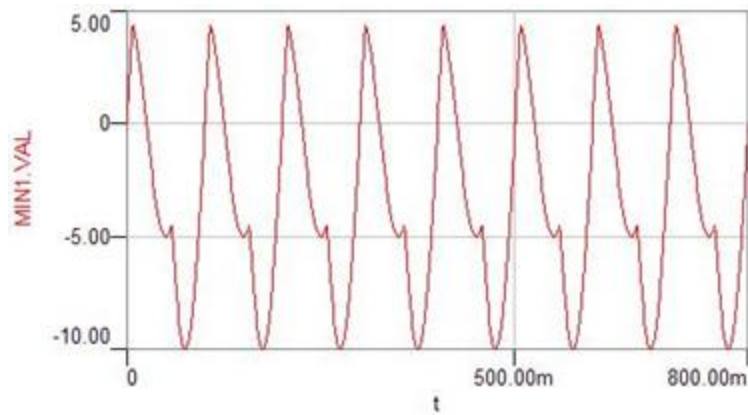
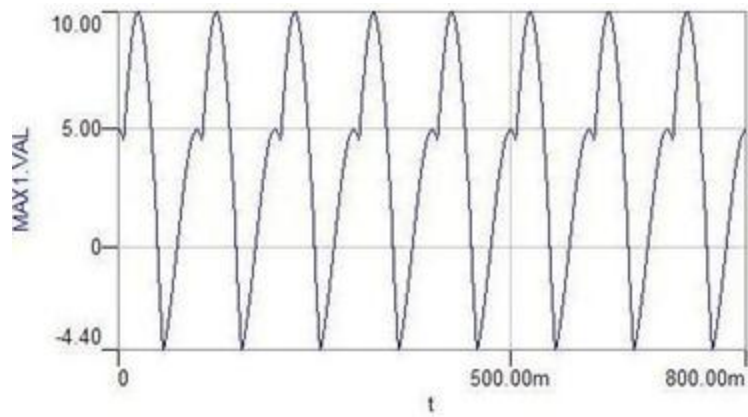


Figure 3. Simulation results-output waveforms of Sine and Cosine**Figure 4. Simulation results-output of MIN1****Figure 5. Simulation results-output of MAX1**[Top](#)**References**

Minimum of Input Signals

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

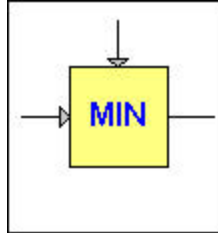


Figure 1. Component Symbol.

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Description

The block provides the minimum value from all input signals at each time step at the block output. The component cannot be used with AC and DC simulation.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

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Mathematical Description

The output of the Minimum of the Input Signal function can be expressed as following:

$$y(k) = \text{Min}(x_1(k), x_2(k), \dots, x_n(k))$$

where $y(k)$ is the output signal at the simulation time step k , and $x_i(k)$ is the i^{th} input signal at the simulation time step k .

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
TS	Sample Time	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real
INPUT[n]	Input Signal	Input	real

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Example

Figure 2 shows application of the Maximum and Minimum of Input Signals models. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 3 - 5.

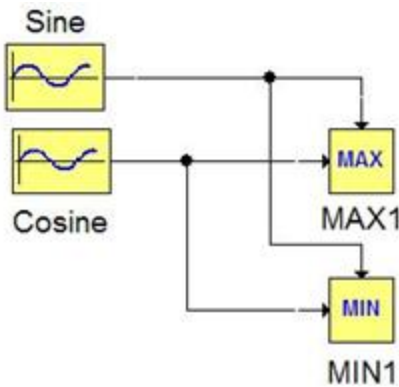


Figure 2. Application example of the Maximum and Minimum of Input Signals models**Table 3**

Component	Parameter	Value
Sine Wave Sine	AMPL	10
	PHASE	0 [degree]
	FREQ	10 [Hz]
	TDELAY	0 [s]
	OFF	0
Sine Wave Cosine	AMPL	5
	PHASE	90 [degree]
	FREQ	10 [Hz]
	TDELAY	0 [s]
	OFF	0

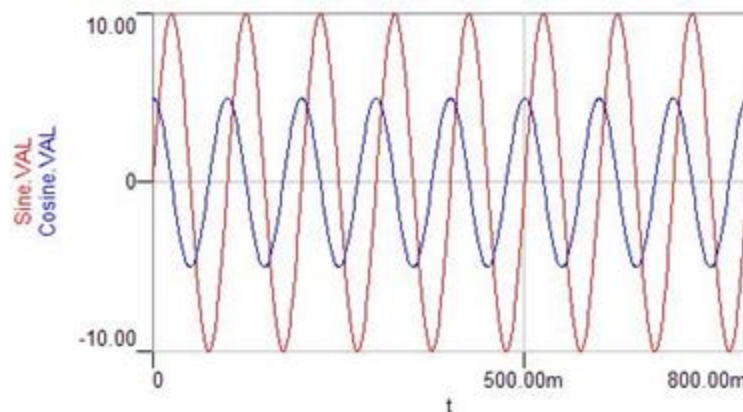
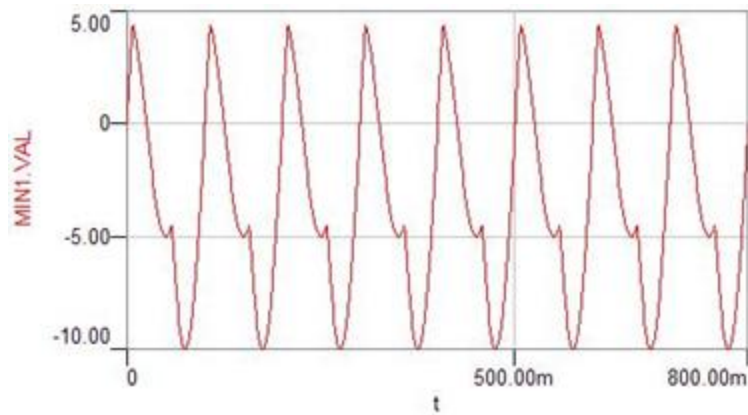
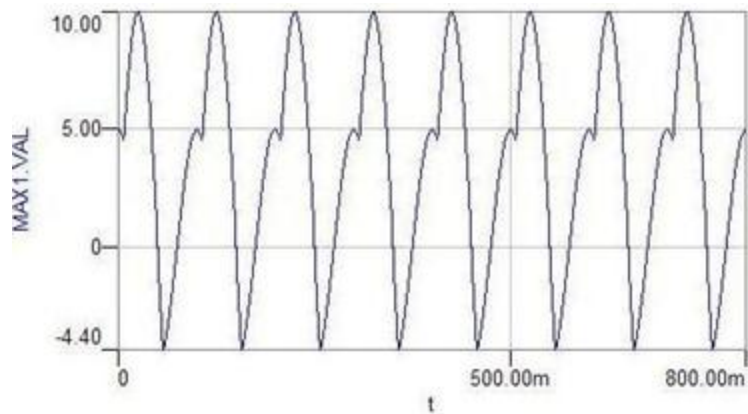


Figure 3. Simulation results-output waveforms of Sine and Cosine**Figure 4. Simulation results-output of MIN1****Figure 5. Simulation results-output of MAX1**[Top](#)**References**

Maximum/Minimum Value at Time T

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

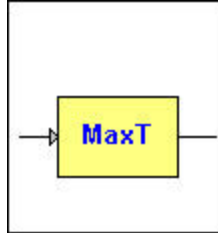


Figure 1. Component Symbol.

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Description

The block provides the maximum/minimum input signal to the current simulation time at the block output. The defined initial value applies at the block output as long as the input signal has crossed this value at least once. The component cannot be used with AC and DC simulation.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

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Mathematical Description

The output of the Maximum/Minimum Value at Time T block can be expressed as following:

If 'Maximum T' option is selected:

$$y(k) = \text{Max}(x(k)) \cdot \text{FACT}, \text{ if } x(k) > \text{Max}(x(k-1)) \quad x(k) > \text{Initial value}$$

If 'Minimum T' option is selected:

$$y(k) = \text{Min}(x(k)) \cdot \text{FACT}, \text{ if } x(k) < \text{Min}(x(k-1)) \quad x(k) < \text{Initial value}$$

where $y(k)$ and $x(k)$ are the output and input signal at the simulation time step k , respectively; $Y0$ is the initial value.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
FACT	Adaption factor for the output signal	real	1
TS	Sample Time	real	0 [s]
Y0	Initial value	real	0

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real
INPUT	Input Signal	Input	real

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Example

Figure 2 shows application of the Maximum/Minimum Value at Time T model. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 3.

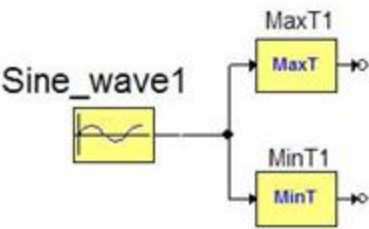


Figure 2. Application example of the Nonlinear Transfer Function model

Table 3

Component	Parameter	Value
Maximum/Minimum Value at Time T (Maximum T) MaxT1	TS*	0 [s]
	FACT	1
	Y0	0
Maximum/Minimum Value at Time T (Minimum T) MinT1	TS*	0 [s]
	FACT	1
	Y0	0
Sine Wave Sine_wave1	AMPL	1
	FREQ	2 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0

* System simulation time step is used for the sample time of MaxT1 and MinT1.

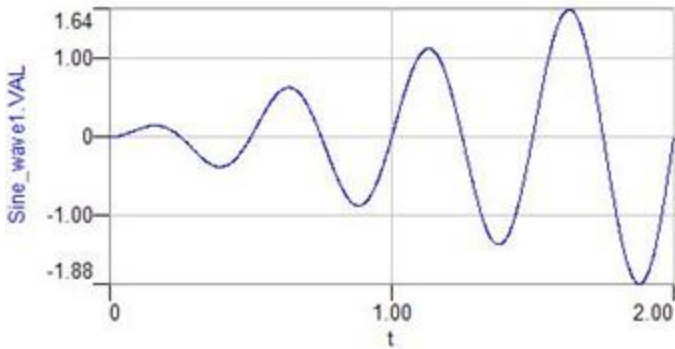
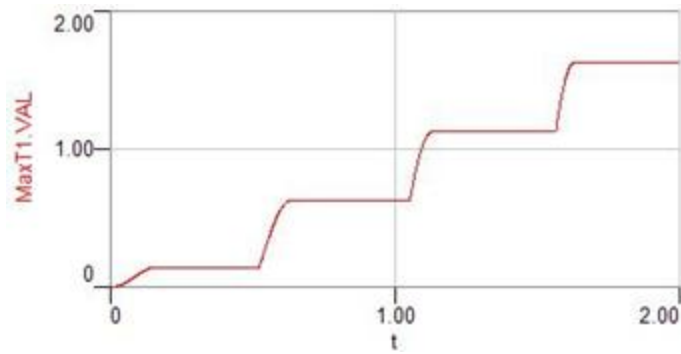
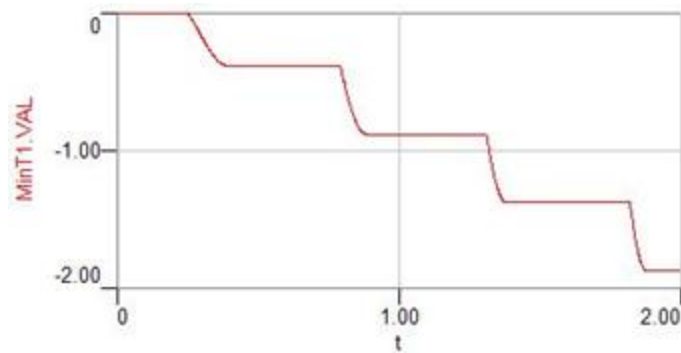


Figure 3. Simulation results – output of Sine_wave1**Figure 4. Simulation results – output of MaxT1****Figure 5. Simulation results – output of MinT1**[Top](#)

References

Multiplier

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

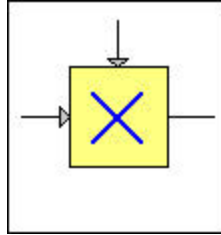


Figure 1. Component Symbol.

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Description

The block multiplies all input signals at each time step and provides the result at the block output.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

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Mathematical Description

The output of the Multiplier block can be expressed as following:

$$y(k) = x_1(k) \cdot x_2(k) \cdot \dots \cdot x_n(k)$$

where $y(k)$ is the output signal at the simulation time step k , and $x_i(k)$ is the i^{th} input signal at the simulation time step k .

Note: In the MUL block, Sign option (+ / -) can be used to negate the input signal. Using the (-) option in the Sign field negates the value of the input signal.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
TS	Sample Time	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real
INPUT[n]	Input Signal	Input	real

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Example

Figure 2 shows application of the Multiplier model. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 3 - 5.

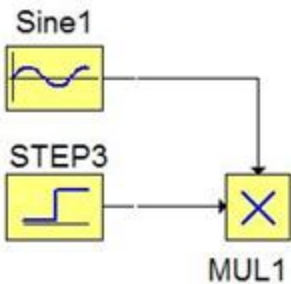


Figure 2. Application example of the Multiplier models**Table 3**

Component	Parameter	Value
Step Function STEP3	AMPL	2
	T0	0.02 [s]
	TS*	0 [s]
	Y0	0
	AC_MAG	1m
	AC_PHASE	0 [degree]
Sine Wave Sine1	AMPL	10
	FREQ	10 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0

* System simulation time step is used for the sample time of STEP3.

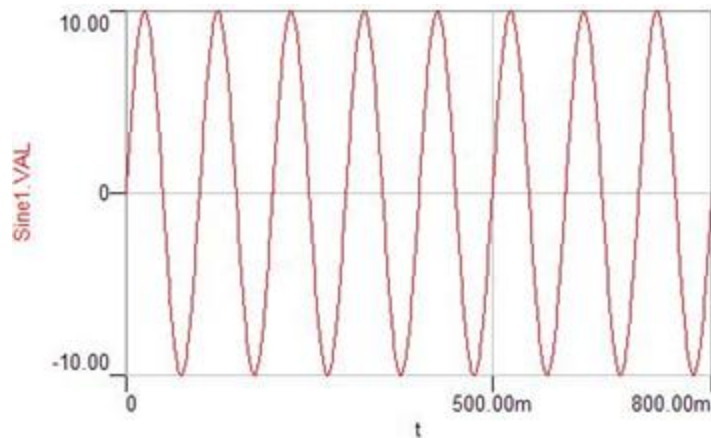
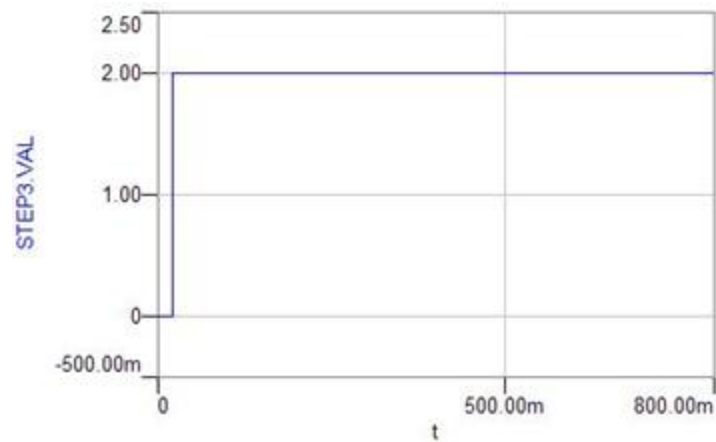
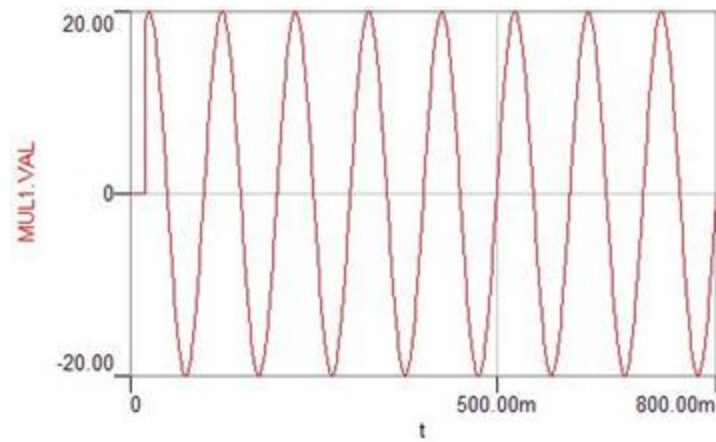


Figure 3. Simulation results-output of Sine1**Figure 4. Simulation results-output of STEP3****Figure 5. Simulation results-output of MUL1**[Top](#)

References

Multidimensional Table Block

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

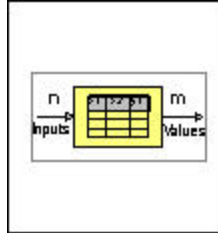


Figure 1. Component Symbol.

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Description

The multidimensional table block provides a table of output signals which dependent on different, nonlinear input signals. Each input signal (non-conservative node) has a specific characteristic with extrapolation type. The characteristics of input signals can also be imported from a Twin Builder .mdx file.

Note: NDTAB and NDNL belong to different component types.

NDTAB is solved by the circuit simulator: for more detailed information, see *Circuit Simulator Processing* in the main Twin Builder help.

NDNL is solved by the block diagram simulator: for more detailed information, see *Block Diagram Simulator Processing* in the main Twin Builder help.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

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Mathematical Description

$$\mathbf{val}[n](t) = f(\mathbf{x}(\text{QUANT})[m])$$

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
INPUT[n]	Input Signal	real	
FILE	Table File Name	string	
IP	Interpolation Type	string	NOSPLINE
EP[n]	Extrapolation Type	string	LINEAR
TS	Sample Time	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL[n]	Output Vector	Output	real
dVAL[n][m]	Derivative of Output Vector	Output	real

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Example

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References

Negator

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

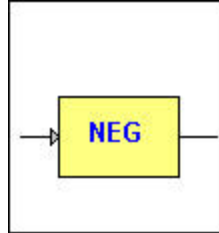


Figure 1. Component Symbol.

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Description

The block multiplies the input signal at each time step with -1 and provides the result at the block output.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

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Mathematical Description

The output of the Negator block can be expressed as following:

$$y(k) = -x(k)$$

where $y(k)$ and $x(k)$ are the output and input signal at the simulation time step k , respectively.

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Netlist Syntax

```
INTERN NEG ?InstanceName(@InstanceName):(@ (Refbase)@(ID)) (INPUT:=@(INPUT),
TS:=@(TS));
```

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
TS	Sample Time	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real
INPUT	Input Signal	Input	real

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Example

Figure 2 shows application of the Negator model. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 3.



Figure 2. Application example of the Negator models

Table 3

Component	Parameter	Value
Negator NEG1	TS*	0 [s]

Sine Wave Sine_wave2	AMPL	1
	FREQ	1 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0

* System simulation time step is used for the sample time of NEG1.

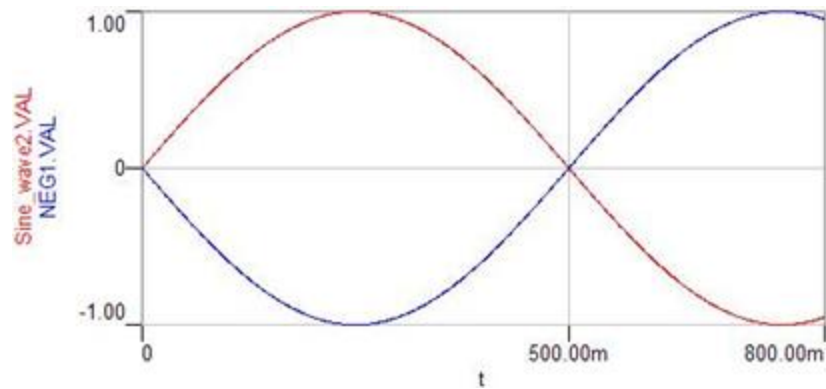


Figure 3. Simulation results-input and output of NEG1

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References

Nonlinear Transfer Function

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

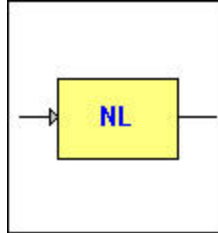


Figure 1. Component Symbol.

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Description

The block represents a nonlinear transfer behavior.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

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Mathematical Description

The output of the Nonlinear Transfer Function block can be expressed as following:

$$y(k) = f(x(k))$$

where $y(k)$ and $x(k)$ are the output and input signal at the simulation time step k , respectively; $f(*)$ is the nonlinear function.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
CH	Characteristic	real	--
TS	Sample Time	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real
INPUT	Input Signal	Input	real

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Example

Figure 2 shows application of the Nonlinear Transfer Function model. The nonlinear characteristic of the Nonlinear Transfer Function model NL1 is defined by the Exponential Function EXP1. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 3.

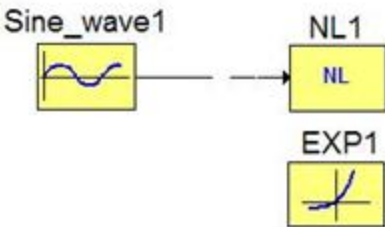


Figure 2. Application example of the Nonlinear Transfer Function model

Table 3

Component	Parameter	Value
Nonlinear Transfer Function NL1	TS*	0 [s]
	CH	EXP1
Sine Wave Sine_Wave1	AMPL	1
	FREQ	2 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0
Exponential Function EXP1	VT	1 [V]
	ISAT	2 [A]
	RR	10 [Ohm]

* System simulation time step is used for the sample time of NL1.

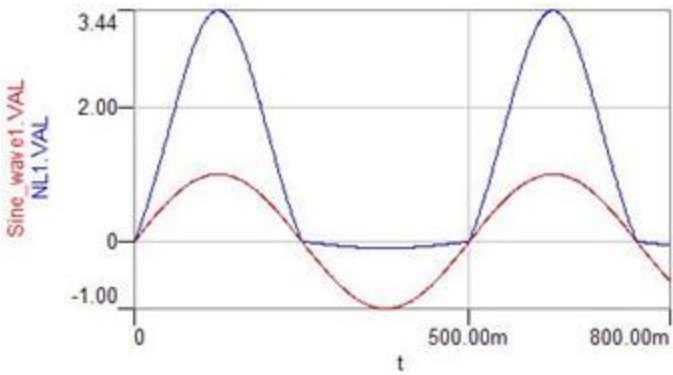


Figure 3. Simulation results-input and output of NL1

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References

N-Point Element

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

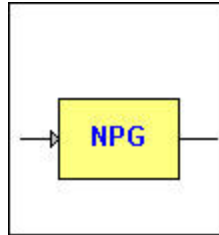


Figure 1. Component Symbol.

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Description

The input signal $x(k)$ is compared with n thresholds starting from the lowest. If the value of x is greater than to the n^{th} threshold the $(n+1)$ threshold amplitude is given to the output. If the input signal is lower than the smallest n^{th} threshold, the n^{th} threshold amplitude is issued.

Note: The user must always define one amplitude more than the number of thresholds.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

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Mathematical Description

The output of the Multiplier block can be expressed as following:

$$\begin{aligned} \text{If } x(k) > \text{THRES}(n) & \quad y(k) = \text{AMPL}(n+1) \\ \text{If } x(k) \leq \text{THRES}(n) & \quad y(k) = \text{AMPL}(n) \end{aligned}$$

where $y(k)$ and $x(k)$ are the output and input signal at the simulation time step k , respectively; $\text{THRES}(n)$ is the n^{th} threshold.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
NTHRES	Number of Thresholds	real	2
THRES[n]	Threshold	real	0
AMPL[n]	Value	real	1
TS	Sample Time	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real
INPUT	Input Signal	Input	real

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Example

Figure 2 shows application of the Two-point Element with Hysteresis model. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 3.

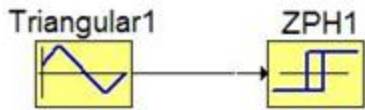


Figure 2. Application example of the Two-point Element with Hysteresis model

Table 3

Component	Parameter	Value
Two-point Element with Hysteresis ZPH1	TS*	0 [s]
	T1	-0.5
	T2	0.8
	VAL1	0.5
	VAL2	-0.6
Triangular Wave Triangular1	AMPL	1
	FREQ	2 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0

* System simulation time step is used for the sample time of ZPH1.

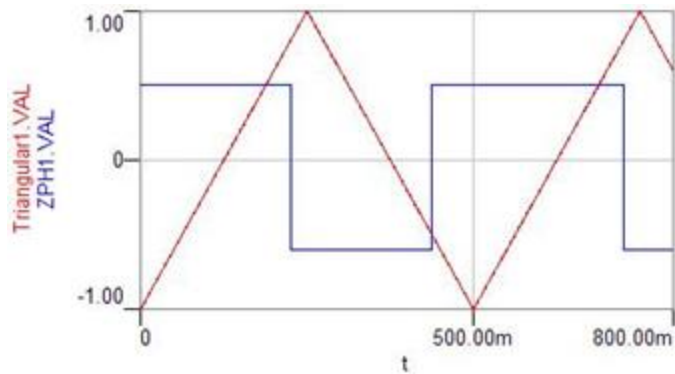


Figure 3. Simulation results-input and output of TPH1

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References

Summation

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

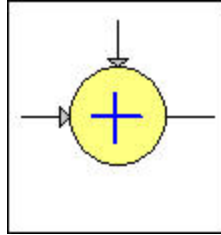


Figure 1. Component Symbol.

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Description

The block adds up all input signals at each time step and provides the result at the block output.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

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Mathematical Description

The output of the Sumation block can be expressed as following:

$$y(k) = x_1(k) + x_2(k) + \dots + x_n(k)$$

where $y(k)$ is the output signal at the simulation time step k , and $x_i(k)$ is the i^{th} input signal at the simulation time step k .

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
TS	Sample Time	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real
INPUT[n]	Input Signal	Input	real

[Top](#)

Example

Figure 2 shows application of the Summation model. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 3 - 5.

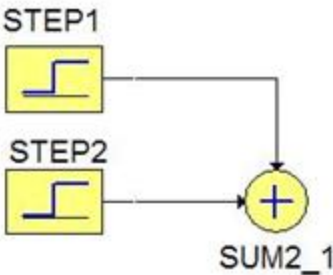


Figure 3. Application example of the Summation model

Table 3

Component	Parameter	Value
Step Function STEP1	AMPL	1
	T0	0 [s]
	TS*	0 [s]
	Y0	0
	AC_MAG	1m
	AC_PHASE	0 [degree]
Step Function STEP2	AMPL	-1
	T0	40m [s]
	TS*	0 [s]
	Y0	0
	AC_MAG	1m
	AC_PHASE	0 [degree]

* System simulation time step is used for the sample time of STEP1 and STEP2.

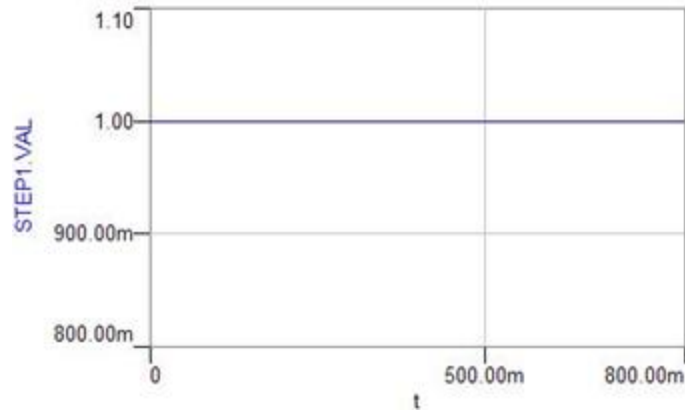
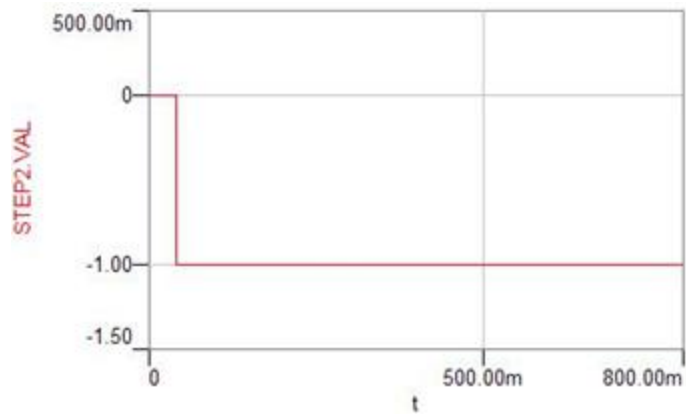
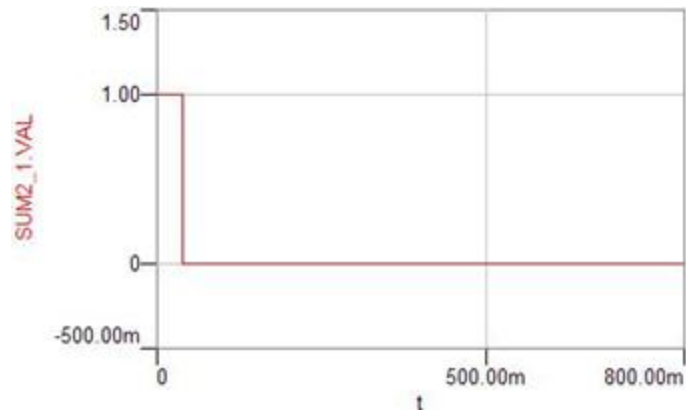


Figure 4. Simulation results-output of STEP1**Figure 5. Simulation results-output of STEP2****Figure 6. Simulation results-output of SUM2_1**[Top](#)**References**

Two-point Element with Hysteresis

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

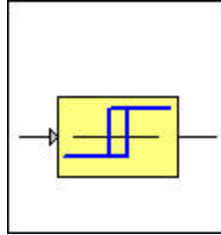


Figure 1. Component Symbol.

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- [Mathematical Description](#)
- [Netlist Syntax](#)
- [Parameters](#)
- [Input/Output Quantities](#)
- [Example](#)
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Description

The block represents a two-point element **with** hysteresis. The component cannot be used with AC and DC simulation.

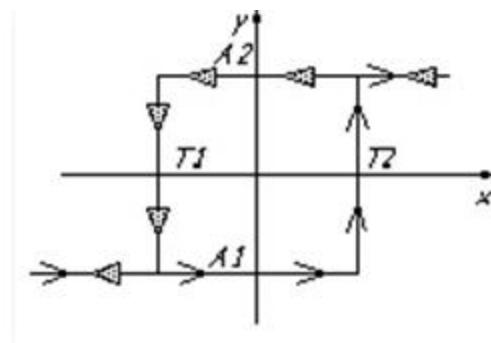


Figure 2. Input and Output waveforms as the input crosses the threshold T

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

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Mathematical Description

The output of the Multiplier block can be expressed as following:

$$\begin{aligned}
 y(k) &= A1, \text{ if } x(k) < T1 \\
 y(k) &= A1, \text{ if } x(k) < T2 \text{ and } A(k-1) = A1 \\
 y(k) &= A2, \text{ if } x(k) > T2 \\
 y(k) &= A2, \text{ if } x(k) > T1 \text{ and } A(k-1) = A2
 \end{aligned}$$

where $y(k)$ and $x(k)$ are the output and input signal at the simulation time step k , respectively; $T1$ and $T2$ are the thresholds.

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Netlist Syntax

```

INTERN TPH ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) (INPUT:=@(INPUT),
THRES1:=@(THRES1), THRES2:=@(THRES2), VAL1:=@(VAL1), VAL2:=@(VAL2), Y0:=@
(Y0), TS:=@(TS));

```

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
T1	Threshold T1	real	0
T2	Threshold T2	real	0
VAL1	Value A1	real	1
VAL2	Value A2	real	-1
TS	Sample Time	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real
INPUT	Input Signal	Input	real

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Example

Figure 2 shows application of the Two-point Element with Hysteresis model. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 3.

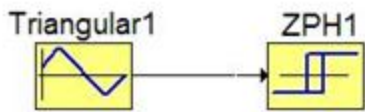


Figure 2. Application example of the Two-point Element with Hysteresis model

Table 3

Component	Parameter	Value
Two-point Element with Hysteresis ZPH1	TS*	0 [s]
	T1	-0.5
	T2	0.8
	VAL1	0.5
	VAL2	-0.6
Triangular Wave Triangular1	AMPL	1
	FREQ	2 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0

* System simulation time step is used for the sample time of ZPH1.

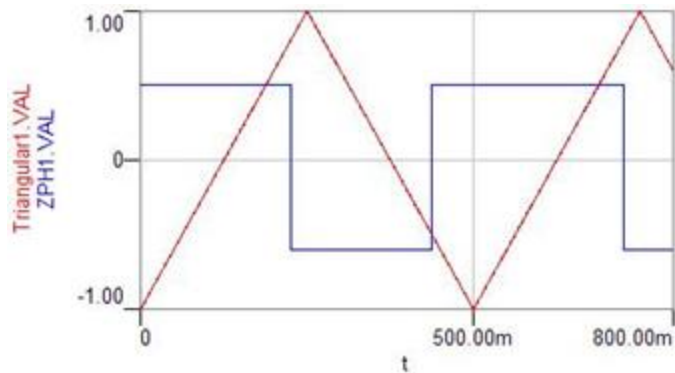


Figure 3. Simulation results-input and output of ZPH1

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References

Source Blocks

- [Constant Value \(CONST\)](#)
- [Random \(RANDOM\)](#)
- [Step Function \(STEP\)](#)

Constant Value

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

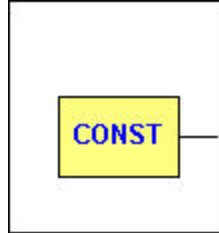


Figure 1. Component Symbol.

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Description

The block provides a value calculated at each simulation step.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

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Mathematical Description

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
CONST	Constant Value	real	1
TS	Sample Time	real	0 [s]
AC_MAG	Magnitude AC Analysis	real	1m
AC_PHASE	Phase Shift AC Analysis	real	0 [degree]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real

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Example

Figure 2 shows application of the Constant Source model. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 3.

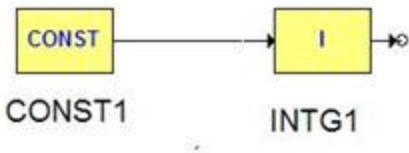


Figure 3. Application example of the Constant Source model

Table 3

Component	Parameter	Value

Constant Source CONST1	CONST	5
	TS*	0 [s]
	AC_MAG	1m
	AC_PHASE	0 [degree]
Integrator INTG1	KI	1
	Y0	0
	UL	4
	LL	0
	TRIGSIG	0
	TRIGVAL	0
	CTRL	0
	TS*	0 [s]

* Sample time of CONST1 and INTG is set to system simulation time.

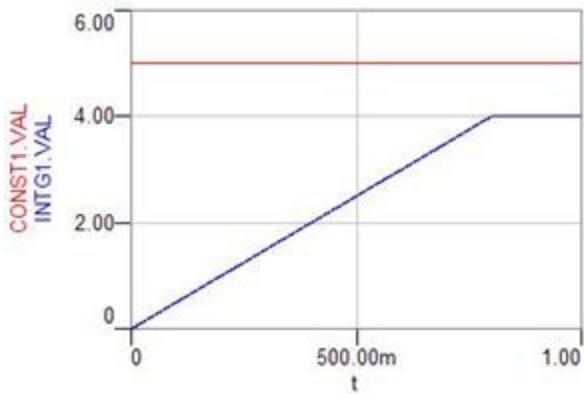


Figure 4. Simulation results-input signal of INTG1

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References

Random

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

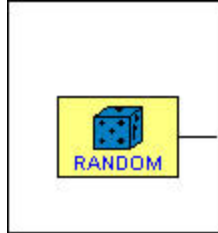


Figure 1. Component Symbol.

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Description

The block provides to each simulation step a random number within the defined range of values at the block output.

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

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Mathematical Description

The output of the Random Source can be expressed as following:

$$\text{MIN} \leq y(k) \leq \text{MAX}$$

where $y(k)$ is the output signal at simulation time step k .

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
MAX	Maximum Random Value	real	1
MIN	Minimum Random Value	real	-1
TS	Sample Time	real	0 [s]
AC_MAG	Magnitude AC Analysis	real	1m
AC_PHASE	Phase Shift AC Analysis [deg]	real	0 [degree]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real

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Example

Figure 2 shows application of the Random Source model. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 3 and 4.



Figure 2. Application example of the Random Source model

Table 3

Component	Parameter	Value
Constant Source CONST1	CONST	5
	TS*	0 [s]
	AC_MAG	1m
	AC_PHASE	0 [degree]
Integrator INTG1	KI	1
	Y0	0
	UL	4
	LL	0
	TRIGSIG	0
	TRIGVAL	0
	CTRL	0
	TS*	0 [s]

* Sample time of CONST1 and INTG is set to system simulation time.

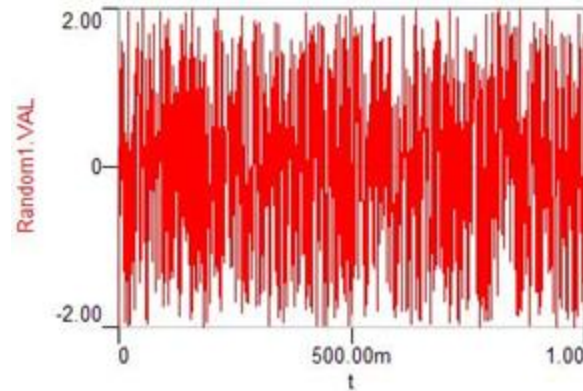


Figure 3. Simulation results-output signal of Random1

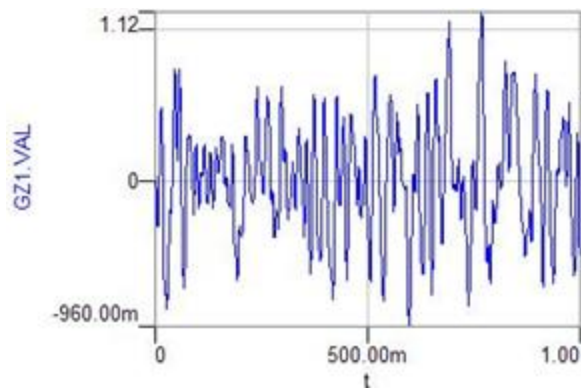


Figure 4. Simulation results-output signal of GZ1

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References

Step Function

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

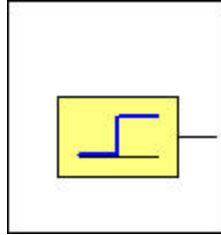


Figure 1. Component Symbol.

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Description

The block provides a signal that changes at time $t=T_0$ instantly from an initial value Y_0 to the specified amplitude value K .

To define the amplitude value and initial delay, enter a numerical value, a variable, or expression in the parameter list. The initial delay is set only once at the start of the simulation.

The sample time is a static value. Enter a numerical value in the parameter list. If '0' is specified, the simulator-defined variable sample time is used. The sample time must be greater than H_{MIN} .

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Assumptions and Limitations

For information regarding connecting block input and outputs, see [Connecting Transfer Blocks](#)

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Mathematical Description

The output of the Step Function can be expressed as following:

$$\begin{aligned} y(k) &= 0 && \text{for } t < T_0 \\ y(k) &= \text{AMPL} && \text{for } t \geq T_0 \end{aligned}$$

where $y(k)$ is the output signal at simulation time step k .

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
T0	Step Time	real	0
AMPL	Final Value	real	1
Y0	Init Value	real	0
TS	Sample Time	real	0 [s]
AC_MAG	Magnitude AC Analysis	real	1m
AC_PHASE	Phase Shift AC Analysis [deg]	real	0 [degree]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Block output signal	Output	real

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Example

Figure 2 shows application of the Discrete Integrator model. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 3.

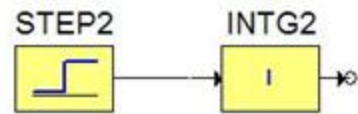


Figure 2. Application example of the Discrete Transfer Function model

Table 3

Component	Parameter	Value
Step Function STEP1	AMPL	1
	T0	0 [s]
	TS*	0 [s]
	Y0	0
	AC_MAG	1m
	AC_PHASE	0 [degree]
Discrete Integrator INTG2	KI	1
	Y0	0
	UL**	
	LL**	
	TRIGSIG	0
	TRIGVAL	0
	CTRL	0
	TS	0 [s]

* System time is used as the sample time for STEP1 and INTG2.

** There are no integration limits.

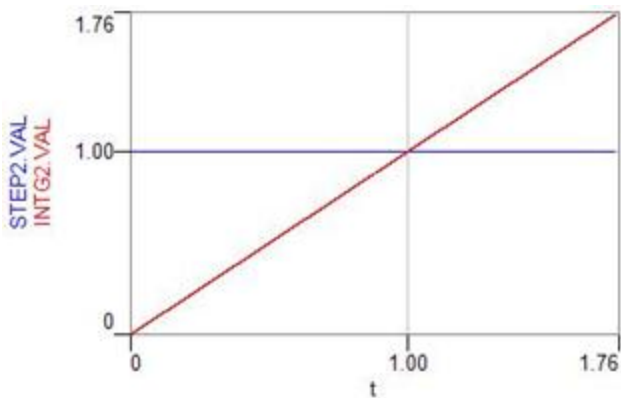


Figure 3. Simulation results-input and output signal of INTG2

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References

Modeling with Circuit Components

An internal identifier, its name, their conservative nodes and a set of parameters define electrical domain components. Terminals of conservative nodes cannot be deleted on the sheet. Electrical domain components appear in the Circuit folder in the Basic Elements library. Select the folder Circuit, choose one of the groups, click a name, drag the component onto the sheet and release the mouse button.

All kinds of linear and nonlinear components can be used to model electrical circuits. However, only electrically reasonable circuits lead to correct simulation results. Voltage sources, current sources and switches are ideal components. Each independent circuit must be connected to a ground node at least once.

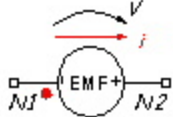
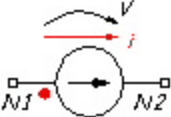
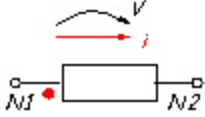
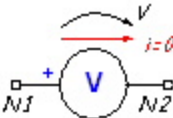
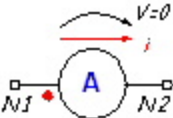
The *Circuits* folder provides components in the following categories:

- [Electrical Machines](#)
- [Ideal Switches](#)
- [Passive Elements](#)
- [Semiconductor System Level](#)
- [Semiconductor Device Level](#)
- [Sources](#)
- [Spice-Compatible Models](#)
- [Transformers](#)

See also [Network Configurations](#)

Reference Arrow System of Circuit Components

The red point or the plus sign at the symbol of electrical components marks the counting direction of current and voltage.

	Voltage Sources	Current Sources	Passive Components
Electrical			
	Voltmeter	Ammeter	Wattmeter
Meters			

Network Configurations

In Simplorer, only ammeters are allowed as controlling components for current-controlled elements. These must be inserted properly in the controlling branch. If sources are part of mutual controlling sources in the circuit, stability problems may occur if the total gain of the loop is greater than or equal to one.

The following types of network configurations are invalid:

- Series connection of ideal current sources
- Series connection of inductors and ideal current sources
- Series connection of inductors with different initial values of current, i.e., $I01 \neq I02$
- Series connection of an inductor with an initial current value and an opened ideal switch or non-conducting system level semiconductor
- Parallel connection of ideal voltage sources
- Parallel connection of capacitors with ideal voltage sources
- Parallel connection of capacitors with different initial values of voltage, i.e., $V01 \neq V02$
- Meshes which consist only of ideal sources (short-circuit)
- Open-ended branches

Electrical Machines

Alternator

- [Alternator Model - Synchronous Machine with Rectifier \(alternator\)](#)
- [Alternator - Average Model with Voltage Control \(alternator_avg\)](#)
- [Alternator - Current Source Static Model \(alternator_cs\)](#)

DC Machine

- [DC Machine Electrical Excitation \(DCME\)](#)
- [DC Machine Electrical Nonlinear Excitation \(DCMENL\)](#)
- [DC Machine with Mechanical Connection \(dcmotor\)](#)
- [DC Machine Permanent Excitation \(DCMP\)](#)
- [Permanently Excited DC Machine \(MchRDcmp\)](#)

Induction Machine

- [Induction Machine \(IM\)](#)
- [Slip-Ring Induction Machine \(MchRAsms\)](#)

Starter

- [Starter Model with Mechanical Connection \(starter\)](#)

Synchronous Machine

- [Permanently Excited Synchronous Machine MchRSymp\)](#)
- [Permanently Excited Synchronous Machine with Damper \(MchRSympd\)](#)
- [Synchronous Machine Electrical Excitation without Damper \(SYME\)](#)
- [Synchronous Machine Electrical Excitation with Damper \(SYMED\)](#)
- [Synchronous Machine Permanent Excitation without Damper \(SYMP\)](#)
- [Synchronous Machine Permanent Excitation with Damper \(SYMPD\)](#)

Alternator — Transient Model

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

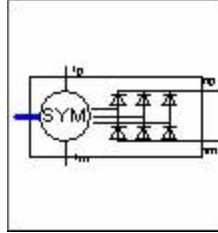


Figure 1. Component symbol

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- [Mathematical Description](#)
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Description

The model represents a fully transient alternator motor using a combination of a synchronous machine without damper and a B6 rectifier bridge using static diode models. The model uses the same equations as the *Synchronous Machine Electrical Excitation without Damper* but treats load torque differently.

[See also Synchronous Machine Electrical Excitation without Damper.](#)

The voltage regulator has to be added to the alternator model, e.g., by inserting a PWM switch with free-wheeling diode between the battery and the field windings of the alternator.

Compared with the other alternator models provided in this folder, the fully transient model covers more dynamic effects (especially transients in the machine), but requires the longest calculation time.

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Assumptions and Limitations

- The mechanical connections of the machines are implemented using conservative nodes that follow the velocity-torque representation (velocity = across quantity, torque = through quantity).
- The model does not calculate thermal effects.
- Only basic mechanical properties are modeled.
- The time constant must be considered for the simulator's minimum time step.

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Mathematical Description

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Netlist Syntax

MODEL alternator ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) fp:= %0, fm:= %1, np:= %2, nm:= %3, rot:= %4 (r1:= @r1, l1d:= @l1d, l1q:= @l1q, lm1ed:= @lm1ed, re:= @re, le:= @le, p:= @p, j:= @j, i1a0:= @i1a0, i1b0:= @i1b0, i1c0:= @i1c0, ie0:= @ie0, phi0:= @phi0, n0:= @n0, vd:= @vd, rb:= @rb) SRC: DB(Lib:=@ModelLibraryName) ;

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
fp	Positive Excitation Terminal	Electrical terminal
fm	Negative Excitation Terminal	Electrical terminal
np	Positive Terminal	Electrical terminal
nm	Negative Terminal	Electrical terminal
rot	Shaft Torque	Rotational_v

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Parameters

Table2

Name	Description	Data Type	Default Value [Unit]
r1	Stator Resistance	real	0.4 [Ohms]
l1d	Stator Inductance d-Axis	real	0.042 [H]
l1q	Stator Inductance q-Axis	real	0.042 [H]
lm1ed	Mutual Inductance stator-exciter d-Axis	real	0.035 [H]
re	Excitation Resistance	real	1 [Ohm]
le	Excitation Inductance d-Axis	real	0.05 [H]
p	Number of Pole Pairs	real	2
j	Moment of Inertia	real	0.075 [kg*m ²]
vd	Forward Voltage of Rectifier Diode	real	0.7 [V]
rb	Bulk Resistance of Rectifier Diode	real	0.01 [Ohms]
i1a0	Initial Current Stator Phase a	real	0 [A]
i1b0	Initial Current Stator Phase b	real	0 [A]
i1c0	Initial Current Stator Phase c	real	0 [A]
ie0	Initial Excitation Current	real	0 [A]
n0	Initial Speed at t=0	real	0 [rpm]
phi0	Initial Rotor Position	real	0 [rad]

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Input/Output Quantities

Table3

Name	Description [Unit]	Direction	Data Type
v	Output Voltage [V]	Output	real
i	Output Current [A]	Output	real
n	Speed [rpm]	Output	real

omega	Angular Velocity [rad/s]	Output	real
torque	Torque [Nm]	Output	real

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Example

In this example, an alternator is run at variable speed and has a changing load resistance.

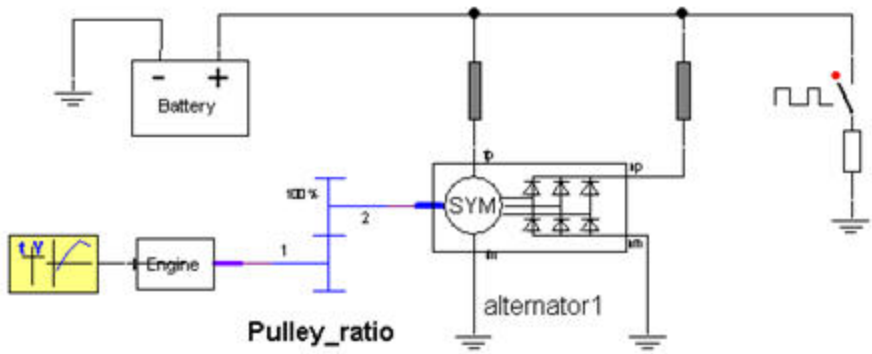


Figure 2. Application example of the Alternator-Transient model

Table 4. System Parameters

Component	Parameter	Value [unit]
Battery (battery1)	vnom	12.9 [V]
	rin	10m [Ohm]
Ideal Gearbox (Pulley_ratio)	ratio	1/3
Engine - Speed Source (engine)	n	DATAPAIRS2.VAL
2D Lookup Table (DATAPAIRS2)	x=0	y=2000
	Wire - Thermal (wire_thermal_static1)	11-0-

		0-0 [-m-m-]
		11-7-.-8-u
	Wire - Thermal (wire_field)	11-0-0-0 [-m-m-]
		11-7-.-8-u
	Alternator - Transient Model (alternator1)	01-.-4 [-O-h-m-]
	vd	0.7 [V]
PWM Load (LOAD)	period	0.5 [s]
	dc	0.5
	r	1 [Ohm]

	td	0.1 [s]

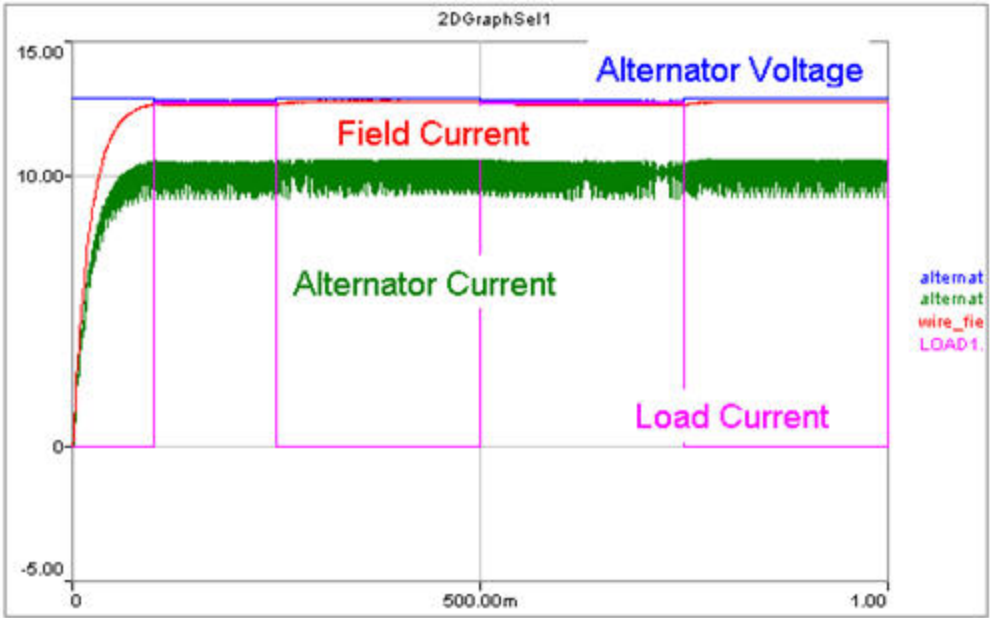


Figure 3. Simulation results-Alternator output and field current, alternator voltage, and load current.

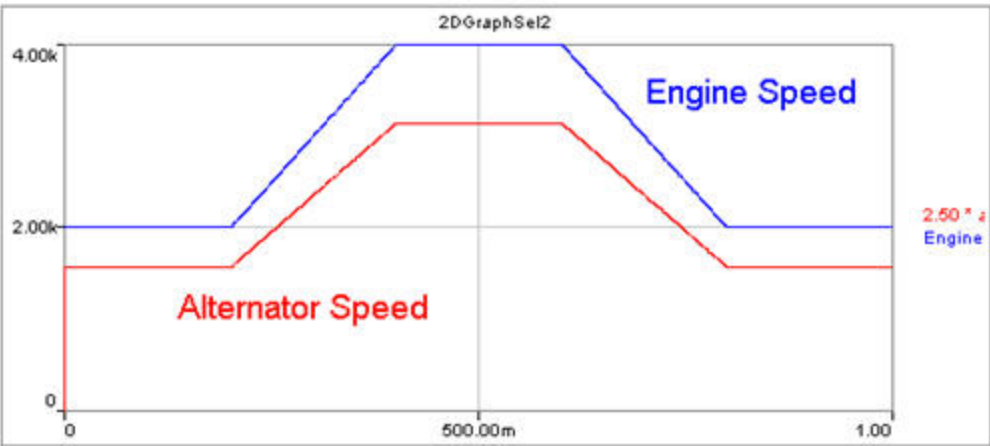


Figure 4. Simulation results-Engine and Alternator speed.

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References

Alternator – Average Model

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

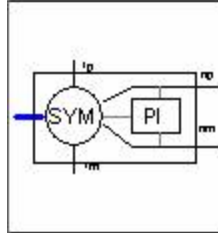


Figure 1. Component symbol

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Description

The model represents the dynamic behavior of the alternator, including its control without the effects caused by the transients inside the machine and the rectifier bridge. The stator windings of the synchronous machine and the rectifier bridge are modeled with a controlled voltage source, a controlled resistance, and a static diode.

The static diode models the rectifier bridge by multiplying the single diode voltage drop (v_d) by a factor of two.

The field winding is modeled as a serial connection of the field inductance and the field resistance. To take into account the function of the voltage regulator, the effective voltage across the field winding is calculated using an average buck-converter model working in the continuous mode.

The control loop of the alternator model consists of a PI-controller that controls the duty cycle of the buck-converter that depends on the measured output voltage and its reference value v_{ref} . The value of the integral controller and the output of the PI-controller are limited to '1'.

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Assumptions and Limitations

- The mechanical connections of the machines are implemented using conservative nodes that follow the *velocity-torque* representation (velocity = across quantity, torque = through quantity).
- The model does not calculate thermal effects.
- Only basic mechanical properties are modeled.
- The following must be considered for the minimum time step of the simulator:
 - a. The time constants of stator and field windings.
 - b. The settings of the PI controller.

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Mathematical Description

Value of voltage source:

$$V_{ind} = k \cdot I_{Field} \cdot \omega$$

Where V_{ind} is the induced voltage across the brushes of the DC machine. It is a function of the field current I_{Field} and the angular velocity, ω , of the machine in rad/sec. The value k is a voltage constant.

Equivalent stator resistance:

$$R_{equ} = \sqrt{(rs^2 + (p \cdot \omega \cdot ls)^2)}$$

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Netlist Syntax

```
MODEL alternator_avg ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) fp:= %0, fm:= %1, np:= %2, nm:= %3, rot:= %4 ( rs:= @rs, ls:= @ls, re:= @re, le:= @le, p:= @p, k:= @k, p_gain:= @p_gain, i_gain:= @i_gain, vref:= @vref, vd:= @vd) SRC: DB(Lib:- :=@ModelLibraryName);
```

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
fp	Positive Excitation Terminal	Electrical terminal

fm	Negative Excitation Terminal	Electrical terminal
np	Positive Terminal	Electrical terminal
nm	Negative Terminal	Electrical terminal
rot	Shaft	Rotational_v

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Parameters

Table2

Name	Description	Data Type	Default Value [Unit]
rs	Stator Resistance	real	0.03 [Ohms]
ls	Stator Stray Inductance	real	0.0002 [H]
re	Excitation Winding Resistance	real	3.5 [Ohms]
le	Excitation Winding Inductance	real	0.8 [H]
k	Voltage Constant	real	0.05 [V/(A*rad/s)]
p	Number of Pole Pairs	real	6
vd	Forward Voltage of Rectifier Diode	real	0.7 [V]
vref	Reference Voltage	real	14 [V]
p_gain	Proportional Gain of Voltage Controller	real	0.1
i_gain	Integral Gain of Voltage Controller	real	0.2

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Input/Output Quantities

Table3

Name	Description [Unit]	Direction	Data Type
v	Terminal Voltage [V]	Output	real
i	Output Current [A]	Output	real
n	Speed [rpm]	Output	real
omega	Angular Velocity [rad/s]	Output	real

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In this example, an alternator is run at variable speed and has a changing load resistance.



Component	Parameter	Value [unit]
Battery (battery1)	vnom	12.9 [V]
	rin	10m [Ohm]
Ideal Gearbox (Pulley_ratio)	ratio	1/3
Engine - Speed Source (engine)	n	DATAPAIRS1.VAL
2D Lookup Table (DATAPAIRS1)	x=0	y=2000
	Wire - Thermal (wire_thermal_static2)	11-0-0-0

		[- m- m-]	11- 0- 7- .- 8- u
		11- 0- 0- 0	[- m- m-]
Wire - Thermal (wire_ field)		11- 0- 0- 0	[- m- m-]
		11- 0- 7- .- 8- u	[- m- m-]
Alternator - Average Model (alternator)		5- 0- m	0.2
p_gain			0.1
i_gain			0.1
PWM Load (LOAD)	period		1 [s]
	dc		0.5
	r		1 [Ohm]

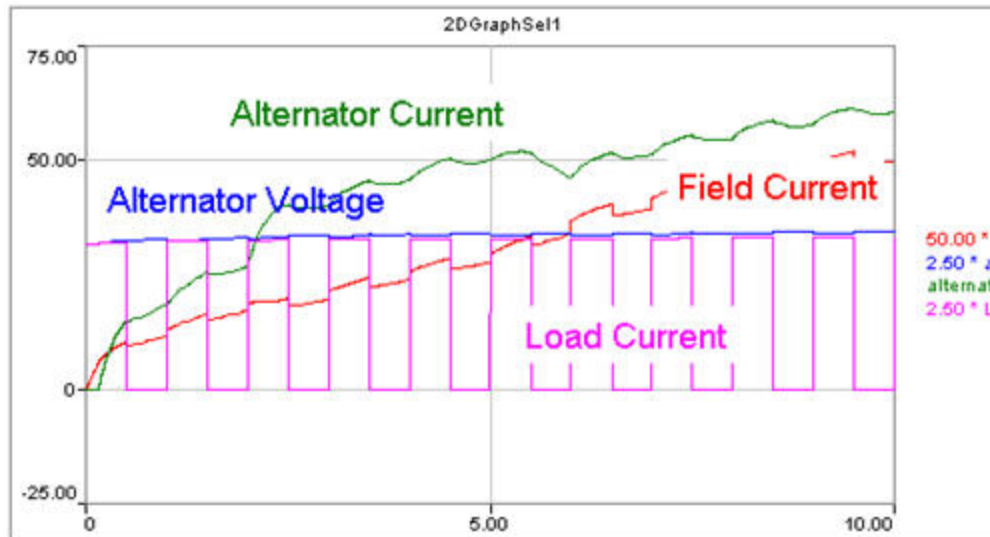


Figure 3. Simulation results-Alternator current and voltage, and load current.

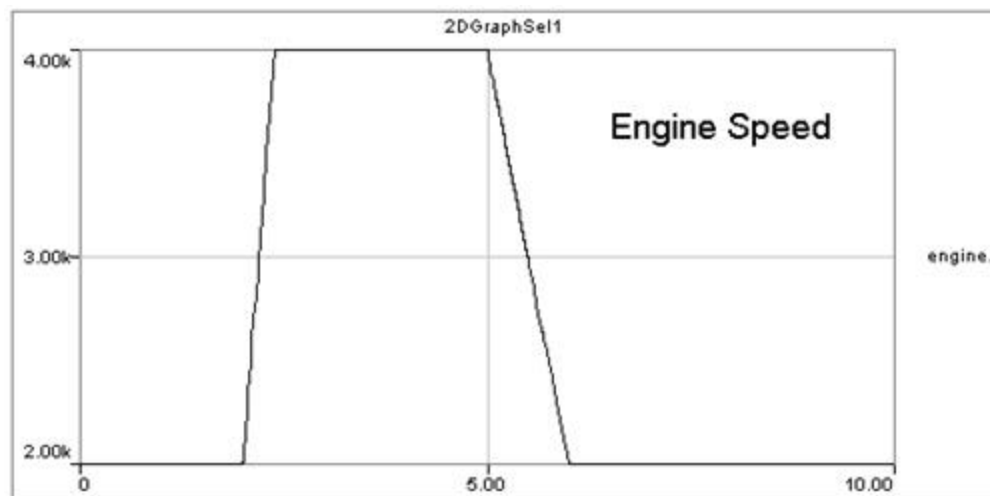


Figure 4. Simulation results-Engine speed.

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References

Alternator — Current Source

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

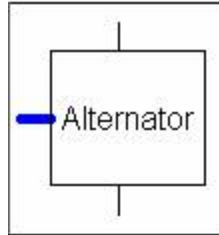


Figure 1. Component symbol

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- [Mathematical Description](#)
- [Netlist Syntax](#)
- [Conservative Pins](#)
- [Parameters](#)
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Description

This model represents an alternator as a simple current source. The current produced by the alternator depends on the alternator speed. The load torque produced by the alternator is calculated from the delivered electrical power of the alternator and its efficiency.

This model is recommended only if the general circuit conditions are close to their nominal values. Since neither the excitation circuit nor the alternator controller is modeled, deviations from the nominal conditions do not change the model behavior.

The alternator characteristic must be stored in an .mdx file. The first row contains the rotational frequency of the alternator shaft [rad/s], and the second row contains the values of the alternator current.

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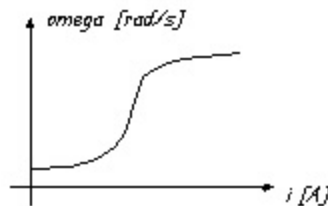
Assumptions and Limitations

- The mechanical connections of the machines are implemented using conservative nodes that follow the *velocity-torque* representation (velocity = across quantity, torque = through quantity).
- The model does not calculate thermal effects.

- Only basic mechanical properties are modeled.
- The time constant must be considered for the simulator's minimum time step.
- The alternator characteristic must be stored in an .mdx file. The first row contains the rotational frequency of the alternator shaft [rad/s], and the second row contains the values of the alternator current.

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Mathematical Description



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Netlist Syntax

```
MODEL alternator_cs ?InstanceName(@InstanceName):(@ (Refbase)@(ID)) np:= %0, nm:= %1, rot:= %2 ( char:= @char, eta:= @eta) SRC: DB(Lib:=@ModelLibraryName);
```

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
np	Positive Terminal	Electrical terminal
nm	Negative Terminal	Electrical terminal
rot	Shaft	Rotational_v

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Parameters

Table2

Name	Description	Data Type	Default Value [Unit]
char	Characteristic $I = f(\omega)$	file	alternator.mdx

eta	Efficiency	real	70 [%]

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Input/Output Quantities

Table3

Name	Description [Unit]	Direction	Data Type
v	Terminal Voltage [V]	Output	real
i	Output Current [A]	Output	real
n	Speed [rpm]	Output	real
omega	Angular Velocity [rad/s]	Output	real
torque	Shaft Torque [Nm]	Output	real

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Example

In this example, an alternator is run at variable speed and has a changing load resistance.

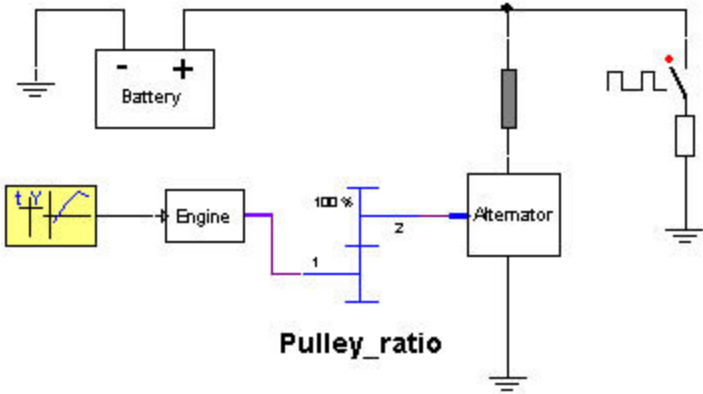


Figure 2. Application example of the Alternator-Current Source model

Table 4. System Parameters

Component	Parameter	Value [unit]
Battery (battery1)	vnom	12 [V]
	rin	10m [Ohm]
Ideal Gearbox (Pulley_ratio)	ratio	1/3
Engine - Speed Source (engine)	n	DATAPAIRS1.VAL
2D Lookup Table (DATAPAIRS1)	x=0	y=2000
	Wire - Thermal (wire_thermal_static2)	11- 0- 0- 0
		[- m- m-]
	Alternator - Current Source (alternator)	1110 7- . - 8- u
		0ta . - 7
		ahar l- t- e- r- n- a- t- o- r- . -

		m-d-x
	PWM Load (LOAD)	period
		[-s-]
dc		0.5
r		1 [Ohm]

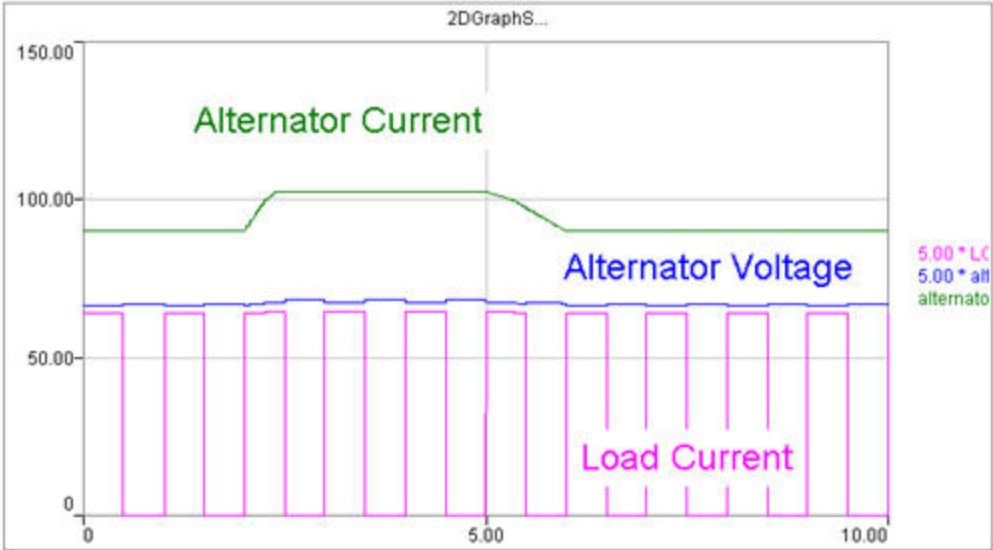
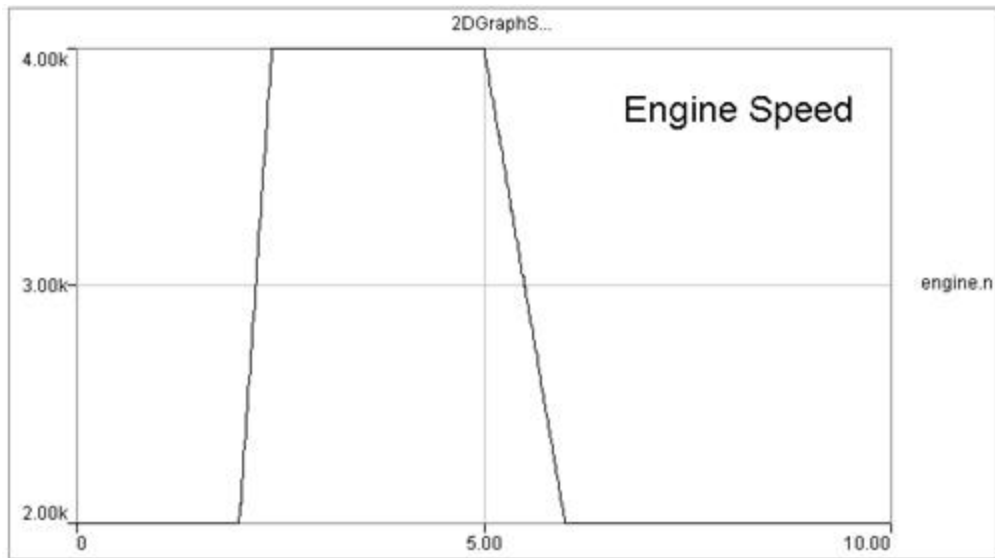


Figure 3. Simulation results-Alternator current and voltage, and load current.**Figure 4. Simulation results-Engine speed.**[Top](#)

References

DC Machine Linear Electrical Excitation

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

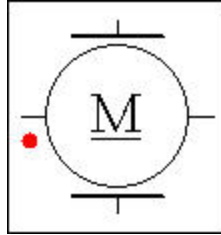


Figure 1. Component Symbol.

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Description

The model represents a DC machine as a lumped circuit component. By proper connection of armature and excitation circuit, separately excited, series and shunt machines can be modeled. The component cannot be used with AC and DC simulation.

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Assumptions and Limitations

Model Limits of DC Machine Models

- The nonlinear magnetic circuit (DC machine with Nonlinear electrical excitation) is able to consider the dependence on excitation flux and inductance caused by the excitation current.
- Armature and exciter circuit of the DC machine model are considered to be completely decoupled.
- No consideration of saturation effects in the armature q-axis caused by the armature current.

- No consideration of armature reaction on exciting field
- No consideration of eddy-current and hysteresis loss caused by armature rotation and pulsating-current supply system
- Friction losses (parasitic torques) are not considered in the model; they can be added with the load torque parameter externally

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Mathematical Description

Equation System

The equation system is implemented on condition of a linear magnetic circuit. Index **a** represents the armature circuit quantities, the index **e** the quantities of excitation circuit.

Voltage Equations

$$v_a(t) = i_a(t) \cdot R_a + \frac{di_a(t)}{dt} \cdot L_a + i_e(t) \cdot IEP\psi I \cdot \omega(t) \quad v_e(t) = i_e(t) \cdot R_e + \frac{di_e(t)}{dt} \cdot L_e$$

Flux-Linkage Equation

$$\Psi_e(t) = i_e(t) \cdot L_e$$

Torque Equation (electromagnetic developed “internal” torque)

$$m_i(t) = i_e(t) \cdot IEP\psi I \cdot i_a(t)$$

Motion Equation

$$\frac{d\omega(t)}{dt} = \frac{1}{J} (m_i(t) - m_w(t))$$

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Netlist Syntax

```
INTERN DCME ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) N1:= %0 , N2:= %1 ,
E1:= %2 , E2:= %3 ( LOAD:=@ (LOAD), RA:=@ (RA), LA:=@ (LA), RE:=@ (RE), LE:=@ (LE),
J:=@ (J), IEP\psi I:=@ (IEP\psi I), IA0:=@ (IA0), IE0:=@ (IE0), N0:=@ (N0), PHI0:=@ (PHI0) ? (Type-
e==DCMENL)(, CHLE:=@ (CHLE), CHM:=@ (CHM));
```

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
N1	Armature Circuit Node N1 (with red point)	electrical
N2	Armature Circuit Node N2	electrical
E1	Excitation Circuit Node E1	electrical
E2	Excitation Circuit Node E2	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
LOAD	Load Torque	real	0 [Nm]
RA	Armature Resistance Sum of resistances of all windings of armature circuit	real	1.2 [Ohm]
LA	Armature Inductance Sum of inductances of all windings of armature circuit	real	9.5m [H]
RE	Excitation Resistance Sum of resistances of all windings of excitation circuit	real	1.2 [Ohm]
LE	Excitation Inductance Sum of inductances of all windings of excitation circuit	real	9.5m [H]
J	Moment of Inertia	real	4m [kg*m ²]
IEPSI	Excitation Current-Flux Rate Nominal excitation flux-linkage normalized to nominal excitation current	real	1 [Vs/A]
IA0	Initial Armature Current	real	0 [A]
IE0	Initial Excitation Current	real	0 [A]
N0	Initial Rotor Speed	real	0 [rpm]
PHI0	Initial Rotor Position	real	0 [deg]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
N	Rotor Speed [rpm]	Output	real
MI	Inner Torque [Nm]	Output	real
OMEGA	Rotor Rational Speed [1/s]	Output	real
ALPHA	Angular Rotor Acceleration [1/s ²]	Output	real
PHI	Rotor Angle in Radians [rad]	Output	real
PHIDEG	Rotor Angle in Degrees [deg]	Output	real
VA	Armature Voltage [V]	Output	real
IA	Armature Current [A]	Output	real
IE	Excitation Current [A]	Output	real
PSIA	Linked Armature Flux [Vs]	Output	real
dVA	1st derivative Armature Voltage [V/s]	Output	real
dIA	1st derivative Armature Current [A/s]	Output	real
dIE	1st derivative Excitation Current [A]	Output	real
dPSIA	1st derivative linked Armature Flux [V]	Output	real
PWRELEC	Electrical Real Power Input [W]	Output	real
PWRMECH	Mechanical power output[W]	Output	real
PWRLOSS	Losses[W]	Output	real

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Example

In this example, the load torque of the DC Machine Linear Electrical Excitation DCME1 is decided by the Step Function MSchub. The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the simulation results are shown in Figure 3 and 4.

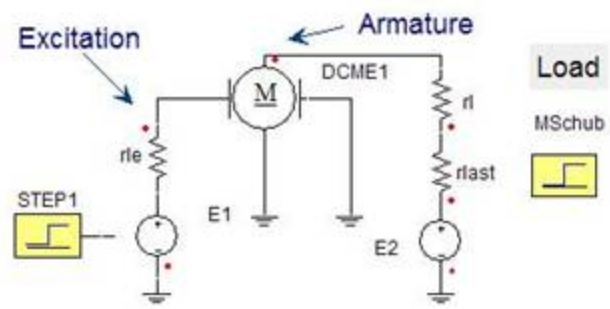


Figure 2. Application examples of DC Machine Linear Electrical Excitation**Table 4. System Parameters**

Component	Parameter	Value [unit]
DC Machine Linear Electrical Excitation DCME1	LOAD	0 [Nm]
	RA	1.2 [Ohm]
	LA	9.5m [H]
	RE	1.2 [Ohm]
	LE	9.5m [H]
	J	4m [kg*m ²]
	IEPSI	1 [Vs/A]
	IA0	0 [A]
	IE0	0 [A]
	N0	0 [rpm]
	PHI0	0 [deg]
Voltage Source E1	EMF	STEP1.VAL [V]
Voltage Source E2	EMF	90 [V]
Resistor rl/rl3	R	1m [Ohm]
Resistor rlast	R	3m [Ohm]
Step Function STEP1	VAL	440
	T0	0 [s]
	Y0	0
Step Function Mschub	VAL	50
	T0	0.5 [s]
	Y0	0

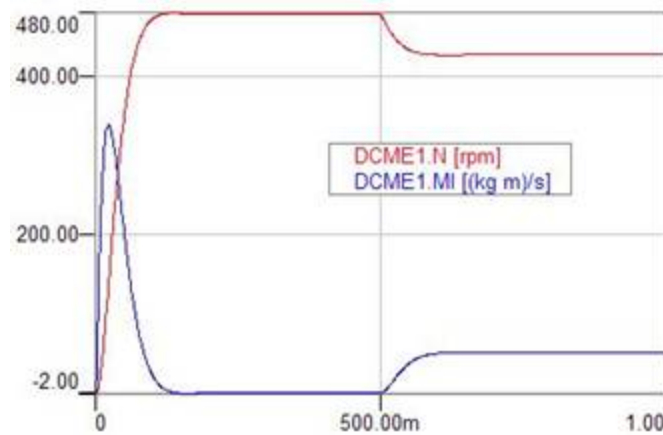


Figure 4. Simulation results-load torque and current of DCME1

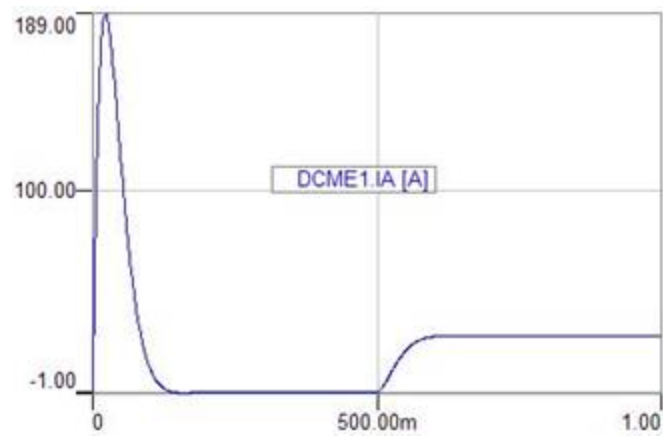


Figure 5. Simulation results-rotor speed of DCME1

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References

DC Machine Nonlinear Electrical Excitation

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

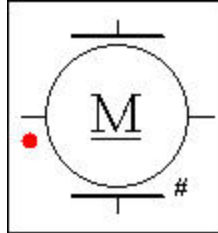


Figure 1. Component Symbol.

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Description

The model represents a DC machine as a lumped circuit component. By proper connection of armature and excitation circuit, separately excited, series and shunt machines can be modeled. The component cannot be used with AC and DC simulation.

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Assumptions and Limitations

Model Limits of DC Machine Models

- The nonlinear magnetic circuit (DC machine with Nonlinear electrical excitation) is able to consider the dependence on excitation flux and inductance caused by the excitation current.
- Armature and exciter circuit of the DC machine model are considered to be completely decoupled.
- No consideration of saturation effects in the armature q-axis caused by the armature current.

- No consideration of armature reaction on exciting field
- No consideration of eddy-current and hysteresis loss caused by armature rotation and pulsating-current supply system
- Friction losses (parasitic torques) are not considered in the model; they can be added with the load torque parameter externally

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Mathematical Description

Equation System

The equation system is implemented on condition of a nonlinear magnetic circuit (saturation) and the resulting nonlinear excitation circuit inductivity. Index **a** represents the armature circuit quantities, the index **e** the quantities of excitation circuit.

Voltage Equations

$$v_a(t) = i_a(t) \cdot R_a + \frac{di_a(t)}{dt} \cdot L_a + \Psi(i_e) \cdot \omega(t) \quad v_e(t) = i_e(t) \cdot R_e + \frac{di_e(t)}{dt} \cdot L_e(i_e)$$

Torque Equation (electromagnetic developed “internal” torque)

$$m_i(t) = \Psi(i_e) \cdot i_a(t)$$

Motion Equation

$$\frac{d\omega(t)}{dt} = \frac{1}{J} (m_i(t) - m_w(t))$$

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
N1	Armature Circuit Node N1 (with red point)	electrical

N2	Armature Circuit Node N2	electrical
E1	Excitation Circuit Node E1	electrical
E2	Excitation Circuit Node E2	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
LOAD	Load Torque	real	0 [Nm]
RA	Armature Resistance Sum of resistances of all windings of armature circuit	real	1.2 [Ohm]
LA	Armature Inductance Sum of inductivities of all windings of armature circuit	real	9.5m [H]
RE	Excitation Resistance Sum of resistances of all windings of excitation circuit	real	1.2 [Ohm]
J	Moment of Inertia	real	4m [kg*m ²]
IA0	Initial Armature Current	real	0 [A]
IE0	Initial Excitation Current	real	0 [A]
N0	Initial Rotor Speed	real	0 [rpm]
PHI0	Initial Rotor Position	real	0 [rad]
CHLE	Excitation Inductance Characteristic Sum of inductivities of all windings of excitation circuit $L_e=f(i_e)$	real	0
CHM	Magnetization Characteristic Nonlinear characteristic of excitation flux-linkage $\Psi=f(i_e)$	real	0

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type

N	Rotor Speed [rpm]	Output	real
MI	Inner Torque [Nm]	Output	real
OMEGA	Rotor rational Speed [1/s]	Output	real
ALPHA	Angular Rotor Acceleration [1/s ²]	Output	real
PHI	Rotor Angle in Radians [rad]	Output	real
PHIDEG	Rotor Angle in Degrees [deg]	Output	real
VA	Armature Voltage [V]	Output	real
IA	Armature Current [A]	Output	real
IE	Excitation Current [A]	Output	real
PSIA	Linked Armature Flux [Vs]	Output	real
dVA	1st derivative Armature Voltage [V/s]	Output	real
dIA	1st derivative Armature Current [A/s]	Output	real
dIE	1st derivative Excitation Current [A]	Output	real
dPSIA	1st derivative linked Armature Flux [V]	Output	real
PWRELEC	Electrical Real Power Input [W]	Output	real
PWRMECH	Mechanical power output[W]	Output	real
PWRLOSS	Losses[W]	Output	real

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Example

In this example, the load torque of the DC Machine Nonlinear Electrical Excitation DCMENL1 is decided by the Step Function MSchub. The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the simulation results are shown in Figure 3.

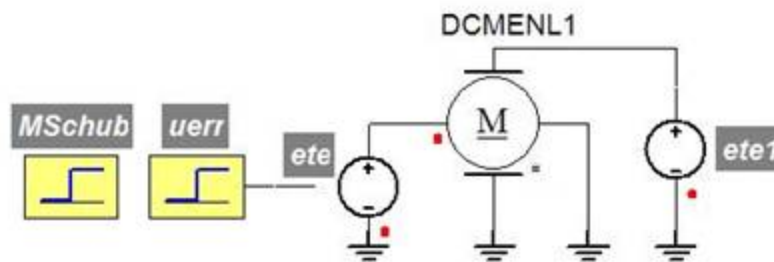


Figure 2. Application examples of DC Machine Nonlinear Electrical Excitation**Table 4. System Parameters**

Component	Parameter	Value [unit]
DC Machine Nonlinear Electrical Excitation DCMENL1	LOAD	0 [Nm]
	RA	1.2 [Ohm]
	LA	9.5m [H]
	RE	1.2 [Ohm]
	J	4m [kg*m ²]
	IA0	0 [A]
	IE0	0 [A]
	N0	0 [rpm]
	PHI0	0 [rad]
	CHLE	0
	CHM	0
Voltage Source ete	EMF	uerr.VAL [V]
Voltage Source ete1	EMF	440 [V]
Resistor rl/rl3	R	1m [Ohm]
Resistor rlast	R	3m [Ohm]
Step Function uerr	VAL	440
	T0	1m [s]
	Y0	0
Step Function Mschub	VAL	235
	T0	10m [s]
	Y0	0

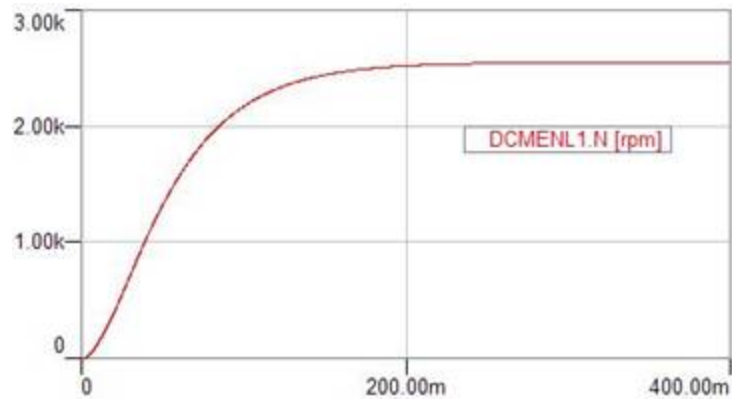


Figure 4. Simulation results-I rotor speed of DCMENL1

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References

DC Machine with Mechanical Connection

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

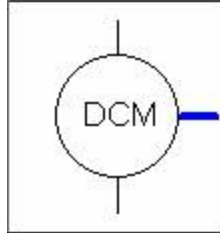


Figure 1. Component symbol

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Description

The model represents a DC machine using commonly-known machine equations.

The mechanical model of the DC machine includes the inertia and a speed-dependent friction.

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Assumptions and Limitations

- The mechanical connections of the machines are implemented using conservative nodes that follow the *velocity-torque* representation (velocity = across quantity, torque = through quantity).
- The model does not calculate thermal effects.
- Only basic mechanical properties are modeled.
- The time constant must be considered for the simulator's minimum time step.
- The mechanical model of the DC machine includes the inertia and a speed-dependent friction.

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Mathematical Description

Armature voltage:

$$V = r_a \cdot i + l_a \cdot \frac{di}{dt} + k_e \cdot \omega$$

Shaft torque:

$$T_{\text{Shaft}} = t_i - j \cdot \frac{d\omega}{dt} - c_f \cdot \omega$$

Internal torque:

$$t_i = k_e \cdot i$$

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Netlist Syntax

MODEL dcmotor ?InstanceName(@InstanceName):(@ (Refbase)@(ID)) np:= %0, nm:= %1, rot:= %2 (ra:= @ra, la:= @la, ke:= @ke, j:= @j, cf:= @cf, n0:= @n0) SRC: DB(Lib:- :=@ModelLibraryName);

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
np	Positive Terminal	Electrical terminal
nm	Negative Terminal	Electrical terminal
rot	Shaft	Rotational_v

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Parameters

Table2

Name	Description	Data Type	Default Value [Unit]
ra	Armature Resistance	real	0.01 [Ohms]
la	Armature Inductance	real	0.001 [H]

ke	Motor Constant	real	0.2 [Vs/rad]
j	Moment of Inertia	real	0.01 [kg*m ²]
cf	Friction Coefficient	real	0.1 [Nm*s/rad]
n0	Initial Speed at t=0	real	0 [rpm]

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Input/Output Quantities

Table3

Name	Description [Unit]	Direction	Data Type
v	Armature Voltage [V]	Output	real
i	Armature Current [A]	Output	real
n	Rotor Speed [rpm]	Output	real
omega	Rotor Angular Velocity [rpm/s]	Output	real
ti	Internal Torque [Nm]	Output	real

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Example

In this example, a dc motor is driven from a switched battery. The motor is loaded with a fan load. Figure 3 shows the motor current and speed as it reaches steady state.

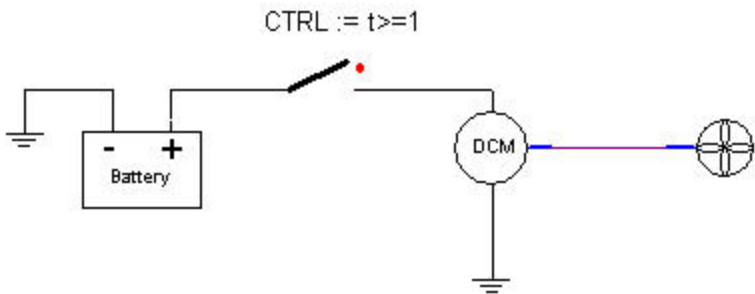


Figure 2. Application example of the dcmotor model

Table 4. System Parameters

Component	Parameter	Value [unit]

Battery (battery1)	vnom	14 [V]
	rin	10m [Ohm]
Ideal Switch (S1)	CTRL	t>=1
Fan (fan1)	cf	0[Nm*s/rad]
	windage	0.001 [Nm*s/rad] ²²
DC Machine (dcmotor1)	ra	10m [Ohm]
	la	1m [H]
	ke	100m [Vs/rad]
	j	100m [kg*m] ²
	cf	1m[Nm*s/rad]
	n0	0 [rpm]

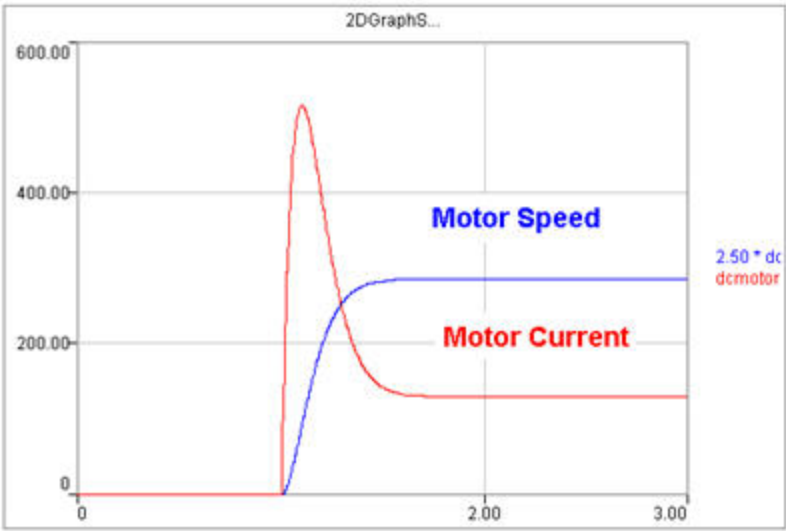


Figure 3. Simulation results-motor current and speed.

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References

DC Machine Permanent Excitation

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

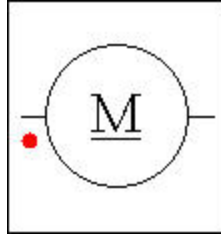


Figure 1. Component Symbol.

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Description

The model represents a DC machine with permanent excitation as a lumped circuit component. The component cannot be used with AC and DC simulation.

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Assumptions and Limitations

Model Limits of DC Machine Models

- The nonlinear magnetic circuit (DC machine with Nonlinear electrical excitation) is able to consider the dependence on excitation flux and inductance caused by the excitation current.
- Armature and exciter circuit of the DC machine model are considered to be completely decoupled.
- No consideration of saturation effects in the armature q-axis caused by the armature current.
- No consideration of armature reaction on exciting field

- No consideration of eddy-current and hysteresis loss caused by armature rotation and pulsating-current supply system
- Friction losses (parasitic torques) are not considered in the model; they can be added with the load torque parameter externally

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Mathematical Description

Equation System

The equation system is implemented on condition of a linear magnetic circuit. Index *a* represents the armature circuit quantities.

Voltage Equation

$$v_a(t) = i_a(t) \cdot R_a + \frac{di_a(t)}{dt} \cdot L_a + k_e \cdot \omega(t)$$

Torque Equation (electromagnetic developed “internal” torque)

$$m_i(t) = k_e \cdot i_a(t)$$

Motion Equation

$$\frac{d\omega(t)}{dt} = \frac{1}{J} (m_i(t) - m_w(t))$$

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Netlist Syntax

```
INTERN DCM ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) N1:= %0 , N2:= %1 (
LOAD:=@ (LOAD), RA:=@ (RA), LA:=@ (LA), KE:=@ (KE), J:=@ (J), IA0:=@ (IA0), N0:=@ (N0),
PHI0:=@ (PHI0)) ;
```

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
N1/N2	Armature Node N1 (with red point) and N2	electrical

[Top](#)**Parameters****Table 2**

Name	Description	Data Type	Default Value [Unit]
LOAD	Load Torque	real	0 [Nm]
RA	Armature Resistance Sum of resistances of all windings of armature circuit	real	1 [Ohm]
LA	Armature Inductance Sum of inductances of all windings of armature circuit	real	10m [H]
KE	Rotor Flux Linkage	real	1 [Vs]
J	Moment of Inertia	real	75m [kg*m ²]
IA0	Initial Armature Current	real	0 [A]
N0	Initial Rotor Speed	real	0 [rpm]
PHI0	Initial Rotor Position	real	0 [deg]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
N	Rotor Speed [rpm]	Output	real
MI	Inner Torque [Nm]	Output	real
OMEGA	Rotor rational Speed [1/s]	Output	real
ALPHA	Angular Rotor Acceleration [1/s ²]	Output	real
PHI	Rotor Angle in Radians [rad]	Output	real
PHIDEG	Rotor Angle in Degrees [deg]	Output	real
VA	Armature Voltage [V]	Output	real
IA	Armature Current [A]	Output	real
PSIA	Linked Armature Flux [Vs]	Output	real
dVA	1st derivative Armature Voltage [V/s]	Output	real
dIA	1st derivative Armature Current [A/s]	Output	real
dPSIA	1st derivative linked Armature Flux [V]	Output	real
PWRELEC	Electrical Real Power Input [W]	Output	real
PWRMECH	Mechanical power output[W]	Output	real
PWRLOSS	Losses[W]	Output	real

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Example

In this example, the DC Machine Permanent Excitation with Damper GSMP_1 is connected to a buck converter. The load torque of GSMP_1 is result of the summation of Step Functions STEP1 and step. The switching state of the Bipolar Junction Transistor TR1 is decided by the Controller block diagram, as shown in Figure 3. The Controller consists of a PI speed regulator and a hysteresis current loop. The schematic of the example is shown in Figure 2 and 3, system parameters are listed in Table 4, and the simulation results are shown in Figure 4 and 5.

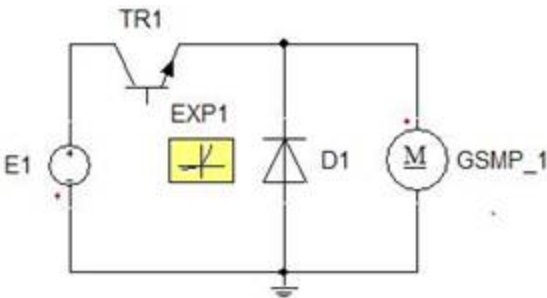


Figure 2. Application examples of DC Machine Permanent Excitation

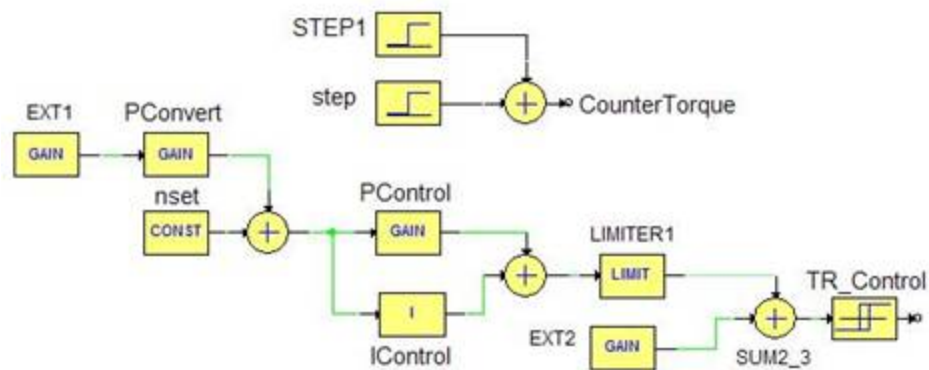


Figure 3. Controller Block Diagram

Table 4. System Parameters

Component	Parameter	Value [unit]
DC Machine Permanent Excitation GSMP_1	LOAD	0 [Nm]
	RA	1 [Ohm]
	LA	10m [H]
	KE	1 [Vs]
	J	75m [kg*m ²]
	IA0	0 [A]
	N0	0 [rpm]
	PHI0	0 [deg]
Voltage Source E1	EMF	326 [V]
Diode D1	CH	EXP1
Bipolar Junction Transistor TR1	CH	EXP1
	CTRL	TR_Control.VAL

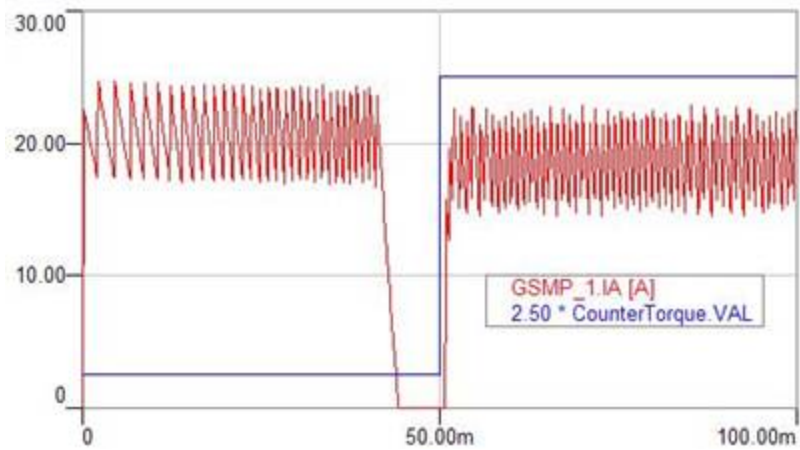


Figure 4. Simulation results-load torque and current of GSMP_1

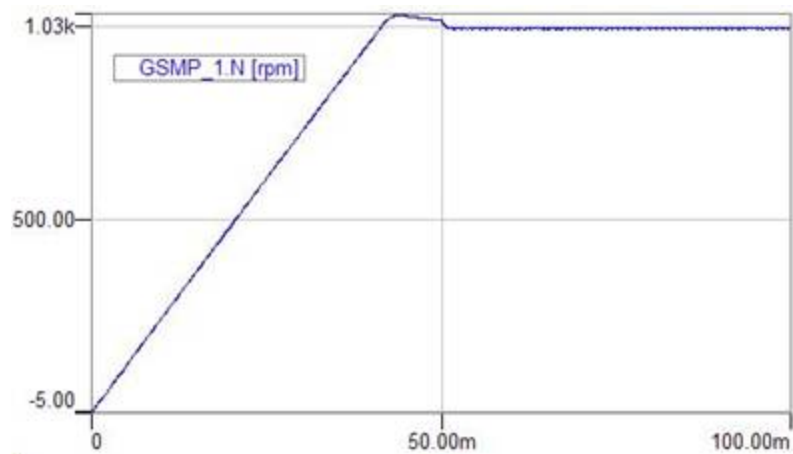


Figure 5. Simulation results-rotor speed of GSMP_1

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References

Permanently Excited DC-Machine DCMC

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

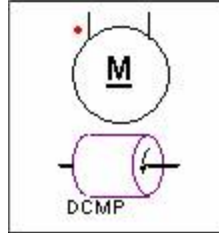


Figure 1. Component symbol

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Description

This component combines all properties of the Twin Builder basic DC Permanent Magnet Machine with those of the mechanical mass component.

$\omega(t)$ represents the mechanical speed of the rotor. The voltage constant K_E is gained by measuring the armature peak voltage in [V] while turning the motor shaft at certain speed measured in [rad/s].

This model is used for mechanical properties, parameters, and computed mechanical quantities.

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Assumptions and Limitations

- No cogging effects.
- Only rotational link between armature and excitation by k_e – no transformational link.
- No armature reaction, no armature circuit saturation effects.

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Mathematical Description

[See also Mass Component \(Rotational\)](#)

Voltage equation

$$v_a(t) = R_a \cdot i_a(t) + L_a \cdot \frac{di_a(t)}{dt} + e(t)$$

Counter-EMF equation

$$e(t) = k_e \cdot \omega(t)$$

Torque equation

$$m_{Int} = k_e \cdot i_a(t)$$

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Netlist Syntax

```
INTERN VM VM_A1_?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) N1 := %0, N2 :=
GND (); INTERN VM VM_A2_?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) N1 :=
%1, N2 := GND (); UMODEL VM_ROT VM_ROT_Pre_?InstanceName(@InstanceName):(@
(Refbase)@ (ID)) ROT1 := %2, ROT2 := GND () SRC: DB (Lib:= "Simplorer Elements\\Basic Ele-
ments\\Basic Elements"); UMODEL VM_ROT VM_ROT_Suc_?InstanceName(@In-
stanceName):(@ (Refbase)@ (ID)) ROT1 := %3, ROT2 := GND () SRC: DB (Lib:= "Simplorer
Elements\\Basic Elements\\Basic Elements"); UMODEL MchRDcmp ?InstanceName(@In-
stanceName):(@ (Refbase)@ (ID)) N1 := %0, N2 := %1, ROT1 := %2, ROT2 := %3, GND := GND
(RA:=@RA, LA:=@LA, KE:=@KE, IA0:=@IA0, J:=@J, KVSC:=@KVSC, KMUL:=@KMUL
, KEXP:=@KEXP, MCLB:=@MCLB, OMEGACLB:=@OMEGACLB, OMEGASTK:=
@OMEGASTK, MSTK:=@MSTK, KSTK:=@KSTK, MFRCCCH:=@MFRCCCH, KFRCCCH:=
@KFRCCCH, MEXT:=@MEXT, KEXT:=@KEXT, OMEGA0:=@OMEGA0, PHI0:=@PHI0
, PHIU:=@PHIU, PHIL:=@PHIL ) SRC: DB (Lib:= "Simplorer Elements\\Basic Elements\\Basic
Elements");
```

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
N1	Armature Node 1 (positive)	Electrical
N2	Armature Node 1 (positive)	Electrical
ROT1	Armature Node 2 (negative)	Rotational_V
ROT2	Successor Node	Rotational_V

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Parameters

Table2

Name	Description	Data Type	Default Value [Unit]
RA	Armature resistance	real	1 [Ohm]
LA	Armature inductance	real	0.01 [H]
KE	Voltage constant	real	1 [Vs]
IA0	Initial armature current	real	0 [A]
J	Moment of inertia	real	1 [kgm ²]
KVSC	Viscous friction coefficient	real	0 [Nms/rad]
KMUL	Polynomial friction multiplier	real	0 [Nms/rad]
KEXP	Polynomial friction exponent	real	0
MCLB	Constant Coulomb friction torque	real	0 [Nm]
OMEGACLB	Coulomb angular velocity	real	0.001 [rad/s]

OMEGASTK	Stick angular velocity	real	0 [rad/s]
MSTK	Stick torque (break-off)	real	0 [Nm]
KSTK	Stick friction coefficient	real	1e+016 [Nms/rad]
MFRCCH	Characteristic friction torque ($m = f(\text{OMEGA})$)	real	0 [Nm]
KFRCCH	Characteristic friction torque coefficient	real	1
MEXT	External (arbitrary) torque ($m = f(t)$)	real	0 [Nm]
KEXT	External (arbitrary) torque coefficient	real	1
OMEGA0	Initial angular velocity	real	0 [rad/s]
PHI0	Initial angular position	real	0 [rad]
PHIU	Upper angular position limit	real	0 [rad]
PHIL	Lower angular position limit	real	0 [rad]
N2	Fixed Component Value	real	0

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Input/Output Quantities

Table3

Name	Description [Unit]	Direction	Data Type
VA	Armature voltage [V]	Output	real
dVA	Armature voltage 1st derivative [V/s]	Output	real
IA	Armature current [A]	Output	real
dIA	Armature current 1st derivative [A/s]	Output	real
PSIA	Armature inductance flux [Vs]	Output	real
dPSIA	Armature inductance flux 1st derivative [V]	Output	real
MI	Intrinsic (magnetic) torque [Nm]	Output	real
dALPHA	Angular jerk [rad/s ³]	Output	real
ALPHA	Angular acceleration [rad/s ²]	Output	real
OMEGA	Angular velocity [rad/s]	Output	real
PHI	Angular position [rad]	Output	real
M1	Torque supplied by predecessor [Nm]	Output	real
M2	Torque supplied to successor [Nm]	Output	real
MACX	Accelerating external torques [Nm]	Output	real
MACC	Accelerating torque [Nm]	Output	real

MFRC	Resulting friction torque [Nm]	Output	real
MVSC	Viscous friction torque [Nm]	Output	real
MFRCPOL	Polynomial friction torque [Nm]	Output	real
MFRCCLB	Coulomb friction torque [Nm]	Output	real
MFRCCH_VAL	Characteristic friction torque [Nm]	Output	real
MEXT_VAL	External (arbitrary) torque [Nm]	Output	real

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Example

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References

Induction Machine with Squirrel Cage Rotor

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

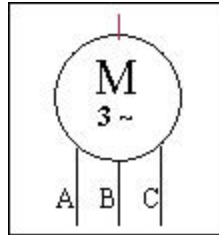


Figure 1. Component Symbol.

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Description

The model represents an induction machine with squirrel cage rotor and star-connected stator windings as a lumped circuit component. The circuit nodes A-B-C are the terminals of star-connected stator windings. Due to its rotational pin, the machine can be connected to mechanical components from the [physical domains](#) folder. This component cannot be used with AC and DC simulation.

Note: If the line-to-line voltage v_{ab} , v_{bc} , v_{ac} or the line currents i_a , i_b , i_c of the induction machine are of special interest, voltmeters or ammeters can be connected to the induction machine.

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Assumptions and Limitations

Model Limits of Induction Machine Model

- 3-phase symmetrical induction machine with squirrel cage rotor and star-connected stator windings without neutral node (no zero phase-sequence system).
- Linear and iron-loss free magnetic circuit.

- No consideration of skin effects in the windings (restricted simulation accuracy at e.g. start-up processes; typical case: current-displacement motor connected to the mains)
- Exclusive consideration of fundamental flux linkage between stator and rotor windings
- Rotor position-independent leakage inductances.
- Friction losses (parasitic torques) are not considered in the model; they can be added with the load torque parameter externally.

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Mathematical Description

Equation System

The equation system is implemented in a stator-fixed coordinate system (α - β coordinates). Index 1 represents the stator quantities, index 2 the rotor quantities. The phase quantities of the real three-phase induction machine are indicated with a, b, c. Ψ is the magnetic flux.

Voltage Equations

$$\begin{aligned} v_{1\alpha}(t) &= i_{1\alpha}(t) \cdot R_1 + \frac{d\Psi_{1\alpha}(t)}{dt} & 0 &= i_{2\alpha}(t) \cdot R_2 + \frac{d\Psi_{2\alpha}(t)}{dt} + p \cdot \omega(t) \cdot \Psi_{2\beta}(t) \\ v_{1\beta}(t) &= i_{1\beta}(t) \cdot R_1 + \frac{d\Psi_{1\beta}(t)}{dt} & 0 &= i_{2\beta}(t) \cdot R_2 + \frac{d\Psi_{2\beta}(t)}{dt} - p \cdot \omega(t) \cdot \Psi_{2\alpha}(t) \end{aligned}$$

Flux Linkage Equations

$$\begin{aligned} \Psi_{1\alpha}(t) &= i_{1\alpha}(t) \cdot L_1 + i_{2\alpha}(t) \cdot L_m \\ \Psi_{1\beta}(t) &= i_{1\beta}(t) \cdot L_1 + i_{2\beta}(t) \cdot L_m \\ \Psi_{2\alpha}(t) &= i_{1\alpha}(t) \cdot L_m + i_{2\alpha}(t) \cdot L_2 \\ \Psi_{2\beta}(t) &= i_{1\beta}(t) \cdot L_m + i_{2\beta}(t) \cdot L_2 \end{aligned}$$

Torque Equation (electromagnetic developed “internal” torque)

$$m_i(t) = \frac{3}{2}p \cdot (\Psi_{1\alpha}(t) \cdot i_{1\beta}(t) - \Psi_{1\beta}(t) \cdot i_{1\alpha}(t))$$

Motion Equation

$$\frac{d\omega(t)}{dt} = \frac{1}{J} (m_i(t) - m_w(t))$$

Electrical Coupling of phase quantities with the orthogonal quantities

$$v_{1\alpha}(t) = \frac{2}{3}v_{1a}(t) - \frac{1}{3}v_{1b}(t) - \frac{1}{3}v_{1c}(t)$$

$$v_{1\beta}(t) = \frac{\sqrt{3}}{3}v_{1b}(t) - \frac{\sqrt{3}}{3}v_{1c}(t)$$

$$v_{1\gamma}(t) = \frac{1}{3}v_{1a}(t) + \frac{1}{3}v_{1b}(t) + \frac{1}{3}v_{1c}(t)$$

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Netlist Syntax

INTERN IM ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) A:= %0 , B:= %1 , C:= %2 ,
 ROT:= %3 (R1:=@ (R1), R2:=@ (R2), LS1:=@ (LS1), LS2:=@ (LS2), LM:=@ (LM), P:=@ (P),
 J:=@ (J), I1A0:=@ (I1A0), I1B0:=@ (I1B0), I1C0:=@ (I1C0), I2A0:=@ (I2A0), I2B0:=@ (I2B0),
 I2C0:=@ (I2C0), N0:=@ (N0), PHI0:=@ (PHI0)) ;

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
A	Stator Node A	electrical
B	Stator Node B	electrical
C	Stator Node C	electrical
ROT	Mechanical node	Rotational_V

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
R1	Stator Resistance	real	1 [Ohm]
R2	Rotor Resistance related to stator side	real	0.88 [Ohm]
LS1	Stator Leakage Inductance leakage inductance of stator side	real	10m [H]
LS2	Rotor Leakage Inductance	real	13m [H]

	leakage inductance of rotor side		
LM	Main Inductance coupling inductance between stator and rotor side	real	0.4 [H]
P	Number of Pole Pairs	real	1 [/]
J	Moment of Inertia	real	75m [kg*m ²]
I1A0	Initial Current Stator Phase a	real	0 [A]
I1B0	Initial Current Stator Phase b	real	0 [A]
I1C0	Initial Current Stator Phase c	real	0 [A]
I2A0	Initial Current Rotor Phase a with ratio of induction machine convert to stator side	real	0 [A]
I2B0	Initial Current Rotor Phase b with ratio of induction machine convert to stator side	real	0 [A]
I2C0	Initial Current Rotor Phase c with ratio of induction machine convert to stator side	real	0 [A]
N0	Initial Rotor Speed	real	0 [rpm]
PHI0	Initial Rotor Position	real	0 [deg]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
N	Rotor Speed [rpm]	Output	real
MI	Inner Torque [Nm]	Output	real
OMEGA	Rotor rational Speed [1/s]	Output	real
ALPHA	Angular Rotor Acceleration [1/s ²]	Output	real
PHI	Rotor Angle in Radians [rad]	Output	real
PHIDEG	Rotor Angle in Degrees [deg]	Output	real
PHIM	Rotor Angle Mechanical in Radians [rad]	Output	real
PHIMDEG	Rotor Angle Mechanical in Degrees [deg]	Output	real
I1A	Current Stator Phase a [A]	Output	real

I1B	Current Stator Phase b [A]	Output	real
I1C	Current Stator Phase c [A]	Output	real
I2A	Current Rotor Phase a [A]	Output	real
I2B	Current Rotor Phase b [A]	Output	real
I2C	Current Rotor Phase c [A]	Output	real
PSI1A	Linked Stator Flux Alpha Component [Vs]	Output	real
PSI1B	Linked Stator Flux Beta Component [Vs]	Output	real
PSI2A	Linked Rotor Flux Alpha Component [Vs]	Output	real
PSI2B	Linked Rotor Flux Beta Component [Vs]	Output	real
dI1A	1st derivative Stator Phase Current a [A/s]	Output	real
dI1B	1st derivative Stator Phase Current b [A/s]	Output	real
dI1C	1st derivative Stator phase Current c [A/s]	Output	real
dI2A	1st derivative Rotor Phase Current a [A/s]	Output	real
dI2B	1st derivative Rotor Phase Current b [A/s]	Output	real
dI2C	1st derivative Rotor Phase Current c [A/s]	Output	real
dPSI1A	1st derivative of linked Stator Flux alpha component [V]	Output	real
dPSI1B	1st derivative of linked Stator Flux beta component [V]	Output	real
dPSI2A	1st derivative of linked Rotor Flux alpha component [V]	Output	real
dPSI2B	1st derivative of linked Rotor Flux beta component [V]	Output	real
PWRELEC	Electrical Real Power Input [W]	Output	real
PWRMECH	Mechanical power output[W]	Output	real
PWRLOSS	Losses[W]	Output	real

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Example

In this example, the Induction Machine ASM_2 is connected to a three-phase power supply composed of Sinusoidal Voltage Sources ET1, ET2 and ET3. The mechanical terminal of ASM_

2 is connected to a Torque Source F_ROT1, whose torque value is decided by the summation of the outputs of the Step Functions Generator_torque and Load_torque. The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the simulation results are shown in Figure 3, 4, and 5.

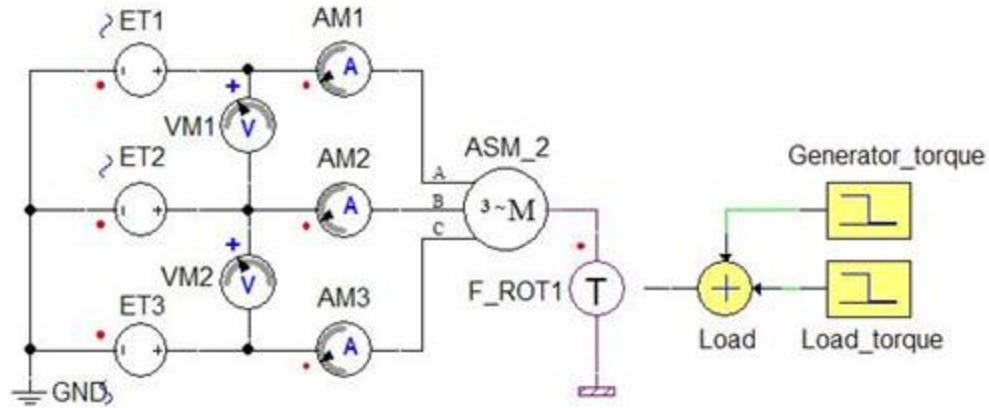


Figure 2. Application examples of the Induction Machine

Table 4. System Parameters

Component	Parameter	Value [unit]
Voltage Source (sinusoidal) ET1/ET2/ET3	AMPL	0.564k [V]
	FREQ	50 [Hz]
	PHASE	0/-120/-240 [degree]
	OFF	0 [V]
	TDELAY	0 [s]

Induction Machine ASM_2	R1	1 [Ohm]
	R2	0.88 [Ohm]
	LS1	10m [H]
	LS2	13m [H]
	LM	0.4 [H]
	P	1 [/]
	J	75m [kg*m2]
	I1A0	0 [A]
	I1B0	0 [A]
	I1C0	0 [A]
	I2A0	0 [A]
	I2B0	0 [A]
	I2C0	0 [A]
	N0	0 [rpm]
	PHI0	0 [deg]
Torque Source	VALUE	Load.VAL [Nm]
Summation Load	INPUT[0]	Generator_torque.VAL
	INPUT[1]	Load_torque.VAL
Step Function Generator_torque	AMPL	-3.2k
	T0	1.2 [s]
	Y0	0
Step Function Load_torque	AMPL	3.204k
	T0	1 [s]
	Y0	0

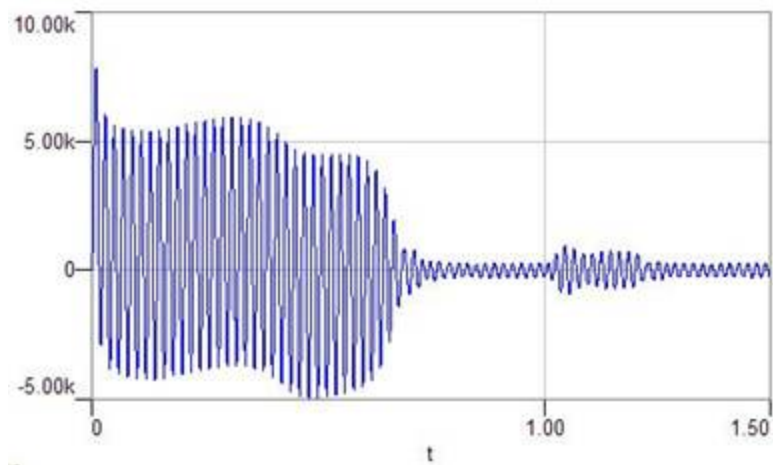


Figure 3. Simulation results-phase A current of ASM_2

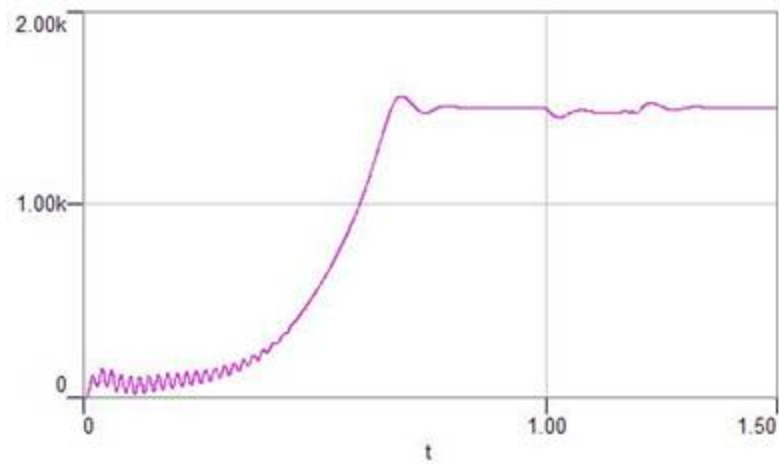


Figure 4. Simulation results-rotor speed of ASM_2

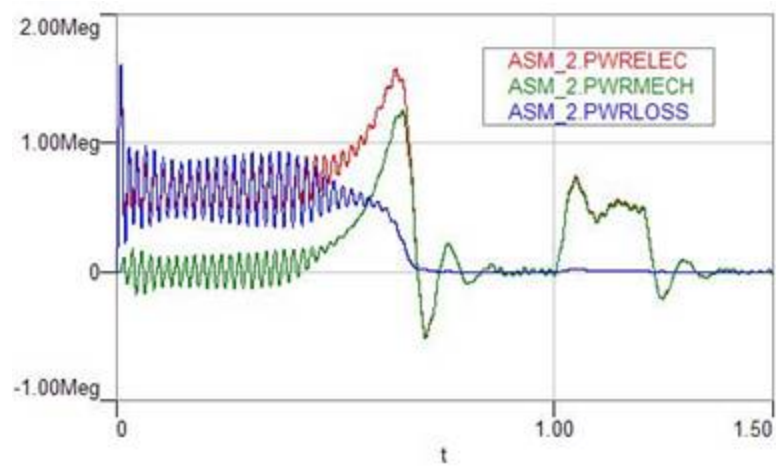


Figure 5. Simulation results-electric power, mechanical power and the power loss of ASM_2

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References

Slip-Ring Induction Machine ASMS

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

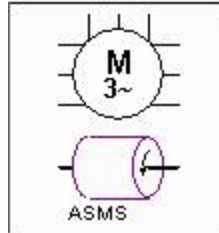


Figure 1. Component symbol

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Description

This component combines all properties of the Twin Builder basic Asynchronous Machine (extended by the Y-point and slip ring properties) with those of the mechanical mass component.

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Assumptions and Limitations

- No saturation effects
- No skin effects

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Mathematical Description

$\omega(t)$ represents the mechanical speed of the rotor. All resistances and inductances are phase quantities. The voltage ratio kV (V_{rt}) is determined by the number of stator/rotor windings and the winding factor:

$$k_V = \frac{(w \cdot \xi_1)_1}{(w \cdot \xi_2)_2} = \frac{V_{10}}{V_{20}}$$

where w = number of windings, x = winding factor, V_0 = open circuit voltages.

Note: All rotor quantities are reduced to stator side by V_{rt} (kV).

Reference Frames:

The induction machine differential equation system is transformed into a coordinate system (reference frame) common to both the stator and rotor equation systems. This reference frame rotates at an arbitrary speed given by ω_C . Choosing an appropriate reference frame factor R_{ff} (kRf) allows for any desirable reference frame speed. This coordinate system is rectangular with a real axis and an imaginary axis, (i.e., all real and imaginary parts in the above equations are true for this frame).

The reference frame factor R_{ff} (kRf) specifies the speed of the reference frame with respect to rotor speed. It determines at what speed and what direction the coordinate system of the ASMS is rotating. The following reference frame factors yield the conventionally used reference frames for induction machines:

Rff	wC	Reference Frame	Components
Rff = 0	wC = 0	Stator reference frame	All real/imaginary quantities equal alpha/beta quantities, e.g., $V1RE = V1A$, etc.
Rff = 1	wC = wE	Rotor reference frame	All real/imaginary quantities equal x/y-quantities, e.g., $V1RE = V1x$, etc.
Rff adapted	wC = w1	Flux reference frame	(flux frequency $w1 = 2pfGrid$)

For most cases, it is sufficient to use $R_{ff} = 1$ or $R_{ff} = 0$.

At simulation start, a message is issued telling the model name, component name, and chosen reference frame. The angle γ is either the stator or rotor reference frame position angle (it depends on where the rotation matrix is applied). For conventional slip ring induction machine rotors are always Y-connected, and the rotor zero-components are not available.

See the rotational mass component for the mechanical properties, corresponding parameters, and computed mechanical quantities.

This model is for mechanical properties, parameters, and computed mechanical quantities.

[See also Mass Component \(Rotational\)](#)

Voltage equations

$$\begin{aligned}v_{1Re}(t) &= R_1 \cdot i_{1Re}(t) + \frac{d\Psi_{1Re}(t)}{dt} - \omega_C \cdot \Psi_{1Im}(t) \\v_{1Im}(t) &= R_1 \cdot i_{1Im}(t) + \frac{d\Psi_{1Im}(t)}{dt} + \omega_C \cdot \Psi_{1Re}(t) \\v_{10}(t) &= R_1 \cdot i_{10}(t) + \frac{d\Psi_{10}(t)}{dt} \\v_{2Re}(t) &= R_2' \cdot i_{2Re}(t) + \frac{d\Psi_{2Re}(t)}{dt} - (\omega_C - \omega_E) \cdot \Psi_{2Im}(t) \\v_{2Im}(t) &= R_2' \cdot i_{2Im}(t) + \frac{d\Psi_{2Im}(t)}{dt} + (\omega_C - \omega_E) \cdot \Psi_{2Re}(t)\end{aligned}$$

Electric frequency

$$\omega_E(t) = p \cdot \varpi(t)$$

Coordinate system (reference frame) frequency

$$\omega_C(t) = k_{Rf} \cdot p \cdot \omega(t)$$

Flux equations

$$\begin{aligned}\Psi_{1Re}(t) &= L_1 \cdot i_{1Re}(t) + L_m \cdot i_{2Re}(t) \\\Psi_{1Im}(t) &= L_1 \cdot i_{1Im}(t) + L_m \cdot i_{2Im}(t) \\\Psi_{10}(t) &= L_{10} \cdot i_{10}(t) \\\Psi_{2Re}(t) &= L_2 \cdot i_{2Re}(t) + L_m \cdot i_{1Re}(t) \\\Psi_{2Im}(t) &= L_2 \cdot i_{2Im}(t) + L_m \cdot i_{1Im}(t)\end{aligned}$$

Inductances

$$L_1 = L_m + L_{1\sigma} \quad L_2 = L_m + L_{2\sigma}$$

Torque equation

$$m_{Int}(t) = \frac{3}{2} \cdot p \cdot (\Psi_{1Re}(t) \cdot i_{1Im}(t) - \Psi_{1Im}(t) \cdot i_{1Re}(t))$$

Rotation matrix**Three-phase - two-phase and two-phase - three-phase transformation matrices**

$$T_{32} = \begin{bmatrix} \frac{2}{3} & -\frac{1}{3} & -\frac{1}{3} \\ 0 & \frac{\sqrt{3}}{3} & -\frac{\sqrt{3}}{3} \\ \frac{1}{3} & \frac{1}{3} & \frac{1}{3} \end{bmatrix} \quad \text{and} \quad T_{23} = \begin{bmatrix} 1 & 0 & 1 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} & 1 \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} & 1 \end{bmatrix}$$

Reference frame transformation - stator voltages

$$\begin{bmatrix} v_{1\alpha} \\ v_{1\beta} \\ v_{10} \end{bmatrix} = T_{32} \cdot \begin{bmatrix} v_{1a} \\ v_{1b} \\ v_{1c} \end{bmatrix} \quad \text{and} \quad \begin{bmatrix} v_{1Re} \\ v_{1Im} \\ v_{10} \end{bmatrix} = R \cdot \begin{bmatrix} v_{1\alpha} \\ v_{1\beta} \\ v_{10} \end{bmatrix}$$

Reference frame transformation - stator currents

$$\begin{bmatrix} i_{1\alpha} \\ i_{1\beta} \\ i_{10} \end{bmatrix} = R^{-1} \cdot \begin{bmatrix} i_{1Re} \\ i_{1Im} \\ i_{10} \end{bmatrix} \quad \text{and} \quad \begin{bmatrix} i_{1a} \\ i_{1b} \\ i_{1c} \end{bmatrix} = T_{23} \cdot \begin{bmatrix} i_{1\alpha} \\ i_{1\beta} \\ i_{10} \end{bmatrix}$$

Reference frame transformation – rotor voltages

$$\begin{bmatrix} v_{2x} \\ v_{2y} \\ v_{20} \end{bmatrix} = T_{32} \cdot k_V \cdot \begin{bmatrix} v_{2a} \\ v_{2b} \\ v_{2c} \end{bmatrix} \quad \text{and} \quad \begin{bmatrix} v_{2Re} \\ v_{2Im} \\ v_{20} \end{bmatrix} = R \cdot \begin{bmatrix} v_{2x} \\ v_{2y} \\ v_{20} \end{bmatrix}$$

Reference frame transformation – rotor currents

$$\begin{bmatrix} i_{2x} \\ i_{2y} \\ i_{20} \end{bmatrix} = R^{-1} \cdot k_V \cdot \begin{bmatrix} i_{2Re} \\ i_{2Im} \\ i_{20} \end{bmatrix} \quad \text{and} \quad \begin{bmatrix} i_{2a} \\ i_{2b} \\ i_{2c} \end{bmatrix} = T_{23} \cdot \begin{bmatrix} i_{2x} \\ i_{2y} \\ i_{20} \end{bmatrix}$$

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Netlist Syntax

```

INTERN VM VM_A11_?InstanceName(@InstanceName):(@Refbase)(@ID)) N1 := %0, N2 :=
GND (); INTERN VM VM_B11_?InstanceName(@InstanceName):(@Refbase)(@ID)) N1 :=
%1, N2 := GND (); INTERN VM VM_C11_?InstanceName(@InstanceName):(@Refbase)(@
ID)) N1 := %2, N2 := GND (); INTERN VM VM_A12_?InstanceName(@InstanceName):(@Ref
base)(@ID)) N1 := %3, N2 := GND (); INTERN VM VM_B12_?InstanceName(@In-
stanceName):(@Refbase)(@ID)) N1 := %4, N2 := GND (); INTERN VM VM_
C12_?InstanceName(@InstanceName):(@Refbase)(@ID)) N1 := %5, N2 := GND (); INTERN
VM VM_A2_?InstanceName(@InstanceName):(@Refbase)(@ID)) N1 := %6, N2 := GND ();
INTERN VM VM_B2_?InstanceName(@InstanceName):(@Refbase)(@ID)) N1 := %7, N2 :=
GND (); INTERN VM VM_C2_?InstanceName(@InstanceName):(@Refbase)(@ID)) N1 :=
%8, N2 := GND (); UMODEL VM_ROT VM_ROT_Pre_?InstanceName(@InstanceName):(@
Refbase)(@ID)) ROT1 := %9, ROT2 := GND () SRC: DB(Lib:= "Simplorer Elements\\Basic Ele-
ments\\Basic Elements"); UMODEL VM_ROT VM_ROT_Suc_?InstanceName(@In-
stanceName):(@Refbase)(@ID)) ROT1 := %10, ROT2 := GND () SRC: DB(Lib:= "Simplorer
Elements\\Basic Elements\\Basic Elements"); UMODEL MchRASms ?InstanceName(@In-
stanceName):(@Refbase)(@ID)) A11 := %0, B11 := %1, C11 := %2, A12 := %3, B12 := %4,
C12 := %5, A2 := %6, B2 := %7, C2 := %8, ROT1 := %9, ROT2 := %10, GND := GND (R1:=@R1
,R2:=@R2 ,LS1:=@LS1 ,LS2:=@LS2 ,L1ZERO:=@L1ZERO ,LM:=@LM ,P:=@P ,RATIOV:-
:=@RATIOV ,KREFF:=@KREFF ,I1A0:=@I1A0 ,I1B0:=@I1B0 ,I1C0:=@I1C0 ,I2A0:=@I2A0
,I2B0:=@I2B0 ,I2C0:=@I2C0 ,J:=@J ,KVSC:=@KVSC ,KMUL:=@KMUL ,KEXP:=@KEXP
,MCLB:=@MCLB ,OMEGACLB:=@OMEGACLB ,OMEGASTK:=@OMEGASTK ,MSTK:-
:=@MSTK ,KSTK:=@KSTK ,MFRCH:=@MFRCH ,KFRCH:=@KFRCH ,MEXT:=@MEXT
,KEXT:=@KEXT ,OMEGA0:=@OMEGA0 ,PHI0:=@PHI0 ,PHIU:=@PHIU ,PHIL:=@PHIL )
SRC: DB(Lib:= "Simplorer Elements\\Basic Elements\\Basic Elements");

```

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
A11	Stator primary node phase A positive (u)	Electrical
B11	Stator primary node phase B positive (v)	Electrical
C11	Stator primary node phase C positive (w)	Electrical
A12	Stator secondary node phase A negative (x) (Y-point)	Electrical
B12	Stator secondary node phase B negative (y) (Y-point)	Electrical

C12	Stator secondary node phase C negative (z) (Y-point)	Electrical
A2	Rotor primary node phase A positive	Electrical
B2	Rotor primary node phase B positive	Electrical
C2	Rotor primary node phase C positive	Electrical
ROT1	Predecessor Node	Rotational_V
ROT2	Successor Node	Rotational_V

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Parameters

Table2

Name	Description	Data Type	Default Value [Unit]
R1	Stator resistance	real	1 [Ohm]
R2	Rotor resistance reduced to stator side	real	1 [Ohm]
LS1	Stator leakage inductance	real	0.05 [H]
LS2	Rotor leakage inductance reduced to stator	real	0.05 [H]
L1ZERO	Stator inductance - zero component	real	0.05 [H]
LM	Mutual inductance	real	0.5 [H]
P	Number of pole pairs	real	1
RATIOV	Stator/rotor voltage ratio (~= U_{10} / U_{20})	real	1

KREFF	Reference frame factor (0 = alpha/beta, 1 = xy)	real	1
I1A0	Initial phase a stator current	real	0 [A]
I1B0	Initial phase b stator current	real	0 [A]
I1C0	Initial phase c stator current	real	0 [A]
I2A0	Initial phase a rotor current	real	0 [A]
I2B0	Initial phase b rotor current	real	0 [A]
I2C0	Initial phase c rotor current	real	0 [A]
J	Moment of inertia	real	1 [kgm ²]
KVSC	Viscous friction coefficient	real	0 [Nms/rad]
KMUL	Polynomial friction multiplier	real	0 [Nms/rad]
KEXP	Polynomial friction exponent	real	0
MCLB	Constant Coulomb friction torque	real	0 [Nm]
OMEGACLB	Coulomb angular velocity	real	0.001 [rad/s]
OMEGASTK	Stick angular velocity	real	0 [rad/s]
MSTK	Stick torque (break-off)	real	0 [Nm]
KSTK	Stick friction coefficient	real	1e+016 [Nms/rad]
MFRCCH	Characteristic friction torque ($m = f(\text{OMEGA})$)	real	0 [Nm]

KFRCCH	Characteristic friction torque coefficient	real	1
MEXT	External (arbitrary) torque ($m = f(t)$)	real	0 [Nm]
KEXT	External source weighting coefficient	real	1
OMEGA0	Initial angular velocity	real	0 [rad/s]
PHI0	Initial angular position	real	0 [rad]
PHIU	Upper angular position limit	real	0 [rad]
PHIL	Lower angular position limit	real	0 [rad]
N2	Fixed Component Value	real	0

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Input/Output Quantities

Table3

Name	Description [Unit]	Direction	Data Type
V1A, V1B, V1C	Stator phase voltages; Phase A, B, C [V]	Output	real
V2A, V2B, V2C	Rotor phase voltages; Phase A, B, C [V]	Output	real
dV1A, dV1B, dV1C	Stator phase voltages 1 st derivative; Phase A, B, C [V/s]	Output	real
dV2A, dV2B, dV2C	Rotor phase voltages 1 st derivative; Phase A, B, C [V/s]	Output	real
I1A, I1B, I1C	Stator phase currents; Phase A, B, C [A]	Output	real

I2A, I2B, I2C	Rotor phase currents; Phase A, B, C [A]	Output	real
dI1A, dI1B, dI1C	Stator phase currents 1 st derivative; Phase A, B, C [A/s]	Output	real
dI2A, dI2B, dI2C	Rotor phase currents 1 st derivative; Phase A, B, C [A/s]	Output	real
V1ALPHA, V1BETA	Stator voltages; alpha and beta component [V]	Output	real
V2X, V2Y	Rotor voltages; x- and y- component [V]	Output	real
dV1ALPHA, dV1BETA	Stator voltages 1 st deriv- ative; alpha and beta com- ponent [V/s]	Output	real
dV2X, dV2Y	Rotor voltages 1 st deriv- ative; alpha and beta com- ponent [V/s]	Output	real
I1ALPHA, I1BETA	Stator currents; alpha and beta component [A]	Output	real
I2X, I2Y	Rotor currents; x- and y- component [A]	Output	real
dI1ALPHA, dI1BETA	Stator currents 1 st deriv- ative; alpha and beta com- ponent [A/s]	Output	real
dI2X, dI2Y	Rotor currents 1 st derivative; x- and y- component [A/s]	Output	real
V1D, V1Q, V1ZERO	Stator voltages; real, ima- ginary, and zero component [V]	Output	real
V2D, V2Q	Rotor voltages; real and ima-	Output	real

	ginary component [V]		
dV1D, dV1Q, dV1ZERO	Stator voltages 1 st deriv- ative; real, imaginary, and zero component [V/s]	Output	real
dV2D, dV2Q	Rotor voltages 1 st deriv; real and imaginary component [V/s]	Output	real
I1D, I1Q, I1ZERO	Stator currents; real, ima- ginary, and zero component [A]	Output	real
I2D, I2Q	Rotor currents; real and ima- ginary component [A]	Output	real
dI1D, dI1Q, dI1ZERO	Stator currents 1 st deriv- ative; real, imaginary, and zero component [A/s]	Output	real
dI2D, dI2Q	Rotor currents 1 st derivative; real and imaginary com- ponent [A/s]	Output	real
PSI1D, PSI1Q, PSI1ZERO	Stator flux; real, imaginary, and zero component [Vs]	Output	real
PSI2D, PSI2Q	Rotor flux; real and ima- ginary component [Vs]	Output	real
dPSI1D, dPSI1Q, dPSI1ZERO	Stator flux; 1 st derivative; real, imaginary, and zero component [V]	Output	real
dPSI2D, dPSI2Q	Rotor flux 1 st derivative; real and imaginary component [V]	Output	real
MI	Intrinsic (magnetic) torque [Nm]	Output	real
dALPHA	Angular jerk [rad/s ³]	Output	real

ALPHA	Angular acceleration [rad/s ²]	Output	real
OMEGA	Angular velocity [rad/s]	Output	real
PHI	Angular position [rad]	Output	real
M1	Torque supplied by pre- decessor [Nm]	Output	real
M2	Torque supplied to suc- cessor [Nm]	Output	real
MACX	Accelerating external torques [Nm]	Output	real
MACC	Accelerating torque [Nm]	Output	real
MFRC	Resulting friction torque [Nm]	Output	real
MVSC	Viscous friction torque [Nm]	Output	real
MFRCPOL	Polynomial friction torque [Nm]	Output	real
MFRCCLB	Coulomb friction torque [Nm]	Output	real
MFRCCH_ VAL	Characteristic friction torque [Nm]	Output	real
MEXT_VAL	External (arbitrary) torque [Nm]	Output	real

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References

Starter

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

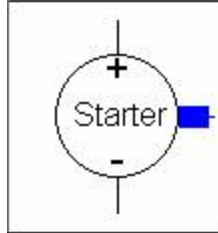


Figure 1. Component symbol

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Description

The model represents a starter model, which consists of a DC machine model and a model of a clutch that opens the mechanical connection between the DC machine and the starter shaft. The mechanical connection can open only once per simulation run. The speed at which the DC motor is disconnected can be set by `n_clutch`. After the clutch has opened, the internal speed of the starter depends only on the starter parameter and the armature voltage.

The mechanical model of the starter includes the starter inertia and a speed-dependent friction.

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Assumptions and Limitations

- The mechanical connections of the machines are implemented using conservative nodes that follow the *velocity-torque* representation (velocity = across quantity, torque = through quantity).
- The model does not calculate thermal effects.
- Only basic mechanical properties are modeled.
- The time constant must be considered for the simulator's minimum time step.

- The mechanical connection can open only once per simulation run.
- The mechanical model of the starter includes the starter inertia and a speed-dependent friction.

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Mathematical Description

Armature voltage:

$$V = r_a \cdot i + l_a \cdot \frac{di}{dt} + k_e \cdot \omega$$

Internal torque:

$$t_i = k_e \cdot i$$

Shaft torque:

$$T_{\text{Shaft}} = t_i - j \cdot \frac{d\omega}{dt} - c_f \cdot \omega$$

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Netlist Syntax

MODEL starter ?InstanceName(@InstanceName):(@ (Refbase)@(ID)) np:= %0, nm:= %1, rot:= %2 (ra:= @ra, la:= @la, ke:= @ke, j:= @j, cf:= @cf, n_clutch:= @n_clutch, n0:= @n0) SRC: DB (Lib:=@ModelLibraryName) ;

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
np	Positive Terminal	Electrical terminal
nm	Negative Terminal	Electrical terminal
rot	Shaft	Rotational_v

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Parameters

Table2

Name	Description	Data	Default Value

		Type	[Unit]
ra	Armature Resistance	real	0.01 [Ohms]
la	Armature Inductance	real	0.0001 [H]
ke	Motor Constant	real	0.2 [Vs/rad]
j	Moment of Inertia	real	0.05 [kg*m ²]
cf	Friction Coefficient	real	0.1 [Nm*s/rad]
n_clutch	Speed for opening mechanical connection	real	800 [rpm]
n0	Initial Speed at t=0	real	0 [rpm]

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Input/Output Quantities

Table3

Name	Description [Unit]	Direction	Data Type
v	Armature Voltage [V]	Output	real
i	Armature Current [A]	Output	real
n	Shaft Speed [rpm]	Output	real
omega	Shaft Angular Velocity [rad/s]	Output	real
n_i	Internal Speed [rpm]	Output	real
omega_i	Internal Angular Velocity [rad/s]	Output	real
ti	Internal Torque [Nm]	Output	real

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Example

In this example, a starter is used to start an engine model. The starter is driven from a standard battery through a switch/relay circuit. Figure 3 shows the starter current and speed as the engine speed is increased until the point where the switch shuts off the starter when the engine speed reaches 800 rpm.

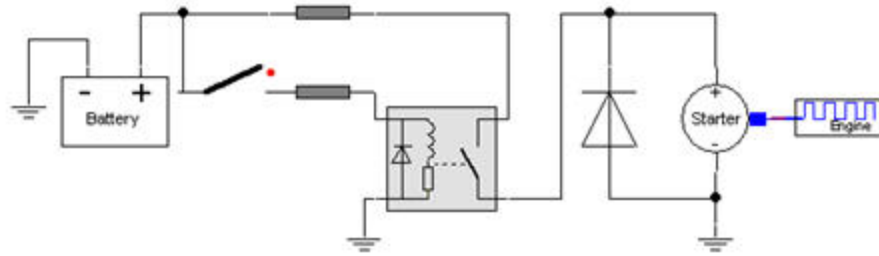


Figure 2. Application example of the starter model

Table 4. System Parameters

Component	Parameter	Value [unit]
Battery (battery1)	vnom	14 [V]
	rin	10m [Ohm]
Relay - Normally Open (rlyno1)	ron	5m [Ohm]
	roff	10Meg [Ohm]
Diode (D1)	VF	0.8 [V]
	RB	1m [Ohm]
	RR	100k [Ohm]
Ideal Switch (S1)	CTRL	Engine.n<800
Wire - Thermal (wire_thermal_static1)	l	1000 [mm]
	rho	17.8u
Wire - Thermal (wire_thermal_static2)	l	1000 [mm]
	rho	17.8u
Starter	ra	1m [Ohm]

	la	1m [H]
	ke	100m [Vs/rad]
	j	10m [kg*m] ²
	cf	10m [Nm*s/rad]
	n0	0 [rpm]
	n_clutch	800 [rpm]
	power_request	0.1
Engine	n0	0 [rpm]
	losses	losses.mdx
	full_load	full_load.mdx

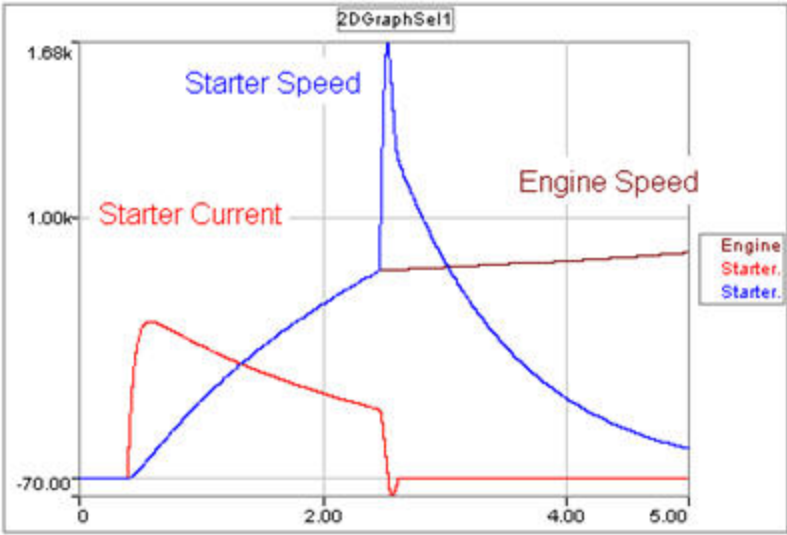


Figure 3. Simulation results-Starter current and speed and Engine speed.

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References

Permanently Excited Synchronous Machine SYMP

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

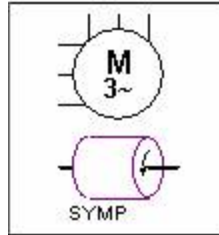


Figure 1. Component symbol

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Description

This component combines all properties of the Twin Builder basic Synchronous Machine (extended by the Y-point properties) with those of the mechanical mass component.

$\omega(t)$ represents the mechanical speed of the rotor. All resistances and inductances are phase quantities. The voltage constant KE is gained by measuring the stator phase peak voltages in [V] while turning the motor shaft at a certain speed measured in [rad/s].

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Assumptions and Limitations

- No saturation effects
- No skin effects

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Mathematical Description

Reference Frames:

The synchronous machine differential equation system is transformed into a coordinate system (reference frame), which is aligned with the electrical rotor d-axis. Therefore, this reference frame is rotating at a rotor speed given by ω_E . The coordinate system is rectangular with a real (d-) axis and an imaginary (q-) axis. The angle γ is the electrical rotor reference frame position angle.

For mechanical properties, parameters, and computed mechanical quantities.

[See also Mass Component \(Rotational\)](#)

Voltage equations

$$\begin{aligned} v_{1d}(t) &= R_1 \cdot i_{1d}(t) + \frac{d\Psi_{1d}(t)}{dt} - \omega_E \cdot \Psi_{1q}(t) \\ v_{1q}(t) &= R_1 \cdot i_{1q}(t) + \frac{d\Psi_{1q}(t)}{dt} + \omega_E \cdot \Psi_{1d}(t) \\ v_{10}(t) &= R_1 \cdot i_{10}(t) + \frac{d\Psi_{10}(t)}{dt} \end{aligned}$$

Electric frequency**Flux equations**

$$\begin{aligned} \Psi_{1d}(t) &= L_1 \cdot i_{1d}(t) + \Psi_{Pm1fd} \\ \Psi_{1q}(t) &= L_1 \cdot i_{1q}(t) \\ \Psi_{10}(t) &= L_{10} \cdot i_{10}(t) \end{aligned}$$

Field equation

$$\Psi_{Pm1fd} = \frac{k_e}{p}$$

Torque equation

$$m_{Int}(t) = \frac{3}{2} \cdot p \cdot (\Psi_{1d}(t) \cdot i_{1q}(t) - \Psi_{1q}(t) \cdot i_{1d}(t))$$

Rotation matrix

$$R = \begin{bmatrix} \cos \gamma & \sin \gamma & 0 \\ -\sin \gamma & \cos \gamma & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Three-phase - two-phase and two-phase - three-phase transformation matrices

$$T_{32} = \begin{bmatrix} \frac{2}{3} & -\frac{1}{3} & -\frac{1}{3} \\ 0 & \frac{\sqrt{3}}{3} & -\frac{\sqrt{3}}{3} \\ \frac{1}{3} & \frac{1}{3} & \frac{1}{3} \end{bmatrix} \quad \text{and} \quad T_{23} = \begin{bmatrix} 1 & 0 & 1 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} & 1 \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} & 1 \end{bmatrix}$$

Reference frame transformation - stator voltages

$$\begin{bmatrix} v_{1\alpha} \\ v_{1\beta} \\ v_{10} \end{bmatrix} = T_{32} \cdot \begin{bmatrix} v_{1a} \\ v_{1b} \\ v_{1c} \end{bmatrix} \quad \text{and} \quad \begin{bmatrix} v_{1d} \\ v_{1q} \\ v_{10} \end{bmatrix} = R \cdot \begin{bmatrix} v_{1\alpha} \\ v_{1\beta} \\ v_{10} \end{bmatrix}$$

Reference frame transformation - stator currents

$$\begin{bmatrix} i_{1\alpha} \\ i_{1\beta} \\ i_{10} \end{bmatrix} = R^{-1} \cdot \begin{bmatrix} i_{1d} \\ i_{1q} \\ i_{10} \end{bmatrix} \quad \text{and} \quad \begin{bmatrix} i_{1a} \\ i_{1b} \\ i_{1c} \end{bmatrix} = T_{23} \cdot \begin{bmatrix} i_{1\alpha} \\ i_{1\beta} \\ i_{10} \end{bmatrix}$$

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Netlist Syntax

```

INTERN VM VM_A11_?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) N1 := %0, N2 :=
GND (); INTERN VM VM_B11_?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) N1 :=
%1, N2 := GND (); INTERN VM VM_C11_?InstanceName(@InstanceName):(@ (Refbase)@
(ID)) N1 := %2, N2 := GND (); INTERN VM VM_A12_?InstanceName(@InstanceName):(@ (Ref-
base)@ (ID)) N1 := %3, N2 := GND (); INTERN VM VM_B12_?InstanceName(@In-
stanceName):(@ (Refbase)@ (ID)) N1 := %4, N2 := GND (); INTERN VM VM_
C12_?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) N1 := %5, N2 := GND ();
UMODEL VM_ROT VM_ROT_Pre_?InstanceName(@InstanceName):(@ (Refbase)@ (ID))
ROT1 := %6, ROT2 := GND () SRC: DB (Lib:= "Simplorer Elements\\Basic Elements\\Basic
Elements"); UMODEL VM_ROT VM_ROT_Suc_?InstanceName(@InstanceName):(@ (Ref-
base)@ (ID)) ROT1 := %7, ROT2 := GND () SRC: DB (Lib:= "Simplorer Elements\\Basic Ele-
ments\\Basic Elements"); UMODEL MchRSymp ?InstanceName(@InstanceName):(@
(Refbase)@ (ID)) A11 := %0, B11 := %1, C11 := %2, A12 := %3, B1 := %4, C12 := %5, ROT1 :=
%6, ROT2 := %7, GND := GND (R1:= @R1 ,L1D:= @L1D ,L1Q:= @L1Q ,L1ZERO:= @L1ZERO
,KE:= @KE ,P:= @P ,I1A0:= @I1A0 ,I1B0:= @I1B0 ,I1C0:= @I1C0 ,J:= @J ,KVSC:= @KVSC
,KMUL:= @KMUL ,KEXP:= @KEXP ,MCLB:= @MCLB ,OMEGACLB:= @OMEGACLB
,OMEGASTK:= @OMEGASTK ,MSTK:= @MSTK ,KSTK:= @KSTK ,MFRCCCH:= @MFRCCCH
,KFRCCCH:= @KFRCCCH ,MEXT:= @MEXT ,KEXT:= @KEXT ,OMEGA0:= @OMEGA0 ,PHI0:=
@PHI0 ,PHIU:= @PHIU ,PHIL:= @PHIL) SRC: DB (Lib:= "Simplorer Elements\\Basic Ele-
ments\\Basic Elements");

```

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
A11	Stator primary node phase A positive (u)	Electrical
B11	Stator primary node phase B positive (v)	Electrical
C11	Stator primary node phase C positive (w)	Electrical
A12	Stator secondary node phase A negative (x) (Y-point)	Electrical
B12	Stator secondary node phase B negative (y) (Y-point)	Electrical
C12	Stator secondary node phase C negative (z) (Y-point)	Electrical

ROT1	Predecessor Node	Rotational_V
ROT2	Successor Node	Rotational_V

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
R1	Stator resistance	real	1 [Ohm]
L1D	Stator inductance d-component	real	0.5 [H]
L1Q	Stator inductance q-component	real	0.5 [H]
L1ZERO	Stator inductance - zero component	real	0.05 [H]
KE	Voltage constant	real	1 [Wb]
P	Number of pole pairs	real	1
I1A0	Initial phase a stator current	real	0 [A]
I1B0	Initial phase b stator current	real	0 [A]
I1C0	Initial phase c stator current	real	0 [A]
J	Moment of inertia	real	1 [kgm ²]
KVSC	Viscous friction coefficient	real	0 [Nms/rad]
KMUL	Polynomial friction multiplier	real	0 [Nms/rad]
KEXP	Polynomial friction expo-	real	0

	nent		
MCLB	Constant Coulomb friction torque	real	0 [Nm]
OMEGACLB	Coulomb angular velocity	real	0.001 [rad/s]
OMEGASTK	Stick angular velocity	real	0 [rad/s]
MSTK	Stick torque (break-off)	real	0 [Nm]
KSTK	Stick friction coefficient	real	1e+016 [Nms/rad]
MFRCCH	Characteristic friction torque ($m = f(\text{OMEGA})$)	real	0 [Nm]
KFRCCH	Characteristic friction torque coefficient	real	1
MEXT	External (arbitrary) torque ($m = f(t)$)	real	0 [Nm]
KEXT	External source weighting coefficient	real	1
OMEGA0	Initial angular velocity	real	0 [rad/s]
PHI0	Initial angular position	real	0 [rad]
PHIU	Upper angular position limit	real	0 [rad]
PHIL	Lower angular position limit	real	0 [rad]
N2	Fixed Component Value	real	0

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Input/Output Quantities

Table3

Name	Description [Unit]	Direction	Data Type
V1A, V1B, V1C	Stator phase voltages; Phase A, B, C [V]	Output	real
dV1A, dV1B, dV1C	Stator phase voltages 1 st derivative; Phase A, B, C [V/s]	Output	real
I1A, I1B, I1C	Stator phase currents; Phase A, B, C [A]	Output	real
dI1A, dI1B, dI1C	Stator phase currents 1 st derivative; Phase A, B, C [A/s]	Output	real
V1ALPHA, V1BETA	Stator voltages; alpha and beta component [V]	Output	real
dV1ALPHA, dV1BETA	Stator voltages 1 st derivative; alpha and beta component [V/s]	Output	real
I1ALPHA, I1BETA	Stator currents; alpha and beta component [A]	Output	real
dI1ALPHA, dI1BETA	Stator currents 1 st derivative; alpha and beta component [A/s]	Output	real
V1D, V1Q, V1ZERO	Stator voltages; d- q-, and zero component [V]	Output	real
dV1D, dV1Q, dV1ZERO	Stator voltages 1 st derivative; d- q-, and zero component [V/s]	Output	real
I1D, I1Q, I1ZERO	Stator currents; d- q-, and zero component [A]	Output	real
dI1D, dI1Q, dI1ZERO	Stator currents 1 st derivative; d- q-, and zero component [A/s]	Output	real

PSI1D, PSI1Q, PSI1ZERO	Stator flux; d- q-, and zero component [Vs]	Output	real
dPSI1D, dPSI1Q, dPSI1ZERO	Stator flux 1 st derivative; d- q-, and zero component [V]	Output	real
MI	Intrinsic (magnetic) torque [Nm]	Output	real
dALPHA	Angular jerk [rad/s ³]	Output	real
ALPHA	Angular acceleration [rad/s ²]	Output	real
OMEGA	Angular velocity [rad/s]	Output	real
PHI	Angular position [rad]	Output	real
M1	Torque supplied by pre- decessor [Nm]	Output	real
M2	Torque supplied to suc- cessor [Nm]	Output	real
MACX	Accelerating external torques [Nm]	Output	real
MACC	Accelerating torque [Nm]	Output	real
MFRC	Resulting friction torque [Nm]	Output	real
MVSC	Viscous friction torque [Nm]	Output	real
MFRCPOL	Polynomial friction torque [Nm]	Output	real
MFRCCLB	Coulomb friction torque [Nm]	Output	real

MFRCCH_VAL	Characteristic friction torque [Nm]	Output	real
MEXT_VAL	External (arbitrary) torque [Nm]	Output	real

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Example

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References

Permanently Excited Synchronous Machine with Damper SYMPD

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

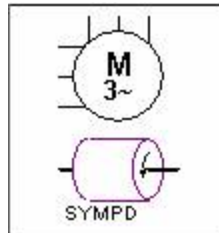


Figure 1. Component symbol

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- [Assumptions and Limitations](#)
- [Mathematical Description](#)
- [Netlist Syntax](#)
- [Conservative Pins](#)
- [Parameters](#)
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Description

This component combines all properties of the Twin Builder basic SYMPMD (extended by the Y-point properties) with those of the mechanical mass component.

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Assumptions and Limitations

- No saturation effects
- No skin effects

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Mathematical Description

$\omega(t)$ represents the mechanical speed of the rotor. Resistances and inductances are phase quantities. The voltage constant KE is gained by measuring the stator phase peak voltages in [V] while turning the motor shaft at a certain speed measured in [rad/s].

The voltage ratio k_V (V_{rt}) is determined by the number of stator/rotor windings and the winding factor:

$$k_V = \frac{(\mathbf{w} \cdot \xi_1)_1}{(\mathbf{w} \cdot \xi_2)_2} = \frac{V_{10}}{V_{20}}$$

where w = number of windings, x = winding factor, V_0 = open circuit voltages.

All rotor quantities are reduced to stator side by V_{rt} (k_V).

Reference Frames:

The synchronous machine differential equation system is transformed into a coordinate system (reference frame), which is aligned with the electrical rotor d-axis. Therefore, this reference frame is rotating at rotor speed given by ω_E . The coordinate system is rectangular with a real (d-) axis and an imaginary (q-) axis. The angle γ is the electrical rotor reference frame position angle.

For mechanical properties, parameters, and computed mechanical quantities.

[See also Mass Component \(Rotational\)](#)

Voltage equations

$$v_{1d}(t) = R_1 \cdot i_{1d}(t) + \frac{d\Psi_{1d}(t)}{dt} - \omega_E \cdot \Psi_{1q}(t)$$

$$v_{1q}(t) = R_1 \cdot i_{1q}(t) + \frac{d\Psi_{1q}(t)}{dt} + \omega_E \cdot \Psi_{1d}(t)$$

$$v_{10}(t) = R_1 \cdot i_{10}(t) + \frac{d\Psi_{10}(t)}{dt}$$

$$v_{2d}(t) = R_{2d}' \cdot i_{2d}(t) + \frac{d\Psi_{2d}(t)}{dt}$$

$$v_{2q}(t) = R_{2q}' \cdot i_{2q}(t) + \frac{d\Psi_{2q}(t)}{dt}$$

Electric frequency

$$\omega_E(t) = p \cdot \varpi(t)$$

Flux equations

$$\begin{aligned}
\Psi_{1d}(t) &= L_{1d} \cdot i_{1d}(t) + L_{m12d} \cdot i_{2d}(t) + \Psi_{Pm1fd} \\
\Psi_{1q}(t) &= L_{1q} \cdot i_{1q}(t) + L_{m12q} \cdot i_{2q}(t) \\
\Psi_{10}(t) &= L_{10} \cdot i_{10}(t) \\
\Psi_{2d}(t) &= L_{2d} \cdot i_{2d}(t) + L_{m12d} \cdot i_{1d}(t) + \Psi_{Pm2fd} \\
\Psi_{2q}(t) &= L_{2q} \cdot i_{2q}(t) + L_{m12q} \cdot i_{1q}(t)
\end{aligned}$$

Field equation

$$\Psi_{Pm1fd}(t) = \Psi_{Pm2fd}(t) = \frac{k_e}{p}$$

Torque equation

$$m_{Int}(t) = \frac{3}{2} \cdot p \cdot (\Psi_{1d}(t) \cdot i_{1q}(t) - \Psi_{1q}(t) \cdot i_{1d}(t))$$

Rotation matrix

$$R = \begin{bmatrix} \cos \gamma & \sin \gamma & 0 \\ -\sin \gamma & \cos \gamma & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Three-phase - two-phase and two-phase - three-phase transformation matrices

$$T_{32} = \begin{bmatrix} \frac{2}{3} & -\frac{1}{3} & -\frac{1}{3} \\ 0 & \frac{\sqrt{3}}{3} & -\frac{\sqrt{3}}{3} \\ \frac{1}{3} & \frac{1}{3} & \frac{1}{3} \end{bmatrix} \quad \text{and} \quad T_{23} = \begin{bmatrix} 1 & 0 & 1 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} & 1 \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} & 1 \end{bmatrix}$$

Reference frame transformation - stator voltages

$$\begin{bmatrix} v_{1\alpha} \\ v_{1\beta} \\ v_{10} \end{bmatrix} = T_{32} \cdot \begin{bmatrix} v_{1a} \\ v_{1b} \\ v_{1c} \end{bmatrix} \quad \text{and} \quad \begin{bmatrix} v_{1Re} \\ v_{1Im} \\ v_{10} \end{bmatrix} = R \cdot \begin{bmatrix} v_{1\alpha} \\ v_{1\beta} \\ v_{10} \end{bmatrix}$$

Reference frame transformation - stator currents

$$\begin{bmatrix} i_{1\alpha} \\ i_{1\beta} \\ i_{10} \end{bmatrix} = R^{-1} \cdot \begin{bmatrix} i_{1Re} \\ i_{1Im} \\ i_{10} \end{bmatrix} \quad \text{and} \quad \begin{bmatrix} i_{1a} \\ i_{1b} \\ i_{1c} \end{bmatrix} = T_{23} \cdot \begin{bmatrix} i_{1\alpha} \\ i_{1\beta} \\ i_{10} \end{bmatrix}$$

Reference frame transformation - rotor currents

$$\begin{bmatrix} i_{2a} \\ i_{2b} \\ i_{2c} \end{bmatrix} = T_{23} \cdot R^{-1} \cdot k_V \cdot \begin{bmatrix} i_{2Re} \\ i_{2Im} \\ i_{20} \end{bmatrix}$$

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Netlist Syntax

```
INTERN VM VM_A11_?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) N1 := %0, N2 :=  
GND (); INTERN VM VM_B11_?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) N1 :=  
%1, N2 := GND (); INTERN VM VM_C11_?InstanceName(@InstanceName):(@ (Refbase)@  
(ID)) N1 := %2, N2 := GND (); INTERN VM VM_A12_?InstanceName(@InstanceName):(@ (Ref-  
base)@ (ID)) N1 := %3, N2 := GND (); INTERN VM VM_B12_?InstanceName(@In-  
stanceName):(@ (Refbase)@ (ID)) N1 := %4, N2 := GND (); INTERN VM VM_  
C12_?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) N1 := %5, N2 := GND ();  
UMODEL VM_ROT VM_ROT_Pre_?InstanceName(@InstanceName):(@ (Refbase)@ (ID))  
ROT1 := %6, ROT2 := GND () SRC: DB (Lib:= "Simplorer Elements\\Basic Elements\\Basic  
Elements"); UMODEL VM_ROT VM_ROT_Suc_?InstanceName(@InstanceName):(@ (Ref-  
base)@ (ID)) ROT1 := %7, ROT2 := GND () SRC: DB (Lib:= "Simplorer Elements\\Basic Ele-  
ments\\Basic Elements"); UMODEL MchRSympd ?InstanceName(@InstanceName):(@  
(Refbase)@ (ID)) A11 := %0, B11 := %1, C11 := %2, A12 := %3, B1 := %4, C12 := %5, ROT1 :=  
%6, ROT2 := %7, GND := GND (R1:=@R1, L1D:=@L1D, L1Q:=@L1Q, L1ZERO:=@L1ZERO  
, R2D:=@R2D, R2Q:=@R2Q, L2D:=@L2D, L2Q:=@L2Q, LM12D:=@LM12D, LM12Q:-  
:=@LM12Q, KE:=@KE, P:=@P, RATIOV:=@RATIOV, I1A0:=@I1A0, I1B0:=@I1B0, I1C0:-  
:=@I1C0, I2A0:=@I2A0, I2B0:=@I2B0, I2C0:=@I2C0, J:=@J, KVSC:=@KVSC
```

,KMUL:=@KMUL ,KEXP:=@KEXP ,MCLB:=@MCLB ,OMEGACLB:=@OMEGACLB
 ,OMEGASTK:=@OMEGASTK ,MSTK:=@MSTK ,KSTK:=@KSTK ,MFRCCCH:=@MFRCCCH
 ,KFRCCCH:=@KFRCCCH ,MEXT:=@MEXT ,KEXT:=@KEXT ,OMEGA0:=@OMEGA0 ,PHI0:-
 :=@PHI0 ,PHIU:=@PHIU ,PHIL:=@PHIL) SRC: DB(Lib:= "Simplorer Elements\\\\Basic Ele-
 ments\\\\Basic Elements") ;

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
A11	Stator primary node phase A positive (u)	Electrical
B11	Stator primary node phase B positive (v)	Electrical
C11	Stator primary node phase C positive (w)	Electrical
A12	Stator secondary node phase A negative (x) (Y-point)	Electrical
B12	Stator secondary node phase B negative (y) (Y-point)	Electrical
C12	Stator secondary node phase C negative (z) (Y-point)	Electrical
ROT1	Predecessor Node	Rotational_V
ROT2	Successor Node	Rotational_V

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
R1	Stator resistance	real	1 [Ohm]
L1D	Stator inductance d-component	real	0.5 [H]
L1Q	Stator inductance q-component	real	0.5 [H]
L1ZERO	Stator inductance - zero component	real	0.05 [H]
R2D	Damper resistance d-comp reduced to stator	real	1 [Ohm]
R2Q	Damper resistance q-comp reduced to stator	real	1 [Ohm]
L2D	Damper inductance d-comp reduced to stator	real	0.5 [H]
L2Q	Damper inductance q-comp reduced to stator	real	0.5 [H]
LM12D	Mutual inductance stator-damper d-component	real	0.5 [H]
LM12Q	Mutual inductance stator-damper q-component	real	0.5 [H]
KE	Voltage constant	real	1 [Wb]
P	Number of pole pairs	real	1
RATIOV	Stator/rotor voltage ratio ($V_{rt} \approx U_{10} / U_{20}$)	real	1
I1A0	Initial phase a stator current	real	0 [A]

I1B0	Initial phase b stator current	real	0 [A]
I1C0	Initial phase c stator current	real	0 [A]
I2A0	Initial phase a rotor current	real	0 [A]
I2B0	Initial phase b rotor current	real	0 [A]
I2C0	Initial phase c rotor current	real	0 [A]
J	Moment of inertia	real	1 [kgm ²]
KVSC	Viscous friction coefficient	real	0 [Nms/rad]
KMUL	Polynomial friction multiplier	real	0 [Nms/rad]
KEXP	Polynomial friction exponent	real	0
MCLB	Constant Coulomb friction torque	real	0 [Nm]
OMEGACLB	Coulomb angular velocity	real	0.001 [rad/s]
OMEGASTK	Stick angular velocity	real	0 [rad/s]
MSTK	Stick torque (break-off)	real	0 [Nm]
KSTK	Stick friction coefficient	real	1e+016 [Nms/rad]
MFRCCH	Characteristic friction torque ($m = f(\text{OMEGA})$)	real	0 [Nm]
KFRCCH	Characteristic friction torque coefficient	real	1
MEXT	External (arbitrary) torque ($m = f(t)$)	real	0 [Nm]

KEXT	External source weighting coefficient	real	1
OMEGA0	Initial angular velocity	real	0 [rad/s]
PHI0	Initial angular position	real	0 [rad]
PHIU	Upper angular position limit	real	0 [rad]
PHIL	Lower angular position limit	real	0 [rad]

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Input/Output Quantities

Table3

Name	Description [Unit]	Direction	Data Type
V1A, V1B, V1C	Stator phase voltages; Phase A, B, C [V]	Output	real
dV1A, dV1B, dV1C	Stator phase voltages 1 st derivative; Phase A, B, C [V/s]	Output	real
I1A, I1B, I1C	Stator phase currents; Phase A, B, C [A]	Output	real
I2A, I2B, I2C	Rotor phase currents; Phase A, B, C [A]	Output	real
dI1A, dI1B, dI1C	Stator phase currents 1 st derivative; Phase A, B, C [A/s]	Output	real
dI2A, dI2B, dI2C	Rotor phase currents 1 st derivative; Phase A, B, C [A/s]	Output	real
V1ALPHA, V1BETA	Stator voltages; alpha and beta component [V]	Output	real

dV1ALPHA, dV1BETA	Stator voltages 1 st derivative; alpha and beta component [V/s]	Output	real
I1ALPHA, I1BETA	Stator currents; alpha and beta component [A]	Output	real
dI1ALPHA, dI1BETA	Stator currents 1 st derivative; alpha and beta component [A/s]	Output	real
V1D, V1Q, V1ZERO	Stator voltages; d- q-, and zero component [V]	Output	real
dV1D, dV1Q, dV1ZERO	Stator voltages 1 st derivative; d- q-, and zero component [V/s]	Output	real
I1D, I1Q, I1ZERO	Stator currents; d- q-, and zero component [A]	Output	real
I2D, I2Q	Rotor currents; d- and q-component [A]	Output	real
dI1D, dI1Q, dI1ZERO	Stator currents 1 st derivative; d- q-, and zero component [A/s]	Output	real
dI2D, dI2Q	Rotor currents 1 st derivative; d- and q-component [A/s]	Output	real
PSI1D, PSI1Q, PSI1ZERO	Stator flux; d- q-, and zero component [Vs]	Output	real
PSI2D, PSI2Q	Rotor flux; d- and q-component [Vs]	Output	real
dPSI1D, dPSI1Q, dPSI1ZERO	Stator flux 1 st derivative; d- q-, and zero component [V]	Output	real
dPSI2D, dPSI2Q	Rotor flux 1 st derivative; d- and q-component [V]	Output	real

MI	Intrinsic (magnetic) torque [Nm]	Output	real
dALPHA	Angular jerk [rad/s ³]	Output	real
ALPHA	Angular acceleration [rad/s ²]	Output	real
OMEGA	Angular velocity [rad/s]	Output	real
PHI	Angular position [rad]	Output	real
M1	Torque supplied by predecessor [Nm]	Output	real
M2	Torque supplied to successor [Nm]	Output	real
MACX	Accelerating external torques [Nm]	Output	real
MACC	Accelerating torque [Nm]	Output	real
MFRC	Resulting friction torque [Nm]	Output	real
MVSC	Viscous friction torque [Nm]	Output	real
MFRCPOL	Polynomial friction torque [Nm]	Output	real
MFRCCLB	Coulomb friction torque [Nm]	Output	real
MFRCH_VAL	Characteristic friction torque [Nm]	Output	real
MEXT_VAL	External (arbitrary) torque [Nm]	Output	real

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Example

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References

Synchronous Machine Electrical Excitation without Damper

Library: Basic Elements

Modeling Language: SML

Version Number: Twin Builder 2025.2

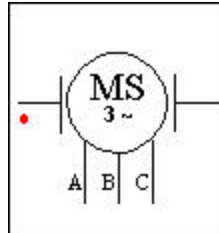


Figure 1. Component Symbol.

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Description

The model represents a linear DC field synchronous machine without damper (internal-field) as a lumped circuit component. Depending on the parameter set, the machine can be operated either as a salient or non-salient pole rotor. The circuit nodes A – B – C are the terminals of star-connected stator winding; the circuit nodes E1 – E2 are the terminals of excitation winding. The component cannot be used with AC and DC simulation.

Note: If the line-to-line voltage v_{ab} , v_{bc} , v_{ac} or the line currents i_a , i_b , i_c of the synchronous machine are of special interest, voltmeters or ammeters can be connected to the synchronous machine. Ψ is the magnetic flux.

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Assumptions and Limitations

Model Limits of Synchronous Machine Models

- 3-phase symmetrical synchronous machine with internal-field system and star-connected stator winding without neutral node (no zero phase-sequence system).
- Linear and iron-loss free magnetic circuit.

- No consideration of skin effects in the windings.
- Exclusive consideration of fundamental flux linkage between stator, damper and excitation windings.
- Rotor position-independent leakage inductances.
- Friction losses (parasitic torques) are not considered in the model; they can be added with the load torque parameter externally.

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Mathematical Description

Equation System

The equation system is implemented in a rotor-fixed (rotor-fixed and also rotor flux-fixed) coordinate system (d-q coordinates). Index *1* represents the stator quantities; the index *e* the quantities of rotor excitation windings. The phase quantities of the real three-phase synchronous machine are indicated with *a*, *b*, *c*. Ψ is the magnetic flux.

Voltage Equations

$$\begin{aligned}v_{1d}(t) &= i_{1d}(t) \cdot R_1 + \frac{d\psi_{1d}(t)}{dt} - p \cdot \omega(t) \cdot \psi_{1q}(t) & v_{ed}(t) &= i_{ed}(t) \cdot R_e + \frac{d\psi_{ed}(t)}{dt} \\v_{1q}(t) &= i_{1q}(t) \cdot R_1 + \frac{d\psi_{1q}(t)}{dt} + p \cdot \omega(t) \cdot \psi_{1d}(t) & v_{eq}(t) &= 0\end{aligned}$$

Flux-Linkage Equations

$$\begin{aligned}\psi_{1d}(t) &= i_{1d}(t) \cdot L_{1d} + i_{ed}(t) \cdot L_{m1ed} \\ \psi_{1q}(t) &= i_{1q}(t) \cdot L_{1q} \\ \psi_{ed}(t) &= i_{1d}(t) \cdot L_{m1ed} + i_{ed}(t) \cdot L_{ed} \\ \psi_{eq}(t) &= 0\end{aligned}$$

Torque Equation (electromagnetic developed “internal” torque)

$$m_i(t) = \frac{3}{2}p \cdot (\psi_{1d}(t) \cdot i_{1q}(t) - \psi_{1q}(t) \cdot i_{1d}(t))$$

Motion Equation

$$\frac{d\omega(t)}{dt} = \frac{1}{J}(m_i(t) - m_w(t))$$

Electrical Coupling of excitation quantities with the orthogonal quantities

$$v_{ed}(t) = v_e(t) \quad i_e(t) = i_{ed}(t)$$

Electrical Coupling of phase quantities with the orthogonal quantities

$$\gamma(t) = p \cdot \int \omega(t) dt$$

$$v_{1\alpha}(t) = \frac{2}{3}v_{1a}(t) - \frac{1}{3}v_{1b}(t) - \frac{1}{3}v_{1c}(t)$$

$$v_{1\beta}(t) = \frac{\sqrt{3}}{3}v_{1b}(t) - \frac{\sqrt{3}}{3}v_{1c}(t)$$

$$v_{1d}(t) = v_{1\alpha}(t) \cdot \cos(\gamma(t)) + v_{1\beta}(t) \cdot \sin(\gamma(t))$$

$$v_{1q}(t) = v_{1\alpha}(t) \cdot \sin(\gamma(t)) - v_{1\beta}(t) \cdot \cos(\gamma(t))$$

$$i_{1\alpha}(t) = i_{1d}(t) \cdot \cos(\gamma(t)) - i_{1q}(t) \cdot \sin(\gamma(t))$$

$$i_{1\beta}(t) = i_{1d}(t) \cdot \sin(\gamma(t)) + i_{1q}(t) \cdot \cos(\gamma(t))$$

$$i_{1a}(t) = i_{1\alpha}(t)$$

$$i_{1b}(t) = -\frac{1}{2}i_{1\alpha}(t) + \frac{\sqrt{3}}{2}i_{1\beta}(t)$$

$$i_{1c}(t) = -\frac{1}{2}i_{1\alpha}(t) - \frac{\sqrt{3}}{2}i_{1\beta}(t)$$

[Top](#)**Netlist Syntax**

```
INTERN SYME ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) A:= %0 , B:= %1 , C:=
%2 , E1:= %3 , E2:= %4 ( LOAD:=@ (LOAD), R1:=@ (R1), L1D:=@ (L1D), L1Q:=@ (L1Q),
LM1ED:=@ (LM1ED), RE:=@ (RE), LE:=@ (LE), P:=@ (P), J:=@ (J), I1A0:=@ (I1A0), I1B0:=@
(I1B0), I1C0:=@ (I1C0), IE0:=@ (IE0), N0:=@ (N0), PHI0:=@ (PHI0));
```

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
A	Stator Node A	electrical
B	Stator Node B	electrical
C	Stator Node C	electrical
E1	Excitation Circuit Node E1	electrical
E2	Excitation Circuit Node E2	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
LOAD	Load Torque	real	0 [Nm]
R1	Stator Resistance	real	0.4 [Ohm]
L1D	Stator Inductance d-Axis	real	42m [H]
L1Q	Stator Inductance q-Axis	real	42m [H]
LM1ED	Mutual Inductance stator-exciter d-Axis	real	35m [H]
RE	Excitation Resistance	real	1 [Ohm]
LE	Excitation Inductance d-Axis	real	50m [H]
P	Number of Pole Pairs	real	2 [/]
J	Moment of Inertia	real	75m [kg*m ²]
I1A0	Initial Current Stator Phase a	real	0 [A]
I1B0	Initial Current Stator Phase b	real	0 [A]
I1C0	Initial Current Stator Phase c	real	0 [A]
IE0	Initial Excitation Current	real	0 [A]
N0	Initial Rotor Speed	real	0[rpm]
PHI0	Initial Rotor Position	real	0 [deg]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
N	Rotor Speed [rpm]	Output	real
MI	Inner Torque [Nm]	Output	real
OMEGA	Rotor rational Speed [1/s]	Output	real
ALPHA	Angular Rotor Acceleration [1/s ²]	Output	real
PHI	Rotor Angle in Radians [rad]	Output	real
PHIDEG	Rotor Angle in Degrees [deg]	Output	real
PHIM	Rotor Angle Mechanical in Radians [rad]	Output	real
PHIMDEG	Rotor Angle Mechanical in Degrees [deg]	Output	real
I1A	Current Stator Phase a [A]	Output	real
I1B	Current Stator Phase b [A]	Output	real
I1C	Current Stator Phase c [A]	Output	real
IE	Excitation Current d-Axis [A]	Output	real
I1D	Real Part of Stator Current [A]	Output	real
I1Q	Imaginary Part of Stator Current [A]	Output	real
V1D	Real Part of Stator Voltage [V]	Output	real
V1Q	Imaginary Part of Stator Voltage [V]	Output	real
PSI1D	Real Part of Stator Flux Linkage [Vs]	Output	real
PSI1Q	Imaginary Part of Stator Flux Linkage [Vs]	Output	real
PSIE	Excitation Flux Linkage d-Axis [Vs]	Output	real
PWRELEC	Electrical Real Power Input [W]	Output	real
PWRMECH	Mechanical power output[W]	Output	real
PWRLOSS	Losses[W]	Output	real

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Example

In this example, the linear DC field Synchronous Machine without Damper SYME1 works as a generator. The value of the drive torque decided by the Step Function mw, and the DC excitation is provided by voltage source E1. The electrical terminals of SYME1 are connected to a symmetrical three-phase resistive load. The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the simulation results are shown in Figure 3, 4, and 5.

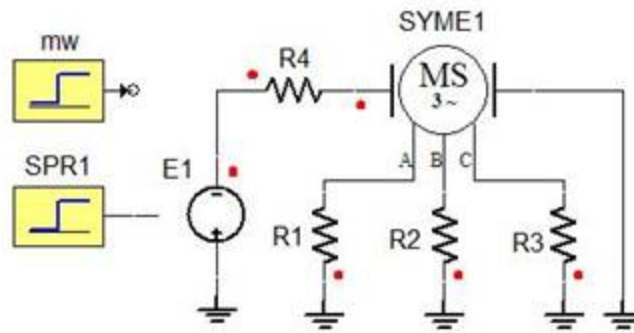


Figure 2. Application examples of Synchronous Machine without Damper

Table 4. System Parameters

Component	Parameter	Value [unit]
Synchronous Machine without Damper SYME1	LOAD	mw.VAL [Nm]
	R1	0.41 [Ohm]
	L1D	41.93m [H]
	L1Q	41.93m [H]
	LM1ED	35m [H]
	RE	1 [Ohm]
	LE	50m [H]
	P	2 [/]
	J	0.0129 [kg*m ²]
	I1A0	0 [A]
	I1B0	0 [A]
	I1C0	0 [A]
	IE0	0 [A]
	N0	0[rpm]
	PHI0	0 [deg]

Voltage Source E1	EMF	SPR1.VAL [V]
Resistor R1/R2/R3	R	15 [Ohm]
Resistor R4	R	20 [Ohm]
Step Function mw	AMPL	20
	T0	0 [s]
	Y0	0
Step Function SPR1	AMPL	500
	T0	0 [s]
	Y0	0

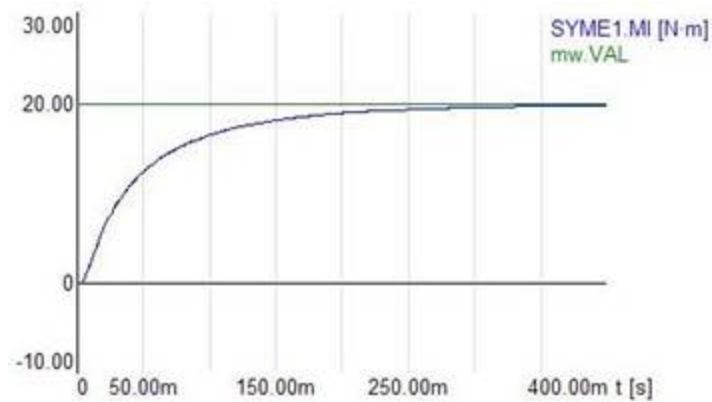


Figure 3. Simulation results-drive and electromagnetic torque of SYME1

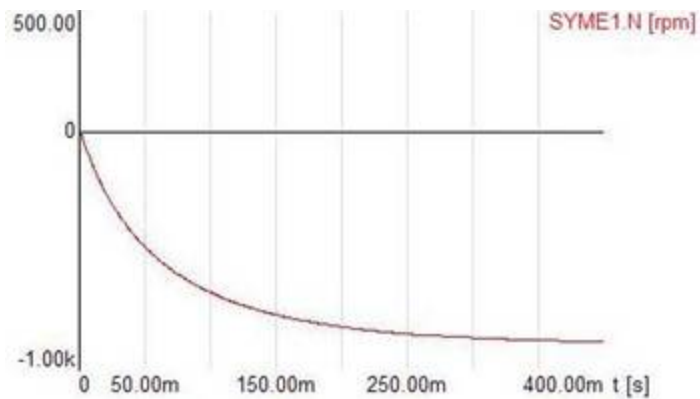


Figure 4. Simulation results-rotor speed of SYME1

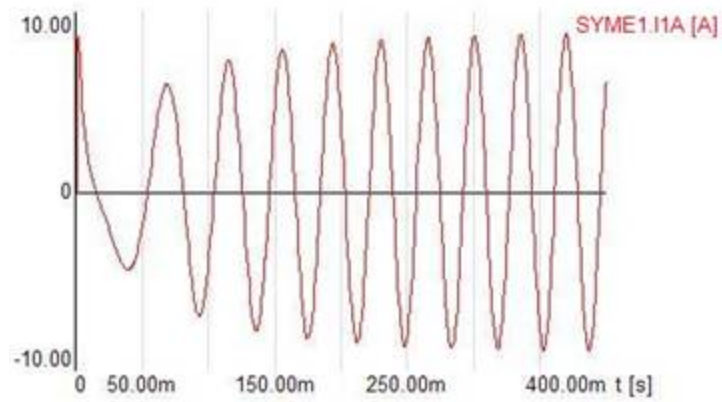


Figure 5. Simulation results-phase A current of SYME1

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References

Synchronous Machine Electrical Excitation with Damper

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

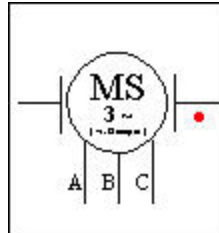


Figure 1. Component Symbol.

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Description

The model represents a linear DC field synchronous machine with damper as a lumped circuit component. The damper circuit is not accessible from outside the machine; the corresponding phase windings are connected at a virtual neutral node. Depending on the parameter set, the machine can be operated either as a salient or non-salient pole rotor. The circuit nodes A – B – C are the terminals of star-connected stator winding; the circuit nodes E1 – E2 are the terminal of excitation winding. The component cannot be used with AC and DC simulation.

Note: If the line-to-line voltage v_{ab} , v_{bc} , v_{ac} or the line currents i_a , i_b , i_c of the synchronous machine are of special interest, voltmeters or ammeters can be connected to the synchronous machine.

In the case of identical parameters for the inductances L1D and L1Q, a synchronous machine with permanent magnet and non-salient pole rotor is modeled. To model a permanent magnet salient-pole machine, the parameters must be different for L1D and L1Q.

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Assumptions and Limitations

Model Limits of Synchronous Machine Models

- 3-phase symmetrical synchronous machine with internal-field system and star-connected stator winding without neutral node (no zero phase-sequence system).
- Linear and iron-loss free magnetic circuit.
- No consideration of skin effects in the windings.
- Exclusive consideration of fundamental flux linkage between stator, damper and excitation windings.
- Rotor position-independent leakage inductances.
- Friction losses (parasitic torques) are not considered in the model; they can be added with the load torque parameter externally.

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Mathematical Description

Equation System

The equation system is implemented in a rotor-fixed (rotor-fixed and also rotor flux-fixed) coordinate system (d-q coordinates). Index 1 represents the stator quantities; the index 2 the equivalent quantities of the damper circuit belonged to the rotor. The phase quantities of the real three-phase synchronous machine are indicated with *a*, *b*, *c*. Ψ is the magnetic flux.

Voltage Equations

$$\begin{aligned}v_{1d}(t) &= i_{1d}(t) \cdot R_1 + \frac{d\psi_{1d}(t)}{dt} - p \cdot \omega(t) \cdot \psi_{1q}(t) & 0 &= i_{e2}(t) \cdot R_2 + \frac{d\psi_{2d}(t)}{dt} \\v_{1q}(t) &= i_{1q}(t) \cdot R_1 + \frac{d\psi_{1q}(t)}{dt} + p \cdot \omega(t) \cdot \psi_{1d}(t) & 0 &= i_{2q}(t) \cdot R_2 + \frac{d\psi_{2q}(t)}{dt} \\v_{ed}(t) &= i_{ed}(t) \cdot R_e + \frac{d\psi_{ed}(t)}{dt} & v_{eq}(t) &= 0\end{aligned}$$

Flux-Linkage Equations

$$\begin{aligned}\psi_{1d}(t) &= i_{1d}(t) \cdot L_{1d} + i_{2d}(t) \cdot L_{m12d} + i_{ed}(t) \cdot L_{m1ed} \\ \psi_{1q}(t) &= i_{1q}(t) \cdot L_{1q} + i_{2d}(t) \cdot L_{m12q} \\ \psi_{2d}(t) &= i_{1d}(t) \cdot L_{m12d} + i_{2d}(t) \cdot L_{2d} + i_{ed}(t) \cdot L_{m2ed} \\ \psi_{2q}(t) &= i_{1q}(t) \cdot L_{m12q} + i_{2q}(t) \cdot L_{2q} \\ \psi_{ed}(t) &= i_{1d}(t) \cdot L_{m1ed} + i_{2d}(t) \cdot L_{m2ed} + i_{ed}(t) \cdot L_{ed} \\ \psi_{eq}(t) &= 0\end{aligned}$$

Torque Equation (electromagnetic developed “internal” torque)

$$m_1(t) = \frac{3}{2}p \cdot (\psi_{1d}(t) \cdot i_{1q}(t) - \psi_{1q}(t) \cdot i_{1d}(t))$$

Motion Equation

$$\frac{d\omega(t)}{dt} = \frac{1}{J}(m_1(t) - m_w(t))$$

Electrical Coupling of excitation quantities with the orthogonal quantities

$$v_{ed}(t) = v_e(t) \quad i_e(t) = i_{ed}(t)$$

Electrical Coupling of phase quantities with the orthogonal quantities

$$\gamma(t) = p \cdot \int \omega(t) dt$$

$$v_{1\alpha}(t) = \frac{2}{3}v_{1a}(t) - \frac{1}{3}v_{1b}(t) - \frac{1}{3}v_{1c}(t)$$

$$v_{1\beta}(t) = \frac{\sqrt{3}}{3}v_{1b}(t) - \frac{\sqrt{3}}{3}v_{1c}(t)$$

$$v_{1d}(t) = v_{1\alpha}(t) \cdot \cos(\gamma(t)) + v_{1\beta}(t) \cdot \sin(\gamma(t))$$

$$v_{1q}(t) = v_{1\alpha}(t) \cdot \sin(\gamma(t)) - v_{1\beta}(t) \cdot \cos(\gamma(t))$$

$$i_{1\alpha}(t) = i_{1d}(t) \cdot \cos(\gamma(t)) - i_{1q}(t) \cdot \sin(\gamma(t))$$

$$i_{1\beta}(t) = i_{1d}(t) \cdot \sin(\gamma(t)) + i_{1q}(t) \cdot \cos(\gamma(t))$$

$$i_{1a}(t) = i_{1\alpha}(t)$$

$$i_{1b}(t) = -\frac{1}{2}i_{1\alpha}(t) + \frac{\sqrt{3}}{2}i_{1\beta}(t)$$

$$i_{1c}(t) = -\frac{1}{2}i_{1\alpha}(t) - \frac{\sqrt{3}}{2}i_{1\beta}(t)$$

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Netlist Syntax

INTERN SYMED ?InstanceName(@InstanceName):(@ (Refbase)@(ID)) A:= %0 , B:= %1 , C:= %2 , E1:= %3 , E2:= %4 (LOAD:=@(LOAD), R1:=@(R1), R2:=@(R2), L1D:=@(L1D), L1Q:=@(L1Q), L2D:=@(L2D), L2Q:=@(L2Q), LM12D:=@(LM12D), LM12Q:=@(LM12Q), RE:=@(RE), LE:=@(LE), LM1ED:=@(LM1ED), LM2ED:=@(LM2ED), P:=@(P), J:=@(J), I1A0:=@(I1A0), I1B0:=@(I1B0), I1C0:=@(I1C0), I2A0:=@(I2A0), I2B0:=@(I2B0), I2C0:=@(I2C0), IE0:=@(IE0), N0:=@(N0), PHI0:=@(PHI0));

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
A	Stator Node A	electrical
B	Stator Node B	electrical
C	Stator Node C	electrical
E1	Excitation Circuit Node E1	electrical
E2	Excitation Circuit Node E2	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
LOAD	Load Torque	real	0 [Nm]
R1	Stator Resistance	real	0.4 [Ohm]
R2	Damper Resistance	real	0.24 [Ohm]
L1D	Stator Inductance d-Axis Leakage inductance of stator side	real	42m [H]
L1Q	Stator Inductance q-Axis Leakage inductance of stator side	real	42m [H]
L2D	Damper Inductance d-Axis Leakage inductance of damper circuit side	real	42m [H]
L2Q	Damper Inductance q-Axis Leakage inductance of damper circuit side	real	42m [H]
LM1D	Mutual Inductance stator-damper d-Axis	real	41m [H]
LM12Q	Mutual Inductance stator-damper q-Axis	real	41m [H]
RE	Excitation Resistance	real	1 [Ohm]
LE	Excitation Inductance d-Axis	real	50m [H]
LM1ED	Mutual Inductance stator-exciter d-Axis	real	35m [H]
LM2EQ	Mutual Inductance damper-exciter q-Axis	real	30m [H]
P	Number of Pole Pairs	real	2 [/]
J	Moment of Inertia	real	75m [kg*m ²]
I1A0	Initial Current Stator Phase a	real	0 [A]
I1B0	Initial Current Stator Phase b	real	0 [A]
I1C0	Initial Current Stator Phase c	real	0 [A]
I2A0	Initial Current Damper Phase a	real	0 [A]
I2B0	Initial Current Damper Phase b	real	0 [A]
I2C0	Initial Current Damper Phase c	real	0 [A]
IE0	Initial Excitation Current	real	0 [A]

N0	Initial Rotor Speed	real	0 [rpm]
PHI0	Initial Rotor Position	real	0 [deg]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
N	Rotor Speed [rpm]	Output	real
MI	Inner Torque [Nm]	Output	real
OMEGA	Rotor rational Speed [1/s]	Output	real
ALPHA	Angular Rotor Acceleration [1/s ²]	Output	real
PHI	Rotor Angle in Radians [rad]	Output	real
PHIDEG	Rotor Angle in Degrees [deg]	Output	real
PHIM	Rotor Angle Mechanical in Radians [rad]	Output	real
PHIMDEG	Rotor Angle Mechanical in Degrees [deg]	Output	real
I1A	Current Stator Phase a [A]	Output	real
I1B	Current Stator Phase b [A]	Output	real
I1C	Current Stator Phase c [A]	Output	real
I2A	Current Damper Phase a [A]	Output	real
I2B	Current Damper Phase b [A]	Output	real
I2C	Current Damper Phase c [A]	Output	real
IE	Excitation Current [A]	Output	real
I1D	Real Part of Stator Current [A]	Output	real
I1Q	Imaginary Part of Stator Current [A]	Output	real
I2D	Real Part of Damper Circuit Current [A]	Output	real
I2Q	Imaginary Part of Damper Circuit Current [A]	Output	real
V1D	Real Part of Stator Voltage [V]	Output	real
V1Q	Imaginary Part of Stator Voltage [V]	Output	real

PSI1D	Real Part of Stator Flux Linkage [Vs]	Output	real
PSI1Q	Imaginary Part of Stator Flux Linkage [Vs]	Output	real
PSI2D	Real Part of Damper Circuit Flux Linkage [Vs]	Output	real
PSI2Q	Imaginary Part of Damper Circuit Flux Linkage [Vs]	Output	real
PSIE	Excitation Flux [Vs]	Output	real
PWRELEC	Electrical Real Power Input [W]	Output	real
PWRMECH	Mechanical power output[W]	Output	real
PWRLOSS	Losses[W]	Output	real

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Example

In this example, the linear DC field Synchronous Machine with Damper SYMEMD1 is connected to a three-phase power supply, which consists of sinusoidal Voltage Source ET1, ET2 and ET3. The DC excitation of SYMEMD1 is provided by voltage source E1. The mechanical load of SYMEMD1 is decided by the Step Function Load. The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the simulation results are shown in Figure 3 and 4.

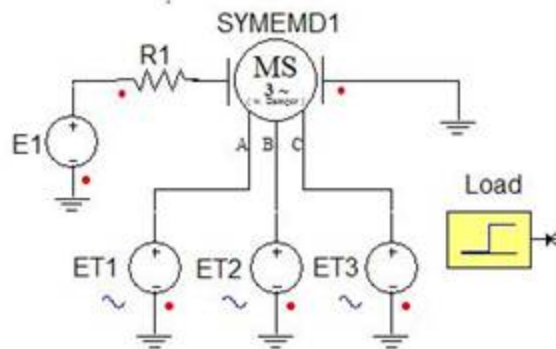


Figure 2. Application examples of Synchronous Machine with Damper

Table 4. System Parameters

Component	Parameter	Value [unit]
Synchronous Machine with Damper SYMEMD1	LOAD	Load.VAL [Nm]
	R1	0.4 [Ohm]
	R2	0.24 [Ohm]

	L1D	42m [H]
	L1Q	42m [H]
	L2D	42m [H]
	L2Q	42m [H]
	LM1D	41m [H]
	LM12Q	41m [H]
	RE	1 [Ohm]
	LE	50m [H]
	LM1ED	35m [H]
	LM2EQ	30m [H]
	P	2 [J]
	J	75m [kg*m ²]
	I1A0	0 [A]
	I1B0	0 [A]
	I1C0	0 [A]
	I2A0	0 [A]
	I2B0	0 [A]
	I2C0	0 [A]
	IE0	0 [A]
	N0	0 [rpm]
	PHI0	0 [deg]
Voltage Source E1		EMF 40[V]
Resistor R1		R 1 [Ohm]
Voltage Source ET1/ET2/ET3	AMPL	326 [V]
	FREQ	0 [s]
	PHASE	0/-120/-240 [degree]
	OFF	0 [V]
	TDELAY	0 [s]

Step Function Load	AMPL	100
	T0	0.2 [s]
	Y0	0

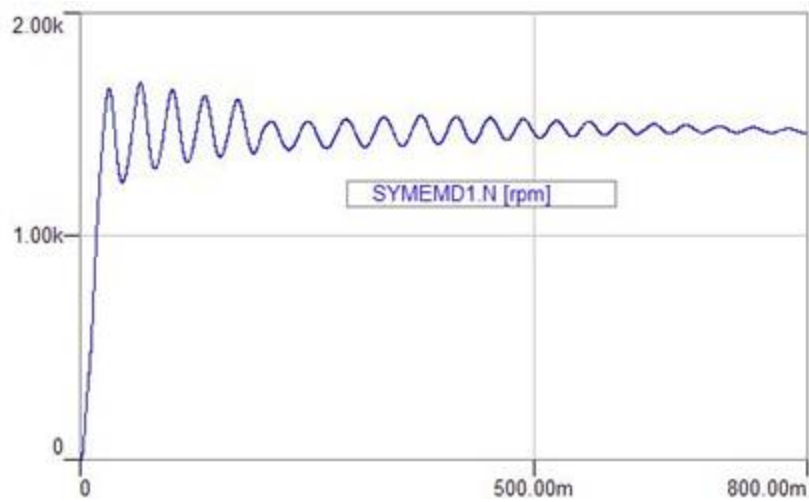


Figure 3. Simulation results-rotor speed of SYMEMD1

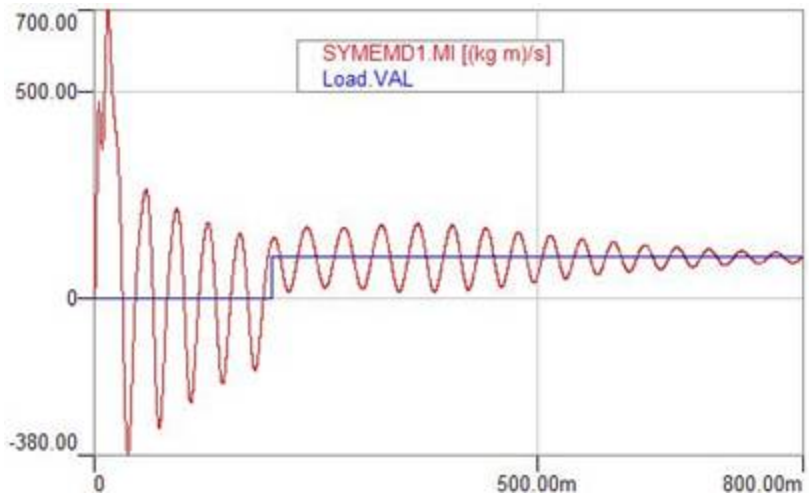


Figure 4. Simulation results-load and electromagnetic torque of SYME1.

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References

Synchronous Machine Permanent Excitation without Damper

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

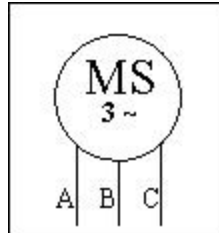


Figure 1. Component Symbol.

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- [References](#)

Description

The model represents a synchronous machine with permanent magnet excitation and without damper as a lumped circuit component. Depending on the parameter set, the machine can be operate either as a salient or non-salient pole rotor. The circuit nodes A – B – C are the terminals of star-connected stator winding. The component cannot be used with AC and DC simulation.

Note: If the line-to-line voltage v_{ab} , v_{bc} , v_{ac} or the line currents i_a , i_b , i_c of the synchronous machine are of special interest, voltmeters or ammeters can be connected to the synchronous machine.

In the case of identical parameters for the inductances L1D and L1Q, a synchronous machine with permanent magnet excitation and non-salient pole rotor is modeled. To model a permanent magnet salient-pole machine, the parameters must be different for L1D and L1Q.

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Assumptions and Limitations

Model Limits of Synchronous Machine Models

- 3-phase symmetrical synchronous machine with internal-field system and star-connected stator winding without neutral node (no zero phase-sequence system).
- Linear and iron-loss free magnetic circuit.
- No consideration of skin effects in the windings.
- Exclusive consideration of fundamental flux linkage between stator, damper and excitation windings.
- Rotor position-independent leakage inductances.
- Friction losses (parasitic torques) are not considered in the model; they can be added with the load torque parameter externally.

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Mathematical Description

Equation System

The equation system is implemented in a rotor-fixed (rotor-fixed and also rotor flux-fixed) coordinate system (d-q-coordinates). Index 1 represents the stator quantities. The phase quantities of the real three-phase synchronous machine are indicated with a, b, c. Ψ is the magnetic flux.

Voltage Equations

$$\begin{aligned}v_{1d}(t) &= i_{1d}(t) \cdot R_1 + \frac{d\psi_{1d}(t)}{dt} - p \cdot \omega(t) \cdot \psi_{1q}(t) \\v_{1q}(t) &= i_{1q}(t) \cdot R_1 + \frac{d\psi_{1q}(t)}{dt} + p \cdot \omega(t) \cdot \psi_{1d}(t)\end{aligned}$$

Flux-Linkage Equations

$$\begin{aligned}\psi_{1d}(t) &= i_{1d}(t) \cdot L_{1d} + k_e \\ \psi_{1q}(t) &= i_{1q}(t) \cdot L_{1q}\end{aligned}$$

Torque Equation (electromagnetic developed “internal” torque)

$$m_i(t) = \frac{3}{2}p \cdot (\psi_{1d}(t) \cdot i_{1q}(t) - \psi_{1q}(t) \cdot i_{1d}(t))$$

Motion Equation

$$\frac{d\omega(t)}{dt} = \frac{1}{J}(m_1(t) - m_w(t))$$

Electrical Coupling of phase quantities with the orthogonal quantities

$$\gamma(t) = p \cdot \int \omega(t) dt$$

$$v_{1\alpha}(t) = \frac{2}{3}v_{1a}(t) - \frac{1}{3}v_{1b}(t) - \frac{1}{3}v_{1c}(t)$$

$$v_{1\beta}(t) = \frac{\sqrt{3}}{3}v_{1b}(t) - \frac{\sqrt{3}}{3}v_{1c}(t)$$

$$v_{1d}(t) = v_{1\alpha}(t) \cdot \cos(\gamma(t)) + v_{1\beta}(t) \cdot \sin(\gamma(t))$$

$$v_{1q}(t) = -v_{1\alpha}(t) \cdot \sin(\gamma(t)) + v_{1\beta}(t) \cdot \cos(\gamma(t))$$

$$i_{1\alpha}(t) = i_{1d}(t) \cdot \cos(\gamma(t)) - i_{1q}(t) \cdot \sin(\gamma(t))$$

$$i_{1\beta}(t) = i_{1d}(t) \cdot \sin(\gamma(t)) + i_{1q}(t) \cdot \cos(\gamma(t))$$

$$i_{1a}(t) = i_{1\alpha}(t)$$

$$i_{1b}(t) = -\frac{1}{2}i_{1\alpha}(t) + \frac{\sqrt{3}}{2}i_{1\beta}(t)$$

$$i_{1c}(t) = -\frac{1}{2}i_{1\alpha}(t) - \frac{\sqrt{3}}{2}i_{1\beta}(t)$$

[Top](#)**Netlist Syntax**

```
INTERN SYMP ?InstanceName(@InstanceName):(@Refbase@ID) A:= %0 , B:= %1 , C:=  
%2 ( LOAD:=@(LOAD), R1:=@(R1), L1D:=@(L1D), L1Q:=@(L1Q), KE:=@(KE), P:=@(P),  
J:=@(J), I1A0:=@(I1A0), I1B0:=@(I1B0), I1C0:=@(I1C0), N0:=@(N0), PHI0:=@(PHI0));
```

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
A	Stator Node A	electrical
B	Stator Node B	electrical
C	Stator Node C	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
LOAD	Load Torque	real	0 [Nm]
R1	Stator Resistance	real	0.4 [Ohm]
L1D	Stator Inductance d-Axis	real	42m [H]
L1Q	Stator Inductance q-Axis	real	42m [H]
KE	Rotor Flux-linkage	real	0.875 [Vs]
P	Number of Pole Pairs	real	2 [/]
J	Moment of Inertia	real	75m [kg*m ²]
I1A0	Initial Current Stator Phase a	real	0 [A]
I1B0	Initial Current Stator Phase b	real	0 [A]
I1C0	Initial Current Stator Phase c	real	0 [A]
N0	Initial Rotor Speed	real	0 [rpm]
PHI0	Initial Rotor Position	real	0 [deg]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
N	Rotor Speed [rpm]	Output	real

MI	Inner Torque [Nm]	Output	real
OMEGA	Rotor rational Speed [1/s]	Output	real
ALPHA	Angular Rotor Acceleration [1/s ²]	Output	real
PHI	Rotor Angle in Radians [rad]	Output	real
PHIDEG	Rotor Angle in Degrees [deg]	Output	real
PHIM	Rotor Angle Mechanical in Radians [rad]	Output	real
PHIMDEG	Rotor Angle Mechanical in Degrees [deg]	Output	real
I1A	Current Stator Phase a [A]	Output	real
I1B	Current Stator Phase b [A]	Output	real
I1C	Current Stator Phase c [A]	Output	real
I1D	Real Part of Stator Current [A]	Output	real
I1Q	Imaginary Part of Stator Current [A]	Output	real
V1D	Real Part of Stator Voltage [V]	Output	real
V1Q	Imaginary Part of Stator Voltage [V]	Output	real
PSI1D	Real Part of Stator Flux Linkage [Vs]	Output	real
PSI1Q	Imaginary Part of Stator Flux Linkage [Vs]	Output	real
PWRELEC	Electrical Real Power Input [W]	Output	real
PWRMECH	Mechanical power output[W]	Output	real
PWRLOSS	Losses[W]	Output	real

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Example

In this example, the Synchronous Machine Permanent Excitation without Damper SYMPOD1 works as a generator. The value of the drive torque decided by the Step Function driveTorq. The electrical terminals of SYME1 are connected to a symmetrical three-phase resistive load. The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the simulation results are shown in Figure 3, 4, and 5.

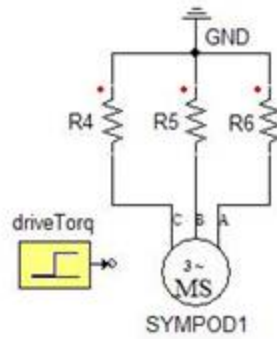


Figure 2. Application examples of Synchronous Machine Permanent Excitation without Damper

Table 4. System Parameters

Component	Parameter	Value [unit]
Synchronous Machine Permanent Excitation without Damper SYMPOD1	LOAD	driveTorq.VAL [Nm]
	R1	0.41 [Ohm]
	L1D	42m [H]
	L1Q	42m [H]
	KE	0.85 [Vs]
	P	2 [/]
	J	75m [kg*m ²]
	I1A0	0 [A]
	I1B0	0 [A]
	I1C0	0 [A]
	N0	0 [rpm]
	PHI0	0 [deg]
Resistor R4/R5/R6	R	15 [Ohm]
Step Function driveTorq	AMPL	20
	T0	0 [s]
	Y0	0

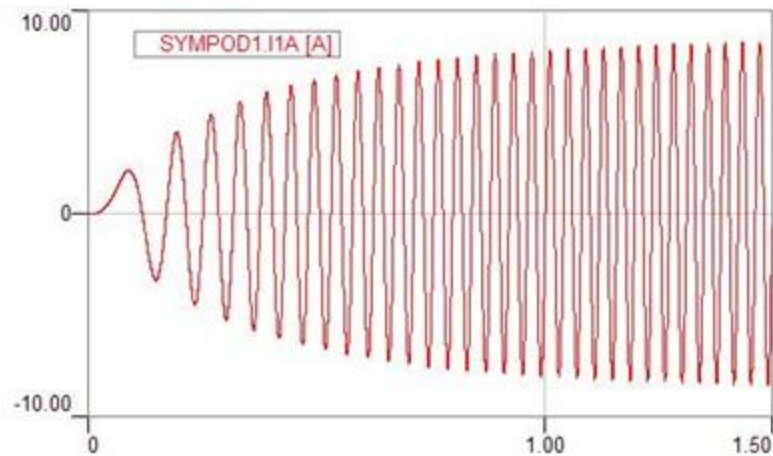


Figure 3. Simulation results-phase A current of SYMPOD1

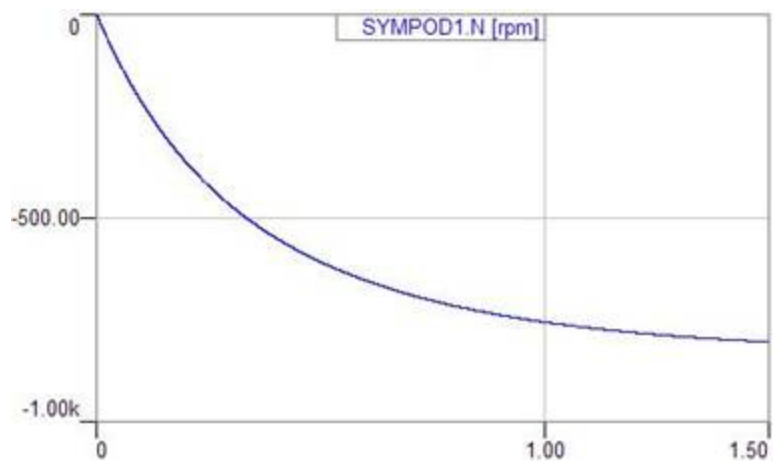


Figure 4. Simulation results-rotor speed of SYMPOD1

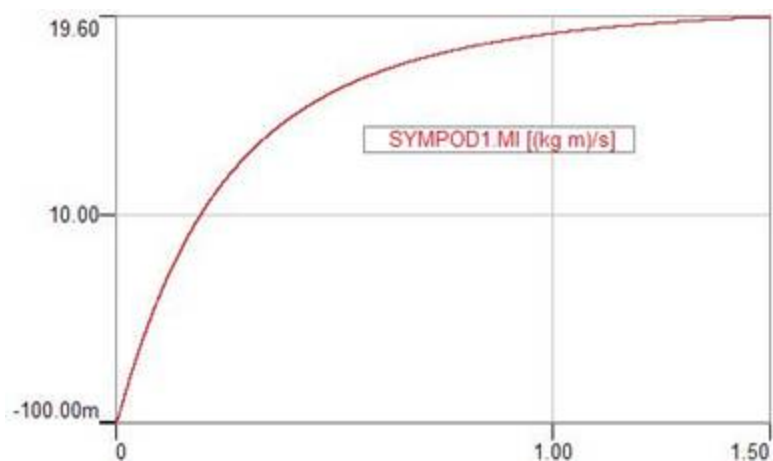


Figure 5. Simulation results- electromagnetic torque of SYMPOD1

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References

Synchronous Machine Permanent Excitation with Damper

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

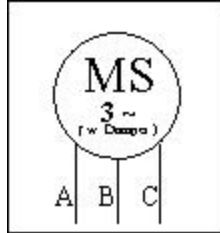


Figure 1. Component Symbol.

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Description

The model represents a permanent excitation synchronous machine with damper circuit i as a lumped circuit component. The damper circuit is not accessible from outside the machine; the corresponding phase windings are connected at a virtual neutral node. Depending on the parameter set, the machine can be operated either as a salient or non-salient pole rotor. The circuit nodes A – B – C are the terminals of star-connected stator winding. The component cannot be used with AC and DC simulation.

Note: If the line-to-line voltage v_{ab} , v_{bc} , v_{ac} or the line currents i_a , i_b , i_c of the synchronous machine are of special interest, voltmeters or ammeters can be connected to the synchronous machine.

In the case of identical parameters for the inductances $L1D$ and $L1Q$, a synchronous machine with permanent magnet and non-salient pole rotor is modeled. To model a permanent magnet salient-pole machine, the parameters must be different for $L1D$ and $L1Q$.

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Assumptions and Limitations

Model Limits of Synchronous Machine Models

- 3-phase symmetrical synchronous machine with internal-field system and star-connected stator winding without neutral node (no zero phase-sequence system).
- Linear and iron-loss free magnetic circuit.
- No consideration of skin effects in the windings.
- Exclusive consideration of fundamental flux linkage between stator, damper and excitation windings.
- Rotor position-independent leakage inductances.
- Friction losses (parasitic torques) are not considered in the model; they can be added with the load torque parameter externally.

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Mathematical Description

Equation System

The equation system is implemented in a rotor-fixed (rotor-fixed and also rotor flux-fixed) coordinate system (d-q-coordinates). Index 1 represents the stator quantities; the index 2 the equivalent quantities of the damper circuit belonged to the rotor. The phase quantities of the real three-phase synchronous machine are indicated with *a*, *b*, *c*. Ψ is the magnetic flux.

Voltage Equations

$$\begin{aligned} v_{1d}(t) &= i_{1d}(t) \cdot R_1 + \frac{d\psi_{1d}(t)}{dt} - p \cdot \omega(t) \cdot \psi_{1q}(t) & 0 &= i_{2d}(t) \cdot R_2 + \frac{d\psi_{2d}(t)}{dt} \\ v_{1q}(t) &= i_{1q}(t) \cdot R_1 + \frac{d\psi_{1q}(t)}{dt} + p \cdot \omega(t) \cdot \psi_{1d}(t) & 0 &= i_{2q}(t) \cdot R_2 + \frac{d\psi_{2q}(t)}{dt} \end{aligned}$$

Flux-Linkage Equations

$$\begin{aligned} \psi_{1d}(t) &= i_{1d}(t) \cdot L_{1d} + i_{2d}(t) \cdot L_{m12d} + k_e \\ \psi_{1q}(t) &= i_{1q}(t) \cdot L_{1q} + i_{2d}(t) \cdot L_{m12q} \\ \psi_{2d}(t) &= i_{1d}(t) \cdot L_{m12d} + i_{2d}(t) \cdot L_{2d} + k_e \\ \psi_{2q}(t) &= i_{1q}(t) \cdot L_{m12q} + i_{2q}(t) \cdot L_{2q} \end{aligned}$$

Torque Equation

$$m_i(t) = \frac{3}{2}p \cdot (\psi_{1d}(t) \cdot i_{1q}(t) - \psi_{1q}(t) \cdot i_{1d}(t))$$

Motion Equation

$$\frac{d\omega(t)}{dt} = \frac{1}{J}(m_i(t) - m_w(t))$$

Electrical Coupling of phase quantities with the orthogonal quantities

$$\gamma(t) = p \cdot \int \omega(t) dt$$

$$v_{1\alpha}(t) = \frac{2}{3}v_{1a}(t) - \frac{1}{3}v_{1b}(t) - \frac{1}{3}v_{1c}(t)$$

$$v_{1\beta}(t) = \frac{\sqrt{3}}{3}v_{1b}(t) - \frac{\sqrt{3}}{3}v_{1c}(t)$$

$$v_{1d}(t) = v_{1\alpha}(t) \cdot \cos(\gamma(t)) + v_{1\beta}(t) \cdot \sin(\gamma(t))$$

$$v_{1q}(t) = v_{1\alpha}(t) \cdot \sin(\gamma(t)) - v_{1\beta}(t) \cdot \cos(\gamma(t))$$

$$i_{1\alpha}(t) = i_{1d}(t) \cdot \cos(\gamma(t)) - i_{1q}(t) \cdot \sin(\gamma(t))$$

$$i_{1\beta}(t) = i_{1d}(t) \cdot \sin(\gamma(t)) + i_{1q}(t) \cdot \cos(\gamma(t))$$

$$i_{1a}(t) = i_{1\alpha}(t)$$

$$i_{1b}(t) = -\frac{1}{2}i_{1\alpha}(t) + \frac{\sqrt{3}}{2}i_{1\beta}(t)$$

$$i_{1c}(t) = -\frac{1}{2}i_{1\alpha}(t) - \frac{\sqrt{3}}{2}i_{1\beta}(t)$$

[Top](#)**Netlist Syntax**

```
INTERN SYMPD ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) A:= %0 , B:= %1 , C:=  
%2 ( LOAD:=@(LOAD), R1:=@(R1), R2:=@(R2), L1D:=@(L1D), L1Q:=@(L1Q), L2D:=@(L2D),  
L2Q:=@(L2Q), LM12D:=@(LM12D), LM12Q:=@(LM12Q), KE:=@(KE), P:=@(P), J:=@(J),
```

I1A0:=@(I1A0), I1B0:=@(I1B0), I1C0:=@(I1C0), I2A0:=@(I2A0), I2B0:=@(I2B0), I2C0:=@(I2C0), N0:=@(N0), PHI0:=@(PHI0));

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
A	Stator Node A	electrical
B	Stator Node B	electrical
C	Stator Node C	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
LOAD	Load Torque	real	0 [Nm]
R1	Stator Resistance	real	0.4 [Ohm]
R2	Damper Resistance	real	0.24 [Ohm]
L1D	Stator Inductance d-Axis Leakage inductance of stator side	real	42m [H]
L1Q	Stator Inductance q-Axis Leakage inductance of stator side	real	42m [H]
L2D	Damper Inductance d-Axis Leakage inductance of damper circuit side	real	42m [H]
L2Q	Damper Inductance q-Axis Leakage inductance of damper circuit side	real	42m [H]
LM12D	Mutual Inductance stator-damper d-Axis	real	41m [H]
LM12Q	Mutual Inductance stator-damper q-Axis	real	41m [H]
KE	Rotor Flux Linkage	real	0.875 [Vs]
P	Number of Pole Pairs	real	2 [/]
J	Moment of Inertia	real	75m [kg*m²]

I1A0	Initial Current Stator Phase a	real	0 [A]
I1B0	Initial Current Stator Phase b	real	0 [A]
I1C0	Initial Current Stator Phase c	real	0 [A]
I2A0	Initial Current Damper Phase a	real	0 [A]
I2B0	Initial Current Damper Phase b	real	0 [A]
I2C0	Initial Current Damper Phase c	real	0 [A]
N0	Initial Rotor Speed	real	0 [rpm]
PHI0	Initial Rotor Position	real	0 [deg]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
N	Rotor Speed [rpm]	Output	real
MI	Inner Torque [Nm]	Output	real
OMEGA	Rotor rational Speed [1/s]	Output	real
ALPHA	Angular Rotor Acceleration [1/s ²]	Output	real
PHI	Rotor Angle in Radians [rad]	Output	real
PHIDEG	Rotor Angle in Degrees [deg]	Output	real
PHIM	Rotor Angle Mechanical in Radians [rad]	Output	real
PHIMDEG	Rotor Angle Mechanical in Degrees [deg]	Output	real
I1A	Current Stator Phase a [A]	Output	real
I1B	Current Stator Phase b [A]	Output	real
I1C	Current Stator Phase c [A]	Output	real
I2A	Current Damper Phase a [A]	Output	real
I2B	Current Damper Phase b [A]	Output	real
I2C	Current Damper Phase c [A]	Output	real
I1D	Real Part of Stator Current [A]	Output	real
I1Q	Imaginary Part of Stator Current [A]	Output	real

I2D	Real Part of Damper Circuit Current [A]	Output	real
I2Q	Imaginary Part of Damper Circuit Current [A]	Output	real
V1D	Real Part of Stator Voltage [V]	Output	real
V1Q	Imaginary Part of Stator Voltage [V]	Output	real
PSI1D	Real Part of Stator Flux Linkage [Vs]	Output	real
PSI1Q	Imaginary Part of Stator Flux Linkage [Vs]	Output	real
PSI2D	Real Part of Damper Circuit Flux Linkage [Vs]	Output	real
PSI2Q	Imaginary Part of Damper Circuit Flux Linkage [Vs]	Output	real
PWRELEC	Electrical Real Power Input [W]	Output	real
PWRMECH	Mechanical power output[W]	Output	real
PWRLOSS	Losses[W]	Output	real

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Example

In this example, the Synchronous Machine Permanent Excitation with Damper SYMPMD1 is connected to a three-phase power supply, which consists of sinusoidal Voltage Source ET1, ET2 and ET3. The mechanical load of SYMEMD1 is decided by the Step Function Load. The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the simulation results are shown in Figure 3 and 4.

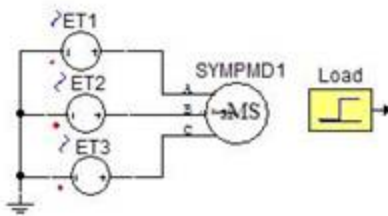


Figure 2. Application examples of Synchronous Machine Permanent Excitation with Damper

Table 4. System Parameters

Component	Parameter	Value [unit]
Synchronous Machine Permanent Excitation with Damper SYMEMD1	LOAD	Load.VAL [Nm]
	R1	0.4 [Ohm]

	R2	0.24 [Ohm]
	L1D	42m [H]
	L1Q	42m [H]
	L2D	42m [H]
	L2Q	42m [H]
	LM12D	41m [H]
	LM12Q	41m [H]
	KE	0.875 [Vs]
	P	2 [/]
	J	75m [kg*m ²]
	I1A0	0 [A]
	I1B0	0 [A]
	I1C0	0 [A]
	I2A0	0 [A]
	I2B0	0 [A]
	I2C0	0 [A]
	N0	0 [rpm]
	PHI0	0 [deg]
Voltage Source ET1/ET2/ET3	AMPL	326 [V]
	FREQ	0 [s]
	PHASE	0/-120/-240 [degree]
	OFF	0 [V]
	TDELAY	0 [s]
Step Function Load	AMPL	60
	T0	0.2 [s]
	Y0	0

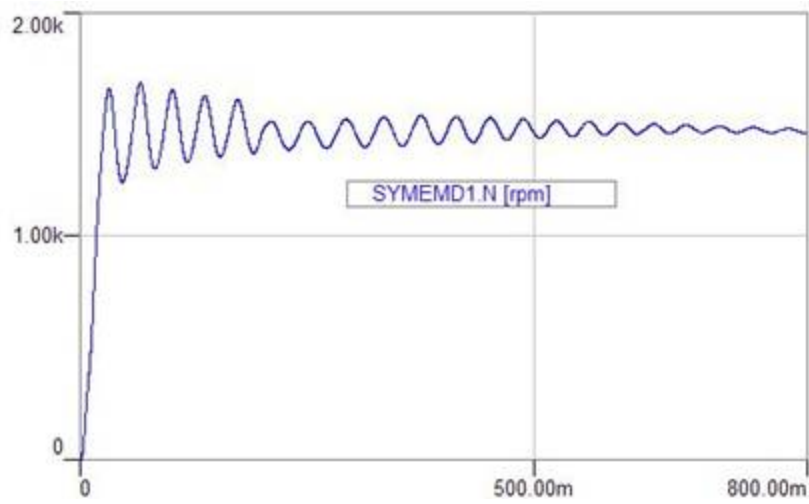


Figure 3. Simulation results-rotor speed of SYMEMD1

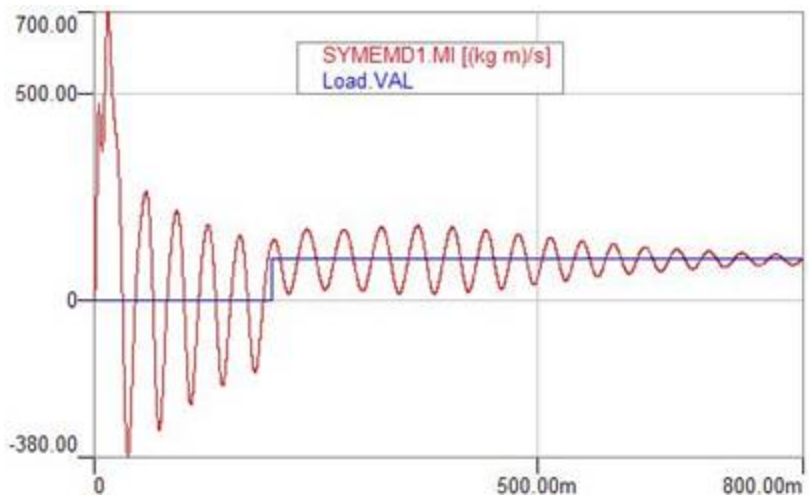


Figure 4. Simulation results-load and electromagnetic torque of SYME1

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References

Switches

- Controlled Switches (CSV/CSI)
- Ideal Switch (S)
- Hysteresis Switch (SH)
- Ideal Transfer Switch (TS)

Controlled Switch

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

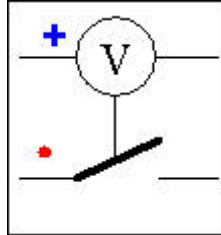


Figure 1. Component symbol

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Description

The component represents a non-ideal electrical switch. Within the dialog you can choose it to be a voltage or current-controlled switch.

If the control quantity (V or I) is greater than threshold plus hysteresis, the controlled switch is on. If the control quantity is lower than threshold minus hysteresis, the controlled switch is off. Since it is a non-ideal switch, you can define an on and off resistance for the line connection.

Note: The ON resistance must always be greater than zero.

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Assumptions and Limitations

The component cannot be used with AC and DC simulation.

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Mathematical Description

If the control signal is voltage, the Controlled Switch under different working conditions can be described as following:

OFF $\rightarrow$ ON, $V > (VTRES + VHYST)$

ON $\rightarrow$ OFF, $V < (VTRES - VHYST)$

If the control signal is current, the Controlled Switch under different working conditions can be described as following:

OFF $\rightarrow$ ON, $I > (ITRES + IHYST)$

ON $\rightarrow$ OFF, $I < (ITRES - IHYST)$

where $VTHRES$ and $ITHRES$ are voltage/current threshold, respectively, and $VHYST$ and $IHYST$ are hysteresis voltage and current, respectively.

where v_1 and i_1 are voltage across and current through N1 to N2, and v_2 and i_2 are voltage across and current through N1 to N3.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
N1	Switch Pin 1 (with red point)	electrical
N2	Switch Pin 2	electrical
NC1	Control Voltage/Current Pin 1 (with blue cross/red point)	electrical
NC2	Control Voltage/Current Pin 2	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
RON	On State Resistance	real	1m [Ohm]
ROFF	Off State Resistance	real	1G [Ohm]
VTHRES/ITHRES	Threshold Voltage/Current	real	0 [V] / [I]
VHYST/IHYST	Hysteresis Voltage/Current	real	0 [V] / [I]
CTRL0	Initial State, 0=OFF 1=ON	real	0

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
V	Voltage [V]	Output	real
I	Current [A]	Output	real
DV	Derivative of Voltage [V/s]	Output	real
DI	Derivative of Current [A/s]	Output	real

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Example

In this example, the switch CSx1 is controlled by the output voltage of the Triangular Voltage Source E1. The Resistor R2 is connected to the Voltage Source E2 when CSx1 is closed, and is

disconnected when CSx1 is open. The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the simulation results are shown in Figure 3.

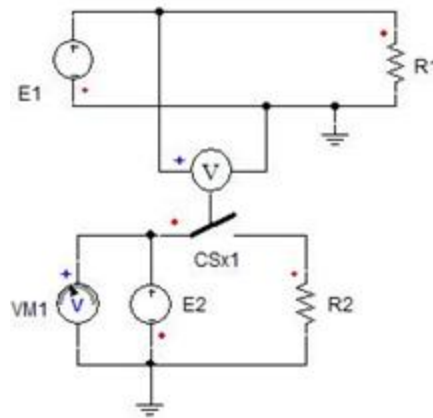


Figure 2. Application example of the Controlled Switch model

Table 4. System Parameters

Component	Parameter	Value [unit]
Voltage Source (triangular) E1	AMPL	1 [V]
	FREQ	50 [Hz]
	TDELAY	0 [s]
	PHASE	30 [degree]
	OFF	0 [V]
Resistor (Linear) R1/R2	R	1k [Ohm]
Controlled Switch (voltage controlled) CSx1	RON	1m [Ohm]
	ROFF	1G [Ohm]
	VTHRES	0.2 [V]
	VHYST	0.3 [V]
	CTRL0	0
Voltage Source (pulse) E2	AMPL	2[V]
	FREQ	100 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [V]

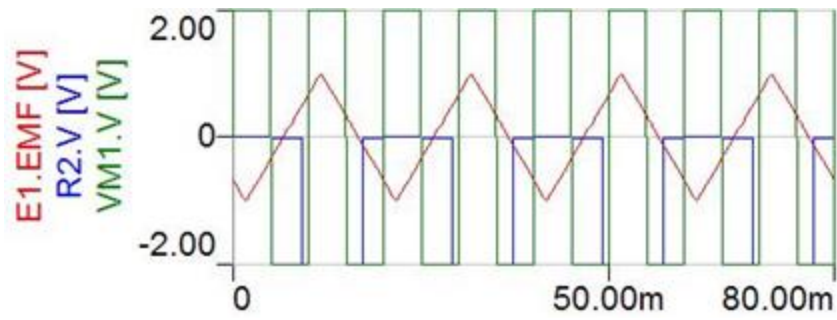


Figure 3. Simulation results

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References

Ideal Switch

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

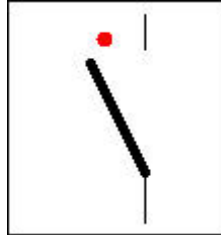


Figure 1. Component symbol

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Description

The component represents an ideal electrical switch. If the control signal is greater than '0', the two terminal nodes of the switch are connected. Since it is an ideal switch, the resistance of the line connection is zero. If the control signal is lower than or equal to '0', the line is disconnected and the resistance is infinite. A logical signal controls the state of the switch.

Note: Since the switch behaves as an ideal, physically meaningful circuits must be obtained in both ON and OFF switching states.

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Assumptions and Limitations

This component represents an ideal switch, hence switching delay and losses are not taken into account.

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Mathematical Description

The Ideal Switch under different working conditions can be described as following:

$v(t) = 0$ if the control signal > 0 (the switch is ON)

$i(t) = 0$ if the control signal ≤ 0 (the switch is OFF)

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Netlist Syntax

```
INTERN S ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) N1 := %0 , N2 := %1 ( CTRL:-  
:=@CTRL) ;
```

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
N1	Pin 1 (with red point)	electrical
N2	Pin 2	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
CTRL	Control Signal	Real	0

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
V	Voltage [V]	Output	real
I	Current [A]	Output	real
DV	Derivative of Voltage [V/s]	Output	real

DI	Derivative of Current [A/s]	Output	real

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Example

In this example, the Voltage Source E1 is connected to a RC load through an Ideal Switch S2. The state of S2 is controlled by a Pulse Wave block. The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the control signal and the voltage across S2 are shown in Figure 3 and 4.

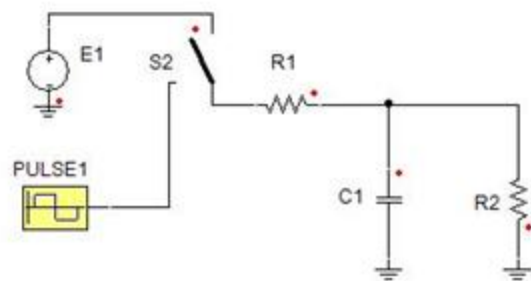


Figure 2. Application example of the Ideal Switch model

Table 4. System Parameters

Component	Parameter	Value [unit]
Pulse Wave PULSE1	AMPL	311
	FREQ	50 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [V]
Resistor (Linear) R1/R2	R	500 [Ohm]
Capacitor C1	C	1u [F]
	V0	0 [V]
Ideal Switch S2	CTRL	PULSE1.VAL

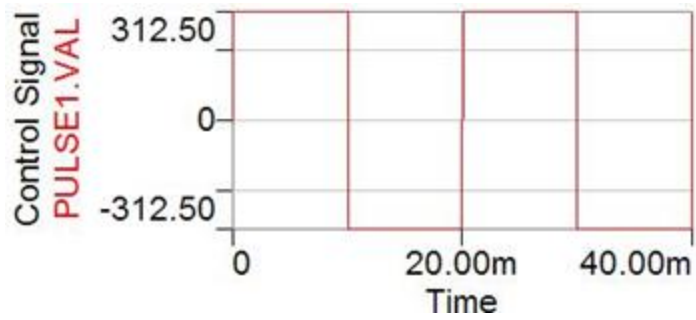


Figure 3. Simulation result-control signal of S2

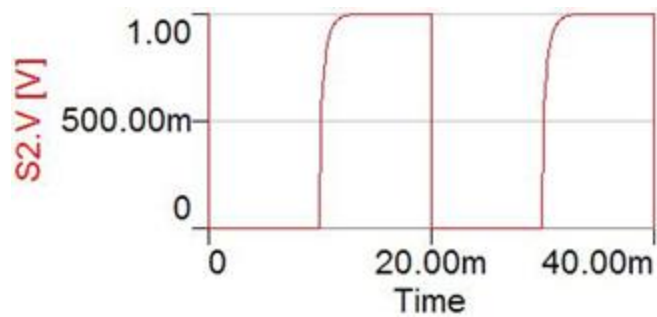


Figure 4. Simulation result-voltage across S2

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References

Hysteresis Switch

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

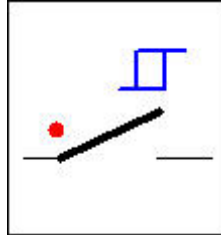


Figure 1. Component symbol

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Description

The component represents a non-ideal electrical switch with hysteresis effect. If the control quantity exceeds a threshold value plus half the hysteresis value, the switch is on. When the control quantity is lower than the threshold value minus half the hysteresis value, then that means it is off. Since the component represents a non-ideal switch, ON and OFF resistance values have to be specified.

Note: The on resistance must always be greater than zero.

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Assumptions and Limitations

The component cannot be used with AC and DC simulation.

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Mathematical Description

The hysteresis Switch under different working conditions can be described as following:

OFF → ON, CTRL > (THRS + HYST)

ON → OFF, CTRL < (THRS - HYST)

where THRS is switching threshold of the control signal, and HYST is the hysteresis.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
N1	Switch Pin 1 (with red dot)	electrical
N2	Switch Pin 2	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
CTRL	Control Input	real	0
RON	On State Resistance	real	1μ [Ohμ]
ROFF	Off State Resistance	real	1Γ [Ohμ]
THRS	Threshold	real	1
HYST	Hysteresis	real	0.5
INITSTATE	Initial State	real	0

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
V	Voltage [V]	Output	real
I	Current [A]	Output	real
DV	Derivative of Voltage [V/s]	Output	real
DI	Derivative of Current [A/s]	Output	real
STATE	State (0=Off, 1=On)	Output	real

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Example

In this example, the Hysteresis Switch SH1 is controlled by the output of the Sine Wave block SINE1. The Resistor R2 is connected to the Voltage Source E2 when SH1 is closed, and is disconnected when SH1 is open. The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the simulation results are shown in Figure 3-5.

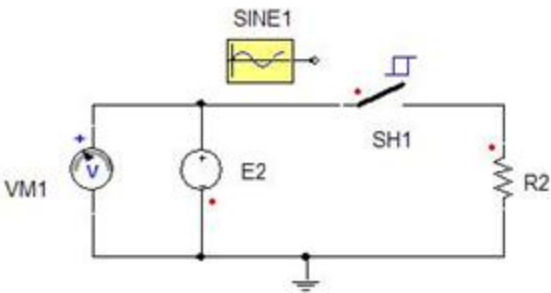


Figure 2. Application example of the Hysteresis Switch model

Table 4. System Parameters

Component	Parameter	Value [unit]
Sine Wave SINE1	AMPL	2

	FREQ	50 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0
Resistor (Linear) R2	R	1k [Ohm]
Hysteresis Switch SH1	RON	1m [Ohm]
	ROFF	1G [Ohm]
	THRES	1 [V]
	HYST	0.5 [V]
	CTRL0	0

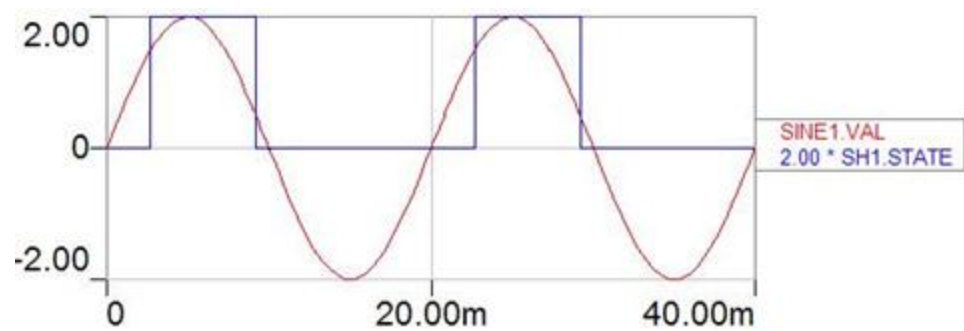


Figure 3. Simulation results-control signal and state of SH1

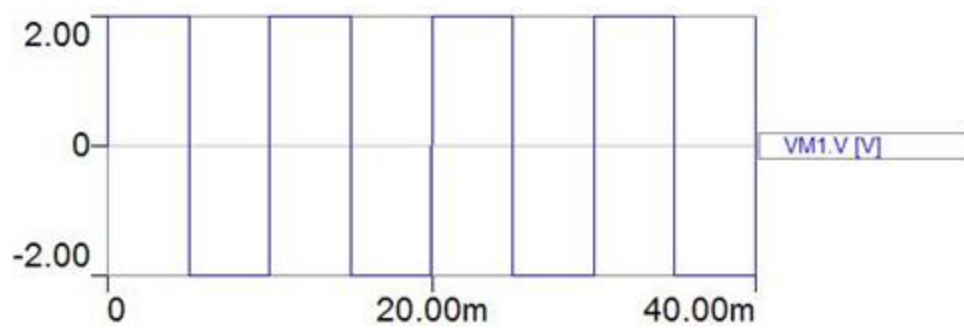


Figure 4. Simulation results-output voltage of E2

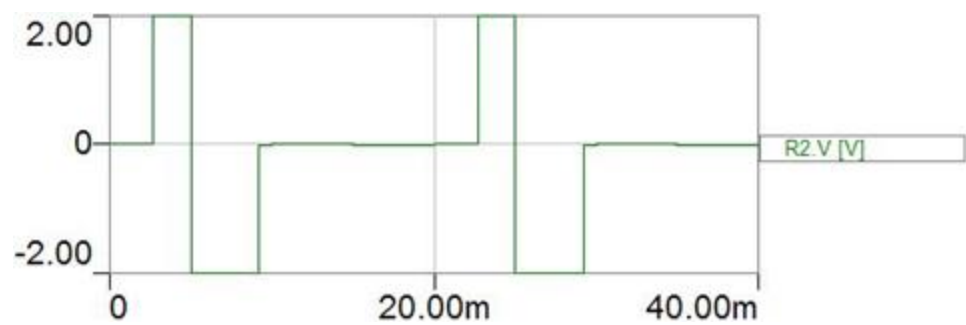


Figure 5. Simulation results-voltage across R2

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References

Ideal Transfer Switch

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

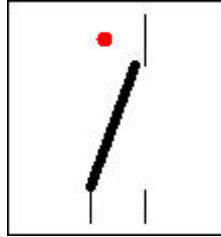


Figure 1. Component symbol

- [Description](#)
- [Assumptions and Limitations](#)
- [Mathematical Description](#)
- [Netlist Syntax](#)
- [Conservative Pins](#)
- [Parameters](#)
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- [Example](#)
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Description

The component represents an ideal electrical transfer switch. If the control signal is greater than '0', the nodes N1 and N2 are connected and the nodes N1 and N3 are disconnected. Since it is an ideal switch, the resistance of the line connection is zero and the resistance of the disconnection is infinite. If the control signal is lower than or equal to '0', the line between N1 and N3 is connected.

Note: Since the switch behaves as an ideal, physically meaningful circuits must be obtained in both ON and OFF switching states.

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Assumptions and Limitations

This component represents an ideal switch, hence switching delay and losses are not taken into account.

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Mathematical Description

The Ideal Switch under different working conditions can be described as following:

$v_1(t) = 0$ and $i_2(t) = 0$ if the control signal > 0 (the switch is ON)

$v_2(t) = 0$ and $i_1(t) = 0$ if the control signal ≤ 0 (the switch is OFF)

where v_1 and i_1 are voltage across and current through N1 to N2, and v_2 and i_2 are voltage across and current through N1 to N3.

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Netlist Syntax

```
INTERN TS ?InstanceName(@InstanceName):(@ (Refbase)@(ID)) N1 := %0 , N2 := %1 , N3 := %2 ( CTRL:=@CTRL);
```

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
N1	Pin 1 (with red point)	electrical
N2	Pin 2	electrical
N3	Pin 3	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
CTRL	Control Signal	real	0

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type

V	Voltage [V]	Output	real
I	Current [A]	Output	real
dV	Derivative of Voltage [V/s]	Output	real
dI	Derivative of Current [A/s]	Output	real

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Example

In this example, the Resistor R1 is connected to a either Voltage Source ESINE1 or ESINE2 depending on the state of the Ideal Transfer Switch TS1. The state of TS1 is controlled by a Pulse Wave block PULSE1. The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the simulation results are shown in Figure 3-6.

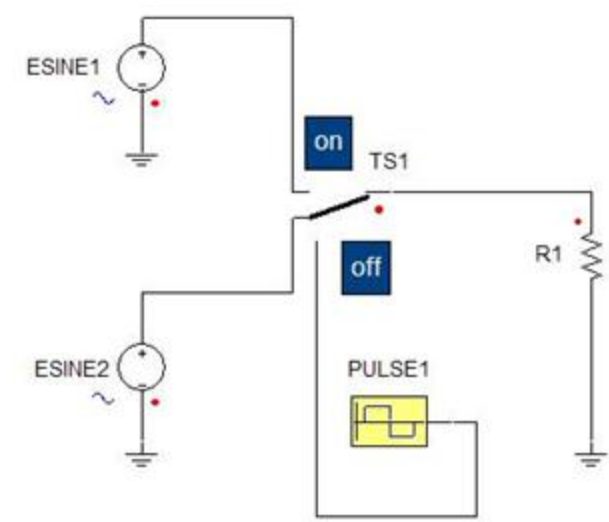


Figure 2. Application example of the Ideal Transfer Switch model

Table 4. System Parameters

Component	Parameter	Value [unit]
Pulse Wave PULSE1	AMPL	32
	FREQ	100 [Hz]
	TDELAY	0 [s]

	PHASE	0 [degree]
	OFF	0 [V]
Resistor (Linear) R1	R	1k [Ohm]
Ideal Transfer Switch TS1	CTRL	PULSE1.VAL
Ideal Switch S2	CTRL	PULSE1.VAL
Voltage Source (sinusoidal) ESINE1	AMPL	32 [V]
	FREQ	500 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	50 [V]
Voltage Source (sinusoidal) ESINE2	AMPL	32 [V]
	FREQ	5000 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	50 [V]

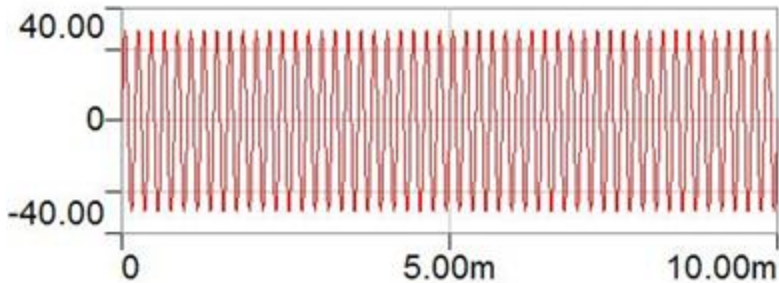


Figure 3. Simulation result-output voltage of ESINE2

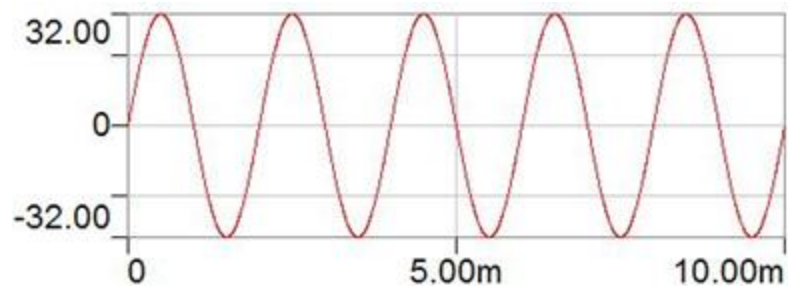


Figure 4. Simulation result-output voltage of ESINE1



Figure 5. Simulation result-control signal of TS1

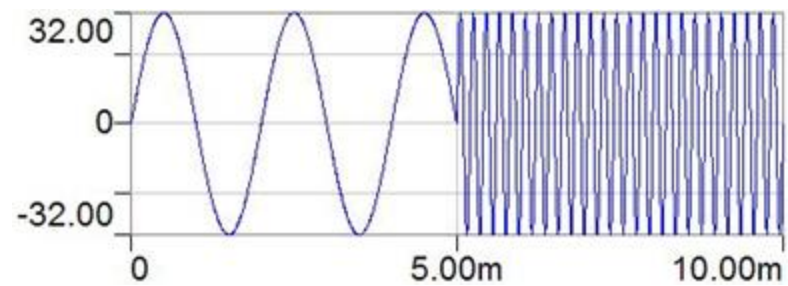


Figure 6. Simulation result-voltage across R1

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References

Passive Elements

- Capacitor (C/CNL/CVNL)
- Conductor (G/GVNL)
- Inductor (L/LNL/LINL)
- Mutual Inductance (M)
- Resistor (R/RNL)

Capacitor

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

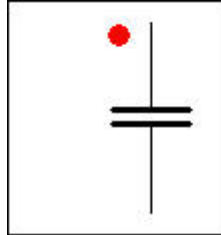


Figure 1. Component symbol

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- [Assumptions and Limitations](#)
- [Mathematical Description](#)
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The component represents an electrical capacitance. Within the dialog you can choose a linear, nonlinear, or nonlinear dual capacitor type.

Linear Capacitor

Description

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Assumptions and Limitations

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Mathematical Description

The linear capacitor can be described by the following equation:

$$i(t) = C \cdot \frac{dv(t)}{dt}$$

where $v(t)$, $i(t)$ are the voltage across and current through the capacitor. Capacitance is equivalent to the present value of the quantity specified in the text box. To specify quantity, you can use any numerical value, variable, mathematical or logical expression can be used. Usually a Constant value, a Time function or a variable are chosen, or the value of the resistance is determined in a state graph. A mathematical expression must conform to the syntax of the Twin Builder expression interpreter. All system quantities and variables can be combined with mathematical and logical operators and constants.

Note: However, the expression must be technically meaningful. If it is not, numerical instability or completely wrong results are possible. In particular, sudden changes in the first derivation of the control quantity should be avoided.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
N1	Pin 1 (with red point)	electrical
N2	Pin 2	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
C	Capacitance	Real	1u [F]
v0	Initial Voltage	Real	0 [V]*

* Note, initial value of capacitor may float if **Initial Value** checkbox is **unselected** in Special Component Dialog

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
V	Voltage [V]	Output	real
I	Current [A]	Output	real
Q	Charge [C]	Output	real
dV	Derivative of Voltage [V/s]	Output	real
dI	Derivative of Current [A/s]	Output	real
dQ	Derivative of Charge [C/s]	Output	real

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Example

In this example, different ways to assign the capacitance value for linear capacitor are demonstrated. The resistance of C1 is assigned to a constant value, that of C_CTR_1 is a variable defined by an equation block, and CT1 gives its resistance value from the output of a 2D Lookup Table. The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the simulation results are shown in Figure 3, 4 and 5.

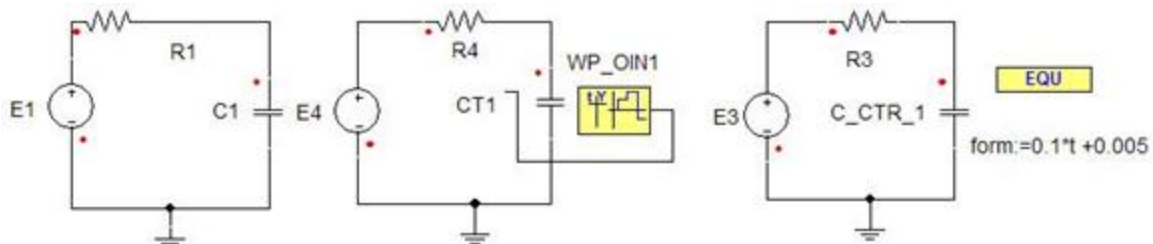


Figure 2. Application examples of the Linear Capacitor model

Table 4. System Parameters

Component	Parameter	Value [unit]
Voltage Source E1, E4	EMF	100 [V]
Voltage Source E3	EMF	10 [V]

Resistor (Linear) R1, R4	R	10k [Ohm]
Resistor (Linear) R3	R	100 [Ohm]
Capacitor (Linear) C1	C	10u [F]
	V0	0 [V]
Capacitor (Linear) C_CTR_1	C	form*
	V0	0 [V]
Capacitor (Linear) CT1	C	WP_OIN1.VAL*
	V0	90 [V]

* These variables are defined by other components on the schematic.

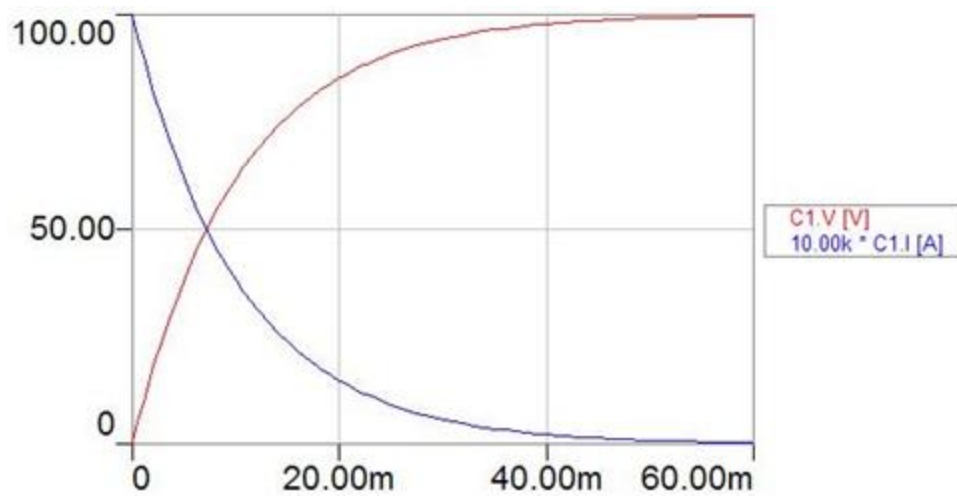


Figure 3. Simulation results-voltage across and current through C1

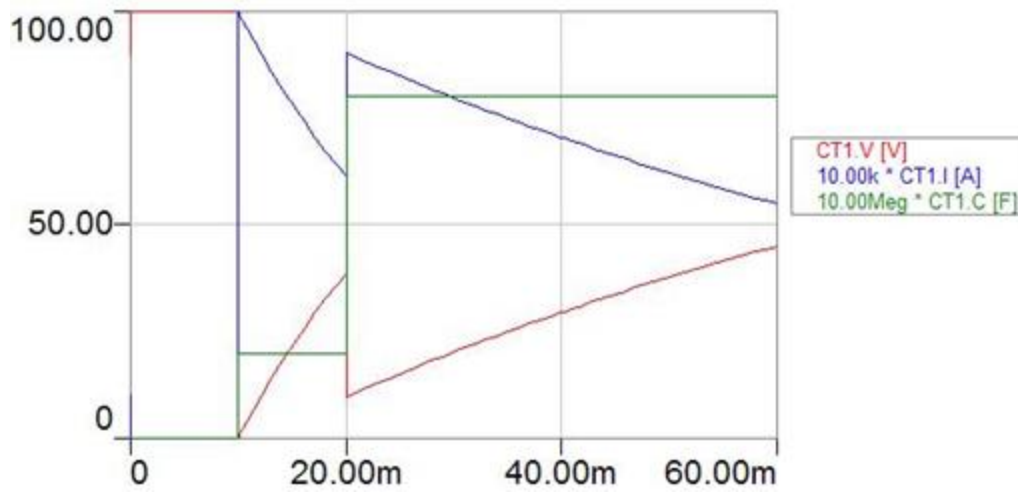


Figure 4. Simulation results-voltage across, current through and capacitance of CT1

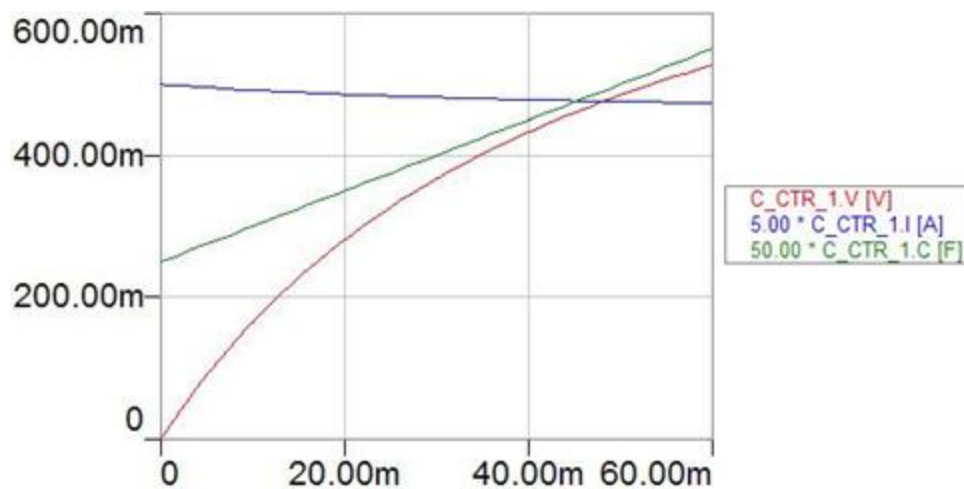


Figure 5. Simulation results- voltage across, current through and capacitance of C_CTR_1

Nonlinear Capacitor

Description

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Assumptions and Limitations

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Mathematical Description

The Nonlinear Capacitor can be described by the following equation:

$$i(t) = \frac{dq(t)}{dt} \quad \text{with} \quad q(t) = f(v(t))$$

where $v(t)$, $i(t)$ are the voltage across and current through the capacitor. The voltage across the controlling component controls the capacitance corresponding to the specified characteristic function. To describe the nonlinear relation, you must specify a name of an appropriate non-linear XY-characteristic function.

[See also Separate Component Characteristic](#)

X-value: charge q (independent quantity)

Y-value: voltage v (dependent quantity)

To define characteristic data, you can do one of the following:

- **Use Pin** : connect the output of an XY component, connected to the pin to provide the characteristic
 - Use the **Characteristic** Dialog: in the Characteristic dialog box, choose the following options
 - **Reference** : specify the output variable of an XY component, e.g. XY1.VAL
 - **Lookup Table** : there are two options if you want to use a lookup table to define the characteristic
1. **File Reference** : the name in the text box specifies a variable which refers to a subsheet port specifying a characteristic file
 2. **Data Pairs** : enter sets of data to define the characteristics

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
N1	Pin 1 (with red point)	electrical
N2	Pin 2	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
V0	Initial Voltage	Real	0 [V]*
CH	Characteristic	Real	[/]

* Note, initial value of capacitor may float if **Initial Value** checkbox is **unselected** in Special Component Dialog

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
V	Voltage [V]	Output	real
I	Current [A]	Output	real
Q	Charge [C]	Output	real
dV	Derivative of Voltage [V/s]	Output	real
dI	Derivative of Current [A/s]	Output	real
dQ	Derivative of Charge [C/s]	Output	real

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Example

Nonlinear Dual Capacitor

Description

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Assumptions and Limitations

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Mathematical Description

The Nonlinear Dual Capacitor can be described by the following equation:

$$i(t) = C(v(t)) \cdot \frac{dv(t)}{dt}$$

where $v(t)$, $i(t)$ are the voltage across and current through the capacitor. The voltage across the controlling component controls the capacitance corresponding to the specified characteristic function. To describe the nonlinear relation, you must specify a name of an appropriate nonlinear XY-characteristic function.

[See also Separate Component Characteristic](#)

X-value: voltage v (independent quantity)

Y-value: Capacitance C (dependent quantity)

To define characteristic data, you can do one of the following:

- **Use Pin** : connect the output of an XY component, connected to the pin to provide the characteristic
 - Use the **Characteristic** Dialog: in the Characteristic dialog box, choose the following options
 - **Reference** : specify the output variable of an XY component, e.g. XY1.VAL
 - **Lookup Table** : there are two options if you want to use a lookup table to define the characteristic
1. **File Reference** : the name in the text box specifies a variable which refers to a subsheet port specifying a characteristic file
 2. **Data Pairs** : enter sets of data to define the characteristics

The primary form CNL of representing nonlinear capacitors leads in general to a better conditioned set of equations and should be preferred. For the engineering model formulation, the dual form of representation may be more useful. If numerical problems appear, an improvement may be obtained with the opposite implementation.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
N1	Pin 1 (with red point)	Electrical
N2	Pin 2	Electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
V0	Initial Voltage	real	0 [V]*
CH	Characteristic	real	[/]

* Note, initial value of capacitor may float if **Initial Value** checkbox is **unselected** in Special Component Dialog

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
V	Voltage [V]	Output	Real
I	Current [A]	Output	Real
dV	Derivative of Voltage [V/s]	Output	Real
dI	Derivative of Current [A/s]	Output	Real

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Example

This example demonstrates the usage of a Nonlinear Dual Capacitor model. Here the capacitance/voltage relation of the nonlinear Dual Capacitor CUNL1 is specified by the 2D Lookup Table XY_LINT1. The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the simulation results are shown in Figure 3.

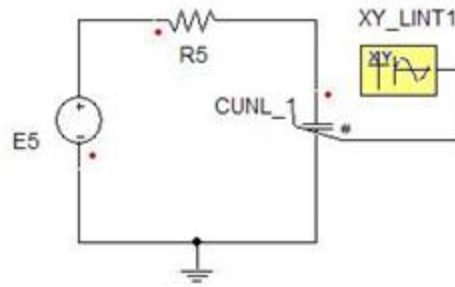


Figure 2. Application examples of the Nonlinear Dual Capacitor model

Table 4. System Parameters

Component	Parameter	Value [unit]
Voltage Source E5	AMPL	100 [V]
Resistor (Linear) R5	R	10k [Ohm]
Capacitor (nonlinear dual) CUNL1	CH	XY_LINT1.VAL*
	V0	1e-6 [V]

* These variables are defined by other components on the schematic.

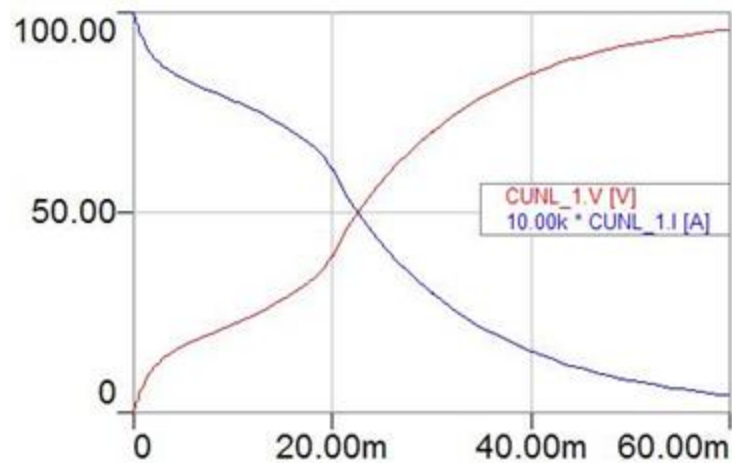


Figure 3. Simulation results- voltage across and current through and capacitance of C_CTR_1

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References

[1] Roland E. Thomas, Albert J. Rosa. "The Analysis and Design of Linear Circuits." John Wiley & Sons, Inc., May, 2003.

Conductor

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

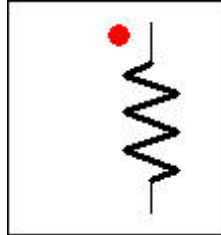


Figure 1. Component symbol

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- [Assumptions and Limitations](#)
- [Mathematical Description](#)
- [Netlist Syntax](#)
- [Conservative Pins](#)
- [Parameters](#)
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This component represents an electrical conductance. Within the dialog you can choose a linear or voltage-controlled conductor type.

Linear Conductor

Description

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Assumptions and Limitations

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Mathematical Description

The linear conductor can be described by the following equation:

$$i(t) = G \cdot v(t)$$

where $v(t)$, $i(t)$ are the voltage across and current through the conductor. The conductivity G is equivalent to the present value of the quantity specified in the text box. For the quantity any numerical value, variable, mathematical or logical expression can be used. Usually a Constant value, a Time function or a variable are chosen, or the value of the resistance is determined in a state graph. A mathematical expression must conform to the syntax of the Twin Builder expression interpreter. All system quantities and variables can be combined with mathematical and logical operators and constants.

Note: However, the expression must be technically meaningful. If it is not, numerical instability or completely wrong results are possible. In particular, sudden changes in the first derivation of the control quantity should be avoided.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
N1	Pin 1 (with red point)	electrical
N2	Pin 2	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
G	Conductivity	real	1m [S]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Directiond	Data Type

V	Voltage [V]	Output	real
I	Current [A]	Output	real
DV	Derivative of Voltage [V/s]	Output	real
DI	Derivative of Current [A/s]	Output	real

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Example

In this example, different ways to assign the conductance value for linear conductors are demonstrated. The conductance of G1 is assigned to a constant value, while that of G_CTR is a variable defined by an equation block. The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the simulation results are shown in Figure 3, and 4.

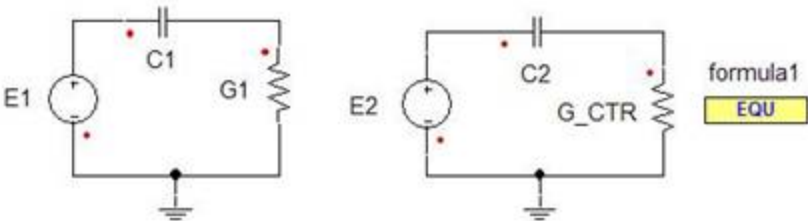


Figure 2. Application examples of the Linear Resistor model

Table 4. System Parameters

Component	Parameter	Value [unit]
Voltage Source E1, E2	EMF	1 [V]
Conductor (Linear) G1	G	1m [S]
Conductor (Linear) G_CTR	G	form*
Capacitor C1/C2	C	1u [F]
	V0	0 [V]

* These variables are defined by other components on the schematic.

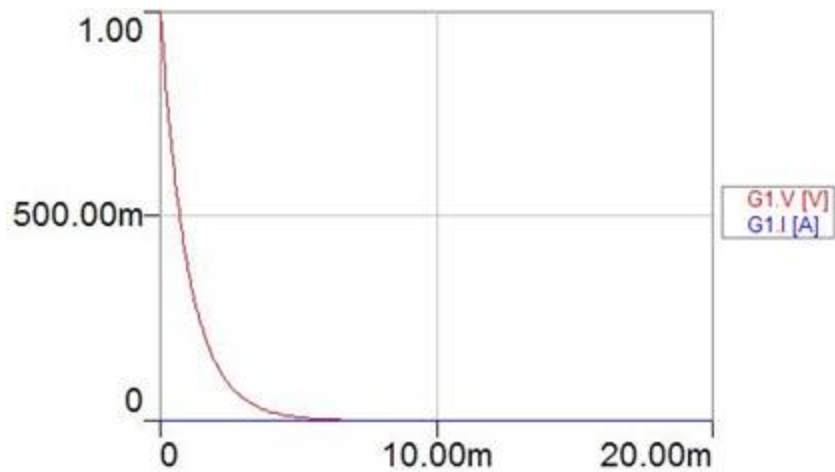


Figure 3. Simulation results-voltage across and current through G1

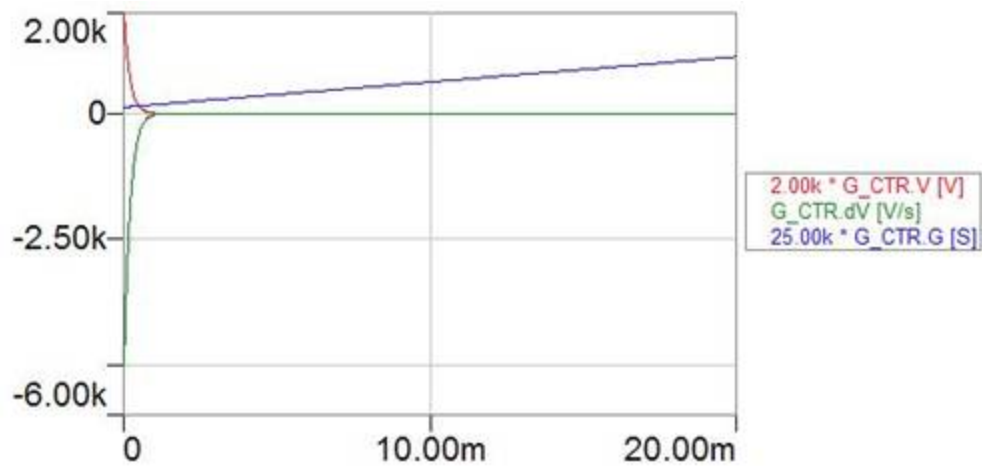


Figure 4. Simulation results-voltage across, current through and conductance of G_CTR

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References

Nonlinear voltage-controlled Conductor

Description

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Assumptions and Limitations

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Mathematical Description

The non-linear conductor can be described by the following equation:

$$i(t) = G(v(t)) \cdot v(t)$$

where $v(t)$, $i(t)$ are the voltage across and current through the conductor. The voltage across the controlling component controls the conductivity corresponding to the specified characteristic function. To describe the nonlinear relation, you must specify a name of an appropriate non-linear XY-characteristic function.

[See also Separate Component Characteristic](#)

X-value: voltage v (independent quantity)

Y-value: current i (dependent quantity)

To define characteristic data, you can do one of the following:

- **Use Pin** : connect the output of an XY component, connected to the pin to provide the characteristic
- Use the **Characteristic** Dialog: in the Characteristic dialog box, choose the following options
 - **Reference** : specify the output variable of an XY component, e.g. XY1.VAL
 - **Lookup Table** : there are two options if you want to use a lookup table to define the characteristic
 1. **File Reference** : the name in the text box specifies a variable which refers to a subsheet port specifying a characteristic file
 2. **Data Pairs** : enter sets of data to define the characteristics

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
N1	Pin 1 (with red point)	electrical
N2	Pin 2	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
QUANT	Control Quantity	real	0 [V]
CH	Characteristic	real	[/]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
V	Voltage [V]	Output	real
I	Current [A]	Output	real
DV	Derivative of Voltage [V/s]	Output	real
DI	Derivative of Current [A/s]	Output	real

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Example

This example demonstrates the usage of a Nonlinear Resistor model. Here the resistance of the nonlinear resistor GUNL1 is specified by the Equivalent Line EQU1. The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the simulation results are shown in Figure 3.

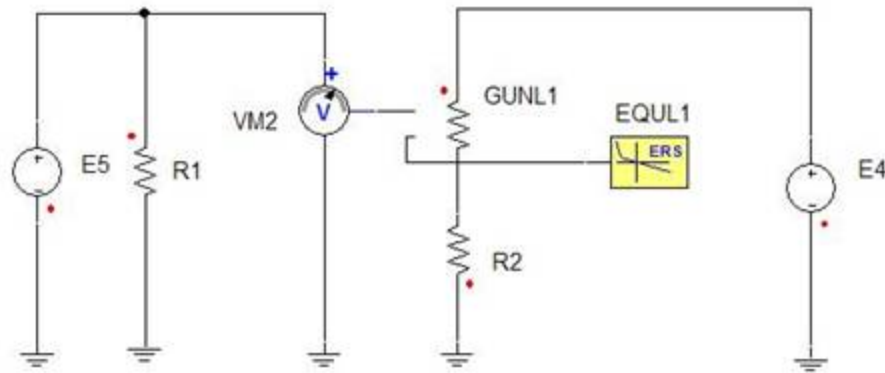


Figure 2. Application examples of the Nonlinear Conductortor model

Table 4. System Parameters

Component	Parameter	Value [unit]
Voltage Source (sin) E5	AMPL	1 [V]
	FREQ	120 [Hz]
	TDELAY	0 [s]
	TPERIO	40 [ms]
	PHASE	1 [degree]
	OFF	0 [V]
Resistor (Linear) R1/R2	R	1 [Ohm]
Conductor (nonlinear) GUNL1	CH	EQUL1.VAL *
	QUANT	VM2.V *
Equivalent Line EQUL1	VF	0.8 [V]
	RB	1m [Ohm]
	RR	100k [Ohm]
Voltage Source E4	EMF	1 [V]

* These variables are defined by other components on the schematic.

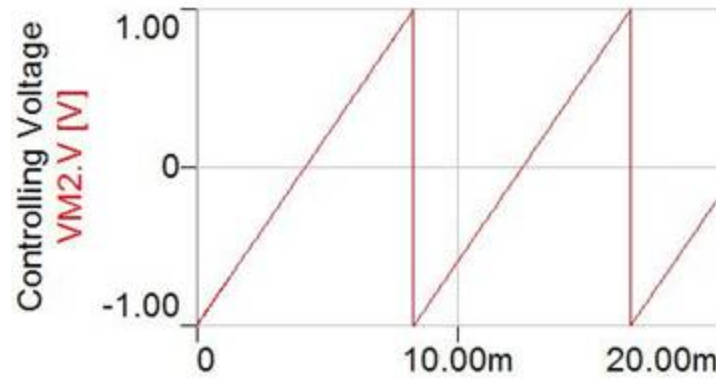


Figure 3. Simulation results-voltage output of the Voltage Meter VM2

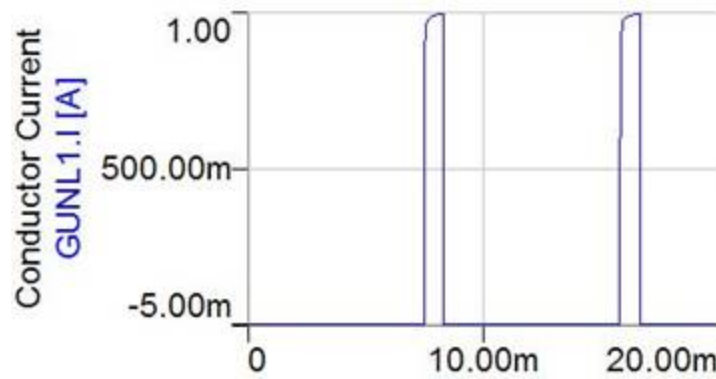


Figure 4. Simulation results-current through the Nonlinear Conductor GUNL1

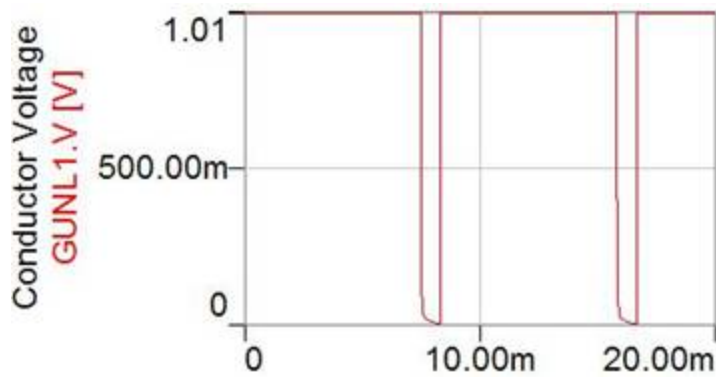


Figure 5. Simulation results-voltage across the Nonlinear Conductor GUNL1

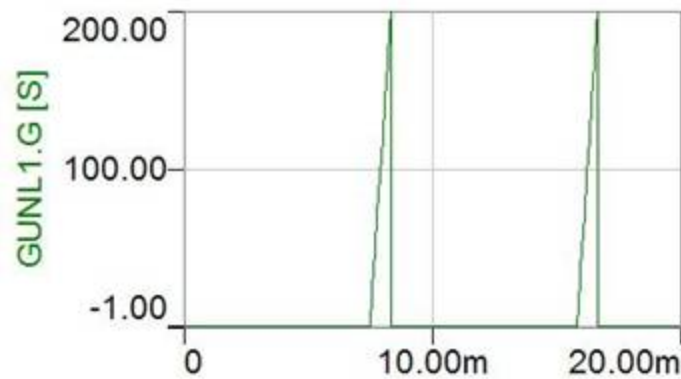


Figure 6. Simulation results-conductance of the Nonlinear Conductor GUN1

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References

[1] Roland E. Thomas, Albert J. Rosa. "The Analysis and Design of Linear Circuits." John Wiley & Sons, Inc., May, 2003.

Inductor

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

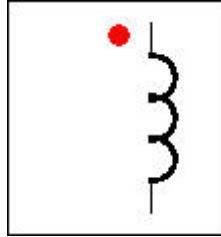


Figure 1. Component symbol

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- [Assumptions and Limitations](#)
- [Mathematical Description](#)
- [Netlist Syntax](#)
- [Conservative Pins](#)
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The component represents an electrical inductance. Within the dialog you can choose a linear, nonlinear, or nonlinear dual inductor type.

Linear Inductor

Description

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Assumptions and Limitations

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Mathematical Description

The linear inductor can be described by the following equation:

$$v(t) = \frac{d\Psi}{dt}$$

where $\Psi(t)$, $v(t)$ are the flux linkage through and voltage across the inductor, respectively. Inductance is equivalent to the present value of the quantity specified in the text box. To specify quantity, you can use any numerical value, variable, mathematical or logical expression can be used. Usually a Constant value, a Time function or a variable are chosen, or the value of the resistance is determined in a state graph. A mathematical expression must conform to the syntax of the Twin Builder expression interpreter. All system quantities and variables can be combined with mathematical and logical operators and constants.

Note: However, the expression must be technically meaningful. If it is not, numerical instability or completely wrong results are possible. In particular, sudden changes in the first derivation of the control quantity should be avoided.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
N1	Pin 1 (with red point)	Electrical
N2	Pin 2	Electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
L	Inductance	real	1m [H]
I0	Initial Current	real	0 [A]*

* Note, initial value of inductor current may float if **Initial Value** checkbox is **unselected** in Special Component Dialog

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
V	Voltage [V]	Output	Real
I	Current [A]	Output	Real
PSI	Flux-linkage [PSI]	Output	Real
dV	Derivative of Voltage [V/s]	Output	Real
dI	Derivative of Current [A/s]	Output	Real
dPSI	Derivative of Flux-linkage [V]	Output	Real

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Example

Nonlinear Inductor

Description

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Assumptions and Limitations

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Mathematical Description

The Nonlinear Inductor can be described by the following equation:

$$v(t) = \frac{d\Psi}{dt} \quad \text{with} \quad \Psi = f(i(t))$$

where $\Psi(t)$, $v(t)$, $i(t)$ are the flux linkage through, voltage across and the current through the inductor, respectively. The current through the controlling component controls the flux linkage through the component corresponding to the specified characteristic function. To describe the

nonlinear relation, you must specify a name of an appropriate nonlinear XY-characteristic function.

[See also Separate Component Characteristic](#)

X-value: coupled flux Ψ (independent quantity)

Y-value: current i (dependent quantity)

To define characteristic data, you can do one of the following:

- **Use Pin** : connect the output of an XY component, connected to the pin to provide the characteristic
 - Use the **Characteristic** Dialog: in the Characteristic dialog box, choose the following options
 - **Reference** : specify the output variable of an XY component, e.g. XY1.VAL
 - **Lookup Table** : there are two options if you want to use a lookup table to define the characteristic
1. **File Reference** : the name in the text box specifies a variable which refers to a subsheet port specifying a characteristic file
 2. **Data Pairs** : enter sets of data to define the characteristics

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
N1	Pin 1 (with red point)	Electrical
N2	Pin 2	Electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]

I0	Initial Current	real	0 [A]*
CH	Characteristic	real	[/]

* Note, initial value of inductor current may float if **Initial Value** checkbox is **unselected** in Special Component Dialog

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
V	Voltage [V]	Output	Real
I	Current [A]	Output	Real
PSI	Flux Linkage [Vs]	Output	Real
dV	Derivative of Voltage [V/s]	Output	Real
dI	Derivative of Current [A/s]	Output	Real
dPSI	Derivative of Flux Linkage [V]	Output	Real

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Example

This example demonstrates the usage of a Nonlinear Inductor model. Here the flux/current relation of the Nonlinear Inductor LNL1 is specified by the 2D Lookup Table mag_straightline. The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the simulation results are shown in Figure 3-7.

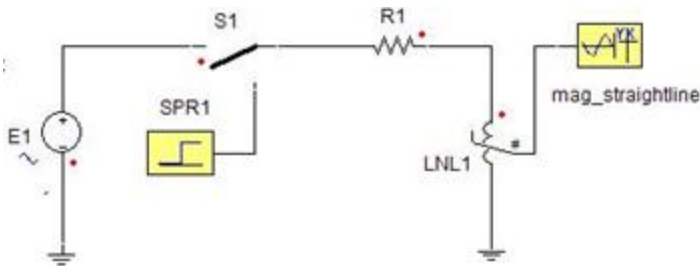


Figure 2. Application examples of the Nonlinear Inductor model

Table 4. System Parameters

Component	Parameter	Value [unit]
Voltage Source (sin) E5	AMPL	500k [V]
	FREQ	1666.667 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [V]
Resistor (Linear) R1	R	0.8 [Ohm]
Inductor (nonlinear) LNL1	CH	mag_straightline.VAL*
	I0	0 [A]
Step Function SPR1	Y0	0
	T0	0.5m [s]
	AMPL	1
Switch S1	CTRL	SPR1.VAL*

* These variables are defined by other components on the schematic.

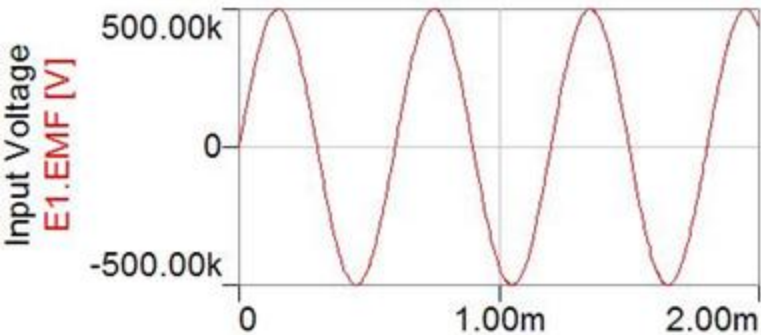


Figure 3. Simulation result-voltage across the voltage source E1

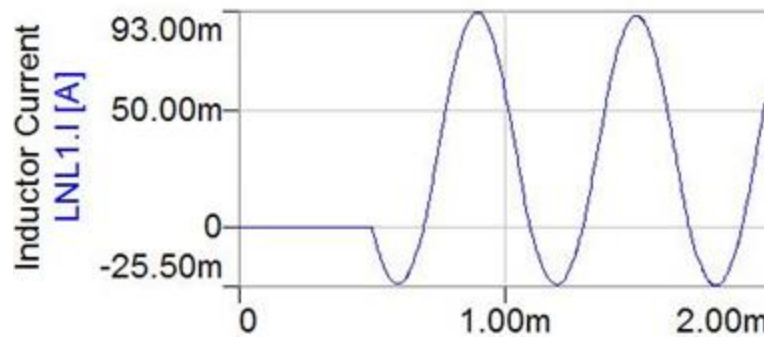


Figure 4. Simulation result-current through the inductor LNL1

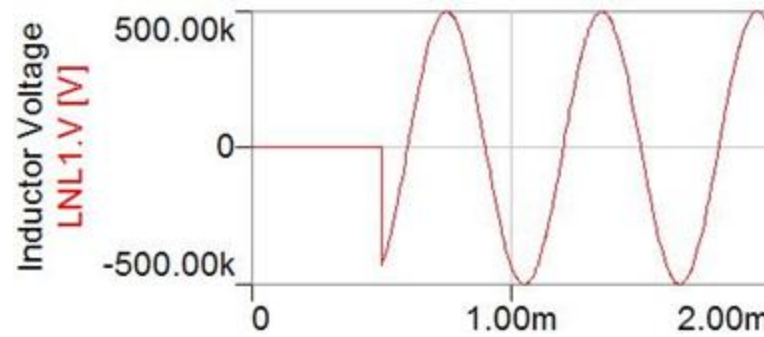


Figure 5. Simulation result-voltage across the inductor LNL1

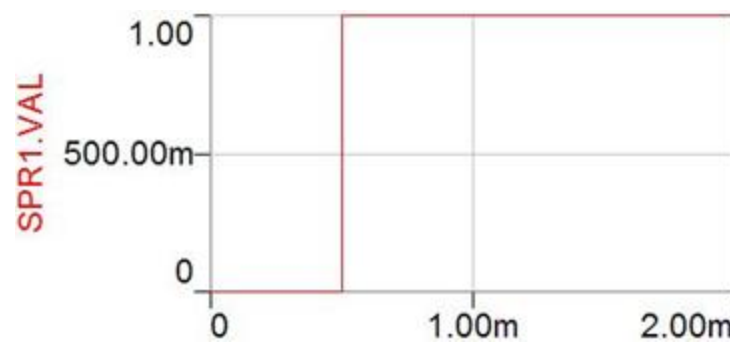


Figure 6. Simulation result-inductance/current relation of LNL1

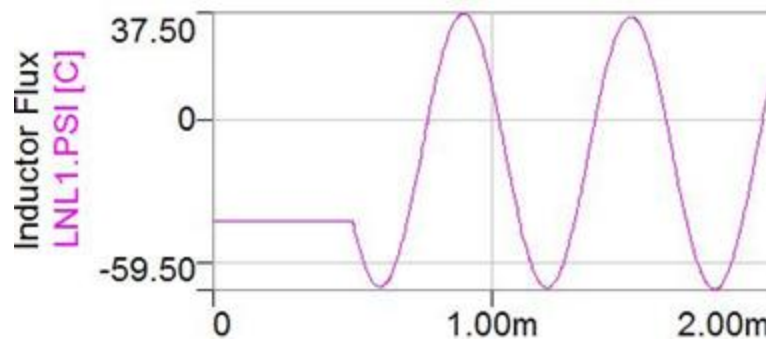


Figure 7. Simulation result-flux through the inductor LNL1

Nonlinear Dual Inductor

Description

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Assumptions and Limitations

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Mathematical Description

The Nonlinear Dual Inductor can be described by the following equation:

$$v(t) = L(i(t)) \cdot \frac{di(t)}{dt}$$

where $v(t)$, $i(t)$ are the voltage across and the current through the inductor, respectively. The current through the controlling component controls the inductance of the component corresponding to the specified characteristic function. To describe the nonlinear relation, you must specify a name of an appropriate nonlinear XY-characteristic function.

[See also Separate Component Characteristic](#)

X-value: current i (independent quantity)

Y-value: inductance L (dependent quantity)

To define characteristic data, you can do one of the following:

- **Use Pin** : connect the output of an XY component, connected to the pin to provide the characteristic
- Use the **Characteristic** Dialog: in the Characteristic dialog box, choose the following options
 - **Reference** : specify the output variable of an XY component, e.g. XY1.VAL

- **Lookup Table** : there are two options if you want to use a lookup table to define the characteristic

1. **File Reference** : the name in the text box specifies a variable which refers to a subsheet port specifying a characteristic file
2. **Data Pairs** : enter sets of data to define the characteristics

The primary form LNL of representing nonlinear inductors (see above) leads in general to a better conditioned set of equations and should usually be preferred. For engineering model formulation, the dual form representation may be more useful. If numerical problems appear, an improvement may be obtained with the opposite implementation.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
N1	Pin 1 (with red point)	Electrical
N2	Pin 2	Electrical

[Top](#)

Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
I0	Initial Current	real	0 [A]*
CH	Characteristic	real	[/]

* Note, initial value of inductor current may float if **Initial Value** checkbox is **unselected** in Special Component Dialog

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
V	Voltage [V]	Output	Real
I	Current [A]	Output	Real
dV	Derivative of Voltage [V/s]	Output	Real
dI	Derivative of Current [A/s]	Output	Real

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Example

This example demonstrates the usage of a Nonlinear Dual Inductor model. Here the inductance/current relation of the Nonlinear Dual Inductor LINL1 is specified by the 2D Lookup Table XY1. The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the simulation results are shown in Figure 3-6.

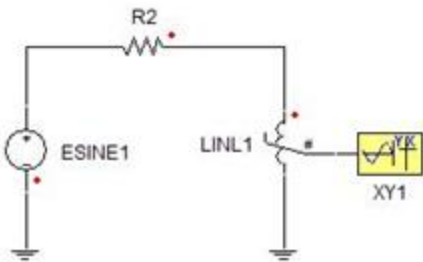


Figure 2. Application examples of the Nonlinear Dual Inductor model

Table 4. System Parameters

Component	Parameter	Value [unit]
Voltage Source (sin) ESINE1	AMPL	100 [V]
	FREQ	2000 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [V]
Resistor (Linear) R2	R	10 [Ohm]
Inductor (nonlinear) LNL1	CH	XY1.VAL*
	I0	0 [A]

* These variables are defined by other components on the schematic

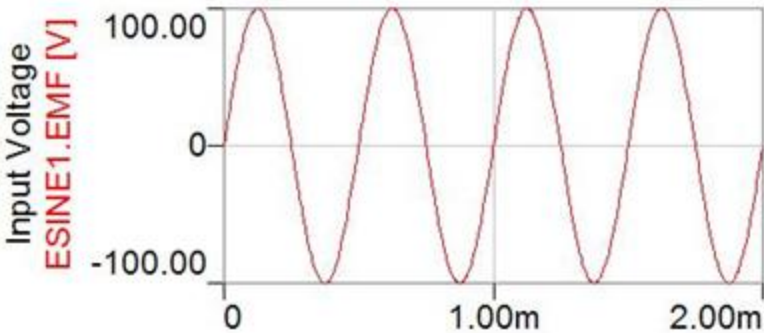


Figure 3. Simulation result-voltage of the voltage source ESINE1

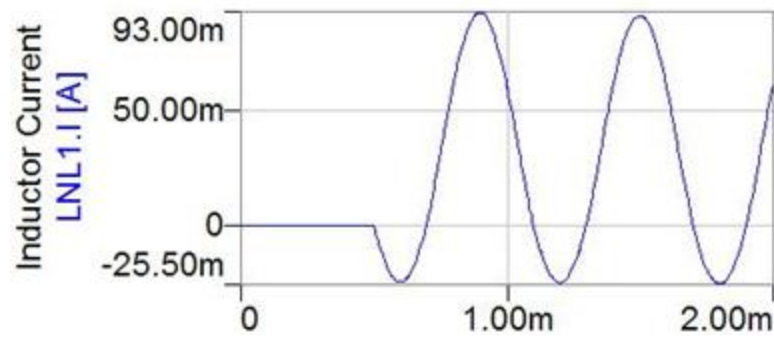


Figure 4. Simulation result-current through the inductor LINL1

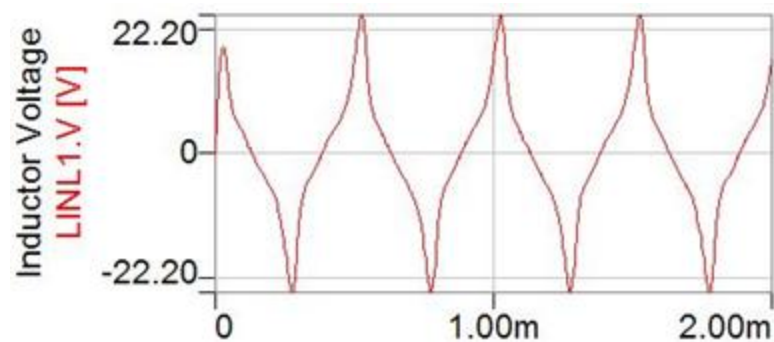


Figure 5. Simulation result-voltage across the inductor LINL1

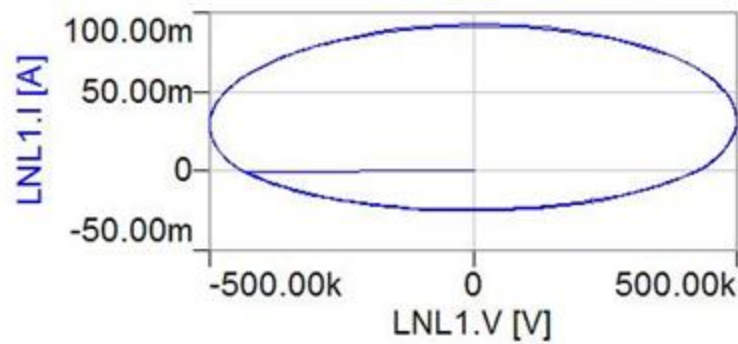


Figure 6. Simulation result-inductance of LINL1 as a function of its voltage

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References

[1] Roland E. Thomas, Albert J. Rosa. "The Analysis and Design of Linear Circuits." John Wiley & Sons, Inc., May, 2003.

Mutual Inductance

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

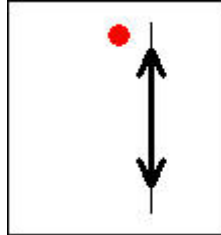


Figure 1. Component symbol

- Description
- Assumptions and Limitations
- Mathematical Description
- Netlist Syntax
- Conservative Pins
- Parameters
- Input/Output Quantities
- Example
- References

Description

The component represents the mutual coupling between two inductors, L1 and L2, quantitatively determined by the factor k.

The mutual inductance is equivalent to the present value of the quantity specified in the text box. For the quantity any numerical value, variable, mathematical or logical expression can be used. Usually a Constant value, a Time function or a variable are chosen, or the value of the inductance is determined in a state graph. A mathematical expression must conform to the syntax of the Twin Builder expression interpreter. All system quantities and variables can be combined with mathematical and logical operators and constants.

However, if the value of this quantity is unstable, numerical problems can occur. In particular, sudden changes in the first derivation of the control quantity should be avoided.

$$M = K \cdot \sqrt{L_1 \cdot L_2} \quad \text{with} \quad K = K_1 \cdot K_2$$

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Assumptions and Limitations

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Mathematical Description

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Netlist Syntax

INTERN M ?InstanceName(@InstanceName):(@ (Refbase)@(ID)) (L1:=@(L1), L2:=@(L2), K:=@(K));

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
N1	Pin 1 (with red point)	Electrical
N2	Pin 2	Electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
L1	Inductance L1	Real	H
L2	Inductance L2	Real	H
K	Coupling Factor	Real	[/]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Data Type

M	Mutual Inductance [H]	Real

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Example

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References

Resistor

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

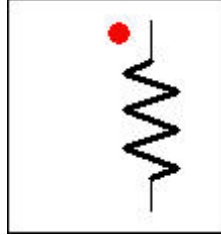


Figure 1. Component symbol

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- [Assumptions and Limitations](#)
- [Mathematical Description](#)
- [Netlist Syntax](#)
- [Conservative Pins](#)
- [Parameters](#)
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This component represents an electrical resistance. Within the dialog you can choose a linear or nonlinear resistor type.

Linear Resistor

Description

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Assumptions and Limitations

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Mathematical Description

The linear resistor can be described by the following equation:

$$v(t) = R \cdot i(t)$$

where $v(t)$, $i(t)$ are the voltage across and current through the resistor. The resistance R is equivalent to the present value of the quantity specified in the text box. For the quantity any numerical value, variable, mathematical or logical expression can be used. Usually a Constant value, a Time function, or a variable are chosen, or the value of the resistance is determined in a state graph. A mathematical expression must conform to the syntax of the Twin Builder expression interpreter. All system quantities and variables can be combined with mathematical and logical operators and constants.

Note: However, the expression must be technically meaningful. If it is not, numerical instability or completely wrong results are possible. In particular, sudden changes in the first derivation of the control quantity should be avoided.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
N1	Pin 1 (with red point)	electrical
N2	Pin 2	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
R	Resistance	real	1000 [Ohm]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type

V	Voltage [V]	Output	real
I	Current [A]	Output	real
DV	Derivative of Voltage [V/s]	Output	real
DI	Derivative of Current [A/s]	Output	real

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Example

In this example, three different ways to assign the resistance value for linear resistors are demonstrated. The resistance of R1 is assigned to a constant value, that of R_CTR_1 is a variable defined by an equation block, and RT1 gives its resistance value from the output of a 2D Lookup Table. The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the simulation results are shown in Figure 3, 4, and 5.

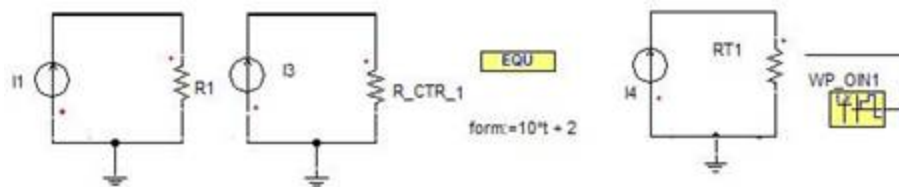


Figure 2. Application examples of the Linear Resistor model

Table 4. System Parameters

Component	Parameter	Value [unit]
Current Source I1, I3, I4	IS	1 [A]
Resistor (Linear) R1	R	2 [Ohm]
Resistor (Linear) R_CTR_1	R	form*
Resistor (Linear) RT1	R	WP_ON1.VAL*

* These variables are defined by other components on the schematic.

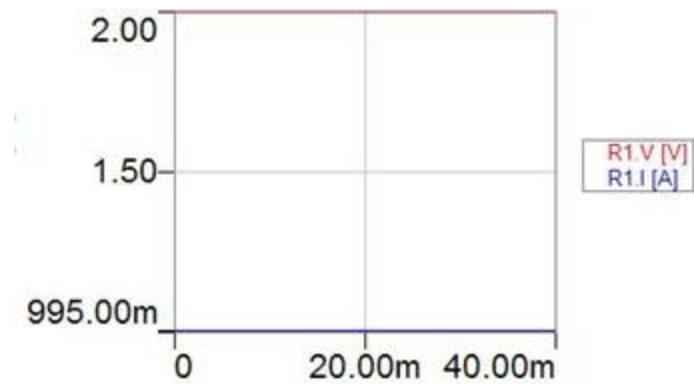


Figure 3. Simulation results-voltage across and current through R1

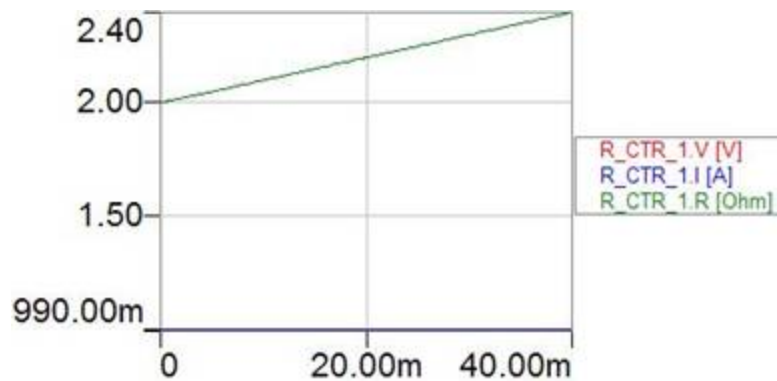


Figure 4. Simulation results-voltage across, current through and the resistance of R_CRT_1

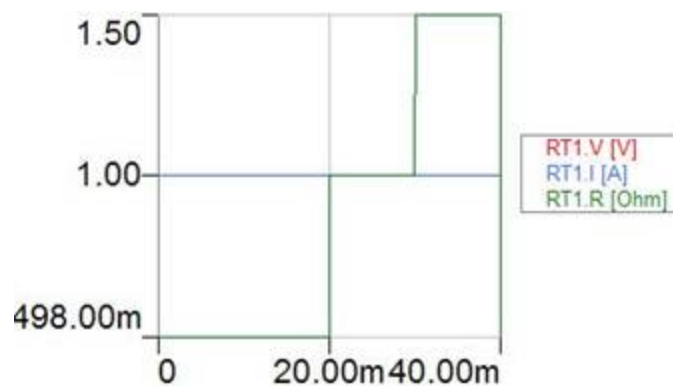


Figure 5. Simulation results-voltage across, current through and the resistance of RT1

Nonlinear Resistor

Description

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Assumptions and Limitations

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Mathematical Description

The non-linear resistor can be described by the following equation:

$$i(t) = f(v(t))$$

where $v(t)$, $i(t)$ are the voltage across and current through the resistor.

To describe the nonlinear relation, you must specify a name of an appropriate XY nonlinear characteristic function.

[See also Separate Component Characteristic](#)

X-value: voltage v (independent quantity)

Y-value: current i (dependent quantity)

To define characteristic data, you can do one of the following:

- **Use Pin** : connect the output of an XY component, connected to the pin to provide the characteristic
 - Use the **Characteristic** Dialog: in the Characteristic dialog box, choose the following options
 - **Reference** : specify the output variable of an XY component, e.g. XY1.VAL
 - **Lookup Table** : there are two options if you want to use a lookup table to define the characteristic
1. **File Reference** : the name in the text box specifies a variable which refers to a subsheet port specifying a characteristic file
 2. **Data Pairs** : enter sets of data to define the characteristics

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
N1	Pin 1 (with red point)	electrical
N2	Pin 2	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
CH	Characteristic	real	[/]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
V	Voltage [V]	Output	real
I	Current [A]	Output	real
dV	Derivative of Voltage [V/s]	Output	real
dI	Derivative of Current [A/s]	Output	real

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Example

This example demonstrates the usage of a Nonlinear Resistor model. Here the resistance of the nonlinear resistor RNL1 is specified by the output variable of the 2D Lookup Table. The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the simulation results are shown in Figure 3.

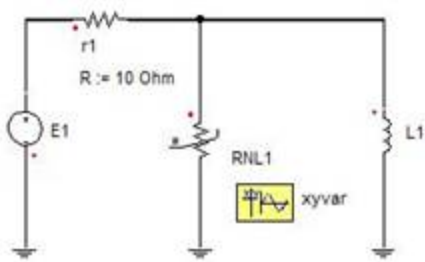


Figure 2. Application examples of the Nonlinear Resistor model

Table 4. System Parameters

Component	Parameter	Value [unit]
Voltage Source (sin) E1	AMPL	1 [A]
	FREQ	50 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [V]
Resistor (Linear) r1	R	10 [Ohm]
Resistor (Linear) RNL1	CH	xyvar.VAL
Inductor (Linear) L1	L	50m [H]
	I0	0 [A]

* These variables are defined by other components on the schematic.

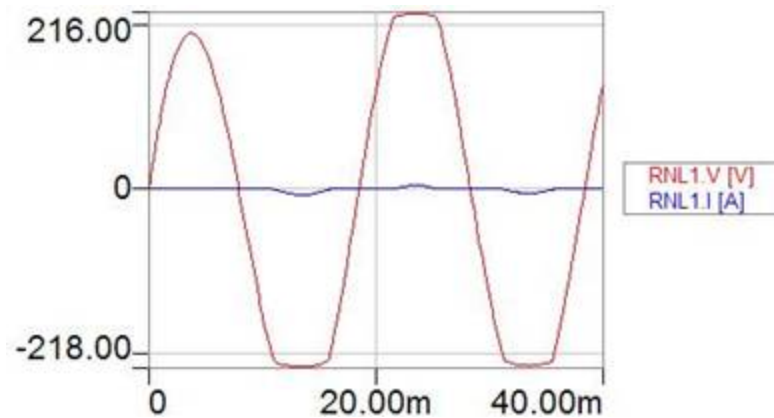


Figure 3. Simulation results-voltage across and current through RNL1

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References

[1] Roland E. Thomas, Albert J. Rosa. "The Analysis and Design of Linear Circuits." John Wiley & Sons, Inc., May, 2003.

Semiconductors Device Level

- Bipolar Junction Transistor
- Diodes
- Power Diode Model
- Field Effect Transistors
- GTOs
- Advanced Dynamic IGBT
- Average IGBT
- Basic Dynamic IGBT
- Operational Amplifier (OPV)
- Thyristor (Legacy Dynamic Model)
- Thyristor (Device Characterization-Compatible Model)
- Power MOSFET Model (Average)

Dynamic BJT Model

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

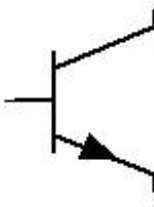


Figure 1. Component symbol

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- [Assumptions and Limitations](#)
- [Mathematical Description](#)
- [Netlist Syntax](#)
- [Conservative Pins](#)
- [Parameters](#)
- [Example](#)
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Description

The BJT model is a modular model with definable simulation levels. Different simulation depths can be selected for the electrical and thermal behavior of the model.

You can define two simulation levels for the electrical and three simulation levels for the thermal behavior. Each level combination has a certain set of parameters. The values of them can be defined in the model dialog box. The component outputs are true of all types of the BJT models. They are listed at the end of the model description.

See also Dynamic Diode Model.

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Assumptions and Limitations

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Mathematical Description

Electrical Model

The model uses an electrical equivalent circuit as shown in the following figure.

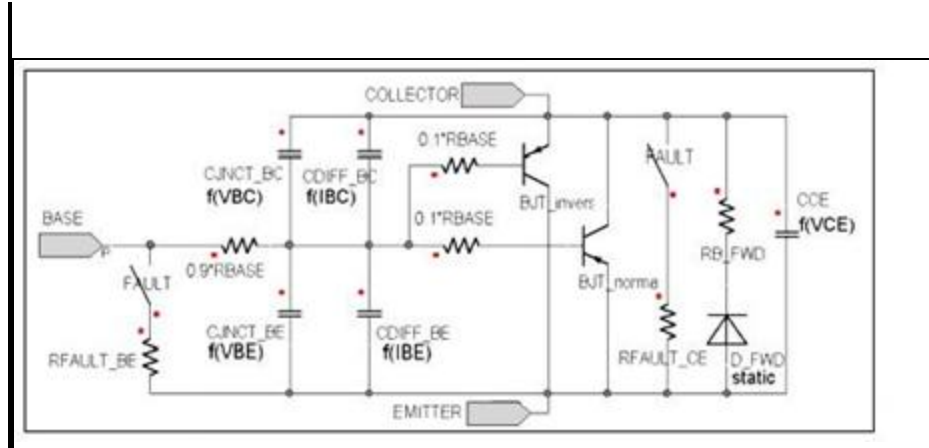


Figure 2. Equivalent circuit used for the Dynamic BJT model

There are two simulation levels regarding the electrical behavior. The level is set at the parameter TYPE_DYN:

TYPE_DYN=0

Only the static behavior is calculated. The charges at the capacitances are ignored, no switching behavior.

TYPE_DYN=1

In addition to the static behavior, charging and discharging of the junction and diffusion capacitances are calculated.

Electrical Behavior Level, Type DYN=0

The two BJT models for normal and inverse operation determine the static transistor current. In the normal operation mode, where the internal base-emitter voltage and the collector-emitter voltage are above 0 V, the current gain values for the BJT models are calculated from:

$$B_N = BN0 \cdot \left(1 + \frac{VCE}{VEARLY}\right) \quad B_I = BI0$$

In the inverse mode:

$$B_N = BN0 \quad B_I = BI0 \cdot \left(1 - \frac{VCE}{VEARLY}\right)$$

The static collector current is calculated from the base currents of the BJT models, and the base currents of the BJT models are calculated from their base-emitter voltages as following:

$$I_{B*} = I_{SAT} \cdot \left(e^{\frac{V_{BE*}}{M_{BJT} \cdot V_T}} - 1 \right)$$

where V_{BE} is the base-emitter voltage of the FET, and M is the ideality factor. The temperature voltage V_T is calculated as following:

$$V_T = \frac{k \cdot (TEMP\_JNCT + 273\text{ K})}{q}$$

where k is the Boltzmann constant, and $k=1.381\text{E-}23$; q is the elementary charge, and $q=1.602\text{E-}19$.

The saturation voltage of the BJT model for normal mode is calculated as following:

$$I_{SAT,N} = ISAT0\_BJT \cdot \left(\frac{TEMP\_JNCT + 273\text{ K}}{TEMP0 + 273\text{ K}} \right)^3 \cdot e^{\left(\frac{VGAP}{V_T} \cdot \frac{TEMP\_JNCT - TEMP0}{TEMP0 + 273\text{ K}} \right)}$$

The saturation voltage of the BJT model for inverse operation is calculated as following:

$$I_{SAT,I} = I_{SAT,N} \cdot \frac{B_N}{B_I}$$

The model has built-in fault detection. During the simulation the collector current and the base current, the voltage drops across base-emitter and collector-emitter as well as the junction temperature is observed. If their limitations are exceeded the model behavior changes. The switches controlled by the FAULT flags are closed and the respective fault resistances determine the model characteristic. Faults at the base do only affect RFAULT_BE. All other faults affect the RFAULT_CE.

Electrical Behavior Level, Type DYN=1

Junction capacitance:

There is a distinction between the calculation of depletion and enhancement capacitance behavior. The curves remain differentiable even at the transition from one region to the other. The transition happens if the junction voltage is less than 0 V.

If the junction voltage is greater than 0 V, the following equation is used:

$$C_{JUNCT} = C0_{JUNCT} \cdot \left(2 - e^{-\left(\frac{V_{JUNCT} \cdot ALPHA \cdot (1 - DELTA)}{VDIFF} \right)} \right)$$

If the junction capacitance is negative (depletion region), the following equation is used:

$$C_{JUNCT} = C0_{JUNCT} \cdot \left(DELTA + \frac{1 - DELTA}{\left(\frac{1 - V_{JUNCT}}{VDIFF} \right)^{ALPHA}} \right)$$

Diffusion capacitances (base-emitter, base-collector) can be calculated as following:

$$CDIFF\_BE = TAU\_BE \cdot \frac{I_{BN}}{M\_BJT \cdot V_T} \quad CDIFF\_BC = TAU\_BC \cdot \frac{I_{BI}}{M\_BJT \cdot V_T}$$

FWD Model

The FWD model is a static one only. The static current follows the formula:

$$I = I_{SAT\_FWD} \cdot \left(e^{\frac{-VDS - I \cdot RB\_FWD}{M \cdot V_T}} - 1 \right)$$

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Netlist Syntax

Netlist generated by Special Component Dialog.

Select the netlist of interest below.

- [NPN6](#)
- [NPN_FWD6](#)
- [PNP6](#)
- [PNP_FWD6](#)

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
BASE	Base	electrical
EMITTER	Emitter	electrical
COLLECTOR	Collector	electrical

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Parameters

Table 2. Parameters of TYPE DYN=0

Name	Description [Unit]	Data Type
BN0	Normal Current Gain	real
ALPHA_BN	Exponential Temperature Coefficient of BN	real
BI0	Inverse Current Gain	real
ALPHA_BI	Exponential Temperature Coefficient of BI	real
VEARLY	Early Voltage [V]	real
ALPHA_VEARLY	Exponential Temperature Coefficient of VEARLY	real
M0	Ideality Factor of Base Junction	real
ALPHA_M	Exponential Temperature Coefficient of Base Junction Ideality Factor	real
ISAT0	Saturation Current of Base Junction [A]	real
ALPHA_ISAT	Exponential Temperature Coefficient of Base Junction Saturation Current [A]	real
RB0	Bulk Resistance of Base Junction [Ohm]	real
ALPHA_RB	Exponential Temperature Coefficient of Base Junction Bulk Resistance	real
VGAP	Band Gap Voltage [V]	real
RC	Collector Connector Resistance [Ohm]	real
RB	Base Connector Resistance [Ohm]	real

RE	Emitter Connector Resistance [Ohm]	real
TEMP0	Reference Temperature [°C]	real
VBREAK_CE	Breakthrough Collector-Emitter Voltage [V]	real
VBREAK_BE	Breakthrough Base-Emitter Voltage [V]	real
IBREAK_C	Breakthrough Collector Current [A]	real
IBREAK_B	Breakthrough Base Current [A]	real
TEMPBREAK	Breakthrough Junction Temperature [°C]	real
RFAULT_CE	Collector-Emitter Resistance after Fault	real
RFAULT_BE	Base-Emitter Resistance after Fault [Ohm]	real

Table 3. Parameters of TYPE DYN=1 (+ Parameters of TYPE DYN=0)

Name	Description [Unit]	Data Type
VNOM	Nominal Voltage [V]	real
INOM	Nominal Current [A]	real
C0_BE	Base-Emitter Reference Capacitance [F]	real
VDIFF_BE	Diffusion Potential of Base-Emitter Capacitance [V]	real
ALPHA_BE	Capacitance Exponent Base-Emitter	real
DELTA_BE	Influence of constant capacitance at Base-Emitter	real
ALPHA_CBE	Exponential Temperature Coefficient of Base-Emitter Depletion Capacitance	real

C0_BC	Base-Collector Reference Capacitance [F]	real
VDIFF_BC	Diffusion Potential of Base-Collector Capacitance [V]	real
ALPHA_BC	Capacitance Exponent Base-Collector	real
DELTA_BC	Influence of constant capacitance at Base-Collector	real
C0_CE	Collector-Emitter Reference Capacitance [F]	real
VDIFF_CE	Diffusion Potential of Collector-Emitter Capacitance [V]	real
ALPHA_CE	Capacitance Exponent Collector-Emitter	real
DELTA_CE	Influence of constant capacitance at Collector-Emitter	real
TAU_BE	Carrier Lifetime at Base-Emitter Junction [s]	real
ALPHA_TAU_BE	Temperature Coefficient of Base-Emitter Carrier Lifetime	real
TAU_BC	Carrier Lifetime at Base-Collector Junction [s]	real
ALPHA_TAU_BC	Temperature Coefficient of Base-Collector Carrier Lifetime	real
LC	Collector Connector Inductance [H]	real
LB	Base Connector Inductance [H]	real
LE	Emitter Connector Inductance [H]	real

Table 4. Parameters of FWD Model

Name	Description [Unit]	Data Type
M_FWD	Ideality Factor of FWD	real
ISAT0_FWD	Saturation Current of FWD at TEMP0 [A]	real
RB_FWD	Bulk Resistance of FWD [Ω]	real

Input/Output Quantities**Table 5**

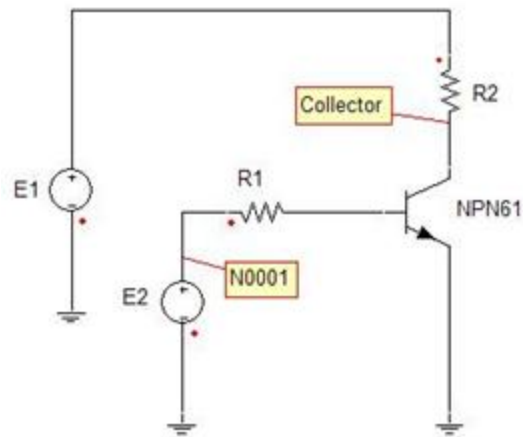
Name	Description [Unit]	Data Type
VBE	Base-Emitter Voltage [V]	real
VBC	Base-Collector Voltage [V]	real
VCE	Collector-Emitter-Voltage [V]	real
IC	Current through Collector Connector [A]	real
IB	Current through Base Connector [A]	real
I_B	Current through Base of Internal Static Model [A]	real
CBE	Base-Emitter Capacitance [F]	real
CBC	Base-Collector Capacitance [F]	real
CCE	Collector-Emitter Capacitance [F]	real
TEMPJNCT	Junction Temperature [°C]	real
TEMPINTR	Chip Temperature [°C]	real
TEMPC	Case Temperature [°C]	real

PEL	Total Component Losses [W]	real
PCOND	Power Transfer by Conduction [W]	real
PCONV	Power Transfer by Convection [W]	real
PRAD	Power Transfer by Radiation [W]	real
ESWITCH	Losses of One Switching Cycle [Ws]	real
PSWITCH	Average Losses of One Switching Cycle [W]	real
ETOT	Total Losses During Simulation [Ws]	real
PTOT	Total Average Losses During Simulation [W]	real
FAULT_VCE	Flag Collector-Emitter Over voltage	real
FAULT_VBE	Flag Base-Emitter Over voltage	real
FAULT_IC	Flag Collector Over current	real
FAULT_IB	Flag Base Over current	real
FAULT_TEMP	Flag Over temperature	real

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Example

This example demonstrates the operation mechanism of the advanced dynamic NPN BJT model through a simple example. The control base current is supplied by a pulse-wave voltage source E2. The schematic of the example is shown in Figure 3, system parameters are listed in Table 6, and the turn-on transient waveforms of the BJT model are shown in Figure 4.

**Figure 3. Application example of the NPN BJT model (advanced dynamic)****Table 6. System Parameters**

Component	Parameter	Value [unit]
Resistor R1	R	10 [Ohm]
Resistor R2	R	50 [Ohm]
Voltage Source (Pulse) E2	AMPL	5 [V]
	FREQ	5000 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [V]
Voltage Source E1	EMF	50 [V]

* All the parameters of the NPN BJT model NPN61 use their default values, therefore they are not included in the parameter table.

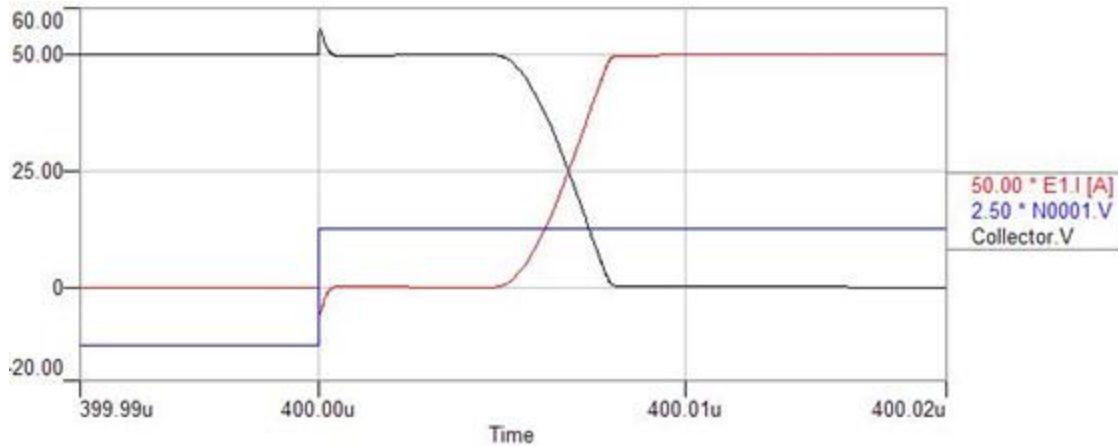


Figure 4. Simulation results-turn-on transients of NPN61

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References

[1] Ned Mohan, Tore M. Undeland, William P. Robbins, "Power Electronics: Converters, Applications, and Design." John Wiley & Sons, INC. New York, 1995.

Dynamic Diode Model

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

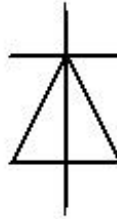


Figure 1. Component symbol

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- [Assumptions and Limitations](#)
- [Mathematical Description](#)
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Description

The diode model is a modular model with definable simulation levels. Different simulation depths can be selected for the electrical and thermal behavior of the model.

You can define three simulation levels for both the electrical and thermal behavior. Each level combination has a certain set of parameters. The values of them can be defined in the component dialog box.

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Assumptions and Limitations

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Mathematical Description

Electrical Model

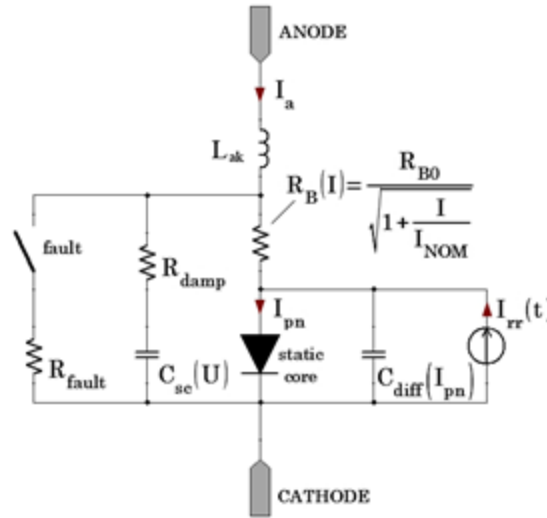


Figure 2. Equivalent circuit of the Diode model

Figure 2 shows the electrical equivalent circuit used by the Diode model. There are three simulation levels regarding the electrical behavior:

TYPE_DYN=0

Only the static behavior is calculated. The charges at the capacitances are ignored, and there is no charge storage and delay in the switching behavior. The static behavior is defined by the following:

$$I = I_s \left(\exp \left(\frac{V - I \cdot RB(I)}{M \cdot V_T} \right) \right), \quad V_T = \frac{k}{q} (TEMP\_JNCT + 273,15K) \quad \text{and} \quad RB(I) = \frac{RB0}{\sqrt{\frac{I}{I_{NOM}} + 1}}$$

where k =Boltzmanns Constant ($1.381e-023$ Ws/K), and q =elementary charge($1.602e-019$ As).

The saturation current is calculated from the given saturation current at reference temperature and the actual junction temperature.

$$IS = ISAT \left(\frac{T_J}{T_0} \right)^3 \exp \left(\frac{q \cdot V_{gap}}{k \cdot 1.4 \cdot T_J} \frac{(TEMP\_JNCT - TEMP0)}{T_0} \right), \quad T_J = TEMP\_JNCT + 273.15 \quad \text{and} \\ T_0 = TEMP0 + 273.15$$

TYPE_DYN=1

In addition to the static behavior, charging and discharging of junction and diffusion capacitance are also calculated. There is a distinction between the calculation of depletion and enhancement capacitance behavior. The curves remain differentiable even at the transition from one region to the other. The transition happens if the effective junction voltage (junction voltage - shift voltage) is less than 0 V. If the effective junction voltage is greater than 0 V, the following equation is used:

$$C_{JNCT} = C0_{JNCT} \left(1 + (BETA_{JNCT} - 1) \left\{ 1 - e^{-\left(ALPHA_{JNCT} \frac{(V_{JNCT} - V_{SHIFT})}{V_{DIFF}} \right) \frac{(1 - DELTA_{JNCT})}{(BETA_{JNCT})}} \right\} \right)$$

If the effective junction voltage is negative (depletion region), the following equation is used:

$$C_{JNCT} = C0_{JNCT} \left(DELTA_{JNCT} + \frac{1 - DELTA_{JNCT}}{\left(1 - \frac{V_{JNCT} - V_{SHIFT}}{V_{DIFF}} \right)^{ALPHA_{JNCT}}} \right)$$

For generality the parameters, BETA_JNCT and V_SHIFT are defined in the model; however, they are set internally to constant values. BETA_JNCT is set to a value of 2.0 and V_SHIFT is internally set to a value of 0.0. The Diffusion Capacitance is given by:

$$C_{DIFF} = Tau \frac{d(I_{JNCT})}{d(V_{JNCT})} = Tau \frac{I_{JNCT} + IS}{M * V_T (1 + TC_M (TEMP_{JNCT} - TEM))}$$

To damp the numerical oscillations that occur in the system, an additional damping resistance is placed in series to the depletion capacitance. The value of the damping resistance depends on the parameter DAMPING, the value of the parasitic inductance and the values of the internal capacitances. The damping resistance is given by:

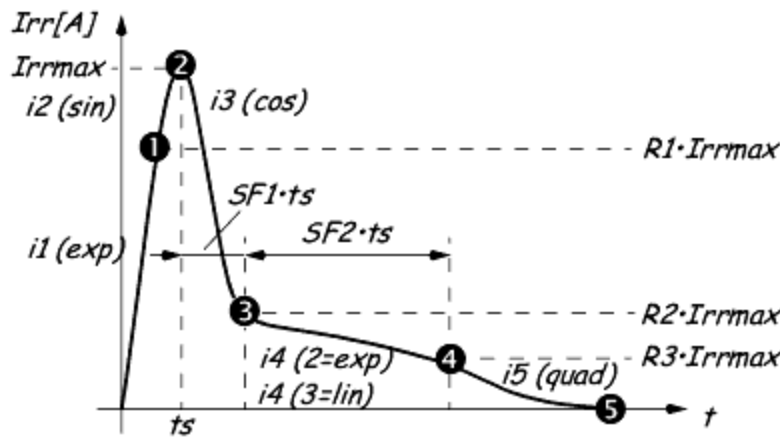
$$R_{DAMP} = DAMPING * \sqrt{\frac{L}{C(V)}}$$

TYPE_DYN=2 / TYPE_DYN=3

If either of these levels is selected, an additional controlled current source used to model the reverse recovery behavior is employed.

The integral of the reverse recovery current is determined by the parameter TAU. Form factors define the curve of the reverse recovery current. The Electrical Behavior Level to 2 and 3 represent two different characteristics. In both the reverse recovery is separated into five sections. The maximum current I_{rrmax} , and the time t_s , when I_{rrmax} is reached, are calculated from the reverse recovery charge and the form factors. All sections are connected so that the curve remains differentiable even at the transition from one region to the other.

- From zero crossing of diode current until the level $R1 \cdot I_{rrmax}$ is reached. The current follows an exponential function with the time constant TAU.
- The current follows a sine wave function until I_{rrmax} is reached.
- The current follows a cosine function. This section lasts for $SF1 \cdot t_s$. At its end the current is at the level $R2 \cdot I_{rrmax}$.
- If the Electrical Behavior Level is set to '2' the current follows an exponential function. For level 3 a linear function is used. Section 4 ends $SF2 \cdot t_s$ after I_{rrmax} was reached. The current at the end of section 4 is $R3 \cdot I_{rrmax}$.
- A quadratic function is used until the current reaches zero again.



Temperature, Voltage, and Current Dependencies

The model parameters may depend on junction temperature, terminal voltage and current. For the representation of these dependencies three groups of parameters were introduced:

- Coefficients for temperature dependencies
The names of these parameters start with TC
- Coefficients for voltage dependencies
The names of these parameters start with VC

- Coefficients for current dependencies
The names of these parameters start with CC

Static parameters M and RB depend on temperature only. The temperature dependency is expressed in the following way (where y_0 represents M0 or RB0 under reference temperature, and y_m is the calculated value under junction temperature):

Linear Dependency, when TYPE_DYN is 0 or 1:

$$y_m = y_0 \left(1 + ALPHA \cdot (T_j - T_0) \right)$$

Exponential Dependency, when TYPE_DYN is 2 or 3:

$$y_m = y_0 \left(\frac{T_j}{T_0} \right)^{ALPHA}$$

Transient parameters TAU and R2 depend on all factors (junction temperature, terminal voltage and current). Two different functions are also used to model the dependencies. The dependency on an additional value z (temperature, voltage, current) is expressed by the coefficient in the following way (where $y=f(x)$ is the original function under reference temperature and m stands for TC, CC, or VC):

Linear Dependency:

$$y_m = \left(1 + m \cdot \frac{z - z_0}{z_0} \right) f(x)$$

Exponential Dependency:

$$y_m = \left(\frac{z}{z_0} \right)^m f(x)$$

Temperature dependency can be linear or exponential while voltage and current dependencies are always linear. Some parameters have more than one coefficient. In this case the individual terms are multiplied. The reference values of temperature, voltage and current are always TNOM, VNOM, and INOM, respectively.

Compatibility of the model parameters with Simplorer v10

Due to the complexity of the exponential temperature dependencies of the static parameters (M, RB) in the Simplorer v10 model, the model was simplified by using a linear temperature dependency for those parameters and assuming some dependencies constant. This leads to an easier and more stable characterization procedure. In order to provide compatibility of manually characterized parameter sets from Simplorer v10, the parameter TYPE_D (through the generic parameter dialog) can be set to 3, which will cause the model to use the exponential dependencies.

$$IS = ISAT \left(\frac{T_J}{T_0} \right)^3 \exp \left(\frac{q * V_{gap}}{k * M \left(\frac{T_J}{T_0} \right)^{TC_M} * T_J} \frac{(TEMP_{JNCT} - TEMP_0)}{T_0} \right)$$

$$C_{DIFF} = Tau \frac{d(I_{JNCT})}{d(V_{JNCT})} = Tau \frac{(I_{JNCT} + IS)}{M \left(\frac{T_J}{T_0} \right)^{TC_M} * V_T}$$

Thermal Semiconductor Model

The structure of the thermal model is shown in Figure 3.

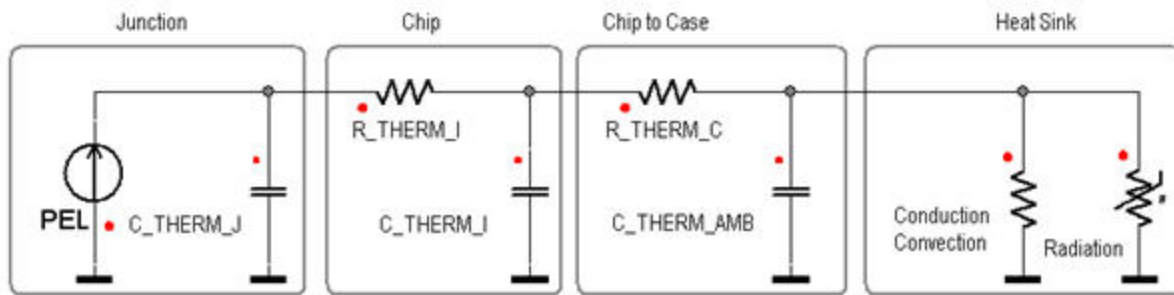


Figure 3. Equivalent thermal model of the Diode

If the built-in model is not sufficient for the simulation purpose, it is possible to use the model output PEL to control a current source in a more complex thermal network. The simulated junction temperature from this network can be fed into the electrical model. In this case TYPE_THERM = 0 has to be set.

The thermal behavior can be defined with the parameter TYP_THERM. There are three levels of the thermal behavior:

TYPE_THERM = 0

The junction temperature is set to the ambient temperature (Parameter 'TAMB'). All temperature dependent semiconductor parameters are re-calculated according to this temperature.

TYPE_THERM=1

The internal losses and the thermal resistances influence the junction and case temperatures. All thermal capacitances are ignored (static thermal model). This can lead to (unnatural) temperature steps that can drive the junction temperature beyond its limits. Therefore this mode should not be used other than for academic reasons.

TYPE_THERM=2

The temperatures are calculated using a dynamic thermal model taking into account all thermal resistances and capacitances.

[Top](#)**Netlist Syntax**

Netlist generated by [Special Component Dialog](#).

[Top](#)**Conservative Pins****Table 1**

Name	Port/Terminal Description	Nature/Data Type
ANODE	Anode	electrical
CATHODE	Cathode	electrical

Electrical Parameters**Table 2****TYPE_DYN=0**

Name	Description	Data Type	Default Value [Unit]
VNOM	Nominal Blocking Voltage	real	100 [V]
INOM	Nominal Current	real	10 [A]
DINOM	Nominal Current Slope	real	1e8 [A/s]
ISAT0	Saturation Current at Reference Temperature	real	1e-013 [A]
M0	Ideality Factor	real	1.35
TC_M	Linear Temperature Coefficient of M	real	0
RB0	Bulk Resistance	real	1e-006 [Ohm]

TC_RB	Exponential Temperature Coefficient of RB	real	0
VGAP	Bandgap Voltage, Si 1.1	real	1.11 [V]
TNOM	Reference Temperature	real	125 [°C]
VBREAK	Breakthrough Voltage	real	1000000 [V]
IBREAK	Breakthrough Current	real	10000 [A]
TBREAK	Breakthrough Junction Temperature	real	1000 [°C]
RFAULT	Resistance A-K after Fault	real	0.001 [Ohm]

TYPE_DYN=1 (+ Parameters of TYPE_DYN=0)

Name	Description [Unit]	Data Type	Default Value [Unit]
C0_JNCT	Total Junction Capacitance at 0V	real	1e-010 [F]
VSHIFT_JNCT	Voltage Shift	real	0 [V]
VDIFF_JNCT	Diffusion Potential	real	0.6 [V]
TC_JNCT	Capacitance Exponent	real	0.5
DELTA_JNCT	Influence of Const. Capacitance	real	0.01
TAU	Effective Lifetime	real	1e-008 [s]
TC_TAU	Exponential Temperature Coefficient of TAU	real	0
CC_TAU	Linear Current Coefficient of	real	0

	TAU		
VC_TAU	Linear Voltage Coefficient of TAU	real	0
L_AK	Parasitic Inductance	real	2e-009 [H]
DAMPING	Damping Factor	real	1

TYPE_DYN=2/3 (+ Parameters of TYPE_DYN=0 and TYPE_DYN=1)

Name	Description	Data Type	Default Value [Unit]
R1	Reverse Recovery Form Factor 1	real	0.01
R2	Reverse Recovery Form Factor 2	real	0.75
R3	Reverse Recovery Form Factor 3	real	0.25
SF1	Reverse Recovery Soft Factor 1	real	0.8
SF2	Reverse Recovery Soft Factor 2	real	4
TC_R2	Exponential Temperature Coefficient of R2	real	0
CC_R2	Linear Current Coefficient of R2	real	0
VC_R2	Linear Voltage Coefficient of R2	real	0
TC_C0	Exponential Temperature Coefficient of C0	real	0
CC_C0	Linear Current Coefficient of C0	real	0
VC_C0	Linear Voltage Coefficient of C0	real	0
TC_SF	Exponential Temperature Coefficient of R2	real	0
CC_R2	Linear Current Coefficient of R2	real	0
VC_R2	Linear Voltage Coefficient of R2	real	0

Thermal Parameters

Table 3

TYPE THERM=0

Name	Description	Data Type	Default Value [Unit]
TAMB	Ambient Temperature	real	Temp [°C]

TYPE THERM=1 (+ Parameters of TYPE THERM=0)

Name	Description [Unit]	Data Type	Default Value [Unit]
R_TH1	Thermal Intrinsic Resistance	real	0.001 [K/W]
R_TH2	Thermal Resistance Chip to Case	real	0.01 [K/W]

TYPE THERM=2 (+ Parameters of TYPE THERM=0 and THERM=1)

Name	Description	Data Type	Default Value [Unit]
TJNCT0	Junction Temperature at Simulation Start	real	Temp [°C]
CTH1	Thermal Junction Capacitance	real	0.001 [Ws/K]
CTH2	Thermal Intrinsic Capacitance	real	0.01 [Ws/K]
CTH3	Thermal Ambient Capacitance	real	0.1 [Ws/K]
CONVECTION	Convection Number	real	0.01 [W/cm²K]
AREA_CONV	Convection Area	real	10 [cm²]

RADIATION	Thermal Radiation Constant	real	5.7e-12 [W/cm ² K ⁴]
AREA_RAD	Thermal Radiation Area	real	10 [cm ²]
GTH3	Thermal Conductivity to Ambient	real	10000 [W/K]

Input/Output Quantities for all Diode Types

Table 4

Name	Description [Unit]	Direction	Data Type
I	Current [A]	Output	real
V	Anode-Cathode-Voltage [V]	Output	real
DIDT	dI/dT of Diode Current	Output	real
I_RR	Reverse Recovery Current	Output	real
CJNCT	Junction Capacitance [F]	Output	real
QDIFF	Diffusion Charge [As]	Output	real
CDIFF	Diffusion Capacitance [F]	Output	real
QRREC	Reverse Recovery Charge [As]	Output	real
T_JNCT	Junction Temperature [°C]	Output	real
T_INNER	Chip Temperature [°C]	Output	real
T_CASE	Case Temperature [°C]	Output	real
PEL	Diode Losses [W]	Output	real

PCOND	Power Transfer by Conduction [W]	Output	real
PCONV	Power Transfer by Convection [W]	Output	real
PRAD	Power Transfer by Radiation [W]	Output	real
ESWITCH	Losses of One Switching Cycle [Ws]	Output	real
PSWITCH	Average Losses of One Switching Cycle [W]	Output	real
ETOT	Total Losses During Simulation [Ws]	Output	real
PTOT	Total Average Losses During Simulation [W]	Output	real
FAULT_V	Flag Over voltage [/]	Output	real
FAULT_I	Flag Over current [/]	Output	real
FAULT_TEMP	Flag Over temperature [/]	Output	real

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Example

Figure 4 shows two diode component instances: D1 is a system level diode that is connected directly to the pulse voltage source E2. The second, Diode601 is a device level diode. The level of detail of the device level diode model switches from average to dynamic at $t=5\mu s$. At dynamic level, the device level diode simulates the reverse recovery current, which can be seen in the simulation results in Figures 5 and 6.

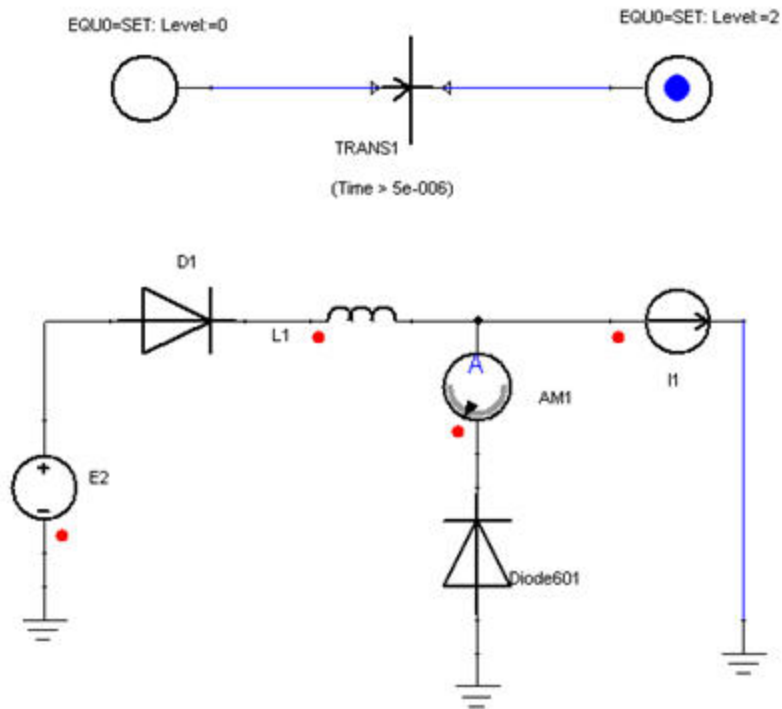


Figure 4. Application example of the Dynamic Diode Model

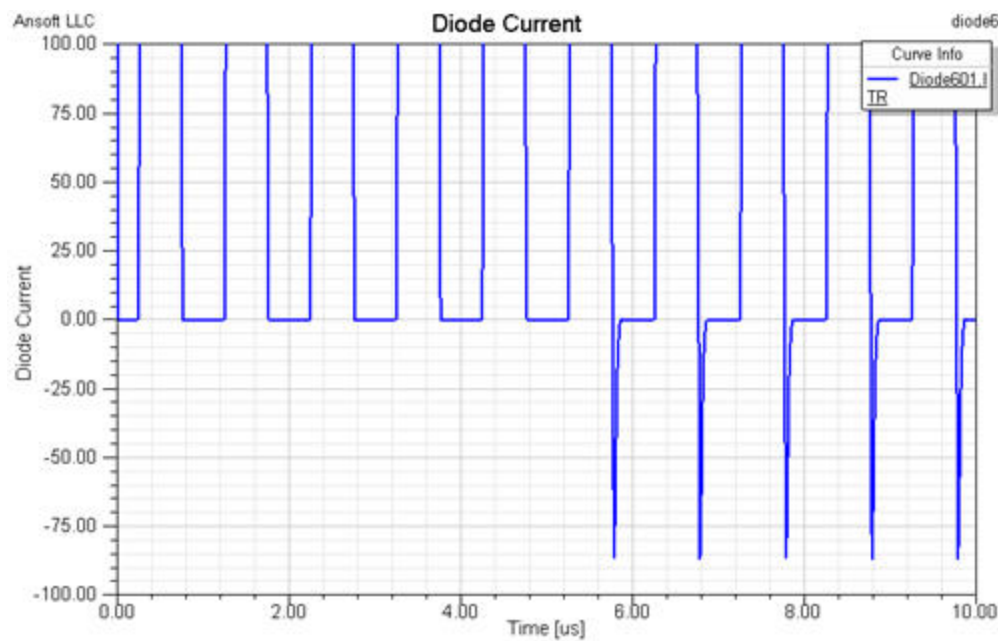


Figure 5. Simulation results-current of Diode601

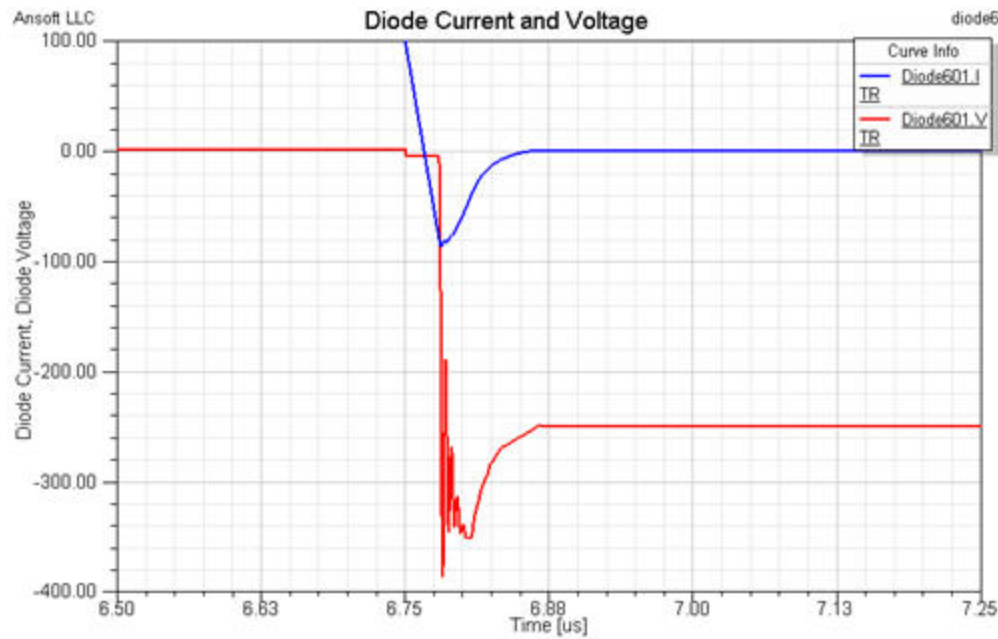


Figure 6. Simulation results- voltage and current of Diode601

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References

[1] Ned Mohan, Tore M. Undeland, William P. Robbins, "Power Electronics: Converters, Applications, and Design." John Wiley & Sons, INC. New York, 1995.

Power Diode Model

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

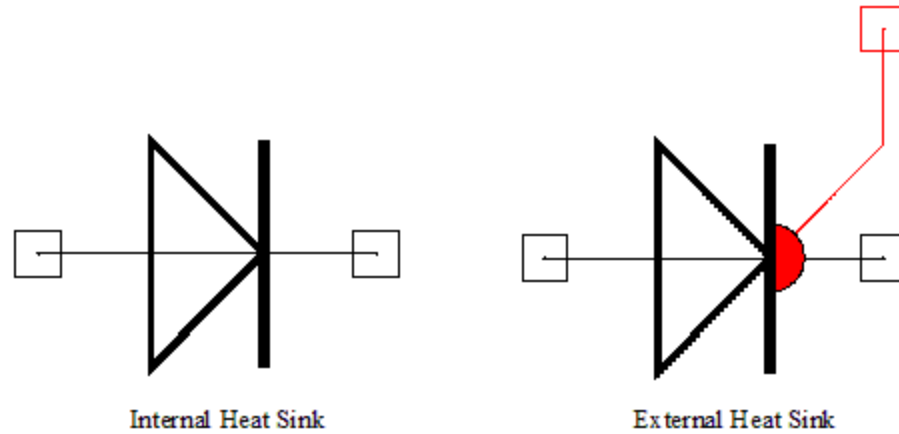


Figure 1. Component symbols for power diode models with internal heat sink and with thermal pins for external heat sink connections

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- [Assumptions and Limitations](#)
- [Mathematical Description](#)
- [Netlist Syntax](#)
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Description

The diode model is a modular model. For models with thermal pins, an external thermal network can be connected.

You can define different levels for the electrical and thermal behavior using the TYPE_DYN and TYPE_THERM parameters, respectively. Each level combination has a certain set of parameters. You can define their values in the model dialog.

Note	The diode model has a synchronization input for use in a steady state operation mode to model more precisely the working point dependency of characteristic value output.

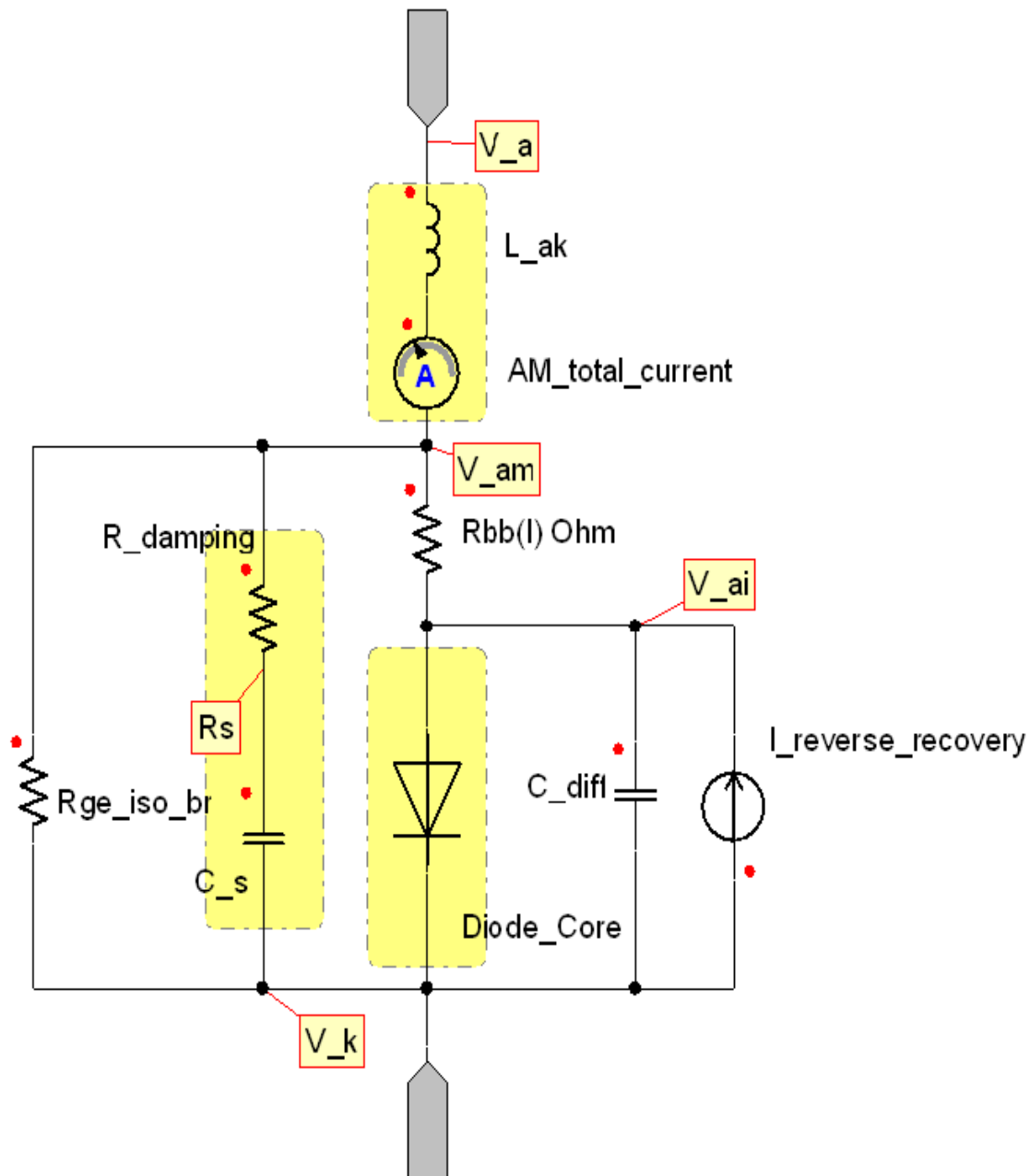
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Assumptions and Limitations

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Mathematical Description

The model uses an electrical equivalent circuit as shown in the following figure.



yellow: one component entry

The TYPE_DYN parameter allows you to modify the dynamic behavior of the IGBT diode. There are two digits to the number, each switch switching a different aspect.

The left-most digit (the 10's) allows you to activate the external device synchronization by a trigger signal which determines the blocking voltage and forward current sampling.

The right-most digit (the 1's) turns on the dynamic model if it is set to greater than zero; otherwise it is turned off and only the DC part of the model is used.

The value of the voltage influencing the reverse current is taken from the previous switching-on. Therefore, it does not give proper results for fault simulation and should be used only for investigations of periodic switching processes.

For all TYPE_DYNs, the static model of the diode is modeled using a Shockley model which is extended by a nonlinear bulk resistance, using the parameters M0, ISAT0, RB0 and VGAP. All these parameters are modeled as temperature dependent except VGAP. In addition, their temperature dependence is corrected using the temperature coefficient parameters TC_M, TC_IS and TC_RB.

For the calculation of the static diode characteristic, the voltage drop V_F across the device is calculated for a given forward current I_F by

$$V_F = V_T \ln \left(\frac{I_F}{I_S} + 1 \right) + I_F \cdot R_B(I_F)$$

V_T

is the so-called temperature voltage including emission coefficient and temperature correction,

$$V_T = V_{T0} \cdot M0 \cdot [1 + TC\_M \cdot \Delta T]$$

where $V_{T0} = \frac{kT_j}{q}$, k : Boltzmann constant, q : elementary charge and T_j : junction temperature in Kelvin.

I_S

is the diode saturation current

$$I_S = \text{ISAT0} \left(\frac{T_j}{\text{TNOM} + T_{\text{NULL}}} \right)^{(3+\text{TC\_IS})} \cdot \exp \left(\frac{\text{VGAP} \cdot \Delta T}{1,4 \cdot V_{T0} \cdot (\text{TNOM} + T_{\text{NULL}})} \right)$$

with $T_{\text{NULL}} = 273,15 \text{ K}$.

$$R_B(I_F)$$

is a nonlinear current dependent bulk resistance which is modeled by

$$R_B(I_F) = \frac{\text{RB0} \cdot (1 + \text{TC\_RB} \cdot \Delta T)}{\sqrt{\frac{I_F}{\text{INOM}} + 1}}$$

The model has built-in fault detection. During the simulation the forward current, the blocking voltage and the junction temperature are observed. The model behavior changes if the limitations are exceeded. The switches controlled by the FAULT flags are closed, and the respective fault resistance determines the model characteristic.

Dynamic Behavior

The semiconductor depletion capacitance C_s is modeled as voltage dependent. A distinction is made between a region where a depletion capacitance is calculated and a region with enhancement capacitance behavior. The curves remain differentiable even at the transition from one region to the other. The transition happens if the shifted voltage across the junction equals zero according to

$$V_{PN} = V_C - \text{VSHIFT\_JNCT}$$

For positive values of V_{PN} (enhancement region), the following formula is used to calculate the capacitance .

$$C = \text{C0\_JNCT} \cdot \left[2 - \exp \left(-\frac{V_{PN}}{V_N} \right) \right]$$

The normalizing voltage is.

$$V_N = \frac{V_{DIFF\_JNCT}}{(1 - DELTA\_JNCT) \cdot ALPHA\_JNCT}$$

At negative values of V_{PN} (depletion region), the following formula applies: .

$$C = C0\_JNCT \cdot \left[DELTA\_JNCT - \frac{1 - DELTA\_JNCT}{\left(1 - \frac{V_{PN}}{V_{DIFF\_JNCT}} \right)^{ALPHA\_JNCT}} \right]$$

To damp the oscillations that may occur in the system, additional damping resistances are placed in the model. The values of the damping resistances depend on the parameter DAMPING, the values of the parasitic inductances, and the values of the internal capacitances.

$$R_{DAMP} = DAMPING \sqrt{\frac{L}{C}}$$

In the forward conduction mode the diffusion capacitance C_D applies. This value is directly proportional to the forward current

$$C_D = \frac{\tau}{V_T} \cdot I_F$$

$$\tau = x_T \cdot x_I \cdot x_V \cdot x_S \cdot TAU$$

with the ambipolar life time and the working point correction functions for temperature, current, voltage and current slope correction which are controlled by the working point correction coefficients TC_TAU, CC0_TAU, CC_TAU, VC0_TAU, VC_TAU, SC0_TAU and SC_TAU. This set of coefficients belongs to each dynamic model parameter which is included in the working point correction triggered by the model synchronization.

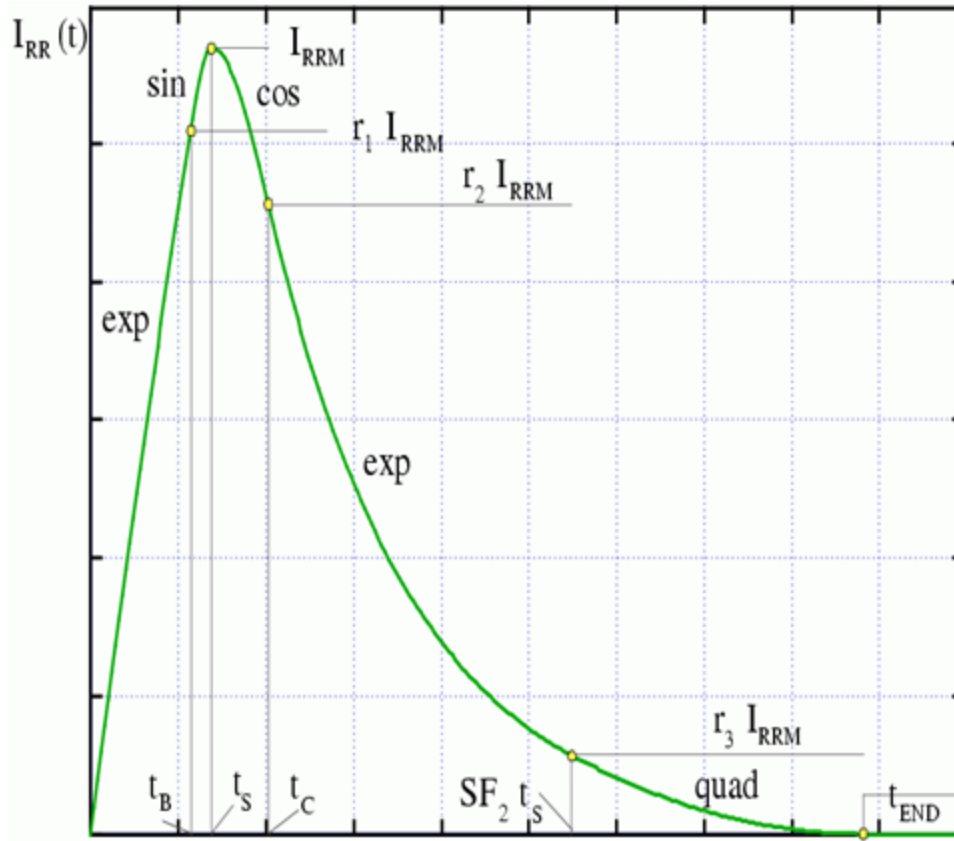
Reverse Recovery Current Model

You can set the behavior of the diode model by using TYPE_DYN in the model parameters. In the wizard, choose **DynX** in the advanced parameters on the extraction page.

- TYPE_DYN=0: Static model. This model is without capacitances and stray inductances. The model has no reverse recovery and is without any dynamic features.
- TYPE_DYN=1: Dynamic model (Dyn0). Voltage and current controlled capacitances and stray inductances are added. The diffusion and depletion capacities, as well as the leakage inductances are enabled. The special IRR model is not activated. Therefore, the model is without reverse recovery.

This selection results in a snappy behavior. When the diffusion capacitance is empty, the reverse current flow stops immediately. Any high di/dt values are generated and have an impact on the circuit. Oscillations arise that are certainly undesirable in the field of power electronics and energy technology.

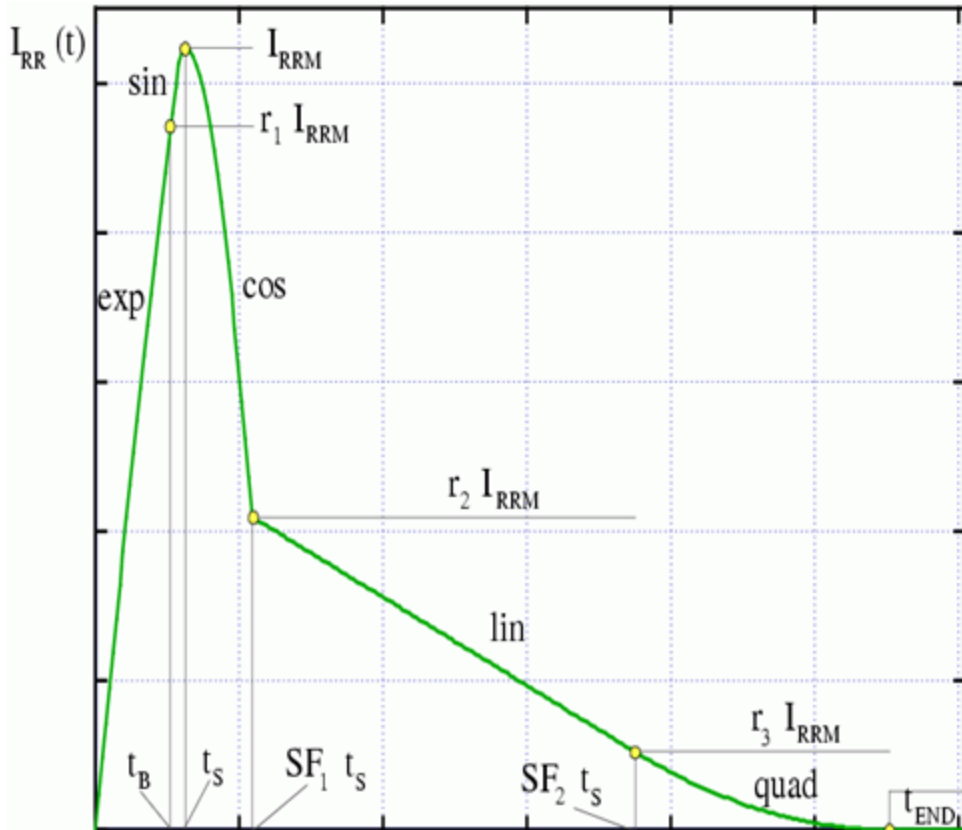
- TYPE_DYN=2: Dynamic model (Dyn1). The reverse recovery model behavior is added. The wave form shows a smooth exponential current decay after the maximum reverse current I_{RRM} . The IRR wave form template is made by a series of functions which are connected continuously and in a differentiable manner. The area under the IRR wave is the diode charge at diode current zero crossing. By changing the template parameters r1, r2, r2 and SF2 = SF very different wave form shapes can be achieved at preserving the charge. All curve shapes have a smooth course, which avoids voltage peaks on the diode reverse voltage. In most cases it is enough to play with SF and R3 to match the peak current IRRM and the reverse recovery time td.



Shape parameters R and SF for exponential current decay.

- TYPE_DYN=3: Dynamic model (Dyn2). With some types of diodes, a **pronounced linear tail current** is observed. Therefore, a different reverse recovery model template is used. The wave form shows a characteristic current tail after the maximum reverse current I_{RRM} and shows at the beginning of this current tail a typical bend. So, the induction voltage jumps at this point and causes oscillation.

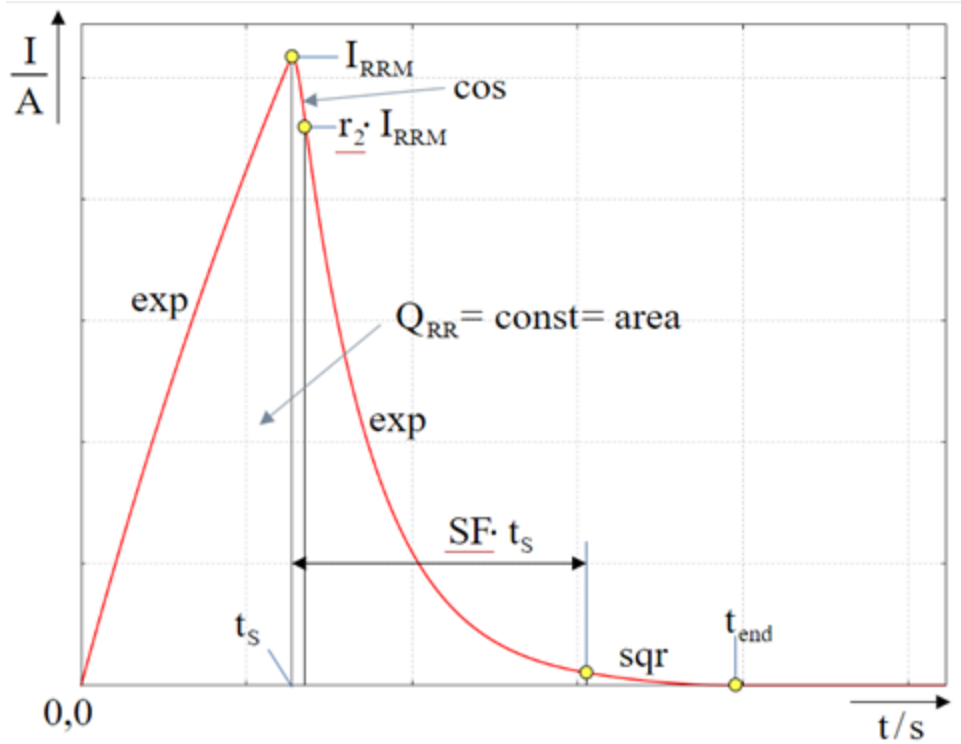
An additional parameter SF1 is used. The parameters SF1, R2, and SF2 are mainly used for curve fitting.



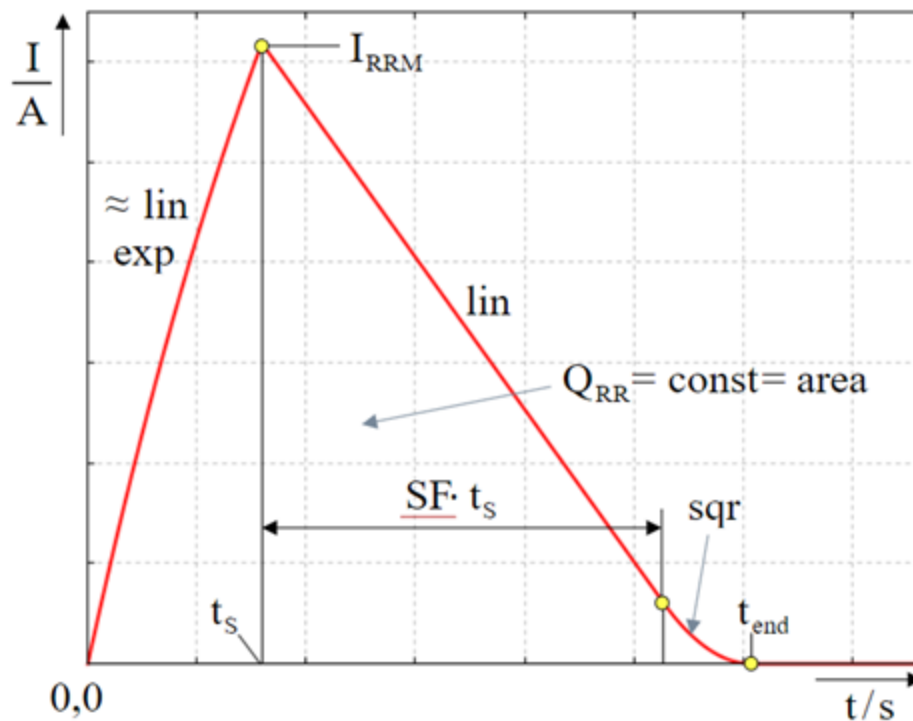
Shape parameters R and SF for linear current decay.

Note	Both (2 and 3) are adopted from real measurement data. This predefinition simplifies the I_{RR} handling.

- TYPE_DYN=4: Dynamic model (Dyn3). To reach higher I_{RRM} values at large t_{rr} this reduced form of the exponential type can be used. In most cases it will be enough to fit for SF to get a good fit to measurement.



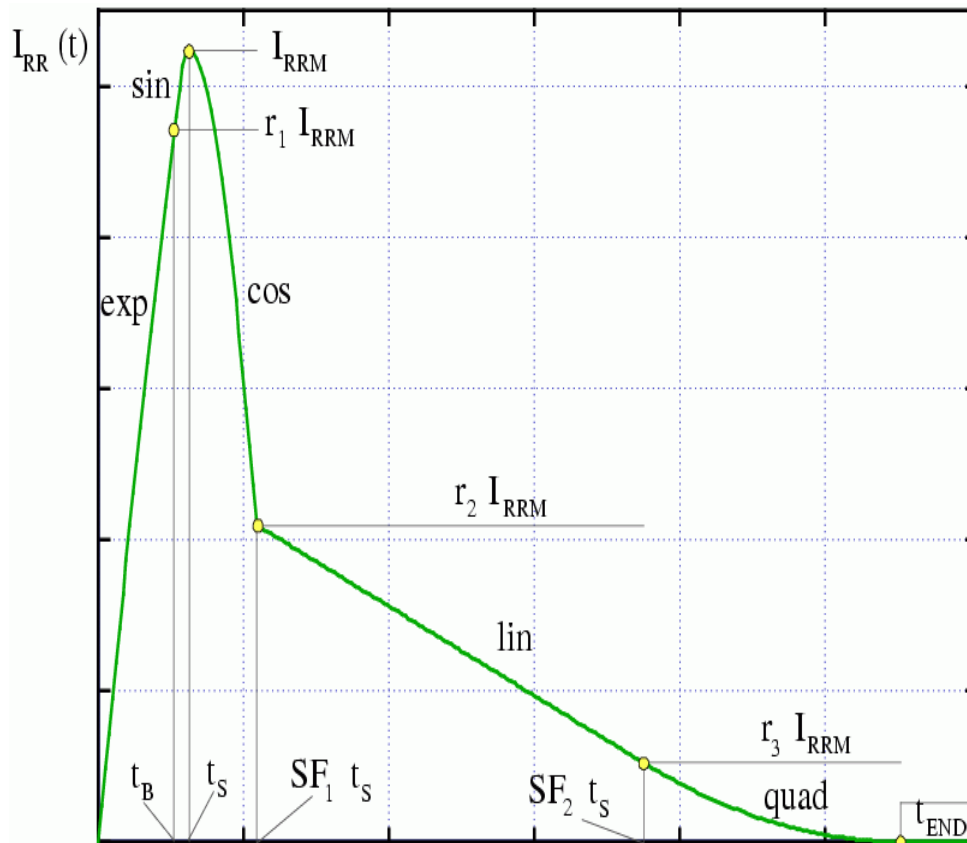
- TYPE_DYN=5: Dynamic model (Dyn4). This near triangular shape can be used if a **high maximum I_{RRM} is required at low t_{rr}** . It is a reduced form of the linear type. The only wave parameter to change both I_{RRM} and t_{rr} is SF.



- TYPE_DYN= x+10: Adding 10 to the previous control numbers activates the synchronization input. Working point correction reaches the desired accuracy only with synchronization. The synchronization signal must cross zero in positive direction for the transition from the blocking to the conducting state and can be any signal available in the simulation which relates to the pulse frequency of the circuit.

The total excess carrier charge is controlled by the parameter TAU and the excess charge is generated during the on state. During the transition from the conduction to the blocking state the

reverse recovery charge Q_{RR} is smaller because of charge extraction at the beginning of this transition. The current is modeled to be continuous and continuously differentiable. The total stored excess charge before switching off is the diode diffusion charge. The following are dependent on the circuit conditions: the maximum reverse current, the current slopes, the remaining charge after the current crosses zero and the duration of the reverse recovery.

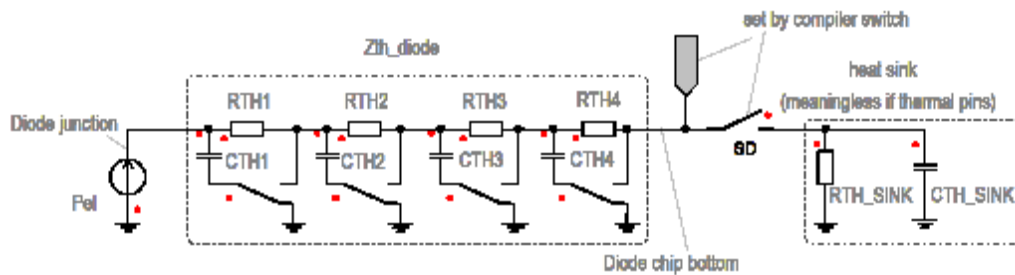


Linear Current Decay

Thermal Pins

The thermal model provides the opportunity to choose between the continued fractional and the partial fractional thermal networks. During the device characterization, one of the model approaches is defined and the parameters are valid only for this selected model. If the thermal capacitances and resistances are considered to be computed from FEM calculation, the physically based continued fractional model (Cauer type) can be used. If the fitting to a thermal impedance curve is desired, the mathematically based partial fraction model (Forster type) can be employed.

As shown in following figure, the electrical power loss of the diode is injected into a thermal network. The position of the S1~S4 switches is decided by the type of thermal network configuration that is chosen: if continued fractional thermal model is chosen, the switches connect the thermal capacitances directly to the ambient node; if partial fractional thermal model is selected, the thermal capacitances are connected in parallel to the corresponding thermal resistances through the switches. Note that in the following figure showing the thermal network of the diode model, the ground symbol means the ambient.



The diode model has a fourth-order internal heat sink model. Use the external thermal pins to connect the device to a customized heat sink thermal network configuration.

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Netlist Syntax

```
UMODEL diode_sync ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) ANODE:= %0,
CATHODE:= %1 ( TYPE_D:= @TYPE_D, TYPE_THERM:= @TYPE_THERM, TYPE_DYN:=
@TYPE_DYN, M0:= @M0, ISAT0:= @ISAT0, RB0:= @RB0, C0_JNCT:= @C0_JNCT, VDIFF_
JNCT:= @VDIFF_JNCT, ALPHA_JNCT:= @ALPHA_JNCT, DELTA_JNCT:= @DELTA_JNCT,
TAU:= @TAU, DAMPING:= @DAMPING, L_AK:= @L_AK, R1:= @R1, R2:= @R2, R3:= @R3,
SF1:= @SF1, SF2:= @SF2, TAMB:= @TAMB, TNOM:= @TNOM, TJNCT0:= @TJNCT0,
VGAP:= @VGAP, VNOM:= @VNOM, INOM:= @INOM, DINOM:= @DINOM, TC_M:= @TC_M,
TC_IS:= @TC_IS, TC_RB:= @TC_RB, TC_TAU:= @TC_TAU, CC0_TAU:= @CC0_TAU, CC_
TAU:= @CC_TAU, VC0_TAU:= @VC0_TAU, VC_TAU:= @VC_TAU, SC0_TAU:= @SC0_
TAU, SC_TAU:= @SC_TAU, TC_SF1:= @TC_SF1, CC0_SF1:= @CC0_SF1, CC_SF1:=
@CC_SF1, VC0_SF1:= @VC0_SF1, VC_SF1:= @VC_SF1, SC0_SF1:= @SC0_SF1, SC_
SF1:= @SC_SF1, TC_SF2:= @TC_SF2, CC0_SF2:= @CC0_SF2, CC_SF2:= @CC_SF2,
VC0_SF2:= @VC0_SF2, VC_SF2:= @VC_SF2, SC0_SF2:= @SC0_SF2, SC_SF2:= @SC_
SF2, TC_R2:= @TC_R2, CC0_R2:= @CC0_R2, CC_R2:= @CC_R2, VC0_R2:= @VC0_R2,
VC_R2:= @VC_R2, SC0_R2:= @SC0_R2, SC_R2:= @SC_R2, TC_DELTA_S:= @TC_
DELTA_S, CC0_DELTA_S:= @CC0_DELTA_S, CC_DELTA_S:= @CC_DELTA_S, VC0_
DELTA_S:= @VC0_DELTA_S, VC_DELTA_S:= @VC_DELTA_S, SC0_DELTA_S:= @SC0_
DELTA_S, SC_DELTA_S:= @SC_DELTA_S, VBREAK:= @VBREAK, IBREAK:= @IBREAK,
TBREAK:= @TBREAK, RFAULT:= @RFAULT, CTH1:= @CTH1, RTH1:= @RTH1, CTH2:=
@CTH2, RTH2:= @RTH2, CTH3:= @CTH3, RTH3:= @RTH3, CTH4:= @CTH4, RTH4:=
@RTH4, CTH_SINK:= @CTH_SINK, RTH_SINK:= @RTH_SINK, SYNC:= @SYNC) SRC: DB
(Lib:=@ModelLibraryName) ;
```

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
ANODE	Anode	electrical
CATHODE	Cathode	electrical
THERM_D	Diode Die Bottom Thermal Contact	thermal

Note THERM_D pins Diode_Sync_T models.

Parameters for Diode_Sync

Table 2

Name	Description	Data Type
TYPE_D	Diode Polarity Flag 1: normal 2: Inverse	real
TYPE_DYN	0:stat 1:dyn 2:IRRexp 3:IRRLin +10: ext sync	real
TYPE_THERM	0:iso 1, 2:dyn +10:contin.fract. +100:degrees Celsius at heat pins +200: degrees Kelvin at heat pins	real
M0	Ideality Factor of diode at TNOM [/]; static parameter	real
ISAT0	Saturation Current of diode at TNOM [A]; static parameter	real
RB0	Bulk Resistance of diode at TNOM [Ω]; static parameter	real
C0_JNCT	Depletion Capacitance Parameter: zero voltage junction capacitance	real
VDIFF_JNCT	Depletion Capacitance Parameter: diffusion voltage	real
ALPHA_JNCT	Depletion Capacitance Parameter: capacitance exponent	real
DELTA_JNCT	Depletion Capacitance Parameter: capacitance minimum factor	real
TAU	Ambipolar Lifetime	real
DAMPING	Damping resistance coefficient	real
L_AK	Module Stray Inductance	real
R1	Reverse Recovery Current Shape Factor 1	real
R2	Reverse Recovery Current Shape Factor 2	real
R3	Reverse Recovery Current Shape Factor 3	real
SF1	Reverse Recovery Current Soft Factor 1	real
SF2	Reverse Recovery Current Soft Factor 2	real
TAMB	Ambient Temperature °C	
TNOM	Reference Temperature °C	
TJNCT0	Junction Temperature °C	

VGAP	Band Gap Voltage [V]	
VNOM	Nominal Voltage [V]	
INOM	Nominal Current [A]	
DINOM	Nominal di/dt	
TC_M	Temperature Coefficient of M0	
TC_IS	Temperature coefficient of ISAT0	
TC_RB	Temperature Coefficient of RB	
TC_TAU	Temperature Coefficient of TAU	
CC0_TAU	Current Coefficient of TAU at TNOM	real
CC_TAU	Linear Current Coefficient of TAU	real
VC0_TAU	Voltage Coefficient of TAU at TNOM	real
VC_TAU	Linear Voltage Coefficient of TAU	real
SC0_TAU	Current Slope Coefficient of TAU at TNOM	
SC_TAU	Linear Current Slope Coefficient of TAU	
TC_SF1	Temperature Coefficient of SF1	
CC0_SF1	Current Coefficient of SF1 at TNOM	real
CC_SF1	Linear Current Coefficient of SF1	real
VC0_SF1	Voltage Coefficient of SF1 at TNOM	real
VC_SF1	Linear Voltage Coefficient of SF1	real
SC0_SF1	Current Slope Coefficient of SF1 at TNOM	
SC_SF1	Linear Current Slope Coefficient of SF1	
TC_SF2	Temperature Coefficient of SF2	
CC0_SF2	Current Coefficient of SF2 at TNOM	
CC_SF2	Linear Current Coefficient of SF2	
VC0_SF2	Voltage Coefficient of SF2 at TNOM	
VC_SF2	Linear Voltage Coefficient of SF2	
SC0_SF2	Current Slope Coefficient of SF2 at TNOM	
SC_SF2	Linear Current Slope Coefficient of SF2	
TC_R2	Temperature Coefficient of R2	
CC0_R2	Current Coefficient of R2 at TNOM	
CC_R2	Linear Current Coefficient of R2	
VC0_R2	Voltage Coefficient of R2 at TNOM	
VC_R2	Linear Voltage Coefficient of R2	
SC0_R2	Current Slope Coefficient of R2 at TNOM	
SC_R2	Linear Current Slope Coefficient of R2	
TC_DELTA_S	Temperature Coefficient of DELTA_JNCT	
CC0_DELTA_S	Current Coefficient of DELTA_JNCT at TNOM	

S		
CC_DELTA_S	Linear Current Coefficient of DELTA_JNCT	
VC0_DELTA_S	Voltage Coefficient of DELTA_JNCT 1at TNOM	
VC_DELTA_S	Linear Voltage Coefficient of DELTA_JNCT	
SC0_DELTA_S	Current Slope Coefficient of DELTA_JNCT at TNOM	
SC_DELTA_S	Linear Current Slope Coefficient of DELTA_JNCT	
VBREAK	Breakthrough Voltage [V]	
IBREAK	Breakthrough Current [A]	
TBREAK	Breakthrough Junction Temperature [°C]	
RFAULT	Resistance after Fault	
CTH1	Thermal Network Parameter	
RTH1	Thermal Network Parameter	
CTH2	Thermal Network Parameter	
RTH2	Thermal Network Parameter	
CTH3	Thermal Network Parameter	
RTH3	Thermal Network Parameter	
CTH4	Thermal Network Parameter	
RTH3	Thermal Network Parameter	
CTH_SINK	Heat Sink Parameter	
RTH_SINK	Heat Sink Parameter	

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References

Dynamic FET Model

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

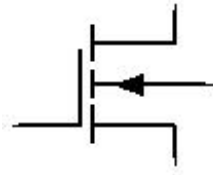


Figure 1. Component symbol

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- [Assumptions and Limitations](#)
- [Mathematical Description](#)
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Description

The FET model is a modular model with definable simulation levels. Different simulation depths can be selected for the electrical and thermal behavior of the model.

At normal operation of the device the diodes D_DB and D_BS are blocking. They have default parameters that cannot be changed by the user.

You can define two simulation levels for the electrical and three simulation levels for the thermal behavior. Each level combination has a certain set of parameters. The values of them can be defined in the model dialog box. All types of the FET models share the same set of output quantities.

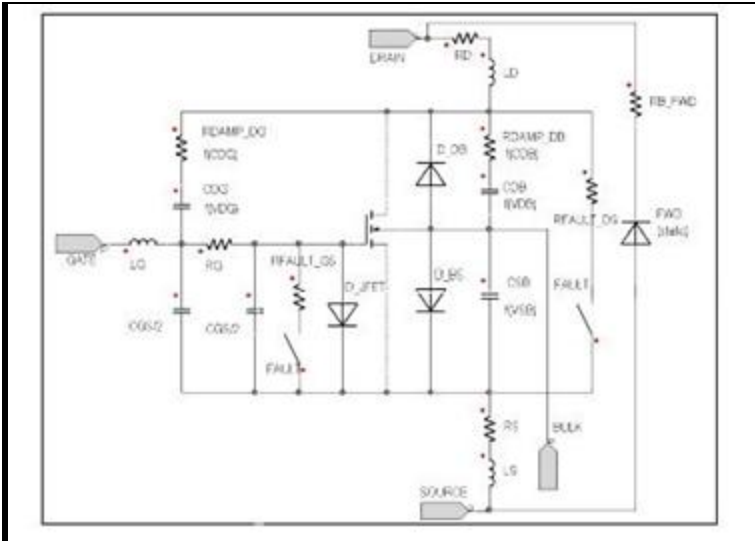
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Assumptions and Limitations

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Mathematical Description

|



Electrical Model

This model uses an electrical equivalent circuit as shown in Figure 2.

Figure 2. Equivalent circuit used by the Dynamic FET Model

There are two simulation levels regarding the electrical behavior. The level is set at the parameter TYPE_DYN:

TYPE_DYN=0

Only the static behavior is calculated. The charges at the capacitances are ignored, no switching behavior.

TYPE_DYN=1

In addition to the static behavior, charging and discharging of the junction and diffusion capacitance are calculated. Values of parasitic capacitances at the terminals can be defined.

Electrical Behavior Level, Type DYN=0

For the calculation of the static FET current a distinction is made between the linear region and the pinch-off region. The so-called saturation voltage is given as following

$$V_{\text{sat}} = A_{\text{FET}} \cdot (V_{\text{GS}} - V_{\text{P}})^{M_{\text{FET}}}$$

The transition happens when the drain current satisfies the following equation

$$I_{sat} = \frac{k}{2} \cdot (V_{GS} - V_P)^{N_{FET}}$$

Within the linear region the following equation is used

$$ID = I_{sat} \cdot \left(1 + KLM \cdot VDS\right) \cdot \left(2 - \frac{VDS}{V_{sat}}\right) \cdot \frac{VDS}{V_{sat}}$$

and for pinch-off applies

$$ID = I_{sat} \cdot (1 + KLM \cdot VDS)$$

The model has a built-in fault detection. During the simulation the drain current, the voltage drop from gate to source and from drain to source as well as the junction temperature are observed. If their limitations are exceeded the model behavior changes. The switches controlled by the FAULT flags are closed and the respective fault resistances determine the model characteristic. If an over voltage across Gate-Source occurs, only RFAULT_GS comes into effect. All other faults affect the RFAULT_DS.

Electrical Behavior Level, Type DYN=1

Apart from the constant gate-source-capacitance, all capacitances are modeled in the same way. A distinction is made between a region where a depletion capacitance is calculated and a region with enhancement capacitance behavior. The curves remain differentiable even at the transition from one region to the other. The transition happens if the difference of a defined fraction of the diffusion and the voltage across the junction equals zero according to:

$$SHIFT \cdot VDIFF - V_{JNCT} = V^*_{JNCT} = 0$$

For positive values of V^*_{JNCT} (enhancement region) the following formula is used to calculate the capacitance:

$$C(V^*_{JNCT}) = C0 \cdot \left[1 + (BETA - 1) \cdot \left(1 - e^{-\frac{V^*_{JNCT} \cdot ALPHA \cdot (1 - DELTA)}{(BETA - 1) \cdot VDIFF}} \right) \right]$$

At negative values of V^*_{JNCT} (depletion region) the following formula applies:

$$C(V^*_{JNCT}) = C0 \cdot \left(DELTA + \frac{1 - DELTA}{\left(1 - \frac{V^*_{JNCT}}{VDIFF}\right)^{APHA}} \right)$$

To damp the oscillations that may occur in the system, additional damping resistances are placed in the model. The values of the damping resistances depend on the parameter DAMPING, the values of the parasitic inductances and the values of the internal capacitances.

$$R_{DAMP} = DAMPING \cdot \sqrt{\frac{L}{C(V)}}$$

Freewheeling Diode Model

The FWD model is a static one only. The static current follows the formula:

The static current of the FWD (if enabled) and the current into the base of the BJT are given by the following formula:

$$I = I_{SAT\_FWD} \cdot \left(e^{\frac{-V_{DS} - I \cdot R_{B\_FWD}}{M \cdot V_T}} - 1 \right)$$

where V_{DS} is the drain-source voltage of the FET, and M is the ideality factor. The temperature voltage V_T is calculated as following:

$$V_T = \frac{k \cdot (TEMP\_JNCT + 273K)}{q}$$

where k is the Boltzmann constant, and $k=1.381E-23$; q is the elementary charge, and $q=1.602E-19$.

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Netlist Syntax

Netlist generated by Special Component Dialog.

Select the netlist of interest below.

- [NJFET6](#)
- [NJFET_FWD6](#)
- [PJFET6](#)
- [PJFET_FWD6](#)
- [NMOS6](#)
- [NMOS_FWD6](#)
- [PMOS6](#)
- [PMOS_FWD6](#)

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
GATE	GATE	electrical
SOURCE	SOURCE	electrical
DRAIN	DRAIN	electrical
BULK	BULK	electrical

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Parameters

Table 2. Parameters of type DYN=0

Name	Description [Unit]	Data Type
K0	Transistor Constant at TEMP0 [A/V^2]	real
VP0	Pinch-off-Voltage at TEMP0 [V]	real
BCF	Bulk Control Factor	real
NBULK	Bulk Doping [$1/cm^3$]	real
NCH	Channel Doping [$1/cm^3$]	real
KLM	Channel Length Modulation Factor	real
A_FET	Saturation Factor	real
M_FET	Saturation Exponent	real
N_FET	Exponent of Transfer Characteristic	real
M0_GATE	Ideality Factor of Gate Diode; only JFET	real
ISAT0_GATE	Saturation Diode of Gate Diode; only JFET	real
RB0_GATE	Bulk Resistance of Gate Diode; only JFET	real
TEMP0	Reference Temperature [$^{\circ}C$]	real
VGAP	Band Gap Voltage [V]	real
ALPHA_VP	Linear Temperature Coefficient of VP	real
ALPHA_K	Exponential Temperature Coefficient of Transistor Constant	real
ALPHA_AFET	Exponential Temperature Coefficient of	real

	A_FET	
ALPHA_MFET	Exponential Temperature Coefficient of M_FET	real
ALPHA_NFET	Exponential Temperature Coefficient of N_FET	real
VBREAK_DS	Breakthrough G-S-Voltage [V]	real
VBREAK_GS	Breakthrough Drain-Source-Voltage [V]	real
IBREAK	Breakthrough Drain Current [A]	real
TEMPBREAK	Breakthrough Junction Temperature [°C]	real
RFAULT_DS	Drain-Source-Resistance after Fault [Ohm]	real
RFAULT_GS	Gate-Source-Resistance after Fault [Ohm]	real
RD	Drain Connector Resistance	real
RG	Gate Connector Resistance	real
RS	Source Connector Resistance	real

Table 3. Parameters of type DYN=1 (+Parameters of TYPE DYN=0)

Name	Description [Unit]	Data Type
C0_GS	Gate-Source Capacitance [F]	real
C0_DG	Drain-Gate Reference Capacitance [F]	real
VDIFF_DG	Diffusion Potential of Drain-Gate Capacitance [V]	real
VSHIFT_DG	Voltage Shift of Drain-Gate Capacitance [V]	real

ALPHA_DG	Capacitance Exponent Drain-Gate	real
BETA_DG	Peak Factor of Drain-Gate Capacitance	real
DELTA_DG	Influence of constant. Capacitance at Drain-Gate	real
C0_DB	Drain Bulk Reference Capacitance [F]	real
VDIFF_DB	Diffusion Potential of Drain-Bulk Capacitance [V]	real
VSHIFT_DB	Voltage Shift of Drain-Bulk Capacitance [V]	real
ALPHA_DB	Capacitance Exponent Drain-Bulk	real
BETA_DB	Peak Factor of Drain-Bulk Capacitance	real
DELTA_DB	Influence of constant. Capacitance at Drain-Bulk	real
C0_SB	Source-Bulk Reference Capacitance [F]	real
VDIFF_SB	Diffusion Potential of SB Capacitance [V]	real
VSHIFT_SB	Voltage Shift of Source-Bulk Capacitance [V]	real
ALPHA_SB	Capacitance Exponent Source-Bulk	real
BETA_SB	Peak Factor of Source-Bulk Capacitance	real
DELTA_SB	Influence of constant. Capacitance at Source-Bulk	real
DAMPING	Damping Factor	real
LD	Drain Connector Inductance [H]	real
LG	Gate Connector Inductance [H]	real

LS	Source Connector Inductance [H]	real
VNOM	Nominal Drain-Source Voltage [V]	real
INOM	Nominal Drain Current [I]	real

Table 4. Parameters FWD Model

Name	Description [Unit]	Data Type
M_FWD	Ideality Factor of FWD	real
ISAT0_FWD	Saturation Current of FWD at TEMP0 [A]	real
RB_FWD	Bulk Resistance of FWD [Ohm]	real
ALPHA_M_FWD	Linear Temperature Coefficient of M_FET	real
ALPHA_ISAT_FWD	Exponential Temperature Coefficient of N_FET	real
ALPHA_RB_FWD	Linear Temperature Coefficient of M_FWD	real

Input/Output Quantities**Table 5**

Name	Description [Unit]	Direction	Data Type
VGS	Internal Gate-Source-Voltage [V]	Output	real
VGD	Internal Gate-Drain-Voltage [V]	Output	real
VDS	Internal Drain-Source-Voltage [V]	Output	real
VBS	Internal Bulk-Source-Voltage [V]	Output	real
VBD	Bulk-Drain-Voltage [V]	Output	real
ID	Current through Drain Connector [A]	Output	real
I_FWD	Current through FWD [A]	Output	real
IG	Current through Gate Connector [A]	Output	real
CGS	Gate-Source-Capacitance [F]	Output	real
CDG	Drain-Gate-Capacitance [F]	Output	real
CDB	Drain-Bulk-Capacitance [F]	Output	real
CSB	Source-Bulk-Capacitance [F]	Output	real
TEMPJNCT	Junction Temperature [°C]	Output	real
TEMPINTR	Chip Temperature [°C]	Output	real

TEMPC	Case Temperature [°C]	Output	real
PEL	Total Component Losses [W]	Output	real
PCOND	Power Transfer by Conduction [W]	Output	real
PCONV	Power Transfer by Convection [W]	Output	real
PRAD	Power Transfer by Radiation [W]	Output	real
ESWITCH	Losses of One Switching Cycle [Ws]	Output	real
PSWITCH	Average Losses of One Switching Cycle [W]	Output	real
ETOT	Total Losses During Simulation [Ws]	Output	real
PTOT	Total Average Losses During Simulation [W]	Output	real
FAULT_VDS	Flag Drain-Source-Over voltage	Output	real
FAULT_VGS	Flag Gate-Source-Over voltage	Output	real
FAULT_I	Flag Over current	Output	real
FAULT_TEMP	Flag Over temperature	Output	real

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Example

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References

[1] Ned Mohan, Tore M. Undeland, William P. Robbins, "Power Electronics: Converters, Applications, and Design." John Wiley & Sons, INC. New York, 1995.

Power MOSFET Model (Basic Dynamic)

Library: Basic Elements

Modeling Language: SML

Version Number: Twin Builder 2025.2

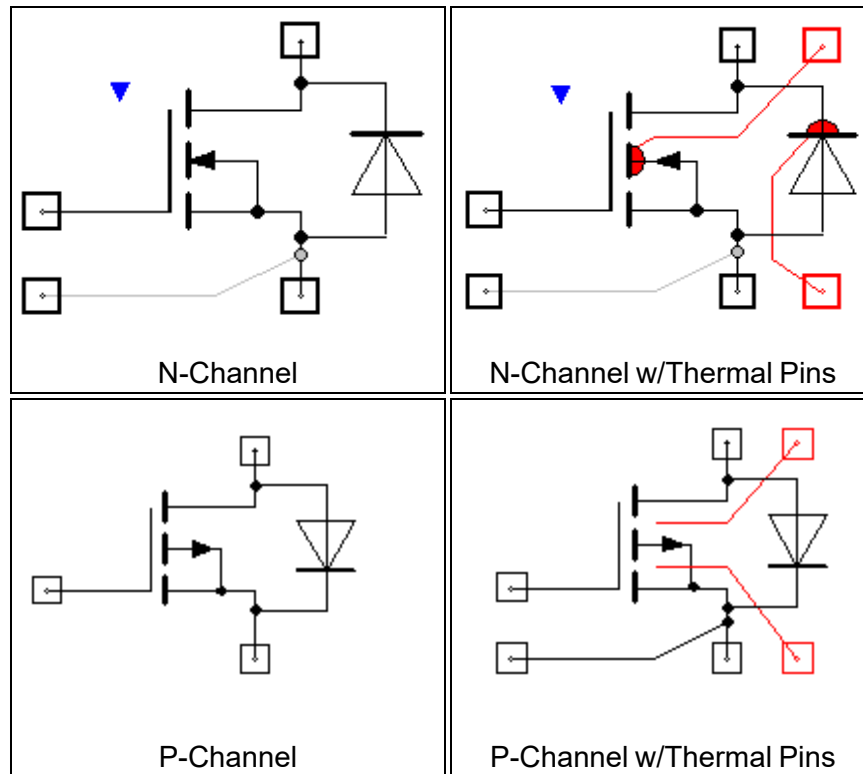


Figure 1. Component symbols

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Description

The Power MOSFET model is a modular model. Different simulation depths can be selected for the electrical and thermal behavior of the model. For the models with a freewheeling diode (FWD), the simulation depth of the diode model can be set separately. For models with thermal pins, an external thermal network can be connected.

You can define different levels for the electrical and thermal behavior using the parameters TYPE_DYN and TYPE_THERM, respectively. Each level combination has a certain set of parameters. The values of them can be defined in the model dialog box. Due to the structural relation to the Basic Dynamic IGBT model, the Basic Dynamic MOSFET's input and output parameters are similar to the IGBT parameters. The component outputs are listed at the end of the model description.

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Assumptions and Limitations

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Mathematical Description

Electrical Model

The model uses an electrical equivalent circuit as shown in Figure 2.

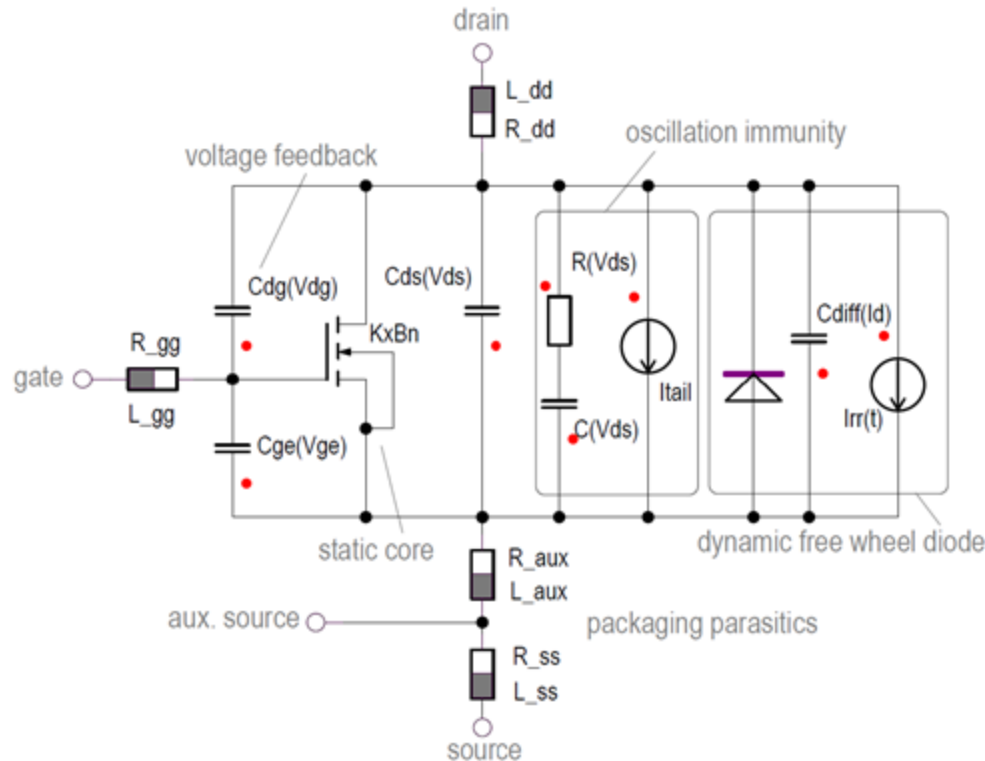


Figure 2. Equivalent circuit of the Power MOSFET model (simplified)

The TYPE_DYN parameter allows the user to modify the dynamic behavior of the Power MOSFET. There are five digits to the number, each switch switching a different aspect.

- The left-most digit (the 10000's) represents the type of modeling of the Off-Switch-Charge Storage. The default value is 2 for the advanced mode using a controlled I-source. The value 1 (using a conductance) should be used only for compatibility reasons to achieve the same outputs as earlier models.
- The next digit (the 1000's) controls the feedback capacitance. This digit needs to be set to 2.
- The next digit (the 100's) allows the user to use a constant Miller capacitance if it is set to 1; otherwise, a bias-dependent Miller capacitance is used.
- The next digit (the 10's) controls the type of synchronization method that is used. If this digit is 0, then no synchronization and working point correction is done. The synchronization signal is also important for the soft recovery behavior as well as for any

energy and time value outputs of the reverse recovery diode. Without synchronization, the FWD does not show soft recovery, and in hard switching conditions that can lead to oscillations. If the digit is 1, the external synchronization signal that is defined by the SYNC parameter is used. The synchronization signal must cross zero in positive direction for the transition from the blocking to the conducting state and can be any signal available in the simulation that is connected with the pulse frequency of the circuit. If the digit is 2, an internal synchronization method that is derived from V_{gs} is used; however, this method might not be as accurate as an external synchronization.

- The right-most digit (the 1's) turns on the dynamic model if it is set to 1; otherwise, the dynamic behavior is turned off and only the DC parts of the model are used.

The Following Applies to All Type DYN's:

The static model of the FET is modeled using a Schichman-Hodges model, using the parameters A_{FET} , K , KLM , M_{FET} , N_{FET} , $RD0$, $RD1$, RDV and VP . These parameters are modeled as temperature dependent. Their temperature dependence is corrected using the parameters TC_{AFET} , TC_K , TC_{MFET} , TC_{NFET} , TC_{RD0} , TC_{RD1} , TC_{RDV} and TC_{VP} .

For the calculation of the static FET current a distinction is made between the linear region and the pinch-off region. The so-called saturation voltage is given by:

$$V_{sat} = A_{FET} \cdot (V_{GS} - V_P)^{M_{FET}}$$

The transition from the linear region to the saturation region happens when the drain current satisfies the following equation:

$$I_{sat} = \frac{K}{2} \cdot (V_{GS} - V_P)^{N_{FET}}$$

Within the linear region, also called triode or ohmic region, the following equation is used:

$$I_D = I_{sat} \cdot (1 + KLM \cdot V_{DS}) \cdot \left(2 - \frac{V_{DS}}{V_{sat}}\right) \cdot \frac{V_{DS}}{V_{sat}}$$

and for the saturation region the following equation applies:

$$I_D = I_{sat} \cdot (1 + KLM \cdot V_{DS})$$

To model behavior of channel length modulation, the static FET model is extended by a nonlinear resistance R_{NL} at the internal drain terminal. Its nonlinear I-V relationship is described by:

$$I(V) = \frac{RDV}{RD0} \tanh\left(\frac{V}{RDV}\right) + \frac{V}{RD1}$$

When RD0=RD1=0 and RDV is nonzero, this nonlinear resistance remains constant 0.

The temperature-dependent parameters are known at the nominal temperature TNOM through parameters of the model. During the simulation their actual values are calculated taking into account the actual value of the junction temperature taken from the thermal model.

The Source-Drain diode is modeled as a simple diode in series with a current-dependent resistor. The parameters M_FWD, ISAT_FWD and RB_FWD are used to model the diode. The temperature coefficients M_FWD, ISAT_FWD and RB_FWD are used to calculate the temperature dependence of the diode. The static current of the diode (if enabled) is given by the following formula:

$$I_{\text{FWD}} = \text{ISAT\_FWD} \cdot \left[e^{\frac{V_{\text{FWD}}}{M_{\text{FWD}} \cdot V_T}} - 1 \right]$$

Where VFWD is the voltage over the FWD.

The temperature voltage V_T is calculated as following:

$$V_T = \frac{k \cdot (\text{TEMP\_JNCT} + 273 \text{ K})}{q}$$

where k is the Boltzmann constant, and $k=1.381\text{E-}23 \text{ m}^2 \text{ kg s}^{-2} \text{ K}^{-1}$; q is the elementary charge, and $q=1.602\text{E-}19 \text{ C}$.

The series resistance is current dependent and given by:

$$R_{\text{BULK}} = \frac{\text{RB\_FWD}}{\sqrt{1 + \frac{I_{\text{FWD}}}{I_{\text{NOM}}}}}$$

The model has built-in fault detection. During the simulation the drain current, the voltage drop from gate to source and from drain to source as well as the junction temperature are observed. The model behavior changes if the limitations are exceeded. The switches controlled by the FAULT flags are closed and the respective fault resistances determine the model characteristic. If an over voltage occurs across gate-emitter, only RFAULT_GE comes into effect. All other faults affect RFAULT_CE.

Dynamic Behavior

All capacitance between the terminals are modeled the same way. A distinction is made between a region where a depletion capacitance is calculated and a region with enhancement capacitance behavior. The curves remain differentiable even at the transition from one region to the other. The transition happens if the shifted voltage across the junction equals zero according to:

$$V_{JNCT}^* = V_C - V_{SHIFT} = 0$$

For positive values of V_{JNCT}^* (enhancement region) the following formula is used to calculate the capacitance

$$C(V_{JNCT}^*) = C0 \cdot \left(1 + (BETA - 1) \cdot \left(1 - e^{-\frac{V_{JNCT}^* \cdot ALPHA \cdot (1 - DELTA)}{(BETA - 1) \cdot VDIFF}} \right) \right)$$

At negative values of V_{JNCT}^* (depletion region) the following formula applies

$$C(V_{JNCT}^*) = C0 \cdot \left(DELTA + \frac{1 - DELTA}{\left(1 - \frac{V_{JNCT}^*}{VDIFF} \right)^{ALPHA}} \right)$$

The capacitance at CGS is modeled using CIN0 and CIN1, while CDG is modeled using CR0 and CR1. This approach allows a great flexibility to model the on- and off-switching behavior, but it is not physically-based. Special care is taken to avoid numerically induced charge when the capacitance values are switched.

To damp the oscillations that may occur in the system, additional damping resistances are placed in the model. The values of the damping resistances depend on the parameter DAMPING, the values of the parasitic inductances and the values of the internal capacitances.

$$R_{DAMP} = DAMPING \cdot \sqrt{\frac{L}{C(V)}}$$

Tail Current and Reverse Recovery Current

The tail current is calculated from the point of the off-switch trigger, as this is a stable measurement point compared to the falling current edge. TAUS controls the duration of the extra base current injection. TAIL and DELTATAIL influence the tail D-S current. DELTATAIL sets the magnitude, while TAIL sets the duration.

Please note: the value of the voltage influencing the tail current is taken from the previous switching-on. Therefore the level does not give proper results for fault simulation and should be used only for investigations of periodic switching processes.

Source-Drain Diode Model

The source-drain diode model is the same as the single diode model without depletion capacitance. The behavior of the diode model can be set using TYPE_FWD.

TYPE_FWD=0 No FWD

TYPE_FWD=1 Static FWD

TYPE_FWD=2 Dynamic FWD with reverse recovery

The total excess carrier charge during the switch to the on-state is controlled by the parameter TAUFD. The reverse recovery charge, Q_{rr} , is smaller because of charge extraction during the on-state. The current is modeled to be continuous and continuously differentiable. The total stored excess charge before switching off is the FWD diffusion charge. The maximum reverse current, the current slopes, the remaining charge after the current crosses zero and the duration of the reverse recovery are depend on the circuit conditions.

The shape of the reverse recovery current is illustrated in the following figure:

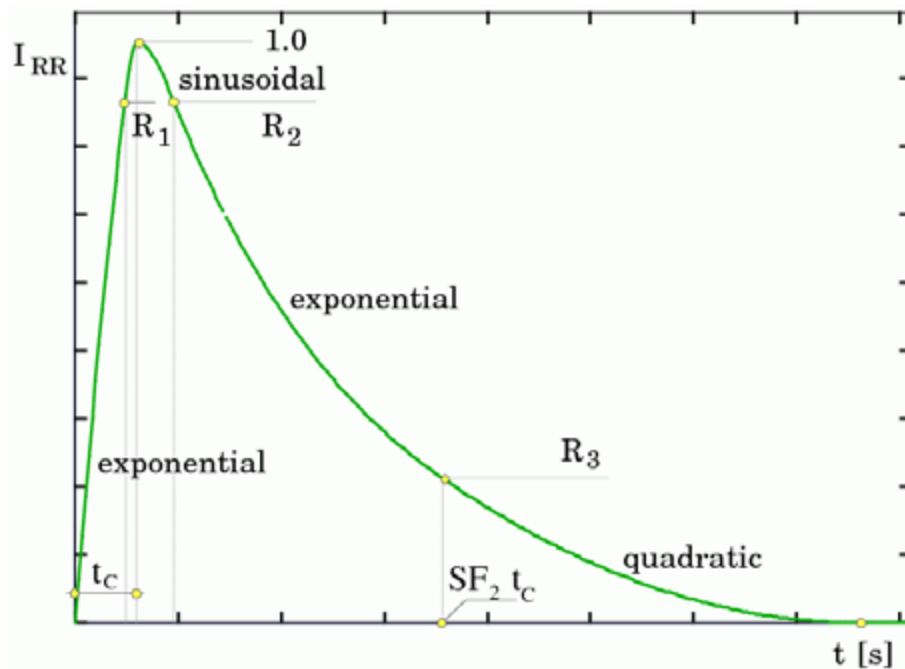


Figure 3. Shape parameters R and SF for exponential current decay

Thermal Pins

The thermal model provides the opportunity to choose between the continued fractional and the partial fractional thermal networks. Both networks show the same thermal impedance. If the thermal capacitances and resistances are considered to be computed from FEM calculation the physically based continued fractional model (Cauer type) can be used or if the fitting to a thermal impedance curve is desired the mathematically based partial fraction model (Forster type) can be employed.

As shown in Figure 4, the electrical power losses of both the transistor ($POWER\_T$) and the diode ($POWER\_D$) are injected into their individual thermal networks. The positions of the ST1~ST4 and SD1~SD4 switches are decided by the type of thermal network configuration that's chosen: if continued fractional thermal model is chosen, the switches connect the thermal capacitances directly to the ambient node; while the thermal capacitances are connected in parallel to the corresponding thermal resistances through the switches if partial fractional thermal model is selected. Note that in Figure 4, the ground symbol means the ambient.

For the MOSFET's models without external thermal pins, switches ST and SD in Figure 4 are closed so that an internal first-order heat sink model is connected, shown as CDT and RDT in Figure 4. Impedance values of the heat sink can be set by thermal parameters CTHDT and RTHDT.

If a more sophisticated heat sink model is needed, use the IGBT components with thermal pins to connect with the external heat sink. In this case, switches ST and SD in Figure 4 are open and thermal pins THERM_T and THERM_D are exposed. When external thermal pins are used, make sure **Model Thermal Output** in the **Thermal Parameters** tab is set to "Kelvin" so it is compatible with external thermal components.

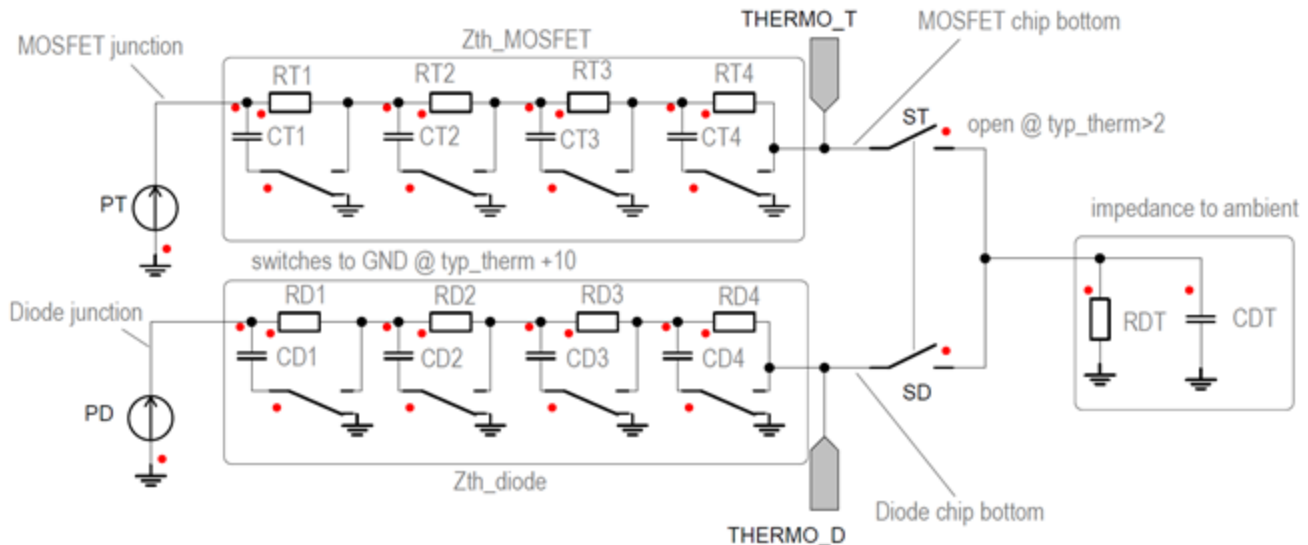


Figure 4. Thermal Network of the MOSFET models

The MOSFET model has a first-order internal heat sink model. Use the external thermal pins to connect the device to a customized heat sink thermal network configuration.

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Netlist Syntax

```
MODEL MOSFET_BasicDyn_T ?InstanceName(@InstanceName):(@ (Refbase) @ (ID))
GATE:= %0, SOURCE:= %1, AUX_SOURCE:= %2, DRAIN:= %3, THERM_T:= %4, THERM_D:= %5 (
TYPE_IGBT:= @TYPE_IGBT, TYPE_FWD:= @TYPE_FWD, TYPE_THERM:= @TYPE_THERM,
TYPE_DYN:= @TYPE_DYN, TYPE_BREAKTHROUGH:= @TYPE_BREAKTHROUGH,
TEMPAMB:= @TEMPAMB, TEMPJNCT0:= @TEMPJNCT0, TNOM:= @TNOM, VNOM:= @VNOM,
INOM:= @INOM, SNOM_ON:= @SNOM_ON, SNOM_OFF:=
```

@SNOM_OFF, VGAP:= @VGAP, LD:= @LD, RD:= @RD, LG:= @LG, RG:= @RG, LS:= @LS,
 RS:= @RS, LAUX:= @LAUX, RAUX:= @RAUX, VBREAK_DS:= @VBREAK_DS, VBREAK_
 GS:= @VBREAK_GS, IBREAK:= @IBREAK, TEMPBREAK:= @TEMPBREAK, RFAULT_DS:=
 @RFAULT_DS, RFAULT_GS:= @RFAULT_GS, CTHT1:= @CTHT1, RTHT1:= @RTHT1,
 CTHT2:= @CTHT2, RTHT2:= @RTHT2, CTHT3:= @CTHT3, RTHT3:= @RTHT3, CTHT4:=
 @CTHT4, RTHT4:= @RTHT4, CTHD1:= @CTHD1, RTHD1:= @RTHD1, CTHD2:= @CTHD2,
 RTHD2:= @RTHD2, CTHD3:= @CTHD3, RTHD3:= @RTHD3, CTHD4:= @CTHD4, RTHD4:=
 @RTHD4, CTHDT:= @CTHDT, RTHDT:= @RTHDT, SYNC:= @SYNC, DAMPING:=
 @DAMPING, VP:= @VP, K:= @K, KLM:= @KLM, A_FET:= @A_FET, M_FET:= @M_FET, N_
 FET:= @N_FET, BN:= @BN, M_BJT:= @M_BJT, ISAT_BJT:= @ISAT_BJT, RB_BJT:= @RB_
 BJT, RP_BJT:= @RP_BJT, M_FWD:= @M_FWD, ISAT_FWD:= @ISAT_FWD, RB_FWD:=
 @RB_FWD, CIN0:= @CIN0, CIN1:= @CIN1, CR0:= @CR0, DELTACR0:= @DELTACR0,
 CR1:= @CR1, DELTACR1:= @DELTACR1, TAUFD:= @TAUFD, SF:= @SF, TAUS:= @TAUS,
 TAUTAIL:= @TAUTAIL, DELTATAIL:= @DELTATAIL, TC_VP:= @TC_VP, TC_K:= @TC_K,
 TC_NFET:= @TC_NFET, TC_AFET:= @TC_AFET, TC_MFET:= @TC_MFET, TC_ISAT_
 BJT:= @TC_ISAT_BJT, TC_M_BJT:= @TC_M_BJT, TC_RB_BJT:= @TC_RB_BJT, TC_M_
 FWD:= @TC_M_FWD, TC_RB_FWD:= @TC_RB_FWD, TC_ISAT_FWD:= @TC_ISAT_FWD,
 TC_CIN0:= @TC_CIN0, CC0_CIN0:= @CC0_CIN0, CC_CIN0:= @CC_CIN0, VC0_CIN0:=
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 @TC_CR0, CC0_CR0:= @CC0_CR0, CC_CR0:= @CC_CR0, VC0_CR0:= @VC0_CR0, VC_
 CR0:= @VC_CR0, TC_CR1:= @TC_CR1, CC0_CR1:= @CC0_CR1, CC_CR1:= @CC_CR1,
 VC0_CR1:= @VC0_CR1, VC_CR1:= @VC_CR1, TC_TAUFD:= @TC_TAUFD, CC0_TAUFD:=
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 @TC_TAUTAIL, CC0_TAUTAIL:= @CC0_TAUTAIL, CC_TAUTAIL:= @CC_TAUTAIL, VC0_
 TAUTAIL:= @VC0_TAUTAIL, VC_TAUTAIL:= @VC_TAUTAIL, TC_DELTATAIL:= @TC_
 DELTATAIL, CC0_DELTATAIL:= @CC0_DELTATAIL, CC_DELTATAIL:= @CC_DELTATAIL,
 VC0_DELTATAIL:= @VC0_DELTATAIL, VC_DELTATAIL:= @VC_DELTATAIL, TC_RG:=
 @TC_RG, CC0_RG:= @CC0_RG, CC_RG:= @CC_RG, VC0_RG:= @VC0_RG, VC_RG:=
 @VC_RG, TC_DAMPING:= @TC_DAMPING, CC0_DAMPING:= @CC0_DAMPING, CC_
 DAMPING:= @CC_DAMPING, VC0_DAMPING:= @VC0_DAMPING, VC_DAMPING:= @VC_
 DAMPING) SRC: DB(Lib:=@ModelLibraryName);

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
COLLECTOR	Collector	electrical
EMITTER	Emitter	electrical
AUX_SOURCE	Auxiliary Source	electrical

GATE	Gate	electrical
THERM_T*	MOSFET Die Bottom Thermal Contact	thermal
THERM_D*	Diode Die Bottom Thermal Contact	thermal

* THERM_T and THERM_D pins exist only when the component was created with pins for the external thermal network.

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Parameters

Table 2. General Parameters

Name	Description	Data Type
TYPE_IGBT	MOSFET Type Flag -2:p-Type 2:n-Type	real
TYPE_FWD	Freewheeling Diode Type 0:no 1:static 2:dynamic including CDiff and Irr	real
TYPE_DYN	Modeling Flags xxxx0: static xxxx1: dynamic xxx0x: no sync xxx1x: external sync xxx2x: internal sync derived from VGE xx0xx: bias dependent Miller capacitance xx1xx: constant Miller capacitance x0xxx: only the feedback cap. Ccg is used x1xxx: only the feedback cap. Cgd is used x2xxx: use both feedback cap. Cgd and Ccg 1xxxx: Off-Switch charge storage (compatibility) 2xxxx: enhanced Off-Switch charge storage	real
TYPE_OUT	Internal measurement condition settings: xxxxxxx0: t_ON and E_ON starting criteria	real

	0: Begin of gate discharging 1: 10% rising V_{ge} from min to max 2: V_{ge} zero crossing 3: 10% rising V_{ge} from zero to max xxxxxx0x: t_OFF and E_OFF starting criteria 0: Begin of gate charging 1: 90% falling V_{ge} from max to zero 2: 90% falling V_{ge} from max to min xxxxx0xx: t_ON stopping criteria 1: 10% rising I_c 2: 90% rising I_c 3: 10% falling V_{ce} 4: 5% falling V_{ce} 5: 3% falling V_{ce} 6: 1% falling V_{ce} xxxx0xxx: t_OFF stopping criteria 1: 10% rising V_{ce} 2: 90% rising V_{ce} 3: 90% falling I_c 4: 50% falling I_c 5: 10% falling I_c 6: 5% falling I_c 7: 3% falling I_c 8: 1% falling I_c xxx0xxxx: E_ON stopping criteria 1: 90% rising I_c 2: 10% falling V_{ce} 3: 5% falling V_{ce} 4: 3% falling V_{ce} 5: 1% falling V_{ce} xx0xxxxx: E_OFF stopping criteria 1: 90% falling I_c 2: 50% falling I_c 3: 10% falling I_c 4: 5% falling I_c 5: 3% falling I_c 6: 1% falling I_c x0xxxxxx: E_RR stopping criteria 1: 25% falling I_{rr} after I_{rrm} 2: 10% falling I_{rr} after I_{rrm} 3: 5% falling I_{rr} after I_{rrm} 4: 1% falling I_{rr} after I_{rrm} 5: until next switching edge 0 xxxxxxx: Measurement source	

	0: Use external node (device terminals) voltage for time and energy measurement 1: Use internal node (die terminals) voltage for time and energy measurement 2: Use internal voltage for energy, and external voltage for time measurement 3: Use external voltage for energy, and internal voltage for time measurement	
TYPE_THERM	xx0: isothermal behavior xx2: dynamic behavior x0x: partial fractional therm. network x1x: cont. fractional therm. network 0xx: output only rise 1xx: output in degrees Celsius 2xx: output in Kelvin	real
TYPE_BREAKTHROUGH	0: disable breakthrough 1: enable breakthrough	real

Table 3. Static Model Parameters (TYPE_DYN=0)

Name	Description	Data Type
VNOM	Nominal Drain-Source Voltage [V]	real
INOM	Nominal Drain Current [A]	real
TNOM	Reference Temperature [°C]	real
A_FET	Saturation Factor of internal FET	real
TC_AFET	Temperature Coefficient of A_FET	real
M_FET	Saturation Exponent of internal FET	real
TC_MFET	Temperature Coefficient of M_FET	real
N_FET	Exponent of Transfer Characteristic of FET	real
TC_NFET	Temperature Coefficient of N_FET	real
K	Transistor Constant of FET at TNOM	real
TC_K	Temperature Coefficient of K	real

RD0	Small Voltage Bulk Resistance [Ohm]	real
TC_RD0	Temperature Correction Coefficient of RD0	real
RD1	Large Voltage Bulk Resistance [Ohm]	real
TC_RD1	Temperature Correction Coefficient of RD1	real
RDV	Bulk Resistance Inflection Voltage [V]	real
TC_RDV	Temperature Correction Coefficient of RDV	real
VP	Pinch-off-Voltage of FET at TNOM [V]	real
TC_VP	Temperature Coefficient of VP	real
KLM	Channel Length Modulation Factor of FET [1/V]	real
VBREAK_DS	Breakthrough Drain-Source Voltage [V]	real
VBREAK_GS	Breakthrough Gate-Source Voltage [V]	real
IBREAK	Breakthrough Drain Current [A]	real
TEMPBREAK	Breakthrough Junction Temperature [°C]	real
RFAULT_DS	Drain-Source Resistance after Fault [Ohm]	real
RFAULT_GS	Gate-Source Resistance after Fault [Ohm]	real

Table 4. Dynamic Model Parameters (TYPE_DYN=xxxx1; include static parameters)

Name	Description [Unit]	Data Type
CIN0	Off-Switch Input Capacitance [F]	real
TC_CIN0	Temperature Corr. Coeff. of CIN0	real
CC0_CIN0	Current Corr. Coeff. of CIN0 ($I_d < I_{NOM}$)	real
CC_CIN0	Current Corr. Coeff. of CIN0 ($I_d > I_{NOM}$)	real
VC0_CIN0	Voltage Corr. Coeff. of CIN0 ($V_{ds} < V_{NOM}$)	real
VC_CIN0	Voltage Corr. Coeff. of CIN0 ($V_{ds} > V_{NOM}$)	real
CIN1	On-Switch Input Capacitance [F]	real
TC_CIN1	Temperature Corr. Coeff. of CIN1	real
CC0_CIN1	Current Corr. Coeff. of CIN1 ($I_d < I_{NOM}$)	real
CC_CIN1	Current Corr. Coeff. of CIN1 ($I_d > I_{NOM}$)	real
VC0_CIN1	Voltage Corr. Coeff. of CIN1	real

	(Vds<VNOM)	
VC_CIN1	Voltage Corr. Coeff. of CIN1 (Vds>VNOM)	real
CR0	Off switch feedback capacitance [F]	real
DELTACR0	Off-Switch Feedback Capacitance Minimum [rel]	real
TC_CR0	Temperature Corr. Coeff. of CR0	real
CC0_CR0	Current Corr. Coeff. of CR0 (Id<INOM)	real
CC_CR0	Current Corr. Coeff. of CR0 (Id>INOM)	real
VC0_CR0	Voltage Corr. Coeff. of CR0 (Vds<VNOM)	real
VC_CR0	Voltage Corr. Coeff. of CR0 (Vds>VNOM)	real
CR1	On-Switch Feedback Capacitance [F]	real
DELTACR1	On-Switch Feedback Capacitance Minimum [rel]	real
TC_CR1	Temperature Corr. Coeff. of CR1	real
CC0_CR1	Current Corr. Coeff. of CR1 (Id<INOM)	real
CC_CR1	Current Corr. Coeff. of CR1 (Id>INOM)	real
VC0_CR1	Voltage Corr. Coeff. of CR1 (Vds<VNOM)	real
VC_CR1	Voltage Corr. Coeff. of CR1 (Vds>VNOM)	real
TAUS	Nominal Base Storage Time [s]	real
TC_TAUS	Temperature Corr. Coeff. of TAUS	real
CC0_TAUS	Current Corr. Coeff. of TAUS (Id<INOM)	real
CC_TAUS	Current Corr. Coeff. of TAUS (Id>INOM)	real
VC0_TAUS	Voltage Corr. Coeff. of TAUS (Vds<VNOM)	real
VC_TAUS	Voltage Corr. Coeff. of TAUS (Vds>VNOM)	real
SF	Diode Reverse Recovery Soft Factor	real
TC_SF	Temperature Corr. Coeff. of SF	real
CC0_SF	Current Corr. Coeff. of SF (Id<INOM)	real
CC_SF	Current Corr. Coeff. of SF (Id>INOM)	real
VC0_SF	Voltage Corr. Coeff. of SF (Vds<VNOM)	real
VC_SF	Voltage Corr. Coeff. of SF (Vds>VNOM)	real

TAUTAIL	Time Constant of Tail Current [s]	real
TC_TAUTAIL	Temperature Corr. Coeff. of TAUTAIL	real
CC0_TAUTAIL	Current Corr. Coeff. of TAUTAIL (Id<INOM)	real
CC_TAUTAIL	Current Corr. Coeff. of TAUTAIL (Id>INOM)	real
VC0_TAUTAIL	Voltage Corr. Coeff. of TAUTAIL (Vds<VNOM)	real
VC_TAUTAIL	Voltage Corr. Coeff. of TAUTAIL (Vds>VNOM)	real
DELTATAIL	Start of Tail Current relative to Maximum Current	real
TC_DELTATAIL	Temperature Corr. Coeff. of DELTATAIL	real
CC0_DELTATAIL	Current Corr. Coeff. of DELTATAIL (Id<INOM)	real
CC_DELTATAIL	Current Corr. Coeff. of DELTATAIL (Id>INOM)	real
VC0_DELTATAIL	Voltage Corr. Coeff. of DELTATAIL (Vds<VNOM)	real
VC_DELTATAIL	Voltage Corr. Coeff. of DELTATAIL (Vds>VNOM)	real
RG	Internal gate resistance [Ohm]	real
TC_RG	Temperature Corr. Coeff. of RG	real
CC0_RG	Current Corr. Coeff. of RG (Id<INOM)	real
CC_RG	Current Corr. Coeff. of RG (Id>INOM)	real
VC0_RG	Voltage Corr. Coeff. of RG (Vds<VNOM)	real
VC_RG	Voltage Corr. Coeff. of RG (Vds>VNOM)	real
DAMPING	Damping constant	real
TC_DAMPING	Temperature Corr. Coeff. of DAMPING	real
CC0_DAMPING	Current Corr. Coeff. of DAMPING (Id<INOM)	real
CC_DAMPING	Current Corr. Coeff. of DAMPING (Id>INOM)	real
VC0_DAMPING	Voltage Corr. Coeff. of DAMPING (Vds<VNOM)	real
VC_DAMPING	Voltage Corr. Coeff. of DAMPING (Vds>VNOM)	real
SYNC	External Synchronization Signal	real

Note: External synchronization signal SYNC is a trigger **necessary** for device models to behave correctly. It is required to cross zero in a positive direction only when a device starts conducting, and cross zero in negative direction only when a device stops conducting or when Irr is formed. It is preferable to use an ideal pulse wave or trapezoidal wave. When using an ideal pulse wave, a signal change between zero and a positive value is also supported.

Note that the synchronization signal may not be the same as the gate drive signal for the same device. Rule of thumb is to give a clear rising edge or zero crossing signal at the moment when conducting status of a device changes or when current flows on a device start to change.

Table 5. Thermal Parameters

Name	Description [Unit]	Data Type
TEMPAMB	Ambient Temperature [°C]*	real
TEMPJNCT0	Junction Temperature at Simulation Start [°C]*	real
CTHT1	1. Thermal Transistor Capacitance [F]	real
RTHT1	1. Thermal Transistor Resistance [ohm]	real
CTHT2	2. Thermal Transistor Capacitance [F]	real
RTHT2	2. Thermal Transistor Resistance [ohm]	real
CTHT3	3. Thermal Transistor Capacitance [F]	real
RTHT3	3. Thermal Transistor Resistance [ohm]	real
CTHT4	4. Thermal Transistor Capacitance [F]	real
RTHT4	4. Thermal Transistor Resistance [ohm]	real
CTHD1	1. Thermal Diode Capacity [F]	real
RTHD1	1. Thermal Diode Resistance [ohm]	real
CTHD2	2. Thermal Diode Capacity [F]	real
RTHD2	2. Thermal Diode Resistance [ohm]	real
CTHD3	3. Thermal Diode Capacity [F]	real
RTHD3	3. Thermal Diode Resistance [ohm]	real
CTHD4	4. Thermal Diode Capacity [F]	real
RTHD4	4. Thermal Diode Resistance [ohm]	real
CTHDT	Common Thermal Capacitance [F]	real
RTHDT	Common Thermal Resistance [ohm]	real

* The unit in which those output values are created depends on the unit flag in the TYPE_THERM parameter (raise only, °C, or K).

Table 6. Parameters FWD Model

Name	Description [Unit]	Data Type
M_FWD	Ideality Factor of FWD at TNOM (static parameter)	real
ISAT_FWD	Saturation Current of FWD at TNOM [A] (static parameter)	real
RB_FWD	Bulk Resistance of FWD at TNOM [ohm] (static parameter)	real
TC_M_FWD	Temperature Coefficient of M_FWD (static parameter)	real
TC_ISAT_FWD	Temperature Coefficient of ISAT_FWD (static parameter)	real
TC_RB_FWD	Temperature Coefficient of RB_FWD	real
TAUFD	Effective Lifetime of FWD	real
TC_TAUFD	Temperature Coefficient of TAUFD	real
CC0_TAUFD	Current Coefficient of TAUFD at TNOM	real
CC_TAUFD	Linear Current Coefficient of TAUFD	real
VC0_TAUFD	Voltage Coefficient of TAUFD at TNOM	real
VC_TAUFD	Linear Voltage Coefficient of TAUFD	real

Table 7. Parameters of External Connections

Name	Description [Unit]	Data Type
RD	Drain Connector Resistance [Ohm]	real
RS	Source Connector Resistance [Ohm]	real
RAUX	Internal Source Resistance	real
LD	Drain Connector Inductance [H]	real
LG	Gate Connector Inductance [H]	real
LS	Source Connector Inductance [H]	real
LAUX	Internal Source Inductance	real

Output Quantities

Table 8. Model Outputs

Name	Description [Unit]
VDS	Drain-Source Voltage [V], terminal voltage waveform, positive for n- and p- channel devices
VGS	Gate-Source Voltage [V], terminal voltage waveform, positive for n- and p- channel devices
VGS_AUX	Gate-Auxilliary Source Voltage [V], terminal voltage waveform, positive for n- and p- channel devices
I_D	Drain Current [A], total drain current, positive in drain to source direction
I_G	Gate Current [A]
IFD	FWD Current [A], free wheeling diode current waveform, positive in diode conducting direction
VD	FWD Voltage Drop [V], positive in diode conducting direction
TRANSCOND	Trans Conductance [A/V], definition is $S = d(I_d)/d(V_{gs})$, depends on the DC quiescent point and is valid for AC simulations
OUTCOND	Output Conductance [A/V], definition is $G = d(I_d)/d(V_{ds})$, depends on the DC quiescent point and is valid for AC simulations
SGS_ON	On switch gate source voltage slope [V/s] at the moment of VP crossing, it controls the on switch delay times, can be used for modeling a gate drive sensitivity
SGS_OFF	Off switch gate source voltage slope [V/s] at the moment of VP crossing, it controls the off switch delay times, can be used for modeling a gate drive sensitivity
TEMPJ_T	Wave form of the transistor junction temperature [°C, K]* at the transistor hot spot at the point of power injection, accuracy depends on correct total power calculation and an appropriate thermal network for the transistor heat dissipation
TEMPJ_D	Wave form of the Diode junction temperature [°C, K]* at the diode hot spot, the point of power injection, accuracy depends on correct total power calculation and an appropriate thermal network for the diode heat dissipation
TEMPBOT_T	MOSFET bottom temperature [°C, K]* at the end of the transistor four stage thermal chain. If external heat pins are used this is the node tem-

	perature, else it is equal TEMP_PLATE
TEMPBOT_D	Diode bottom temperature [°C, K]* at the end of the diode four stage thermal chain. If external heat pins are used this is the node temperature, else equal TEMP_PLATE
TEMP_PLATE	Temperature difference [°C, K]* across the one stage internal heat sink if internal sink is selected, else ambient temperature
T_ON	On-Switch Delay Time [s], internal measurement depending on TYPE_OUT setting
T_OFF	Off-Switch Delay Time [s], internal measurement depending on TYPE_OUT setting
POWER_T	Transistor power loss time function [W], suitable to be injected directly into an external thermal transistor network.
POWER_D	Diode power loss time function [W], suitable to be injected directly into an external thermal diode network.
STEP	Actual time step size [s]
E_ON	on switching energy [J], internal measurement depending on TYPE_OUT setting
E_OFF	off switching energy [J], internal measurement depending on TYPE_OUT setting
E_RR	loss energy of diode reverse recovery [J], internal measurement depending on TYPE_OUT setting
VDS_FAULT	Vds fault flag [0/1], Vds hits the absolute limits, can be watched during the simulation for break at fault
VGS_FAULT	Vgs fault flag [0/1]
ID_FAULT	drain current fault flag [0/1]
TEMPJ_FAULT	junction temperature fault flag [0/1]

The units in which those output values are created depend on the unit flag in the TYPE_THERM parameter (raise only, °C, or K).

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Example

Two examples are available, representing the N-Type Basic Dynamic MOSFET model and the P-Type Basic Dynamic MOSFET model. The examples are shown below.

N-channel MOSFET Example

Use the **File>Open Examples** menu command to open the example project:

\Examples\Simplorer\Components\Basic\Circuit\Semiconductors_device_level\Device_Characterization\Power_MOSFET\Example_IXFN130N301.aedt

This example demonstrates the operation mechanism of the basic dynamic N-Channel MOSFET model through a simple example. The control gate voltage is supplied by a pulse-wave voltage source E1. The schematic of the example is shown in Figure 5, system parameters are listed in Table 9, and the simulation results are shown in Figures 6 and 7.

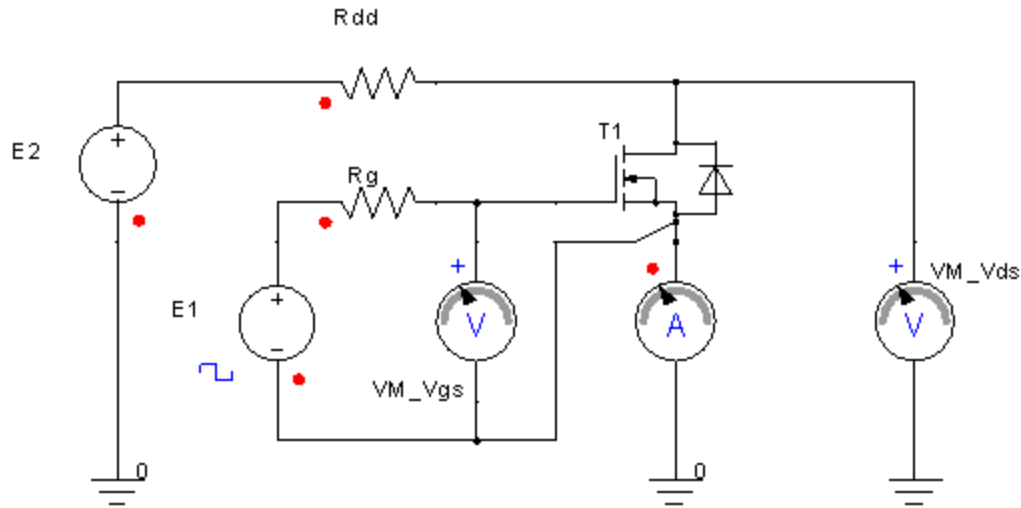


Figure 5. Application example of the N-Channel MOSFET model (basic dynamic)

Table 9. System Parameters

Component	Parameter	Value [unit]
Resistor Rdd	R	10 [Ohm]
Resistor Rg	R	1 [Ohm]
Voltage Source (Pulse) E1	AMPL	10 [V]
	FREQ	1000 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [V]
Voltage Source E2	EMF	150 [V]
Basic Dynamic N-MOSFET T1	TYPE_DYN	2011
	VNOM	150
	INOM	65
	SYNC	E1.EMF
	TYPE_BREAKTHROUGH	0

* All other parameters of the N-Channel MOSFET model use their default values; therefore, they are not included in the parameter table.

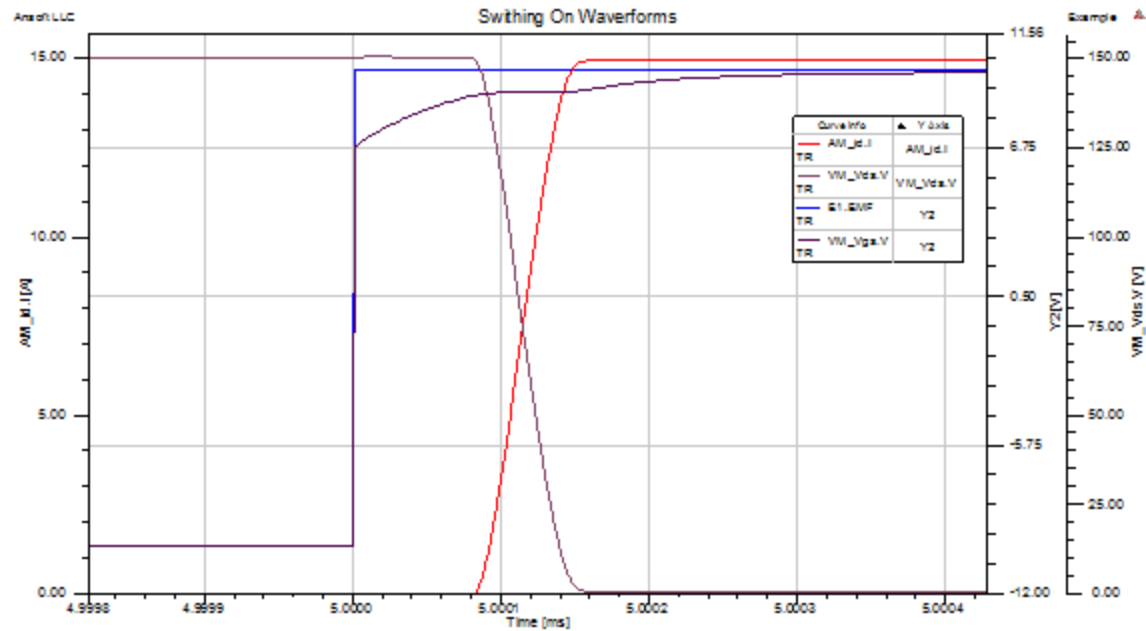


Figure 6. Simulation result-Switching ON Waveforms for N-MOSFET T1

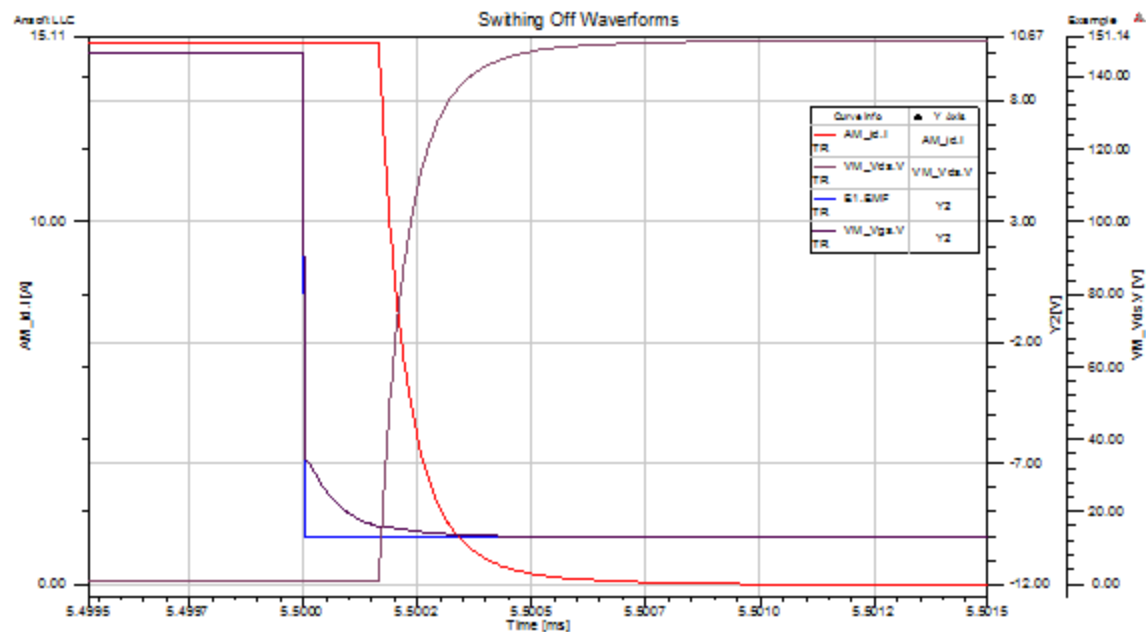


Figure 7. Simulation result-Switching OFF Waveforms for N-MOSFET T1

P-channel MOSFET Example

Use the **File>Open Examples** menu command to open the example project:

\Examples\Simplorer\Components\Basic\Circuit\Semiconductors_device_level\Device_Characterization\Power_MOSFET\Example_IRF9540N.aedt

This example demonstrates the operation mechanism of the basic dynamic P-Channel IGBT model with FWD through a simple example. The control gate voltage is supplied by a pulse-wave voltage source E1. The schematic of the example is shown in Figure 14, system parameters are listed in Table 10, and the simulation results are shown in Figures 9 and 10.

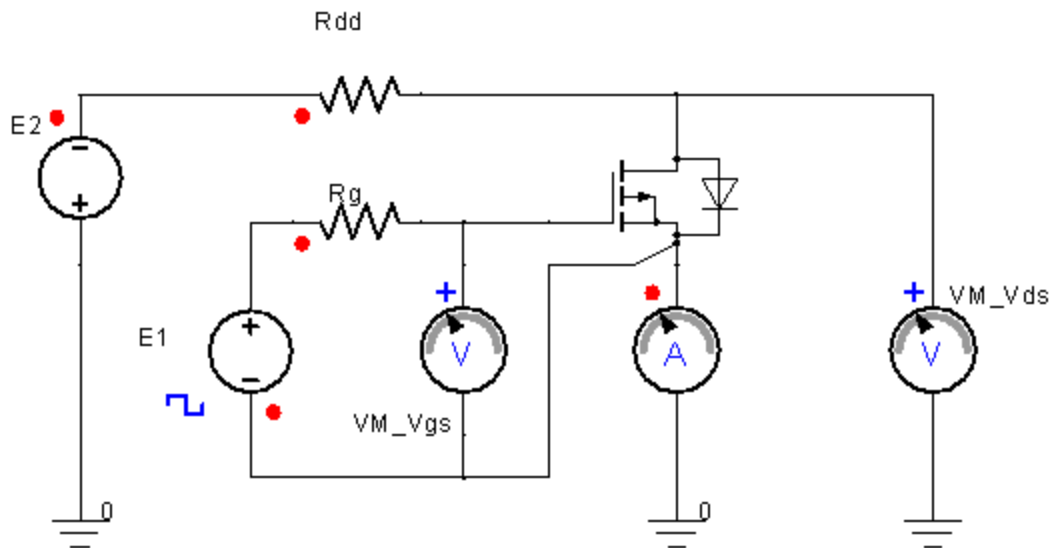


Figure 8. Application example of the P-Channel MOSFET model (basic dynamic)

Table 10. System Parameters

Component	Parameter	Value [unit]
Resistor Rdd	R	10 [Ohm]
Resistor Rg	R	1 [Ohm]
Voltage Source (Pulse) E1	AMPL	10 [V]
	FREQ	1000 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [V]
Voltage Source E2	EMF	50 [V]

Basic Dynamic P-MOSFET T1	TYPE_DYN	2011
	VNOM	50
	INOM	11
	SYNC	E1.EMF
	TYPE_BREAKTHROUGH	0

* All other parameters of the P-Channel MOSFET model use their default values; therefore, they are not included in the parameter table.

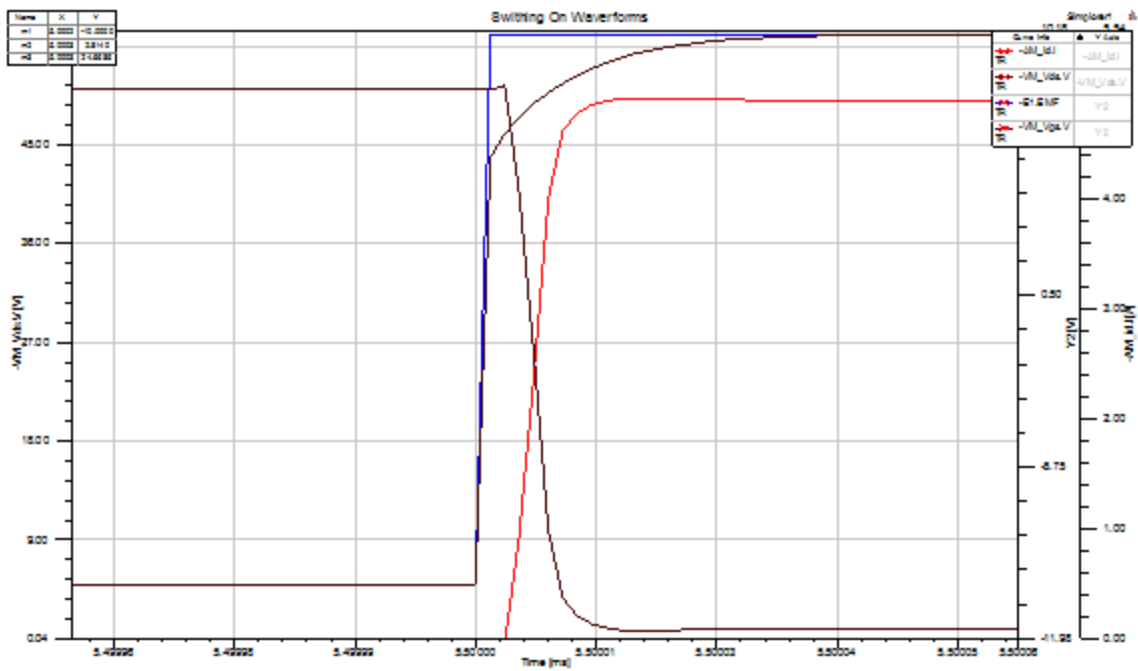


Figure 9. Simulation result-Switching ON Waveforms for P-MOSFET T1

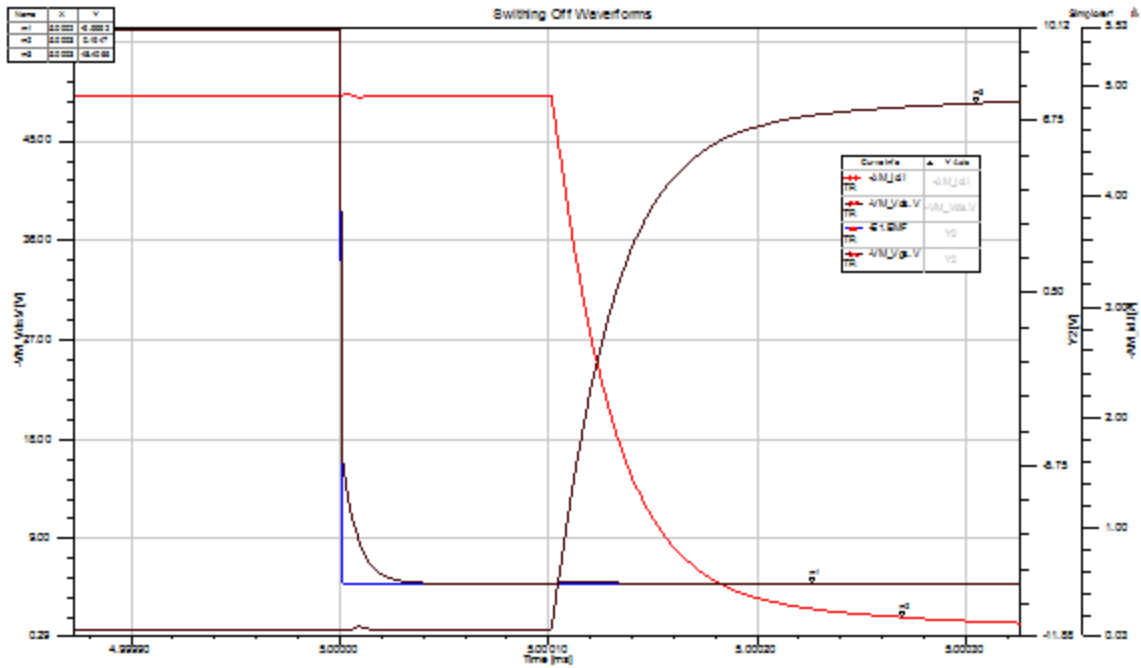


Figure 10. Simulation result-Switching OFF Waveforms for P-MOSFET T1

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References

[1] Ned Mohan, Tore M. Undeland, William P. Robbins, "Power Electronics: Converters, Applications, and Design". John Wiley & Sons, INC. New York, 1995.

Power MOSFET Model (Average) V2

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

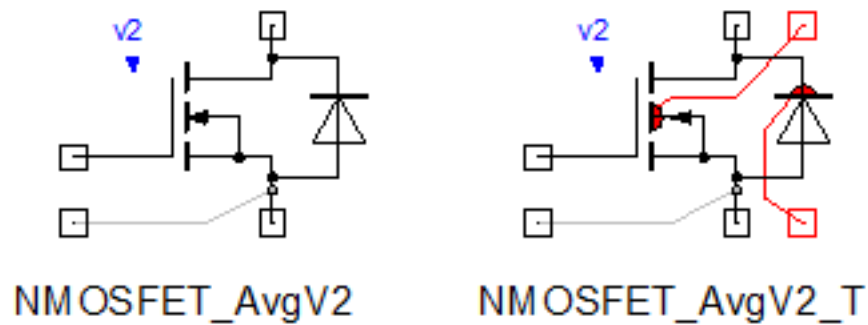


Figure 1. Average MOSFET V2 Component symbols

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- [Assumptions and Limitations](#)
- [Mathematical Description](#)
- [Netlist Syntax](#)
- [Conservative Pins](#)
- [Parameters](#)
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Description

The purpose of the average model is to simulate correct energy loss and junction temperature with least computation. It is most suitable for energy/power loss and temperature estimation over large scale designs or long timespans.

The average model is a static model. It contains the same static and thermal model as used in basic dynamic MOSFET model, but its switching energy is estimated based on actual working conditions during simulation. As a result, all DC characteristics are accurate, switching energy loss and junction temperature output are also very good approximations, but the switching waveform has no dynamic details. This means one cannot measure the actual switching time and energy loss from the switching voltage and current waveform, but can get the right energy value from model output E_ON, E_OFF and E_RR.

Generally, the amount of power loss dissipated from a MOSFET is determined by conduction loss and switching loss. While conduction loss can be accurately calculated from static voltage and current waveforms of the average model, the switching energy loss is estimated through multi-dimensional interpolation based on current, voltage, temperature, and gate resistance. These quantities are from simulation in the following ways:

- Voltage and current are sampled at switching; see [Mathematical Description](#) for details. Please note the importance of the Synchronization signal in Electrical Parameters.
- Temperature is directly measured during simulation.
- Gate resistance in the schematic is taken as parameters RG_ON and RG_OFF of the average MOSFET model. These two parameters are not physical resistances inside the model but values of external gate drive resistance. In other words, after users build their own gate drive circuit in the schematic, they should set the two parameters in the average MOSFET model to match their drive circuit.

Twin Builder provides the Characterize Device option to extract electrical and thermal model parameters from the manufacturer catalog datasheet. The key for characterizing an average model is to provide data at as many different working points as possible in Energy Characteristics [10/12], so the model can learn the device's working point dependency. Such data can be sampled from switching losses curves in the datasheet. This is not required for dynamic models, but necessary for average model characterization.

The version 2 (V2) average MOSFET model includes all capabilities of the legacy average model, but also extends it with extra options of using simplified electrical model for faster electro-thermal simulation. For more details, see [Mathematical Description](#).

Starting with Twin Builder 2019.1, new average models extracted by the characterization wizard will be version 2 components.

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Assumptions and Limitations

The average model is a static model: its current and voltage waveforms do not contain switching dynamics. Switching loss cannot be directly measured from these waveforms.

Switching energy and power are internally estimated by interpolation; thus the working point related coefficients are very important for correct loss and temperature simulation if the model is operated away from nominal working point. The coefficients can be extracted by the Device Characterization Wizard, which needs the user to provide data at as many different working conditions as possible in Energy Characteristics [10/12].

Besides characteristics related parameters, an average MOSFET requires the user to:

- Use the Internal Synchronization signal (default), or properly set the External Synchronization signal in Electrical Parameters.
- Include gate drive resistance in the external schematic and set the values in External Connectors, in which parameters RG_ON and RG_OFF are **not** physical gate resistance.

- Properly set Hmin and Hmax; see [Mathematical Description](#) for details.
- Simulate for at least 10-20 switches in order to get good estimation of loss and temperature.

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Mathematical Description

Electrical Model (full)

The model uses an electrical equivalent circuit as shown in Figure 2.

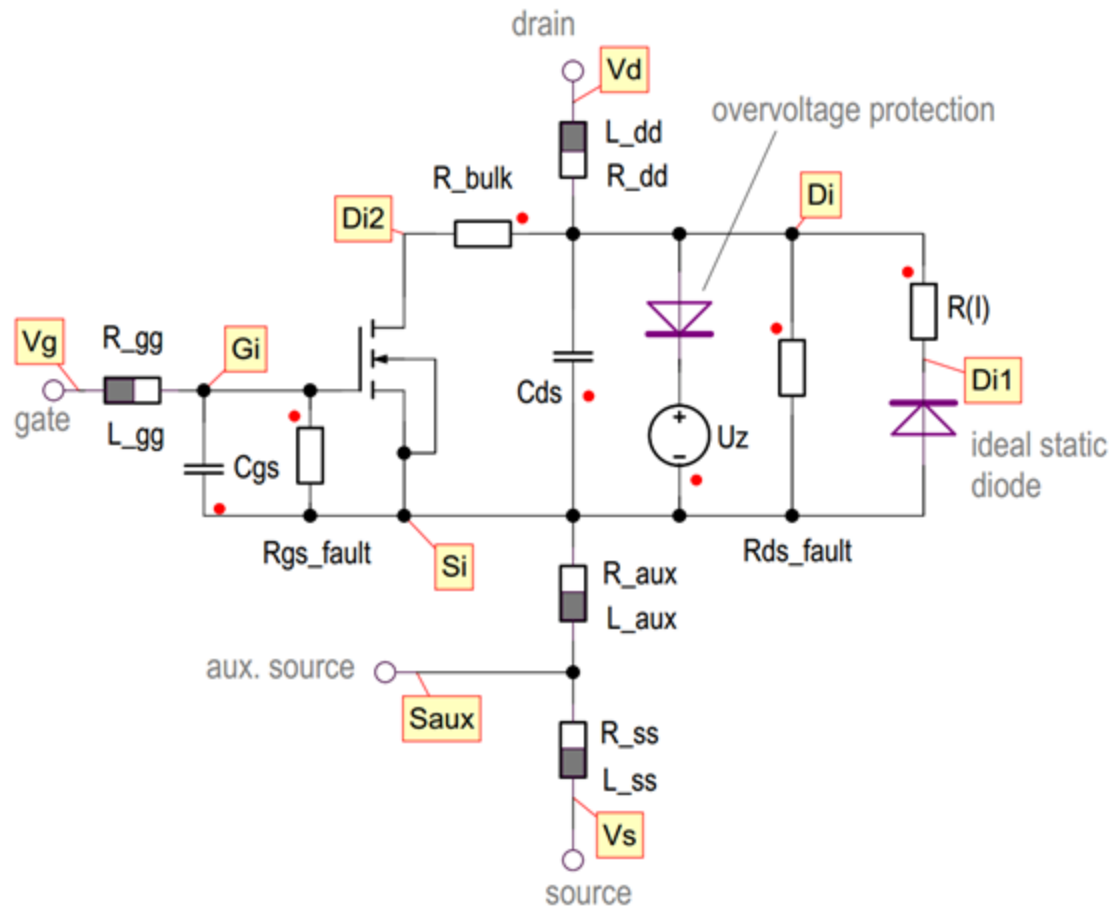


Figure 2. Equivalent circuit of the Average Power MOSFET model

The average power MOSFET model contains the same static model that is used in basic dynamic power MOSFET model. Using the Device Characterization Wizard, the datasheet transfer characteristics $I_d(V_{gs})@V_{ds}=const.$ and the output characteristics $I_d(V_{ds})@V_{gs}=const.$ can be reproduced by simulation. The accuracy is very important for the load current dependency of the saturation voltage $V_{ds sat}(I_d)$ which is necessary for the DC loss calculation

Because external stray inductances cause large induction voltage spikes across the drain source branch according to:

$$u_i = L_{STRAY} \left(\frac{di_c}{dt} \right) \quad (1)$$

an internal over voltage limitation is included as well as for voltage, current and temperature overload as breakdown indication. Although the model is basically a static one, an input capacitance is included to obtain reasonable switching response times.

Electrical Model (simplified)

While the full electrical model has the complete static characteristics of a MOSFET, it requires solving the nonlinear output characteristics with the whole schematic, which can sometimes cause convergence difficulty depends on the external circuit. In this case, the simulation would require very small Hmin and take long time to run.

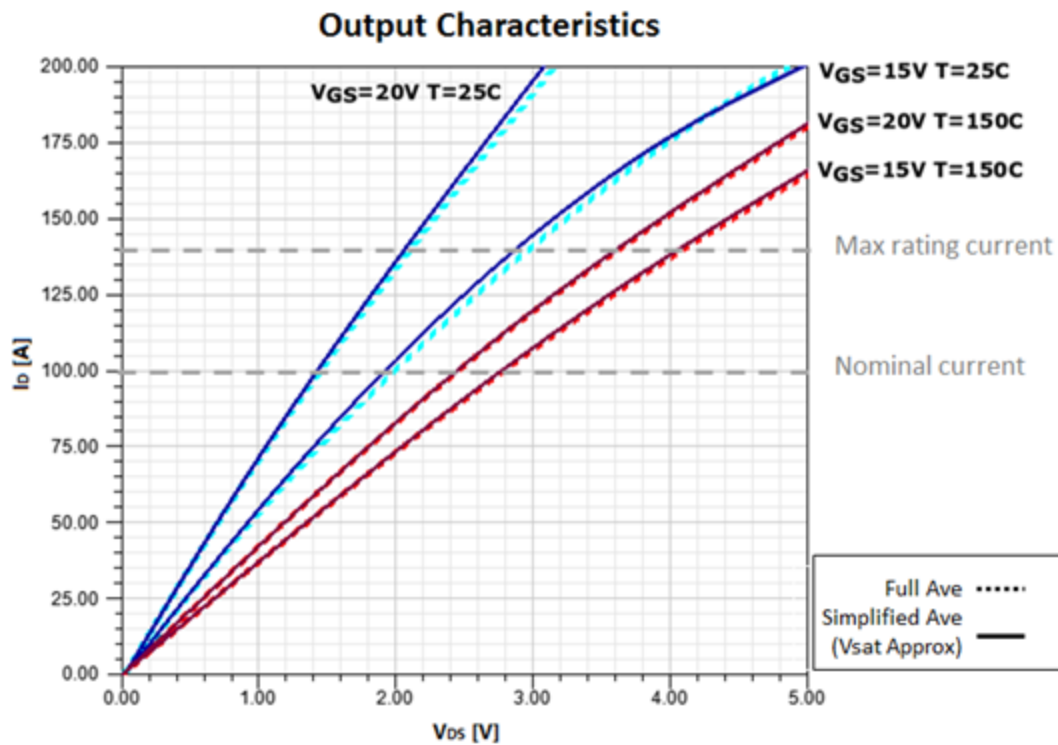
To provide a much faster yet still accurate option in this situation, the **Use Simplified Model** option is provided in the V2 average MOSFET. You can activate this mode by checking the **Use Simplified Model** check box on the **Electrical Parameters** tab of the component's **Parameters** dialogue.

The simplified model still uses the full set of static parameters extracted from datasheet static characteristics. But the output characteristics are calculated instead of solved in the circuit, which can accurately estimate conducting power PEL_T on the transistor. Meanwhile, switching loss and thermal models in the simplified model are identical to that of the full model.

Besides estimated conducting loss, there are two approximation options available for the electrical behavior (current and voltage waveforms). You can select these under **Static Core Behavior**:

- Static Core Behavior: Vsat Approximation (recommended)

In this mode, Id, Vds and Vgs relations and their temperature dependency are calculated in a similar way as conducting loss, so user can measure accurate output characteristics within datasheet rated max current. The figure below compares the output characteristics simulation results of the full average model and simplified model in Vsat approximation mode.



This shows that this simplified mode is a good approximation of full average model, except that the simplified model does not have the correct current saturation effect (data for this effect is not available in the datasheet of this example device). This means the simplified model can provide accurate results of on-state voltage and load current, but cannot be used for short circuit analysis if current saturation data is available.

NOTE: The **Use Simplified Model** setting in **Vsat Approximation** mode is recommended in most cases, due to good accuracy and performance. The only limitation is short circuit simulation, which requires the full average model.

- Static Core Behavior: Ideal Switch

In this mode, the MOSFET behaves simply as an ideal switch in the electrical circuit, even though it still gives accurate loss estimation. So, when using the model in this mode, on-state voltage is always zero, and load current will be ideal without realistic ON-resistance. This ideal switch mode can only simulate accurate loss and temperature, but is slightly (5%-10%) faster than the **Vsat Approximation** mode.

Switching Loss Estimation

A novel synchronization technique and working point dependency are introduced to perform the calculations for the switching losses, which would not be possible using a pure static model.

Figure 3 shows the voltage and current sampling which is done at the moment of the trigger signal edge. This sampling scheme is called “synchronization” because the model is triggered by an internal or external sync signal to get the instantaneous load current and blocking voltage of the device without overshoot and oscillation. Together with the actual junction temperature and the gate drive condition the sampled values form the actual working point $W(t)=[V(t), I(t), T(t), R_{ON}(t), R_{OFF}(t)]$ are valid for every half of a switching cycle. Once the model has the working point information knowing the switching time due to the synchronization technique employed, the energy calculation can be performed by straight forward analytical formulation, which serves as either interpolation or extrapolation function of the data sheet or measurement values.

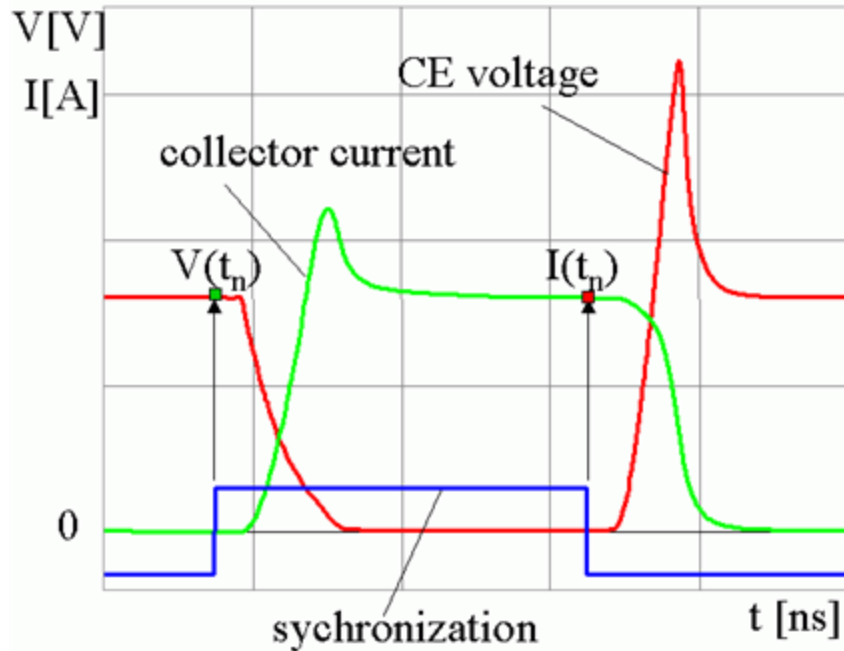


Figure 3. Synchronization Technique

The nominal working point W_{NOM} stands for nominal operating conditions found in a manufacturer data sheet, which includes the nominal blocking voltage V_{NOM} , the nominal load current I_{NOM} , the nominal junction temperature T_{NOM} and the usual gate drive conditions belong to the nominal working point. Assuming constant gate drive voltages and stray inductances in the gate circuit, the external gate resistors for the on-switch and off-switch belong to the nominal working point definition as:

$$W_{NOM}=[V_{NOM}, I_{NOM}, T_{NOM}, R_{ONNOM}(t), R_{OFFNOM}(t)]$$

When the model parameters are fitted to W_{NOM} the model will work accurately under this working condition. Normally during simulation, the blocking voltage remains constant at the bus bar voltage. In case of fault condition this value may change in the range of 0...200%. For an inverter application the load current changes in the range of 0...100% periodically. As a consequence, the temperature will vary in the range of 300K to 420K (up to 140%) while the gate drive conditions remain unchanged. Usually the actual working point $W(t)$ differs from nominal condition W_{NOM} . As $W(t)$ deviates from W_{NOM} , the accuracy of the simulation decreases. Although $W(t)$

differs from W_{NOM} , the simulation results can be rectified by using the "working point correction coefficients" given below.

$$E_{ON} = Y_{ON}(T, I, V, R, \alpha, \kappa, \sigma, \rho) \cdot E_{ON, NOM}$$

$$E_{OFF} = Y_{OFF}(T, I, V, R, \alpha, \kappa, \sigma, \rho) \cdot E_{OFF, NOM}$$

$$E_{RR} = Y_{RR}(T, I, V, R, \alpha, \kappa, \sigma, \rho) \cdot E_{RR, NOM}$$

(2)

$$Y(T, I, V, R, \alpha, \kappa, \sigma, \rho) = X_T(T, \alpha) \cdot X_I(I, \kappa) \cdot X_V(V, \sigma) \cdot X_R(R, \rho)$$

(3)

where, X is a set of independent partial correction functions and

$\alpha, \kappa, \sigma, \rho$

are the correction coefficients calculated independently for each working point condition. Each product term of this approach can be fitted to a linear or power function X (as presented in Figure 4 and according to the Eq.5-8) which depends on either the interpolation or extrapolation conditions to ensure non-negative and limited values for the total working point correction function Y (shown in Eq. 3).

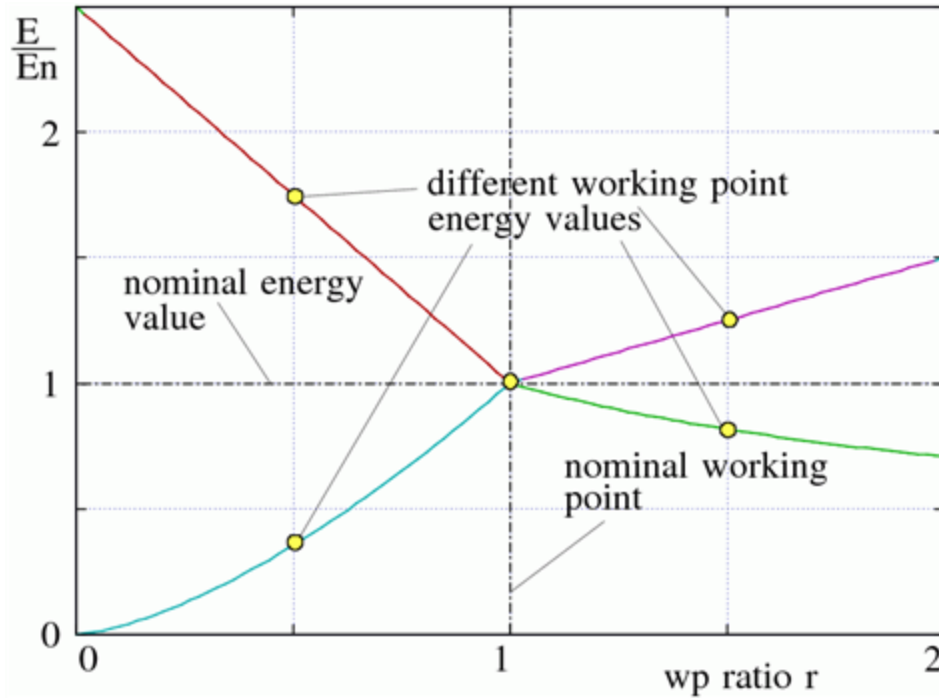


Figure 4. Working point correction coefficients map

The correction coefficients are extracted one by one by varying only the corresponding working point parameter (T , I , V or R) and holding the other parameters at their nominal values. To illustrate this procedure, the calculation of the temperature correction coefficient α is used as an

example. The same extraction algorithm is applied to the other coefficients. To calculate temperature coefficient α , the energy values at a temperature different from the nominal condition (either greater or less than the nominal condition) are measured. As illustrated in the working point correction map (shown in Figure 4), a particular pattern, which represents the variation of partial correction function X , is chosen to compute the temperature correction coefficient based on the energy ratio and the working point ratio r_T . Using the Eq.2 and Eq.3 all terms are known except for the term $X_T(T, \alpha)$. Introducing Eq.3 into Eq.2 and knowing the measured value of the energy, the temperature partial correction function is given by,

$$X_T(T, \alpha) = \frac{E_{ON/OFF/RR}}{E_{ON/OFF/RR.NOM}} \quad (4)$$

Based on the employed mapping algorithm and the value of $X_T(T, \alpha)$ the correction coefficient for temperature can be evaluated. Now this temperature correction coefficient can be used to determine the partial correction function $X_T(T, \alpha)$ for any variation of the temperature during any simulation. As a general observation in this modeling approach, only one correction coefficient is used for temperature partial correction function estimation, while for voltage (Eq.6), current (Eq.7) and gate resistance (Eq.8) two correction coefficients are being used. Consequently, when considering the temperature dependency it is recommended that choose the nominal working point condition to reflect the hot temperature dependency.

$$r_T = \frac{T}{T_{NOM}}$$

$$X_T = \begin{cases} r_T^\alpha & \text{when } (r_T < 1.0 \text{ and } \alpha > 1.0) \text{ or } (r_T > 1.0 \text{ and } \alpha < 0.0) \\ 1 + \alpha \cdot (r_T - 1.0) & \text{when } (r_T < 1.0 \text{ and } \alpha \leq 1.0) \text{ or } (r_T > 1.0 \text{ and } \alpha \geq 0.0) \\ 1.0 & \text{when } r_T = 1.0 \end{cases}$$

(5)

$$r_V = \frac{V}{V_{NOM}}$$

$$X_V = \begin{cases} r_V^{\sigma_0} & \text{when } r_V < 1.0 \text{ and } \sigma_0 > 1.0 \\ 1 + \sigma_0 \cdot (r_V - 1.0) & \text{when } r_V < 1.0 \text{ and } \sigma_0 \leq 1.0 \\ r_V^\sigma & \text{when } r_V > 1.0 \text{ and } \sigma > 0.0 \\ 1 + \sigma \cdot (r_V - 1.0) & \text{when } r_V > 1.0 \text{ and } \sigma \leq 0.0 \\ 1.0 & r_V = 1.0 \end{cases}$$

(6)

$$r_I = \frac{I}{I_{\text{NOM}}}$$

$$X_I = \begin{cases} r_I^{\kappa_0} & \text{when } r_I < 1.0 \text{ and } \kappa_0 > 1.0 \\ 1 + \kappa_0 \cdot (r_I - 1.0) & \text{when } r_I < 1.0 \text{ and } \kappa_0 \leq 1.0 \\ r_I^{\kappa} & \text{when } r_I > 1.0 \text{ and } \kappa > 0.0 \\ 1 + \kappa \cdot (r_I - 1.0) & \text{when } r_I > 1.0 \text{ and } \kappa \leq 0.0 \\ 1.0 & r_I = 1.0 \end{cases}$$

(7)

$$r_R = \frac{R}{R_{\text{NOM}}}$$

$$X_R = \begin{cases} r_R^{\rho_0} & \text{when } r_R < 1.0 \text{ and } \rho_0 > 1.0 \\ 1 + \rho_0 \cdot (r_R - 1.0) & \text{when } r_R < 1.0 \text{ and } \rho_0 \leq 1.0 \\ r_R^{\rho} & \text{when } r_R > 1.0 \text{ and } \rho > 0.0 \\ 1 + \rho \cdot (r_R - 1.0) & \text{when } r_R > 1.0 \text{ and } \rho \leq 0.0 \\ 1.0 & r_R = 1.0 \end{cases}$$

(8)

In the partial temperature correction function $X_T(T, \alpha)$, T denotes the Kelvin temperature. All functions take the value 1 for the nominal working point as shown in Figure 4. The “wp ratio” represents the ratio between the actual temperature, voltage, current, gate resistance and their corresponding nominal values. For working point conditions different from the nominal working point ($r=1$), larger or smaller loss energy values are given by the data sheet or measurements (indicated as points in Figure 4). The partial correction functions are designed to result in non-negative and limited values for all possible working point conditions. All correction functions meet the nominal working point in $[1, 1]$ which ensure the best accuracy for the nominal working point and exhibit a knee at $r=1$ because the functions are double sided to reproduce the full operating range of the device at a minimum energy error.

Thermal Model

The average power MOSFET model contains the same thermal model that is used in basic dynamic power MOSFET model.

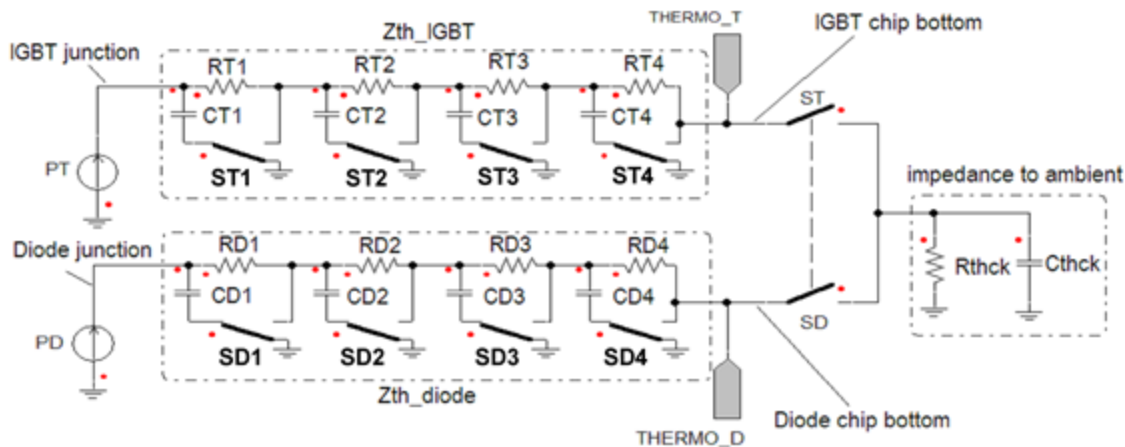


Figure 5. Thermal Network of the MOSFET models

In the Average MOSFET model, the power injection (PD and PT in Figure 5) are pulse-wise waveforms, and their amplitude is calculated using the switching/conduction energy losses and the user-specified pulse width. The pulse width is related to the setting of the thermal behavior level. The average MOSFET model provides three thermal behavior levels: isothermal, average and dynamic. Users can change this setting in the **Thermal Parameters** tab of the component parameters.

When **Thermal Behavior Level** is set to dynamic, the switching pulses are calculated and injected into the thermal network at each switching period. Users need to specify TON, TOFF and TRR according to the datasheet of the device. This option provides the detailed transient behavior of the junction temperature, but requires a relatively small minimum time step and therefore results in lower simulation speed. The power injections during the on/off switch and conduction are calculated as follows:

On switch power injection: $P_{ON} = E_{ON}/T_{ON}$

Off switch power injection: $P_{OFF} = E_{OFF}/T_{OFF}$

Conduction power injection is directly calculated from current and voltage on internal transistor and diode; loss on stray elements is excluded from injected power.

When **Thermal Behavior Level** is set to average, average power pulse amplitude is calculated over a user-specified sampling time TSAMPLE, which can be several times the switching period. The average thermal behavior preserves the transient trend of the junction temperature without the dynamic detail, and increases the simulation speed using minimum simulation time step requirements. A comparison between the dynamic and the average thermal behavior is made in Figure 6.

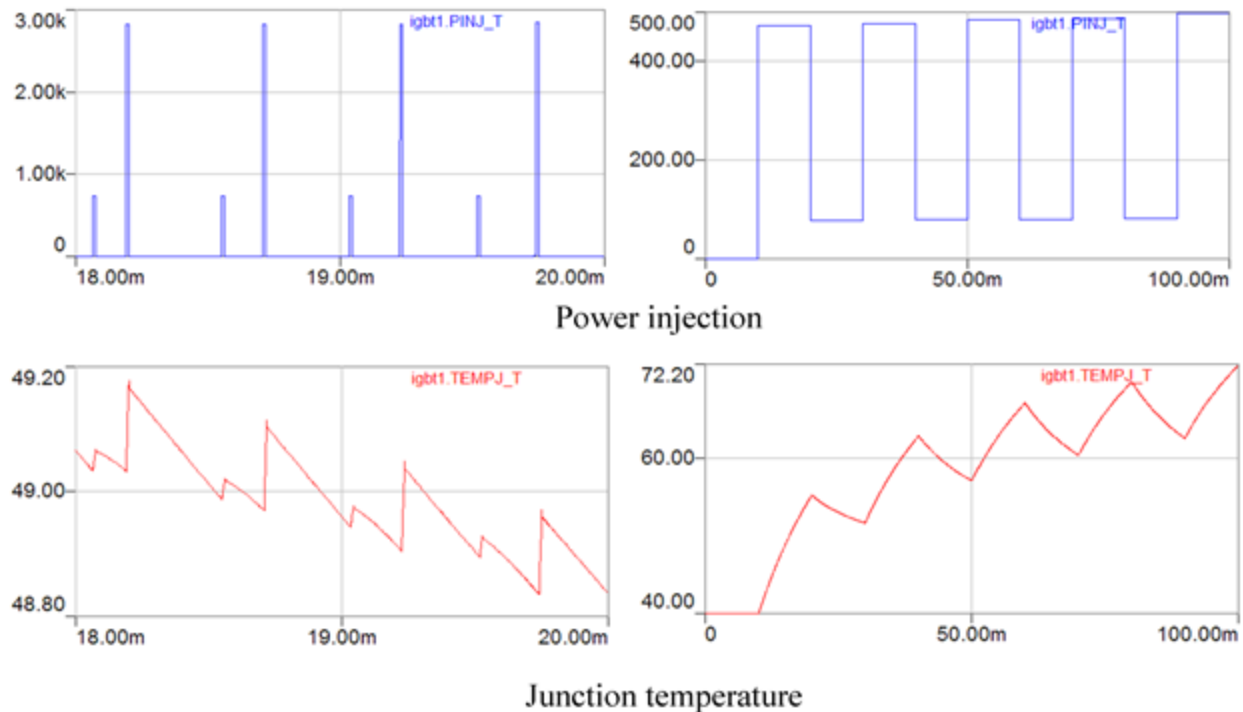


Figure 6. Comparison between the dynamic(left) and the average(right) thermal behavior of the Average MOSFET model

The following table summarizes the use of different thermal behavior levels:

Thermal Behavior Level	Simulation Goal	Hmin, Hmax*	Other Parameters
Average	Estimate average junction temperature and its transient trend without dynamic detail. Short simulation time.	Hmin < 1/20 of duty cycle; Hmax can be large, but should not exceed TON, TOFF, or TRR.	TSAMPLE is integer times of switching cycle.
Dynamic	Estimate maximum junction temperature with dynamic detail. Long simulation time.	Hmin < 1/15 of Min (TON, TOFF, or TRR); Hmax cannot be much larger and should not exceed TON, TOFF, or TRR.	TON, TOFF and TRR from data-sheet or measurement.

* Principle of setting simulation time step Hmin is: At least 20-30 steps per duty cycle (conducting cycle), and 15-20 steps per switching power pulse (For dynamic thermal behavior level only, switching power pulse duration is set by TON, TOFF, and TRR). For dynamic thermal behavior, Hmax cannot be much larger than Hmin. In general, Hmax should not exceed TON, TOFF, or TRR. Otherwise the switching energy may have a large error.

NOTE:

For fastest simulation time (3-5 times the runtime taken by system level model):

- Setting: **Use Simplified Model** and **Average** thermal behavior level
- Set parameters **CCE** and **CGE** to 0 (can be found in component **Parameters>Electrical Parameters** tab in table of **Electrical Parameters**, the two editable parameters are listed at Level **Dynamic**)
- For PWM type gate control signals, set Hmin as large as 1/3 of the narrowest conducting pulse

*Larger Hmin and Hmax beyond this pulse width is possible, but will introduce a tradeoff between runtime and accuracy due to missed switching pulses.

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Netlist Syntax

NOTE: THERM_T and THERM_D only exist in the NMOSFET_AvgV2_T model.

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
DRAIN	Drain	electrical
SOURCE	Source	electrical
AUX_SOURCE	Auxiliary Source	electrical
GATE	Gate	electrical
THERM_T	MOSFET Die Bottom Thermal Contact	thermal
THERM_D	Diode Die Bottom Thermal Contact	thermal

NOTE: THERM_T and THERM_D pins only exist in the NMOSFET_AvgV2_T model.

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Parameters

Table 2. General Parameters

Name	Description	Data Type
TYPE_FET	MOSFET Type Flag -2:p-Type 2:n-Type	real
TYPE_FWD	Freewheeling Diode Type 0:no 1:static	real
TYPE_DYN (for full average model)	0:stat 1:dyn +10:ext sync +20:mixed (gate driven + external) - (recommended) +30:internal (gate driven)	real
TYPE_DYN (for simplified average model)	0:stat 1:dyn +10:ext sync +20:mixed (gate driven + external) - (recommended) +30:internal (gate driven) +100: Static Behavior as Ideal Switch +400: Static Behavior Vsat Approximation (recommended)	
TYPE_THERM	xxx0: isothermal behavior xxx1: average behavior xxx2: dynamic behavior xx0x: partial fractional, therm. network xx1x: cont. fractional, therm. network xx2x: partial fractional, therm. equations xx3x: cont. fractional, therm. equations x0xx: output temperature rise only x1xx: output in degrees Celsius x2xx: output in Kelvin 0xxx: diode and transistor on separated dies 1xxx: diode and transistor on a single die	real
TYPE_BREAKTHROUGH	0:disable breakthrough 1:enable breakthrough	real

Table 3. Static Model Parameters

Name	Description	Data Type
VNOM	Nominal Drain-Source Voltage [V]	real
INOM	Nominal Drain Current [A]	real
TNOM	Reference Temperature [°C]	real
A_FET	Saturation Factor of internal FET	real
TC_A_FET	Temperature Coefficient of A_FET	real
M_FET	Saturation Exponent of internal FET	real
TC_M_FET	Temperature Coefficient of M_FET	real
N_FET	Exponent of Transfer Characteristic of FET	real
TC_N_FET	Temperature Coefficient of N_FET	real
K	Transistor Constant of FET at TNOM	real
TC_K	Temperature Coefficient of K	real
RD0	Small Voltage Bulk Resistance [Ohm]	real
TC_RD0	Temperature Correction Coefficient of RD0	real
RD1	Large Voltage Bulk Resistance [Ohm]	real
TC_RD1	Temperature Correction Coefficient of RD1	real
RDV	Bulk Resistance Inflection Voltage [V]	real
TC_RDV	Temperature Correction Coefficient of RDV	real
VP	Pinch-off-Voltage of FET at TNOM [V]	real
TC_VP	Temperature Coefficient of VP	real
KLM	Channel Length Modulation Factor of FET [1/V]	real

VBREAK_DS	Breakthrough Drain-Source Voltage [V]	real
VBREAK_GS	Breakthrough Gate-Source Voltage [V]	real
IBREAK	Breakthrough Drain Current [A]	real
TEMPBREAK	Breakthrough Junction Temperature [°C]	real
RFAULT_DS	Drain-Source Resistance after Fault [Ohm]	real
RFAULT_GS	Gate-Source Resistance after Fault [Ohm]	real

Table 4. Switching Loss Model Parameters

Name	Description [Unit]	Data Type
EON_NOM	Nominal On-Switch Loss Energy [J]	real
EOFF_NOM	Nominal Off-Switch Loss Energy [J]	real
ERR_NOM	Nominal Reverse Recovery Loss Energy [J]	real
RG_ON	On-Switch External Gate Resistance [ohm]; This is not a physical resistance but the value of gate resistance in the external gate drive. You should include proper gate resistance in your designs and put the value in this parameter.	real
RG_OFF	Off-Switch External Gate Resistance [ohm]; This is not a physical resistance but the value of gate resistance in the external gate drive. You should include proper gate resistance in your designs and put the value in this parameter.	real
RG_NOM_ON	Nominal On-Switch External Gate Resistance [ohm]	real
RG_NOM_OFF	Nominal Off-Switch External Gate Resistance [ohm]	real
TC_EON	Temperature coefficient of EON	real
CC0_EON	Current coefficient of EON (IC	real
CC_EON	Current coefficient of EON (IC>=ICNOM)	real
VC_EON	Voltage coefficient of EON	real
RC0_EON	Gate resistance coefficient of EON (RG_ON	real
RC_EON	Gate resistance coefficient of EON (RG_ON>=RG_NOM_ON)	real
TC_EOFF	Temperature coefficient of EOFF	real
CC0_EOFF	Current coefficient of EOFF (IC	real

CC_EOFF	Current coefficient of EOFF ($IC \geq IC_{NOM}$)	real
VC_EOFF	Voltage coefficient of EOFF	real
RC0_EOFF	Gate resistance coefficient of EOFF (RG_{OFF})	real
RC_EOFF	Gate resistance coefficient of EOFF ($RG_{ON} \geq RG_{NOM\_OFF}$)	real
TC_ERR	Temperature coefficient of ERR	real
CC0_ERR	Current coefficient of ERR (IC)	real
CC_ERR	Current coefficient of ERR ($IC \geq IC_{NOM}$)	real
VC0_ERR	Voltage coefficient of ERR ($VC < VC_{NOM}$)	real
VC_ERR	Voltage coefficient of ERR ($VC < VC_{NOM}$)	real
RC0_ERR	Gate resistance coefficient of ERR (RG_{ON})	real
RC_ERR	Gate resistance coefficient of ERR ($RG_{ON} \geq RG_{NOM\_ON}$)	real
SYNC	External synchronization signal	real

Note: An average model can generate an internal sync signal which triggers the loss calculation. If more control on the triggering is needed, you can choose 'mixed' or 'external' to add external synchronization signal SYNC. The SYNC signal is required to cross zero in a positive direction only when the device starts conducting, and crosses zero in a negative direction only when the device stops conducting or when I_{rr} is formed. It is preferable to use an ideal pulse wave, or trapezoidal wave. When using an ideal pulse wave, a signal change between zero and a positive value is also supported.

Note that the synchronization signal may not be the same as the gate drive signal for the same device. Rule of thumb is to give a clear rising edge or zero crossing signal at the moment when the conducting status of a device changes, or when current flows on the device start to change.

Table 5. Thermal Parameters

Name	Description [Unit]	Data Type
TEMPAMB	Ambient Temperature [$^{\circ}C$]*	real
TEMPJNCT0	Junction Temperature at Simulation Start [$^{\circ}C$]*	real
CTHT1	1. thermal transistor capacity [F]	real
RTHT1	1. thermal transistor resistance [ohm]	real
CTHT2	2. thermal transistor capacity [F]	real
RTHT2	2. thermal transistor resistance [ohm]	real

CTHT3	3. thermal transistor capacity [F]	real
RTHT3	3. thermal transistor resistance [ohm]	real
CTHT4	4. thermal transistor capacity [F]	real
RTHT4	4. thermal transistor resistance [ohm]	real
CTHD1	1. thermal diode capacity [F]	real
RTHD1	1. thermal diode resistance [ohm]	real
CTHD2	2. thermal diode capacity [F]	real
RTHD2	2. thermal diode resistance [ohm]	real
CTHD3	3. thermal diode capacity [F]	real
RTHD3	3. thermal diode resistance [ohm]	real
CTHD4	4. thermal diode capacity [F]	real
RTHD4	4. thermal diode resistance [ohm]	real
CTHDT	common thermal capacitance [F]	real
RTHDT	common thermal resistance [ohm]	real
TON	on switch power pulse time [s] (dynamic thermal behavior)	real
TOFF	off switch power pulse time [s] (dynamic thermal behavior)	real
TRR	reverse recovery power pulse time [s] (dynamic thermal behavior)	real
TSAMPLE	Thermal sampling time [s] (average thermal behavior)	real

* The unit in which those output values are created depends on the unit flag in the TYPE_THERM parameter (raise only, °C, or K).

Table 6. Parameter FWD Model

Name	Description [Unit]	Data Type
M_FWD	Ideality Factor of FWD at TNOM (static parameter)	real
ISAT_FWD	Saturation Current of FWD at TNOM [A] (static parameter)	real
RB_FWD	Bulk Resistance of FWD at TNOM [ohm] (static parameter)	real
TC_M_FWD	Temperature Coefficient of M_FWD (static parameter)	real
TC_ISAT_FWD	Temperature Coefficient of ISAT_FWD (static parameter)	real
TC_RB_FWD	Temperature Coefficient of RB_FWD	real

FWD		

Table 7. Parameters of External Connections

Name	Description [Unit]	Data Type
RD	Drain Connector Resistance [Ohm]	real
RS	Source Connector Resistance [Ohm]	real
RAUX	Internal Source Resistance	real
LD	Drain Connector Inductance [H]	real
LG	Gate Connector Inductance [H]	real
LS	Source Connector Inductance [H]	real
LAUX	Internal Source Inductance	real

Note: Parameters LS and LD determine internal R_{DAMP} as described in Dynamic Behavior.

Input/Output Quantities

Table 8. Model Outputs

Name	Description [Unit]
VDS	Drain-Source Voltage [V], terminal voltage waveform, positive for n- and p- channel devices
I_D	Drain Current [A], total drain current, positive in drain to source direction
I_G	Gate Current [A]
IFD	FWD Current [A], free wheeling diode current waveform, positive in diode conducting direction
V_D	FWD Voltage Drop [V], positive in diode conducting direction]
TRANSCOND	Trans Conductance [A/V], definition is $S = d(I_d)/d(V_{gs})$, depends on the DC quiescent point and is valid for AC simulations
OUTCOND	Output Conductance [A/V], definition is $G = d(I_d)/d(V_{ds})$, depends on the DC quiescent point and is valid for AC simulations
TEMPJ_T	Wave form of the transistor junction temperature [°C, K]* at the transistor hot spot at the point of power injection, accuracy depends on correct total power calculation and an appropriate thermal network for the transistor heat dissipation
TEMPJ_D	Wave form of the Diode junction temperature [°C, K]* at the diode hot spot, the point of power injection, accuracy depends on correct total power calculation and an appropriate thermal network for the diode heat dissipation
TEMPBOT_T	MOSFET bottom temperature [°C, K]* at the end of the transistor four stage thermal chain. If

	external heat pins are used this is the node temperature, else it is equal TEMP_PLATE
TEMPBOT_D	Diode bottom temperature [°C, K]* at the end of the diode four stage thermal chain. If external heat pins are used this is the node temperature, else equal TEMP_PLATE
TEMP_PLATE	Temperature difference [°C, K]* across the one stage internal heat sink if internal sink is selected, else ambient temperature
PINJ_T	Transistor thermal model power injection [W], sum of DC and switching loss
PINJ_D	Diode thermal model power injection [W], sum of DC and switching loss
PEL_T	DC losses of transistor [W]
PEL_D	DC losses of Diode [W]
STEP	actual time step size [s]
E_ON	on switching energy [J]
E_OFF	off switching energy [J]
E_RR	loss energy of diode reverse recovery [J]
VDS_FAULT	Vds fault flag [0/1], Vds hits the absolute limits, can be watched during the simulation for break at fault
VGS_FAULT	Vgs fault flag [0/1]
ID_FAULT	drain current fault flag [0/1]
TEMPJ_FAULT	junction temperature fault flag [0/1]

The units in which those output values are created depend on the unit flag in the TYPE_THERM parameter (raise only, °C, or K).

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Example

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References

Legacy Power MOSFET Model (Average)

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

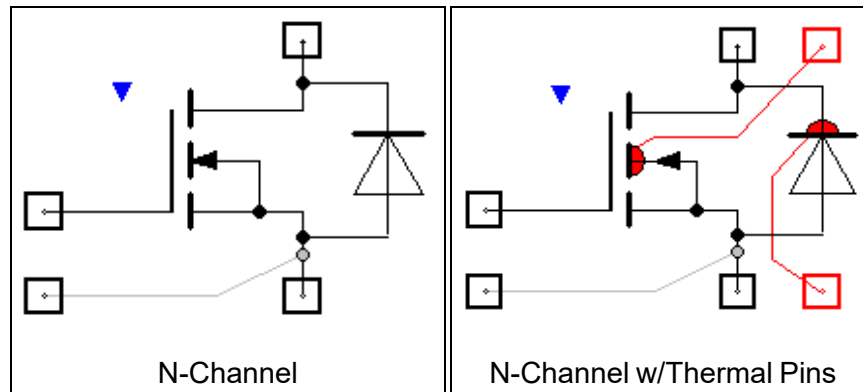


Figure 1. Legacy Average MOSFET Component symbols

- [Description](#)
- [Assumptions and Limitations](#)
- [Mathematical Description](#)
- [Netlist Syntax](#)
- [Conservative Pins](#)
- [Parameters](#)
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Description

The purpose of the average model is to simulate correct energy loss and junction temperature with least computation. It is most suitable for energy/power loss and temperature estimation over large scale designs or long timespans.

The average model is a static model. It contains the same static and thermal model as used in basic dynamic MOSFET model, but its switching energy is estimated based on actual working conditions during simulation. As a result, all DC characteristics are accurate, switching energy loss and junction temperature output are also very good approximations, but the switching waveform has no dynamic details. This means one cannot measure the actual switching time and energy loss from the switching voltage and current waveform, but can get the right energy value from model output E_ON, E_OFF and E_RR.

Generally, the amount of power loss dissipated from a MOSFET is determined by conduction loss and switching loss. While conduction loss can be accurately calculated from static voltage and current waveforms of the average model, the switching energy loss is estimated through multi-dimensional interpolation based on current, voltage, temperature, and gate resistance. These quantities are from simulation in the following ways:

- Voltage and current are sampled at switching; see [Mathematical Description](#) for details. Please note the importance of the External Synchronization signal in Electrical Parameters.
- Temperature is directly measured during simulation.
- Gate resistance in the schematic is taken as parameters RG_ON and RG_OFF of the average IGBT model. These two parameters are not physical resistances inside the model but values of external gate drive resistance. In other words, after users build their own gate drive circuit in the schematic, they should set the two parameters in the average IGBT model to match their drive circuit.

Twin Builder provides the Characterize Device option to extract electrical and thermal model parameters from the manufacturer catalog datasheet. The key for characterizing an average model is to provide data at as many different working points as possible in Energy Characteristics [10/12], so the model can learn the device's working point dependency. Such data can be sampled from switching losses curves in the datasheet. This is not required for dynamic models, but necessary for average model characterization.

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Assumptions and Limitations

The average model is a static model: its current and voltage waveforms do not contain switching dynamics. Switching loss cannot be directly measured from these waveforms.

Switching energy and power are internally estimated by interpolation; thus the working point related coefficients are very important for correct loss and temperature simulation if the model is operated away from nominal working point. The coefficients can be extracted by the Device Characterization Wizard, which needs the user to provide data at as many different working conditions as possible in Energy Characteristics [10/12].

Besides characteristics related parameters, an average MOSFET requires the user to:

- Properly set the External Synchronization signal in Electrical Parameters
- Include gate drive resistance in the external schematic and set the values in External Connectors, in which parameters RG_ON and RG_OFF are **not** physical gate resistance.
- Properly set Hmin and Hmax; see [Mathematical Description](#) for details.
- Simulate for at least 10-20 switches in order to get good estimation of loss and temperature.

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Mathematical Description

Electrical Model

The model uses an electrical equivalent circuit as shown in Figure 2.

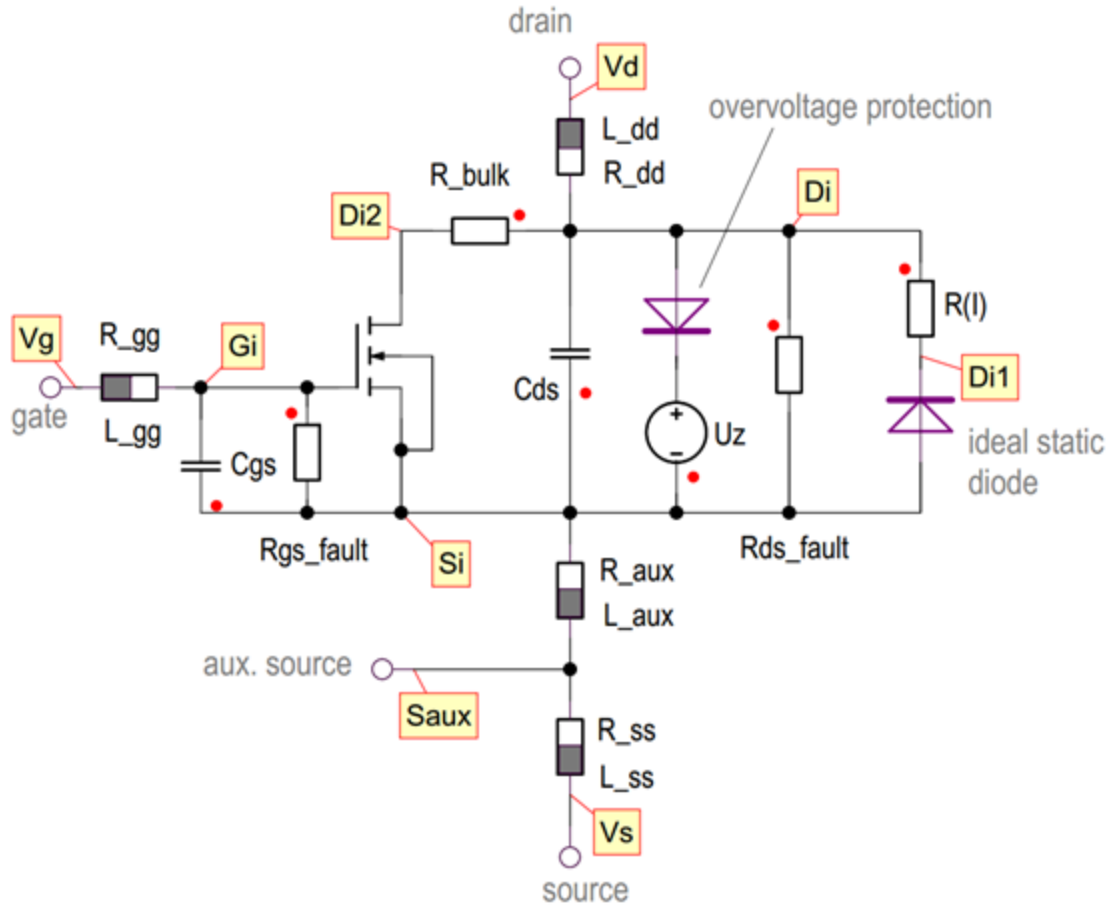


Figure 2. Equivalent circuit of the Average Power MOSFET model

The average power MOSFET model contains the same static model that is used in basic dynamic power MOSFET model. Using the Device Characterization Wizard, the datasheet transfer characteristics $I_d(V_{gs})@V_{ds}=\text{const.}$ and the output characteristics $I_d(V_{ds})@V_{gs}=\text{const.}$ can be reproduced by simulation. The accuracy is very important for the load current dependency of the saturation voltage $V_{ds\text{ sat}}(I_d)$ which is necessary for the DC loss calculation

Because external stray inductances cause large induction voltage spikes across the drain source branch according to:

$$u_i = L_{\text{STRAY}} \left(\frac{di_c}{dt} \right) \quad (1)$$

an internal over voltage limitation is included as well as for voltage, current and temperature overload as breakdown indication. Although the model is basically a static one, an input capacitance is included to obtain reasonable switching response times.

A novel synchronization technique and working point dependency are introduced to perform the calculations for the switching losses, which would not be possible using a pure static model. Figure 3 shows the voltage and current sampling which is done at the moment of the trigger signal edge. This sampling scheme is called “synchronization” because the model is triggered externally to get the instantaneous load current and blocking voltage of the device without overshoot and oscillation. Together with the actual junction temperature and the gate drive condition the sampled values form the actual working point $W(t)=[V(t), I(t), T(t), R_{ON}(t), R_{OFF}(t)]$ are valid for every half of a switching cycle. Once the model has the working point information knowing the switching time due to the synchronization technique employed, the energy calculation can be performed by straight forward analytical formulation, which serves as either interpolation or extrapolation function of the data sheet or measurement values.

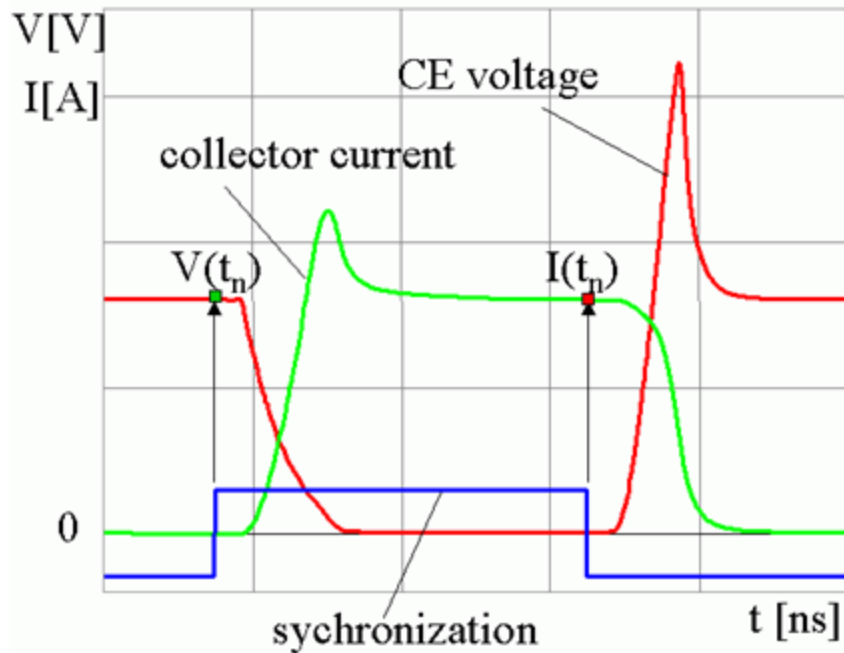


Figure 3. Synchronization Technique

The nominal working point W_{NOM} stands for nominal operating conditions found in a manufacturer data sheet, which includes the nominal blocking voltage V_{NOM} , the nominal load current I_{NOM} , the nominal junction temperature T_{NOM} and the usual gate drive conditions belong to the nominal working point. Assuming constant gate drive voltages and stray inductances in the gate circuit, the external gate resistors for the on-switch and off-switch belong to the nominal working point definition as:

$$W_{NOM}=[V_{NOM}, I_{NOM}, T_{NOM}, R_{ONNOM}(t), R_{OFFNOM}(t)]$$

When the model parameters are fitted to W_{NOM} the model will work accurately under this working condition. Normally during simulation, the blocking voltage remains constant at the bus bar

voltage. In case of fault condition this value may change in the range of 0...200%. For an inverter application the load current changes in the range of 0...100% periodically. As a consequence, the temperature will vary in the range of 300K to 420K (up to 140%) while the gate drive conditions remain unchanged. Usually the actual working point $W(t)$ differs from nominal condition W_{NOM} . As $W(t)$ deviates from W_{NOM} , the accuracy of the simulation decreases. Although $W(t)$ differs from W_{NOM} , the simulation results can be rectified by using the "working point correction coefficients" given below.

$$\begin{aligned} E_{ON} &= Y_{ON}(T, I, V, R, \alpha, \kappa, \sigma, \rho) \cdot E_{ON, NOM} \\ E_{OFF} &= Y_{OFF}(T, I, V, R, \alpha, \kappa, \sigma, \rho) \cdot E_{OFF, NOM} \\ E_{RR} &= Y_{RR}(T, I, V, R, \alpha, \kappa, \sigma, \rho) \cdot E_{RR, NOM} \end{aligned} \quad (2)$$

$$Y(T, I, V, R, \alpha, \kappa, \sigma, \rho) = X_T(T, \alpha) \cdot X_I(I, \kappa) \cdot X_V(V, \sigma) \cdot X_R(R, \rho) \quad (3)$$

where, X is a set of independent partial correction functions and

$\alpha, \kappa, \sigma, \rho$

are the correction coefficients calculated independently for each working point condition. Each product term of this approach can be fitted to a linear or power function X (as presented in Figure 4 and according to the Eq.5-8) which depends on either the interpolation or extrapolation conditions to ensure non-negative and limited values for the total working point correction function Y (shown in Eq. 3).

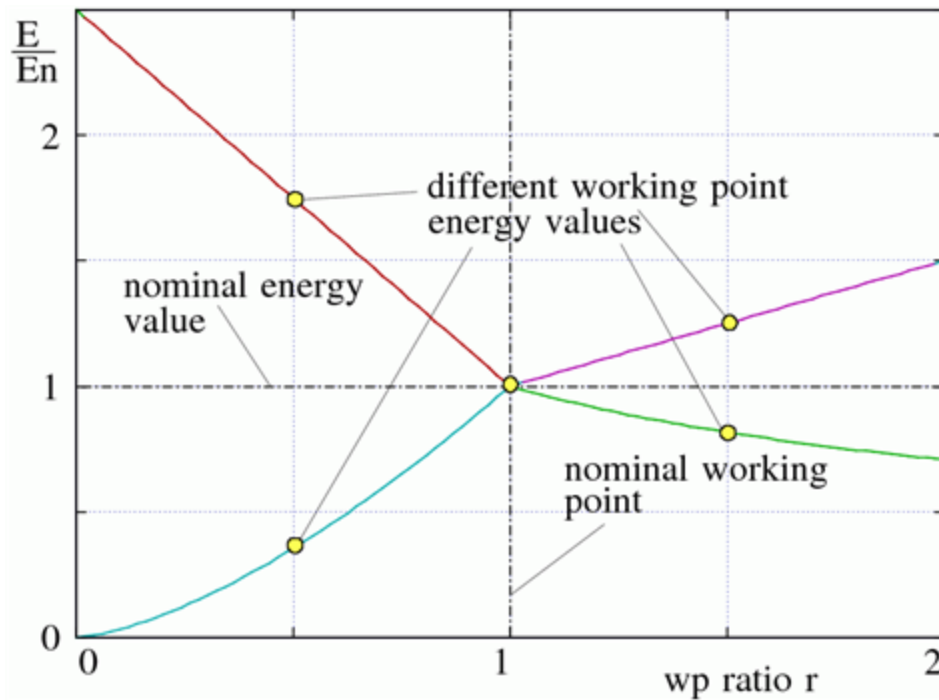


Figure 4. Working point correction coefficients map

The correction coefficients are extracted one by one by varying only the corresponding working point parameter (T , I , V or R) and holding the other parameters at their nominal values. To illustrate this procedure, the calculation of the temperature correction coefficient α is used as an example. The same extraction algorithm is applied to the other coefficients. To calculate temperature coefficient α , the energy values at a temperature different from the nominal condition (either greater or less than the nominal condition) are measured. As illustrated in the working point correction map (shown in Figure 4), a particular pattern, which represents the variation of partial correction function X , is chosen to compute the temperature correction coefficient based on the energy ratio and the working point ratio r_T . Using the Eq.2 and Eq.3 all terms are known except for the term $X_T(T, \alpha)$. Introducing Eq.3 into Eq.2 and knowing the measured value of the energy, the temperature partial correction function is given by,

$$X_T(T, \alpha) = \frac{E_{ON/OFF/RR}}{E_{ON/OFF/RR.NOM}} \quad (4)$$

Based on the employed mapping algorithm and the value of $X_T(T, \alpha)$ the correction coefficient for temperature can be evaluated. Now this temperature correction coefficient can be used to determine the partial correction function $X_T(T, \alpha)$ for any variation of the temperature during any simulation. As a general observation in this modeling approach, only one correction coefficient is used for temperature partial correction function estimation, while for voltage (Eq.6), current (Eq.7) and gate resistance (Eq.8) two correction coefficients are being used. Consequently, when considering the temperature dependency it is recommended that choose the nominal working point condition to reflect the hot temperature dependency.

$$r_T = \frac{T}{T_{NOM}}$$

$$X_T = \begin{cases} r_T^\alpha & \text{when } (r_T < 1.0 \text{ and } \alpha > 1.0) \text{ or } (r_T > 1.0 \text{ and } \alpha < 0.0) \\ 1 + \alpha \cdot (r_T - 1.0) & \text{when } (r_T < 1.0 \text{ and } \alpha \leq 1.0) \text{ or } (r_T > 1.0 \text{ and } \alpha \geq 0.0) \\ 1.0 & \text{when } r_T = 1.0 \end{cases} \quad (5)$$

$$r_V = \frac{V}{V_{\text{NOM}}}$$

$$X_V = \begin{cases} r_V^{\sigma_0} & \text{when } r_V < 1.0 \text{ and } \sigma_0 > 1.0 \\ 1 + \sigma_0 \cdot (r_V - 1.0) & \text{when } r_V < 1.0 \text{ and } \sigma_0 \leq 1.0 \\ r_V^{\sigma} & \text{when } r_V > 1.0 \text{ and } \sigma > 0.0 \\ 1 + \sigma \cdot (r_V - 1.0) & \text{when } r_V > 1.0 \text{ and } \sigma \leq 0.0 \\ 1.0 & r_V = 1.0 \end{cases}$$

(6)

$$r_I = \frac{I}{I_{\text{NOM}}}$$

$$X_I = \begin{cases} r_I^{\kappa_0} & \text{when } r_I < 1.0 \text{ and } \kappa_0 > 1.0 \\ 1 + \kappa_0 \cdot (r_I - 1.0) & \text{when } r_I < 1.0 \text{ and } \kappa_0 \leq 1.0 \\ r_I^{\kappa} & \text{when } r_I > 1.0 \text{ and } \kappa > 0.0 \\ 1 + \kappa \cdot (r_I - 1.0) & \text{when } r_I > 1.0 \text{ and } \kappa \leq 0.0 \\ 1.0 & r_I = 1.0 \end{cases}$$

(7)

$$r_R = \frac{R}{R_{\text{NOM}}}$$

$$X_R = \begin{cases} r_R^{\rho_0} & \text{when } r_R < 1.0 \text{ and } \rho_0 > 1.0 \\ 1 + \rho_0 \cdot (r_R - 1.0) & \text{when } r_R < 1.0 \text{ and } \rho_0 \leq 1.0 \\ r_R^{\rho} & \text{when } r_R > 1.0 \text{ and } \rho > 0.0 \\ 1 + \rho \cdot (r_R - 1.0) & \text{when } r_R > 1.0 \text{ and } \rho \leq 0.0 \\ 1.0 & r_R = 1.0 \end{cases}$$

(8)

In the partial temperature correction function $X_T(T, \alpha)$, T denotes the Kelvin temperature. All functions take the value 1 for the nominal working point as shown in Figure 4. The “wp ratio” represents the ratio between the actual temperature, voltage, current, gate resistance and their corresponding nominal values. For working point conditions different from the nominal working point ($r=1$), larger or smaller loss energy values are given by the data sheet or measurements (indicated as points in Figure 4). The partial correction functions are designed to result in non-negative and limited values for all possible working point conditions. All correction functions

meet the nominal working point in [1,1] which ensure the best accuracy for the nominal working point and exhibit a knee at $r=1$ because the functions are double sided to reproduce the full operating range of the device at a minimum energy error.

Thermal Model

The average power MOSFET model contains the same thermal model that is used in basic dynamic power MOSFET model.

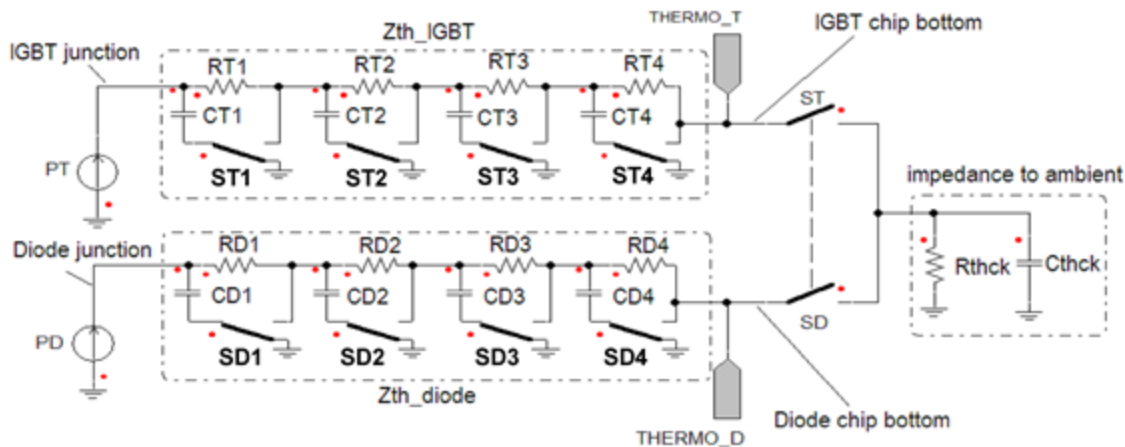


Figure 5. Thermal Network of the MOSFET models

In the Average MOSFET model, the power injection (PD and PT in Figure 5) are pulse-wise waveforms, and their amplitude is calculated using the switching/conduction energy losses and the user-specified pulse width. The pulse width is related to the setting of the thermal behavior level. The average IGBT model provides three thermal behavior levels: isothermal, average and dynamic. Users can change this setting in the **Thermal Parameters** tab of the component parameters.

When **Thermal Behavior Level** is set to dynamic, the switching pulses are calculated and injected into the thermal network at each switching period. Users need to specify TON, TOFF and TRR according to the datasheet of the device. This option provides the detailed transient behavior of the junction temperature, but requires a relatively small minimum time step and therefore results in lower simulation speed. The power injections during the on/off switch and conduction are calculated as follows:

On switch power injection: $P_{ON} = E_{ON}/T_{ON}$

Off switch power injection: $P_{OFF} = E_{OFF}/T_{OFF}$

Conduction power injection is directly calculated from current and voltage on internal transistor and diode; loss on stray elements is excluded from injected power.

When **Thermal Behavior Level** is set to average, average power pulse amplitude is calculated over a user-specified sampling time T_{SAMPLE} , which can be several times the switching period. The average thermal behavior preserves the transient trend of the junction temperature without the dynamic detail, and increases the simulation speed using minimum simulation time step

requirements. A comparison between the dynamic and the average thermal behavior is made in Figure 6.

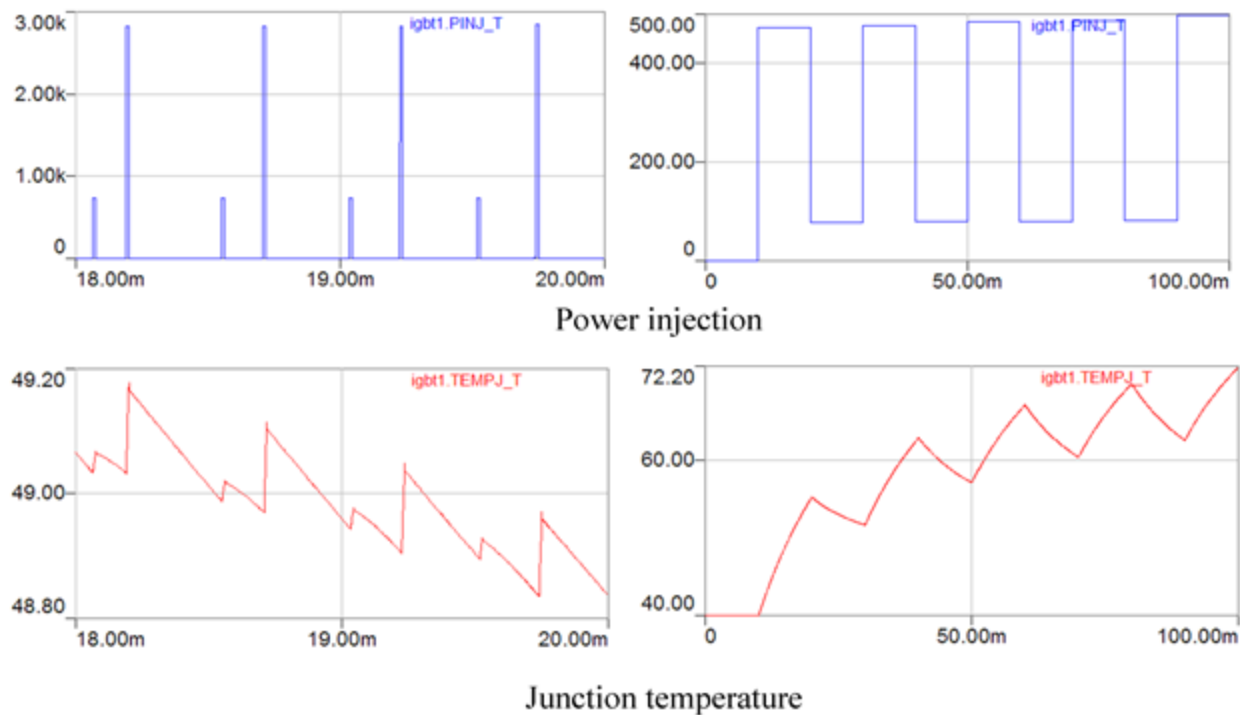


Figure 6. Comparison between the dynamic(left) and the average(right) thermal behavior of the Average IGBT model

The following table summarizes the use of different thermal behavior levels:

Thermal Behavior Level	Simulation Goal	Hmin*	Other Parameters
Average	Estimate average junction temperature and its transient trend without dynamic detail. Short simulation time	<1/20 of duty cycle; Hmax can be large.	TSAMPLE is integer times of switching cycle
Dynamic	Estimate maximum junction temperature with dynamic detail. Long simulation time.	<1/15 of Min (TON,TOFF,TRR); Hmax cannot be much larger.	TON, TOFF and TRR from datasheet or measurement

* Principle of setting simulation time step Hmin is: At least 20-30 steps per duty cycle (conducting cycle), and 15-20 steps per switching power pulse (For dynamic thermal behavior level only, switching power pulse duration is set by TON, TOFF, and TRR). For dynamic thermal behavior, Hmax cannot be too much larger than Hmin, or the switching energy may have a large error.

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Netlist Syntax

NOTE: THERM_T and THERM_D only exist in the NIGBT_Average_T and PIGBT_Average_T models.

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
DRAIN	Drain	electrical
SOURCE	Source	electrical
AUX_SOURCE	Auxiliary Source	electrical
GATE	Gate	electrical
THERM_T	MOSFET Die Bottom Thermal Contact	thermal
THERM_D	Diode Die Bottom Thermal Contact	thermal

NOTE: THERM_T and THERM_D pins only exist in the NIGBT_Average_T and PIGBT_Average_T models.

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Parameters

Table 2. General Parameters

Name	Description	Data Type
TYPE_FET	MOSFET Type Flag -2:p-Type 2:n-Type	real
TYPE_FWD	Freewheeling Diode Type 0:no 1:static	real

TYPE_DYN	Modeling Flags x0: static x1: dynamic 0x: no sync 1x: external sync 2x: internal sync derived from VGE	real
TYPE_THERM	xxx0: isothermal behavior xxx1: average behavior xxx2: dynamic behavior xx0x: partial fractional therm. network xx1x: cont. fractional therm. network x0xx: output only rise x1xx: output in degrees Celsius x2xx: output in Kelvin 0xxx: diode and transistor on separated dies 1xxx: diode and transistor on a single die	real
TYPE_BREAKTHROUGH	0:disable breakthrough 1:enable breakthrough	real

Table 3. Static Model Parameters

Name	Description	Data Type
VNOM	Nominal Drain-Source Voltage [V]	real
INOM	Nominal Drain Current [A]	real
TNOM	Reference Temperature [°C]	real
A_FET	Saturation Factor of internal FET	real
TC_A_FET	Temperature Coefficient of A_FET	real
M_FET	Saturation Exponent of internal FET	real
TC_M_FET	Temperature Coefficient of M_FET	real
N_FET	Exponent of Transfer Characteristic of FET	real

TC_N_FET	Temperature Coefficient of N_FET	real
K	Transistor Constant of FET at TNOM	real
TC_K	Temperature Coefficient of K	real
RD0	Small Voltage Bulk Resistance [Ohm]	real
TC_RD0	Temperature Correction Coefficient of RD0	real
RD1	Large Voltage Bulk Resistance [Ohm]	real
TC_RD1	Temperature Correction Coefficient of RD1	real
RDV	Bulk Resistance Inflection Voltage [V]	real
TC_RDV	Temperature Correction Coefficient of RDV	real
VP	Pinch-off-Voltage of FET at TNOM [V]	real
TC_VP	Temperature Coefficient of VP	real
KLM	Channel Length Modulation Factor of FET [1/V]	real
VBREAK_DS	Breakthrough Drain-Source Voltage [V]	real
VBREAK_GS	Breakthrough Gate-Source Voltage [V]	real
IBREAK	Breakthrough Drain Current [A]	real
TEMPBREAK	Breakthrough Junction Temperature [°C]	real
RFAULT_DS	Drain-Source Resistance after Fault [Ohm]	real
RFAULT_GS	Gate-Source Resistance after Fault [Ohm]	real

Table 4. Switching Loss Model Parameters

Name	Description [Unit]	Data Type
EON_NOM	Nominal On-Switch Loss Energy [J]	real
EOFF_NOM	Nominal Off-Switch Loss Energy [J]	real
ERR_NOM	Nominal Reverse Recovery Loss Energy [J]	real
RG_ON	On-Switch External Gate Resistance [ohm]; This is not a physical resistance but the value of gate resistance in the external gate drive. Users should include proper gate resistance in their designs and put the value in this parameter.	real

RG_OFF	Off-Switch External Gate Resistance [ohm]; This is not a physical resistance but the value of gate resistance in the external gate drive. Users should include proper gate resistance in their designs and put the value in this parameter.	real
RGNOM_ON	Nominal On-Switch External Gate Resistance [ohm]	real
RGNOM_OFF	Nominal Off-Switch External Gate Resistance [ohm]	real
TC_EON	Temperature coefficient of EON	real
CC0_EON	Current coefficient of EON (IC	real
CC_EON	Current coefficient of EON (IC>=ICNOM)	real
VC_EON	Voltage coefficient of EON	real
RC0_EON	Gate resistance coefficient of EON (RG_ON	real
RC_EON	Gate resistance coefficient of EON (RG_ON>=RGNOM_ON)	real
TC_EOFF	Temperature coefficient of EOFF	real
CC0_EOFF	Current coefficient of EOFF (IC	real
CC_EOFF	Current coefficient of EOFF (IC>=ICNOM)	real
VC_EOFF	Voltage coefficient of EOFF	real
RC0_EOFF	Gate resistance coefficient of EOFF (RG_OFF	real
RC_EOFF	Gate resistance coefficient of EOFF (RG_ON>=RGNOM_OFF)	real
TC_ERR	Temperature coefficient of ERR	real
CC0_ERR	Current coefficient of ERR (IC	real
CC_ERR	Current coefficient of ERR(IC>=ICNOM)	real
VC0_ERR	Voltage coefficient of ERR (VC<VCNOM)	real
VC_ERR	Voltage coefficient of ERR (VC<VCNOM)	real
RC0_ERR	Gate resistance coefficient of ERR (RG_ON	real
RC_ERR	Gate resistance coefficient of ERR (RG_ON>=RGNOM_ON)	real
SYNC	External synchronization signal	real

Note: External synchronization signal SYNC is a trigger **necessary** for the device model to behave correctly. It is required to cross zero in positive direction only when device start conducting, and cross zero in negative direction only when device stop conducting or when I_{rr} is formed. It is preferable to use an ideal pulse wave, or trapezoidal wave. When using ideal pulse wave, a signal change between zero and a positive value is also supported.

Note that the synchronization signal may not be the same as the gate drive signal for the same device. Rule of thumb is to give a clear rising edge or zero crossing signal at the moment when the conducting status of a device changes, or when current flows on the device start to change.

Table 5. Thermal Parameters

Name	Description [Unit]	Data Type
TEMPAMB	Ambient Temperature [°C]*	real
TEMPJNCT0	Junction Temperature at Simulation Start [°C]*	real
CTHT1	1. thermal transistor capacity [F]	real
RTHT1	1. thermal transistor resistance [ohm]	real
CTHT2	2. thermal transistor capacity [F]	real
RTHT2	2. thermal transistor resistance [ohm]	real
CTHT3	3. thermal transistor capacity [F]	real
RTHT3	3. thermal transistor resistance [ohm]	real
CTHT4	4. thermal transistor capacity [F]	real
RTHT4	4. thermal transistor resistance [ohm]	real
CTHD1	1. thermal diode capacity [F]	real
RTHD1	1. thermal diode resistance [ohm]	real
CTHD2	2. thermal diode capacity [F]	real
RTHD2	2. thermal diode resistance [ohm]	real
CTHD3	3. thermal diode capacity [F]	real
RTHD3	3. thermal diode resistance [ohm]	real
CTHD4	4. thermal diode capacity [F]	real
RTHD4	4. thermal diode resistance [ohm]	real
CTHDT	common thermal capacitance [F]	real
RTHDT	common thermal resistance [ohm]	real
TON	on switch power pulse time [s] (dynamic thermal behavior)	real
TOFF	off switch power pulse time [s] (dynamic thermal behavior)	real
TRR	reverse recovery power pulse time [s] (dynamic thermal behavior)	real
TSAMPLE	Thermal sampling time [s] (average thermal behavior)	real

* The unit in which those output values are created depends on the unit flag in the TYPE_THERM parameter (raise only, °C, or K).

Table 6. Parameter FWD Model

Name	Description [Unit]	Data Type
M_FWD	Ideality Factor of FWD at TNOM (static parameter)	real
ISAT_FWD	Saturation Current of FWD at TNOM [A] (static parameter)	real
RB_FWD	Bulk Resistance of FWD at TNOM [ohm] (static parameter)	real
TC_M_FWD	Temperature Coefficient of M_FWD (static parameter)	real
TC_ISAT_FWD	Temperature Coefficient of ISAT_FWD (static parameter)	real
TC_RB_FWD	Temperature Coefficient of RB_FWD	real

Table 7. Parameters of External Connections

Name	Description [Unit]	Data Type
RD	Drain Connector Resistance [Ohm]	real
RS	Source Connector Resistance [Ohm]	real
RAUX	Internal Source Resistance	real
LD	Drain Connector Inductance [H]	real
LG	Gate Connector Inductance [H]	real
LS	Source Connector Inductance [H]	real
LAUX	Internal Source Inductance	real

Input/Output Quantities

Table 8. Model Outputs

Name	Description [Unit]
VDS	Drain-Source Voltage [V], terminal voltage waveform, positive for n- and p- channel devices
I_D	Drain Current [A], total drain current, positive in drain to source direction
I_G	Gate Current [A]
IFD	FWD Current [A], free wheeling diode current waveform, positive in diode conducting direction
V_D	FWD Voltage Drop [V], positive in diode conducting direction]
TRANSCOND	Trans Conductance [A/V], definition is $S = d(I_d)/d(V_{gs})$, depends on the DC quiescent point and is valid for AC simulations
OUTCOND	Output Conductance [A/V], definition is $G = d(I_d)/d(V_{ds})$, depends on the DC quiescent point and is valid for AC simulations
TEMPJ_T	Wave form of the transistor junction temperature [°C, K]* at the transistor hot spot at the point of power injection, accuracy depends on correct total power calculation and an appropriate thermal network for the transistor heat dissipation
TEMPJ_D	Wave form of the Diode junction temperature [°C, K]* at the diode hot spot, the point of power injection, accuracy depends on correct total power calculation and an appropriate thermal network for the diode heat dissipation
TEMPBOT_T	MOSFET bottom temperature [°C, K]* at the end of the transistor four stage thermal chain. If

	external heat pins are used this is the node temperature, else it is equal TEMP_PLATE
TEMPBOT_D	Diode bottom temperature [°C, K]* at the end of the diode four stage thermal chain. If external heat pins are used this is the node temperature, else equal TEMP_PLATE
TEMP_PLATE	Temperature difference [°C, K]* across the one stage internal heat sink if internal sink is selected, else ambient temperature
PINJ_T	Transistor thermal model power injection [W], sum of DC and switching loss
PINJ_D	Diode thermal model power injection [W], sum of DC and switching loss
PEL_T	DC losses of transistor [W]
PEL_D	DC losses of Diode [W]
STEP	actual time step size [s]
E_ON	on switching energy [J]
E_OFF	off switching energy [J]
E_RR	loss energy of diode reverse recovery [J]
VDS_FAULT	Vds fault flag [0/1], Vds hits the absolute limits, can be watched during the simulation for break at fault
VGS_FAULT	Vgs fault flag [0/1]
ID_FAULT	drain current fault flag [0/1]
TEMPJ_FAULT	junction temperature fault flag [0/1]

The units in which those output values are created depend on the unit flag in the TYPE_THERM parameter (raise only, °C, or K).

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Example

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References

Dynamic GTO Model

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

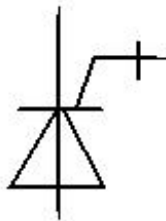


Figure 1. Component symbol

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Description

The static behavior of the model (normal mode and reverse operation) is determined by static diode models and current-controlled current sources. The dynamic behavior is determined by nonlinear capacitances (junction and diffusion capacitances).

All diode models use an exponential characteristic with the same value of saturation current defined by the model parameter IS (see figure below). The emission coefficients NF and NR affect the thermal voltages of the internal diode models. NF affects the diodes at the Anode and Cathode; NR is used for the diodes DMPNP and DMNPN, which model the reverse operation mode of the GTO.

For all current amplification factors in common mode constant values are used. The current amplification of ITCNNPN is adjustable by the parameter K. Recommended values for K are in the range of 1 to 5.

Due to the short time constants of the systems, a small value of the minimum step size (usually some nanoseconds) should be set. The influences of the parameters on the model behavior are listed below:

Table 1

Modification	Element	Effect
Increase of TT1	CNL_DIDA	Increase of current rise time Increase of peak reverse current
Increase of CJO1	CNL_SPDA	Increase of gate-controlled delay time
Increase of TT2	CNL_DIDMP, CNL_DIDMN	Increase of critical hold-off interval
Increase of CJO2	CNL_SPDMP, CNL_SPDMN	Decrease of gate-controlled delay time
Increase of TT3	CNL_DIDC	Increase of current rise time
Increase of CJO3	CNL_SPDC	Increase of gate-controlled delay time
Increase of K	ICNNPN	Increase of gate trigger current

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Assumptions and Limitations

This model does not consider the influence of critical rates of change in voltage and current in the outer circuit on the switching behavior of the GTO.

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Mathematical Description

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Netlist Syntax

```
MODEL GTO4 ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) ANODE:= %0, GATE:= %1, CATHODE:= %2 ( IS:= @IS, NF:= @NF, NR:= @NR, TT1:= @TT1, TT2:= @TT2, TT3:= @TT3, CJO1:= @CJO1, CJO2:= @CJO2, CJO3:= @CJO3, RA:= @RA, RG:= @RG, RC:= @RC, K:= @K) SRC: DB(Lib:=@ModelLibraryName);
```

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Conservative Pins

Table 2

Name	Port/Terminal Description	Nature/Data Type
ANODE	Anode Pin	electrical
GATE	Gate Pin	electrical
CATHODE	Cathode Pin	electrical

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Parameters

Table 3

Name	Description	Data Type	Default Value [Unit]
IS	Saturation Current, static parameter	real	10f [A]
NF	Forward Emission Coefficient, static parameter	real	1.5
NR	Reverse Emission Coefficient, static parameter	real	1
RA	Bulk Resistance Anode, static parameter	real	1m [Ohm]
RG	Bulk Resistance Gate, static parameter	real	5m [Ohm]
RC	Bulk Resistance Cathode, static parameter	real	1m [Ohm]
K	Amplification Factor, static parameter	real	1
TT1	Carrier lifetime, dynamic parameter	real	10u [s]

	meter		
TT2	Carrier lifetime, dynamic parameter	real	0.5u [s]
TT3	Carrier lifetime, dynamic parameter	real	50n [s]
CJO1	Junction Capacitance, dynamic parameter	real	10n [F]
CJO2	Junction Capacitance, dynamic parameter	real	25n [F]
CJO3	Junction Capacitance, dynamic parameter	real	12u [F]

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Example

This example demonstrates the operating mechanism of the Dynamic GTO model through a simple circuit. The schematic of the example is shown in Figure 3, system parameters are listed in Table 4, and the simulation results are shown in Figure 4-5.

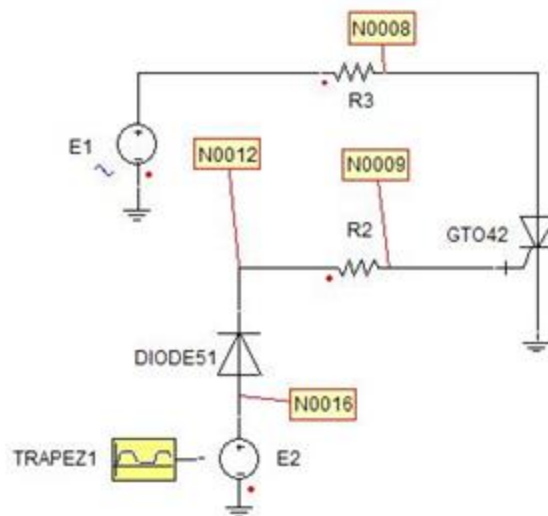


Figure 3. Application example of the Dynamic GTO model**Table 4. System Parameters**

Component	Parameter	Value [unit]
Resistor R2	R	5 [Ohm]
Resistor R3	R	10 [Ohm]
Trapezoidal Wave TRAPEZ1	AMPL	50
	TPERIO	20m [s]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [V]
	TRISE	100u [s]
	TFALL	100u [s]
	PWIDTH	2m [s]
Voltage Source E2	EMF	TRAPEZ1.val
Voltage Source (Sine) E1	AMPL	0.326k [V]
	FREQ	100 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [V]

* All the parameters of the Dynamic GTO model GTO42 and the Dynamic Diode model DIODE51 use their default values, therefore they are not included in the parameter table.

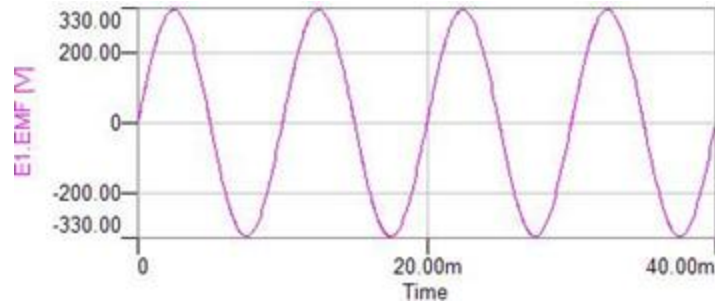


Figure 4. Simulation result-input voltage of GTO42

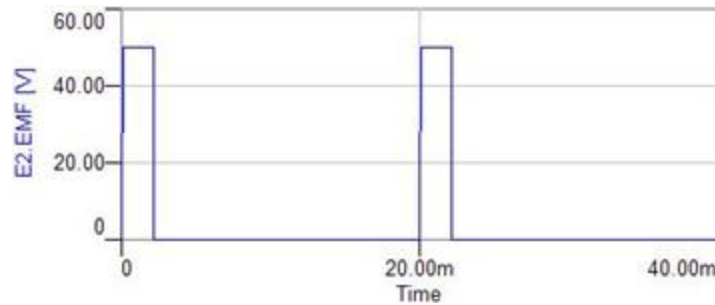


Figure 5. Simulation result-control voltage of GTO42

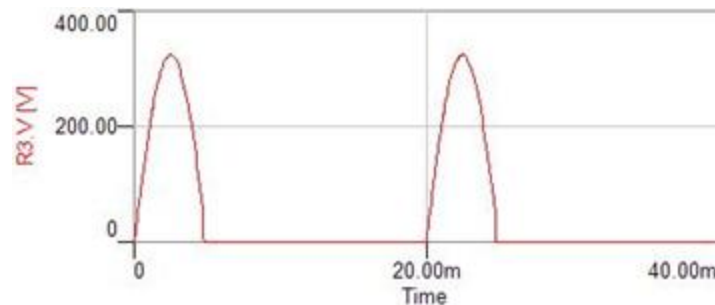


Figure 6. Simulation result-voltage across R3

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References

[1] Ned Mohan, Tore M. Undeland, William P. Robbins, "Power Electronics: Converters, Applications, and Design." John Wiley & Sons, INC. New York, 1995.

Advanced Dynamic IGBT Model

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

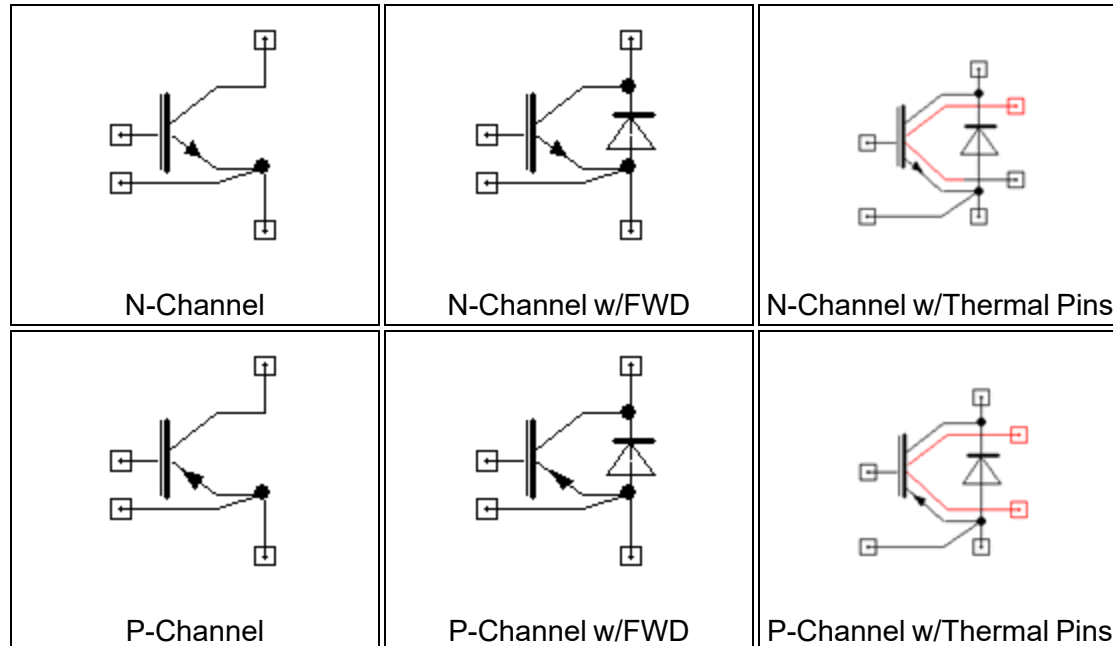


Figure 1. Component symbol

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Description

The IGBT model is a modular model with definable simulation levels. Different simulation depths can be selected for the electrical and thermal behavior of the model. For the models with a free wheeling diode (FWD) the simulation depth of the diode model can be set separately.

The IGBT is a combination of an MOSFET and a bipolar junction transistor (BJT). The internal MOSFET is similar to the single MOSFET model. Since the internal BJT is always in the forward

active regime, only its current gain B_{N0} is available as parameter of the IGBT model. The internal model of the free wheeling diode (FWD) is similar to that of the single diode.

You can define different levels for the electrical and the thermal behavior, respectively using the parameters `TYPE_DYN` and `TYPE_THERM`. Each level combination has a certain set of parameters. The values of them can be defined in the model dialog box. The component outputs are true of all types of the IGBT models. They are listed at the end of the model description.

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Assumptions and Limitations

Basic dynamic IGBT provides full switching dynamics but with limited tuning capability due to the number of parameters. Using the Device Characterization Wizard, the extracted model has a good match with measurements available in the datasheet, such as switching time and energy, but waveform details like level and duration of Miller plateau, voltage/current overshoot, and length of tail current may not be accurate.

Besides characteristics related parameters, basic dynamic IGBT requires the user to:

- Properly set the External Synchronization signal in Electrical Parameters
- Properly set H_{min} to guarantee 30-50 simulation steps during switching. In general, a minimum time step in order of nanoseconds is required.

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Mathematical Description

Electrical Model

The model uses an electrical equivalent circuit as shown in Figure 2.

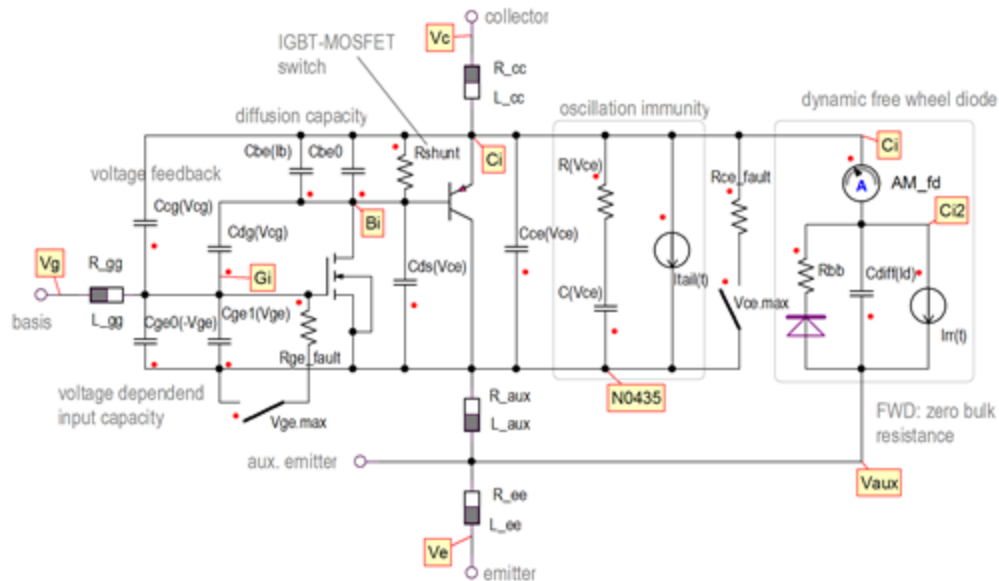


Figure 2. Equivalent circuit of the IGBT model

There are five simulation levels regarding the electrical behavior. The level is set at the parameter TYPE_DYN:

TYPE_DYN (10,000's position) allows the user to select if the extra base current injection controlled by TAU_S is used (1).

TYPE_DYN(1000's position) If 2 Both Cce and Cds used, If 1 only Cds, If 0 only Cce.

TYPE_DYN (100's position) If 2 Both Ccg and Cdg used, If 1 only Cdg, If 0 only Ccg.

TYPE_DYN (10's position) 2 internal sync, 1 external sync, 0 no sync.

TYPE DYN (0's position)

If 0 only the static behavior is calculated. The charges at the capacitances are ignored, no switching behavior.

If 1 in addition to the static behavior, charging and discharging of the junction and diffusion capacitance are calculated. Values of parasitic capacitances at the terminals can be defined.

If 2 the model is expanded by a current source that models the tail current between collector and emitter. The tail current is calculated considering the junction temperature and the influence of the collector current on the time constant of the tail current. At this level the dependency of the tail current on the collector-emitter voltage is taking into account in addition to all other effects modeled in the previous levels.

If 3 All previous effects plus the slope of VGE is taken into account in the model (when the proper parameterization of the working point correction is done).

The Following Applies to All Type DYN's:

The static model of the FET is modeled using a Schichman-Hodges model, using the parameters A_FET, K, KLM, M_FET, N_FET, VGAP and VP. All these parameters are modeled as temperature dependent except VGAP. Their temperature dependence is corrected using the parameters TC_AFET, TC_K, TC_KLM, TC_MFET, TC_NFET and TC_VP.

For the calculation of the static FET current a distinction is made between the linear region and the pinch-off region. The so-called saturation voltage is given by

$$V_{sat} = A_{FET} \cdot (V_{GS} - V_P)^{M_{FET}}$$

The transition from the linear region to the saturation region happens when the drain current satisfies the following equation:

$$I_{sat} = \frac{K}{2} \cdot (V_{GS} - V_P)^{N_{FET}}$$

Within the linear region, also called triode or ohmic region, the following equation is used:

$$I_D = I_{sat} \cdot (1 + KLM \cdot V_{DS}) \cdot \left(2 - \frac{V_{DS}}{V_{sat}}\right) \cdot \frac{V_{DS}}{V_{sat}}$$

and for the saturation region the following equation applies:

$$I_D = I_{sat} \cdot (1 + KLM \cdot V_{DS})$$

The static IGBT is modeled using a simple diode and gain model. The model uses the parameters BN, ISAT_BJT, M_BJT, RB_BJT and RP_BJT. All these parameters are temperature dependent. Their temperature dependence is calculated using TC_ISAT_BJT and TC_M_BJT. For the saturation current, the parameter is a correction on the physical temperature-based model which is used.

The static IGBT current is calculated by

$$I_C = BN \cdot I_B$$

where IB is the base current. Though in most cases IB=ID.

The base current is given by:

$$I_B = I_{SAT\_BJT} \cdot \left[e^{\frac{V_{BE}}{(M\_BJT \cdot V_T)}} - 1 \right]$$

where V_{BE} is the base-emitter voltage of the BJT, and M_BJT is the ideality factor. The saturation current I_{SAT_BJT} is temperature dependent and is calculated using the parameter I_{SAT0} and the actual junction temperature imported from the thermal model. The temperature voltage V_T is calculated as following:

$$V_T = \frac{k \cdot (TEMP\_JNCT + 273\text{ K})}{q}$$

where k is the Boltzmann constant, and $k=1.381\text{E-}23\text{ m}^2\text{ kg s}^{-2}\text{ K}^{-1}$; q is the elementary charge, and $q=1.602\text{E-}19\text{ C}$.

The temperature-dependent parameters are known at the nominal temperature T_{NOM} through parameters of the model. During the simulation their actual values are calculated taking into account the actual value of the junction temperature taken from the thermal model.

The Freewheeling diode is modeled as a simple diode in series with a current-dependent resistor. The parameters M_FWD , I_{SAT_FWD} and R_{B_FWD} are used to model the FWD. The temperature coefficients M_FWD , I_{SAT_FWD} and R_{B_FWD} are used to calculate the temperature dependence of the diode. The static current of the FWD (if enabled) is given by the following formula:

$$I_{FWD} = I_{SAT\_FWD} \cdot \left[e^{\frac{V_{FWD}}{(M\_FWD \cdot V_T)}} - 1 \right]$$

Where V_{FWD} is the voltage over the FWD.

The series resistance is current dependent and given by:

$$\frac{R_{B\_FWD}}{\sqrt{1 + \frac{I_{FWD}}{I_{NOM}}}}$$

The model has built-in fault detection. During the simulation the collector current, the voltage drop from gate to emitter and from collector to emitter as well as the junction temperature are observed. The model behavior changes if the limitations are exceeded. The switches controlled by the FAULT flags are closed and the respective fault resistances determine the model characteristic. If an over voltage occurs across gate-emitter, only R_{FAULT_GE} comes into effect. All other faults affect R_{FAULT_CE} .

Dynamic Behavior

All capacitance between the terminals are modeled the same way. A distinction is made between a region where a depletion capacitance is calculated and a region with enhancement capacitance behavior. The curves remain differentiable even at the transition from one region to the other. The transition happens if the difference of a defined fraction of the diffusion and the voltage across the junction equals zero according to

$$\text{SHIFT} \cdot \text{VDIFF} - V_{\text{JNCT}} = V^*_{\text{JNCT}} = 0$$

For positive values of V^*_{JNCT} (enhancement region) the following formula is used to calculate the capacitance

$$C(V^*_{\text{JNCT}}) = C0 \cdot \left(1 + (\text{BETA} - 1) \cdot \left(1 - e^{-\frac{V^*_{\text{JNCT}} \cdot \text{ALPHA} \cdot (1 - \text{DELTA})}{(\text{BETA} - 1) \cdot \text{VDIFF}}} \right) \right)$$

At negative values of V^*_{JNCT} (depletion region) the following formula applies

$$C(V^*_{\text{JNCT}}) = C0 \left(\text{DELTA} + \frac{1 - \text{DELTA}}{\left(1 - \frac{V^*_{\text{JNCT}}}{\text{VDIFF}} \right)^{\text{ALPHA}}} \right)$$

The capacitances at C_{gc} are modeled using the parameters $C0\_CG$, DELTA_CG_ON , DELTA_CG_OFF , ALPHA_CG_OFF , ALPHA_CG_ON , BETA_CG_ON , BETA_CG_OFF , VSHIFT_CG_ON , VSHIFT_CG_OFF , VDIFF_CG_ON and VDIFF_CG_OFF . DELTA_CG_ON and DELTA_CG_OFF are corrected by TC_DELTA_CG_ON and TC_DELTA_CG_OFF for the temperature, CC0_DELTA_CG_ON and CC_DELTA_CG_ON and CC0_DELTA_CG_OFF and CC_DELTA_CG_OFF for the current, VC0_DELTA_CG_ON and VC_DELTA_CG_ON and VC0_DELTA_CG_OFF and VC_DELTA_CG_OFF for the voltage and SC0_DELTA_CG_ON and SC_DELTA_CG_ON and SC0_DELTA_CG_OFF and SC_DELTA_CG_OFF for the slope of VGE.

The capacitance at C_{ce} and at C_{ds} are modeled by the parameters $C0\_CE$, VDIFF_CE , VSHIFT_CE , ALPHA_CE , DELTA_CE and BETA_CE .

THE CGE capacitance is modeled differently. It uses the parameters $C0\_GE$, VSHIFT_GE , ALPHA_GE and DELTA_GE . But the capacitance is modeled as two anti-parallel capacitances; when one is in deep depletion, the other is in enhancement. There is an overlapping depletion region, where the capacity drops as it was a ditch. The parameter $C0\_GE$ is corrected at a different working point by the parameters TC_C0_GE , CC0_C0_GE , CC_C0_GE , VC0_C0_GE and VC_C0_GE (for the temperature, current and voltage).

The diffusion capacitances at the base-emitter path of the BJT and at the FWD are modeled using the same approach and the parameters TAU_BE and TAU_FWD. TAU_BE is corrected for the temperature by TC_TAU_BE, the current by CC0_TAU_BE and CC_TAU_BE and the voltage by VC0_TAU_BE and VC_TAU_BE. TAU_FWD is corrected for the temperature by TC_TAU_FWD, the current by CC0_TAU_FWD and CC_TAU_FWD, the voltage by VC0_TAU_FWD and VC_TAU_FWD and the slope of VGE by SC0_TAU_FWD and SC_TAU_FWD. :

$$C_{diff} = TAU \cdot \frac{i(t) + ISAT}{M \cdot V_T}$$

To damp the oscillations that may occur in the system, additional damping resistances are placed in the model. The values of the damping resistances depend on the parameters DAMPING_C and DAMPING_R, the values of the parasitic inductances and the values of the internal capacitances.

$$R_{DAMP} = DAMPING \cdot \sqrt{\frac{L}{C(V)}}$$

Tail Current and Reverse Recovery Current

The tail current is calculated from the point of the off-switch trigger, as this is a stable measurement point compared to the falling current edge. TAU_S controls the duration of the extra base current injection. TAUTAIL and DELTATAIL influence the tail C-E current. DELTATAIL sets the magnitude, while TAUTAIL sets the duration. If TAU_S gets large it will interfere with the current tail definition.

TAU_S is corrected for the temperature by TC_TAU_S, the current by CC0_TAU_S and CC_TAU_S, the voltage by VC0_TAU_S and VC_TAU_S and the slope of VGE by SC0_TAU_S and SC_TAU_S. TAU_TAIL is corrected for the temperature by TC_TAU_TAIL, the current by CC0_TAU_TAIL and CC_TAU_TAIL, the voltage by VC0_TAU_TAIL and VC_TAU_TAIL and the slope of VGE by SC0_TAU_TAIL and SC_TAU_TAIL. DELTA_TAIL is corrected for the temperature by TC_DELTA_TAIL, the current by CC0_DELTA_TAIL and CC_DELTA_TAIL, the voltage by VC0_DELTA_TAIL and VC_DELTA_TAIL and the slope of VGE by SC0_DELTA_TAIL and SC_DELTA_TAIL.

Please note: the value of the voltage influencing the tail current is taken from the previous switching-on. Therefore the level does not give proper results for fault simulation and should be used only for investigations of periodic switching processes.

Freewheeling Diode Model

The freewheeling diode model is the same as the single diode model without junction capacitance. The behavior of the diode model can be set using TYPE_FWD.

TYPE_FWD=0 No FWD

TYPE_FWD=1 Static FWD

TYPE_FWD=2 or 3 Dynamic FWD with reverse recovery

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The total excess carrier charge during the switch to the on-state is controlled by the parameter TAU_FWD. The reverse recovery charge, Q_{rr} , is smaller because of charge extraction during the on-state. The current is modeled to be continuous and continuously differentiable. The total stored excess charge before switching off is the FWD diffusion charge. The maximum reverse current, the current slopes, the remaining charge after the current crosses zero and the duration of the reverse recovery are depend on the circuit conditions. The parameters $R1\_FWD$, $R2\_FWD$, $R3\_FWD$, $SF1\_FWD$ and $SF2\_FWD$ control the shape of the reverse recovery current. TC_R2 corrects $R2\_FWD$ for temperature, $CC0\_R2$ and CC_R2 correct it for current, $VC0\_R2$ and VC_R2 correct it for voltage, while $SC0\_R2$ and SC_R2 correct it for the slope of VGE. TC_SF1 and TC_SF2 correct $SF1\_FWD$ and $SF2\_FWD$ for temperature, $CC0\_SF1$ and CC_SF1 and $CC0\_SF2$ and CC_SF2 correct them for current, $VC0\_SF1$ and VC_SF1 and $VC0\_SF2$ and VC_SF2 correct them for voltage, while $SC0\_SF1$ and SC_SF1 and $SC0\_SF2$ and SC_SF2 correct them for the slope of VGE.

The shape of the reverse recovery current is illustrated in the following figures:

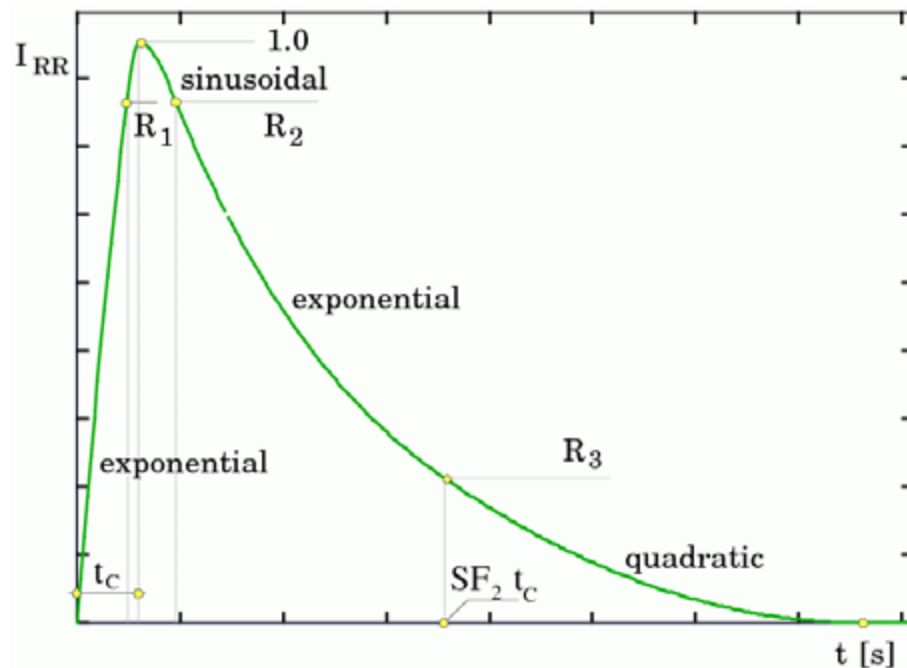


Figure 3a. Shape parameters R and SF for exponential current decay

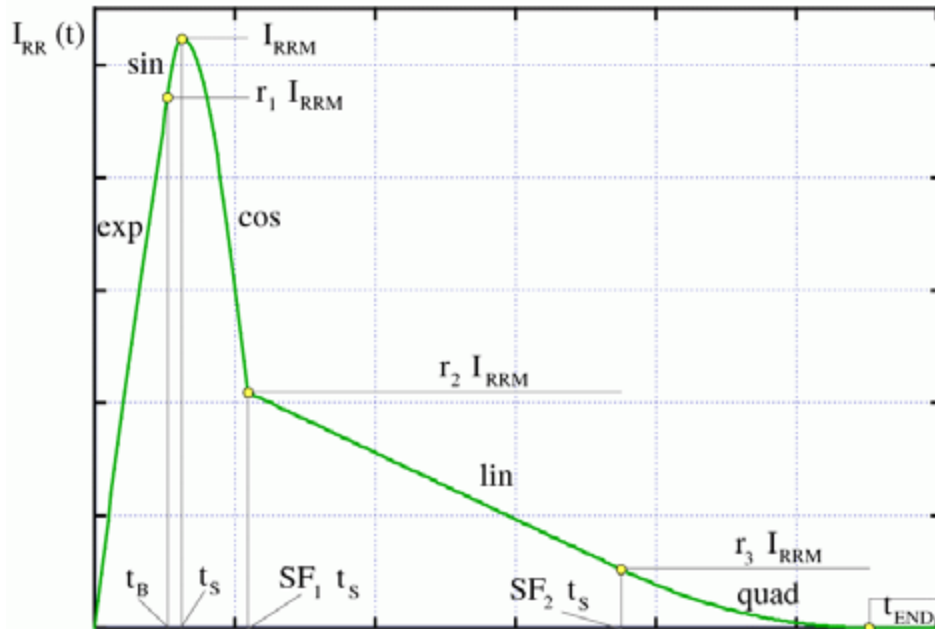


Figure 3b. Shape parameters for the piecewise linear current decay (hard recovery can be modelled)

Netlist Syntax

```

UMODEL IGBT_AdvDyn ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) GATE:= %0,
AUX_EMITTER:= %1, EMITTER:= %2, COLLECTOR:= %3 ( TYPE_IGBT:=@TYPE_IGBT,
TYPE_FWD:=@TYPE_FWD, TYPE_THERM:=@TYPE_THERM, TYPE_DYN:=@TYPE_DYN,
TYPE_OUT:=@TYPE_OUT, TYPE_BREAKTHROUGH:=@TYPE_BREAKTHROUGH, VP:-
:=@VP, K:=@K, KLM:=@KLM, A_FET:=@A_FET, M_FET:=@M_FET, N_FET:=@N_FET, BN:-
:=@BN, M_BJT:=@M_BJT, ISAT_BJT:=@ISAT_BJT, :=@RB_BJT, RP_BJT:=@RP_BJT, M_
FWD:=@M_FWD, ISAT_FWD:=@ISAT_FWD, RB_FWD:=@RB_FWD, C0_GE:=@C0_GE,
VSHIFT_GE:=@VSHIFT_GE, ALPHA_GE:=@ALPHA_GE, DELTA_GE:=@DELTA_GE, C0_
CG:=@C0.CG, VDIFF.CG_OFF:=@VDIFF.CG_OFF, VDIFF.CG_ON:=@VDIFF.CG_ON,
VSHIFT.CG_OFF:=@VSHIFT.CG_OFF, VSHIFT.CG_ON:=@VSHIFT.CG_ON, ALPHA_
CG_OFF:=@ALPHA.CG_OFF, ALPHA.CG_ON:=@ALPHA.CG_ON, BETA.CG_OFF:-
:=@BETA.CG_OFF, BETA.CG_ON:=@BETA.CG_ON, DELTA.CG_OFF:=@DELTA.CG_
OFF, DELTA.CG_ON:=@DELTA.CG_ON, C0_CE:=@C0.CE, VDIFF_CE:=@VDIFF_CE,
VSHIFT_CE:=@VSHIFT_CE, ALPHA_CE:=@ALPHA_CE, BETA_CE:=@BETA_CE, DELTA_
CE:=@DELTA_CE, TAU_BE:=@TAU_BE, TAU_S:=@TAU_S, TAU_T:=@TAU_T, TAU_FWD:-
:=@TAU_FWD, TAU_TAIL:=@TAU_TAIL, DELTA_TAIL:=@DELTA_TAIL, DAMP_
C:=@DAMP_C, DAMP_R:=@DAMP_R, R1_FWD:=@R1_FWD, R2_FWD:=@R2_FWD, R3_
FWD:=@R3_FWD, SF1_FWD:=@SF1_FWD, SF2_FWD:=@SF2_FWD, LC:=@LC, RC:-
:=@RC, LG:=@LG, RG:=@RG, LAUX:=@LAUX, RAUX:=@RAUX, LE:=@LE, RE:=@RE,
TEMPAMB:=@TEMPAMB, TEMPJNCT0:=@TEMPJNCT0, TNOM:=@TNOM, VNOM:-
:=@VNOM, INOM:=@INOM, SON_NOM:=@SON_NOM, SOFF_NOM:=@SOFF_NOM,
VGAP:=@VGAP, TC_VP:=@TC_VP, TC_K:=@TC_K, TC_NFET:=@TC_NFET, TC_AFET:-
:=@TC_AFET, TC_MFET:=@TC_MFET, TC_ISAT_BJT:=@TC_ISAT_BJT, TC_M_

```

BJT:=@TC_M_BJT, TC_ISAT_FWD:=@TC_ISAT_FWD, TC_M_FWD:=@TC_M_FWD, TC_RB_FWD:=@TC_RB_FWD, TC_C0_GE:=@TC_C0_GE, CC0_C0_GE:=@CC0_C0_GE, CC_C0_GE:=@CC_C0_GE, VC0_C0_GE:=@VC0_C0_GE, VC_C0_GE:=@VC_C0_GE, TC_RGG:=@TC_RGG, CC0_RGG:=@CC0_RGG, CC_RGG:=@CC_RGG, VC0_RGG:=@VC0_RGG, VC_RGG:=@VC_RGG, TC_C0_CG:=@TC_C0_CG, CC0_C0_CG:=@CC0_C0_CG, CC_C0_CG:=@CC_C0_CG, VC0_C0_CG:=@VC0_C0_CG, VC_C0_CG:=@VC_C0_CG, SC0_C0_CG:=@SC0_C0_CG, SC_C0_CG:=@SC_C0_CG, TC_SHIFT_OFF:=@TC_SHIFT_OFF, CC0_SHIFT_OFF:=@CC0_SHIFT_OFF, CC_SHIFT_OFF:=@CC_SHIFT_OFF, VC0_SHIFT_OFF:=@VC0_SHIFT_OFF, VC_SHIFT_OFF:=@VC_SHIFT_OFF, SC0_SHIFT_OFF:=@SC0_SHIFT_OFF, SC_SHIFT_OFF:=@SC_SHIFT_OFF, TC_SHIFT_ON:=@TC_SHIFT_ON, CC0_SHIFT_ON:=@CC0_SHIFT_ON, CC_SHIFT_ON:=@CC_SHIFT_ON, VC0_SHIFT_ON:=@VC0_SHIFT_ON, VC_SHIFT_ON:=@VC_SHIFT_ON, SC0_SHIFT_ON:=@SC0_SHIFT_ON, SC_SHIFT_ON:=@SC_SHIFT_ON, TC_DELTA_OFF:=@TC_DELTA_OFF, CC0_DELTA_OFF:=@CC0_DELTA_OFF, CC_DELTA_OFF:=@CC_DELTA_OFF, VC0_DELTA_OFF:=@VC0_DELTA_OFF, VC_DELTA_OFF:=@VC_DELTA_OFF, SC_DELTA_OFF:=@SC_DELTA_OFF, SC0_DELTA_OFF:=@SC0_DELTA_OFF, TC_DELTA_ON:=@TC_DELTA_ON, CC0_DELTA_ON:=@CC0_DELTA_ON, CC_DELTA_ON:=@CC_DELTA_ON, VC0_DELTA_ON:=@VC0_DELTA_ON, VC_DELTA_ON:=@VC_DELTA_ON, SC0_DELTA_ON:=@SC0_DELTA_ON, SC_DELTA_ON:=@SC_DELTA_ON, TC_BETA_OFF:=@TC_BETA_OFF, CC0_BETA_OFF:=@CC0_BETA_OFF, CC_BETA_OFF:=@CC_BETA_OFF, VC0_BETA_OFF:=@VC0_BETA_OFF, VC_BETA_OFF:=@VC_BETA_OFF, SC_BETA_OFF:=@SC_BETA_OFF, SC0_BETA_OFF:=@SC0_BETA_OFF, TC_BETA_ON:=@TC_BETA_ON, CC0_BETA_ON:=@CC0_BETA_ON, CC_BETA_ON:=@CC_BETA_ON, VC0_BETA_ON:=@VC0_BETA_ON, VC_BETA_ON:=@VC_BETA_ON, SC0_BETA_ON:=@SC0_BETA_ON, SC_BETA_ON:=@SC_BETA_ON, TC_DIFF_OFF:=@TC_DIFF_OFF, CC0_DIFF_OFF:=@CC0_DIFF_OFF, CC_DIFF_OFF:=@CC_DIFF_OFF, VC0_DIFF_OFF:=@VC0_DIFF_OFF, VC_DIFF_OFF:=@VC_DIFF_OFF, SC_DIFF_OFF:=@SC_DIFF_OFF, SC0_DIFF_OFF:=@SC0_DIFF_OFF, TC_DIFF_ON:=@TC_DIFF_ON, CC0_DIFF_ON:=@CC0_DIFF_ON, CC_DIFF_ON:=@CC_DIFF_ON, VC0_DIFF_ON:=@VC0_DIFF_ON, VC_DIFF_ON:=@VC_DIFF_ON, SC0_DIFF_ON:=@SC0_DIFF_ON, SC_DIFF_ON:=@SC_DIFF_ON, TC_C0_CE:=@TC_C0_CE, CC0_C0_CE:=@CC0_C0_CE, CC_C0_CE:=@CC_C0_CE, VC0_C0_CE:=@VC0_C0_CE, VC_C0_CE:=@VC_C0_CE, SC0_C0_CE:=@SC0_C0_CE, SC_C0_CE:=@SC_C0_CE, TC_DELTA_CE:=@TC_DELTA_CE, CC0_DELTA_CE:=@CC0_DELTA_CE, CC_DELTA_CE:=@CC_DELTA_CE, VC0_DELTA_CE:=@VC0_DELTA_CE, VC_DELTA_CE:=@VC_DELTA_CE, SC0_DELTA_CE:=@SC0_DELTA_CE, SC_DELTA_CE:=@SC_DELTA_CE, TC_TAU_BE:=@TC_TAU_BE, CC0_TAU_BE:=@CC0_TAU_BE, CC_TAU_BE:=@CC_TAU_BE, VC0_TAU_BE:=@VC0_TAU_BE, VC_TAU_BE:=@VC_TAU_BE, TC_TAU_S:=@TC_TAU_S, CC0_TAU_S:=@CC0_TAU_S, CC_TAU_S:=@CC_TAU_S, VC0_TAU_S:=@VC0_TAU_S, VC_TAU_S:=@VC_TAU_S, SC0_TAU_S:=@SC0_TAU_S, SC_TAU_S:=@SC_TAU_S, TC_TAU_T:=@TC_TAU_T, CC0_TAU_T:=@CC0_TAU_T, CC_TAU_T:=@CC_TAU_T, VC0_TAU_T:=@VC0_TAU_T, VC_TAU_T:=@VC_TAU_T, SC0_TAU_T:=@SC0_TAU_T, SC_TAU_T:=@SC_TAU_T, TC_TAU_FWD:=@TC_TAU_FWD, CC0_TAU_FWD:=@CC0_TAU_FWD, CC_TAU_FWD:=@CC_TAU_FWD, VC0_TAU_FWD:=@VC0_TAU_FWD, VC_TAU_FWD:=@VC_TAU_FWD, SC0_TAU_FWD:=@SC0_TAU_FWD, SC_TAU_FWD:=@SC_TAU_FWD, TC_SF1:=@TC_SF1, CC0_SF1:=@CC0_SF1, CC_SF1:=@CC_SF1, VC0_SF1:=@VC0_SF1, VC_SF1:=@VC_SF1, SC0_SF1:=@SC0_SF1, SC_SF1:=@SC_SF1, TC_SF2:=@TC_SF2, CC0_SF2:=@CC0_SF2, CC_SF2:=@CC_SF2, VC0_SF2:=@VC0_SF2, VC_SF2:=@VC_SF2, SC0_SF2:=@SC0_SF2, SC_SF2:=@SC_SF2,

TC_R2:=@TC_R2, CC0_R2:=@CC0_R2, CC_R2:=@CC_R2, VC0_R2:=@VC0_R2, VC_R2:-
 :=@VC_R2, SC0_R2:=@SC0_R2, SC_R2:=@SC_R2, TC_TAU_TAIL:=@TC_TAU_TAIL,
 CC0_TAU_TAIL:=@CC0_TAU_TAIL, CC_TAU_TAIL:=@CC_TAU_TAIL, VC0_TAU_TAIL:-
 :=@VC0_TAU_TAIL, VC_TAU_TAIL:=@VC_TAU_TAIL, SC0_TAU_TAIL:=@SC0_TAU_TAIL,
 SC_TAU_TAIL:=@SC_TAU_TAIL, TC_DELTA_TAIL:=@TC_DELTA_TAIL, CC0_DELTA_
 TAIL:=@CC0_DELTA_TAIL, CC_DELTA_TAIL:=@CC_DELTA_TAIL, VC0_DELTA_TAIL:-
 :=@VC0_DELTA_TAIL, VC_DELTA_TAIL:=@VC_DELTA_TAIL, SC0_DELTA_TAIL:=@SC0_
 DELTA_TAIL, SC_DELTA_TAIL:=@SC_DELTA_TAIL, TC_DAMP_C:=@TC_DAMP_C, CC0_
 DAMP_C:=@CC0_DAMP_C, CC_DAMP_C:=@CC_DAMP_C, VC0_DAMP_C:=@VC0_
 DAMP_C, VC_DAMP_C:=@VC_DAMP_C, SC0_DAMP_C:=@SC0_DAMP_C, SC_DAMP_
 C:=@SC_DAMP_C, TC_DAMP_R:=@TC_DAMP_R, CC0_DAMP_R:=@CC0_DAMP_R, CC_
 DAMP_R:=@CC_DAMP_R, VC0_DAMP_R:=@VC0_DAMP_R, VC_DAMP_R:=@VC_DAMP_
 R, SC0_DAMP_R:=@SC0_DAMP_R, SC_DAMP_R:=@SC_DAMP_R, TC_LAUX:=@TC_
 LAUX, CC0_LAUX:=@CC0_LAUX, CC_LAUX:=@CC_LAUX, VC0_LAUX:=@VC0_LAUX,
 VC_LAUX:=@VC_LAUX, SC0_LAUX:=@SC0_LAUX, SC_LAUX:=@SC_LAUX, VBREAK_CE:-
 :=@VBREAK_CE, VBREAK_GE:=@VBREAK_GE, IBREAK:=@IBREAK, TEMPBREAK:-
 :=@TEMPBREAK, RFAULT_CE:=@RFAULT_CE, RFAULT_GE:=@RFAULT_GE,
 CTHT1:=@CTHT1, RTHT1:=@RTHT1, CTHT2:=@CTHT2, RTHT2:=@RTHT2, CTHT3:-
 :=@CTHT3, RTHT3:=@RTHT3, CTHT4:=@CTHT4, RTHT4:=@RTHT4, CTHD1:=@CTHD1,
 RTHD1:=@RTHD1, CTHD2:=@CTHD2, RTHD2:=@RTHD2, CTHD3:=@CTHD3, RTHD3:-
 :=@RTHD3, CTHD4:=@CTHD4, RTHD4:=@RTHD4, CTHDT:=@CTHDT, RTHDT:=@RTHDT,
 SYNC:=@SYNC) SRC: DB(Lib:=@ModelLibraryName)

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
COLLECTOR	Collector	electrical
EMITTER	Emitter	electrical
AUX_EMITTER	Auxiliary Emitter	electrical
GATE	Gate	electrical

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Parameters

Table 2. Nominal Parameters

Name	Description [Unit]	Data Type

VNOM	Nominal Collector-Emitter Voltage [V]	real
INOM	Nominal Collector Current [A]	real
TNOM	Reference Temperature [°C]	real
SON_NOM	Nominal On-Switch Gate Voltage Slope [V/s]	real
SOFF_NOM	Nominal Off-Switch Gate Voltage Slope [V/s]	real
TEMPJNCT0	Junction Temperature at Simulation Start [°C]	real
TEMPAMB	Ambient Temperature [°C]	real

Table 3. Parameters of Connectors

Name	Description [Unit]	Data Type
LC	Collector Connector Inductance [H]	real
RC	Collector Connector Resistance [Ohm]	real
RE	Emitter Connector Resistance [Ohm]	real
LG	Emitter Connector Inductance [H]	real
LE	Source Connector Inductance [H]	real

Note: Parameters LC and LE determine internal R_{DAMP} as described in Dynamic Behavior.

Table 4. Static Parameters

Name	Description	Data Type
A_FET	Saturation Factor of internal FET	real
TC_AFET	Temperature Coefficient of A_FET	real
M_FET	Saturation Exponent of internal FET	real
TC_MFET	Temperature Coefficient of M_FET	real
N_FET	Exponent of Transfer Characteristic of FET	real

TC_NET	Temperature Coefficient of N_FET	real
K	Transistor Constant of FET at TEMP0	real
TC_K	Temperature Coefficient of K	real
VP	Pinch-off-Voltage of FET at TEMP0 [V]	real
TC_VP	Temperature Coefficient of VP	real
KLM	Channel Length Modulation Factor of FET [1/V]	real
VGAP	Band Gap Voltage of FET [V]	real
BN	Current Gain of BJT at TEMP0	real
ISAT_BJT	Saturation Current of BJT Base at TEMP0 [A]	real
TC_ISAT_BJT	Temperature Coefficient of ISAT	real
M_BJT	Ideality Factor of BJT Base at TEMP0	real
TC_M_BJT	Temperature Coefficient of M_BJT	real
RB_BJT	Bulk Resistance of BJT Base [Ohm]	real
RP_BJT	BJT Base Shut	real
VBREAK_CE	Breakthrough Collector-Emitter Voltage [V]	real
VBREAK_GE	Breakthrough Gate-Emitter Voltage [V]	real
IBREAK	Breakthrough Collector Current [A]	real
TEMPBREAK	Breakthrough Junction Temperature [°C]	real
RFAULT_CE	Collector-Emitter Resistance after Fault	real

	[Ohm]	
RFAULT_GE	Gate-Emitter Resistance after Fault [Ohm]	real

Table 5. Dynamic Parameters

Name	Description [Unit]	Data Type
C0_GE	Zero voltage Gate-Emitter Capacitance [F]	real
VSHIFT_GE	Shift of the symmetry line on the voltage axis	real
ALPHA_GE	Depth of the capacity ditch	real
DELTA_GE	Width of the capacity ditch	real
CO_CG	Collector-Gate Reference Capacitance [F]	real
VSHIFT_CG_ON	Voltage Shift of Collector-Gate Capacitance during the on-switch [V]	real
VSHIFT_CG_OFF	Voltage Shift of Collector-Gate Capacitance during the off-switch [V]	real
VDIFF_CG_ON	Diffusion Potential of Collector-Gate Capacitance during the on-switch [V]	real
VDIFF_CG_OFF	Diffusion Potential of Collector-Gate Capacitance during the off-switch [V]	real
ALPHA_CG_ON	Capacitance Exponent Collector-Gate during on-switch	real
ALPHA_CG_OFF	Capacitance Exponent Collector-Gate during off-switch	real
BETA_CG_ON	Peak Factor of Collector-Gate Capacitance during on-switch	real
BETA_CG_OFF	Peak Factor of Collector-Gate Capacitance during off-switch	real
DELTA_CG_ON	Influence of constant Capacitance at Collector-Gate during on-switch	real
DELTA_CG_OFF	Influence of constant Capacitance at Collector-Gate during off-switch	real
CO_CE	Collector-Emitter Reference Capacitance [F]	real
VDIFF_CE	Diffusion Potential of Collector-Emitter	real

	Capacitance [F]	
VSHIFT_CE	Voltage Shift of Collector-Emitter Capacitance [V]	real
ALPHA_CE	Capacitance Exponent Collector-Emitter	real
BETA_CE	Peak Factor of Collector-Emitter Capacitance	real
VC_DELTA_CG_OFF	Voltage Coefficient of DELTA_CG_OFF	real
SC0_DELTA_CG_ON	Slope Coefficient of DELTA_CG_ON	real
SC0_DELTA_CG_OFF	Slope Coefficient of DELTA_CG_OFF	real
SC_DELTA_CG_ON	Slope Coefficient of DELTA_CG_ON	real
SC_DELTA_CG_OFF	Slope Coefficient of DELTA_CG_OFF	real
CO_CE	Collector-Emitter Reference Capacitance [F]	real
VDIFF_CE	Diffusion Potential of Collector-Emitter Capacitance [F]	real
VSHIFT_CE	Voltage Shift of Collector-Emitter Capacitance [V]	real
ALPHA_CE	Capacitance Exponent Collector-Emitter	real
BETA_CE	Peak Factor of Collector-Emitter Capacitance	real
DELTA_CE	Influence of constant Capacitance at Collector-Emitter	real
TAU_BE	Carrier Lifetime at Base-Emitter Junction [s]	real
DAMP_C	Scaling Coupling Capacitor	real
DAMP_R	Scaling Damping Resistor	real
TC_C0_GE	Temperature Coefficient of TC_C0_GE	real
CC0_C0_GE	Current Coefficient of CC0_C0_GE	real

CC_C0_GE	Current Coefficient of CC_C0_GE	real
VC0_C0_GE	Voltage Coefficient of VC0_C0_GE	real
VC_C0_GE	Voltage Coefficient of VC_C0_GE	real
TC_C0_CG	Temperature Coefficient of TC_C0_CG	real
CC0_C0_CG	Current Coefficient of CC0_C0_CG	real
CC_C0_CG	Current Coefficient of CC_C0_CG	real
VC0_C0_CG	Voltage Coefficient of VC0_C0_CG	real
VC_C0_CG	Voltage Coefficient of VC_C0_CG	real
SC0_C0_CG	Slope Coefficient of SC0_C0_CG	real
SC_C0_CG	Slope Coefficient of SC_C0_CG	real
TC_SHIFT_ OFF	Temperature Coefficient of TC_SHIFT_ OFF	real
CC0_SHIFT_ OFF	Current Coefficient of CC0_SHIFT_OFF	real
CC_SHIFT_ OFF	Current Coefficient of CC_SHIFT_OFF	real
VC0_SHIFT_ OFF	Voltage Coefficient of VC0_SHIFT_OFF	real
VC_SHIFT_ OFF	Voltage Coefficient of VC_SHIFT_OFF	real
SC0_SHIFT_ OFF	Slope Coefficient of SC0_SHIFT_OFF	real
SC_SHIFT_ OFF	Slope Coefficient of SC_SHIFT_OFF	real
TC_SHIFT_ ON	Temperature Coefficient of TC_SHIFT_ ON	real
CC0_SHIFT_ ON	Current Coefficient of CC0_SHIFT_ON	real
CC_SHIFT_ ON	Current Coefficient of CC_SHIFT_ON	real
VC0_SHIFT_ ON	Voltage Coefficient of VC0_SHIFT_ON	real
VC_SHIFT_ ON	Voltage Coefficient of VC_SHIFT_ON	real
SC0_SHIFT_ ON	Slope Coefficient of SC0_SHIFT_ON	real
SC_SHIFT_ ON	Slope Coefficient of SC_SHIFT_ON	real
TC_DELTA_ OFF	Temperature Coefficient of TC_DELTA_ OFF	real
CC0_DELTA_ OFF	Current Coefficient of CC0_DELTA_ OFF	real
CC_DELTA_ OFF	Current Coefficient of CC_DELTA_OFF	real

OFF		
VC0_DELTA_OFF	Voltage Coefficient of VC0_DELTA_OFF	real
VC_DELTA_OFF	Voltage Coefficient of VC_DELTA_OFF	real
SC_DELTA_OFF	Slope Coefficient of SC_DELTA_OFF	real
SC0_DELTA_OFFI	Slope Coefficient of SC0_DELTA_OFF	real
TC_DELTA_ON	Temperature Coefficient of TC_DELTA_ON	real
CC0_DELTA_ON	Current Coefficient of CC0_DELTA_ON	real
CC_DELTA_ON	Current Coefficient of CC_DELTA_ON	real
VC0_DELTA_ON	Voltage Coefficient of VC0_DELTA_ON	real
VC_DELTA_ON	Voltage Coefficient of VC_DELTA_ON	real
SC0_DELTA_ON	Slope Coefficient of SC0_DELTA_ON	real
SC_DELTA_ON	Slope Coefficient of SC_DELTA_ON	real
TC_BETA_OFF	Temperature Coefficient of TC_BETA_OFF	real
CC0_BETA_OFF	Current Coefficient of CC0_BETA_OFF	real
CC_BETA_OFF	Current Coefficient of CC_BETA_OFF	real
VC0_BETA_OFF	Voltage Coefficient of VC0_BETA_OFF	real
VC_BETA_OFF	Voltage Coefficient of VC_BETA_OFF	real
SC_BETA_OFF	Slope Coefficient of SC_BETA_OFF	real
SC0_BETA_OFF	Slope Coefficient of SC0_BETA_OFF	real
TC_BETA_ON	Temperature Coefficient of TC_BETA_ON	real
CC0_BETA_ON	Current Coefficient of CC0_BETA_ON	real
CC_BETA_ON	Current Coefficient of CC_BETA_ON	real
VC0_BETA_ON	Voltage Coefficient of VC0_BETA_ON	real
VC_BETA_ON	Voltage Coefficient of VC_BETA_ON	real
SC0_BETA_ON	Slope Coefficient of SC0_BETA_ON	real

SC_BETA_ON	Slope Coefficient of SC_BETA_ON	real
TC_DIFF_OFF	Temperature Coefficient of TC_DIFF_OFF	real
CC0_DIFF_OFF	Current Coefficient of CC0_DIFF_OFF	real
CC_DIFF_OFF	Current Coefficient of CC_DIFF_OFF	real
VC0_DIFF_OFF	Voltage Coefficient of VC0_DIFF_OFF	real
VC_DIFF_OFF	Voltage Coefficient of VC_DIFF_OFF	real
SC_DIFF_OFF	Slope Coefficient of SC_DIFF_OFF	real
SC0_DIFF_OFF	Slope Coefficient of SC0_DIFF_OFF	real
TC_DIFF_ON	Temperature Coefficient of TC_DIFF_ON	real
CC0_DIFF_ON	Current Coefficient of CC0_DIFF_ON	real
CC_DIFF_ON	Current Coefficient of CC_DIFF_ON	real
VC0_DIFF_ON	Voltage Coefficient of VC0_DIFF_ON	real
VC_DIFF_ON	Voltage Coefficient of VC_DIFF_ON	real
SC0_DIFF_ON	Slope Coefficient of SC0_DIFF_ON	real
SC_DIFF_ON	Slope Coefficient of SC_DIFF_ON	real
TC_C0_CE	Temperature Coefficient of TC_C0_CE	real
CC0_C0_CE	Current Coefficient of CC0_C0_CE	real
CC_C0_CE	Current Coefficient of CC_C0_CE	real
VC0_C0_CE	Voltage Coefficient of VC0_C0_CE	real
VC_C0_CE	Voltage Coefficient of VC_C0_CE	real
SC0_C0_CE	Slope Coefficient of SC0_C0_CE	real
SC_C0_CE	Slope Coefficient of SC_C0_CE	real
TC_DELTA_CE	Temperature Coefficient of TC_DELTA_CE	real
CC0_DELTA_CE	Current Coefficient of CC0_DELTA_CE	real
CC_DELTA_CE	Current Coefficient of CC_DELTA_CE	real
VC0_DELTA_CE	Voltage Coefficient of VC0_DELTA_CE	real
VC_DELTA_CE	Voltage Coefficient of VC_DELTA_CE	real

CE		
SC0_DELTA_CE	Slope Coefficient of SC0_DELTA_CE	real
SC_DELTA_CE	Slope Coefficient of SC_DELTA_CE	real
TC_TAU_BE	Temperature Coefficient of TC_TAU_BE	real
CC0_TAU_BE	Current Coefficient of CC0_TAU_BE	real
CC_TAU_BE	Current Coefficient of CC_TAU_BE	real
VC0_TAU_BE	Voltage Coefficient of VC0_TAU_BE	real
VC_TAU_BE	Voltage Coefficient of VC_TAU_BE	real
TC_DAMP_C	Temperature Coefficient of DAMP_C	real
CC0_DAMP_C	Current Coefficient of DAMP_C	real
CC_DAMP_C	Current Coefficient of DAMP_C	real
VC0_DAMP_C	Voltage Coefficient of DAMP_C	real
VC_DAMP_C	Voltage Coefficient of DAMP_C	real
SC0_DAMP_C	Slope Coefficient of DAMP_C	real
SC_DAMP_C	Slope Coefficient of DAMP_C	real
TC_LAUX	Temperature Coefficient of LAUX	real
CC0_LAUX	Current Coefficient of LAUX	real
CC_LAUX	Current Coefficient of LAUX	real
VC0_LAUX	Voltage Coefficient of LAUX	real
VC_LAUX	Voltage Coefficient of LAUX	real
SC0_LAUX	Slope Coefficient of LAUX	real
SC_LAUX	Slope Coefficient of LAUX	real
TC_RGG	Temperature Coefficient of RGG	real
CC0_RGG	Current Coefficient of RGG	real
CC_RGG	Current Coefficient of RGG	real
VC0_RGG	Voltage Coefficient of RGG	real
VC_RGG	Voltage Coefficient of RGG	real
SC0_RGG	Slope Coefficient of RGG	real
SC_RGG	SC_RGG	real

Table 6. Parameters for tail current

Name	Description [Unit]	Data Type
TAU_TAIL	Time Constant of Tail Current [s]	real
TC_TAU_TAIL	Temperature Coefficient of TAU_TAIL	real
CC0_TAU_TAIL	Current Coefficient of TAU_TAIL	real
CC_TAU_TAIL	Current Coefficient of TAU_TAIL	real
VC0_TAU_TAIL	Voltage Coefficient of TAU_TAIL	real
VC_TAU_TAIL	Voltage Coefficient of TAU_TAIL	real
SC0_TAU_TAIL	Slope Coefficient of TAU_TAIL	real
SC_TAU_TAIL	Slope Coefficient of TAU_TAIL	real
DELTA_TAIL	Start of Tail Current relative to Maximum Current	real
TC_DELTA_TAIL	Temperature Coefficient of DELTA_TAIL	real
CC0_DELTA_TAIL	Current Coefficient of DELTA_TAIL	real
CC_DELTA_TAIL	Current Coefficient of DELTA_TAIL	real
VC0_DELTA_TAIL	Voltage Coefficient of DELTA_TAIL	real
VC_DELTA_TAIL	Voltage Coefficient of DELTA_TAIL	real
SC0_DELTA_TAIL	Slope Coefficient of DELTA_TAIL	real
SC_DELTA_TAIL	Slope Coefficient of DELTA_TAIL	real
TAU_S	Nominal Off-Switch Storage Time [s]	real

TC_TAU_S	Temperature Coefficient of TAU_S	real
CC0_TAU_S	Current Coefficient of TAU_S	real
CC_TAU_S	Current Coefficient of TAU_S	real
VC0_TAU_S	Voltage Coefficient of TAU_S	real
VC_TAU_S	Voltage Coefficient of TAU_S	real
SC0_TAU_S	Slope Coefficient of TAU_S	real
SC_TAU_S	Slope Coefficient of TAU_S	real
TAU_T	Nominal Off-Switch Transition Time [s]	real
TC_TAU_T	Temperature Coefficient of TAU_T	real
CC0_TAU_T	Current Coefficient of TAU_T	real
CC_TAU_T	Current Coefficient of TAU_T	real
VC0_TAU_T	Voltage Coefficient of TAU_T	real
VC_TAU_T	Voltage Coefficient of TAU_T	real
SC0_TAU_T	Slope Coefficient of TAU_T	real
SC_TAU_T	Slope Coefficient of TAU_T	real

Table 7. Parameters FWD Model

Name	Description [Unit]	Data Type
M_FWD	Ideality Factor of FWD at TEMP0 [/]; static parameter	real
ISAT_FWD	Saturation Current of FWD at TEMP0 [A]; static parameter	real
RB_FWD	Bulk Resistance of FWD at TEMP0 [Ohm]; static parameter	real
TC_M_FWD	Temperature Coefficient of M_FWD; static parameter	real
TC_ISAT_FWD	Temperature Coefficient of ISAT_FWD; static parameter	real

TC_RB_FWD	Temperature Coefficient of RB_FWD	real
TAU_FWD	Effective Lifetime of FWD	real
TC_TAU_FWD	Temperature Coefficient of TAU_FWD	real
CC0_TAU_FWD	Current Coefficient of TAU_FWD	real
CC_TAU_FWD	Current Coefficient of TAU_FWD	real
VC0_TAU_FWD	Voltage Coefficient of TAU_FWD	real
VC_TAU_FWD	Voltage Coefficient of TAU_FWD	real
SC0_TAU_FWD	Slope Coefficient of TAU_FWD	real
SC_TAU_FWD	Slope Coefficient of TAU_FWD	real
R1_FWD	Reverse Recovery Forma Factor 1	real
R2_FWD	Reverse Recovery Forma Factor 2	real
TC_R2	Temperature Coefficient of R2_FWD	real
CC0_R2	Current Coefficient of R2_FWD	real
CC_R2	Current Coefficient of R2_FWD	real
VC0_R2	Voltage Coefficient of R2_FWD	real
VC_R2	Voltage Coefficient of R2_FWD	real
SC0_R2	Slope Coefficient of R2_FWD	real
SC_R2	Slope Coefficient of R2_FWD	real
R3_FWD	Reverse Recovery Form Factor 3	real
SF1_FWD	Soft Factor 1 of FWD	real
TC_SF1	Temperature Coefficient of SF1_FWD	real

CC0_SF1	Current Coefficient of SF1_FWD	real
CC_SF1	Current Coefficient of SF1_FWD	real
VC0_SF1	Voltage Coefficient of SF1_FWD	real
VC_SF1	Voltage Coefficient of SF1_FWD	real
SC0_SF1	Slope Coefficient of SF1_FWD	real
SC_SF1	Slope Coefficient of SF1_FWD	real
SF2_FWD	Soft Factor 2 of FWD	real
TC_SF2	Temperature Coefficient of SF2_FWD	real
CC0_SF2	Current Coefficient of SF2_FWD	real
CC_SF2	Current Coefficient of SF2_FWD	real
VC0_SF2	Voltage Coefficient of SF2_FWD	real
VC_SF2	Voltage Coefficient of SF2_FWD	real
SC0_SF2	Slope Coefficient of SF2_FWD	real
SC_SF2	Slope Coefficient of SF2_FWD	real

Table 8. Input/Output Quantities

Name	Description [Unit]	Direction	Data Type
VGE	Gate-Emitter Voltage [V]	Output	real
VBE	Base-Emitter Voltage of BJT [V]	Output	real
VCE	Collector-Emitter Voltage [V]	Output	real
IC	Current through Collector Connector [A]	Output	real
IG	Current through Gate Connector [A]	Output	real

IFWD	Current through FWD [A]	Output	real
VP	Pinch-off Voltage [V]	Output	real
K	Transistor Constant	Output	real
BN	Current Gain of BJT	Output	real
CGE	Gate-Emitter Capacitance [F]	Output	real
CCG	Collector-Gate Capacitance [F]	Output	real
CCE	Collector-Emitter Capacitance [F]	Output	real
CDS	Gate-Source Capacitance [F]	Output	real
CFWD	Capacitance at FWD [F]	Output	real
Q_TAIL	Tail Current Charge [As]	Output	real
TEMPJNCT	Junction Temperature [°C]	Output	real
TEMPCHIP	Chip Temperature [°C]	Output	real
TEMPCASE	Case Temperature [°C]	Output	real
PEL	Total Component Losses [W]	Output	real
PCOND	Power Transfer by Conduction [W]	Output	real
PCONV	Power Transfer by Convection [W]	Output	real
PRAD	Power Transfer by Radiation [W]	Output	real

ESWITCH	Losses of One Switching Cycle [Ws]	Output	real
PSWITCH	Average Losses of One Switching Cycle [W]	Output	real
ETOT	Total Losses During Simulation [Ws]	Output	real
PTOT	Total Average Losses During Simulation [W]	Output	real
FAULT_VCE	Flag Collector-Emitter-Over voltage	Output	real
FAULT_VGE	Flag Gate-Emitter-Over voltage	Output	real
FAULT_I	Flag Over current	Output	real
FAULT_TEMP	Flag Over temperature	Output	real

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Example

Four examples are available, representing the N-Type Advanced Dynamic model, the N-Type Advanced Dynamic model with FWD diode, the P-Type Advanced Dynamic model and the P-Type Advanced Dynamic model with FWD diode. The examples are shown below.

This example demonstrates the operation mechanism of the advanced dynamic N-Channel IGBT model through a simple example. The control gate voltage is supplied by a pulse-wave voltage source E1. The schematic of the example is shown in Figure 3, system parameters are listed in Table 7, and the simulation results are shown in Figure 4 and 5.

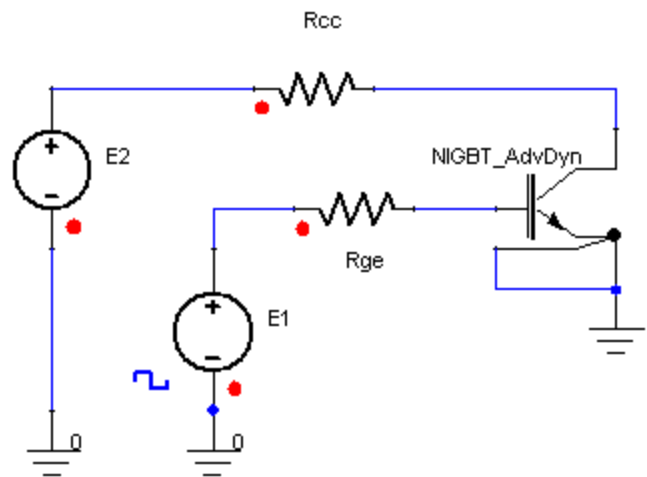


Figure 3. Application example of the N-Channel IGBT model (advanced dynamic)

Table 9. System Parameters

Component	Parameter	Value [unit]
Resistor Rge	R	10 [Ohm]
Resistor Rcc	R	1 [Ohm]
Voltage Source (Pulse) E1	AMPL	15 [V]
	FREQ	1000 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [V]
Voltage Source E2	EMF	500 [V]
Advanced Dynamic IGBT NIGBT_ADVDYN	VNOM	1000
	INOM	500

	SYNC	E1.EMF
	TYPE_DYN	2011
	TYPE_OUT	63

* All other parameters of the N-Channel IGBT model use their default values, therefore they are not included in the parameter table.

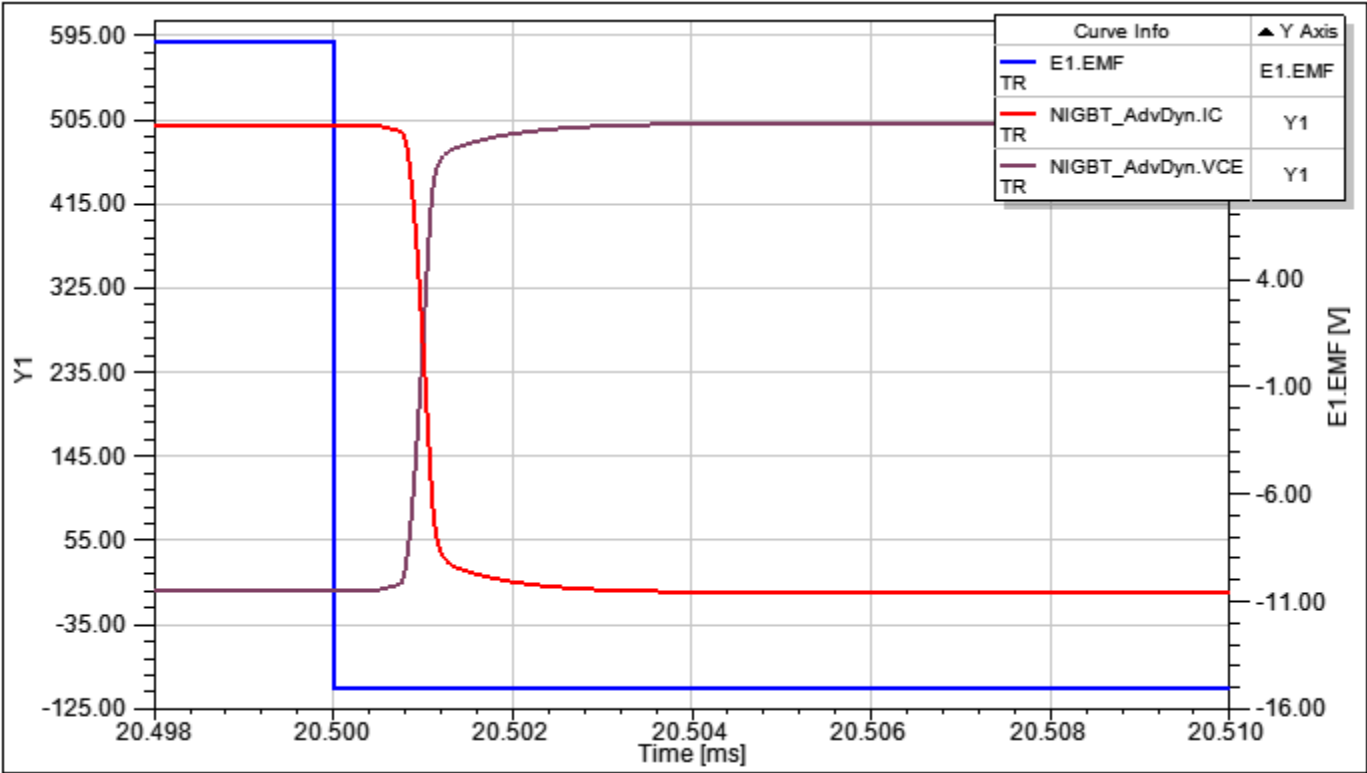


Figure 4. Simulation result-switching OFF waveforms for NIGBT_ADVDYN

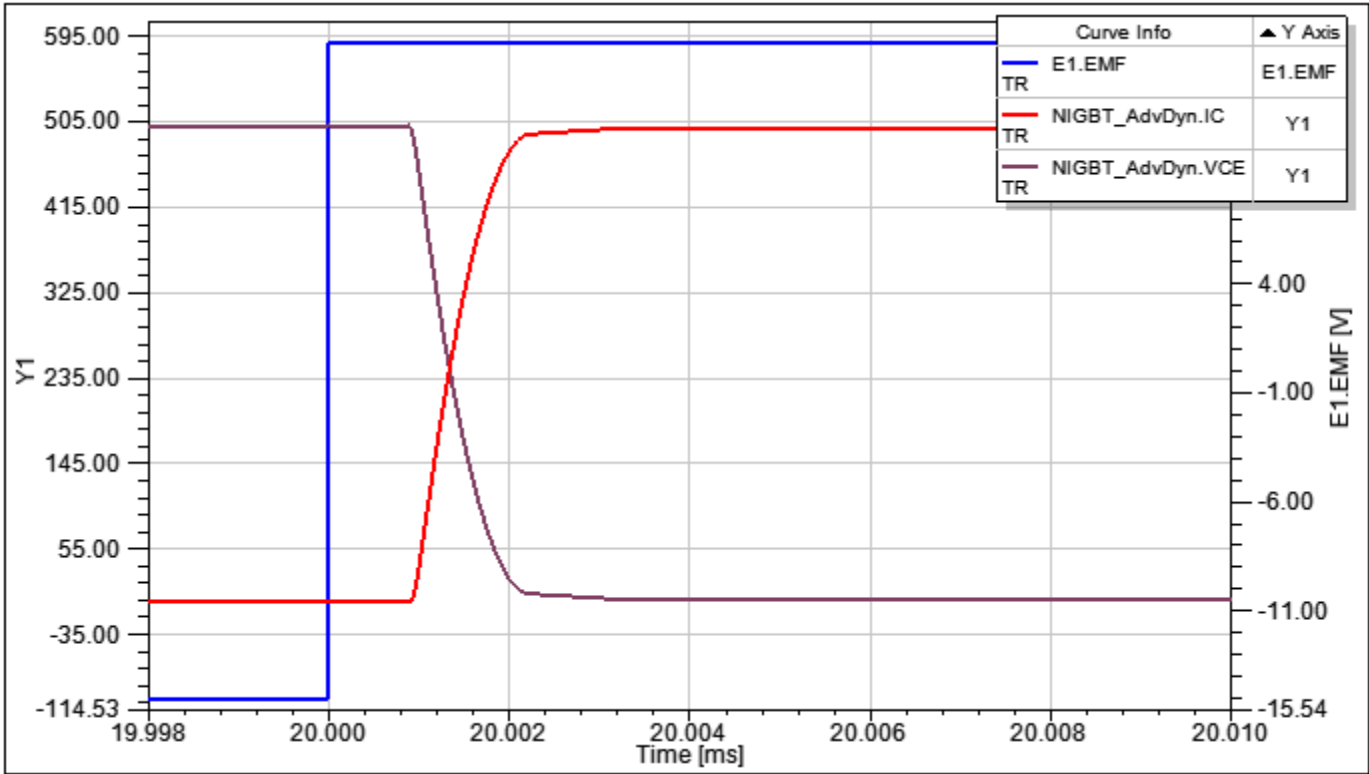


Figure 5. Simulation result-switching ON waveforms for NIGBT_ADVDYN

This example demonstrates the operation mechanism of the advanced dynamic N-Channel IGBT model with FWD through a simple example. The control gate voltage is supplied by a pulse-wave voltage source E1. The schematic of the example is shown in Figure 6, system parameters are listed in Table 8, and the simulation results are shown in Figure 7 and 8.

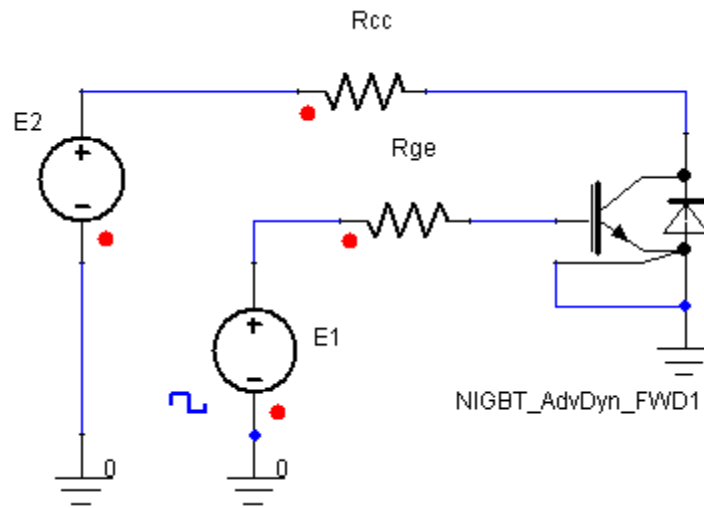


Figure 6. Application example of the N-Channel IGBT model with FWD (advanced dynamic)

Table 10. System Parameters

Component	Parameter	Value [unit]
Resistor Rge	R	10 [Ohm]
Resistor Rcc	R	1 [Ohm]
Voltage Source (Pulse) E1	AMPL	15 [V]
	FREQ	1000 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [V]
Voltage Source E2	EMF	500 [V]
Advanced Dynamic IGBT NIGBT_ADVDYN_FWD1	VNOM	1000
	INOM	500

	SYNC	E1.EMF
	TYPE_DYN	2011
	TYPE_OUT	63
	TYPE_FWD	1

* All other parameters of the N-Channel IGBT model use their default values, therefore they are not included in the parameter table.

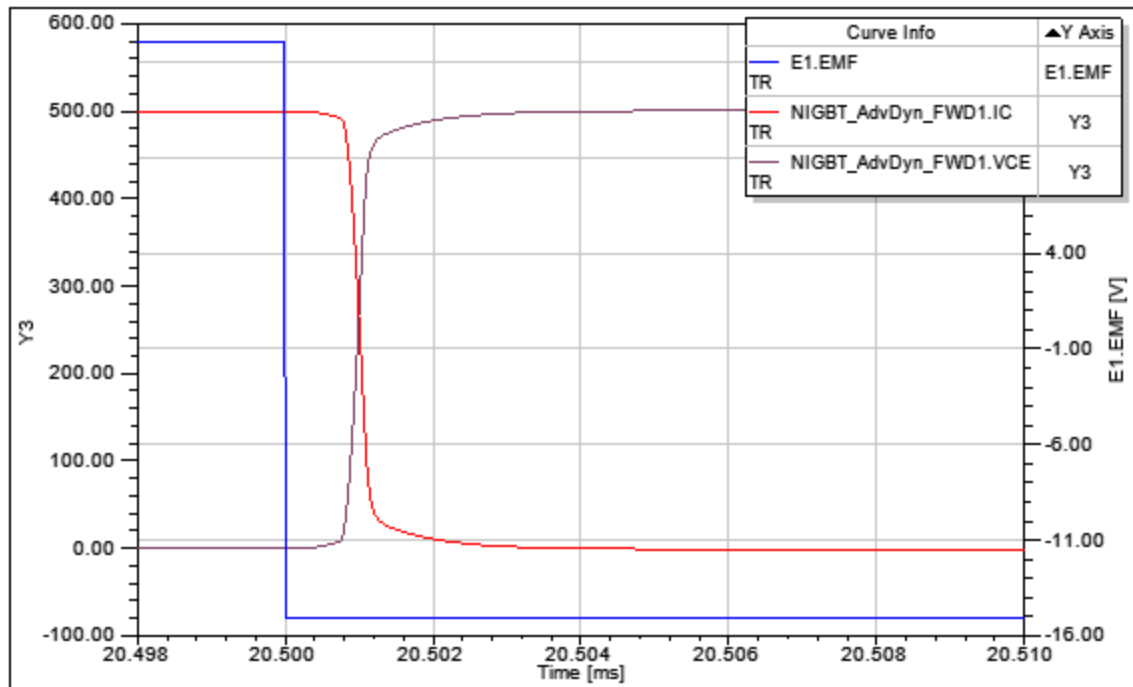


Figure 7. Simulation result-switching OFF waveforms for NIGBT_ADVDYN_FWD1

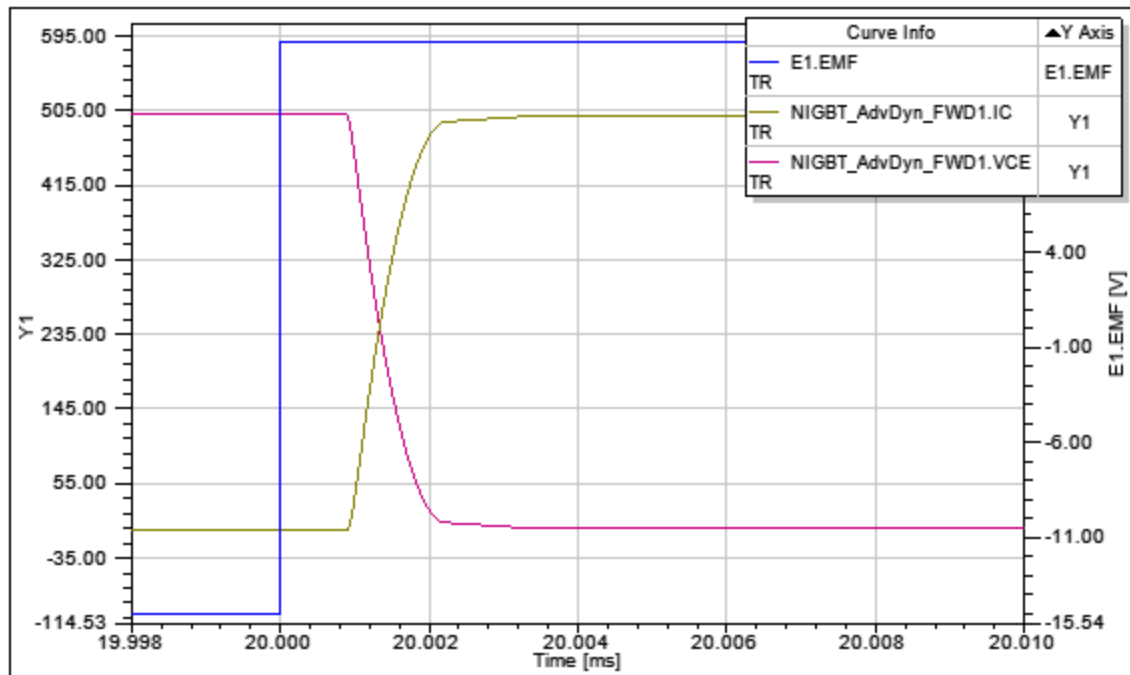


Figure 8. Simulation result-switching ON waveforms for NIGBT_ADVDYN_FWD1

This example demonstrates the operation mechanism of the advanced dynamic P-Channel IGBT model through a simple example. The control gate voltage is supplied by a pulse-wave voltage source E1. The schematic of the example is shown in Figure 9, system parameters are listed in Table 9, and the simulation results are shown in Figure 10 and 11.

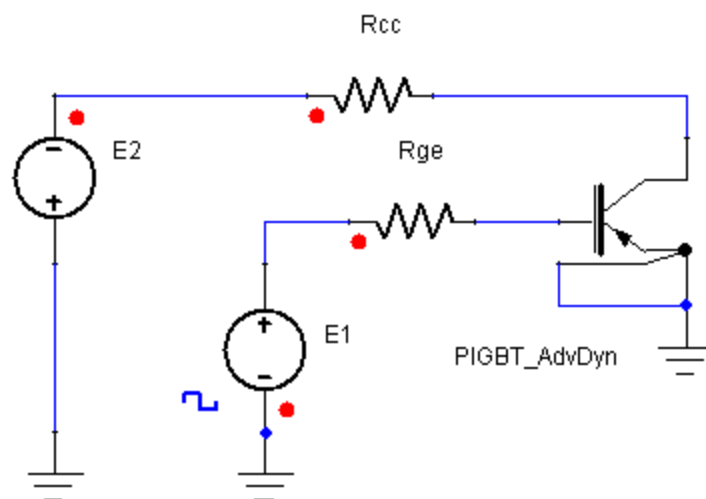


Figure 9. Application example of the P-Channel IGBT model (advanced dynamic)**Table 11. System Parameters**

Component	Parameter	Value [unit]
Resistor Rge	R	10 [Ohm]
Resistor Rcc	R	1 [Ohm]
Voltage Source (Pulse) E1	AMPL	15 [V]
	FREQ	1000 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [V]
Voltage Source E2	EMF	500 [V]
Advanced Dynamic IGBT PIGBT_ ADVDYN	VNOM	1000
	INOM	500
	SYNC	E1.EMF
	TYPE_DYN	2011
	TYPE_OUT	63
	TYPE_THERM	10
	VP	-6

* All other parameters of the P-Channel IGBT model use their default values, therefore they are not included in the parameter table.

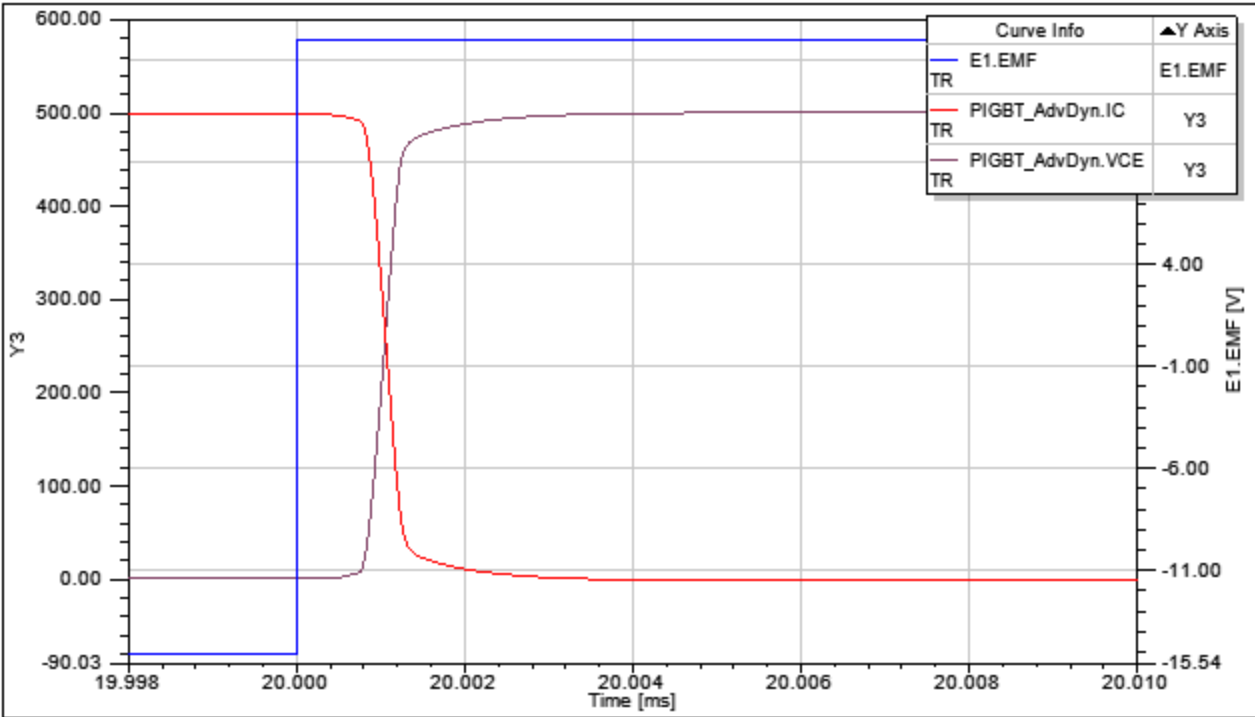


Figure 10. Simulation result-switching OFF waveforms for PIGBT_ADVDYN

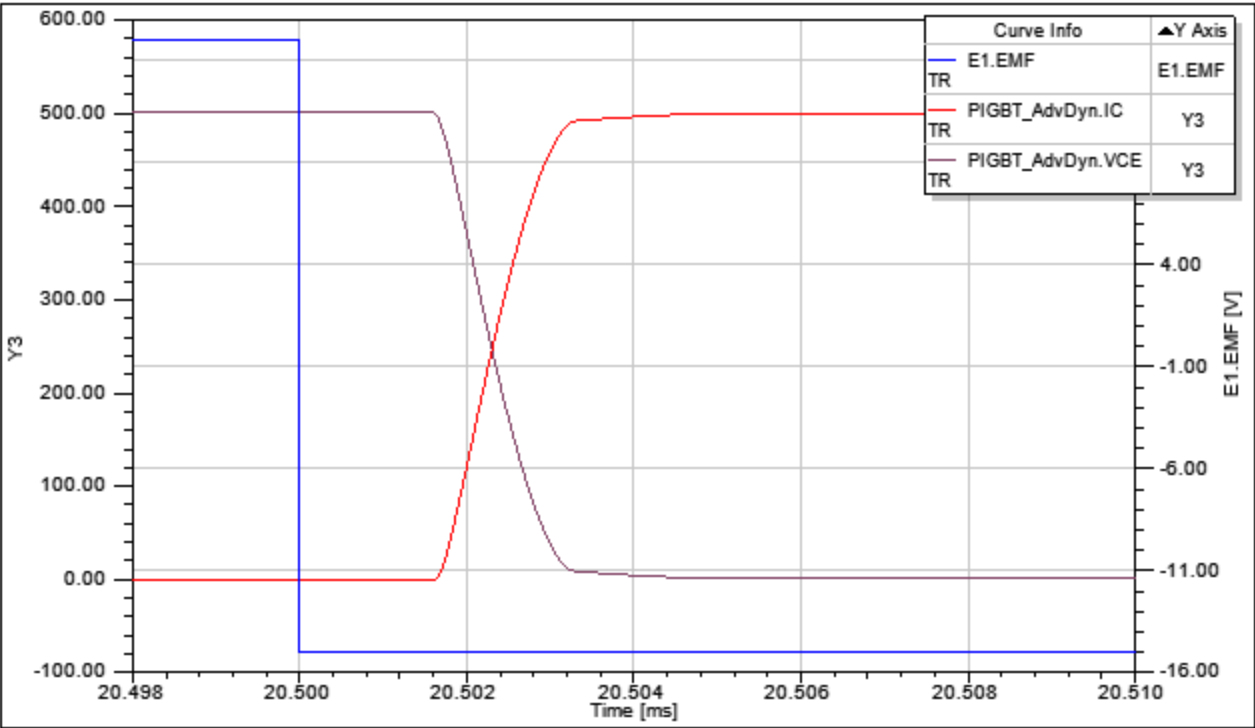


Figure 11. Simulation result-switching ON waveforms for PIGBT_ADVDYN

This example demonstrates the operation mechanism of the advanced dynamic P-Channel IGBT model with FWD through a simple example. The control gate voltage is supplied by a pulse-wave voltage source E1. The schematic of the example is shown in Figure 12, system parameters are listed in Table 10, and the simulation results are shown in Figure 13 and 14.

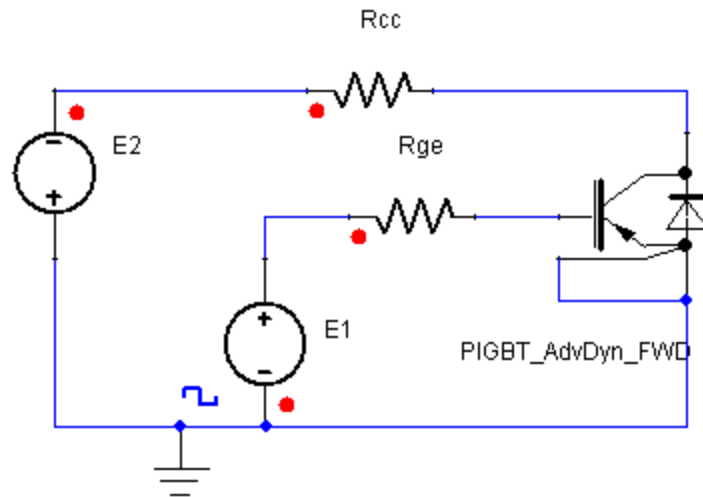
**Figure 12. Application example of the P-Channel IGBT model with FWD (advanced dynamic)**

Table 12. System Parameters

Component	Parameter	Value [unit]
Resistor Rge	R	10 [Ohm]
Resistor Rcc	R	1 [Ohm]
Voltage Source (Pulse) E1	AMPL	15 [V]
	FREQ	1000 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [V]
Voltage Source E2	EMF	500 [V]
Advanced Dynamic IGBT PIGBT_ADVDYN_FWD1	VNOM	3000
	INOM	3000
	SYNC	E1.EMF
	TYPE_DYN	2011
	TYPE_OUT	63
	TYPE_THERM	10
	VP	-6
	TYPE_FWD	1

* All other parameters of the P-Channel IGBT model use their default values, therefore they are not included in the parameter table.

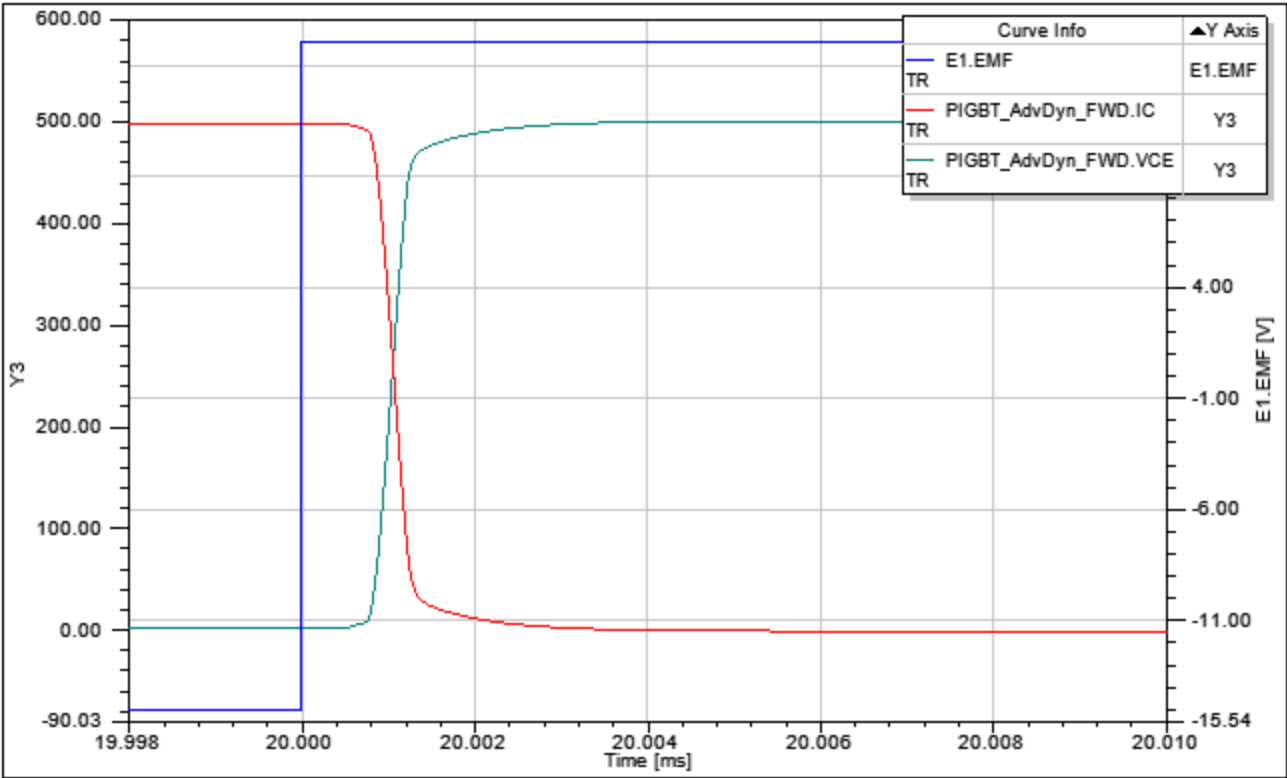


Figure 13. Simulation result-switching OFF waveforms for PIGBT_ADVDYN_FWD1

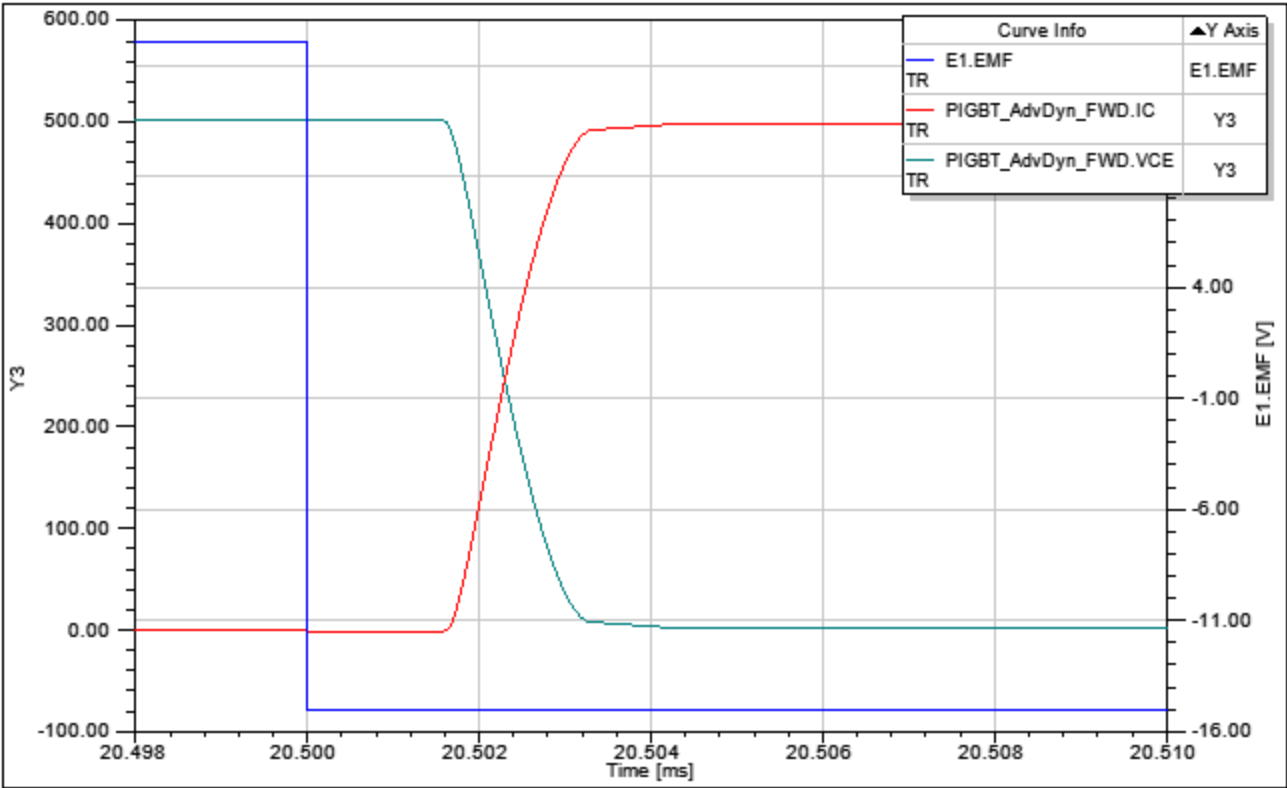


Figure 14. Simulation result-switching ON waveforms for PIGBT_ADVDYN_FWD1

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References

[1] Ned Mohan, Tore M. Undeland, William P. Robbins, "Power Electronics: Converters, Applications, and Design." John Wiley & Sons, INC. New York, 1995.

Average IGBT Model V2

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

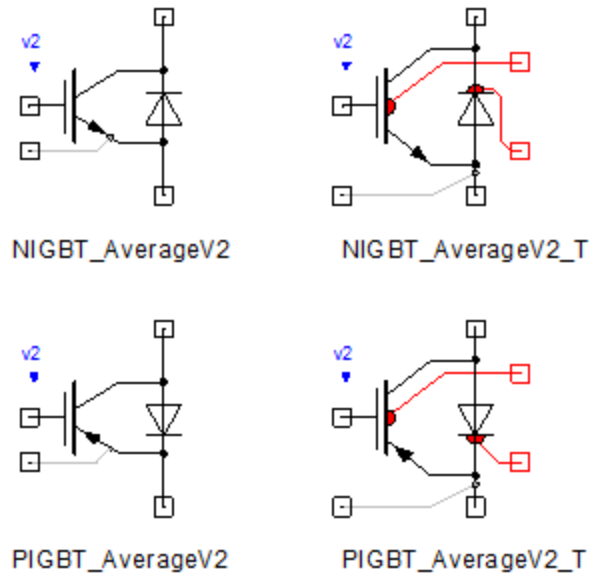


Figure 1. Average IGBT V2 Component symbols

- [Description](#)
- [Assumptions and Limitations](#)
- [Mathematical Description](#)
- [Netlist Syntax](#)
- [Conservative Pins](#)
- [Parameters](#)
- [Example](#)
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Description

The purpose of the average model is to simulate correct energy loss and junction temperature with least computation. It is most suitable for energy/power loss and temperature estimation over large scale designs or long timespans.

The average model is a static model. It contains the same static and thermal model as used in dynamic IGBT models, but its switching energy is estimated based on actual working conditions

during simulation. As a result, all DC characteristics are accurate, switching energy loss and junction temperature output are also very good approximations, but the switching waveform has no dynamic details. This means one cannot measure the actual switching time and energy loss from the switching voltage and current waveform, but can get the right energy value from model output E_ON, E_OFF and E_RR.

Generally, the amount of power loss dissipated from an IGBT is determined by conduction loss and switching loss. While conduction loss can be accurately calculated from static voltage and current waveforms of the average IGBT model, the switching energy loss is estimated through multi-dimensional interpolation based on current, voltage, temperature, and gate resistance. These quantities are from simulation in the following ways:

- Voltage and current are sampled at switching; see [Mathematical Description](#) for details. Please note the importance of the Synchronization signal in Electrical Parameters.
- Temperature is directly measured during simulation.
- Gate resistance in the schematic is taken as parameters RG_ON and RG_OFF of the average IGBT model. These two parameters are not physical resistances inside the model but values of external gate drive resistance. In other words, after users build their own gate drive circuit in the schematic, they should set the two parameters in the average IGBT model to match their drive circuit.

Twin Builder provides the Characterize Device option to extract electrical and thermal model parameters from the manufacturer catalog datasheet. The key for characterizing an average model is to provide data at as many different working points as possible in Energy Characteristics [10/12], so the model can learn the device's working point dependency. Such data can be sampled from switching losses curves in the datasheet. This is not required for dynamic models, but necessary for average model characterization.

The version 2 (V2) average IGBT model includes all of the capabilities of the legacy average model, but also extends it with new options using a simplified static electrical model for faster electro-thermal simulation. For more details, refer to "Mathematical Description" on the next page.

Beginning with Twin Builder 2019.1, new average models extracted by the characterization wizard will be version 2 components.

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Assumptions and Limitations

The average model is a static model: its current and voltage waveforms do not contain switching dynamics. Switching loss cannot be directly measured from these waveforms.

Switching energy and power are internally estimated by interpolation; thus the working point related coefficients are very important for correct loss and temperature simulation if the model is operated away from nominal working point. The coefficients can be extracted by the Device Characterization Wizard, which needs the user to provide data at as many different working conditions as possible in Energy Characteristics [10/12].

Besides characteristics related parameters, an average IGBT requires the user to:

- Use the External Synchronization signal (default), or properly set the External Synchronization signal in Electrical Parameters.
- Include gate drive resistance in the external schematic and set the values in External Connectors, in which parameters RG_ON and RG_OFF are **not** physical gate resistance.
- Properly set Hmin and Hmax; see [Mathematical Description](#) for details.
- Simulate for at least 10-20 switches in order to get good estimation of loss and temperature.

The working voltage (VCE) of the Average IGBT is limited to $1.5 \times V_{NOM}$. A higher VCE will cause the breakthrough of an equivalent Zener diode in the Average IGBT and result in incorrect simulation results.

If the Average IGBT needs to be operated at a high VCE, the VNOM should be selected to be that voltage value during characterization.

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Mathematical Description

Electrical Model (full)

The electrical component of the IGBT model involves a complete DC sub-circuit (as seen in Figure 2) comprising of a bipolar transistor driven by a MOSFET and a free wheeling diode.

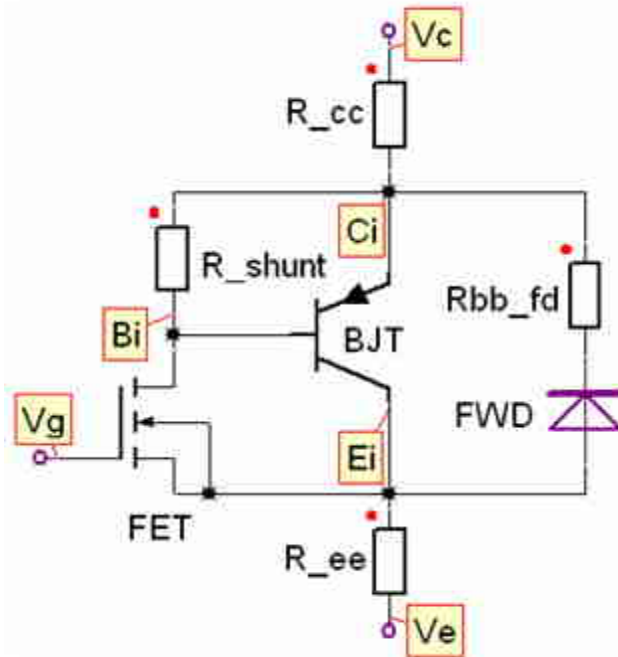


Figure 2. Equivalent circuit of the Average IGBT model

Using a parameter extraction algorithm the transfer characteristics $I_c(V_{ge})@V_{ce}=\text{const.}$ and the output characteristics $I_c(V_{ce})@V_{ge}=\text{const.}$ can be reproduced by simulation. The accuracy is very important for the load current dependency of the saturation voltage $V_{ce\text{ sat}}(I_c)$ which is necessary for the DC loss calculation. Because external stray inductances cause large induction voltage spikes across the collector emitter branch according to:

$$u_i = L_{\text{STRAY}} \left(\frac{di_c}{dt} \right) \quad (1)$$

an internal over voltage limitation is included as well as for voltage, current and temperature overload as breakdown indication. Although the model is basically a static one an input capacitance is included to obtain reasonable switching response times.

Electrical Model (simplified)

While the full electrical model has the complete static characteristics of an IGBT, it requires solving the nonlinear output characteristics with the whole schematic, which can sometimes cause convergence difficulty (depending on the external circuit). In such a case, the simulation would require a very small H_{min} and take a long time to run.

To provide a much faster, yet still accurate, option in this situation, the **Use Simplified Model** option is provided in the V2 average IGBT. The user can activate this mode by checking the **Use Simplified Model** check box on the **Electrical Parameters** tab of the component's **Parameters** dialogue.

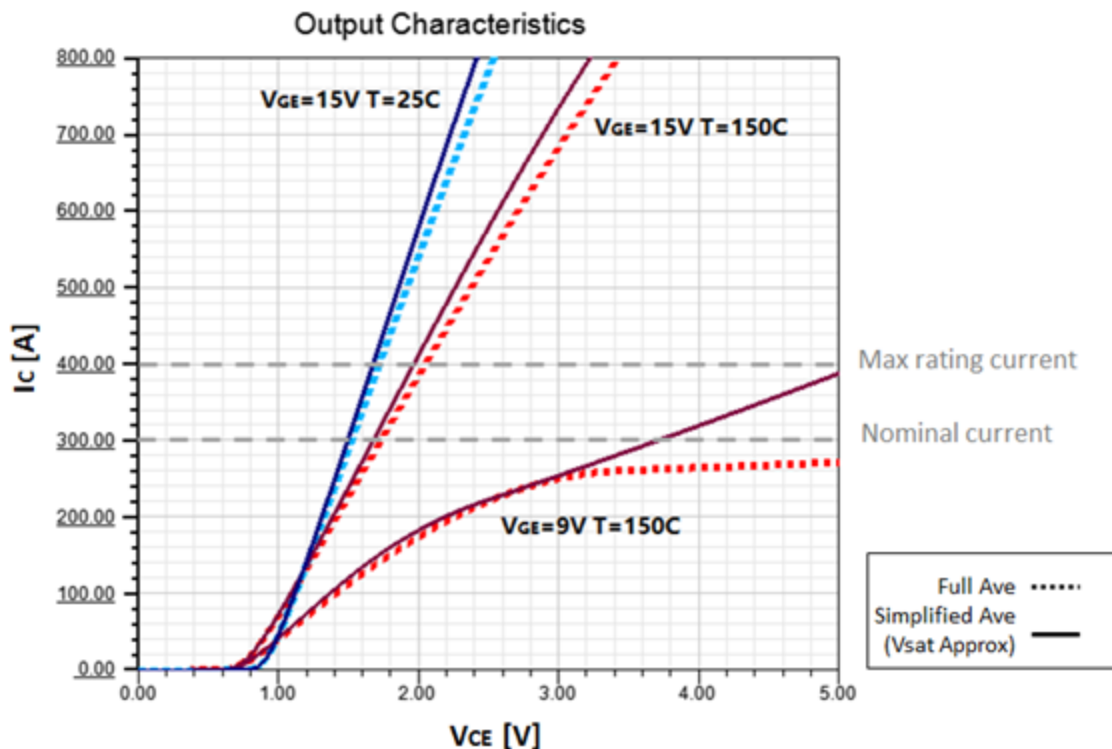
The simplified model still uses the full set of static parameters extracted from datasheet static characteristics, but the output characteristics are calculated instead of solved in the circuit.

which can accurately estimate conducting power PEL_T on the transistor. Meanwhile, switching loss and thermal model in the simplified model are identical to that of the full model.

Besides estimated conducting loss, there are two options of approximation available for the electrical behavior (current and voltage waveforms). User can select one under **Static Core Behavior**:

- **Static Core Behavior: Vsat Approximation (recommended)**

In this mode, I_c , V_{ce} and V_{ge} relations and their temperature dependency are calculated in a similar way as conducting loss, so user can measure accurate output characteristics within datasheet rated max current. The figure below compares the output characteristics simulation results of the full average model and simplified model in Vsat approximation mode:



The above shows that this simplified mode is a good approximation of full average model, except that the simplified model does not have correct current saturation effect. This means the simplified model can provide accurate results of on-state voltage and load current, but cannot be used for short-circuit analysis.

NOTE: The **Use Simplified Model** setting in **Vsat Approximation** mode is recommended in most cases, due to good accuracy and performance. The only limitation is short-circuit simulation, which requires the full average model.

- **Static Core Behavior: Ideal Switch**

In this mode, the IGBT behaves simply as an ideal switch in the electrical circuit, while still giving accurate loss estimation. When using the model in this mode, on-state voltage is always zero, and load current will be ideal without realistic ON-resistance. This ideal switch mode can only simulate accurate loss and temperature, but is slightly (5%-10%) faster than the **Vsat Approximation** mode

Switching Loss Estimation

A novel synchronization technique and working point dependency are introduced to perform the calculations for the switching losses, which would not be possible using a pure static model. Figure 3 shows the voltage and current sampling which is done at the moment of the trigger signal edge. This sampling scheme is called “synchronization” because the IGBT model is triggered by an internal or external sync signal to get the instantaneous load current and blocking voltage of the device without overshoot and oscillation. Together with the actual junction temperature and the gate drive condition the sampled values form the actual working point $W(t)=[V(t), I(t), T(t), R_{ON}(t), R_{OFF}(t)]$ are valid for every half of a switching cycle. Once the model has the working point information knowing the switching time due to the synchronization technique employed, the energy calculation can be performed by straight forward analytical formulation, which serves as either interpolation or extrapolation function of the data sheet or measurement values.

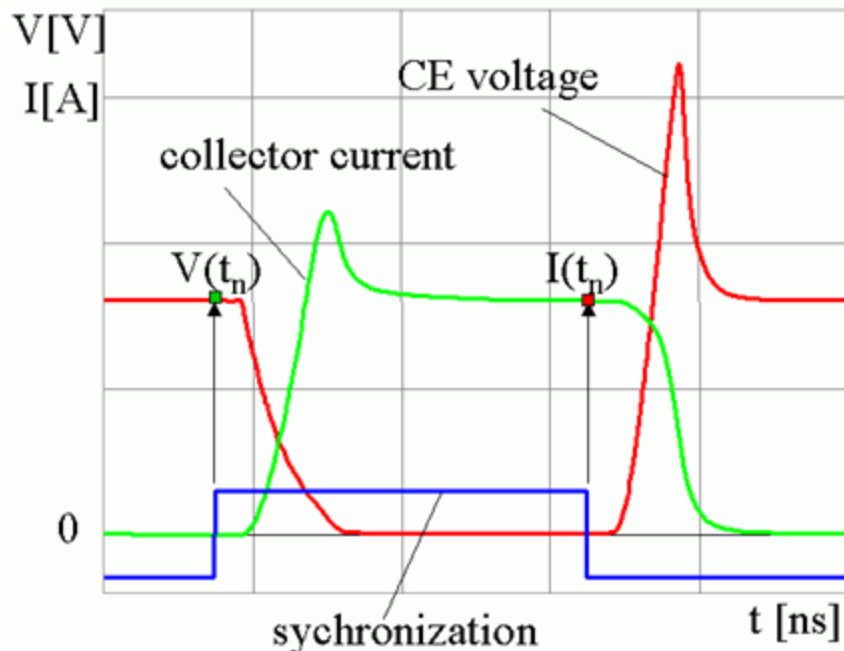


Figure 3. Synchronization Technique

The nominal working point W_{NOM} stands for nominal operating conditions found in a manufacturer data sheet, which includes the nominal blocking voltage V_{NOM} , the nominal load current I_{NOM} , the nominal junction temperature T_{NOM} and the usual gate drive conditions belong to

the nominal working point. Assuming constant gate drive voltages and stray inductances in the gate circuit, the external gate resistors for the on-switch and off-switch belong to the nominal working point definition as:

$$W_{NOM}=[V_{NOM}, I_{NOM}, T_{NOM}, R_{ONNOM}(t), R_{OFFNOM}(t)]$$

When the model parameters are fitted to W_{NOM} the model will work accurately under this working condition. Normally during simulation, the blocking voltage remains constant at the bus bar voltage. In case of fault condition this value may change in the range of 0...200%. For an inverter application the load current changes in the range of 0... 100% periodically. As a consequence, the temperature will vary in the range of 300K to 420K (up to 140%) while the gate drive conditions remain unchanged. Usually the actual working point $W(t)$ differs from nominal condition W_{NOM} . As $W(t)$ deviates from W_{NOM} , the accuracy of the simulation decreases. Although $W(t)$ differs from W_{NOM} , the simulation results can be rectified by using the "working point correction coefficients" given below.

$$\begin{aligned} E_{ON} &= Y_{ON}(T, I, V, R, \alpha, \kappa, \sigma, \rho) \cdot E_{ON, NOM} \\ E_{OFF} &= Y_{OFF}(T, I, V, R, \alpha, \kappa, \sigma, \rho) \cdot E_{OFF, NOM} \\ E_{RR} &= Y_{RR}(T, I, V, R, \alpha, \kappa, \sigma, \rho) \cdot E_{RR, NOM} \end{aligned}$$

(2)

$$Y(T, I, V, R, \alpha, \kappa, \sigma, \rho) = X_T(T, \alpha) \cdot X_I(I, \kappa) \cdot X_V(V, \sigma) \cdot X_R(R, \rho)$$

(3)

where, X is a set of independent partial correction functions and

$$\alpha, \kappa, \sigma, \rho$$

are the correction coefficients calculated independently for each working point condition. Each product term of this approach can be fitted to a linear or power function X (as presented in Figure 4 and according to the Eq.5-8) which depends on either the interpolation or extrapolation conditions to ensure non-negative and limited values for the total working point correction function Y (shown in Eq. 3).

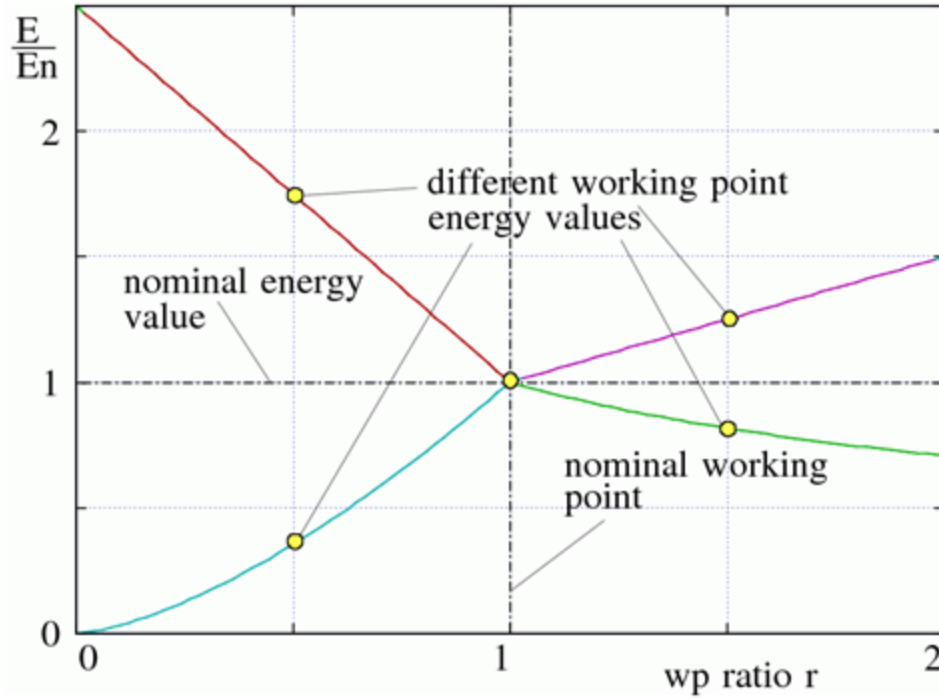


Figure 4. Working point correction coefficients map

The correction coefficients are extracted one by one by varying only the corresponding working point parameter (T , I , V or R) and holding the other parameters at their nominal values. To illustrate this procedure, the calculation of the temperature correction coefficient α is used as an example. The same extraction algorithm is applied to the other coefficients. To calculate temperature coefficient α , the energy values at a temperature different from the nominal condition (either greater or less than the nominal condition) are measured. As illustrated in the working point correction map (shown in Figure 4), a particular pattern, which represents the variation of partial correction function X , is chosen to compute the temperature correction coefficient based on the energy ratio and the working point ratio r_T . Using the Eq.2 and Eq.3 all terms are known except for the term $X_T(T, \alpha)$. Introducing Eq.3 into Eq.2 and knowing the measured value of the energy, the temperature partial correction function is given by,

$$(4) \quad X_T(T, \alpha) = \frac{E_{ON/OFF/RR}}{E_{ON/OFF/RR.NOM}}$$

Based on the employed mapping algorithm and the value of $X_T(T, \alpha)$ the correction coefficient for temperature can be evaluated. Now this temperature correction coefficient can be used to determine the partial correction function $X_T(T, \alpha)$ for any variation of the temperature during any simulation. As a general observation in this modeling approach, only one correction coefficient is used for temperature partial correction function estimation, while for voltage (Eq.6), current (Eq.7) and gate resistance (Eq.8) two correction coefficients are being used. Consequently, when considering the temperature dependency it is recommended that choose the nominal working point condition to reflect the hot temperature dependency.

$$r_T = \frac{T}{T_{\text{NOM}}}$$
$$X_T = \begin{cases} r_T^\alpha & \text{when } (r_T < 1.0 \text{ and } \alpha > 1.0) \text{ or } (r_T > 1.0 \text{ and } \alpha < 0.0) \\ 1 + \alpha \cdot (r_T - 1.0) & \text{when } (r_T < 1.0 \text{ and } \alpha \leq 1.0) \text{ or } (r_T > 1.0 \text{ and } \alpha \geq 0.0) \\ 1.0 & \text{when } r_T = 1.0 \end{cases}$$

(5)

$$r_V = \frac{V}{V_{\text{NOM}}}$$
$$X_V = \begin{cases} r_V^{\sigma_0} & \text{when } r_V < 1.0 \text{ and } \sigma_0 > 1.0 \\ 1 + \sigma_0 \cdot (r_V - 1.0) & \text{when } r_V < 1.0 \text{ and } \sigma_0 \leq 1.0 \\ r_V^\sigma & \text{when } r_V > 1.0 \text{ and } \sigma > 0.0 \\ 1 + \sigma \cdot (r_V - 1.0) & \text{when } r_V > 1.0 \text{ and } \sigma \leq 0.0 \\ 1.0 & r_V = 1.0 \end{cases}$$

(6)

$$r_I = \frac{I}{I_{\text{NOM}}}$$
$$X_I = \begin{cases} r_I^{\kappa_0} & \text{when } r_I < 1.0 \text{ and } \kappa_0 > 1.0 \\ 1 + \kappa_0 \cdot (r_I - 1.0) & \text{when } r_I < 1.0 \text{ and } \kappa_0 \leq 1.0 \\ r_I^\kappa & \text{when } r_I > 1.0 \text{ and } \kappa > 0.0 \\ 1 + \kappa \cdot (r_I - 1.0) & \text{when } r_I > 1.0 \text{ and } \kappa \leq 0.0 \\ 1.0 & r_I = 1.0 \end{cases}$$

(7)

$$r_R = \frac{R}{R_{\text{NOM}}}$$

$$X_R = \begin{cases} r_I^{\rho_0} & \text{when } r_R < 1.0 \text{ and } \rho_0 > 1.0 \\ 1 + \rho_0 \cdot (r_R - 1.0) & \text{when } r_R < 1.0 \text{ and } \rho_0 \leq 1.0 \\ r_I^{\rho} & \text{when } r_R > 1.0 \text{ and } \rho > 0.0 \\ 1 + \rho \cdot (r_R - 1.0) & \text{when } r_R > 1.0 \text{ and } \rho \leq 0.0 \\ 1.0 & r_R = 1.0 \end{cases}$$

(8)

In the partial temperature correction function $X_T(T, \alpha)$, T denotes the Kelvin temperature. All functions take the value 1 for the nominal working point as shown in Figure 4. The “wp ratio” represents the ratio between the actual temperature, voltage, current, gate resistance and their corresponding nominal values. For working point conditions different from the nominal working point ($r=1$), larger or smaller loss energy values are given by the data sheet or measurements (indicated as points in Figure 4). The partial correction functions are designed to result in non-negative and limited values for all possible working point conditions. All correction functions meet the nominal working point in $[1, 1]$ which ensure the best accuracy for the nominal working point and exhibit a knee at $r=1$ because the functions are double sided to reproduce the full operating range of the device at a minimum energy error.

Thermal Model

IGBT and the free wheeling diode are on separate dies and mounted close together on the same substrate. Consequently for both, IGBT and diode, separate thermal networks are provided which are connected together on the level of the base plate forming a Y-type thermal network to the heat sink. The IGBT model provides the opportunity to choose between the continued fractional and the partial fractional thermal networks. Both networks show the same thermal impedance. If the thermal capacitances and resistances are considered to be computed from FEM calculation the physically based continued fraction model can be used or if the fitting to a thermal impedance curve is desired the mathematically based partial fractional model can be employed.

As shown in Figure 5, the electrical power losses of both the transistor (PINJ_T) and the diode (PINJ_D) are injected into their individual thermal networks. The positions of the switches ST1~ST4 and SD1~SD4 are decided by the type of thermal network configuration that's chosen: if continued fraction thermal model is chosen, the switches connect the thermal capacitances directly to the ambient node, while the thermal capacitances are connected in parallel to the corresponding thermal resistances through the switches if partial fraction thermal model is selected. Note that in Figure 5, the ground symbol means the ambient.

Note: Partial fraction model is in general easier to fit, and commonly used in the datasheet. On the other hand, the continued fraction model can reflect the internal physical structure of a semiconductor. It is possible to assign individual RC elements to layers inside a module so the temperature of internal layers can be simulated. However, such mapping requires detailed structural and material data. Fitting this model only from the thermal curve may not give good results.

For the IGBT components without external thermal pins, switches ST and SD in Figure 4 are closed so that an internal first-order heat sink model is connected, shown as Cthck and Rthck in Figure 5. Impedance values of the heat sink can be set by thermal parameters CTHDT and RTHDT.

If more sophisticated heat sink model is needed, use the IGBT components with thermal pins to connect with external heat sink. In this case, switches ST and SD in Figure 4 are open and thermal pins THERMO_T and THERMO_D are exposed. When external thermal pins are used, make sure **Model Thermal Output** in the **Thermal Parameters** tab is set to Kelvin, so it is compatible with external thermal components.

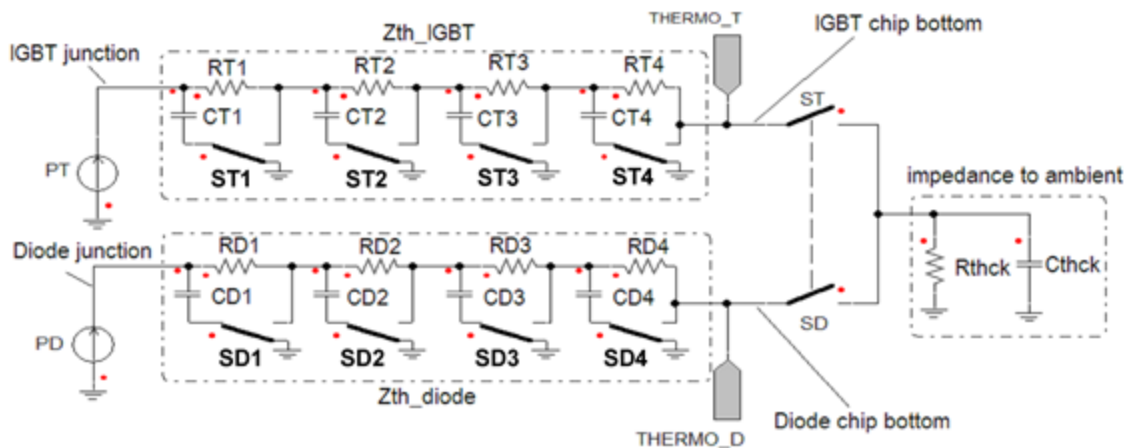


Figure 5. Thermal Network of the IGBT models

In the Average IGBT model, the power injection (PD and PT in Figure 5) are pulse-wise waveforms, and their amplitude is calculated using the switching/conduction energy losses and the user-specified pulse width. The pulse width is related to the setting of the thermal behavior level. The average IGBT model provides three thermal behavior levels: isothermal, average and dynamic. Users can change this setting in the **Thermal Parameters** tab of the component parameters.

When **Thermal Behavior Level** is set to dynamic, the switching pulses are calculated and injected into the thermal network at each switching period. Users need to specify TON, TOFF and TRR according to the datasheet of the device. This option provides the detailed transient behavior of the junction temperature, but requires a relatively small minimum time step and therefore results in lower simulation speed. The power injections during the on/off switch and conduction are calculated as follows:

On switch power injection: $P_{ON} = E_{ON}/T_{ON}$

Off switch power injection: $P_{OFF} = E_{OFF}/T_{OFF}$

Conduction power injection is directly calculated from current and voltage on internal transistor and diode; loss on stray elements is excluded from injected power.

When **Thermal Behavior Level** is set to average, average power pulse amplitude is calculated over a user-specified sampling time TSAMPLE, which can be several times the switching period.

The average thermal behavior preserves the transient trend of the junction temperature without the dynamic detail, and increases the simulation speed using minimum simulation time step requirements. A comparison between the dynamic and the average thermal behavior is made in Figure 6.

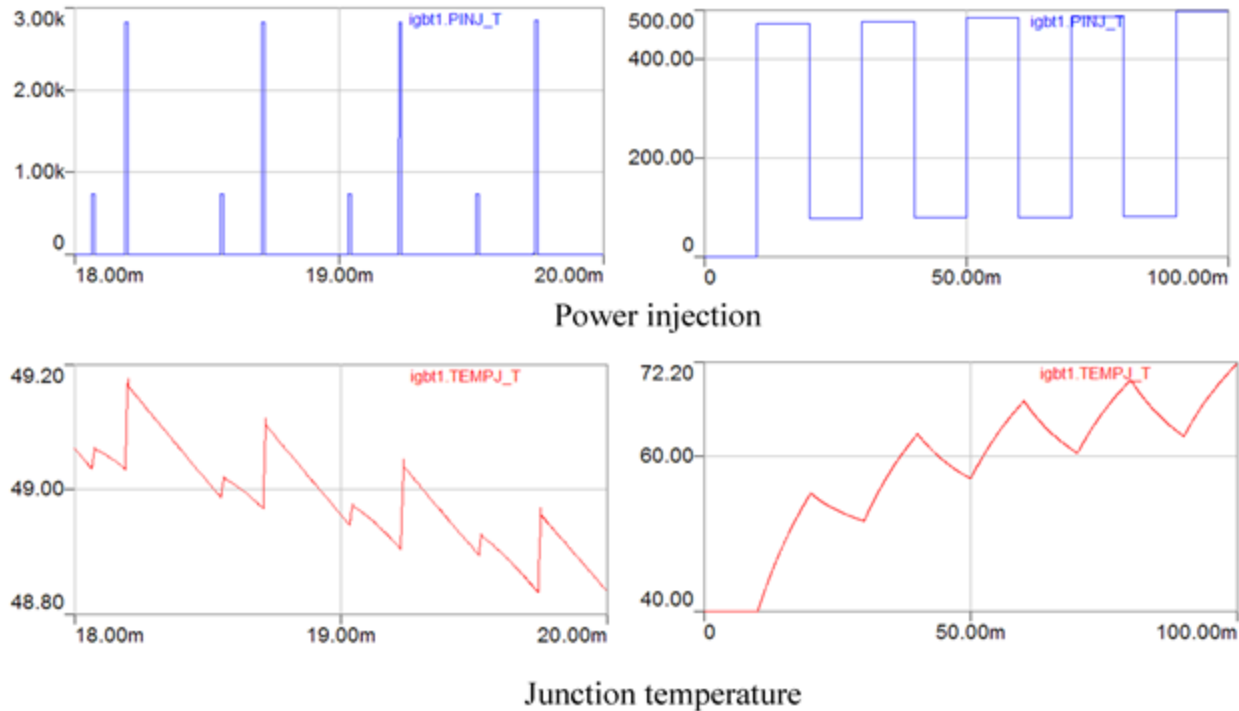


Figure 6. Comparison between the dynamic(left) and the average(right) thermal behavior of the Average IGBT model

The following table summarizes the use of different thermal behavior levels:

Thermal Behavior Level	Simulation Goal	Hmin, Hmax*	Other Parameters
Average	Estimate average junction temperature and its transient trend without dynamic detail. Short simulation time.	Hmin < 1/20 of duty cycle; Hmax can be large, but should not exceed TON, TOFF, or TRR.	TSAMPLE is integer times of switching cycle.
Dynamic	Estimate maximum junction temperature with dynamic detail. Long simulation time.	Hmin < 1/15 of Min (TON, TOFF, or TRR); Hmax cannot be much larger, and should not exceed TON, TOFF, or TRR.	TON, TOFF and TRR from data-sheet or measurement.

* Principle of setting simulation time step Hmin is: At least 20-30 steps per duty cycle (conducting cycle), and 15-20 steps per switching power pulse (For dynamic thermal behavior level only, switching power pulse duration is set by TON, TOFF, and TRR). For dynamic thermal behavior, Hmax cannot be much larger than Hmin. In general, Hmax should not exceed TON, TOFF, or TRR. Otherwise, the switching energy may have a large error.

NOTE:For fastest simulation time (3-5 times the runtime taken by system level model):

- Setting: **Use Simplified Model** and **Average** thermal behavior level
- Set parameters **CCE** and **CGE** to 0 (can be found in component **Parameters>Electrical Parameters** tab in table of **Electrical Parameters**, the two editable parameters are listed at Level **Dynamic**)
- For PWM type gate control signals, set Hmin as large as 1/3 of the narrowest conducting pulse

*Larger Hmin and Hmax beyond this pulse width is possible but will introduce a tradeoff between runtime and accuracy due to missed switching pulses.

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Netlist Syntax

```
UMODEL IGBT_Average ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) GATE:= %0,  
AUX_EMITTER:= %1, EMITTER:= %2, COLLECTOR:= %3, THERM_T:= %4, THERM_D:= %5  
( TYPE_IGBT:= @TYPE_IGBT, TYPE_FWD:= @TYPE_FWD, TYPE_THERM:= @TYPE_  
THERM, TYPE_DYN:= @TYPE_DYN, TYPE_BREAKTHROUGH:= @TYPE_  
BREAKTHROUGH, VP:= @VP, K:= @K, KLM:= @KLM, A_FET:= @A_FET, M_FET:= @M_  
FET, N_FET:= @N_FET, BN:= @BN, M_BJT:= @M_BJT, ISAT_BJT:= @ISAT_BJT, RB_BJT:=  
@RB_BJT, RP_BJT:= @RP_BJT, M_FWD:= @M_FWD, ISAT_FWD:= @ISAT_FWD, RB_  
FWD:= @RB_FWD, CGE:= @CGE, CCE:= @CCE, TON:= @TON, TOFF:= @TOFF, TRR:=  
@TRR, LC:= @LC, RC:= @RC, LE:= @LE, RE:= @RE, RAUX:= @RAUX, RG:= @RG \ , RG_  
ON:= @RG_ON, RG_OFF:= @RG_OFF, TEMPAMB:= @TEMPAMB, TEMPJNCT0:=  
@TEMPJNCT0, TNOM:= @TNOM, VNOM:= @VNOM, INOM:= @INOM, RGNOM_ON:=  
@RGNOM_ON, RGNOM_OFF:= @RGNOM_OFF, EON_NOM:= @EON_NOM, EOFF_NOM:=  
@EOFF_NOM, ERR_NOM:= @ERR_NOM, VGAP:= @VGAP, TC_VP:= @TC_VP, TC_K:=  
@TC_K, TC_N_FET:= @TC_N_FET, TC_A_FET:= @TC_A_FET, TC_M_FET:= @TC_M_  
FET, TC_ISAT_BJT:= @TC_ISAT_BJT, TC_M_BJT:= @TC_M_BJT, TC_M_FWD:= @TC_M_  
FWD, TC_ISAT_FWD:= @TC_ISAT_FWD, TC_RB_FWD:= @TC_RB_FWD, TC_EON:=  
@TC_EON, CC0_EON:= @CC0_EON, CC_EON:= @CC_EON, VC_EON:= @VC_EON, RC0_  
EON:= @RC0_EON, RC_EON:= @RC_EON, TC_EOFF:= @TC_EOFF \ , CC0_EOFF:=  
@CC0_EOFF, CC_EOFF:= @CC_EOFF, VC_EOFF:= @VC_EOFF, RC0_EOFF:= @RC0_  
EOFF, RC_EOFF:= @RC_EOFF, TC_ERR:= @TC_ERR, CC0_ERR:= @CC0_ERR, CC_  
ERR:= @CC_ERR, VC_ERR:= @VC_ERR, RC0_ERR:= @RC0_ERR, RC_ERR:= @RC_  
ERR, VBREAK_CE:= @VBREAK_CE, VBREAK_GE:= @VBREAK_GE, IBREAK:= @IBREAK,  
TEMPBREAK:= @TEMPBREAK, RFAULT_CE:= @RFAULT_CE, RFAULT_GE:= @RFAULT_  
GE, CHT1:= @CHT1, RHT1:= @RHT1, CHT2:= @CHT2, RHT2:= @RHT2,  
CHT3:= @CHT3, RHT3:= @RHT3, CHT4:= @CHT4, RHT4:= @RHT4, CHTD1:=  
@CHTD1, RHTD1:= @RHTD1, CHTD2:= @CHTD2, RHTD2:= @RHTD2, CHTD3:= @CHTD3  
\ , RHTD3:= @RHTD3, CHTD4:= @CHTD4, RHTD4:= @RHTD4, CHTDT:= @CHTDT,  
RHTDT:= @RHTDT, TSAMPLE:= @TSAMPLE, SYNC:= @SYNC) SRC: DB(Lib:-  
:=@ModelLibraryName);
```

NOTE: THERM_T and THERM_D only exist in the NIGBT_Average_T and PIGBT_Average_T models.

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
GATE	Gate Contact	electrical
EMITTER	Emitter Contact	electrical
AUX_EMITTER	Auxiliary Emitter Contact	electrical
COLLECTOR	Collector Contact	electrical
THERM_T	IGBT Die Bottom Thermal Contact	thermal
THERM_D	Diode Die Bottom Thermal Contact	thermal

NOTE: THERM_T and THERM_D pins only exist in the NIGBT_Average_T and PIGBT_Average_T models.

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Parameters

Table 2.

Name	Description	Data Type
TYPE_IGBT	IGBT Type Flag -2:p-Type 2:n-Type	real
TYPE_FWD	Freewheeling Diode Type 0:no 1:static	real
TYPE_DYN (for full average model)	0:stat 1:dyn +10:ext sync +20: mixed (gate driven + external) - (recommended) +30: internal (gate driven)	real
TYPE_DYN (for simplified average model)	0:stat 1:dyn +10:ext sync +20:mixed (gate driven + external) - (recommended) +30:internal (gate driven) +100:Static Behavior as Ideal Switch +400:Static Behavior Vsat Approximation (recommended)	real
TYPE_THERM	xx0: isothermal behavior xx1: average behavior xx2: dynamic behavior x0x: partial fractional, therm. network x1x: cont. fractional, therm. network x2x: partial fractional, therm. equations x3x: cont. fractional, therm. equations 0xx: output temperature rise only 1xx: output in degrees Celsius 2xx: output in Kelvin0	real
TYPE_BREAKTHROUGH	0:disable breakthrough 2:enable breakthrough	real

VGAP	Band Gap Voltage	real
VP	FET Pinch-off Voltage at nominal temperature	real
K	FET Transfer Constant at nominal temperature	real
KLM	FET Channel Length Modulation Factor	real
A_FET	FET Saturation Factor	real
M_FET	FET Saturation Exponent	real
N_FET	Exponent of FET Transfer Characteristic of FET	real
RD0	Small Voltage Bulk Resistance [Ohm]	real
RD1	Large Voltage Bulk Resistance [Ohm]	real
RDV	Bulk Resistance Inflection Voltage [V]	real
BN	BJT Current Gain at nominal temperature	real
M_BJT	BJT Ideality Factor	real
ISAT_BJT	BJT Saturation Current at reference temperature [A]	real
RB_BJT	BJT Bulk Resistance [ohm]	real
RP_BJT	BJT Base Shunt [ohm]	real
M_FWD	FWD Ideality Factor	real
ISAT_FWD	FWD Saturation Current at nominal	real

	temperature [A]	
RB_FWD	FWD Bulk Resistance [ohm]	real
TC_VP	Temperature Coefficient of VP0	real
TC_K	Temperature Coefficient of K0	real
TC_N_FET	Temperature Coefficient of N_FET	real
TC_A_FET	Temperature Coefficient of A_FET	real
TC_M_FET	Temperature Coefficient of M_FET	real
TC_RD0	Temperature Coefficient of RD0	real
TC_RD1	Temperature Coefficient of RD1	real
TC_RDV	Temperature Coefficient of RDV	real
TC_ISAT_BJT	Temperature Coefficient of ISAT_ BJT	real
TC_M_BJT	Temperature Coefficient of M_BJT	real
TC_M_FWD	Temperature Coefficient of M_FWD	real
TC_ISAT_FWD	Temperature Coefficient of ISAT_ FWD	real
TC_RB_FWD	Temperature Coefficient of RB_ FWD	real
RE	Emitter Connector Resistance [ohm]	real
LE	Emitter Connector Inductance [H]	real
LC	Collector Connector Inductance [H]	real
RC	Collector Connector Resistance	real

	[ohm]	
RG	Gate Connector Ref. Resistance [ohm]	real
RAUX	Internal Emitter Resistance [ohm]	real
CGE	Gate Emitter Reference Capacitance [F]	real
CCE	Collector Emitter Reference Capacitance [F]	real
TEMPAMB	Ambient Temperature [°C]	real
TEMPJNCT0	Junction Temperature at Simulation Start [°C]	real
TNOM	Nominal Temperature [°C]	real
VNOM	Nominal Collector-Emitter Voltage [V]	real
INOM	Nominal Collector Current [A]	real
EON_NOM	Nominal On-Switch Loss Energy [J]	real
EOFF_NOM	Nominal Off-Switch Loss Energy [J]	real
ERR_NOM	Nominal Reverse Recovery Loss Energy [J]	real
RG_ON	On-Switch External Gate Resistance [ohm]; This is not a physical resistance but the value of gate resistance in the external gate drive. Users should include proper gate resistance in their designs and put the value in this parameter.	real
RG_OFF	Off-Switch External Gate Resistance [ohm]; This is not a physical	real

	resistance but the value of gate resistance in the external gate drive. Users should include proper gate resistance in their designs and put the value in this parameter.	
RGNOM_ON	Nominal On-Switch External Gate Resistance [ohm]	real
RGNOM_OFF	Nominal Off-Switch External Gate Resistance [ohm]	real
TC_EON	Temperature coefficient of EON	real
CC0_EON	Current coefficient of EON (IC	real
CC_EON	Current coefficient of EON (IC>=>=ICNOM)	real
VC_EON	Voltage coefficient of EON	real
RC0_EON	Gate resistance coefficient of EON (RG_ON	real
RC_EON	Gate resistance coefficient of EON (RG_ON>=RGNOM_ON)	real
TC_EOFF	Temperature coefficient of EOFF	real
CC0_EOFF	Current coefficient of EOFF (IC	real
CC_EOFF	Current coefficient of EOFF (IC>=>=ICNOM)	real
VC_EOFF	Voltage coefficient of EOFF	real
RC0_EOFF	Gate resistance coefficient of EOFF (RG_OFF	real
RC_EOFF	Gate resistance coefficient of EOFF (RG_ON>=RGNOM_OFF)	real
TC_ERR	Temperature coefficient of ERR	real

CC0_ERR	Current coefficient of ERR (IC	real
CC_ERR	Current coefficient of ERR(IC>->=ICNOM)	real
VC_ERR	Voltage coefficient of ERR	real
RC0_ERR	Gate resistance coefficient of ERR (RG_ON	real
RC_ERR	Gate resistance coefficient of ERR (RG_ON>=RGNOM_ON)	real
VBREAK_CE	Output Voltage Breakdown [V]	real
VBREAK_GE	Input Voltage Breakdown [V]	real
IBREAK	Output Current Breakdown [A]	real
TEMPBREAK	Temperature Breakdown [°C]	real
RFAULT_CE	Remaining Breakdown Output Resistance [ohm]	real
RFAULT_GE	Remaining Breakdown Input Resistance [ohm]	real
CTHT1	1. thermal transistor capacity [F]	real
RTHT1	1. thermal transistor resistance [ohm]	real
CTHT2	2. thermal transistor capacity [F]	real
RTHT2	2. thermal transistor resistance [ohm]	real
CTHT3	3. thermal transistor capacity [F]	real
RTHT3	3. thermal transistor resistance [ohm]	real

CTHT4	4. thermal transistor capacity [F]	real
RTHT4	4. thermal transistor resistance [ohm]	real
CTHD1	1. thermal diode capacity [F]	real
RTHD1	1. thermal diode resistance [ohm]	real
CTHD2	2. thermal diode capacity [F]	real
RTHD2	2. thermal diode resistance [ohm]	real
CTHD3	3. thermal diode capacity [F]	real
RTHD3	3. thermal diode resistance [ohm]	real
CTHD4	4. thermal diode capacity [F]	real
RTHD4	4. thermal diode resistance [ohm]	real
CTHDT	common thermal capacity [F]	real
RTHDT	common thermal resistance [ohm]	real
SYNC	External synchronization signal	real
TON	on switch power pulse time [s]	real
TOFF	off switch power pulse time [s]	real
TRR	reverse recovery power pulse time [s]	real
TSAMPLE	Thermal sampling time [s]	real

Note: Average model can generate an internal sync signal which triggers the loss calculation. If more control on the triggering is needed, you can choose 'mixed' or 'external' to add external synchronization signal SYNC. The SYNC signal is required to cross zero in positive direction only when device start conducting, and cross zero in a negative direction only when the device stops conducting or when I_{rr} is formed. It is preferable to use an ideal pulse wave, or trapezoidal wave.

When using an ideal pulse wave, a signal change between zero and a positive value is also supported.

Note that the synchronization signal may not be the same as the gate drive signal for the same device. Rule of thumb is to give a clear rising edge or zero crossing signal at the moment when the conducting status of a device changes, or when current flows on the device start to change.

Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
VCE	Collector-Emitter Voltage [V]	Output	real
IC	Collector Current [A]	Output	real
IG	Gate Current [A]	Output	real
IFD	FWD Current [A]	Output	real
VD	FWD Voltage Drop [V]	Output	real
TRANSCOND	Trans Conductance [A/V]	Output	real
OUTCOND	Output Conductance [A/V]	Output	real
TEMPJ_T	IGBT junction temperature [°C]	Output	real
TEMPJ_D	Diode junction temperature [°C]	Output	real
TEMPBOT_T	IGBT bottom temperature [°C]	Output	real
TEMPBOT_D	Diode bottom temperature [°C]	Output	real
TEMP_PLATE	copper plate top temperature [°C]	Output	real
PINJ_T	IGBT model power injection [W]	Output	real
PINJ_D	Diode model power injection [W]	Output	real

E_ON	on switching energy [J]	Output	real
E_OFF	off switching energy [J]	Output	real
E_RR	loss energy of diode reverse recovery [J]	Output	real
PEL_T	DC losses of IGBT [W]	Output	real
PEL_D	DC losses of DIODE [W]	Output	real
STEP	actual time step size [s]	Output	real
STEP_VISUAL	Rectangular Visualization of Step Size	Output	real
VCE_FAULT	Vce fault flag [0/1]	Output	real
VGE_FAULT	Vge fault flag [0/1]	Output	real
IC_FAULT	collector current fault flag [0/1]	Output	real
TEMPJ_FAULT	junction temperature fault flag [0/1]	Output	real

Note that the internal calculation of switching energies and power will not start until after a couple of switches, in order to avoid influence of large initial transients.

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Example

Four examples are available, representing the N-Type Average model, the N-Type Average model with FWD diode, the P-Type Average model and the P-Type Average model with FWD diode. The examples are shown below.

This example demonstrates the operation mechanism of the N-Channel IGBT Average model through a simple example. The control gate voltage is supplied by a pulse-wave voltage source E1. The schematic of the example is shown in Figure 7, system parameters are listed in Table 4, and the simulation results are shown in Figure 8 and 9.

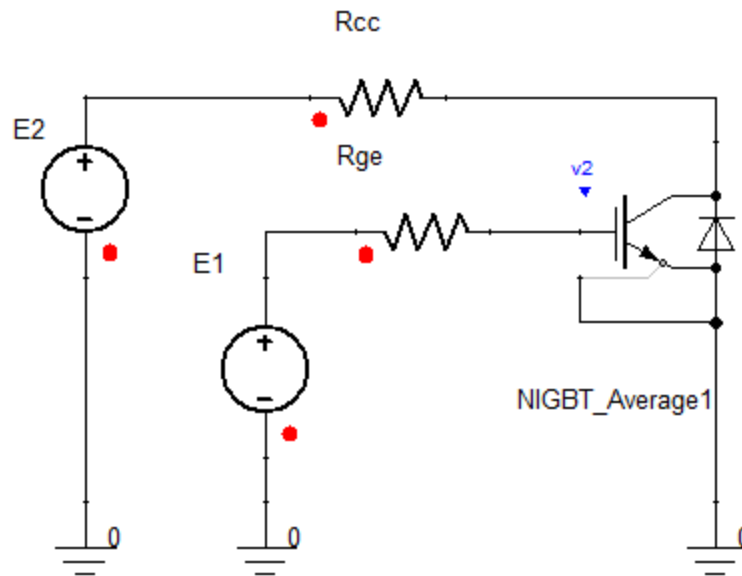


Figure 7. Application example of the N-Channel IGBT model (Average)

Table 4. System Parameters

Component	Parameter	Value [unit]
Resistor Rge	R	10 [Ohm]
Resistor Rcc	R	1 [Ohm]
Voltage Source (Pulse) E1	AMPL	15 [V]
	FREQ	1000 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [V]
Voltage Source E2	EMF	500 [V]

Average IGBT NIGBT_ AVERAGE1	TYPE_DYN	11
	VCE	0
	IC	0
	VNOM	1200
	INOM	600
	SYNC	E1.EMF
	TYPE_ BREAKTHROUGH	1

* All other parameters of the N-Channel IGBT model use their default values, therefore they are not included in the parameter table.

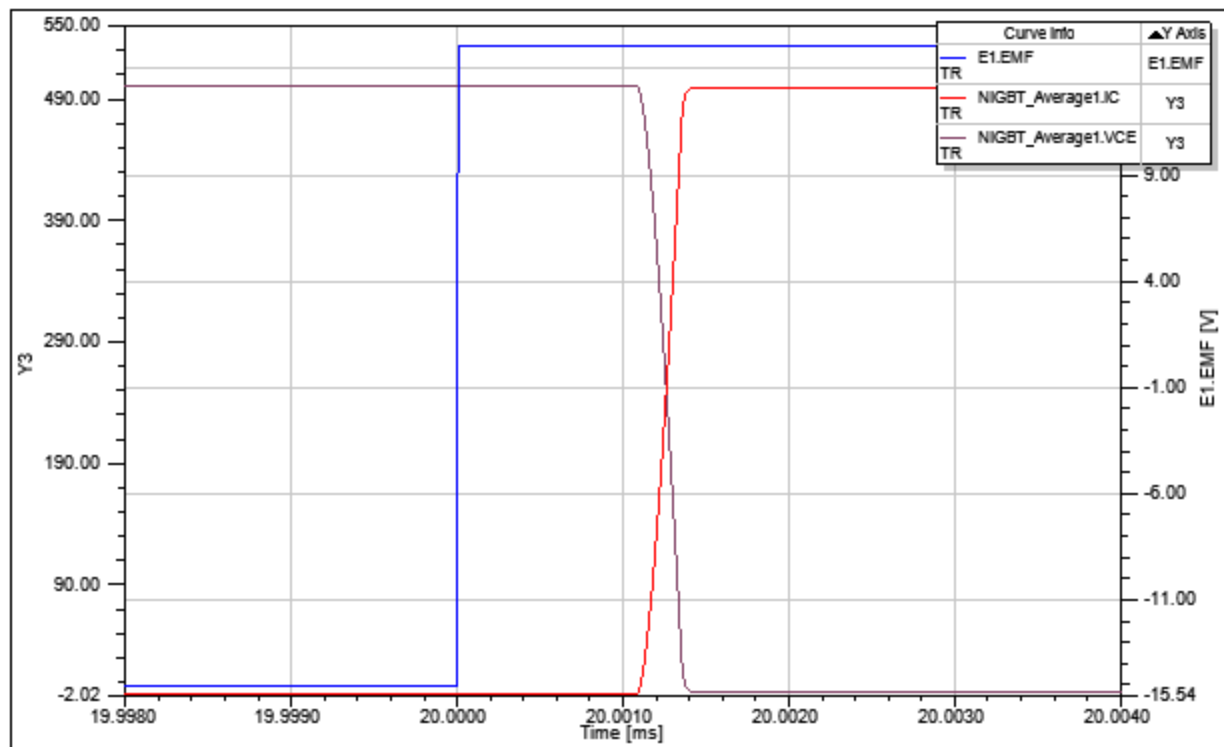


Figure 8. Simulation result-Switching ON Waveforms for NIGBT_AVERAGE1

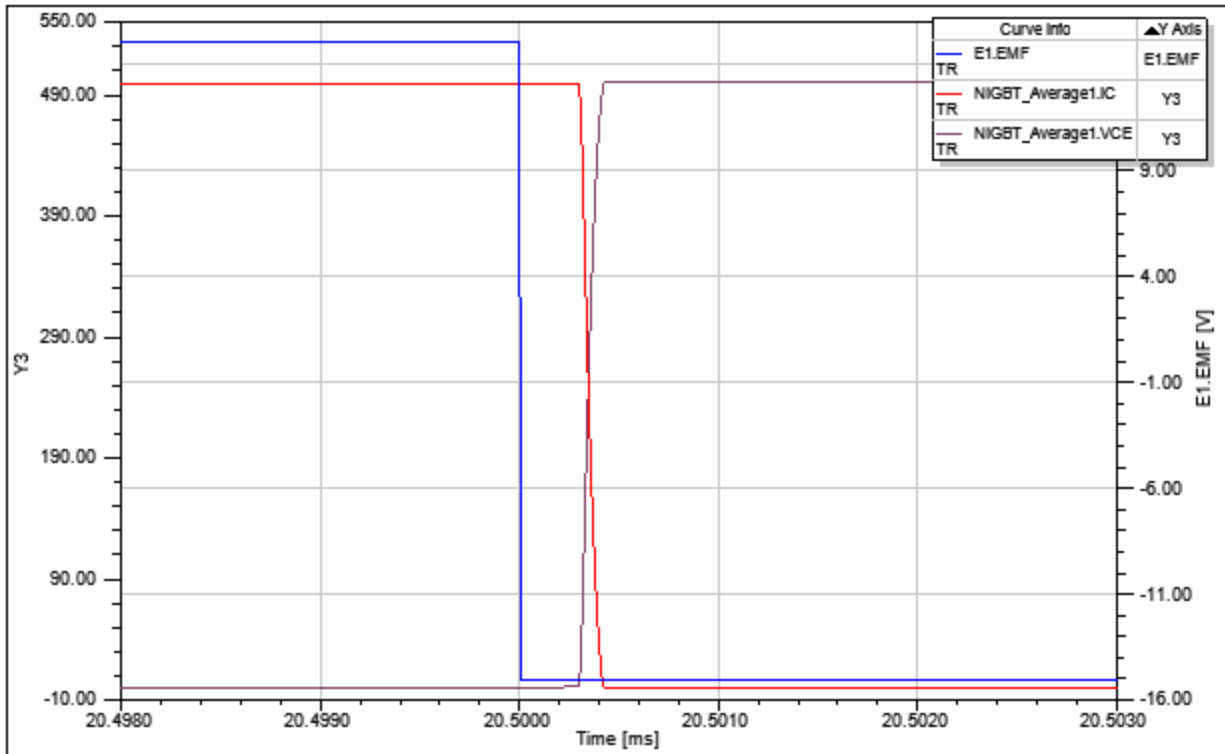


Figure 9. Simulation result-Switching OFF Waveforms for NIGBT_AVERAGE1

This example demonstrates the operation mechanism of the average N-Channel IGBT model with thermal pin through a simple example. The control gate voltage is supplied by a pulse-wave voltage source E1. The schematic of the example is shown in Figure 10, system parameters are listed in Table 5, and the simulation results are shown in Figure 11 and 12.

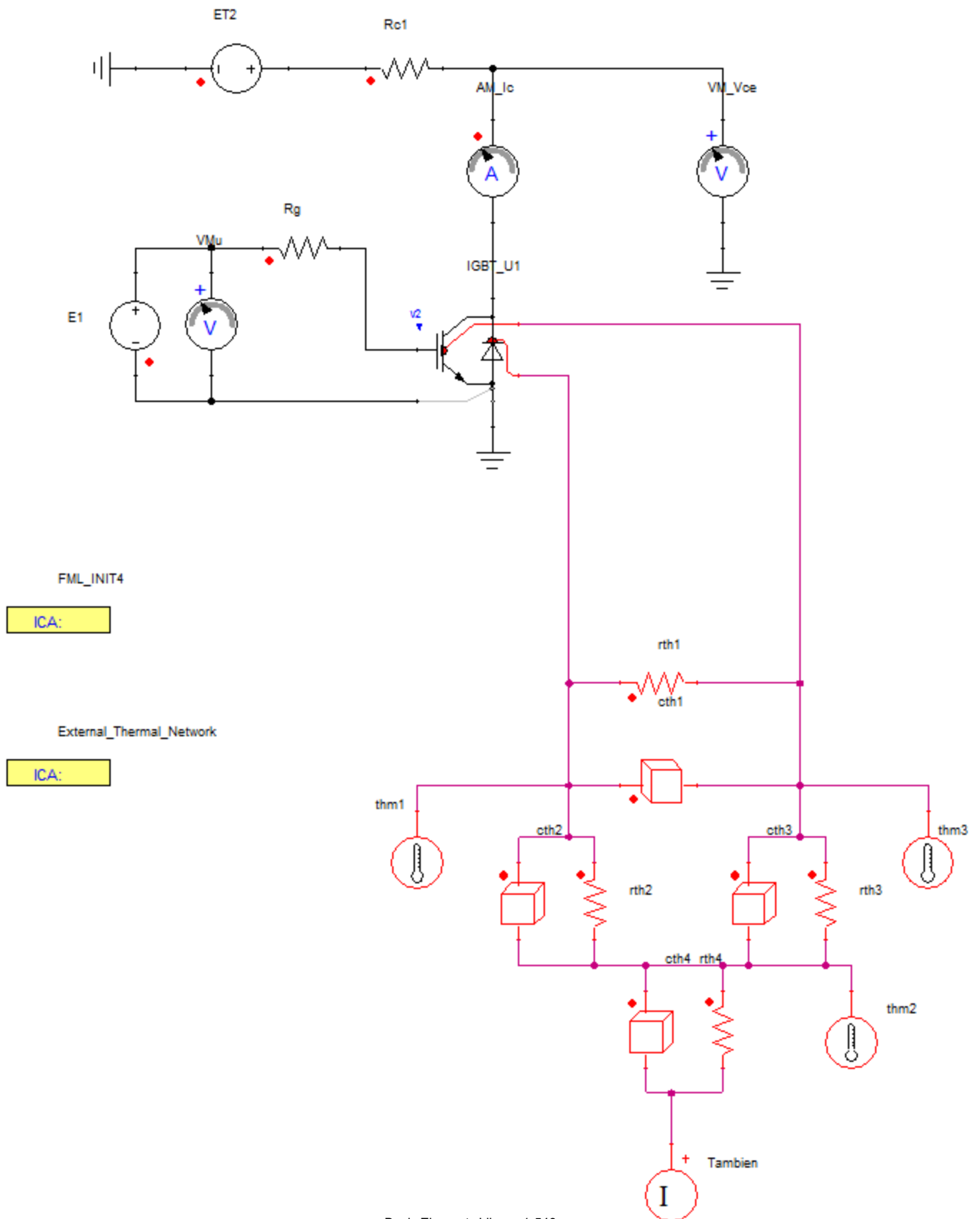


Figure 10. Application example of the N-Channel IGBT model with Thermal Pin (Average)

Table 5. System Parameters

Component	Parameter	Value [unit]
Resistor Rg/Rc1	R	10 [Ohm]
Resistor R1	R	R4 [Ohm]
Resistor R4	R	R1 [Ohm]
Resistor R2/R3	R	R2 [Ohm]
Capacitor C1	C	C4 [F]
Capacitor C4	C	C1 [F]
Capacitor C2/C3	C	C2 [F]
Voltage Source (Pulse) E1	AMPL	15 [V]
	FREQ	10000 [Hz]
	TDELAY	0 [s]
	PHASE	90 [degree]
	OFF	0 [V]
Voltage Source ET2	EMF	1200 [V]
Initial Values EXTERNAL_THERMAL_NETWORK	EQU0	CT4:=3.1
	EQU1	RT4:=0.032
	EQU2	R1:=0.2*RT4
	EQU3	R2:=0.2*RT4
	EQU4	R3:=5*RT4

	EQU5	$R4:=0.05*RT4$
	EQU6	$C1:=CT4$
	EQU7	$C2:=5*CT4$
	EQU8	$C3:=10*CT4$
	EQU9	$C4:=20*CT4$
Average IGBT NIGBT_ AVERAGE_T1	RG_OFF	10
	RGNOM_ON	10
	RGNOM_OFF	10
	RC0_EON	1
	RC_EON	0
	RC0_EOFF	1
	RC0_ERR	1
	RAUX	0
	VNOM	600
	INOM	225
	EON_NOM	0.015
	EOFF_NOM	0.036
	ERR_NOM	0.020
	TC_VP	-0.5
	TC_K	-2.3

TC_N_FET	9e-004
TC_A_FET	-7.4
TC_M_FET	0.010
TC_ISAT_BJT	-19
TC_M_BJT	0.0014
TC_M_FWD	-0.0065
TC_ISAT_FWD	-25
TC_RB_FWD	0.0034
TC_EON	0.364
CC0_EON	0.470
CC_EON	1.5
TC_EOFF	0.717
CC0_EOFF	0.087
CC_EOFF	1
VC_EOFF	1
TC_ERR	2
CC0_ERR	0.275
CC_ERR	0.560
CTHT1	1.5
RTHT1	0.0066
CTHT2	

	0.550
RTHT2	0.036
CTHT3	1.4
RTHT3	0.035
CTHT4	3.1
RTHT4	0.032
CTHD1	1.4
RTHD1	0.047
CTHD2	0.235
RTHD2	0.073
CTHD3	1.4
RTHD3	0.0352
CTHD4	3
RTHD4	0.032
CTHDT	1
RTHDT	0.005
SYNC	VMu.V [V]
TEMPJ_T	0
TEMPJ_D	0
TYPE_FWD	1
TYPE_THERM	101

TYPE_DYN	11
VP	5.5
K	2.5
KLM	0
A_FET	0.55
M_FET	1.1
M_BJT	5
ISAT_BJT	0.038
RB_BJT	0.001
RP_BJT	1e+010
M_FWD	1.25
ISAT_FWD	3e-006
RB_FWD	0.0046
CGE	16e-009
CCE	160e-012
TON	10e-006
TOFF	10e-006
TRR	10e-006
LC	20e-009
RC	550e-006

	RG	3.3
	TSAMPLE	200e-006
	TYPE_BREAKTHROUGH	1

* All other parameters of the N-Channel IGBT model use their default values, therefore they are not included in the parameter table.

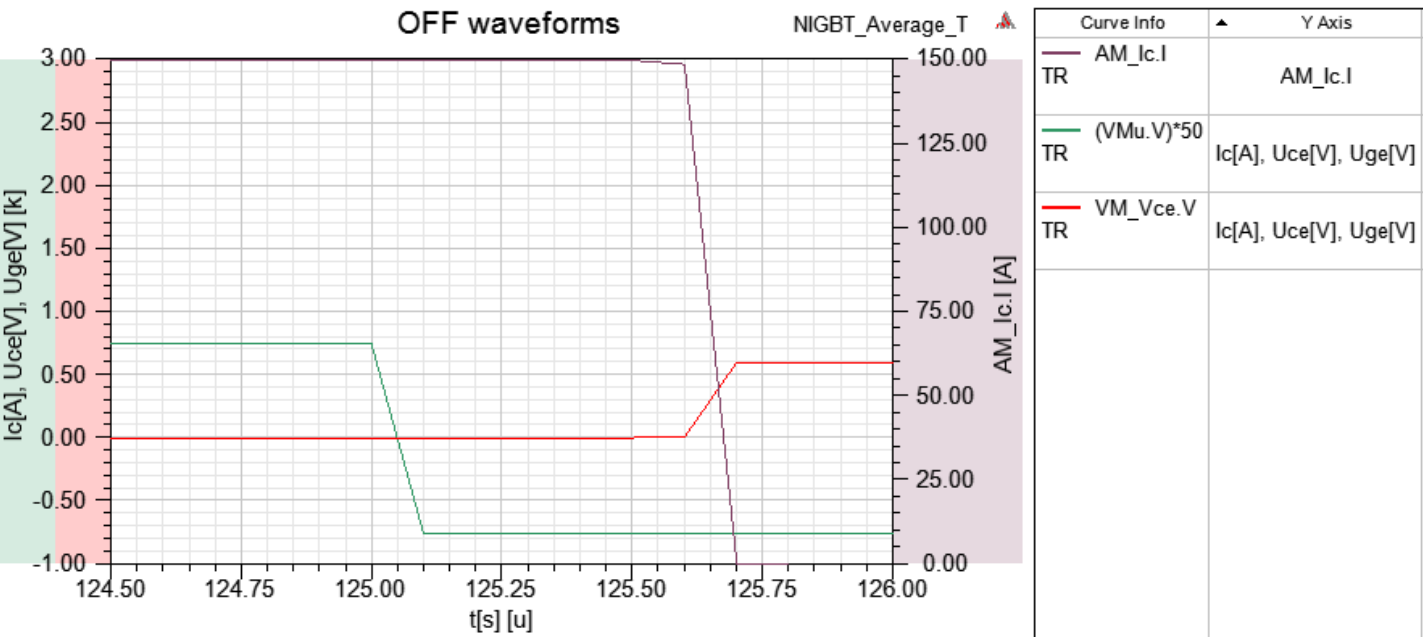
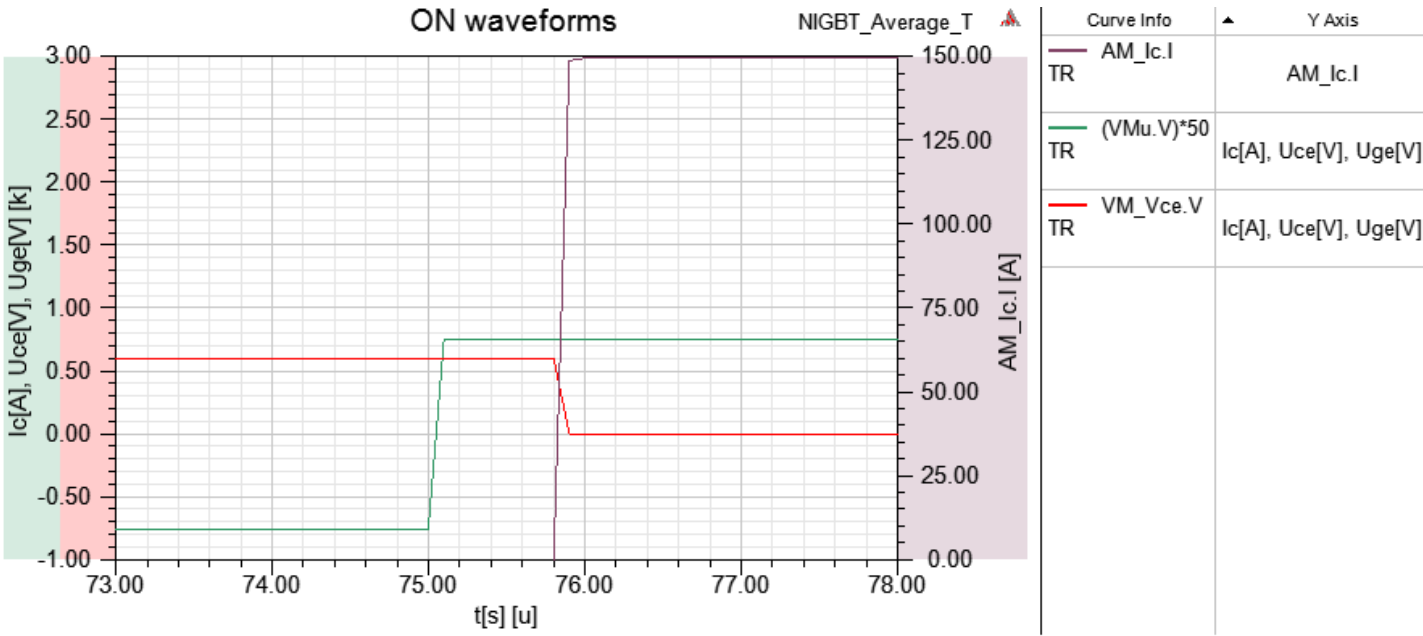


Figure 11. Simulation result-Switching ON Waveforms(Top) and OFF Waveforms(Bottom) for NIGBT_AVERAGE_T1

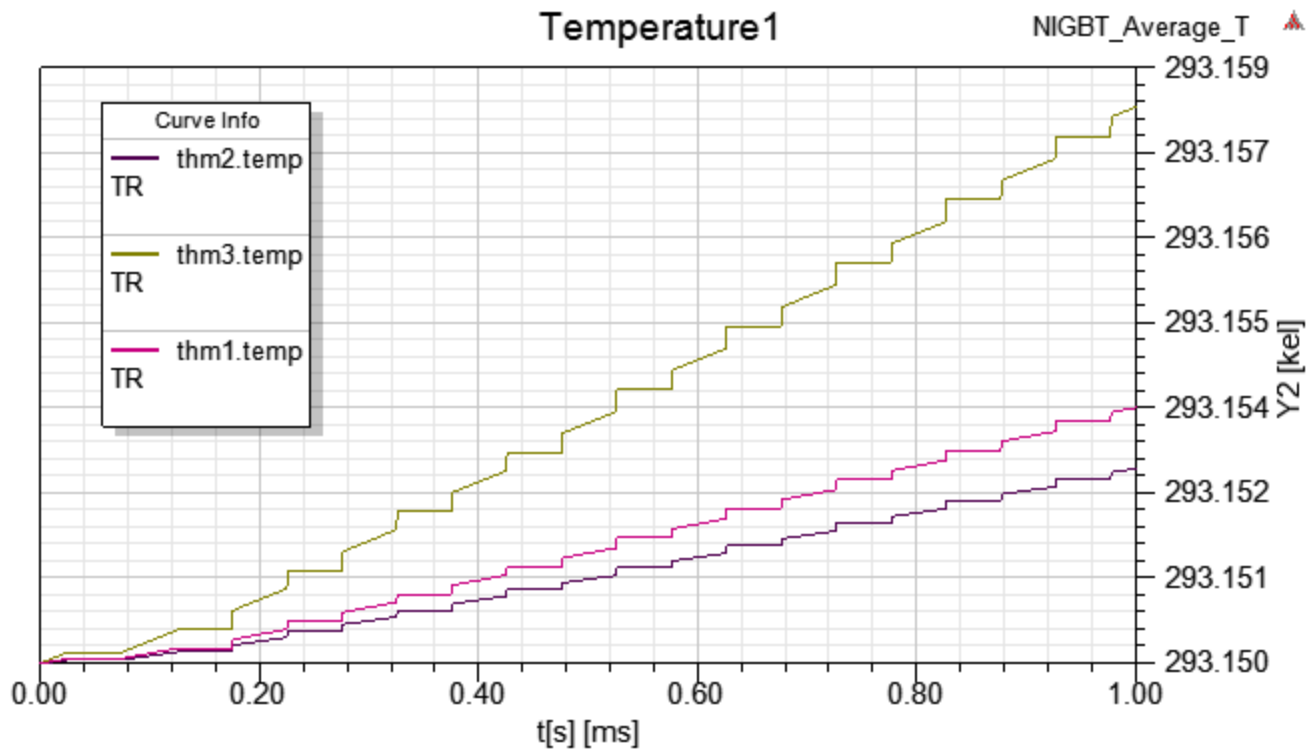


Figure 12. Simulation result-Temperature

This example demonstrates the operation mechanism of the average P-Channel IGBT model through a simple example. The control gate voltage is supplied by a pulse-wave voltage source E1. The schematic of the example is shown in Figure 13, system parameters are listed in Table 6, and the simulation results are shown in Figure 14 and 15.

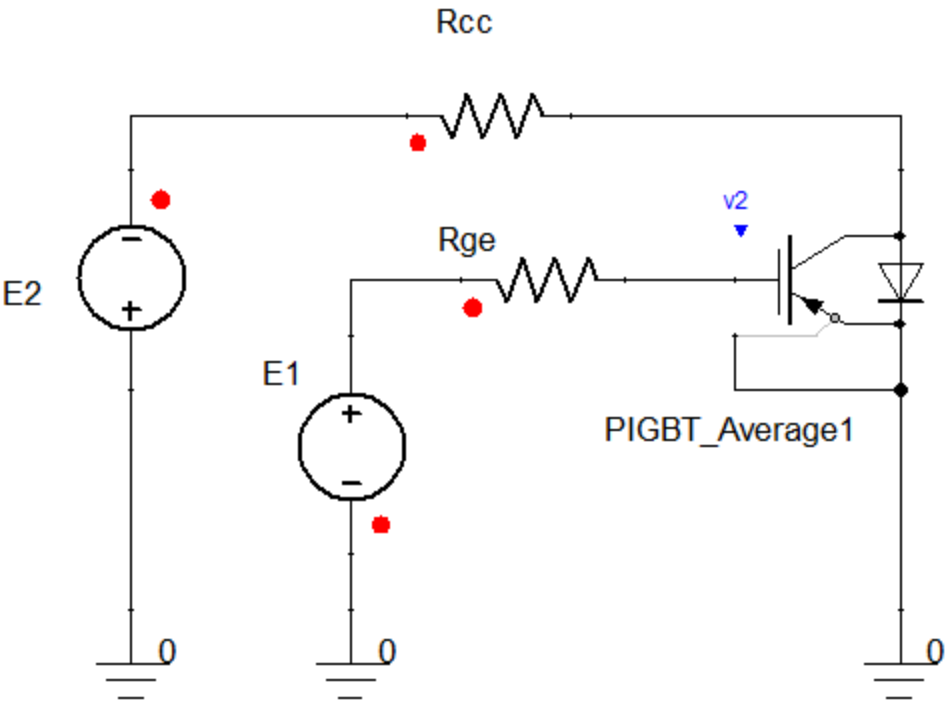


Figure 13. Application example of the P-Channel IGBT model (Average)

Table 6. System Parameters

Component	Parameter	Value [unit]
Resistor Rge	R	10 [Ohm]
Resistor Rcc	R	1 [Ohm]
Voltage Source (Pulse) E1	AMPL	15 [V]
	FREQ	1000 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [V]
Voltage Source E2	EMF	500 [V]

Average IGBT PIGBT_ AVERAGE1	VCE	0
	IC	0
	VNOM	1200
	INOM	600
	SYNC	E1.EMF
	TYPE_ BREAKTHROUGH	1

* All other parameters of the P-Channel IGBT model use their default values, therefore they are not included in the parameter table.

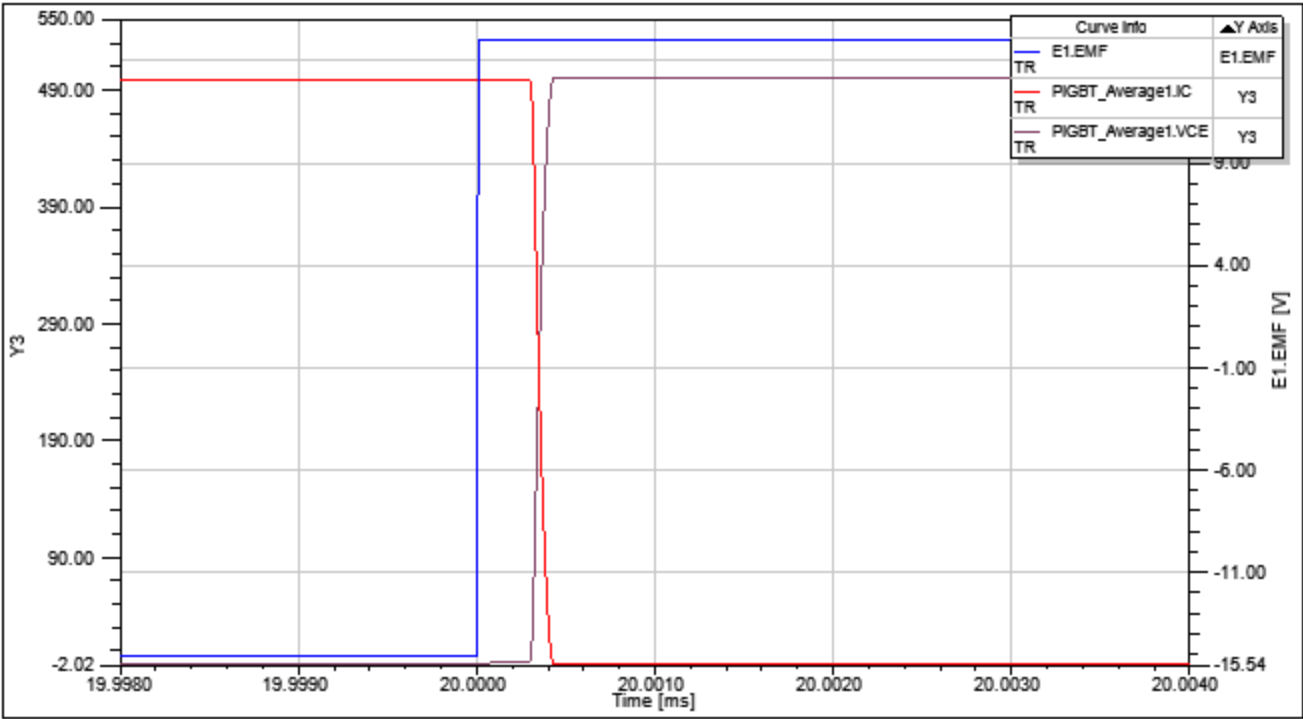


Figure 14. Simulation result-Switching ON Waveforms for PIGBT_AVERAGE1

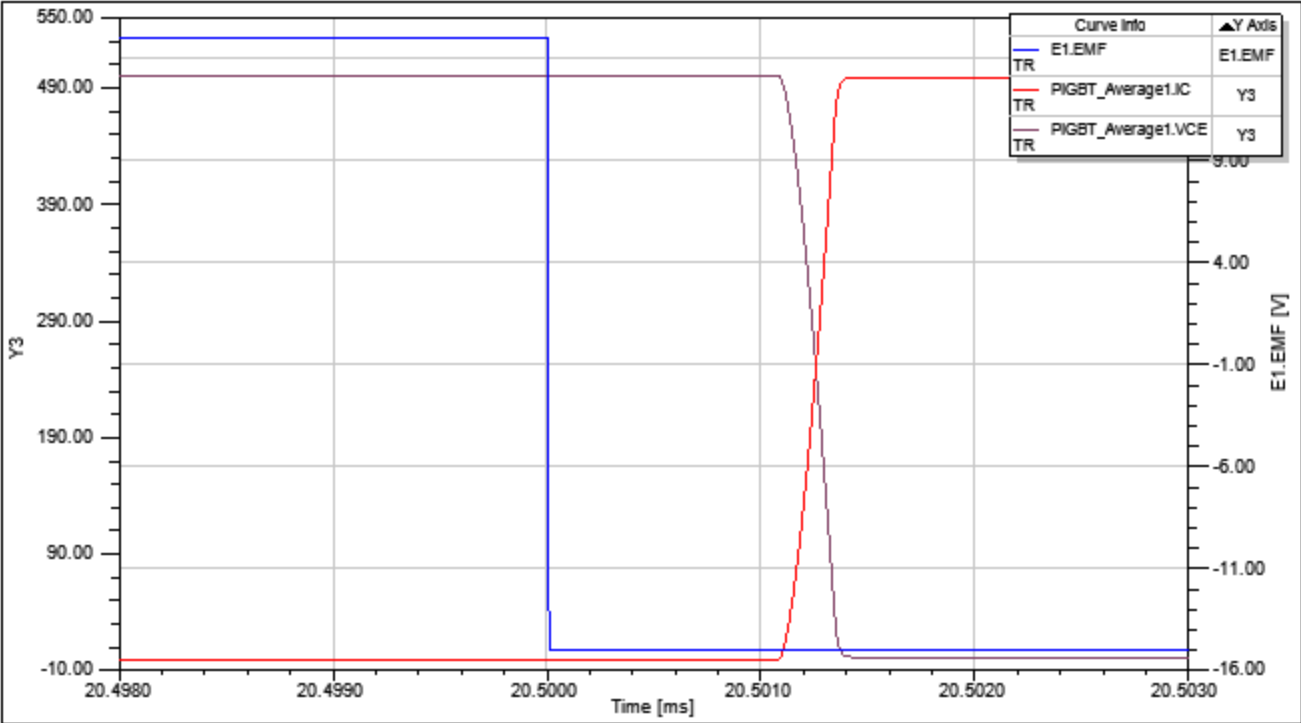


Figure 15. Simulation result-Switching OFF Waveforms for PIGBT_AVERAGE1

This example demonstrates the operation mechanism of the Average P-Channel IGBT model with thermal pin through a simple example. The control gate voltage is supplied by a pulse-wave voltage source E1. The schematic of the example is shown in Figure 16, system parameters are listed in Table 7, and the simulation results are shown in Figure 17 and 18.

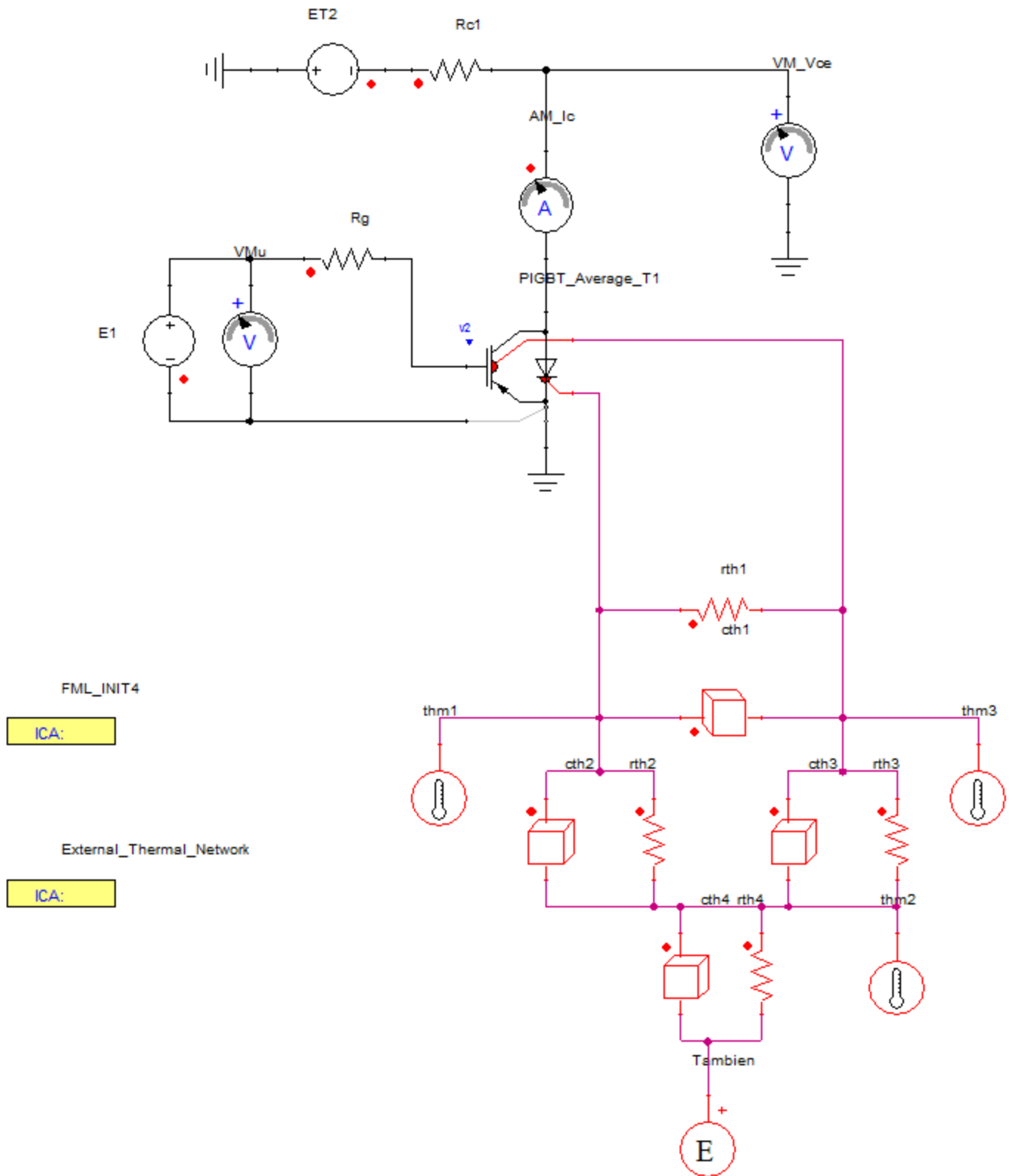


Figure 16. Application example of the P-Channel IGBT model with Thermal Pin (Average)**Table 7. System Parameters**

Component	Parameter	Value [unit]
Resistor Rg/Rc1	R	10 [Ohm]
Resistor R1	R	R4 [Ohm]
Resistor R4	R	R1 [Ohm]
Resistor R2/R3	R	R2 [Ohm]
Capacitor C1	C	C4 [F]
Capacitor C4	C	C1 [F]
Capacitor C2/C3	C	C2 [F]
Voltage Source (Pulse) E1	AMPL	15 [V]
	FREQ	10000 [Hz]
	TDELAY	0 [s]
	PHASE	90 [degree]
	OFF	0 [V]
Voltage Source ET2	EMF	1200 [V]
Initial Values EXTERNAL_THERMAL_NETWORK	EQU0	CT4:=3.1
	EQU1	RT4:=0.032
	EQU2	R1:=0.2*RT4
	EQU3	R2:=0.2*RT4
	EQU4	R3:=5*RT4

	EQU5	$R4:=0.05*RT4$
	EQU6	$C1:=CT4$
	EQU7	$C2:=5*CT4$
	EQU8	$C3:=10*CT4$
	EQU9	$C4:=20*CT4$
Average IGBT NIGBT_ AVERAGE_T1	RG_OFF	10
	RG_ON	10
	RGNOM_ON	10
	RGNOM_OFF	10
	RC0_EON	1
	RC_EON	0
	RC0_EOFF	1
	RC0_ERR	0
	RAUX	0
	VNOM	600
	INOM	225
	EON_NOM	0.015
	EOFF_NOM	0.036
	ERR_NOM	0.020
	TC_VP	-0.5

TC_K	-2.3
TC_NFET	9e-004
TC_AFET	-7.4
TC_MFET	0.010
TC_ISAT_BJT	-19
TC_M_BJT	0.0014
TC_M_FWD	-0.0065
TC_ISAT_FWD	-25
TC_RB_FWD	0.0034
TC_EON	0.364
CC0_EON	0.470
CC_EON	1.5
TC_EOFF	0.717
CC0_EOFF	0.087
CC_EOFF	1
VC_EOFF	1
TC_ERR	2
CC0_ERR	0.275
CC_ERR	0.560
CTHT1	1.5
RTHT1	0.0066

CTHT2	0.550
RTHT2	0.036
CTHT3	1.4
RTHT3	0.035
CTHT4	3.1
RTHT4	0.032
CTHD1	1.4
RTHD1	0.047
CTHD2	0.235
RTHD2	0.073
CTHD3	1.4
RTHD3	0.0352
CTHD4	3
RTHD4	0.032
CTHDT	1000
RTHDT	1e-005
SYNC	VMu.V [V]
TEMPJ_T	0
TEMPJ_D	0
TYPE_FWD	1

TYPE_THERM	102
TYPE_DYN	11
VP	-5.5
K	2.5
KLM	0
A_FET	0.55
M_FET	1.1
M_BJT	5
ISAT_BJT	0.038
RB_BJT	0.001
RP_BJT	1e+010
M_FWD	1.25
ISAT_FWD	3e-006
RB_FWD	0.0046
CGE	16e-009
CCE	160e-012
TON	10e-006
TOFF	10e-006
TRR	1e-006
LC	20e-009
RC	550e-006

	RG	3.3
	TSAMPLE	200e-006
	TYPE_BREAKTHROUGH	1

* All other parameters of the P-Channel IGBT model use their default values, therefore they are not included in the parameter table.

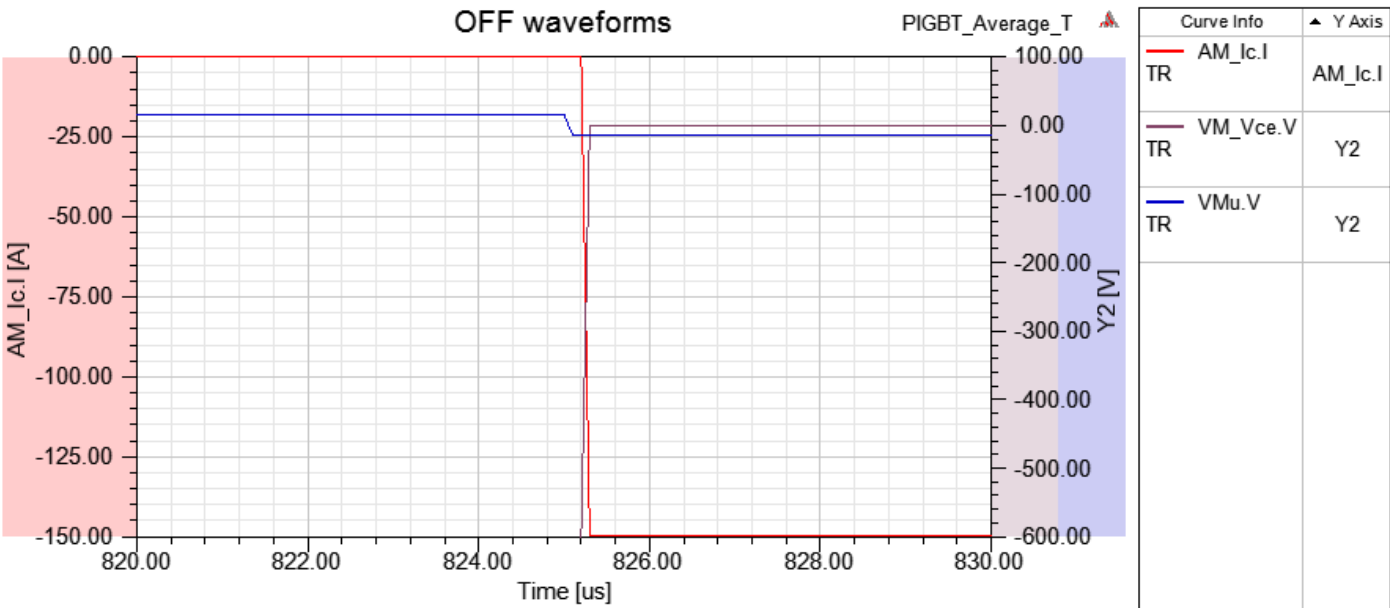
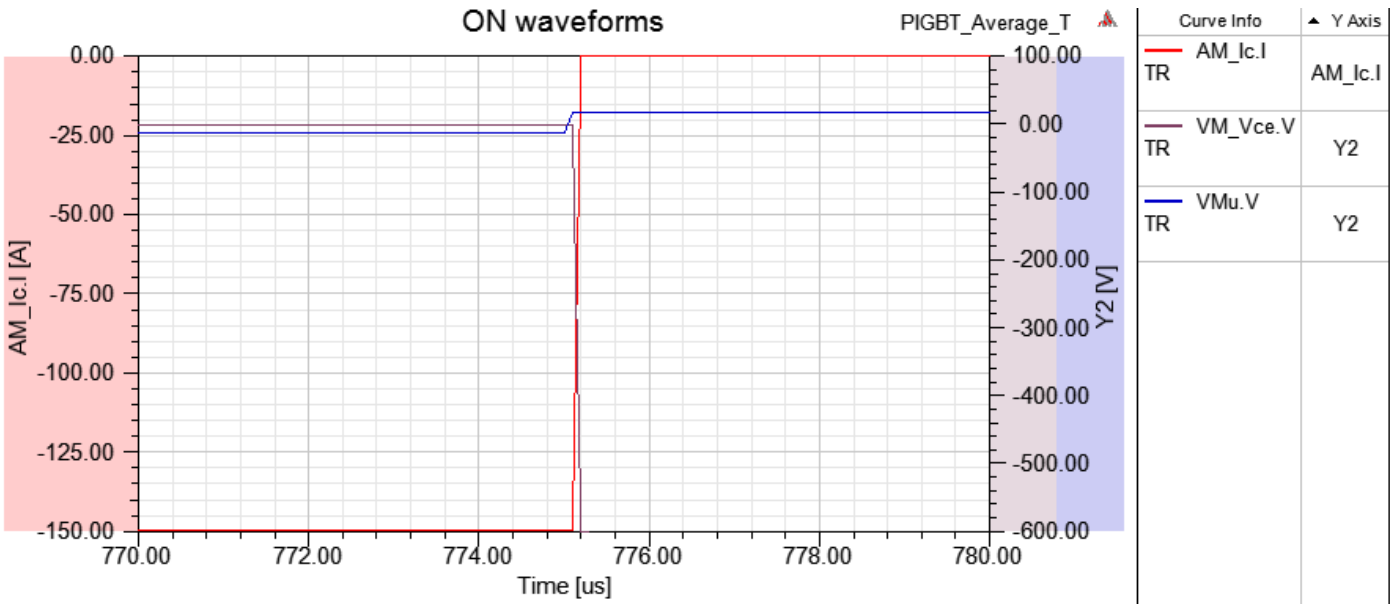


Figure 17. Simulation result-Switching ON Waveforms(Top) and OFF Waveforms(Bottom) for PIGBT_AVERAGE_T1

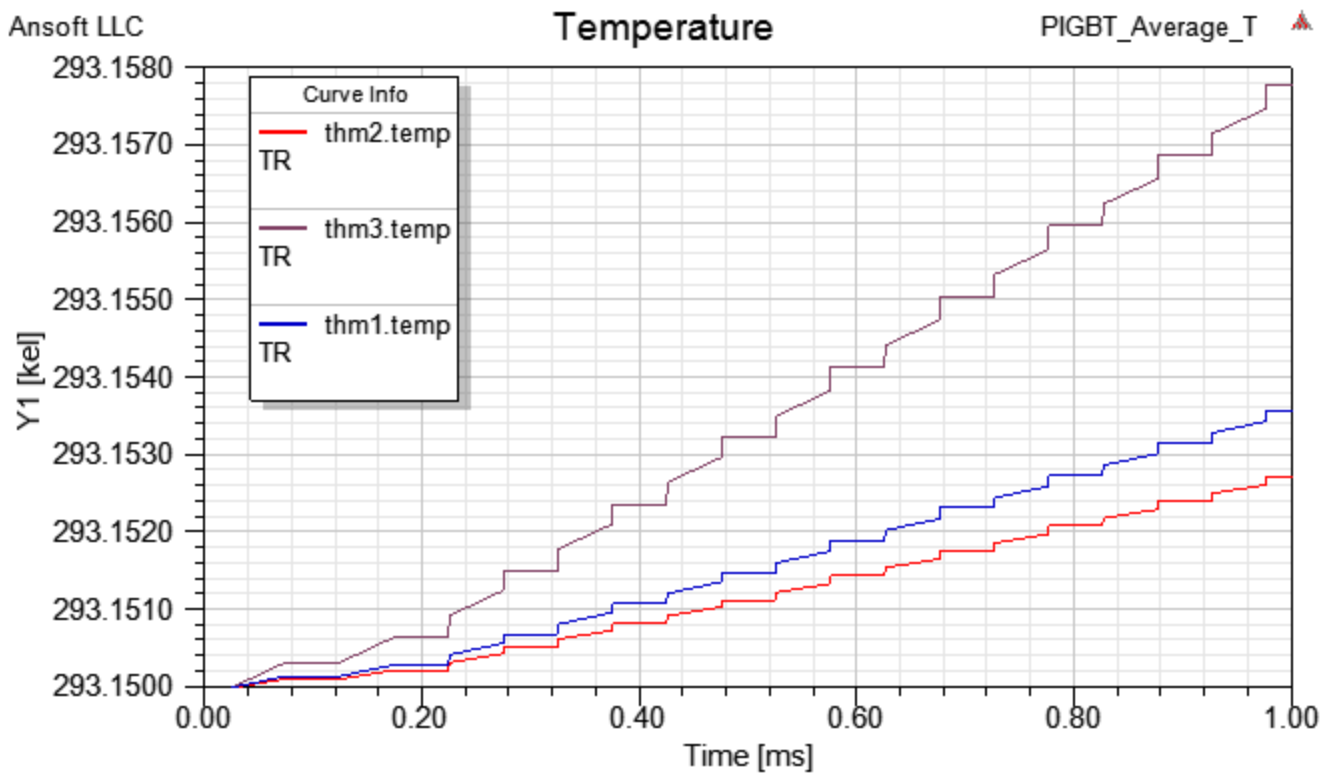


Figure 18. Simulation result-Temperature

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References

[1] Ned Mohan, Tore M. Undeland, William P. Robbins, "Power Electronics: Converters, Applications, and Design". John Wiley & Sons, INC. New York, 1995.

Legacy Average IGBT Model

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

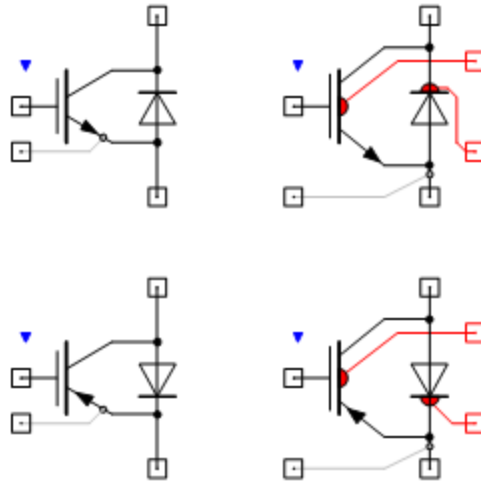


Figure 1. Legacy Average IGBT Component symbols

- [Description](#)
- [Assumptions and Limitations](#)
- [Mathematical Description](#)
- [Netlist Syntax](#)
- [Conservative Pins](#)
- [Parameters](#)
- [Example](#)
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Description

The purpose of the average model is to simulate correct energy loss and junction temperature with least computation. It is most suitable for energy/power loss and temperature estimation over large scale designs or long timespans.

The average model is a static model. It contains the same static and thermal model as used in dynamic IGBT models, but its switching energy is estimated based on actual working conditions during simulation. As a result, all DC characteristics are accurate, switching energy loss and junction temperature output are also very good approximations, but the switching waveform has no dynamic details. This means one cannot measure the actual switching time and energy loss

from the switching voltage and current waveform, but can get the right energy value from model output E_ON, E_OFF and E_RR.

Generally, the amount of power loss dissipated from an IGBT is determined by conduction loss and switching loss. While conduction loss can be accurately calculated from static voltage and current waveforms of the average IGBT model, the switching energy loss is estimated through multi-dimensional interpolation based on current, voltage, temperature, and gate resistance. These quantities are from simulation in the following ways:

- Voltage and current are sampled at switching; see [Mathematical Description](#) for details. Please note the importance of the External Synchronization signal in Electrical Parameters.
- Temperature is directly measured during simulation.
- Gate resistance in the schematic is taken as parameters RG_ON and RG_OFF of the average IGBT model. These two parameters are not physical resistances inside the model but values of external gate drive resistance. In other words, after users build their own gate drive circuit in the schematic, they should set the two parameters in the average IGBT model to match their drive circuit.

Twin Builder provides the Characterize Device option to extract electrical and thermal model parameters from the manufacturer catalog datasheet. The key for characterizing an average model is to provide data at as many different working points as possible in Energy Characteristics [10/12], so the model can learn the device's working point dependency. Such data can be sampled from switching losses curves in the datasheet. This is not required for dynamic models, but necessary for average model characterization.

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Assumptions and Limitations

The average model is a static model: its current and voltage waveforms do not contain switching dynamics. Switching loss cannot be directly measured from these waveforms.

Switching energy and power are internally estimated by interpolation; thus the working point related coefficients are very important for correct loss and temperature simulation if the model is operated away from nominal working point. The coefficients can be extracted by the Device Characterization Wizard, which needs the user to provide data at as many different working conditions as possible in Energy Characteristics [10/12].

Besides characteristics related parameters, an average IGBT requires the user to:

- Properly set the External Synchronization signal in Electrical Parameters
- Include gate drive resistance in the external schematic and set the values in External Connectors, in which parameters RG_ON and RG_OFF are **not** physical gate resistance.
- Properly set Hmin and Hmax; see [Mathematical Description](#) for details.

$$u_i = L_{\text{STRAY}} \left(\frac{di_c}{dt} \right)$$

(1)

an internal over voltage limitation is included as well as for voltage, current and temperature overload as breakdown indication. Although the model is basically a static one an input capacitance is included to obtain reasonable switching response times.

A novel synchronization technique and working point dependency are introduced to perform the calculations for the switching losses, which would not be possible using a pure static model. Figure 3 shows the voltage and current sampling which is done at the moment of the trigger signal edge. This sampling scheme is called “synchronization” because the IGBT model is triggered externally to get the instantaneous load current and blocking voltage of the device without overshoot and oscillation. Together with the actual junction temperature and the gate drive condition the sampled values form the actual working point $W(t)=[V(t), I(t), T(t), R_{\text{ON}}(t), R_{\text{OFF}}(t)]$ are valid for every half of a switching cycle. Once the model has the working point information knowing the switching time due to the synchronization technique employed, the energy calculation can be performed by straight forward analytical formulation, which serves as either interpolation or extrapolation function of the data sheet or measurement values.

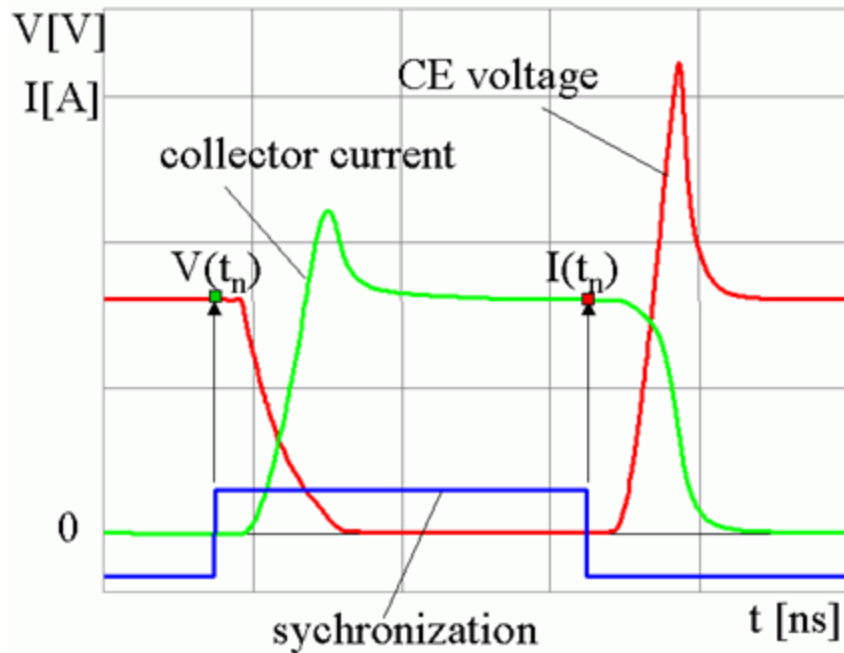


Figure 3. Synchronization Technique

The nominal working point W_{NOM} stands for nominal operating conditions found in a manufacturer data sheet, which includes the nominal blocking voltage V_{NOM} , the nominal load current I_{NOM} , the nominal junction temperature T_{NOM} and the usual gate drive conditions belong to the nominal working point. Assuming constant gate drive voltages and stray inductances in the gate circuit, the external gate resistors for the on-switch and off-switch belong to the nominal working point definition as:

$$W_{NOM}=[V_{NOM}, I_{NOM}, T_{NOM}, R_{ONNOM}(t), R_{OFFNOM}(t)]$$

When the model parameters are fitted to W_{NOM} the model will work accurately under this working condition. Normally during simulation, the blocking voltage remains constant at the bus bar voltage. In case of fault condition this value may change in the range of 0...200%. For an inverter application the load current changes in the range of 0... 100% periodically. As a consequence, the temperature will vary in the range of 300K to 420K (up to 140%) while the gate drive conditions remain unchanged. Usually the actual working point $W(t)$ differs from nominal condition W_{NOM} . As $W(t)$ deviates from W_{NOM} , the accuracy of the simulation decreases. Although $W(t)$ differs from W_{NOM} , the simulation results can be rectified by using the "working point correction coefficients" given below.

$$\begin{aligned} E_{ON} &= Y_{ON}(T, I, V, R, \alpha, \kappa, \sigma, \rho) \cdot E_{ON, NOM} \\ E_{OFF} &= Y_{OFF}(T, I, V, R, \alpha, \kappa, \sigma, \rho) \cdot E_{OFF, NOM} \\ E_{RR} &= Y_{RR}(T, I, V, R, \alpha, \kappa, \sigma, \rho) \cdot E_{RR, NOM} \end{aligned} \quad (2)$$

$$Y(T, I, V, R, \alpha, \kappa, \sigma, \rho) = X_T(T, \alpha) \cdot X_I(I, \kappa) \cdot X_V(V, \sigma) \cdot X_R(R, \rho) \quad (3)$$

where, X is a set of independent partial correction functions and

$$\alpha, \kappa, \sigma, \rho$$

are the correction coefficients calculated independently for each working point condition. Each product term of this approach can be fitted to a linear or power function X (as presented in Figure 4 and according to the Eq.5-8) which depends on either the interpolation or extrapolation conditions to ensure non-negative and limited values for the total working point correction function Y (shown in Eq. 3).

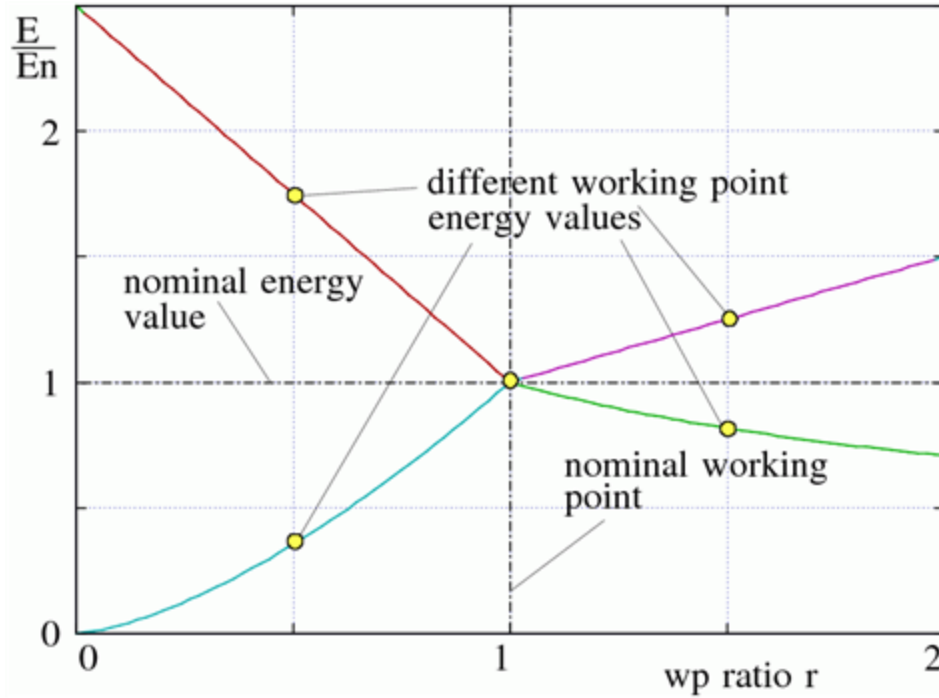


Figure 4. Working point correction coefficients map

The correction coefficients are extracted one by one by varying only the corresponding working point parameter (T , I , V or R) and holding the other parameters at their nominal values. To illustrate this procedure, the calculation of the temperature correction coefficient α is used as an example. The same extraction algorithm is applied to the other coefficients. To calculate temperature coefficient α , the energy values at a temperature different from the nominal condition (either greater or less than the nominal condition) are measured. As illustrated in the working point correction map (shown in Figure 4), a particular pattern, which represents the variation of partial correction function X , is chosen to compute the temperature correction coefficient based on the energy ratio and the working point ratio r_T . Using the Eq.2 and Eq.3 all terms are known except for the term $X_T(T, \alpha)$. Introducing Eq.3 into Eq.2 and knowing the measured value of the energy, the temperature partial correction function is given by,

$$X_T(T, \alpha) = \frac{E_{ON/OFF/RR}}{E_{ON/OFF/RR.NOM}} \quad (4)$$

Based on the employed mapping algorithm and the value of $X_T(T, \alpha)$ the correction coefficient for temperature can be evaluated. Now this temperature correction coefficient can be used to determine the partial correction function $X_T(T, \alpha)$ for any variation of the temperature during any simulation. As a general observation in this modeling approach, only one correction coefficient is used for temperature partial correction function estimation, while for voltage (Eq.6), current (Eq.7) and gate resistance (Eq.8) two correction coefficients are being used. Consequently, when considering the temperature dependency it is recommended that choose the nominal working point condition to reflect the hot temperature dependency.

$$r_T = \frac{T}{T_{\text{NOM}}}$$

$$X_T = \begin{cases} r_T^\alpha & \text{when } (r_T < 1.0 \text{ and } \alpha > 1.0) \text{ or } (r_T > 1.0 \text{ and } \alpha < 0.0) \\ 1 + \alpha \cdot (r_T - 1.0) & \text{when } (r_T < 1.0 \text{ and } \alpha \leq 1.0) \text{ or } (r_T > 1.0 \text{ and } \alpha \geq 0.0) \\ 1.0 & \text{when } r_T = 1.0 \end{cases}$$

(5)

$$r_V = \frac{V}{V_{\text{NOM}}}$$

$$X_V = \begin{cases} r_V^{\sigma_0} & \text{when } r_V < 1.0 \text{ and } \sigma_0 > 1.0 \\ 1 + \sigma_0 \cdot (r_V - 1.0) & \text{when } r_V < 1.0 \text{ and } \sigma_0 \leq 1.0 \\ r_V^\sigma & \text{when } r_V > 1.0 \text{ and } \sigma > 0.0 \\ 1 + \sigma \cdot (r_V - 1.0) & \text{when } r_V > 1.0 \text{ and } \sigma \leq 0.0 \\ 1.0 & r_V = 1.0 \end{cases}$$

(6)

$$r_I = \frac{I}{I_{\text{NOM}}}$$

$$X_I = \begin{cases} r_I^{\kappa_0} & \text{when } r_I < 1.0 \text{ and } \kappa_0 > 1.0 \\ 1 + \kappa_0 \cdot (r_I - 1.0) & \text{when } r_I < 1.0 \text{ and } \kappa_0 \leq 1.0 \\ r_I^\kappa & \text{when } r_I > 1.0 \text{ and } \kappa > 0.0 \\ 1 + \kappa \cdot (r_I - 1.0) & \text{when } r_I > 1.0 \text{ and } \kappa \leq 0.0 \\ 1.0 & r_I = 1.0 \end{cases}$$

(7)

$$r_R = \frac{R}{R_{\text{NOM}}}$$

$$X_R = \begin{cases} r_I^{\rho_0} & \text{when } r_R < 1.0 \text{ and } \rho_0 > 1.0 \\ 1 + \rho_0 \cdot (r_R - 1.0) & \text{when } r_R < 1.0 \text{ and } \rho_0 \leq 1.0 \\ r_I^{\rho} & \text{when } r_R > 1.0 \text{ and } \rho > 0.0 \\ 1 + \rho \cdot (r_R - 1.0) & \text{when } r_R > 1.0 \text{ and } \rho \leq 0.0 \\ 1.0 & r_R = 1.0 \end{cases}$$

(8)

In the partial temperature correction function $X_T(T, \alpha)$, T denotes the Kelvin temperature. All functions take the value 1 for the nominal working point as shown in Figure 4. The “wp ratio” represents the ratio between the actual temperature, voltage, current, gate resistance and their corresponding nominal values. For working point conditions different from the nominal working point ($r=1$), larger or smaller loss energy values are given by the data sheet or measurements (indicated as points in Figure 4). The partial correction functions are designed to result in non-negative and limited values for all possible working point conditions. All correction functions meet the nominal working point in $[1, 1]$ which ensure the best accuracy for the nominal working point and exhibit a knee at $r=1$ because the functions are double sided to reproduce the full operating range of the device at a minimum energy error.

IGBT and the free wheeling diode are on separate dies and mounted close together on the same substrate. Consequently for both, IGBT and diode, separate thermal networks are provided which are connected together on the level of the base plate forming a Y-type thermal network to the heat sink. The IGBT model provides the opportunity to choose between the continued fractional and the partial fractional thermal networks. Both networks show the same thermal impedance. If the thermal capacitances and resistances are considered to be computed from FEM calculation the physically based continued fraction model can be used or if the fitting to a thermal impedance curve is desired the mathematically based partial fractional model can be employed.

As shown in Figure 5, the electrical power losses of both the transistor (PINJ_T) and the diode (PINJ_D) are injected into their individual thermal networks. The positions of the switches ST1~ST4 and SD1~SD4 are decided by the type of thermal network configuration that's chosen: if continued fraction thermal model is chosen, the switches connect the thermal capacitances directly to the ambient node, while the thermal capacitances are connected in parallel to the corresponding thermal resistances through the switches if partial fraction thermal model is selected. Note that in Figure 5, the ground symbol means the ambient.

Note: Partial fraction model is in general easier to fit, and commonly used in the datasheet. On the other hand, the continued fraction model can reflect the internal physical structure of a semiconductor. It is possible to assign individual RC elements to layers inside a module so the temperature of internal layers can be simulated. However, such mapping requires detailed structural and material data. Fitting this model only from the thermal curve may not give good results.

For the IGBT components without external thermal pins, switches ST and SD in Figure 4 are closed so that an internal first-order heat sink model is connected, shown as Cthck and Rthck in

Figure 5. Impedance values of the heat sink can be set by thermal parameters CTHDT and RTHDT.

If more sophisticated heat sink model is needed, use the IGBT components with thermal pins to connect with external heat sink. In this case, switches ST and SD in Figure 4 are open and thermal pins THERMO_T and THERMO_D are exposed. When external thermal pins are used, make sure **Model Thermal Output** in the **Thermal Parameters** tab is set to Kelvin, so it is compatible with external thermal components.

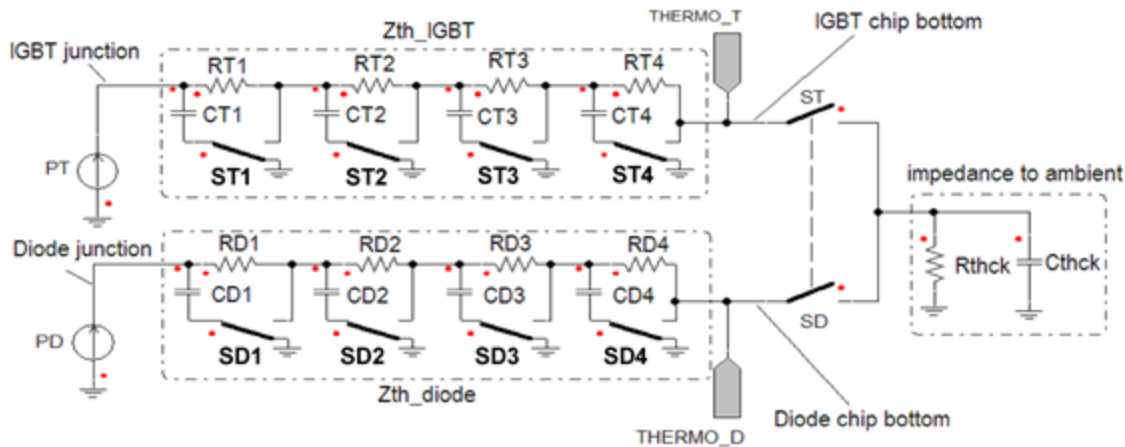


Figure 5. Thermal Network of the IGBT models

In the Average IGBT model, the power injection (PD and PT in Figure 5) are pulse-wise waveforms, and their amplitude is calculated using the switching/conduction energy losses and the user-specified pulse width. The pulse width is related to the setting of the thermal behavior level. The average IGBT model provides three thermal behavior levels: isothermal, average and dynamic. Users can change this setting in the **Thermal Parameters** tab of the component parameters.

When **Thermal Behavior Level** is set to dynamic, the switching pulses are calculated and injected into the thermal network at each switching period. Users need to specify TON, TOFF and TRR according to the datasheet of the device. This option provides the detailed transient behavior of the junction temperature, but requires a relatively small minimum time step and therefore results in lower simulation speed. The power injections during the on/off switch and conduction are calculated as follows:

On switch power injection: $P_{ON} = E_{ON}/T_{ON}$

Off switch power injection: $P_{OFF} = E_{OFF}/T_{OFF}$

Conduction power injection is directly calculated from current and voltage on internal transistor and diode; loss on stray elements is excluded from injected power.

When **Thermal Behavior Level** is set to average, average power pulse amplitude is calculated over a user-specified sampling time TSAMPLE, which can be several times the switching period. The average thermal behavior preserves the transient trend of the junction temperature without the dynamic detail, and increases the simulation speed using minimum simulation time step

requirements. A comparison between the dynamic and the average thermal behavior is made in Figure 6.

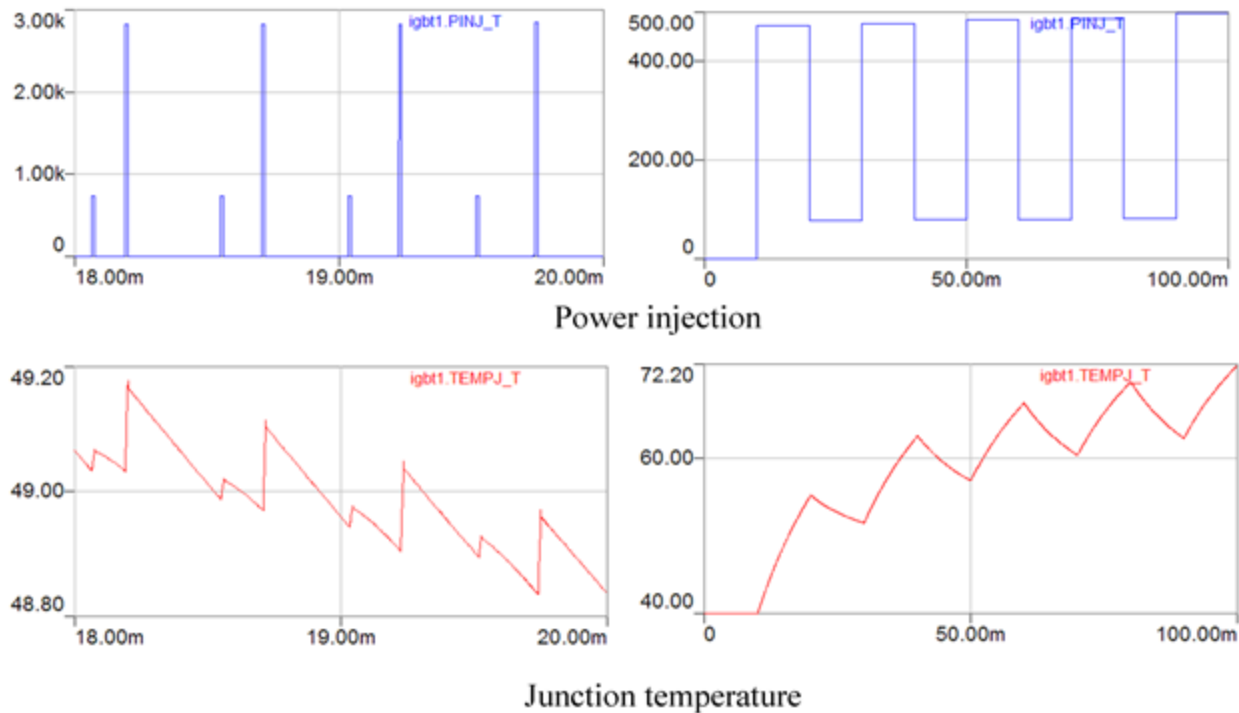


Figure 6. Comparison between the dynamic(left) and the average(right) thermal behavior of the Average IGBT model

The following table summarizes the use of different thermal behavior levels:

Thermal Behavior Level	Simulation Goal	Hmin*	Other Parameters
Average	Estimate average junction temperature and its transient trend without dynamic detail. Short simulation time	<1/20 of duty cycle; Hmax can be large.	TSAMPLE is integer times of switching cycle
Dynamic	Estimate maximum junction temperature with dynamic detail. Long simulation time.	<1/15 of Min (TON,TOFF,TRR); Hmax cannot be much larger.	TON, TOFF and TRR from datasheet or measurement

* Principle of setting simulation time step Hmin is: At least 20-30 steps per duty cycle (conducting cycle), and 15-20 steps per switching power pulse (For dynamic thermal behavior level only, switching power pulse duration is set by TON, TOFF, and TRR). For dynamic thermal behavior, Hmax cannot be too much larger than Hmin, or the switching energy may have a large error.

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Netlist Syntax

```

UMODEL IGBT_Average ?InstanceName(@InstanceName):(@Refbase)@(ID)) GATE:= %0,
AUX_EMITTER:= %1, EMITTER:= %2, COLLECTOR:= %3, THERM_T:= %4, THERM_D:= %5
( TYPE_IGBT:= @TYPE_IGBT, TYPE_FWD:= @TYPE_FWD, TYPE_THERM:= @TYPE_
THERM, TYPE_DYN:= @TYPE_DYN, TYPE_BREAKTHROUGH:= @TYPE_
BREAKTHROUGH, VP:= @VP, K:= @K, KLM:= @KLM, A_FET:= @A_FET, M_FET:= @M_
FET, N_FET:= @N_FET, BN:= @BN, M_BJT:= @M_BJT, ISAT_BJT:= @ISAT_BJT, RB_BJT:=
@RB_BJT, RP_BJT:= @RP_BJT, M_FWD:= @M_FWD, ISAT_FWD:= @ISAT_FWD, RB_
FWD:= @RB_FWD, CGE:= @CGE, CCE:= @CCE, TON:= @TON, TOFF:= @TOFF, TRR:=
@TRR, LC:= @LC, RC:= @RC, LE:= @LE, RE:= @RE, RAUX:= @RAUX, RG:= @RG \ , RG_
ON:= @RG_ON, RG_OFF:= @RG_OFF, TEMPAMB:= @TEMPAMB, TEMPJNCT0:=
@TEMPJNCT0, TNOM:= @TNOM, VNOM:= @VNOM, INOM:= @INOM, RGNOM_ON:=
@RGNOM_ON, RGNOM_OFF:= @RGNOM_OFF, EON_NOM:= @EON_NOM, EOFF_NOM:=
@EOFF_NOM, ERR_NOM:= @ERR_NOM, VGAP:= @VGAP, TC_VP:= @TC_VP, TC_K:=
@TC_K, TC_N_FET:= @TC_N_FET, TC_A_FET:= @TC_A_FET, TC_M_FET:= @TC_M_
FET, TC_ISAT_BJT:= @TC_ISAT_BJT, TC_M_BJT:= @TC_M_BJT, TC_M_FWD:= @TC_M_
FWD, TC_ISAT_FWD:= @TC_ISAT_FWD, TC_RB_FWD:= @TC_RB_FWD, TC_EON:=
@TC_EON, CC0_EON:= @CC0_EON, CC_EON:= @CC_EON, VC_EON:= @VC_EON, RC0_
EON:= @RC0_EON, RC_EON:= @RC_EON, TC_EOFF:= @TC_EOFF \ , CC0_EOFF:=
@CC0_EOFF, CC_EOFF:= @CC_EOFF, VC_EOFF:= @VC_EOFF, RC0_EOFF:= @RC0_
EOFF, RC_EOFF:= @RC_EOFF, TC_ERR:= @TC_ERR, CC0_ERR:= @CC0_ERR, CC_
ERR:= @CC_ERR, VC_ERR:= @VC_ERR, RC0_ERR:= @RC0_ERR, RC_ERR:= @RC_
ERR, VBREAK_CE:= @VBREAK_CE, VBREAK_GE:= @VBREAK_GE, IBREAK:= @IBREAK,
TEMPBREAK:= @TEMPBREAK, RFAULT_CE:= @RFAULT_CE, RFAULT_GE:= @RFAULT_
GE, CTHT1:= @CTHT1, RTHT1:= @RTHT1, CTHT2:= @CTHT2, RTHT2:= @RTHT2,
CTHT3:= @CTHT3, RTHT3:= @RTHT3, CTHT4:= @CTHT4, RTHT4:= @RTHT4, CTHD1:=
@CTHD1, RTHD1:= @RTHD1, CTHD2:= @CTHD2, RTHD2:= @RTHD2, CTHD3:= @CTHD3
\ , RTHD3:= @RTHD3, CTHD4:= @CTHD4, RTHD4:= @RTHD4, CTHDT:= @CTHDT,
RTHDT:= @RTHDT, TSAMPLE:= @TSAMPLE, SYNC:= @SYNC) SRC: DB(Lib:-
:=@ModelLibraryName);

```

NOTE: THERM_T and THERM_D only exist in the NIGBT_Average_T and PIGBT_Average_T models.

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
GATE	Gate Contact	electrical
EMITTER	Emitter Contact	electrical

AUX_EMITTER	Auxiliary Emitter Contact	electrical
COLLECTOR	Collector Contact	electrical
THERM_T	IGBT Die Bottom Thermal Contact	thermal
THERM_D	Diode Die Bottom Thermal Contact	thermal

NOTE: THERM_T and THERM_D pins only exist in the NIGBT_Average_T and PIGBT_Average_T models.

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Parameters

Table 2.

Name	Description	Data Type
TYPE_IGBT	IGBT Type Flag -2:p-Type 2:n-Type	real
TYPE_FWD	Freewheeling Diode Type 0:no 1:static	real
TYPE_DYN	0:stat 1:dyn +10:ext sync +20:gate driven	real
TYPE_THERM	0:iso 1:aver 2:dyn +10:cont.fract +100:pins	real
TYPE_BREAKTHROUGH	0:disable breakthrough 2:enable breakthrough	real
VGAP	Band Gap Voltage	real
VP	FET Pinch-off Voltage at nominal temperature	real
K	FET Transfer Constant at nominal temperature	real
KLM	FET Channel Length Modulation Factor	real
A_FET	FET Saturation Factor	real
M_FET	FET Saturation Exponent	real

N_FET	Exponent of FET Transfer Characteristic of FET	real
RD0	Small Voltage Bulk Resistance [Ohm]	real
RD1	Large Voltage Bulk Resistance [Ohm]	real
RDV	Bulk Resistance Inflection Voltage [V]	real
BN	BJT Current Gain at nominal temperature	real
M_BJT	BJT Ideality Factor	real
ISAT_BJT	BJT Saturation Current at reference temperature [A]	real
RB_BJT	BJT Bulk Resistance [ohm]	real
RP_BJT	BJT Base Shunt [ohm]	real
M_FWD	FWD Ideality Factor	real
ISAT_FWD	FWD Saturation Current at nominal temperature [A]	real
RB_FWD	FWD Bulk Resistance [ohm]	real
TC_VP	Temperature Coefficient of VP0	real
TC_K	Temperature Coefficient of K0	real
TC_N_FET	Temperature Coefficient of N_FET	real
TC_A_FET	Temperature Coefficient of A_FET	real
TC_M_FET	Temperature Coefficient of M_FET	real
TC_RD0	Temperature Coefficient of RD0	real

TC_RD1	Temperature Coefficient of RD1	real
TC_RDV	Temperature Coefficient of RDV	real
TC_ISAT_BJT	Temperature Coefficient of ISAT_BJT	real
TC_M_BJT	Temperature Coefficient of M_BJT	real
TC_M_FWD	Temperature Coefficient of M_FWD	real
TC_ISAT_FWD	Temperature Coefficient of ISAT_FWD	real
TC_RB_FWD	Temperature Coefficient of RB_FWD	real
RE	Emitter Connector Resistance [ohm]	real
LE	Emitter Connector Inductance [H]	real
LC	Collector Connector Inductance [H]	real
RC	Collector Connector Resistance [ohm]	real
RG	Gate Connector Ref. Resistance [ohm]	real
RAUX	Internal Emitter Resistance [ohm]	real
CGE	Gate Emitter Reference Capacitance [F]	real
CCE	Collector Emitter Reference Capacitance [F]	real
TEMPAMB	Ambient Temperature [°C]	real
TEMPJNCT0	Junction Temperature at Simulation	real

	Start [°C]	
TNOM	Nominal Temperature [°C]	real
VNOM	Nominal Collector-Emitter Voltage [V]	real
INOM	Nominal Collector Current [A]	real
EON_NOM	Nominal On-Switch Loss Energy [J]	real
EOFF_NOM	Nominal Off-Switch Loss Energy [J]	real
ERR_NOM	Nominal Reverse Recovery Loss Energy [J]	real
RG_ON	On-Switch External Gate Resistance [ohm]; This is not a physical resistance but the value of gate resistance in the external gate drive. Users should include proper gate resistance in their designs and put the value in this parameter.	real
RG_OFF	Off-Switch External Gate Resistance [ohm]; This is not a physical resistance but the value of gate resistance in the external gate drive. Users should include proper gate resistance in their designs and put the value in this parameter.	real
RGNOM_ON	Nominal On-Switch External Gate Resistance [ohm]	real
RGNOM_OFF	Nominal Off-Switch External Gate Resistance [ohm]	real
TC_EON	Temperature coefficient of EON	real
CC0_EON	Current coefficient of EON (IC	real
CC_EON	Current coefficient of EON (IC>-	real

	=ICNOM)	
VC_EON	Voltage coefficient of EON	real
RC0_EON	Gate resistance coefficient of EON (RG_ON	real
RC_EON	Gate resistance coefficient of EON (RG_ON>=RGNOM_ON)	real
TC_EOFF	Temperature coefficient of EOFF	real
CC0_EOFF	Current coefficient of EOFF (IC	real
CC_EOFF	Current coefficient of EOFF (IC>- >=ICNOM)	real
VC_EOFF	Voltage coefficient of EOFF	real
RC0_EOFF	Gate resistance coefficient of EOFF (RG_OFF	real
RC_EOFF	Gate resistance coefficient of EOFF (RG_ON>=RGNOM_OFF)	real
TC_ERR	Temperature coefficient of ERR	real
CC0_ERR	Current coefficient of ERR (IC	real
CC_ERR	Current coefficient of ERR(IC>- >=ICNOM)	real
VC_ERR	Voltage coefficient of ERR	real
RC0_ERR	Gate resistance coefficient of ERR (RG_ON	real
RC_ERR	Gate resistance coefficient of ERR (RG_ON>=RGNOM_ON)	real
VBREAK_CE	Output Voltage Breakdown [V]	real

VBREAK_GE	Input Voltage Breakdown [V]	real
IBREAK	Output Current Breakdown [A]	real
TEMPBREAK	Temperature Breakdown [°C]	real
RFAULT_CE	Remaining Breakdown Output Resistance [ohm]	real
RFAULT_GE	Remaining Breakdown Input Resistance [ohm]	real
CTHT1	1. thermal transistor capacity [F]	real
RTHT1	1. thermal transistor resistance [ohm]	real
CTHT2	2. thermal transistor capacity [F]	real
RTHT2	2. thermal transistor resistance [ohm]	real
CTHT3	3. thermal transistor capacity [F]	real
RTHT3	3. thermal transistor resistance [ohm]	real
CTHT4	4. thermal transistor capacity [F]	real
RTHT4	4. thermal transistor resistance [ohm]	real
CTHD1	1. thermal diode capacity [F]	real
RTHD1	1. thermal diode resistance [ohm]	real
CTHD2	2. thermal diode capacity [F]	real
RTHD2	2. thermal diode resistance [ohm]	real
CTHD3	3. thermal diode capacity [F]	real

RTHD3	3. thermal diode resistance [ohm]	real
CTHD4	4. thermal diode capacity [F]	real
RTHD4	4. thermal diode resistance [ohm]	real
CTHDT	common thermal capacity [F]	real
RTHDT	common thermal resistance [ohm]	real
SYNC	External synchronization signal	real
TON	on switch power pulse time [s]	real
TOFF	off switch power pulse time [s]	real
TRR	reverse recovery power pulse time [s]	real
TSAMPLE	Thermal sampling time [s]	real

Note: External synchronization signal SYNC is a trigger **necessary** for the device model to behave correctly. It is required to cross zero in positive direction only when device start conducting, and cross zero in negative direction only when device stop conducting or when I_{rr} is formed. It is preferable to use an ideal pulse wave, or trapezoidal wave. When using ideal pulse wave, a signal change between zero and a positive value is also supported.

Note that the synchronization signal may not be the same as the gate drive signal for the same device. Rule of thumb is to give a clear rising edge or zero crossing signal at the moment when the conducting status of a device changes, or when current flows on the device start to change.

Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
VCE	Collector-Emitter Voltage [V]	Output	real
IC	Collector Current [A]	Output	real
IG	Gate Current [A]	Output	real

IFD	FWD Current [A]	Output	real
VD	FWD Voltage Drop [V]	Output	real
TRANSCOND	Trans Conductance [A/V]	Output	real
OUTCOND	Output Conductance [A/V]	Output	real
TEMPJ_T	IGBT junction temperature [°C]	Output	real
TEMPJ_D	Diode junction temperature [°C]	Output	real
TEMPBOT_T	IGBT bottom temperature [°C]	Output	real
TEMPBOT_D	Diode bottom temperature [°C]	Output	real
TEMP_PLATE	copper plate top temperature [°C]	Output	real
PINJ_T	IGBT model power injection [W]	Output	real
PINJ_D	Diode model power injection [W]	Output	real
E_ON	on switching energy [J]	Output	real
E_OFF	off switching energy [J]	Output	real
E_RR	loss energy of diode reverse recovery [J]	Output	real
PEL_T	DC losses of IGBT [W]	Output	real
PEL_D	DC losses of DIODE [W]	Output	real
STEP	actual time step size [s]	Output	real

STEP_VISUAL	Rectangular Visualization of Step Size	Output	real
VCE_FAULT	Vce fault flag [0/1]	Output	real
VGE_FAULT	Vge fault flag [0/1]	Output	real
IC_FAULT	collector current fault flag [0/1]	Output	real
TEMPJ_FAULT	junction temperature fault flag [0/1]	Output	real

Note that the internal calculation of switching energies and power will not start until after a couple of switches, in order to avoid influence of large initial transients.

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Example

Four examples are available, representing the N-Type Average model, the N-Type Average model with FWD diode, the P-Type Average model and the P-Type Average model with FWD diode. The examples are shown below.

This example demonstrates the operation mechanism of the N-Channel IGBT Average model through a simple example. The control gate voltage is supplied by a pulse-wave voltage source E1. The schematic of the example is shown in Figure 7, system parameters are listed in Table 4, and the simulation results are shown in Figure 8 and 9.

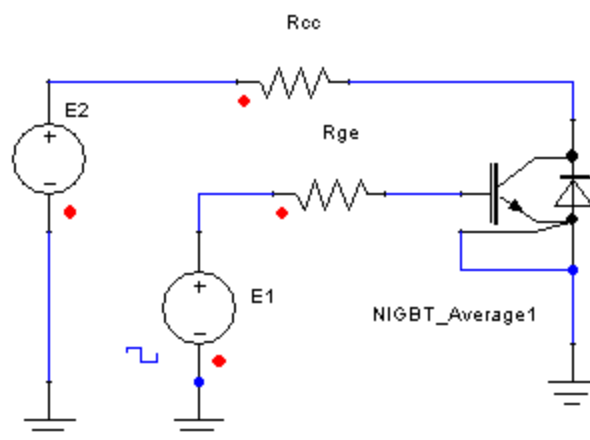


Figure 7. Application example of the N-Channel IGBT model (Average)

Table 4. System Parameters

Component	Parameter	Value [unit]
Resistor Rge	R	10 [Ohm]
Resistor Rcc	R	1 [Ohm]
Voltage Source (Pulse) E1	AMPL	15 [V]
	FREQ	1000 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [V]
Voltage Source E2	EMF	500 [V]
Average IGBT NIGBT_ AVERAGE1	TYPE_DYN	11
	VCE	0
	IC	0
	VNOM	1200
	INOM	600
	SYNC	E1.EMF
	TYPE_ BREAKTHROUGH	1

* All other parameters of the N-Channel IGBT model use their default values, therefore they are not included in the parameter table.

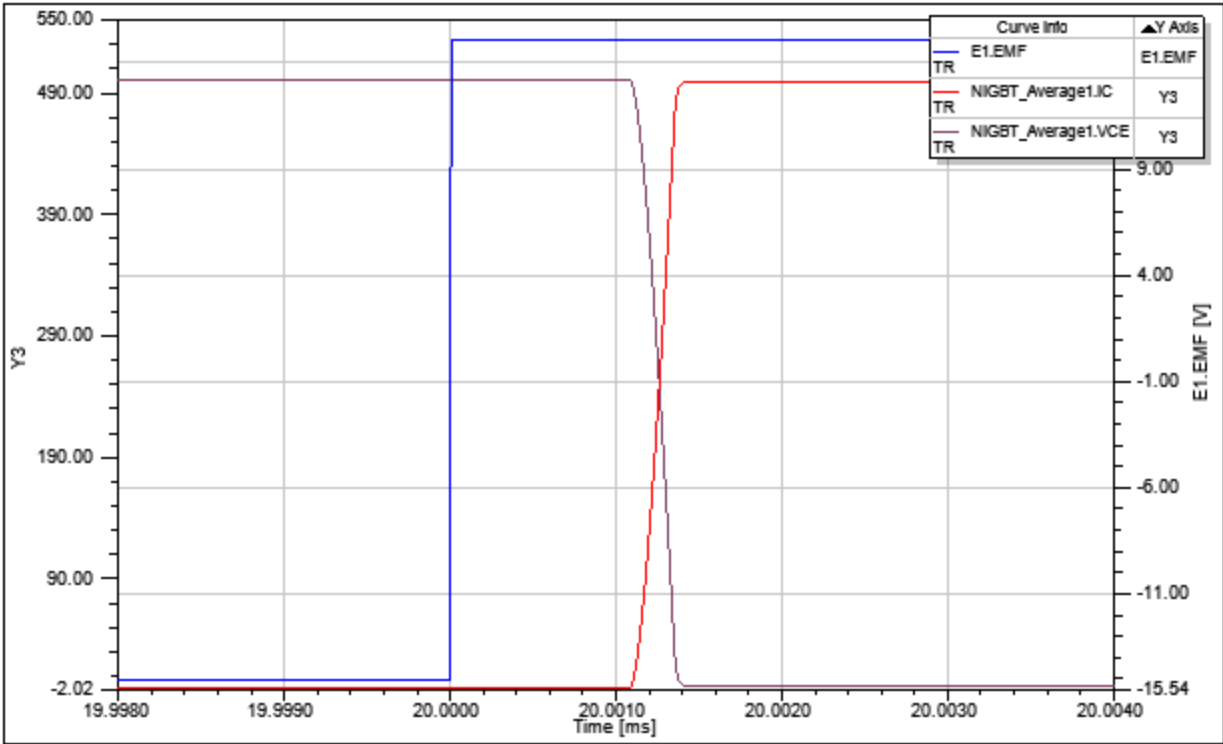


Figure 8. Simulation result-Switching ON Waveforms for NIGBT_AVERAGE1

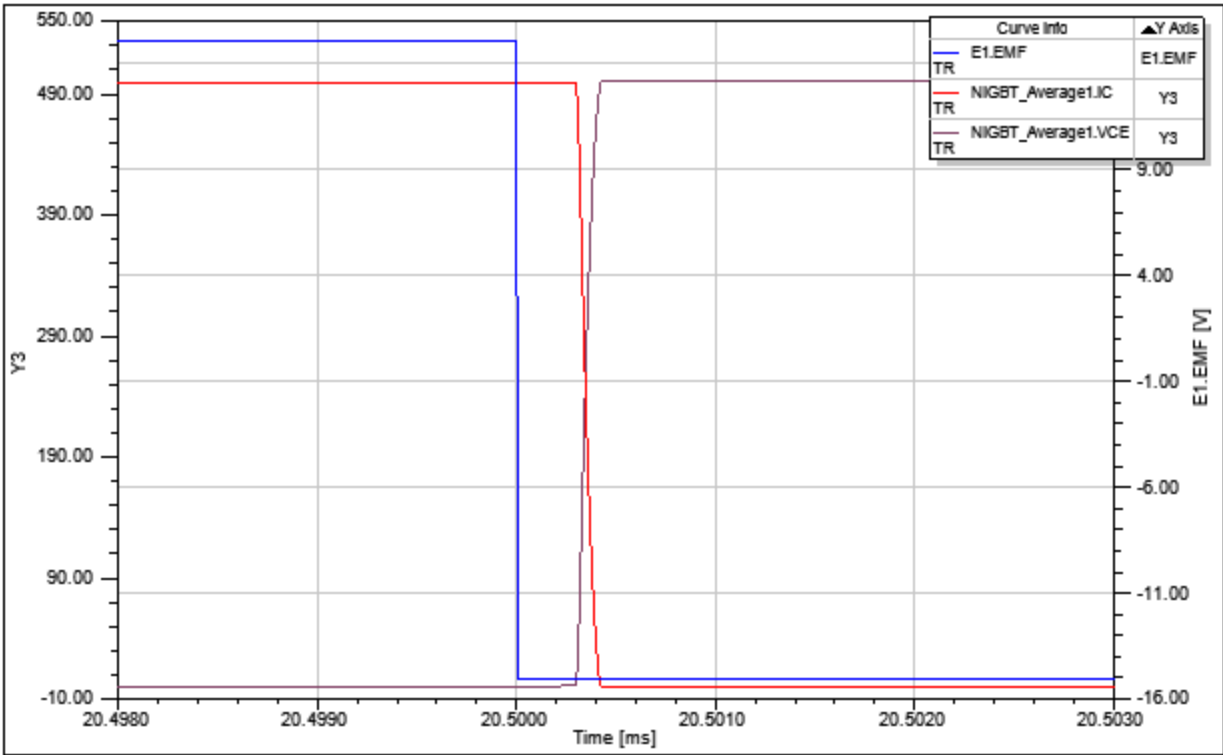


Figure 9. Simulation result-Switching OFF Waveforms for NIGBT_AVERAGE1

This example demonstrates the operation mechanism of the average N-Channel IGBT model with thermal pin through a simple example. The control gate voltage is supplied by a pulse-wave voltage source E1. The schematic of the example is shown in Figure 10, system parameters are listed in Table 5, and the simulation results are shown in Figure 11 and 12.

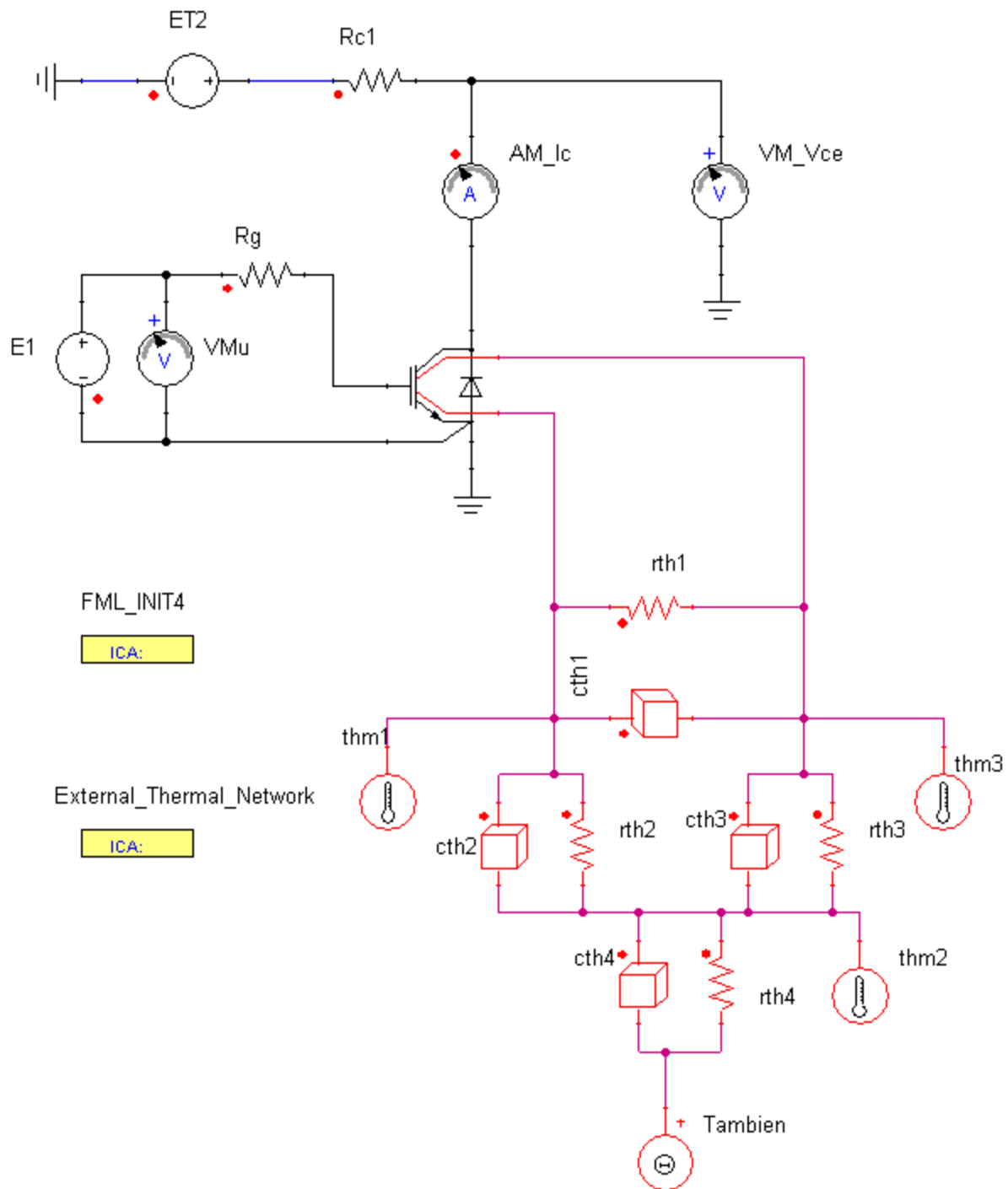


Figure 10. Application example of the N-Channel IGBT model with Thermal Pin (Average)

Table 5. System Parameters

Component	Parameter	Value [unit]
Resistor Rg/Rc1	R	10 [Ohm]
Resistor R1	R	R4 [Ohm]
Resistor R4	R	R1 [Ohm]
Resistor R2/R3	R	R2 [Ohm]
Capacitor C1	C	C4 [F]
Capacitor C4	C	C1 [F]
Capacitor C2/C3	C	C2 [F]
Voltage Source (Pulse) E1	AMPL	15 [V]
	FREQ	10000 [Hz]
	TDELAY	0 [s]
	PHASE	90 [degree]
	OFF	0 [V]
Voltage Source ET2	EMF	1200 [V]
Initial Values EXTERNAL_THERMAL_NETWORK	EQU0	CT4:=3.1
	EQU1	RT4:=0.032
	EQU2	R1:=0.2*RT4
	EQU3	R2:=0.2*RT4
	EQU4	R3:=5*RT4
	EQU5	R4:=0.05*RT4

	EQU6	C1:=CT4
	EQU7	C2:=5*CT4
	EQU8	C3:=10*CT4
	EQU9	C4:=20*CT4
Average IGBT NIGBT_ AVERAGE_T1	RG_OFF	10
	RGNOM_ON	10
	RGNOM_OFF	10
	RC0_EON	1
	RC_EON	0
	RC0_EOFF	1
	RC0_ERR	1
	RAUX	0
	VNOM	600
	INOM	225
	EON_NOM	0.015
	EOFF_NOM	0.036
	ERR_NOM	0.020
	TC_VP	-0.5
	TC_K	-2.3
	TC_N_FET	9e-004
	TC_A_FET	-7.4

TC_M_FET	0.010
TC_ISAT_BJT	-19
TC_M_BJT	0.0014
TC_M_FWD	-0.0065
TC_ISAT_FWD	-25
TC_RB_FWD	0.0034
TC_EON	0.364
CC0_EON	0.470
CC_EON	1.5
TC_EOFF	0.717
CC0_EOFF	0.087
CC_EOFF	1
VC_EOFF	1
TC_ERR	2
CC0_ERR	0.275
CC_ERR	0.560
CTHT1	1.5
RTHT1	0.0066
CTHT2	0.550
RTHT2	0.036

CTHT3	1.4
RTHT3	0.035
CTHT4	3.1
RTHT4	0.032
CTHD1	1.4
RTHD1	0.047
CTHD2	0.235
RTHD2	0.073
CTHD3	1.4
RTHD3	0.0352
CTHD4	3
RTHD4	0.032
CTHDT	1
RTHDT	0.005
SYNC	VMu.V [V]
TEMPJ_T	0
TEMPJ_D	0
TYPE_FWD	1
TYPE_THERM	101
TYPE_DYN	11
VP	5.5

K	2.5
KLM	0
A_FET	0.55
M_FET	1.1
M_BJT	5
ISAT_BJT	0.038
RB_BJT	0.001
RP_BJT	1e+010
M_FWD	1.25
ISAT_FWD	3e-006
RB_FWD	0.0046
CGE	16e-009
CCE	160e-012
TON	10e-006
TOFF	10e-006
TRR	10e-006
LC	20e-009
RC	550e-006
RG	3.3
TSAMPLE	200e-006

	TYPE_ BREAKTHROUGH	1

* All other parameters of the N-Channel IGBT model use their default values, therefore they are not included in the parameter table.

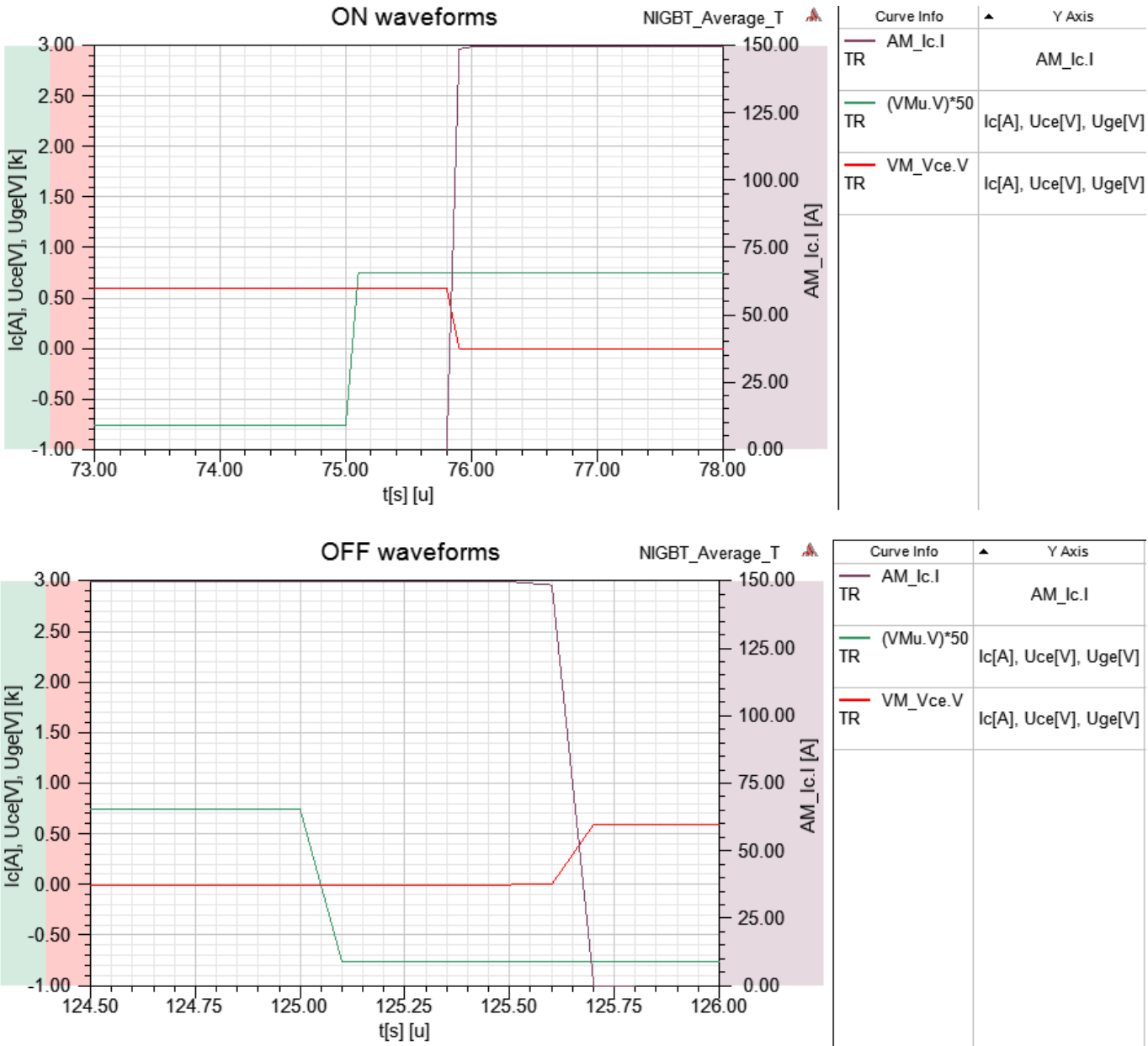


Figure 11. Simulation result-Switching ON Waveforms(Top) and OFF Waveforms(Bottom) for NIGBT_AVERAGE_T1

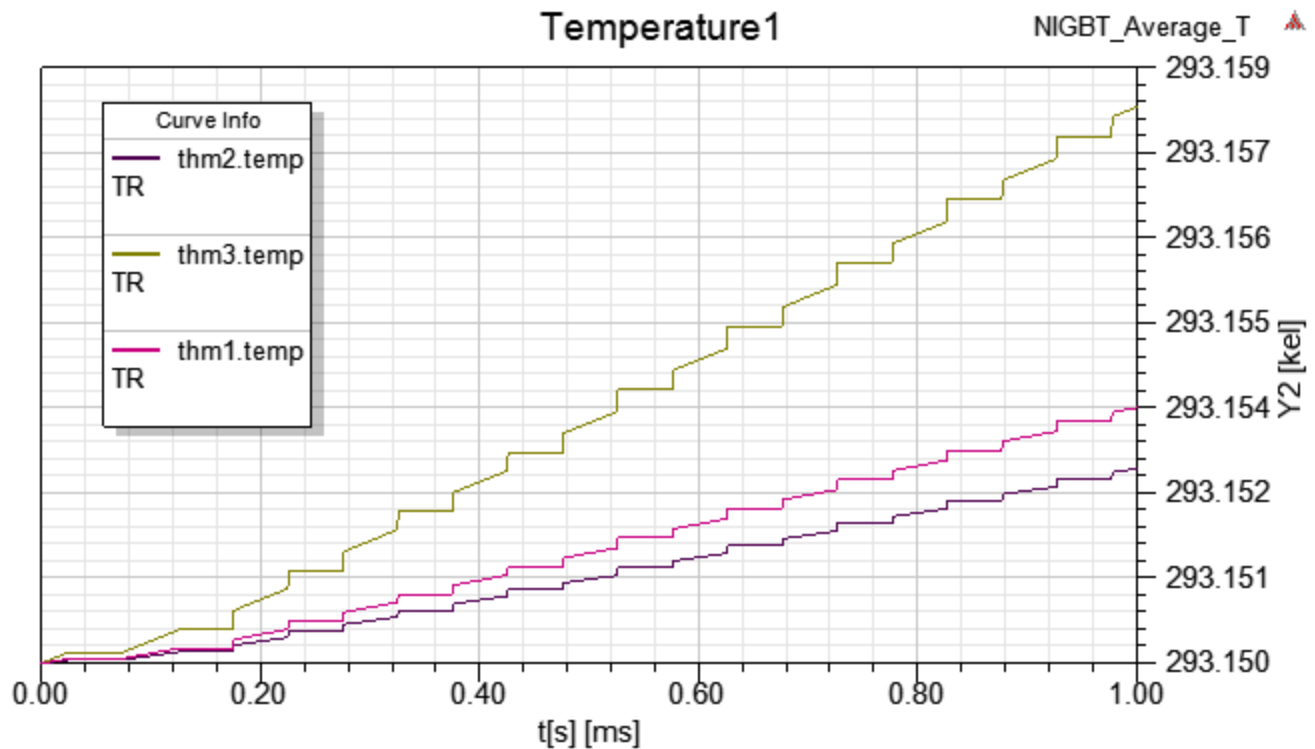


Figure 12. Simulation result-Temperature

This example demonstrates the operation mechanism of the average P-Channel IGBT model through a simple example. The control gate voltage is supplied by a pulse-wave voltage source E1. The schematic of the example is shown in Figure 13, system parameters are listed in Table 6, and the simulation results are shown in Figure 14 and 15.

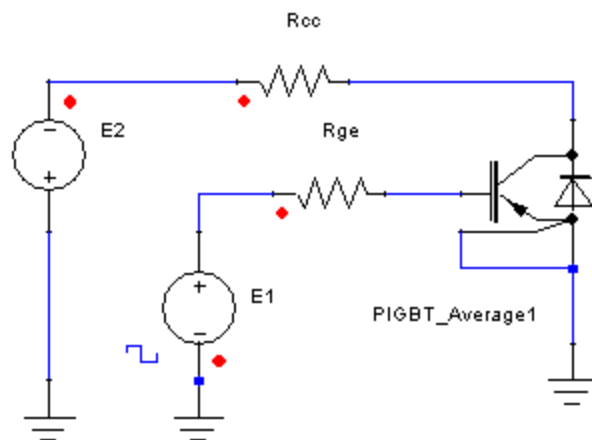


Figure 13. Application example of the P-Channel IGBT model (Average)

Table 6. System Parameters

Component	Parameter	Value [unit]
Resistor Rge	R	10 [Ohm]
Resistor Rcc	R	1 [Ohm]
Voltage Source (Pulse) E1	AMPL	15 [V]
	FREQ	1000 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [V]
Voltage Source E2	EMF	500 [V]
Average IGBT PIGBT_ AVERAGE1	VCE	0
	IC	0
	VNOM	1200
	INOM	600
	SYNC	E1.EMF
	TYPE_ BREAKTHROUGH	1

* All other parameters of the P-Channel IGBT model use their default values, therefore they are not included in the parameter table.

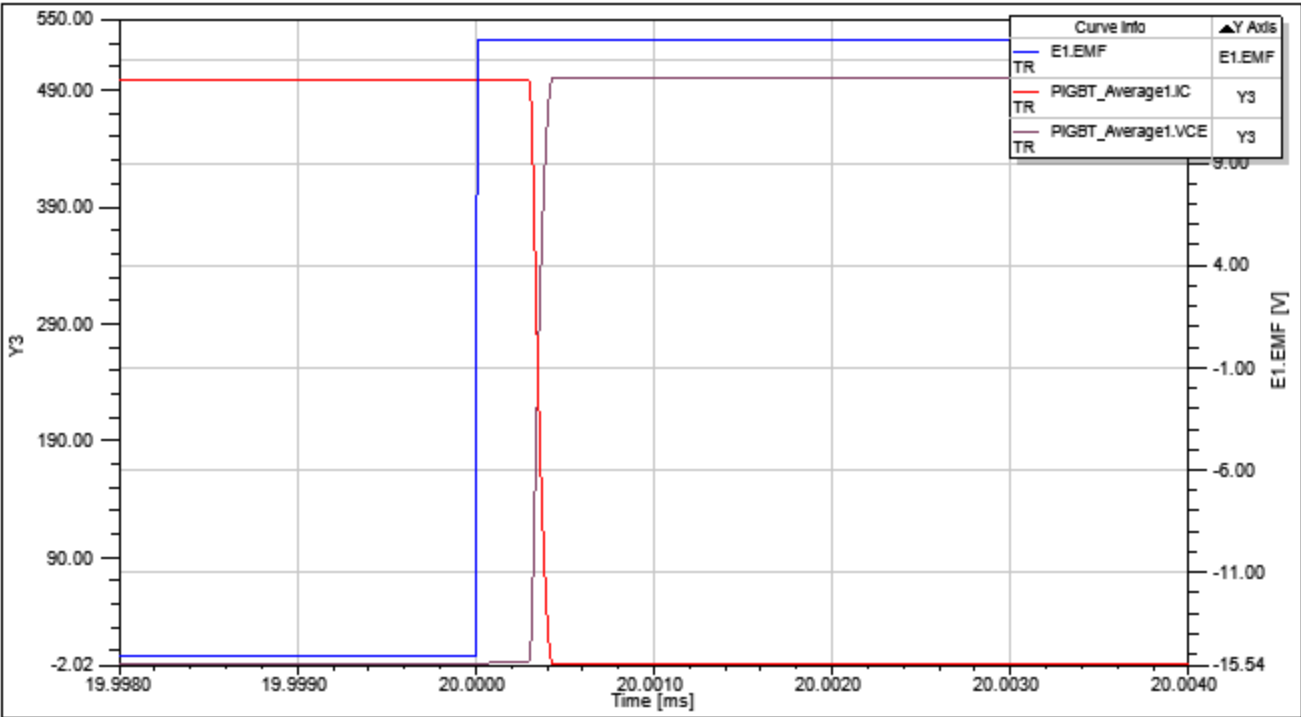


Figure 14. Simulation result-Switching ON Waveforms for PIGBT_AVERAGE1

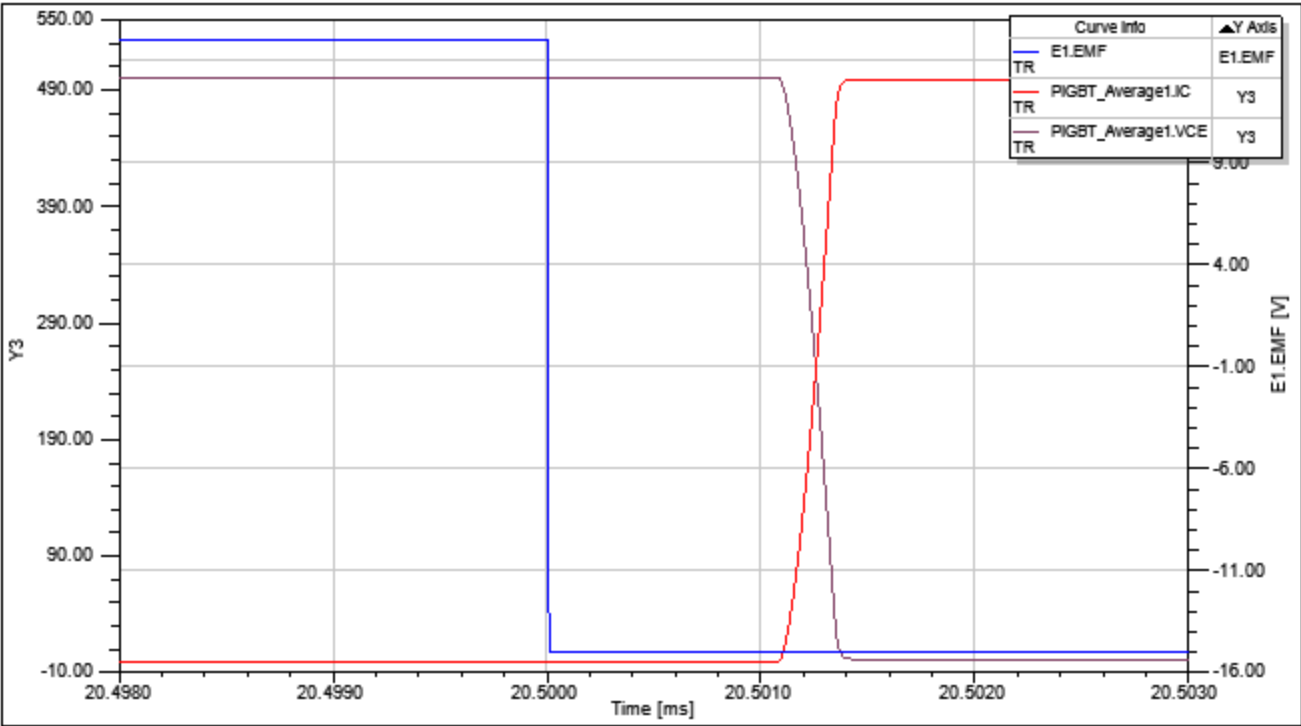


Figure 15. Simulation result-Switching OFF Waveforms for PIGBT_AVERAGE1

This example demonstrates the operation mechanism of the Average P-Channel IGBT model with thermal pin through a simple example. The control gate voltage is supplied by a pulse-wave voltage source E1. The schematic of the example is shown in Figure 16, system parameters are listed in Table 7, and the simulation results are shown in Figure 17 and 18.

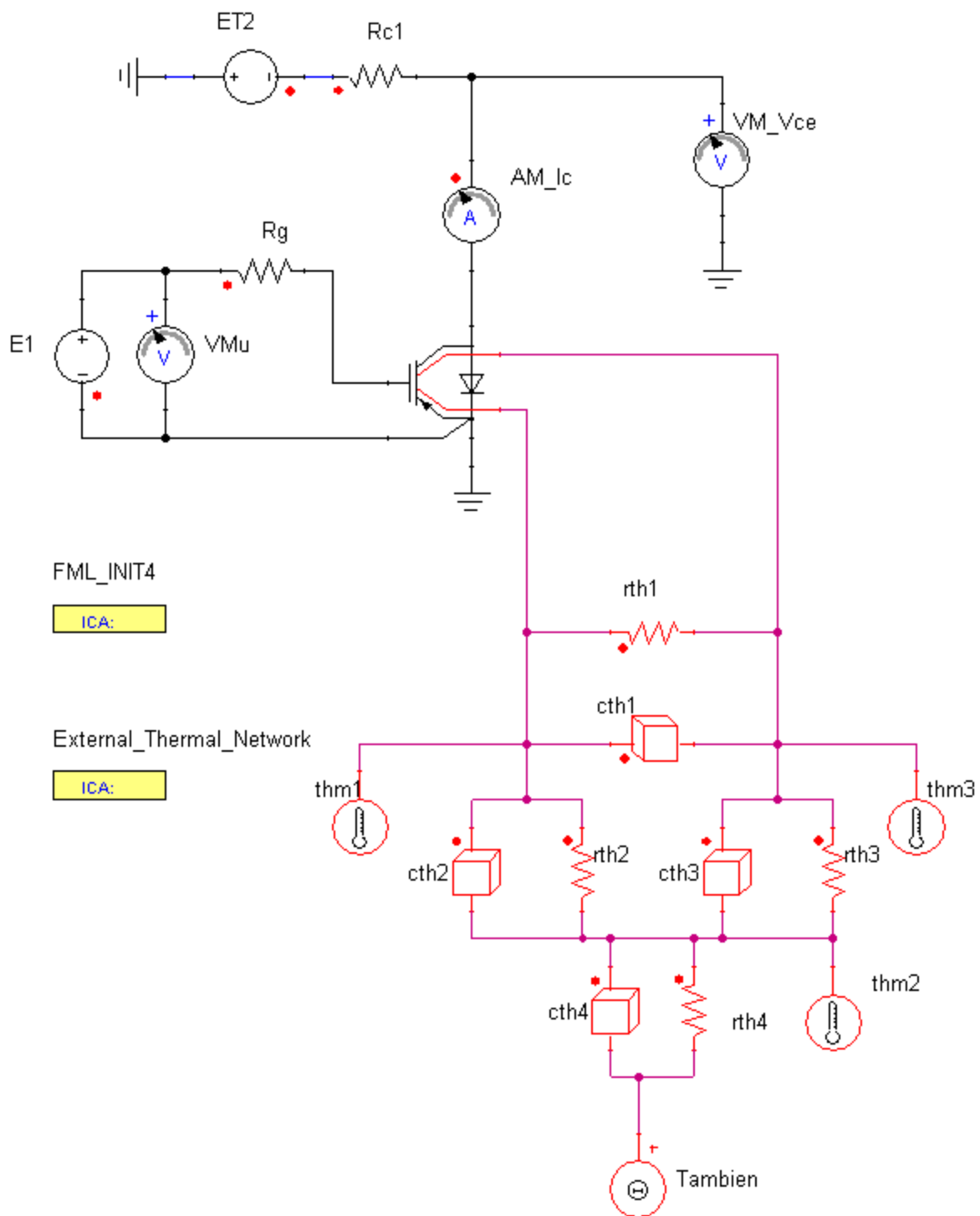


Figure 16. Application example of the P-Channel IGBT model with Thermal Pin (Average)

Table 7. System Parameters

Component	Parameter	Value [unit]
Resistor Rg/Rc1	R	10 [Ohm]
Resistor R1	R	R4 [Ohm]
Resistor R4	R	R1 [Ohm]
Resistor R2/R3	R	R2 [Ohm]
Capacitor C1	C	C4 [F]
Capacitor C4	C	C1 [F]
Capacitor C2/C3	C	C2 [F]
Voltage Source (Pulse) E1	AMPL	15 [V]
	FREQ	10000 [Hz]
	TDELAY	0 [s]
	PHASE	90 [degree]
	OFF	0 [V]
Voltage Source ET2	EMF	1200 [V]
Initial Values EXTERNAL_THERMAL_NETWORK	EQU0	CT4:=3.1
	EQU1	RT4:=0.032
	EQU2	R1:=0.2*RT4
	EQU3	R2:=0.2*RT4
	EQU4	R3:=5*RT4
	EQU5	R4:=0.05*RT4

	EQU6	C1:=CT4
	EQU7	C2:=5*CT4
	EQU8	C3:=10*CT4
	EQU9	C4:=20*CT4
Average IGBT NIGBT_ AVERAGE_T1	RG_OFF	10
	RG_ON	10
	RGNOM_ON	10
	RGNOM_OFF	10
	RC0_EON	1
	RC_EON	0
	RC0_EOFF	1
	RC0_ERR	0
	RAUX	0
	VNOM	600
	INOM	225
	EON_NOM	0.015
	EOFF_NOM	0.036
	ERR_NOM	0.020
	TC_VP	-0.5
	TC_K	-2.3
	TC_NFET	9e-004

TC_AFET	-7.4
TC_MFET	0.010
TC_ISAT_BJT	-19
TC_M_BJT	0.0014
TC_M_FWD	-0.0065
TC_ISAT_FWD	-25
TC_RB_FWD	0.0034
TC_EON	0.364
CC0_EON	0.470
CC_EON	1.5
TC_EOFF	0.717
CC0_EOFF	0.087
CC_EOFF	1
VC_EOFF	1
TC_ERR	2
CC0_ERR	0.275
CC_ERR	0.560
CTHT1	1.5
RTHT1	0.0066
CTHT2	0.550

RTHT2	0.036
CTHT3	1.4
RTHT3	0.035
CTHT4	3.1
RTHT4	0.032
CTHD1	1.4
RTHD1	0.047
CTHD2	0.235
RTHD2	0.073
CTHD3	1.4
RTHD3	0.0352
CTHD4	3
RTHD4	0.032
CTHDT	1000
RTHDT	1e-005
SYNC	VMu.V [V]
TEMPJ_T	0
TEMPJ_D	0
TYPE_FWD	1
TYPE_THERM	102
TYPE_DYN	11

VP	-5.5
K	2.5
KLM	0
A_FET	0.55
M_FET	1.1
M_BJT	5
ISAT_BJT	0.038
RB_BJT	0.001
RP_BJT	1e+010
M_FWD	1.25
ISAT_FWD	3e-006
RB_FWD	0.0046
CGE	16e-009
CCE	160e-012
TON	10e-006
TOFF	10e-006
TRR	1e-006
LC	20e-009
RC	550e-006
RG	3.3

	TSAMPLE	200e-006
	TYPE_BREAKTHROUGH	1

* All other parameters of the P-Channel IGBT model use their default values, therefore they are not included in the parameter table.

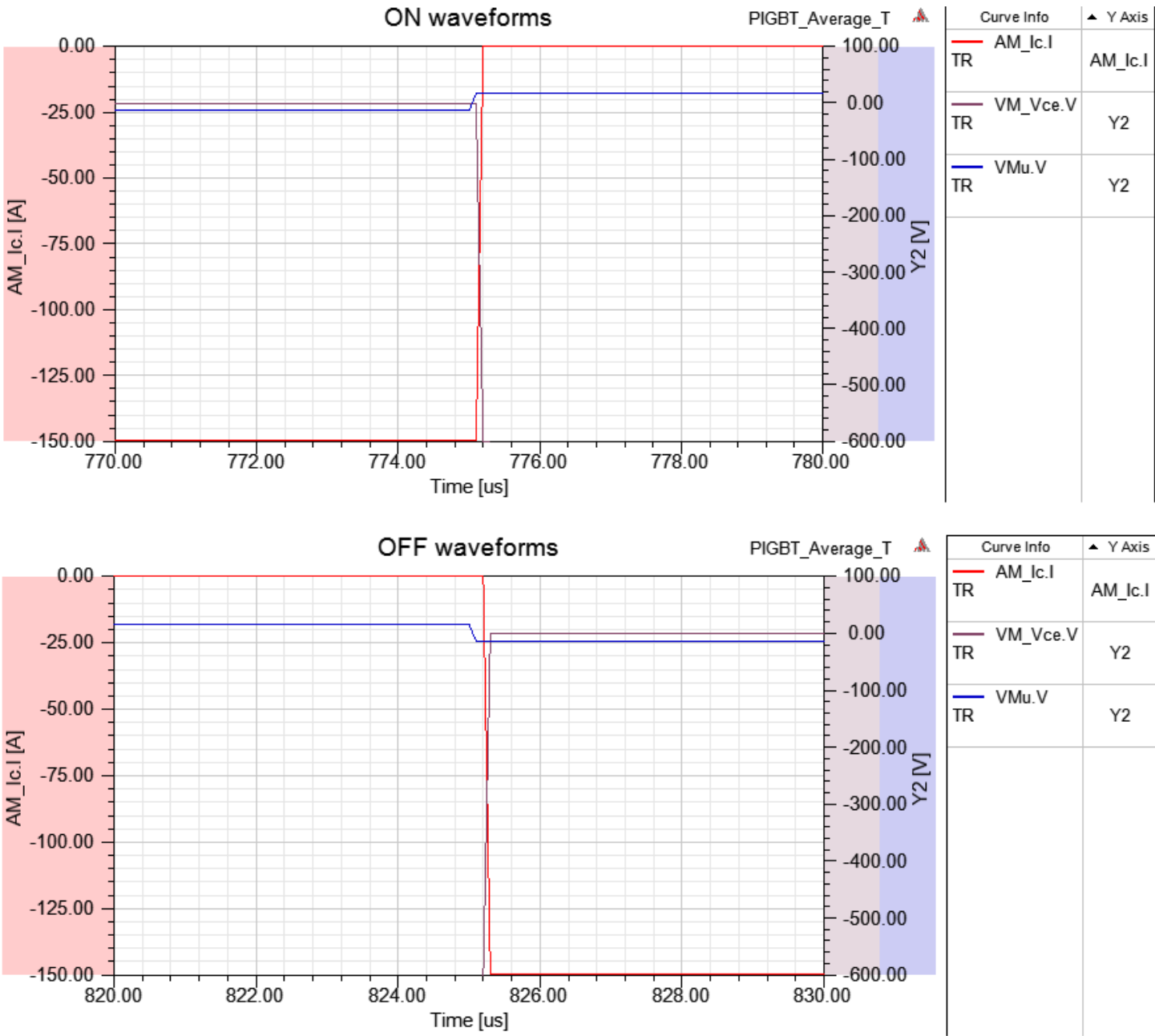


Figure 17. Simulation result-Switching ON Waveforms(Top) and OFF Waveforms(Bottom) for PIGBT_AVERAGE_T1

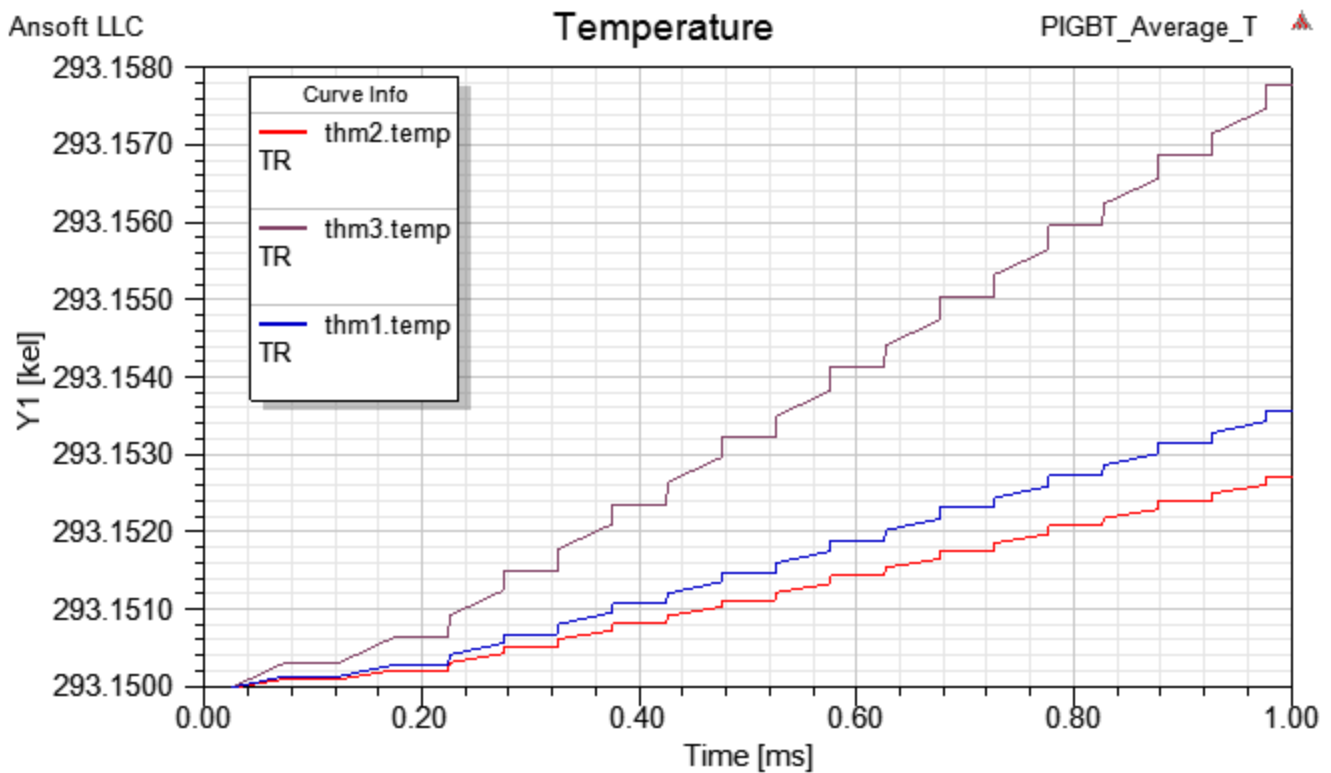


Figure 18. Simulation result-Temperature

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References

[1] Ned Mohan, Tore M. Undeland, William P. Robbins, "Power Electronics: Converters, Applications, and Design". John Wiley & Sons, INC. New York, 1995.

Basic Dynamic IGBT Model

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

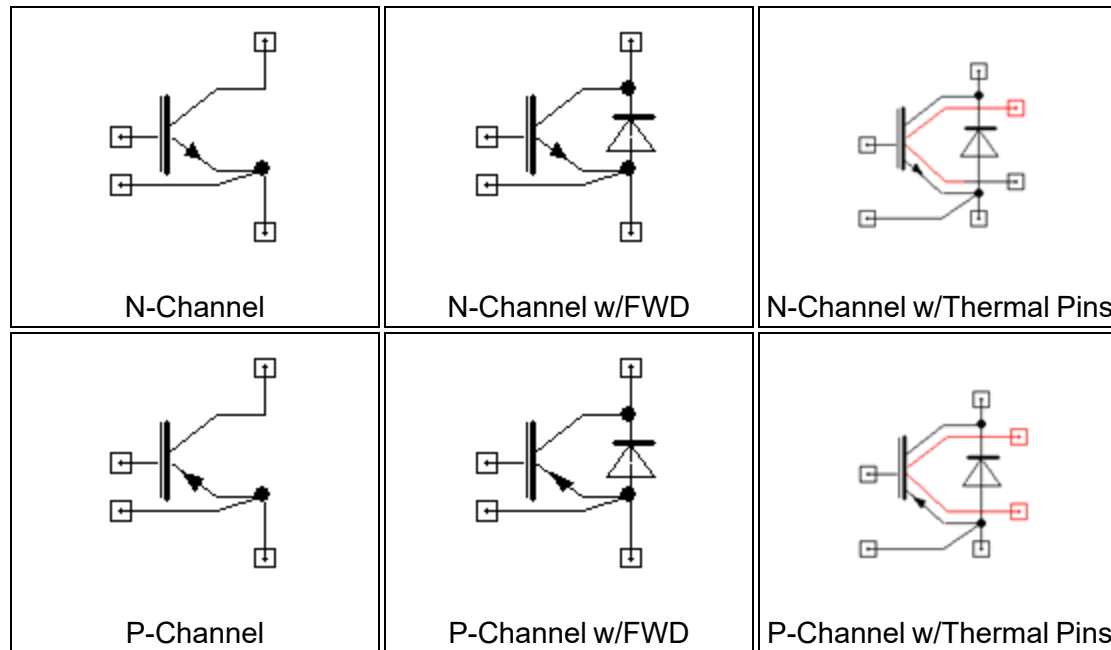


Figure 1. Component symbols

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Description

The IGBT model is a modular model with definable simulation levels. Different simulation depths can be selected for the electrical and thermal behavior of the model. For the models with a free-wheeling diode (FWD) the simulation depth of the diode model can be set separately. For models with thermal pins, an external thermal network can be connected.

The IGBT is a combination of a MOSFET and a bipolar junction transistor (BJT). The internal MOSFET is similar to the single MOSFET model. Since the internal BJT is always in the forward active regime, only its current gain β_{N0} is available as parameter of the IGBT model. The internal model of the freewheeling diode (FWD) is similar to that of the single diode.

You can define different levels for the electrical and thermal behavior using the parameters `TYPE_DYN` and `TYPE_THERM`, respectively. Each level combination has a certain set of parameters. The values of them can be defined in the model dialog box. The component outputs are true of all types of the IGBT models. They are listed at the end of the model description.

The basic dynamic model contains the same static and thermal model as used in average IGBT and advanced dynamic IGBT models. Their difference is in switching dynamics. The basic dynamic model has realistic switching waveforms, and it provides a basic set of dynamic parameters that can shape the switching dynamics to match the switching time and energy of a certain device. Twin Builder provides the **Characterize Device** option to extract the model from the manufacturer datasheet.

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Assumptions and Limitations

Basic dynamic IGBT provides full switching dynamics but with limited tuning capability due to the number of parameters. Using the Device Characterization Wizard, the extracted model has a good match with measurements available in the datasheet, such as switching time and energy, but waveform details like level and duration of Miller plateau, voltage/current overshoot, and length of tail current may not be accurate.

Besides characteristics related parameters, basic dynamic IGBT requires the user to:

- Properly set the External Synchronization signal in Electrical Parameters
- Properly set H_{min} to guarantee 30-50 simulation steps during switching. In general, a minimum time step in order of nanoseconds is required.

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Mathematical Description

Electrical Model

The model uses an electrical equivalent circuit as shown in Figure 2.

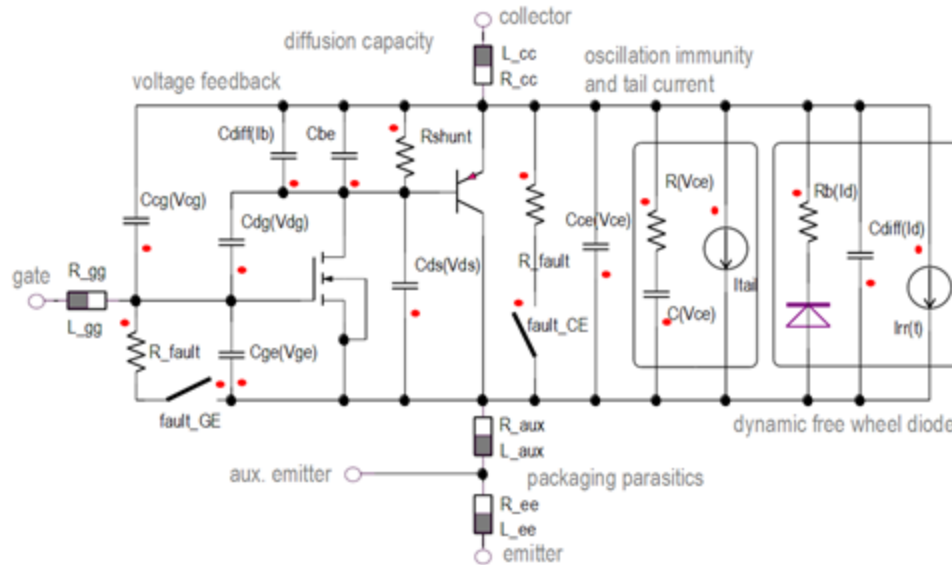


Figure 2. Equivalent circuit of the IGBT model

The TYPE_DYN parameter allows the user to modify the dynamic behavior of the IGBT. There are five digits to the number, each switch switching a different aspect.

- The left-most digit (the 10000's) represents the type of modeling of the Off-Switch-Charge Storage. The default value is 2 for the advanced mode using a controlled I-source. The value 1 (using a conductance) should be used only for compatibility reasons to achieve the same outputs as earlier models.
- The next digit (the 1000's) allows the user to switch the capacitances that are calculated. If the digit is 2, both Cdg and Ccg are calculated (all conserved nodes are supported by capacitances so node values can't jump). If the digit is 1, only Cdg is calculated (internal feedback still provides a good protection against oscillations). If it is 0, only Ccg is calculated and only external feedback is used.
- The next digit (the 100's) allows the user to use a constant Miller capacitance if the digit is set to 1; otherwise, a bias-dependent Miller capacitance is used.
- The next digit (the 10's) controls the type of synchronization method that is used. If this digit is 0, then no synchronization and working point correction are done. The synchronization signal is also important for the soft recovery behavior as well as for any energy and time value outputs of the reverse recovery diode. Without synchronization, the FWD does not show soft recovery, and in hard switching conditions that can lead to oscillations. If the digit is 1, the external synchronization signal that is defined by the SYNC parameter is used. The synchronization signal must cross zero in positive direction for the transition from the blocking to the conducting state and can be any signal available in the simulation which is connected with the pulse frequency of the circuit. If the digit is 2, an

internal synchronization that is derived from V_{ge} is used; however, this method might not be as accurate as an external synchronization.

- The right-most digit (the 1's) turns on the dynamic model if it is set to 1; otherwise, the dynamic behavior is turned off and only the DC parts of the model are used.

The Following Applies to All Type DYN's:

The static model of the FET is modeled using a Schichman-Hodges model, using the parameters A_{FET} , K , KLM , M_{FET} , N_{FET} , $RD0$, $RD1$, RDV and VP . These parameters are modeled as temperature dependent. Their temperature dependence is corrected using the parameters TC_{AFET} , TC_K , TC_{MFET} , TC_{NFET} , TC_{RD0} , TC_{RD1} , TC_{RDV} and TC_{VP} .

For the calculation of the static FET current a distinction is made between the linear region and the pinch-off region. The so-called saturation voltage is given by

$$V_{sat} = A_{FET} \cdot (V_{GS} - V_P)^{M_{FET}}$$

The transition from the linear region to the saturation region happens when the drain current satisfies the following equation:

$$I_{sat} = \frac{K}{2} \cdot (V_{GS} - V_P)^{N_{FET}}$$

Within the linear region, also called triode or ohmic region, the following equation is used:

$$I_D = I_{sat} \cdot (1 + KLM \cdot V_{DS}) \cdot \left(2 - \frac{V_{DS}}{V_{sat}}\right) \cdot \frac{V_{DS}}{V_{sat}}$$

and for the saturation region the following equation applies:

$$I_D = I_{sat} \cdot (1 + KLM \cdot V_{DS})$$

To model behavior of channel length modulation, the static FET model is extended by a nonlinear resistance R_{NL} at the internal drain terminal. Its nonlinear I-V relationship is described by:

$$I(V) = \frac{RDV}{RD0} \tanh\left(\frac{V}{RDV}\right) + \frac{V}{RD1}$$

When $RD0=RD1=0$ and RDV is nonzero, this nonlinear resistance remains constant 0.

The static IGBT is modeled using a simple diode and gain model. The model uses the parameters BN , $ISAT\_BJT$, M_BJT , RB_BJT and RP_BJT . Some parameters are temperature dependent. Their temperature dependence is calculated using TC_ISAT_BJT , TC_M_BJT . For

the saturation current, the parameter is a correction on the physical temperature-based model which is used.

The static IGBT current is calculated by

$$I_C = \beta_N \cdot I_B$$

where I_B is the base current. Though in most cases $I_B = I_D$.

The base current is given by:

$$I_B = I_{SAT\_BJT} \cdot \left[e^{\frac{V_{BE}}{(M\_BJT \cdot V_T)}} - 1 \right]$$

where V_{BE} is the base-emitter voltage of the BJT, and M_BJT is the ideality factor. The saturation current I_{SAT_BJT} is temperature dependent and is calculated using the parameter I_{SAT0} and the actual junction temperature imported from the thermal model. The temperature voltage V_T is calculated as following:

$$V_T = \frac{k \cdot (TEMP\_JNCT + 273\text{ K})}{q}$$

where k is the Boltzmann constant, and $k = 1.381 \times 10^{-23} \text{ m}^2 \text{ kg s}^{-2} \text{ K}^{-1}$; q is the elementary charge, and $q = 1.602 \times 10^{-19} \text{ C}$.

The temperature-dependent parameters are known at the nominal temperature T_{NOM} through parameters of the model. During the simulation their actual values are calculated taking into account the actual value of the junction temperature taken from the thermal model.

The Freewheeling diode is modeled as a simple diode in series with a current-dependent resistor. The parameters M_FWD , I_{SAT_FWD} and R_{B_FWD} are used to model the FWD. The temperature coefficients M_FWD , I_{SAT_FWD} and R_{B_FWD} are used to calculate the temperature dependence of the diode. The static current of the FWD (if enabled) is given by the following formula:

$$I_{FWD} = I_{SAT\_FWD} \cdot \left[e^{\frac{V_{FWD}}{(M\_FWD \cdot V_T)}} - 1 \right]$$

Where V_{FWD} is the voltage over the FWD.

The series resistance is current dependent and given by:

$$\frac{R_{B\_FWD}}{\sqrt{1 + \frac{I_{FWD}}{I_{NOM}}}}$$

The model has built-in fault detection. During the simulation the collector current, the voltage drop from gate to emitter and from collector to emitter as well as the junction temperature are observed. The model behavior changes if the limitations are exceeded. The switches controlled by the FAULT flags are closed and the respective fault resistances determine the model characteristic. If an over voltage occurs across gate-emitter, only RFAULT_GE comes into effect. All other faults affect RFAULT_CE.

Dynamic Behavior

All capacitance between the terminals are modeled the same way. A distinction is made between a region where a depletion capacitance is calculated and a region with enhancement capacitance behavior. The curves remain differentiable even at the transition from one region to the other. The transition happens if the difference of a defined fraction of the diffusion and the voltage across the junction equals zero according to

$$\text{SHIFT} \cdot \text{VDIFF} - V_{\text{JNCT}} = V^*_{\text{JNCT}} = 0$$

For positive values of V^*_{JNCT} (enhancement region) the following formula is used to calculate the capacitance

$$C(V^*_{\text{JNCT}}) = C0 \cdot \left(1 + (\text{BETA} - 1) \cdot \left(1 - e^{-\frac{V^*_{\text{JNCT}} \cdot \text{ALPHA} \cdot (1 - \text{DELTA})}{(\text{BETA} - 1) \cdot \text{VDIFF}}} \right) \right)$$

At negative values of V^*_{JNCT} (depletion region) the following formula applies

$$C(V^*_{\text{JNCT}}) = C0 \cdot \left(\text{DELTA} + \frac{1 - \text{DELTA}}{\left(1 - \frac{V^*_{\text{JNCT}}}{\text{VDIFF}} \right)^{\text{APHA}}} \right)$$

The capacitance at Cge is modeled using CIN0 and CIN1, while Cg and/or Cgd are modeled using CR0 and CR1. This approach allows a great flexibility to model the on- and off-switching behavior, but it is not physically-based. Special care is taken to avoid numerically induced charge when the capacitance values are switched.

The diffusion capacitances at the base-emitter path of the BJT and at the FWD are modeled using the same approach and the same parameter TAUFWD. The lifetime in the BJT is taken as a tenth of the lifetime of the FWD.

$$C_{\text{diff}} = \text{TAU} \cdot \frac{i(t) + I_{\text{SAT}}}{M \cdot V_T}$$

To damp the oscillations that may occur in the system, additional damping resistances are placed in the model. The values of the damping resistances depend on the parameter DAMPING, the values of the parasitic inductances and the values of the internal capacitances.

$$R_{\text{DAMP}} = \text{DAMPING} \cdot \sqrt{\frac{L}{C(V)}}$$

Tail Current and Reverse Recovery Current

The tail current is calculated from the point of the off-switch trigger, as this is a stable measurement point compared to the falling current edge. TAUS controls the duration of the extra base current injection. TAUTAIL and DELTATAIL influence the tail C-E current. DELTATAIL sets the magnitude, while TAUTAIL sets the duration. If TAUS gets large it will interfere with the current tail definition.

Please note: the value of the voltage influencing the tail current is taken from the previous switching-on. Therefore the level does not give proper results for fault simulation and should be used only for investigations of periodic switching processes.

Freewheeling Diode Model

The freewheeling diode model is the same as the single diode model without junction capacitance. The behavior of the diode model can be set using TYPE_FWD.

TYPE_FWD=0 No FWD

TYPE_FWD=1 Static FWD

TYPE_FWD=2 Dynamic FWD with reverse recovery

The total excess carrier charge during the switch to the on-state is controlled by the parameter TAUFWD. The reverse recovery charge, Q_{rr}, is smaller because of charge extraction during the on-state. The current is modeled to be continuous and continuously differentiable. The total stored excess charge before switching off is the FWD diffusion charge. The maximum reverse current, the current slopes, the remaining charge after the current crosses zero and the duration of the reverse recovery are depend on the circuit conditions.

The shape of the reverse recovery current is illustrated in the following figure:

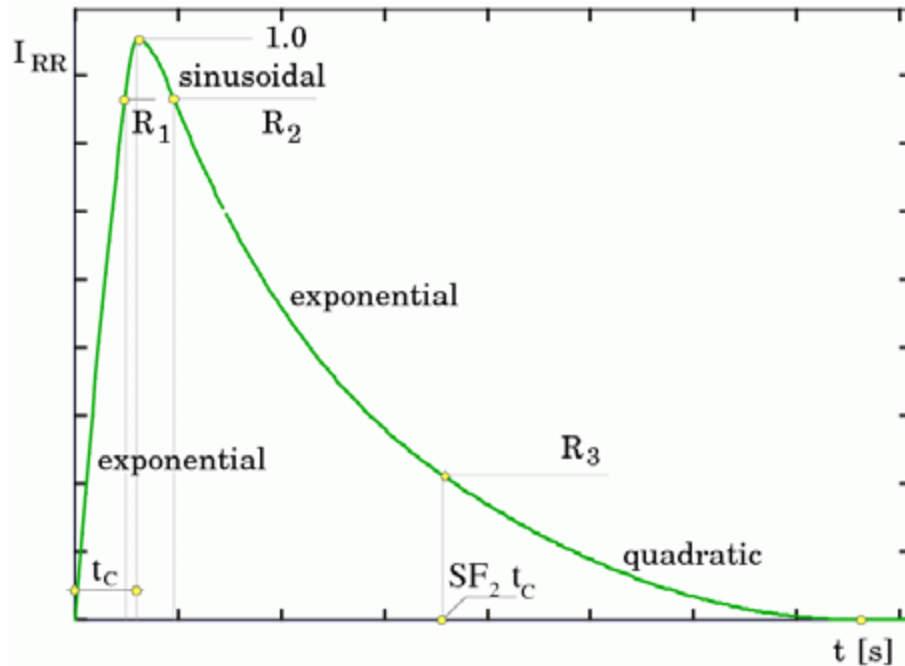


Figure 3. Shape parameters R and SF for exponential current decay

Thermal Pins

IGBT and the freewheeling diode (FWD) are on separate dies and mounted close together on the same substrate. Consequently for both IGBT and diode, separate thermal networks are provided which are connected together on the level of the base plate forming a Y-type thermal network to the heat sink. The IGBT model provides the opportunity to choose between the continued fractional and the partial fractional thermal networks. Both networks show the same thermal impedance. If the thermal capacitances and resistances are considered to be computed from FEM calculation the physically based continued fractional model can be used or if the fitting to a thermal impedance curve is desired the mathematically based partial fraction model can be employed.

As shown in Figure 4, the electrical power losses of both the transistor (POWER_T) and the diode (POWER_D) are injected into their individual thermal networks. The positions of the switches ST1~ST4 and SD1~SD4 are decided by the type of thermal network configuration that's chosen: if continued fraction thermal model is chosen, the switches connect the thermal capacitances directly to the ambient node, while the thermal capacitances are connected in parallel to the corresponding thermal resistances through the switches if partial fraction thermal model is selected. Note that in Figure 4, the ground symbol means the ambient.

Note: The partial fraction model is in general easier to fit, and commonly used in the datasheet. On the other hand, the continued fraction model may reflect the internal physical structure of a semiconductor. It is possible to assign individual RC elements to layers inside a module, so the temperature of internal layers can be simulated. However, such mapping requires detailed structural and material data. Fitting this model only from the thermal curve may not give good results.

For the IGBT components without external thermal pins, switches ST and SD in Figure 4 are closed so that an internal first-order heat sink model is connected, shown as CDT and RDT in

Figure 4. Impedance values of the heat sink can be set by thermal parameters CTHDT and RTHDT.

If a more sophisticated heat sink model is needed, use the IGBT components with thermal pins to connect with the external heat sink. In this case, switches ST and SD in Figure 4 are open and thermal pins THERM_T and THERM_D are exposed. When external thermal pins are used, make sure **Model Thermal Output** in the **Thermal Parameters** tab is set to Kelvin so it is compatible with external thermal components.

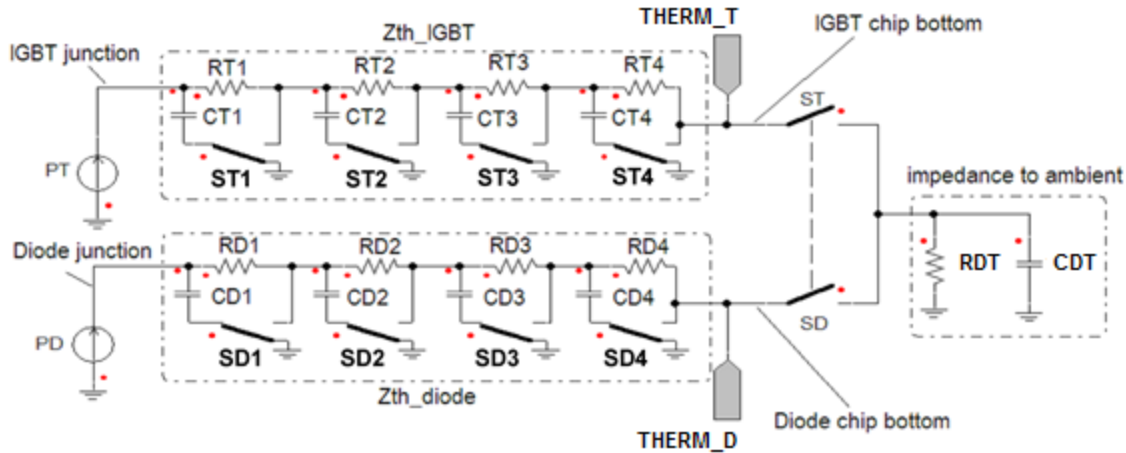


Figure 4. Thermal Network of the IGBT models

The IGBT model has a first-order internal heat sink model. Use the external thermal pins to connect the device to a customized heat sink thermal network configuration.

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Netlist Syntax

```
UMODEL IGBT_BasicDyn ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) GATE:= %0,
AUX_EMITTER:= %1, EMITTER:= %2, COLLECTOR:= %3, THERM_T:= %4, THERM_D:= %5
( TYPE_IGBT:= @TYPE_IGBT, TYPE_FWD:= @TYPE_FWD, TYPE_THERM:= @TYPE_
THERM, TYPE_DYN:= @TYPE_DYN, TYPE_OUT:= @TYPE_OUT, TYPE_
BREAKTHROUGH:= @TYPE_BREAKTHROUGH, VP:= @VP, K:= @K, KLM:= @KLM, A_
FET:= @A_FET, M_FET:= @M_FET, N_FET:= @N_FET, BN:= @BN, M_BJT:= @M_BJT,
ISAT_BJT:= @ISAT_BJT, RB_BJT:= @RB_BJT, RP_BJT:= @RP_BJT, M_FWD:= @M_FWD,
ISAT_FWD:= @ISAT_FWD, RB_FWD:= @RB_FWD, CIN0:= @CIN0, CIN1:= @CIN1, CR0:=
@CR0, DELTACR0:= @DELTACR0, CR1:= @CR1, DELTACR1:= @DELTACR1, TAUFD:=
@TAUFD, SF:= @SF, TAUS:= @TAUS, TAUTAIL:= @TAUTAIL, DELTATAIL:= @DELTATAIL,
DAMPING:= @DAMPING, LC:= @LC, RC:= @RC, LG:= @LG, RG:= @RG, LAUX:= @LAUX,
RAUX:= @RAUX, LE:= @LE, RE:= @RE, TEMPAMB:= @TEMPAMB, TEMPJNCT0:=
@TEMPJNCT0, TNOM:= @TNOM, VNOM:= @VNOM, INOM:= @INOM, SNOM_ON:=
@SNOM_ON, SNOM_OFF:= @SNOM_OFF, VGAP:= @VGAP, TC_VP:= @TC_VP, TC_K:=
@TC_K, TC_NFET:= @TC_NFET, TC_AFET:= @TC_AFET, TC_MFET:= @TC_MFET, TC_
ISAT_BJT:= @TC_ISAT_BJT, TC_M_BJT:= @TC_M_BJT, TC_RB_BJT:= @TC_RB_BJT,
TC_M_FWD:= @TC_M_FWD, TC_ISAT_FWD:= @TC_ISAT_FWD, TC_RB_FWD:= @TC_
RB_FWD, TC_CIN0:= @TC_CIN0, CC0_CIN0:= @CC0_CIN0, CC_CIN0:= @CC_CIN0, VC0_
```

CIN0:= @VC0_CIN0, VC_CIN0:= @VC_CIN0, TC_CIN1:= @TC_CIN1, CC0_CIN1:= @CC0_CIN1, CC_CIN1:= @CC_CIN1, VC0_CIN1:= @VC0_CIN1, VC_CIN1:= @VC_CIN1, TC_CR0:= @TC_CR0, CC0_CR0:= @CC0_CR0, CC_CR0:= @CC_CR0, VC0_CR0:= @VC0_CR0, VC_CR0:= @VC_CR0, TC_CR1:= @TC_CR1, CC0_CR1:= @CC0_CR1, CC_CR1:= @CC_CR1, VC0_CR1:= @VC0_CR1, VC_CR1:= @VC_CR1, TC_TAUFD:= @TC_TAUFD, CC0_TAUFD:= @CC0_TAUFD, CC_TAUFD:= @CC_TAUFD, VC0_TAUFD:= @VC0_TAUFD, VC_TAUFD:= @VC_TAUFD, TC_SF:= @TC_SF, CC0_SF:= @CC0_SF, CC_SF:= @CC_SF, VC0_SF:= @VC0_SF, VC_SF:= @VC_SF, TC_TAUS:= @TC_TAUS, CC0_TAUS:= @CC0_TAUS, CC_TAUS:= @CC_TAUS, VC0_TAUS:= @VC0_TAUS, VC_TAUS:= @VC_TAUS, TC_TAUTAIL:= @TC_TAUTAIL, CC0_TAUTAIL:= @CC0_TAUTAIL, CC_TAUTAIL:= @CC_TAUTAIL, VC0_TAUTAIL:= @VC0_TAUTAIL, VC_TAUTAIL:= @VC_TAUTAIL, TC_DELTATAIL:= @TC_DELTATAIL, CC0_DELTATAIL:= @CC0_DELTATAIL, CC_DELTATAIL:= @CC_DELTATAIL, VC0_DELTATAIL:= @VC0_DELTATAIL, VC_DELTATAIL:= @VC_DELTATAIL, TC_RG:= @TC_RG, CC0_RG:= @CC0_RG, CC_RG:= @CC_RG, VC0_RG:= @VC0_RG, VC_RG:= @VC_RG, TC_DAMPING:= @TC_DAMPING, CC0_DAMPING:= @CC0_DAMPING, CC_DAMPING:= @CC_DAMPING, VC0_DAMPING:= @VC0_DAMPING, VC_DAMPING:= @VC_DAMPING, VBREAK_CE:= @VBREAK_CE, VBREAK_GE:= @VBREAK_GE, IBREAK:= @IBREAK, TEMPBREAK:= @TEMPBREAK, RFAULT_CE:= @RFAULT_CE, RFAULT_GE:= @RFAULT_GE, CTHT1:= @CTHT1, RTHT1:= @RTHT1, CTHT2:= @CTHT2, RTHT2:= @RTHT2, CTHT3:= @CTHT3, RTHT3:= @RTHT3, CTHT4:= @CTHT4, RTHT4:= @RTHT4, CTHD1:= @CTHD1, RTHD1:= @RTHD1, CTHD2:= @CTHD2, RTHD2:= @RTHD2, CTHD3:= @CTHD3, RTHD3:= @RTHD3, CTHD4:= @CTHD4, RTHD4:= @RTHD4, CTHDT:= @CTHDT, RTHDT:= @RTHDT, SYNC:= @SYNC) SRC: DB(Lib:=@ModellibraryName);

NOTE: THERM_T and THERM_D exist only in the NIGBT_BasicDyn_T and PIGBT_BasicDyn_T models.

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Conservative Pins

Table 1

Name	Description	Nature
COLLECTOR	Collector	electrical
EMITTER	Emitter	electrical
AUX_EMITTER	Auxiliary Emitter	electrical
GATE	Gate	electrical
THERM_T*	IGBT Die Bottom Thermal Contact	thermal
THERM_D*	Diode Die Bottom Thermal Contact	thermal

* THERM_T and THERM_D pins exist only in the NIGBT_BasicDyn_T and PIGBT_BasicDyn_T models.

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Parameters

Table 2. General Parameters

Name	Description	Data Type
TYPE_IGBT	IGBT Type Flag -2:p-Type 2:n-Type	real
TYPE_FWD	Freewheeling Diode Type 0:none 1:static 2:dynamic including CDiff and Irr	real
TYPE_DYN	Modeling Flags xxxx0: static xxxx1: dynamic xxx0x: no sync xxx1x: external sync xxx2x: internal sync derived from VGE xx0xx: use bias dependent Miller capacitance xx1xx: use constant Miller capacitance x0xxx: only the feedback cap. Ccg* is used x1xxx: only the feedback cap. Cgd* is used x2xxx: use both feedback cap. Cgd and Ccg* 1xxxx: Off-Switch charge storage (compatibility) 2xxxx: enhanced Off-Switch charge storage * if Ccg and Cgd are use in parallel, both will be assigned a value of $0.5 \cdot CR_x$	real
TYPE_OUT	Internal measurement condition settings: xxxxxxx0: t_ON and E_ON starting criteria 0: Begin of gate discharging 1: 10% rising Vge from min to max 2: Vge zero crossing 3: 10% rising Vge fom zero to max xxxxxxx0x: t_OFF and E_OFF starting criteria 0: Begin of gate charging	real

	1: 90% falling Vge from max to zero 2: 90% falling Vge from max to min xxxxx0xx: t_ON stopping criteria 1: 10% rising Ic 2: 90% rising Ic 3: 10% falling Vce 4: 5% falling Vce 5: 3% falling Vce 6: 1% falling Vce xxxx0xxx: t_OFF stopping criteria 1: 10% rising Vce 2: 90% rising Vce 3: 90% falling Ic 4: 50% falling Ic 5: 10% falling Ic 6: 5% falling Ic 7: 3% falling Ic 8: 1% falling Ic xxx0xxxx: E_ON stopping criteria 1: 90% rising Ic 2: 10% falling Vce 3: 5% falling Vce 4: 3% falling Vce 5: 1% falling Vce xx0xxxxx: E_OFF stopping criteria 1: 90% falling Ic 2: 50% falling Ic 3: 10% falling Ic 4: 5% falling Ic 5: 3% falling Ic 6: 1% falling Ic x0xxxxxx: E_RR stopping criteria 1: 25% falling Irr after Irrm 2: 10% falling Irr after Irrm 3: 5% falling Irr after Irrm 4: 1% falling Irr after Irrm 5: until next switching edge 0xxxxxxx: Measurement source 0: Use external node (device terminals) voltage for time and energy measurement 1: Use internal node (die terminals) voltage for time and energy measurement 2: Use internal voltage for energy, and external voltage for time meas-	

	urement 3: Use external voltage for energy, and internal voltage for time meas- urement	
TYPE_THERM	xx0: isothermal behavior xx2: dynamic behavior x0x: partial fractional therm. net- work x1x: cont. fractional therm. network 0xx: output only rise 1xx: output in degrees Celsius 2xx: output in Kelvin	real
TYPE_BREAKTHROUGH	0: disable breakthrough 1: enable breakthrough	real

Table 3. Static Model Parameters (TYPE DYN=0)

Name	Description	Data Type
VNOM	Nominal Collector-Emitter Voltage [V]	real
INOM	Nominal Collector Current [A]	real
TNOM	Reference Temperature [°C]	real
A_FET	Saturation Factor of internal FET	real
TC_AFET	Temperature Correction Coefficient of A_FET	real
M_FET	Saturation Exponent of internal FET	real
TC_MFET	Temperature Correction Coefficient of M_FET	real
N_FET	Exponent of Transfer Characteristic of FET	real
TC_NET	Temperature Correction Coefficient of N_FET	real
K	Transistor Constant of FET at TNOM	real
TC_K	Temperature Correction Coefficient of K	real
RD0	Small Voltage Bulk Resistance [Ohm]	real
TC_RD0	Temperature Correction Coefficient of RD0	real
RD1	Large Voltage Bulk Resistance [Ohm]	real
TC_RD1	Temperature Correction Coefficient of RD1	real
RDV	Bulk Resistance Inflection Voltage [V]	real
TC_RDV	Temperature Correction Coefficient of RDV	real
VP	Pinch-Off-Voltage of FET at TNOM [V]	real
TC_VP	Temperature Correction Coefficient of VP	real
KLM	Channel Length Modulation Factor of FET [1/V]	real
BN	Current Gain of BJT at TNOM	real
ISAT_BJT	Saturation Current of BJT Base at TEMP0 [A]	real
TC_ISAT_BJT	Temperature Correction Coefficient of ISAT	real
M_BJT	Ideality Factor of BJT Base at TNOM	real

TC_M_BJT	Temperature Correction Coefficient of M_BJT	real
RB_BJT	Bulk Resistance of BJT Base [Ohm]	real
RP_BJT	BJT Base Shut	real
VBREAK_CE	Breakthrough Collector-Emitter Voltage [V]	real
VBREAK_GE	Breakthrough Gate-Emitter Voltage [V]	real
IBREAK	Breakthrough Collector Current [A]	real
RFAULT_CE	Collector-Emitter Resistance after Fault [Ohm]	real
RFAULT_GE	Gate-Emitter Resistance after Fault [Ohm]	real

Table 4. Dynamic Model Parameters (TYPE DYN=xxxx1; include static parameters)

Name	Description [Unit]	Data Type
CIN0	Off-Switch Input Capacitance [F]	real
TC_CIN0	Temperature Corr. Coeff. of CIN0	real
CC0_CIN0	Current Corr. Coeff. of CIN0 ($I_c < I_{NOM}$)	real
CC_CIN0	Current Corr. Coeff. of CIN0 ($I_c > I_{NOM}$)	real
VC0_CIN0	Voltage Corr. Coeff. of CIN0 ($V_{ce} < V_{NOM}$)	real
VC_CIN0	Voltage Corr. Coeff. of CIN0 ($V_{ce} > V_{NOM}$)	real
CIN1	On-Switch Input Capacitance [F]	real
TC_CIN1	Temperature Corr. Coeff. of CIN1	real
CC0_CIN1	Current Corr. Coeff. of CIN1 ($I_c < I_{NOM}$)	real
CC_CIN1	Current Corr. Coeff. of CIN1 ($I_c > I_{NOM}$)	real
VC0_CIN1	Voltage Corr. Coeff. of CIN1 ($V_{ce} < V_{NOM}$)	real
VC_CIN1	Voltage Corr. Coeff. of CIN1 ($V_{ce} > V_{NOM}$)	real
CR0	Off-Switch Feedback Capacitance [F]	real
DELTACR0	Off-Switch Feedback Capacitance Minimum [rel]	real
TC_CR0	Temperature Corr. Coeff. of CR0	real

CC0_CR0	Current Corr. Coeff. of CR0 ($I_c < I_{NOM}$)	real
CC_CR0	Current Corr. Coeff. of CR0 ($I_c > I_{NOM}$)	real
VC0_CR0	Voltage Corr. Coeff. of CR0 ($V_{ce} < V_{NOM}$)	real
VC_CR0	Voltage Corr. Coeff. of CR0 ($V_{ce} > V_{NOM}$)	real
CR1	On-Switch Feedback Capacitance [F]	real
DELTACR1	On-Switch Feedback Capacitance Minimum [rel]	real
TC_CR1	Temperature Corr. Coeff. of CR1	real
CC0_CR1	Current Corr. Coeff. of CR1 ($I_c < I_{NOM}$)	real
CC_CR1	Current Corr. Coeff. of CR1 ($I_c > I_{NOM}$)	real
VC0_CR1	Voltage Corr. Coeff. of CR1 ($V_{ce} < V_{NOM}$)	real
VC_CR1	Voltage Corr. Coeff. of CR1 ($V_{ce} > V_{NOM}$)	real
TAUS	Nominal Base Storage Time [s]	real
TC_TAUS	Temperature Corr. Coeff. of TAUS	real
CC0_TAUS	Current Corr. Coeff. of TAUS ($I_c < I_{NOM}$)	real
CC_TAUS	Current Corr. Coeff. of TAUS ($I_c > I_{NOM}$)	real
VC0_TAUS	Voltage Corr. Coeff. of TAUS ($V_{ce} < V_{NOM}$)	real
VC_TAUS	Voltage Corr. Coeff. of TAUS ($V_{ce} > V_{NOM}$)	real
SF	Diode Reverse Recovery Soft Factor	real
TC_SF	Temperature Corr. Coeff. of SF	real
CC0_SF	Current Corr. Coeff. of SF ($I_c < I_{NOM}$)	real
CC_SF	Current Corr. Coeff. of SF ($I_c > I_{NOM}$)	real
VC0_SF	Voltage Corr. Coeff. of SF ($V_{ce} < V_{NOM}$)	real
VC_SF	Voltage Corr. Coeff. of SF ($V_{ce} > V_{NOM}$)	real
TAUTAIL	Time Constant of Tail Current [s]	real
TC_TAUTAIL	Temperature Corr. Coeff. of TAUTAIL	real
CC0_TAUTAIL	Current Corr. Coeff. of TAUTAIL ($I_c < I_{NOM}$)	real
CC_TAUTAIL	Current Corr. Coeff. of TAUTAIL ($I_c > I_{NOM}$)	real
VC0_TAUTAIL	Voltage Corr. Coeff. of TAUTAIL ($V_{ce} < V_{NOM}$)	real

VC_TAUTAIL	Voltage Corr. Coeff. of TAUTAIL (Vce>VNOM)	real
DELTATAIL	Start of Tail Current relative to Maximum Current	real
TC_DELTATAIL	Temperature Corr. Coeff. of DELTATAIL	real
CC0_DELTATAIL	Current Corr. Coeff. of DELTATAIL (Ic<INOM)	real
CC_DELTATAIL	Current Corr. Coeff. of DELTATAIL (Ic>INOM)	real
VC0_DELTATAIL	Voltage Corr. Coeff. of DELTATAIL (Vce<VNOM)	real
VC_DELTATAIL	Voltage Corr. Coeff. of DELTATAIL (Vce>VNOM)	real
RG	Internal gate resistance [Ohm]	real
TC_RG	Temperature Corr. Coeff. of RG	real
CC0_RG	Current Corr. Coeff. of RG (Ic <INOM)	real
CC_RG	Current Corr. Coeff. of RG (Ic >INOM)	real
VC0_RG	Voltage Corr. Coeff. of RG (Vce <VNOM)	real
VC_RG	Voltage Corr. Coeff. of RG (Vce >VNOM)	real
DAMPING	Damping constant	real
TC_DAMPING	Temperature Corr. Coeff. of DAMPING	real
CC0_DAMPING	Current Corr. Coeff. of DAMPING (Ic <INOM)	real
CC_DAMPING	Current Corr. Coeff. of DAMPING (Ic >INOM)	real
VC0_DAMPING	Voltage Corr. Coeff. of DAMPING (Vce <VNOM)	real
VC_DAMPING	Voltage Corr. Coeff. of DAMPING (Vce >VNOM)	real
SYNC	External Synchronization Signal	real

Note: External synchronization signal SYNC is a trigger **necessary** for device model to behave correctly. It is required to cross zero in a positive direction only when a device starts conducting, and cross zero in negative direction only when a device stops conducting or when Irr is formed. It is preferable to use an ideal pulse wave or trapezoidal wave. When using an ideal pulse wave, a signal change between zero and a positive value is also supported.

Note that the synchronization signal may not be the same as the gate drive signal for the same device. Rule of thumb is to give a clear rising edge or zero crossing signal at the moment when conducting status of a device changes or when current flows on a device start to change.

Table 5. Thermal Parameters

Name	Description [Unit]	Data Type
TEMPAMB	Ambient Temperature [°C]*	real
TEMPJNCT0	Junction Temperature at Simulation Start [°C]*	real
CTHT1	1. Thermal Transistor Capacitance [F]	real
RTHT1	1. Thermal Transistor Resistance [ohm]	real
CTHT2	2. Thermal Transistor Capacitance [F]	real
RTHT2	2. Thermal Transistor Resistance [ohm]	real
CTHT3	3. Thermal Transistor Capacitance [F]	real
RTHT3	3. Thermal Transistor Resistance [ohm]	real
CTHT4	4. Thermal Transistor Capacitance [F]	real
RTHT4	4. Thermal Transistor Resistance [ohm]	real
CTHD1	1. Thermal Diode Capacitance [F]	real
RTHD1	1. Thermal Diode Resistance [ohm]	real
CTHD2	2. Thermal Diode Capacitance [F]	real
RTHD2	2. Thermal Diode Resistance [ohm]	real
CTHD3	3. Thermal Diode Capacitance [F]	real
RTHD3	3. Thermal Diode Resistance [ohm]	real
CTHD4	4. Thermal Diode Capacitance [F]	real
RTHD4	4. Thermal Diode Resistance [ohm]	real
CTHDT	4. Thermal Diode Resistance [ohm]	real
RTHDT	4. Common Thermal Resistance [ohm] [ohm]	real

* The unit in which those output values are created depends on the unit flag in the TYPE_THERM parameter (raise only, °C, or K).

Table 6. Parameters of FWD Model

Name	Description [Unit]	Data Type
M_FWD	Ideality Factor of FWD at TNOM (static parameter)	real

ISAT_FWD	Saturation Current of FWD at TNOM [A] (static parameter)	real
RB_FWD	Bulk Resistance of FWD at TNOM [Ohm] (static parameter)	real
TC_M_FWD	Temperature Coefficient of M_FWD (static parameter)	real
TC_ISAT_FWD	Temperature Coefficient of ISAT_FWD (static parameter)	real
TC_RB_FWD	Temperature Coefficient of RB_FWD	real
TAUFWD	Effective Lifetime of FWD	real
TC_TAUFD	Temperature Coefficient of TAUFD	real
CC0_TAUFD	Current Coefficient of TAUFD at TNOM	real
CC_TAUFD	Linear Current Coefficient of TAUFD	real
VC0_TAUFD	Voltage Coefficient of TAUFD at TNOM	real
VC_TAUFD	Linear Voltage Coefficient of TAUFD	real

Table 7. Parameters of External Connections

Name	Description [Unit]	Data Type
RC	Collector Connector Resistance [Ohm]	real
RE	Emitter Connector Resistance [Ohm]	real
RAUX	Internal Emitter Resistance [Ohm]	real
LC	Collector Connector Inductance [H]	real
LG	Emitter Connector Inductance [H]	real
LE	Source Connector Inductance [H]	real
LAUX	Internal Emitter Inductance [H]	real

Note: Parameters LC and LE determine internal R_{DAMP} as described in Dynamic Behavior.

Output Quantities

Table 8. Model Outputs

Name	Description [Unit]
VCE	Collector-Emitter Voltage [V], terminal voltage wave form, positive for n- and p- channel devices
IC	Collector Current [A], total collector current, wave form positive for n- and p- channel devices

IG	Gate Current [A], wave form, sign depends on the channel type n/p
IFD	FWD Current [A], free wheeling diode current wave form, positive in diode conducting direction
VD	FWD Voltage Drop [V], actual voltage drop across the junction and bulk resistance, positive in diode conducting direction
TRANSCOND	Trans Conductance [A/V], definition is $S = d(I_c)/d(V_{ge})$, depends on the DC quiescent point and is valid for AC simulations
OUTCOND	Output Conductance [A/V], definition is $G = d(I_c)/d(V_{ce})$, depends on the DC quiescent point and is valid for AC simulations
SGE_ON	On switch gate emitter voltage slope [V/s] at the moment of VP crossing, it controls the on switch delay times, can be used for modeling a gate drive sensitivity
SGE_OFF	Off switch gate emitter voltage slope [V/s] at the moment of VP crossing, it controls the off switch delay times, can be used for modeling a gate drive sensitivity
TEMPJ_T	Wave form of the transistor junction temperature [°C, K]* at the transistor hot spot at the point of power injection, accuracy depends on correct total power calculation and an appropriate thermal network for the transistor heat dissipation
TEMPJ_D	Wave form of the Diode junction temperature [°C, K]* at the diode hot spot, the point of power injection, accuracy depends on correct total power calculation and an appropriate thermal network for the diode heat dissipation
TEMPBOT_T	IGBT bottom temperature [°C, K]* at the end of the transistor four stage thermal chain. If external heat pins are used this is the node temperature, else it is equal TEMP_PLATE
TEMPBOT_D	Diode bottom temperature [°C, K]* at the end of the diode four stage thermal chain. If external heat pins are used this is the node temperature, else equal TEMP_PLATE
TEMP_PLATE	Temperature difference [°C, K]* across the one stage internal heat sink if internal sink is selected, else ambient temperature
E_ON	On-Switch Energy [J], internal measurement depending on TYPE_OUT setting
E_OFF	Off-Switch Energy [J], internal measurement depending on TYPE_OUT setting
E_RR	Diode's Reverse Recovery Energy Loss [J], internal measurement depending on TYPE_OUT setting

t_ON	On-Switch Delay Time [s], internal measurement depending on TYPE_OUT setting
t_OFF	Off-Switch Delay Time [s], internal measurement depending on TYPE_OUT setting
E_TOT	Power integral across a full switching cycle without any threshold values [J], includes a step-like function at the switching edges and the increasing section during the conduction mode. E_TOT is the suitable value for heat calculations. E_TOT can be sampled to get E_ON or E_OFF according to different measurement conditions.
P_TOT	Total power loss time function $V_{IGBT}(t) \times I_{IGBT}(t)$ [W], includes transistor and diode current, controlled by digit Dxxxxxxx of TYPE_OUT, D=3,0: external Vce; 2,1: internal Vce directly at the silicon die
STEP	Actual used Time Step [s]
POWER_T	Transistor power loss time function [W], suitable to be injected directly into an external thermal transistor network.
POWER_D	Diode power loss time function [W], suitable to be injected directly into an external thermal diode network
VCE_FAULT	Vce Fault Flag [0/1] Vce hits the absolute limits, can be watched during the simulation for break at fault
VGE_FAULT	Vge Fault Flag [0/1]
IC_FAULT	Collector Current Fault Flag [0/1]
TEMPJ_FAULT	JunctionTemperature Fault Flag [0/1]

* The units in which those output values are created depend on the unit flag in the TYPE_THERM parameter (raise only, °C, or K).

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Example

Four examples are available, representing the N-Type Basic Dynamic model, the N-Type Basic Dynamic model with FWD diode, the P-Type Basic Dynamic model and the P-Type Basic Dynamic model with FWD diode. The examples are shown below.

This example demonstrates the operation mechanism of the basic dynamic N-Channel IGBT model through a simple example. The control gate voltage is supplied by a pulse-wave voltage source E1. The schematic of the example is shown in Figure 5, system parameters are listed in Table 9, and the simulation results are shown in Figures 6 and 7.

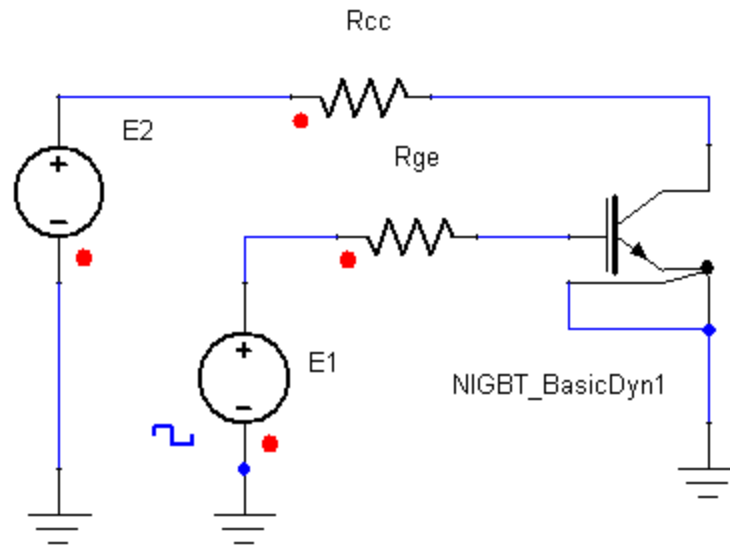


Figure 5. Application example of the N-Channel IGBT model (basic dynamic)

Table 9. System Parameters

Componen	Parameter	Value [unit]
Resistor Rge	R	10 [Ohm]
Resistor Rcc	R	1 [Ohm]
Voltage Source (Pulse) E1	AMPL	15 [V]
	FREQ	1000 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [V]
Voltage Source E2	EMF	500 [V]
Basic Dynamic IGBT NIGBT_ BASICDYN1	TYPE_DYN	2011
	VNOM	600
	INOM	600
	SYNC	E1.EMF
	TYPE_BREAKTHROUGH	0

* All other parameters of the N-Channel IGBT model use their default values, therefore they are not included in the parameter table.

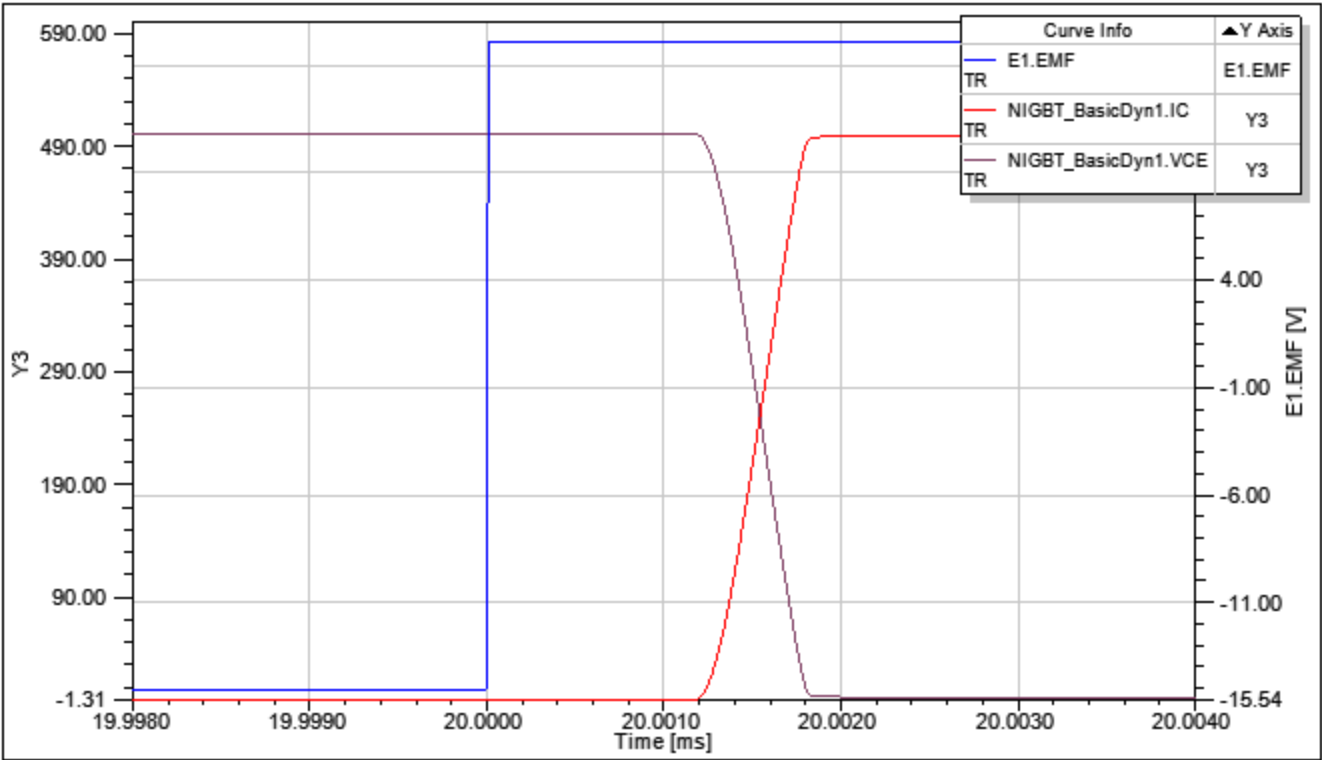


Figure 6. Simulation result-Switching ON Waveforms for NIGBT_BASICDYN1

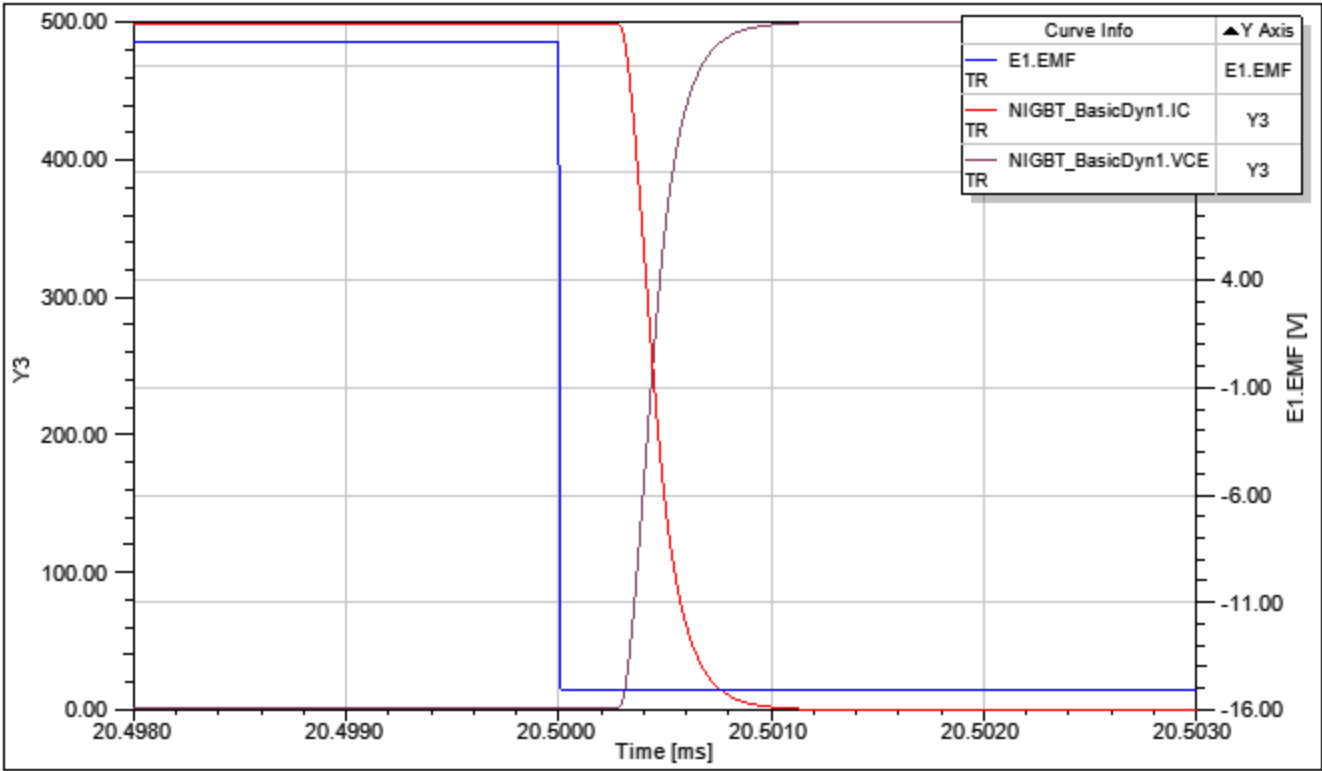


Figure 7. Simulation result-Switching OFF Waveforms for NIGBT_BASICDYN1

This example demonstrates the operation mechanism of the basic dynamic N-Channel IGBT model with FWD through a simple example. The control gate voltage is supplied by a pulse-wave voltage source E1. The schematic of the example is shown in Figure 8, system parameters are listed in Table 10, and the simulation results are shown in Figures 9 and 10.

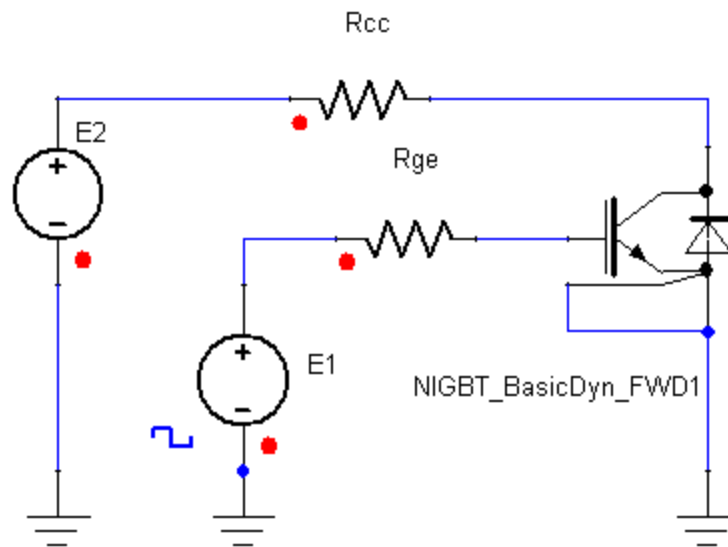


Figure 8. Application example of the N-Channel IGBT model with FWD (basic dynamic)

Table 10. System Parameters

Componen	Parameter	Value [unit]
Resistor Rge	R	10 [Ohm]
Resistor Rcc	R	1 [Ohm]
Voltage Source (Pulse) E1	AMPL	15 [V]
	FREQ	1000 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [V]
Voltage Source E2	EMF	500 [V]
Basic Dynamic IGBT NIGBT_BASICDYN_FWD1	TYPE_DYN	2011
	VCE	0
	IC	0
	SYNC	E1.EMF

* All other parameters of the N-Channel IGBT model use their default values, therefore they are not included in the parameter table.

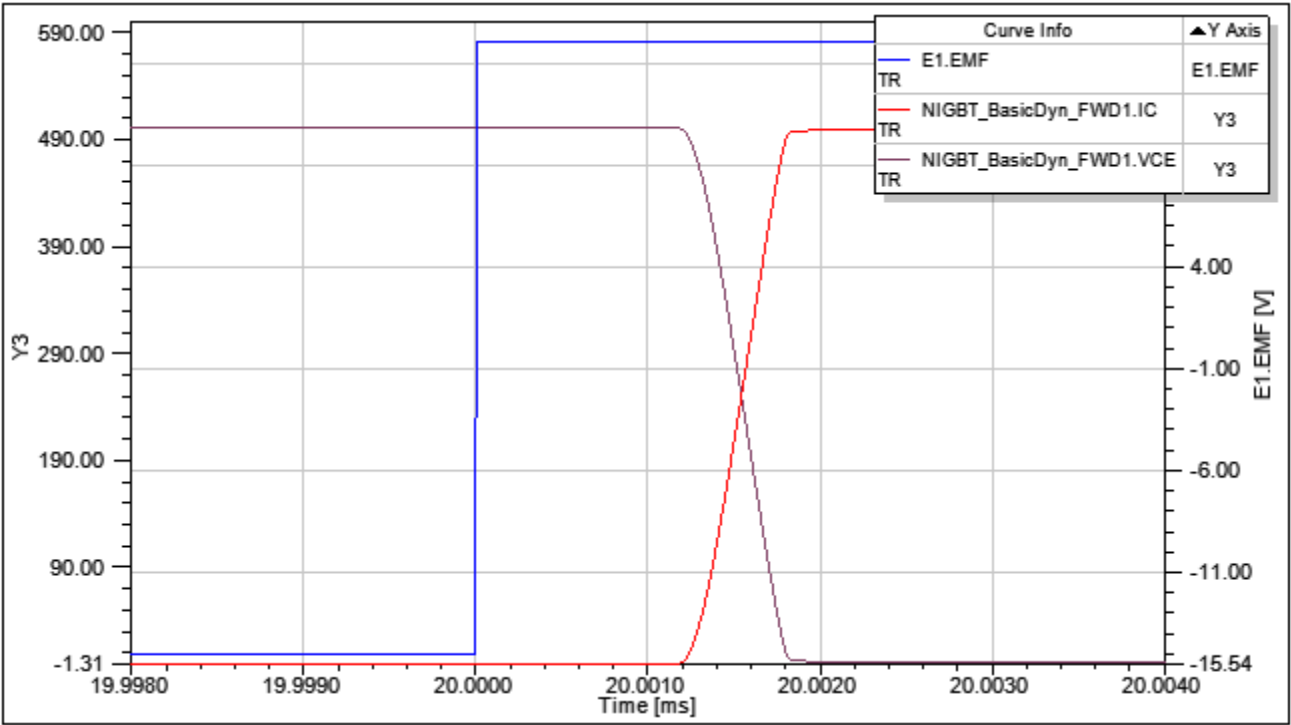


Figure 9. Simulation result-Switching ON Waveforms for NIGBT_BASICDYN_FWD1

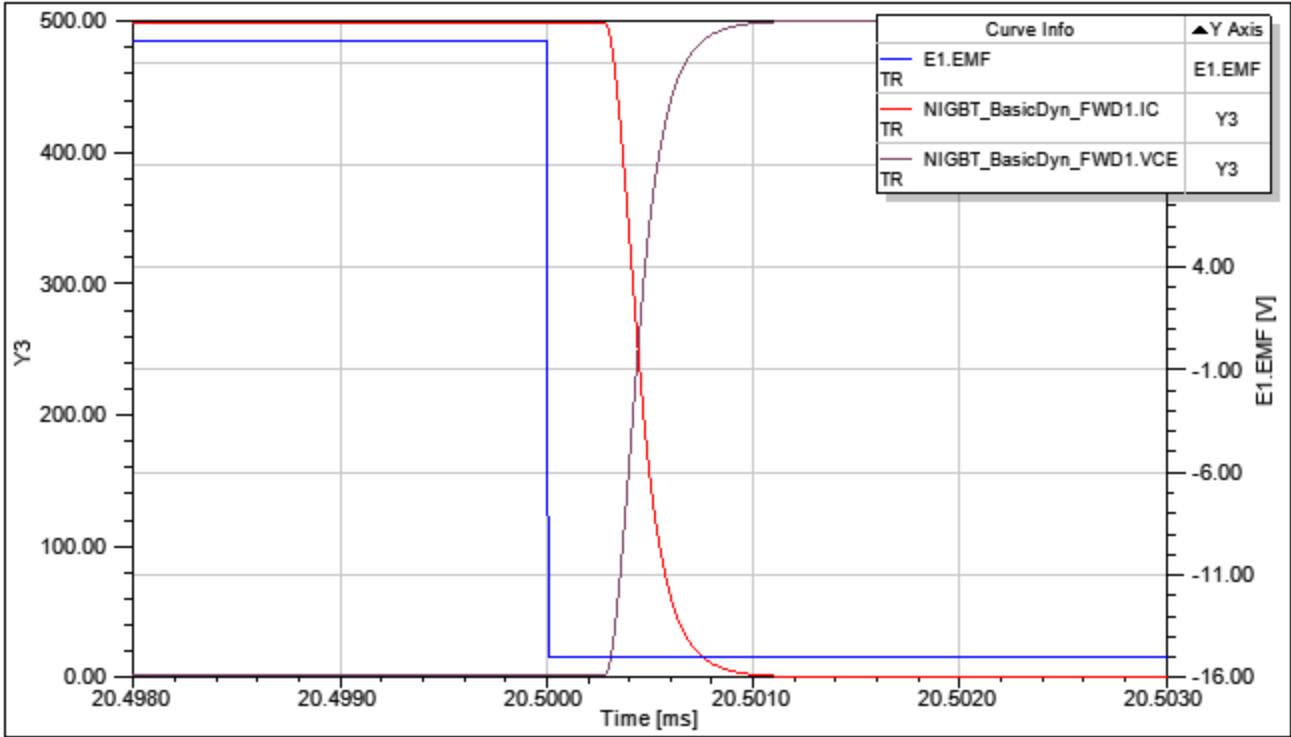
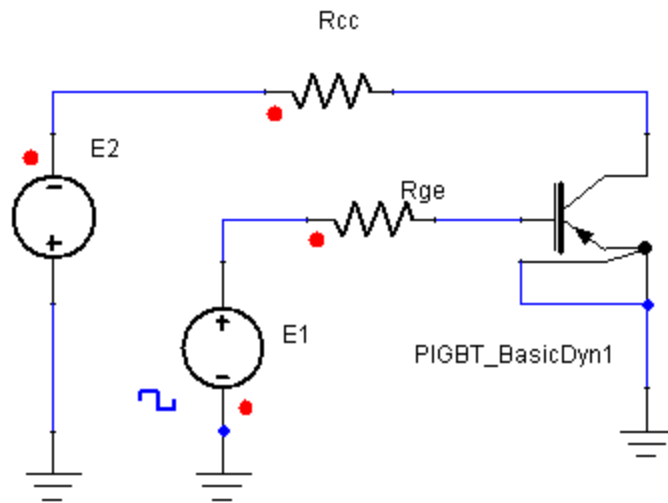


Figure 10. Simulation result-Switching OFF Waveforms for NIGBT_BASICDYN_FWD1

This example demonstrates the operation mechanism of the basic dynamic P-Channel IGBT model through a simple example. The control gate voltage is supplied by a pulse-wave voltage source E1. The schematic of the example is shown in Figure 11, system parameters are listed in Table 11, and the simulation results are shown in Figures 12 and 13.

**Figure 11. Application example of the P-Channel IGBT model (basic dynamic)****Table 11. System Parameters**

Component	Parameter	Value [unit]
Resistor Rge	R	10 [Ohm]
Resistor Rcc	R	1 [Ohm]
Voltage Source (Pulse) E1	AMPL	15 [V]
	FREQ	1000 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [V]
Voltage Source E2	EMF	500 [V]

Basic Dynamic IGBT PIGBT_ BASICDYN1	TYPE_DYN	2011
	VNOM	3000
	INOM	3000
	SYNC	E1.EMF
	TYPE_ BREAKTHROUGH	1

* All other parameters of the P-Channel IGBT model use their default values, therefore they are not included in the parameter table.

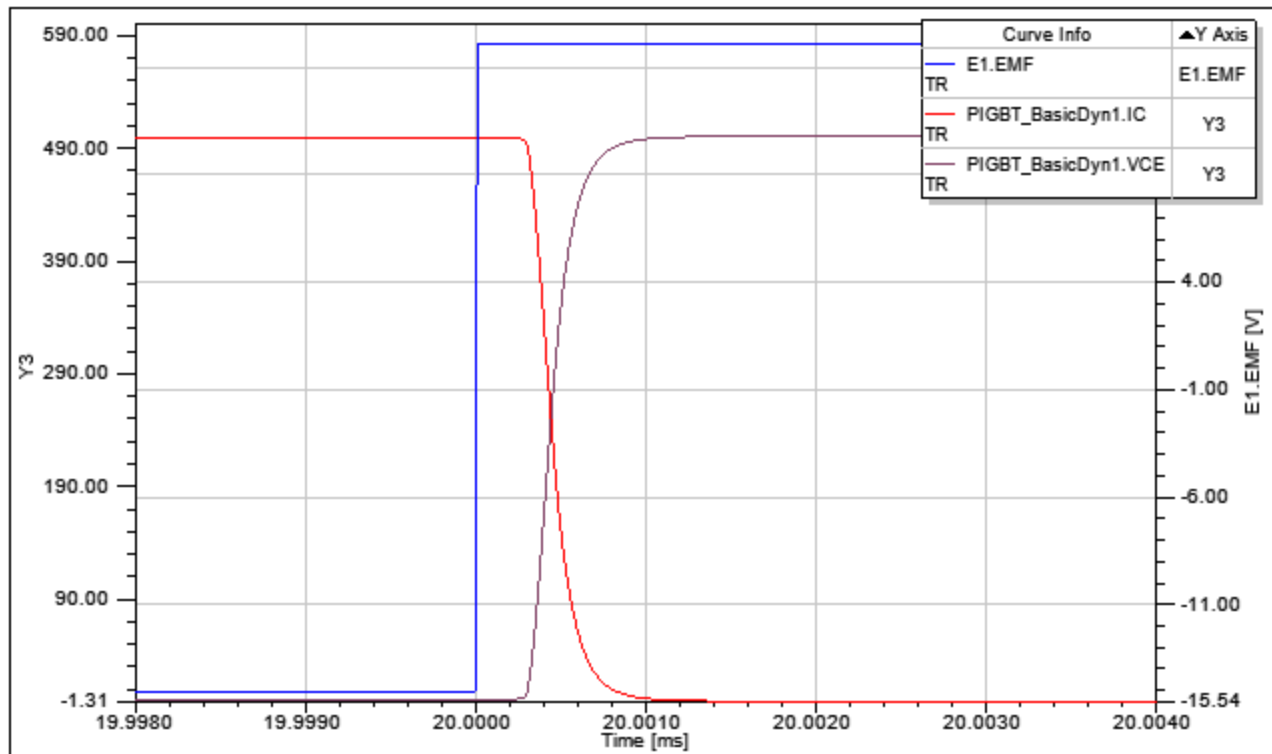


Figure 12. Simulation result-Switching ON Waveforms for PIGBT_BASICDYN1

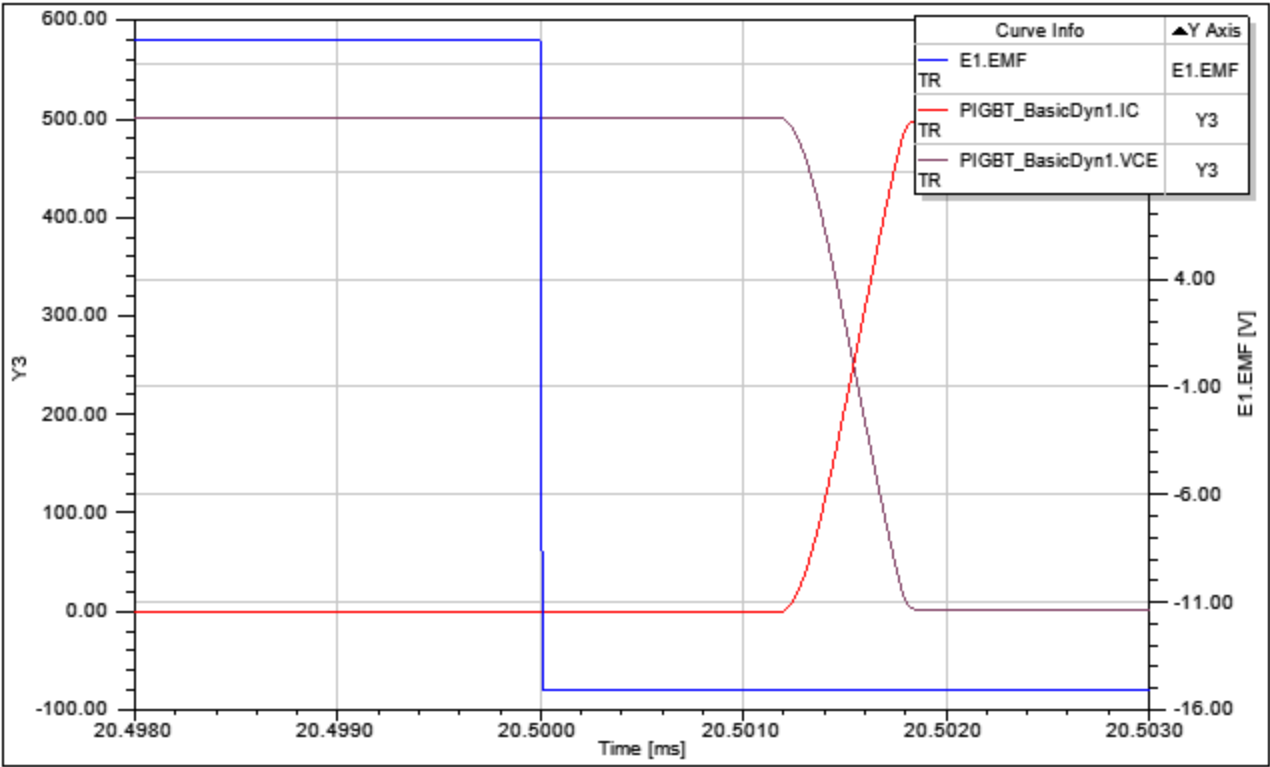


Figure 13. Simulation result-Switching OFF Waveforms for PIGBT_BASICDYN1

This example demonstrates the operation mechanism of the basic dynamic P-Channel IGBT model with FWD through a simple example. The control gate voltage is supplied by a pulse-wave voltage source E1. The schematic of the example is shown in Figure 14, system parameters are listed in Table 12, and the simulation results are shown in Figures 15 and 16.

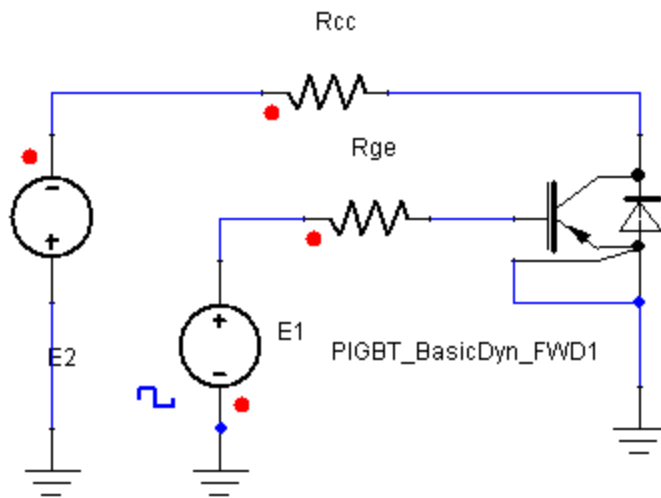


Figure 14. Application example of the P-Channel IGBT model with FWD (basic dynamic)**Table 12. System Parameters**

Component	Parameter	Value [unit]
Resistor Rge	R	10 [Ohm]
Resistor Rcc	R	1 [Ohm]
Voltage Source (Pulse) E1	AMPL	15 [V]
	FREQ	1000 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [V]
Voltage Source E2	EMF	500 [V]
Basic Dynamic IGBT PIGBT_BASICDYN_FWD1	TYPE_DYN	2011
	VCE	0
	IC	0
	SYNC	E1.EMF

* All other parameters of the P-Channel IGBT model use their default values, therefore they are not included in the parameter table.

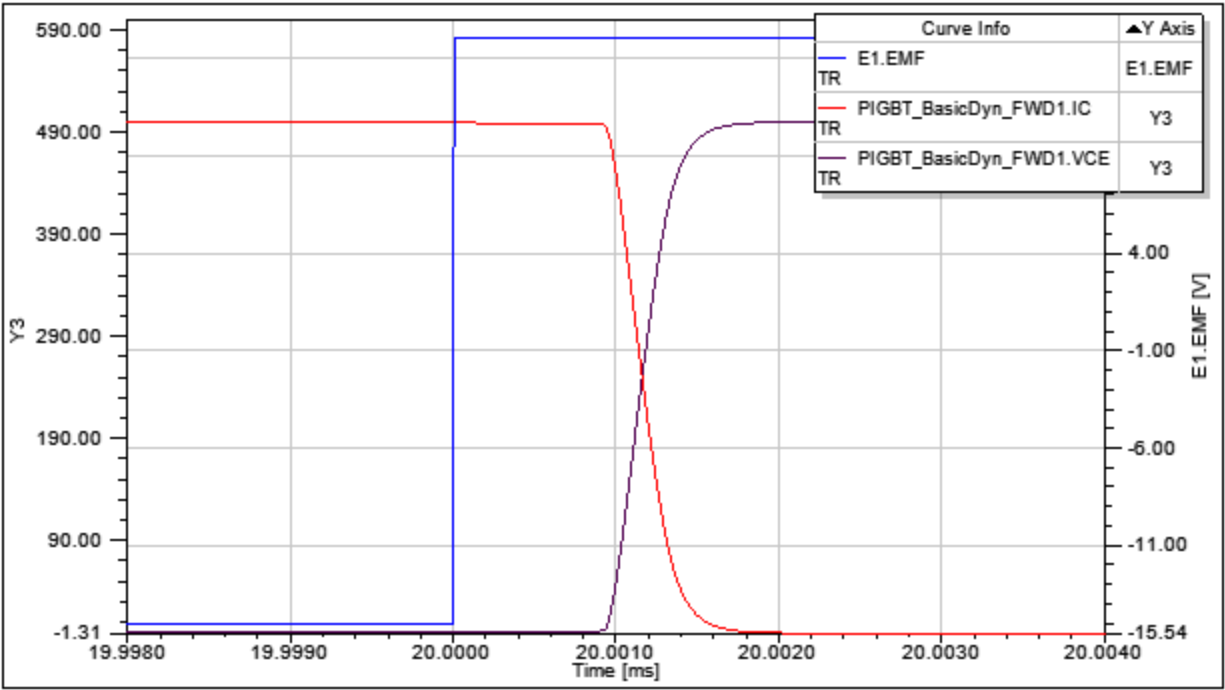


Figure 15. Simulation result-Switching ON Waveforms for PIGBT_BASICDYN_FWD1

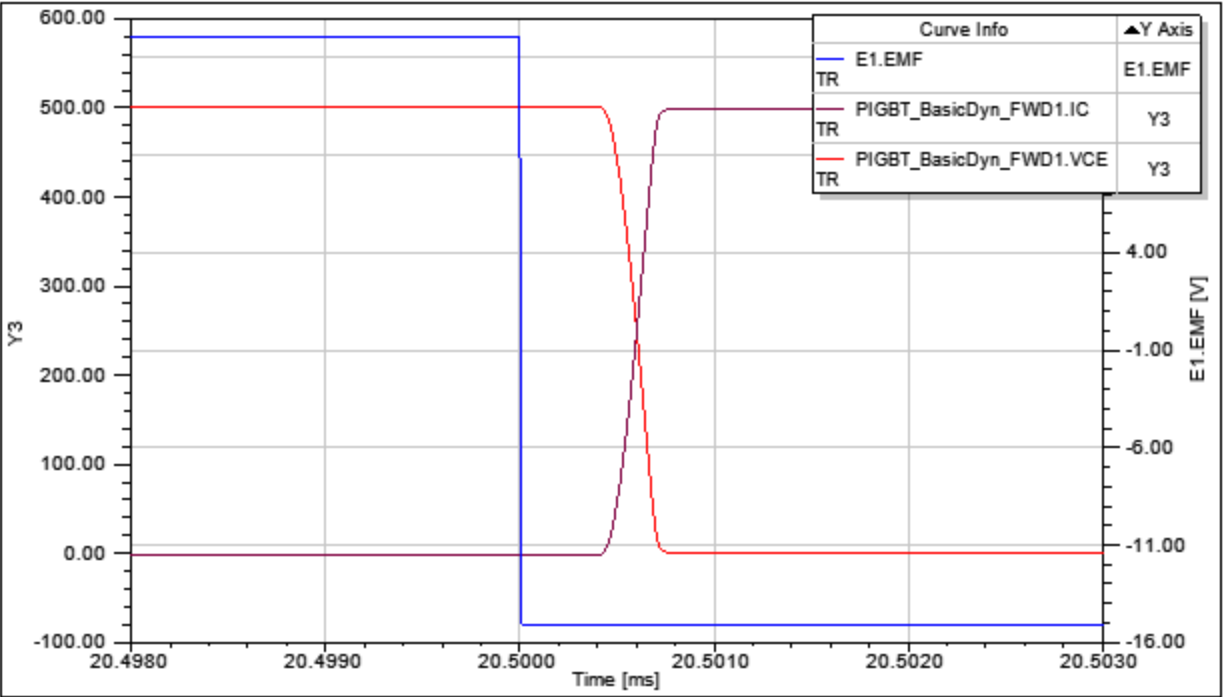


Figure 16. Simulation result-Switching OFF Waveforms for PIGBT_BASICDYN_FWD1

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References

[1] Ned Mohan, Tore M. Undeland, William P. Robbins, "Power Electronics: Converters, Applications, and Design." John Wiley & Sons, INC. New York, 1995.

Dynamic OPV Model

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

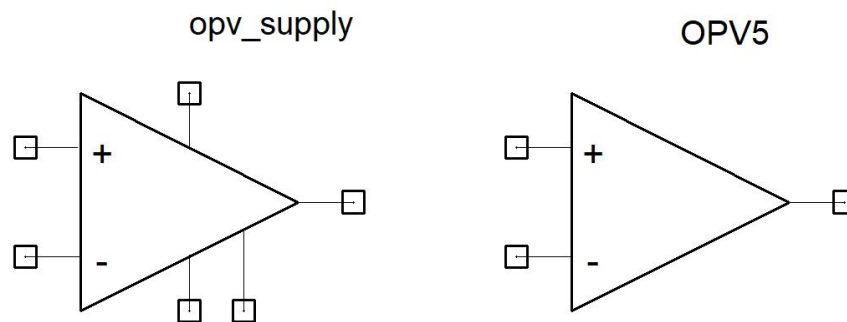


Figure 1. Component symbol

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- [Assumptions and Limitations](#)
- [Mathematical Description](#)
- [Netlist Syntax](#)
- [Conservative Pins](#)
- [Parameters](#)
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Description

The model represents a differential-voltage amplifier with or without universal frequency compensation for digital and analog applications. The operational amplifier is a general amplifier with differential input. It is used for controlling purposes, analog computation, filters, video techniques, digital techniques, ADC/DAC and power amplifiers in analog or digital systems.

Both components opv_supply (6-pin) and OPV5 (3-pin) base on the same model. The difference is opv_supply requires external supply voltage source. For component OPV5, the power supply is not modeled as an electrical node; instead, the supply voltage and, if necessary, the noise on it, can be entered as parameters.

The frequency characteristic of the operational amplifier is determined primarily by the parameter F_{TR} , which is the transit frequency of the model. At this frequency, the gain of the operational amplifier equals '1', i.e. 0 dB. The Slew Rate parameter (SR) also affects the frequency characteristic. The two parameters are interpreted following the rule:

When $SR=0$ and $F_{TR}=0$, the operational amplifier is a static model;

When $SR=0$ and $F_{TR}>0$, only F_{TR} is used to determine internal capacitor by $C=AD/(2\pi \times F_{TR} \times RO)$;

When $SR>0$ and $F_{TR}=0$, only SR is used to determine internal capacitor by $C=AD/(RO \times SR)$;

When $SR>0$ and $F_{TR}>0$, two capacitance values are calculated from both data. The smaller capacitor is finally used in model. This condition is not suggested.

Please note that the thermal behavior is not taken into account, i.e. the model cannot simulate temperature change due to power dissipation. Also note that frequency behavior with oscillation tendency (phase shift $< -90^\circ$) is not compensated, i.e. instability of the gain cannot be modeled.

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Assumptions and Limitations

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Mathematical Description

The equivalent circuit used for this model is shown in Figure 2. Also shown in Figure 3 is the Bode diagram of the model.

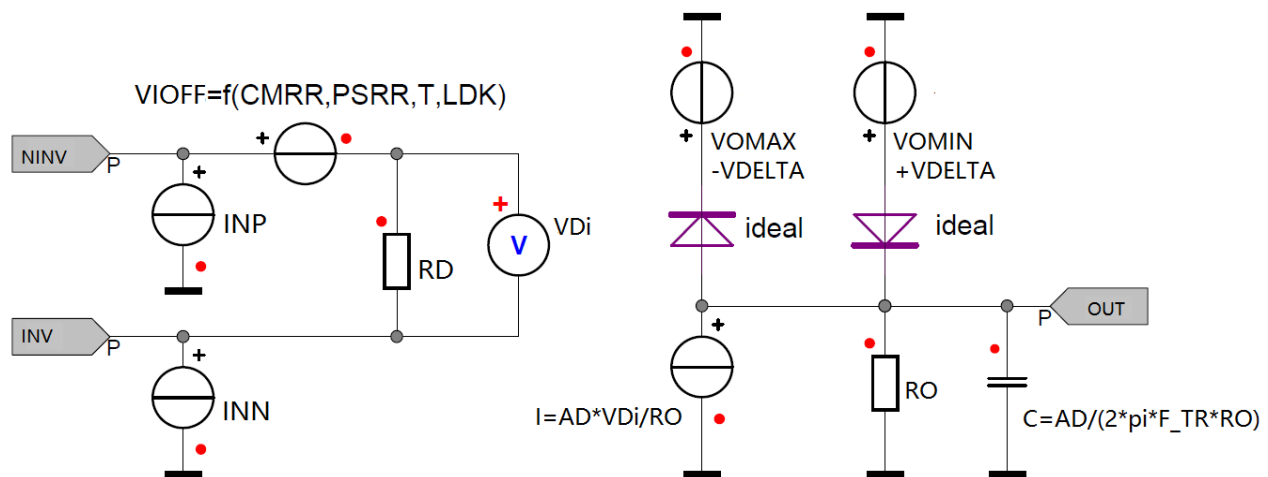


Figure 2. Equivalent circuit of the Dynamic OPV Model

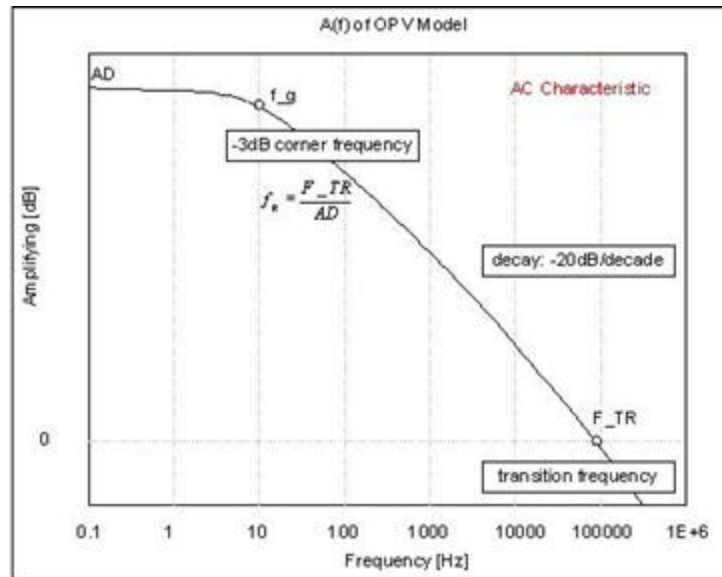


Figure 3. Bode diagram of the Dynamic OPV Model

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Netlist Syntax

```
UMODEL opv50 ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) NINV:= %0, INV:= %1,
OUT:= %2 ( AD:= @AD, VOMAX:= @VOMAX, VOMIN:= @VOMIN, SR:= @SR, VIOFF0:=
@VIOFF0, INN:= @INN, INP:= @INP, RD:= @RD, RO:= @RO, CMRR:= @CMRR, PSRR:=
@PSRR, TEMP:= @TEMP, COEFF_VIOFF:= @COEFF_VIOFF, TEMP0:= @TEMP0, LDK:=
@LDK, VDELTA:= @VDELTA, VNSUPPLY:= @VNSUPPLY, F_TR:= @F_TR) SRC: DB(Lib:-
:=@ModelLibraryName) ;
```

```
UMODEL opv_supply ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) NINV:= %0,
INV:= %1, OUT:= %2, REF:= %3, VPP:= %4, VNN:= %5 ( AD:= @AD, F_TR:= @F_TR, TEMP:=
@TEMP, TEMP0:= @TEMP0, SR:= @SR, VIOFF0:= @VIOFF0, INN:= @INN, INP:= @INP,
RD:= @RD, RO:= @RO, CMRR:= @CMRR, PSRR:= @PSRR, COEFF_VIOFF:= @COEFF_
VIOFF, LDK:= @LDK) SRC: DB(Lib:=@ModelLibraryName) ;
```

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
NINV	Non-Inverting Input	electrical
INV	Inverting Input	electrical
OUT	Output	electrical
REF	Reference Voltage (opv_supply only)	electrical
VPP	Positive Supply Voltage (opv_supply only)	electrical
VNN	Negative Supply Voltage (opv_supply only)	electrical

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Parameters

Table 2

Name	Description [Unit]	Data Type
AD	Differential Gain [V/V]	real
VOMAX	Maximum Output Voltage, only OPV without supply pin [V]	real
VOMIN	Minimum Output Voltage, only OPV without supply pin [V]	real
VIOFF0	Input-Offset-Voltage at Reference Temperature [V]	real
INN	Input Quiescent Current at Negative Input [A]	real
INP	Input Quiescent Current at Positive Input [A]	real
RD	Differential Input Resistance [Ohm]	real
RO	Output Resistance [Ohm]	real
CMRR	Common Mode Rejection Ratio [dB]	real
PSRR	Power Supply Rejection [dB]	real
TEMP	Temperature [°C]	real
TEMP0	Reference Temperature [°C]	real
COEFF_VIOFF	Temperature coefficient of VIOFF [V/K]	real
LDK	Long Term Drift Coefficient [V/h]	real
VDELTA	Min. Difference to Supply Voltage, OPV	real

	without supply [V]	
VNSUPPLY	Noise at Supply Voltage, OPV without supply [V]	real
F_TR	Transit Frequency [Hz]	real
SR	Voltage Slew Rate [V/s]	real

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
VD	Differential Input Voltage [V]	Output	real
VCM	Common Input Voltage [V]	Output	real
VOUT_IDEAL	Ideal Output Voltage without Limitation [V]	Output	real

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Example of OPV5

In this example, the Dynamic OPV model is used to form a voltage follower and an inverse amplifier. The schematic of the example is shown in Figure 4, system parameters are listed in Table 4, and the simulation results are shown in Figure 5 and 6. Notice that in Figure 5, the input and output voltages of the voltage follower overlaps each other, and in Figure 6, the output current is 0.001 (which is the ratio between the input and output resistance R_3/R_{out2}) of the input current.

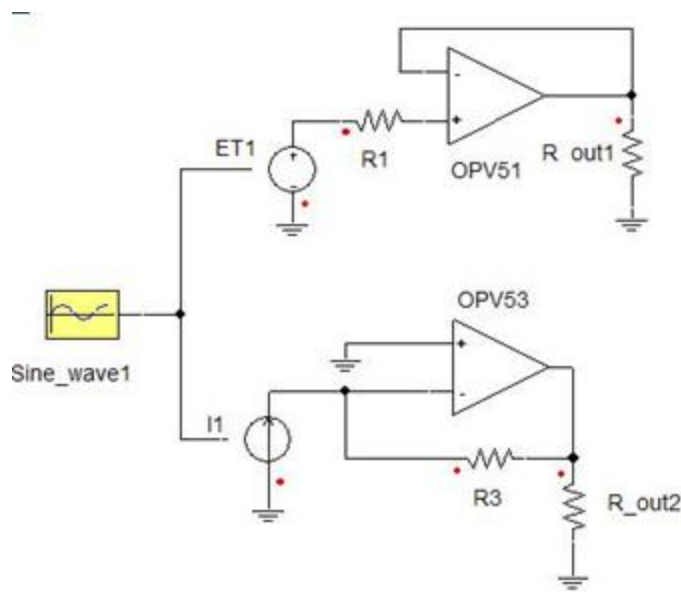


Figure 4. Application example of the dynamic OPV model

Table 4. System Parameters

Component	Parameter	Value [unit]
Resistor R1/R_out1	R	10k [Ohm]
Resistor R3	R	1 [Ohm]
Resistor R_out2	R	1k [Ohm]
Sine Wave Sine_wave1	AMPL	8 [V]
	FREQ	60k [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [V]
Voltage Source ET1	EMF	Sine_wave1.val
Current Source I1	IS	Sine_wave1.val

* All the parameters of the Dynamic OPV model OPV51 and OPV53 use their default values, therefore they are not included in the parameter table.

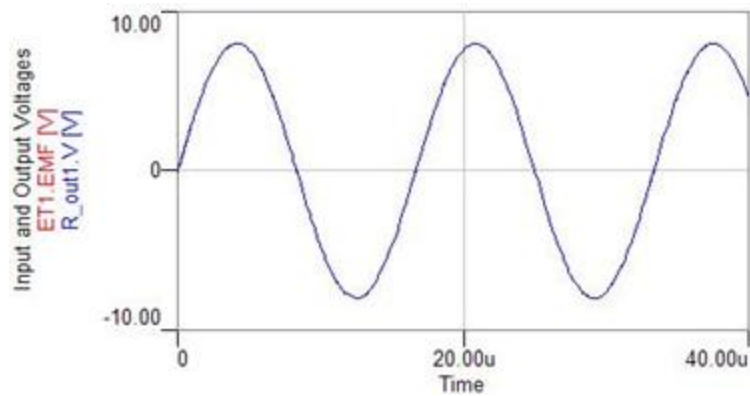


Figure 5. Simulation results-input and output voltage of OPV51

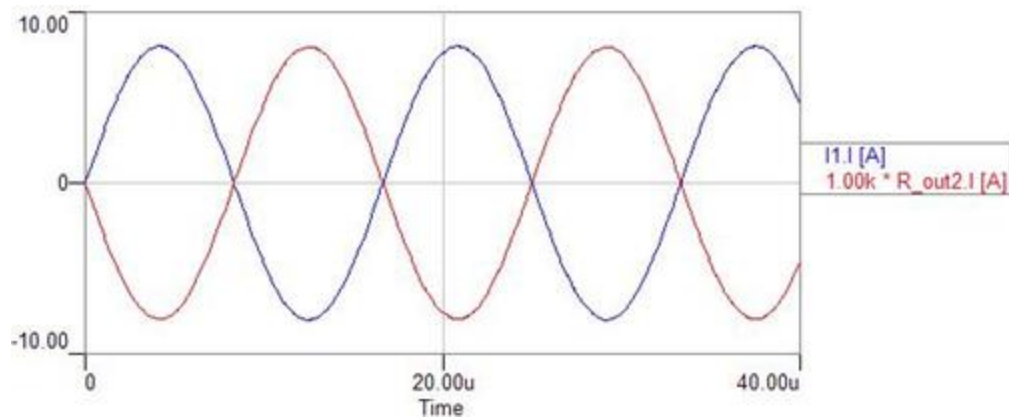


Figure 6. Simulation results-input and output current of OPV53

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References

[1] Ned Mohan, Tore M. Undeland, William P. Robbins, "Power Electronics: Converters, Applications, and Design". John Wiley & Sons, INC. New York, 1995.

Dynamic Thyristor Model (Device Characterization-Compatible Model)

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

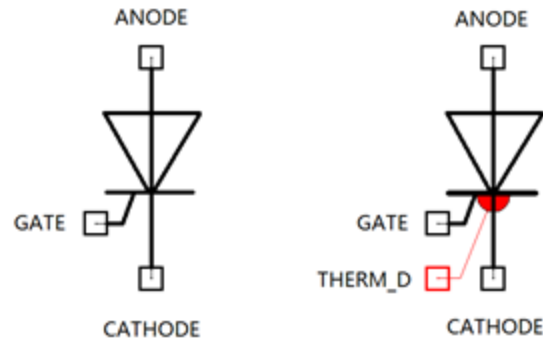


Figure 1. Component symbol

- [Description](#)
- [Assumptions and Limitations](#)
- [Mathematical Description](#)
- [Conservative Pins](#)
- [Parameters](#)
- [Output Quantities](#)
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Description

The thyristor model is a modular model with definable simulation levels. Different simulation depths or levels can be selected for the electrical and thermal behavior of the model. Each level combination has a certain set of active parameters. The values for them can be defined in the component dialog box.

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Assumptions and Limitations

The model is a combination of a sub circuit representation using lumped components and current or voltage sources that generate the effects of distributed charge storage and charge displacement. It can be used to simulate for

- Forward DC characteristic respectively DC power losses in the conduction mode
- A simplified ignition process
- Reverse recovery effect at the off switch transient

- Thermal punch through in the blocking mode
- Reverse saturation current
- Delay and storage times at transient operation
- dV/dt ignition or dV/dt sensitivity

An RC- snubber circuit is included in the model. The break through processes are simplified to a limit watching and a transition from the normal model to a conductive state after break through.

Currently only the digital ignition is available. So the gate circuit impact is not taken into consideration. But simple gate signal delay and gate thresholds are implemented with digital ignition.

The transition from blocking to conducting mode is managed by activation of the non linear bulk resistance R_BB. With active R_BB the model behaves like a diode including its true reverse recovery behavior.

The thyristor model can be used to simulate inductive power line rectifier and inverter applications, power converter circuit and any drive application which may be sensitive to the thyristor reverse recovery effect and dv/dt issues.

The model use for gate driver development is restricted because the real electrical behavior of the gate circuit is not yet provided.

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Mathematical Description

In forward conduction mode the DC voltage drop is due to the serial circuit of Diode D and the nonlinear bulk resistance

$$U_{th} = mU_T \ln\left(\frac{I_{th}}{I_s} + 1\right) + R_{BB}(I_{th})I_{th}$$

with m: emission coefficient M0 , I_s : Saturation current ISAT0, U_T : temperature voltage kT/q .

The capacitance model shows depletion mode in reverse and blocking mode. The magnitude of depletion can be controlled by the according capacitance parameters. In case of conduction mode after ignition the diffusion capacitance $C_D(I)$ dominates the semiconductor capacitance and enhancement mode is not modeled. For more detailed information see diode model.

Electrical Model

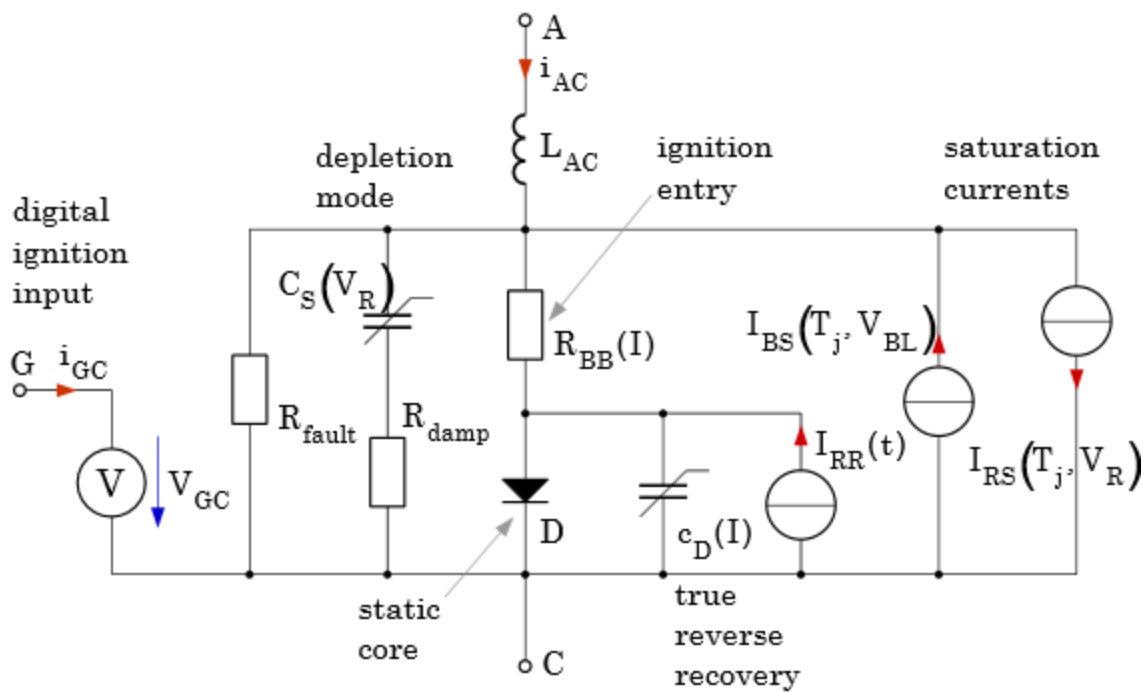


Figure 2. Electrical equivalent circuit used by the Thyristor model

Figure 2 shows the electrical equivalent circuit used by the Thyristor model.

Temperature, Voltage, and Current Dependencies

The model parameters may depend on junction temperature, terminal voltage and current. For the representation of these dependencies three groups of parameters were introduced:

- Coefficients for temperature dependencies. The names of these parameters start with TC
- Coefficients for voltage dependencies. The names of these parameters start with VC
- Coefficients for current dependencies. The names of these parameters start with CC

Two different functions are used to model the dependencies. The dependency on a working point value z (temperature, voltage, current, current slope, voltage slope) is expressed by the coefficient in the following way (where $y = f(z)$ is the original function and c stands for TC, VC, or CC):

Linear Dependency:

$$y = y_{base} + c \cdot (z - z_{base})$$

Exponential Dependency:

$$y = y_{base} \left(\frac{z + z_{offset}}{z_{base} + z_{offset}} \right)^{(c + c_{offset})}$$

All working point dependency function guarantee meaningful parameter values when the working point conditions approach zero and provide a good guess for extrapolation if the actual

working point (temperature, voltage, current, current slope, voltage slope) exceed the expected range.

Some parameters have more than one coefficient. In this case the individual terms are multiplied. The reference values of temperature, voltage and current are always T_{NOM} , V_{NOM} , I_{NOM} D_{INOM} and D_{VNOM} , respectively.

Thermal Semiconductor Model

The structure of the thermal model is shown in Figure 3. Power loss PEL is calculated inside the thyristor model and injected to the thermal model. Junction temperature rise can be simulated using the Forster or the Cauer model depending on the $TYPE\_THERM$ settings. A simple internal heat sink is provided but an external heat sink representation can be connected at a heat pin. Four thermal stages are enough for accurate thermal simulation. Different number of known stages can be recalculated to the circuit according to Figure 3.

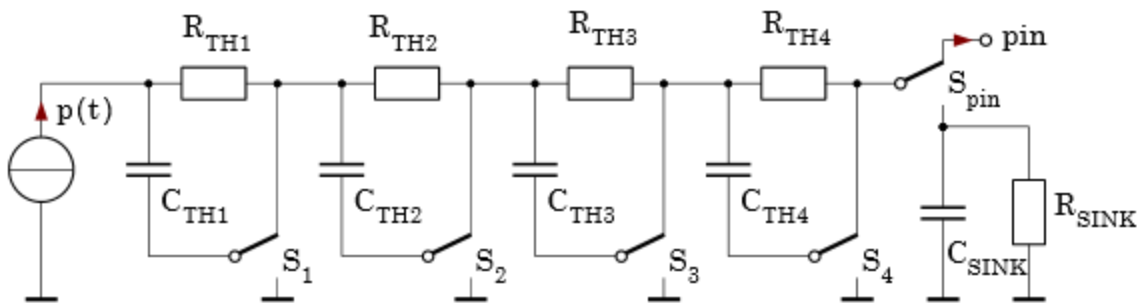


Figure 3: Thermal net

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
ANODE	Anode	electrical
CATHODE	cathode	electrical
GATE	gate	electrical
THERM_D*	die bottom thermal contact	thermal

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Parameters

Table 2. General Parameters

Name	Description	Data Type
TYPE_THERM	Thermal Flags xx0: isothermal, constant junction temperature xx1: dynamic thermal x0x: partial fractional thermal network x1x: continued fractional thermal network 0xx: temperature output in dT (rise only) 1xx: temperature output in Celsius 2xx: temperature output in Kelvin (must use this setting for external thermal pin)	real
TYPE_DYN	Modeling Flags xxxx0: static xxxx1: dynamic but no Irr xxxx2: dynamic with exponential Irr xxxx3: dynamic with linear Irr xxx1x: external synchronization x00xx: no ignition (diode) x01xx: digital ignition 0xxxx: disable model's internal RC snubber circuit 1xxxx: use model's internal RC snubber circuit	real

Table 3. Gate Ignition Condition Parameters (TYPE_DYN=x01xx)

Name	Description	Data Type
VTRG	minimum forward voltage across GC to enable ignition [A]	real
VBLM	minimum blocking voltage across AC to enable ignition [A]	real
IHOLD	minimum forward current (holding current) [A]	real
TD_G	digital ignition delay time [s]	real
TQ	reverse voltage charge free time (turn-off time) [s]	real

Table 4. Nominal Condition Parameters (static; TYPE_DYN= xxxx0)

Name	Description	Data Type
VNOM	Nominal Collector-Emitter Voltage [V]	real
INOM	Nominal Collector Current [A]	real
TNOM	Reference Temperature [°C]	real
DINOM	nominal di/dt at Irr zero crossing [A/s]	real
DVNOM	nominal du/dt in blocking mode [V/s]	real

Table 5. DC Model Parameters (static; TYPE_DYN= xxxx0)

Name	Description	Data Type
M0	forward ideality factor	real
ISAT0	forward saturation current [A]	real
RB0	bulk resistance [Ohm] at I=INOM, kappa=1, t->inf	real
RATIO	linearity ratio	real
KAPPA	non-linearity coefficient	real
RP0	parallel forward resistance [Ohm]	real
RR0	reverse resistance [Ohm]	real
ISREV	reverse mode saturation current [A]	real
MREV	reverse mode ideality factor	real
ISBL	blocking mode saturation current [A] (for future use)	real
MBL	blocking mode ideality factor (for future use)	real
TC_M	temperature coefficient of M0	real
TC_IS	temperature coefficient of ISAT0	real
TC_RB	temperature coefficient of RB0	real
TC_RATIO	temperature coefficient of RATIO	real
TC_KAPPA	temperature coefficient of KAPPA	real
TC_ISR	temperature coefficient of ISREV	real
VC_ISR	voltage coefficient of ISREV	real
TC_ISB	temperature coefficient of ISBL (for future use)	real
VC_ISB	voltage coefficient of ISBL (for future use)	real

Table 6. Charging Spreading Parameters (static; TYPE_DYN= xxxx0)

Name	Description	Data Type
A_SPREAD	ignition area ratio	real
TAU_SPREAD	ignition charge spreading time [s]	real
E_SPREAD	spreading time exponent 0.2 .. 2	real
TC_TAU_SPREAD	temperature coefficient of TAU_SPREAD	real
TC_E_SPREAD	temperature coefficient of E_SPREAD	real

Table 7. Limits and Break Through Parameters (static; TYPE_DYN= xxxx0)

Name	Description	Data Type
VBLOCK	maximum DC blocking voltage [V]	real
VBREAK	maximum reverse voltage [V]	real
IBREAK	break through current [A]	real
TBREAK	temperature punch through limit [C]	real
RFAULT	fault resistor [Ohm]	real

Table 8. Dynamic Model Parameters (TYPE_DYN= xxxj, j=1..3; include static parameters)

Name	Description	Data Type
CNULL	zero voltage reverse capacitance [F]	real
VSHIFT_R	blocking voltage shift [V]	real
VDIFF_R	blocking diffusion voltage [V]	real
ALPHA_R	blocking capacity exponent	real
DELTA_R	blocking capacity minimum factor	real
R1	reverse recovery waveform factor 1	real
R2	reverse recovery waveform factor 2	real
R3	reverse recovery waveform factor 3	real
SF1	reverse recovery soft factor 1	real
SF2	reverse recovery soft factor 2	real
TAU	effective lifetime [s]	real
DAMPING	relative damping factor	real
L_AK	device stray inductance [H]	real
TC_TAU	temperature coefficient of TAU	real
CC0_TAU	lower current coefficient of TAU	real

Name	Description	Data Type
CC_TAU	higher current coefficient of TAU	real
VC0_TAU	lower reverse voltage coefficient of TAU	real
VC_TAU	higher reverse voltage coefficient of TAU	real
TC_SF2	temperature coefficient of SF2	real
CC0_SF2	lower current coefficient of SF2	real
CC_SF2	higher current coefficient of SF2	real
TC_DELTAS	temperature coefficient of DELTA_R	real

Table 9. Thermal Parameters

Name	Description	Data Type
TAMB	ambient temperature [C]	real
TJNCT0	initial junction temperature [C]	real
CTH_SINK	heat sink capacitance [Ws/K]	real
RTH_SINK	heat sink resistance [K/W]	real
CTH1	1st thermal (junction) capacitance [Ws/K]	real
RTH1	1st thermal resistance [K/W]	real
CTH2	2nd thermal capacitance [Ws/K]	real
RTH2	2nd thermal resistance [K/W]	real
CTH3	3rd thermal capacitance [Ws/K]	real
RTH3	3rd thermal resistance [K/W]	real
CTH4	4th thermal capacitance [Ws/K]	real
RTH4	4th thermal resistance [K/W]	real

Table 10. Model Built-in Snubber Circuit Parameters (TYPE_DYN=1xxxx)

Name	Description	Data Type
CSN	snubber capacitance [F]	real
RSN	snubber resistance [ohm]	real

Output quantities

Table 11. Model Outputs

Name	Description [Unit]
I	current through thyristor[A]
V	voltage across thyristor [V]
I_RR	reverse recovery injection current [A]
CJNCT	semiconductor junction capacity [F]
RS_DAMP	serial damping resistor [Ohm]
QDIFF	diffusion charge [As]
CDIFF	diffusion capacity [F]
QRREC	reverse recovery charge [As]
ITRG_C	ignition current contribution by du/dt [A]
ITRG_IS	Ig by blocking mode leakage current [A]
ITRG_PN	Ig by regular current injection [A]
ITRG_SUM	ignition current total value [A]
IG	gate to cathode current, ignition current [A]
T_JNCT	Tj at 1st thermal stage input [grdC or K]
T_INNER	Ti at 2nd thermal stage output [grdC or K]
T_CASE	Tc at 4th thermal stage output [grdC or K]
PEL	power loss [W], injected to thermal model
PCOND	conduction power loss [W] (for future use)
PCONV	convection power loss [W] (for future use)
PRAD	radiation power loss [W] (for future use)
ESWITCH	energy per switch [Ws]
PSWITCH	switching power loss [W]
ETOT	total loss energy [Ws]
PTOT	mean power loss [W]
DELTA_T	time step size [s]
STEP_CLOCK	the step size depicted like a digital clock
FAULT_VR	voltage fault flag
FAULT_I	current fault flag
FAULT_TJ	junction temperature fault flag
FAULT_VB0	zero current blocking voltage fault flag
FAULT_TQ	thyristor protection fail flag

Name	Description [Unit]
tPROTECT	thyristor protection time [s]
IACT	actual load current [A]
VACT	actual reverse voltage [V]

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References

[1] Ned Mohan, Tore M. Undeland, William P. Robbins, "Power Electronics: Converters, Applications, and Design." John Wiley & Sons, INC. New York, 1995.

Dynamic Thyristor Model (Legacy Dynamic Model)

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

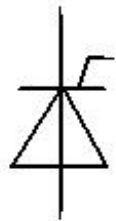


Figure 1. Component symbol

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- [Netlist Syntax](#)
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Description

The static behavior of the model (normal mode and reverse operation) is determined by static diode models and current-controlled current sources. The dynamic behavior is determined by nonlinear capacitances (junction and diffusion capacitances).

All diode models use an exponential characteristic with the same value of saturation current defined by the model parameter IS (see figure below). The emission coefficients NF and NR affect the thermal voltages of the internal diode models. NF affects the diodes at the Anode and Cathode; NR is used for the diodes DMPNP and DMNPN, which model the reverse operation mode of the thyristor.

For all current amplification factors in common mode constant values are used. The current amplification of ITCNNPN is adjustable by the parameter K. Recommended values for K are in the range of 0,01 to 0,5.

Due to the short time constants of the systems, a small value of the minimum step size (usually some nanoseconds) should be set. In the following the influences of the parameters on the model behavior are listed:

Table 1

Modification	Element	Effect
Increase of TT1	CNL_DIDA	Increase of current rise time Increase of peak reverse current
Increase of CJO1	CNL_SPDA	Increase of gate-controlled delay time
Increase of TT2	CNL_DIDMP, CNL_DIDMN	Increase of critical hold-off interval
Increase of CJO2	CNL_SPDMP, CNL_SPDMN	Decrease of gate-controlled delay time
Increase of TT3	CNL_DIDC	Increase of current rise time
Increase of CJO3	CNL_SPDC	Increase of gate-controlled delay time
Increase of K	ICNNPN	Increase of igniting current

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Assumptions and Limitations

The model does not consider the influence of critical rates of change in voltage and current in the outer circuit on the switching behavior of the thyristor.

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Mathematical Description

The equivalent circuit used for this model is shown in Figure 2.

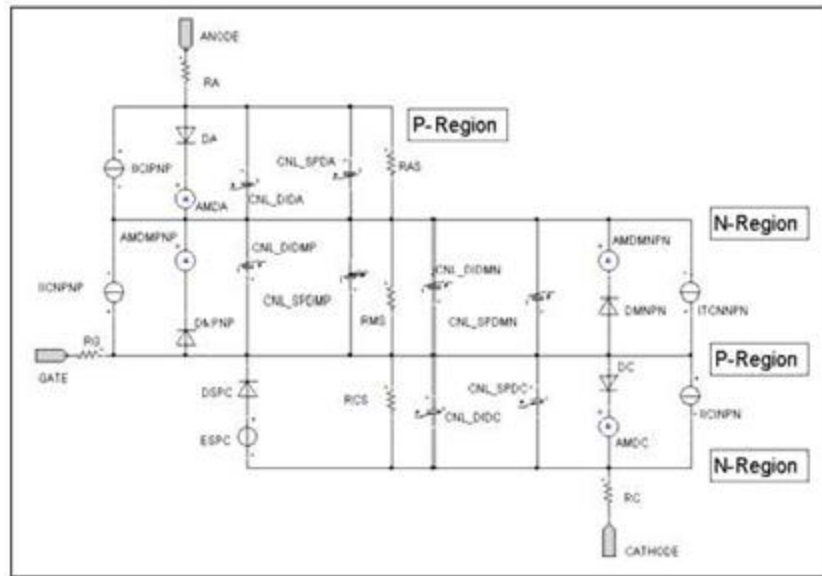


Figure 2. Equivalent circuit the Dynamic Thyristor Model

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Netlist Syntax

```
MODEL THY4 ?InstanceName(@InstanceName):(@Refbase)@ID) ANODE:= %0, GATE:= %1, CATHODE:= %2 ( IS:= @IS, NF:= @NF, NR:= @NR, TT1:= @TT1, TT2:= @TT2, TT3:= @TT3, CJO1:= @CJO1, CJO2:= @CJO2, CJO3:= @CJO3, RA:= @RA, RG:= @RG, RC:= @RC, K:= @K) SRC: DB(Lib:=@ModelLibraryName);
```

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Conservative Pins

Table 2

Name	Port/Terminal Description	Nature/Data Type
ANODE	Anode Pin	electrical
GATE	Gate Pin	electrical
CATHODE	Cathode Pin	electrical

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Parameters

Table 3

Name	Description	Data Type	Default Value [Unit]
IS	Saturation Current, static parameter	real	10f [A]
NF	Forward Emission Coefficient, static parameter	real	1.5
NR	Reverse Emission Coefficient, static parameter	real	1
RA	Bulk Resistance Anode, static parameter	real	1m [Ohm]
RG	Bulk Resistance Gate, static parameter	real	5m [Ohm]
RC	Bulk Resistance Cathode, static parameter	real	1m [Ohm]
K	Amplification Factor, static parameter	real	1
TT1	Carrier lifetime, dynamic parameter	real	10u [s]
TT2	Carrier lifetime, dynamic parameter	real	0.5u [s]
TT3	Carrier lifetime, dynamic parameter	real	50n [s]
CJO1	Junction Capacitance, dynamic parameter	real	10n [F]
CJO2	Junction Capacitance, dynamic parameter	real	25n [F]
CJO3	Junction Capacitance, dynamic parameter	real	12u [F]

Typical parameter values and characteristic values for thyristors of different ratings are:

Table 4

Parameter	Nominal current		
	25A	100A	1500A
IS	1*E-14	1*E-14	1*E-3
NF	1,5	1,5	1,5
NR	1	1	1
TT1	100*E-9	300*E-9	300*E-9
TT2	25*E-9	200*E-9	200*E-9
TT3	10*E-9	50*E-9	1500*E-9
CJ01	10*E-9	1*E-9	10*E-9
CJ02	1*E-9	1*E-9	1*E-9
CJ03	40*E-9	40*E-9	100*E-9
RA	1*E-3	1*E-3	1*E-3
RG	5*E-3	5*E-3	7,5
RC	1*E-3	10*E-6	10*E-6
K	0.01	0.03	0.25
Igniting current [mA]	60	80	400
Holding current [mA]	55	110	800
Igniting voltage [V]	1.4	1.4	3.6
Forward voltage [V]	1.9	1.9	2.3

Turn-on time [ms]	1.1	1.1	1.1
Current rise time [ms]	0.15	0.45	4.5

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Example

In this example, the Dynamic Thyristor model is used to form an H-Bridge converter. The control voltage are sent out by Trapezoidal voltage sources. The schematic of the example is shown in Figure 3, system parameters are listed in Table 5, and the simulation results are shown in Figure 4-6.

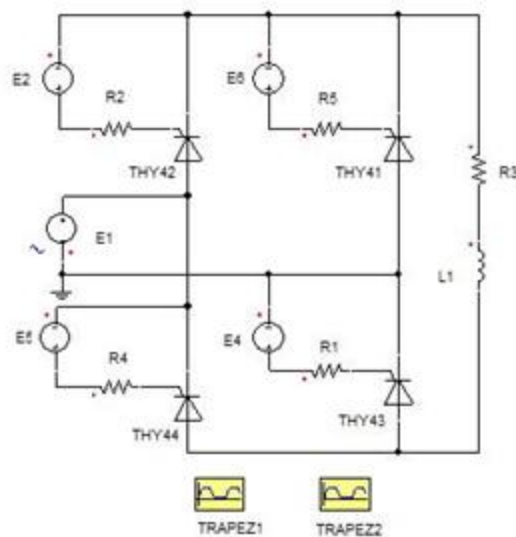


Figure 3. Application example of the Dynamic Thyristor model

Table 5. System Parameters

Component	Parameter	Value [unit]
Resistor R1/R2/R4/R5	R	5 [Ohm]
Resistor R3	R	10 [Ohm]
Inductor L1	L	1m [H]
	I0	0 [A]
Trapezoidal Wave TRAPEZ1	AMPL	50

	TPERIO	20m [s]
	TDELAY	2.5m [s]
	PHASE	0 [degree]
	OFF	0 [V]
	TRISE	100u [s]
	TFALL	100u [s]
	PWIDTH	2m [s]
Trapezoidal Wave TRAPEZ2	AMPL	50
	TPERIO	20m [s]
	TDELAY	12.5m [s]
	PHASE	0 [degree]
	OFF	0 [V]
	TRISE	100u [s]
	TFALL	100u [s]
	PWIDTH	2m [s]
Voltage Source E2/E4	EMF	TRAPEZ1.VAL
Voltage Source E5/E6	EMF	TRAPEZ2.VAL
Voltage Source (Sine) E1	AMPL	0.326k [V]
	FREQ	100 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]

	OFF	0 [V]

* All the parameters of the Dynamic Thyristor models in this example use their default values, therefore they are not included in the parameter table.

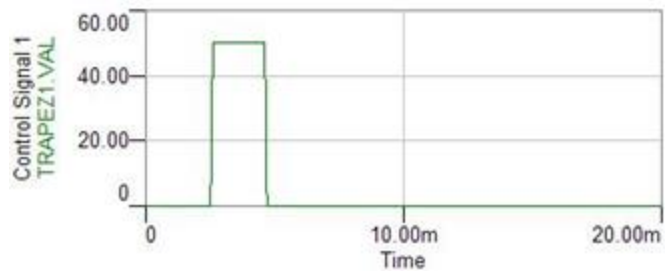


Figure 4. Simulation result-control signal for THY42 and THY43

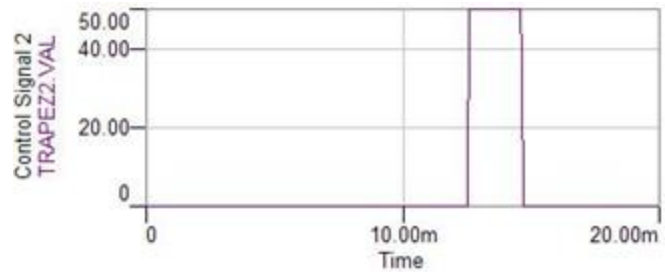


Figure 5. Simulation result-control signal for THY44 and THY41

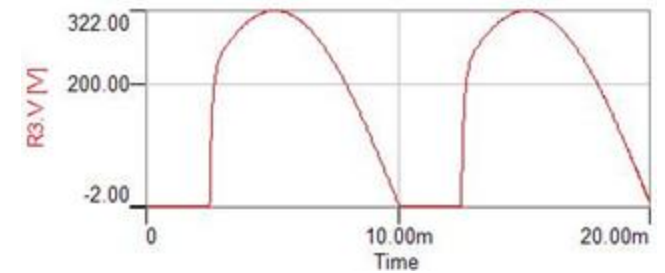


Figure 6. Simulation result-voltage across the load resistor R3

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References

[1] Ned Mohan, Tore M. Undeland, William P. Robbins, "Power Electronics: Converters, Applications, and Design." John Wiley & Sons, INC. New York, 1995.

Gate Driver

- [Gate_Driver_V](#)

Voltage Source Gate Driver

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

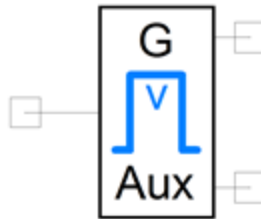


Figure 1. Component Symbol

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Description

The Gate_Driver_V is a controlled voltage source to drive voltage-driven power semiconductor components in Twin Builder, including generic or characterized IGBTs, MOSFETs, etc. It transfers switching control signal to user-specified on/off gate voltage and has built-in configurable RLC elements.

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Assumptions and Limitations

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Mathematical Description

The model uses an equivalent circuit as shown in Figure 2.

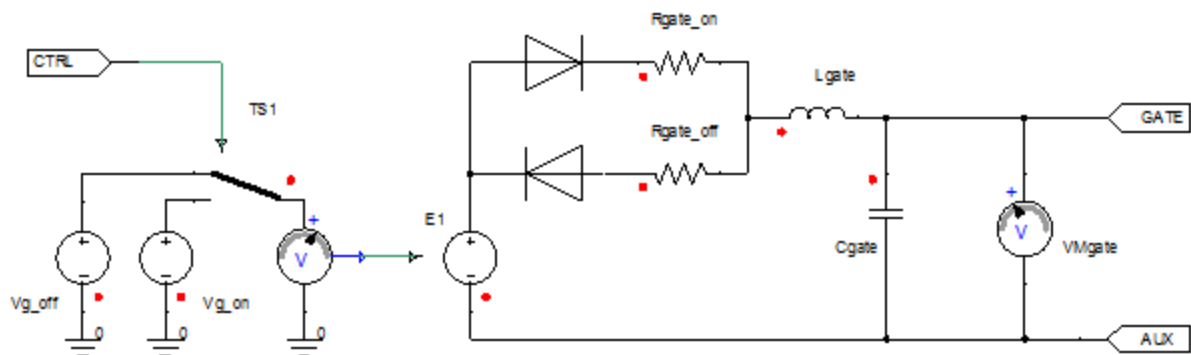


Figure 2. Equivalent circuit of gate driver

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Netlist Syntax

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Conservative Pins

Table 1

Name	Description	Nature
GATE	Gate voltage supply	electrical
AUX	Reference pin for gate voltage, connect to AUX_ pin of device level semiconductor components	electrical

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Parameters

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
CTRL	Switching control	Input	real
Vg_on	On gate voltage	Input	real
Vg_off	Off gate voltage	Input	real
Rgate_on	On gate resistance (external)	Input	real
Rgate_off	Off gate resistance (external)	Input	real
Lgate	Gate inductance (external)	Input	real
Cgate	Gate capacitance (external)	Input	real
SYNC	E1.EMF of equivalent circuit in Figure 2. Suitable for setting the SYNC signal in device level IGBT and MOSFET models.	Output	real
VG	VMgate.V in equivalent circuit in Figure 2. So user can directly plot gate voltage without adding external meter at gate.	Output	real

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Example

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References

Semiconductors System Level

- Bipolar Junction Transistor (BJT))
- Diode (D)
- GTO-Thyristor (GTO)
- IGBT (IGBT)
- MOS Field Effect Transistor (MOS)
- Thyristor (TH)
- TRIAC (TRIAC)

Bipolar Junction Transistor

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

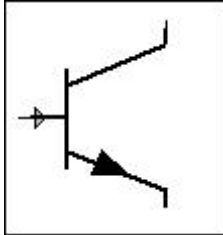


Figure 1. Component symbol

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Description

The System level BJT (Bipolar Junction Transistor) is used to simulate a static voltage-current-relation. Each voltage causes a corresponding current depending on the selected characteristic and the applied control signal.

The predefined output characteristics defined in the component dialog guarantee a high calculation speed. Besides the predefined characteristic types (equivalent line, exponential function, lookup table) other user-defined characteristics can also be used. Usually an Equivalent line, Exponential function, Hyperbolic function, Polynom or the XY Lookup Table should be used. Characteristics based on XY-Data pairs allow simple access to measured curves for the switching behavior of the components.

To control the BJT apply a logical signal. This signal can originate from any Twin Builder system variable.

Control Signal (Base Current)	Component State
> 0	ON

≤ 0	OFF

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Assumptions and Limitations

This component models a static voltage-current-relation of the BJT. Therefore, the dynamic behaviors are not taken into account.

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Mathematical Description

The static output voltage-current-relation of the BJT model can be described as:

$$v(t) = f(i(t), [\text{control signal}])$$

where f is the characteristics specified by users.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
C	Collector	electrical
E	Emitter	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
CH	Characteristic; BJT	real	--
CTRL	Control Signal; All components	real	0
VF	Forward Voltage; BJTEQUL	real	0.8 [V]
RB	Bulk Resistance; BJTEQUL	real	1m [Ohm]
RR	Reverse Resistance;	real	100k [Ohm]

	BJTEQUL/BJTEXP		
ISAT	Saturation Current; BJTEXP	real	1p [A]
VT	Thermal Voltage; BJTEXP	real	35m [V]
FILE	Characteristic; BJTXY	file	--

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
V	Voltage [V]	Output	real
I	Current [A]	Output	real
G	Conductivity [S]	Output	real
DV	Derivative of Voltage [V/s]	Output	real
DI	Derivative of Current [A/s]	Output	real

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Example

This example demonstrates the usage of BJT models in an H-bridge inverter. The characteristics of the BJTs are defined by the internal equivalent lines; while those of the diodes are specified by an external exponential function EXP1. The control signals for the BJTs are decided by a state diagram; a bang-bang controller is used to force the load current to track the current reference. The current reference and the bandwidth of the current controller are defined in the Equation block FML1. The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the simulation results are shown in Figure 4.

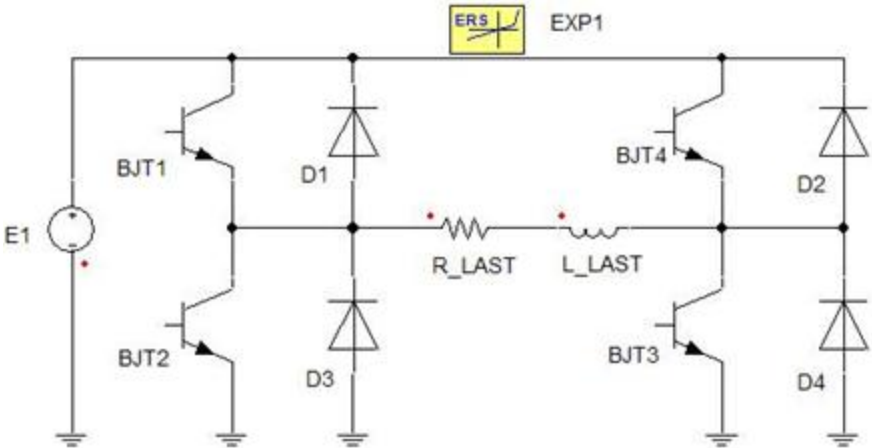


Figure 2. Application example of the System Level BJT model

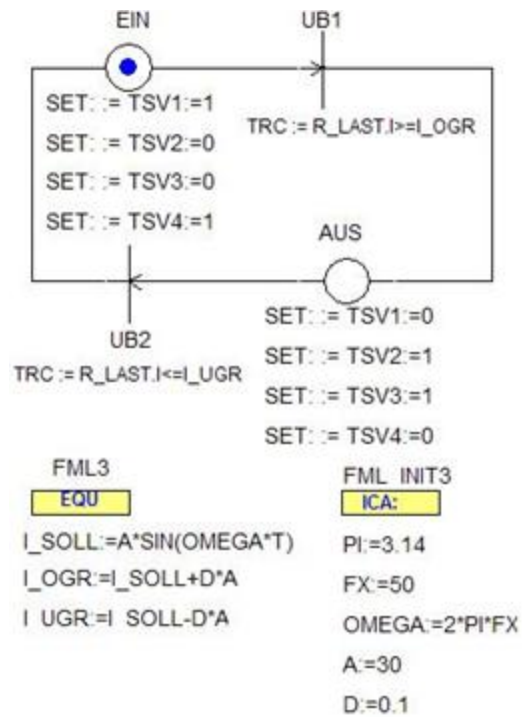


Figure 3. Bang-bang current controller

Table 4. System Parameters

Component	Parameter	Value [unit]
BJT(Equivalent Line) BTJ1/BTJ3	CTRL	TSV1
	VF	0.8 [V]
	RB	1m [Ohm]
	RR	100k [Ohm]
BJT(Equivalent Line) BTJ2/BTJ4	CTRL	TSV2
	VF	0.8 [V]
	RB	1m [Ohm]
	RR	100k [Ohm]

Diode D1/D2/D3/D4	CH	EXP1
Resistor R_LAST	R	2 [Ohm]
Inductor L_LAST	L	10m [Ohm]
	I0	0 [A]
Voltage Source E1	EMF	200 [V]
Exponential Function EXP1	VF	0.8 [V]
	RB	1m [A]
	RR	100k [Ohm]

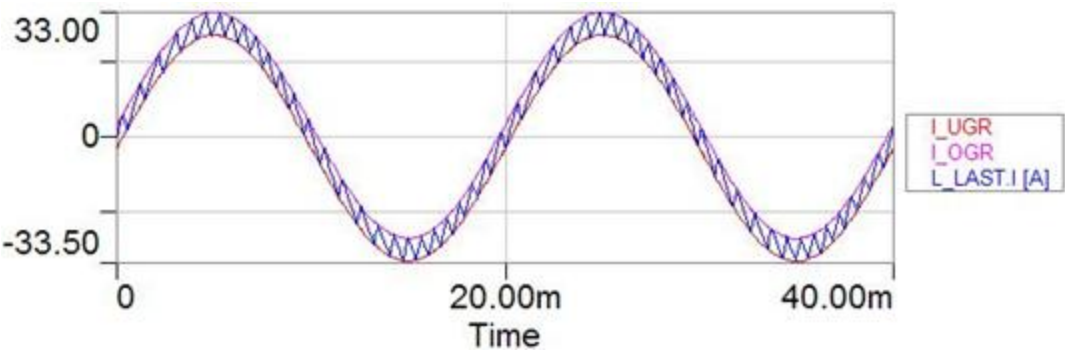


Figure 4. Simulation results-reference current bands and the resulting load current

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References

[1] Ned Mohan, Tore M. Undeland, William P. Robbins, “Power Electronics: Converters, Applications, and Design”. John Wiley & Sons, INC. New York, 1995.

Diode

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

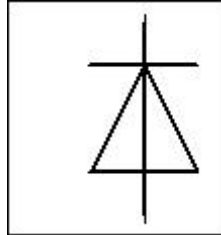


Figure 1. Component symbol

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- [Mathematical Description](#)
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Description

The system level Diode model is used to simulate a static voltage-current-relation. Each voltage causes a corresponding current depending on the selected characteristic.

The predefined output characteristics defined in the component dialog guarantee a high calculation speed. Besides the predefined characteristic types (equivalent line, exponential function, lookup table) other user-defined characteristics can also be used. Characteristics based on Lookup tables allow simple access to measured curves for the switching behavior of the components.

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Assumptions and Limitations

This component models a static voltage-current-relation of the diode. Therefore, the dynamic behaviors, such as charge storage effect, are not taken into account.

NOTE: The SML diode is limiting - i.e., above a certain maximum voltage value, current is calculated via linear interpolation above the maximum current. Currently, the criteria checks for $V > VT \cdot \log(100000 \cdot VT / ISAT)$. Above this value, the current is limited to $I = ISAT / VT \cdot \exp(VLim / VT)$

$(V - V_{Lim}) + ISAT \cdot (\exp(V_{Lim}/V_T) - 1.0)$, where $V_{Lim} = V_T \cdot \log(100000 \cdot V_T / ISAT)$). Otherwise, current is calculated normally as $I = ISAT \cdot (\exp(V/V_T) - 1.0)$.

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Mathematical Description

A static output voltage-current-relation is used for this component.

$$v(t) = f(i(t))$$

where f is the characteristics specified by users.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
A	Anode	electrical
C	Cathode	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
CH	Characteristic; D	Real	--
VF	Forward Voltage; DEQUL	Real	0.8 [V]
RB	Bulk Resistance; DEQUL	Real	1m [Ohm]
RR	Reverse Resistance; DEQUL/DEXP	Real	100k [Ohm]

ISAT	Saturation Current; DEXP	Real	1p [A]
VT	Thermal Voltage; DEXP	Real	35m [V]
FILE	Characteristic; DXY	File	--

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
V	Voltage [V]	Output	real
I	Current [A]	Output	real
G	Conductivity [S]	Output	real
dV	Derivative of Voltage [V/s]	Output	real
dI	Derivative of Current [A/s]	Output	real

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Example

In this example, an equivalent line is used to define the characteristics of the Diode DEQUL1. At the beginning of the simulation, DEQUL1 blocks the ESINE1 from the R//L circuit during the first half cycle of the sinusoidal voltage output of ESINE1; in the second half cycle, DEQUL1 is conducted when it becomes positive biased, and the Inductor L1 gets charged by ESINE1. The remaining current in the Inductor L1 (i_L) continues to flow through DEQUL1 even when the output voltage of ESINE1 enters the positive cycle; DEQUL1 remains conducted till i_L attenuates to 0A. The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the simulation results are shown in Figure 3 and 4.

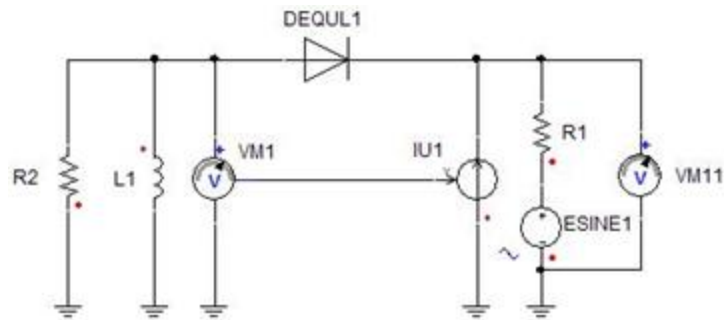


Figure 2. Application example of the System Level Diode model

Table 4. System Parameters

Component	Parameter	Value [unit]
Voltage Source (sinusoidal) ESINE1	AMPL	3000 [V]
	FREQ	50 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [V]
Resistor R1	R	0.1m [Ohm]
Resistor R2	R	1e-6 [Ohm]
Inductor L1	L	1e-9 [H]
	I0	0 [A]
Diode (equivalent line) DEUQL1	VF	0.8 [V]
	RB	1m [Ohm]
	RR	100k [V]

Controlled Current Source (Voltage-Controlled) IU1	QUANT	VM1.V
	FACT	1

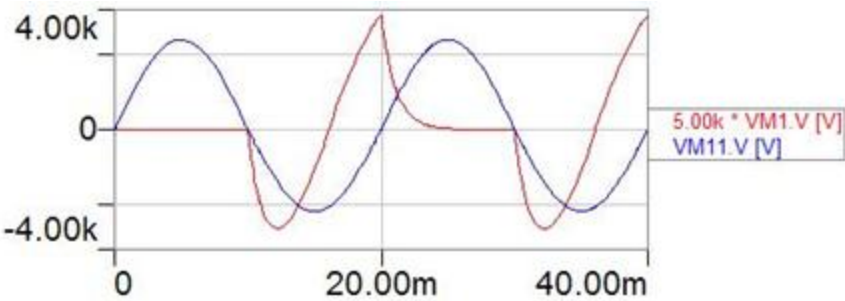


Figure 3. Simulation results

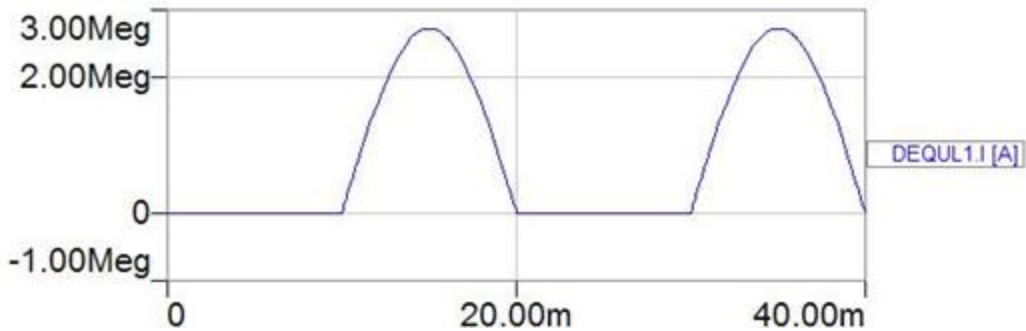


Figure 4. Simulation results

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References

[1] Ned Mohan, Tore M. Undeland, William P. Robbins, "Power Electronics: Converters, Applications, and Design." John Wiley & Sons, INC. New York, 1995.

GTO-Thyristor

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

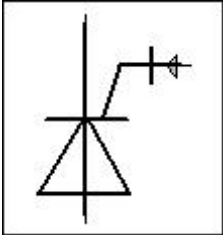


Figure 1. Component symbol

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- [Mathematical Description](#)
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- [Parameters](#)
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Description

The System level GTO-Thyristor is used to simulate a static voltage-current-relation. Each voltage causes a corresponding current depending on the selected characteristic and the applied control signal. The predefined output characteristics defined in the component dialog guarantee a high calculation speed. Besides the predefined characteristic types (equivalent line, exponential function, lookup table) other user-defined characteristics can also be used. Usually an Equivalent line, Exponential function, Hyperbolic function, Polynom or the XY Lookup Table should be used. Characteristics based on XY-Data pairs allow simple access to measured curves for the switching behavior of the components.

To control the GTO-Thyristor, apply a logical signal. This signal can originate from any Twin Builder system variable.

Control Signal (Ignition Current)	Component State
> 0	ON, if $v(t) > V_F$

≤ 0	OFF

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Assumptions and Limitations

This component models a static voltage-current-relation of GTO-Thyristor. Therefore, the dynamic behaviors are not taken into account.

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Mathematical Description

The static output voltage-current-relation of the GTO-Thyristor model can be described as:

$$v(t) = f(i(t), [\text{control signal}])$$

where f is the characteristics specified by users.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
A	Anode	electrical
C	Cathode	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
CH	Characteristic; GTO	real	--

CTRL	Control Signal; All components	real	0
VF	Forward Voltage; GTOEQUL	real	0.8 [V]
RB	Bulk Resistance; GTOEQUL	real	1m [Ohm]
RR	Reverse Resistance; GTOEQUL/GTOEXP	real	100k [Ohm]
ISAT	Saturation Current; GTOEXP	real	1e-12[A]
VT	Thermal Voltage; GTOEXP	real	35m [V]
FILE	Characteristic; GTOXY	file	--

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
V	Voltage [V]	Output	real
I	Current [A]	Output	real
	Conductivity [S]	Output	real
DV	Derivative of Voltage [V/s]	Output	real
DI	Derivative of Current [A/s]	Output	real

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Example

This example demonstrates the operation mechanism of GTO_Thyristor model through a simple example. The characteristic of the GTO_Thyristor GTOERS1 is defined by the internal equivalent lines. The control signal for GTOERS1 is decided by the Pulse Wave block PULSE1. The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the simulation results are shown in Figure 3-6.

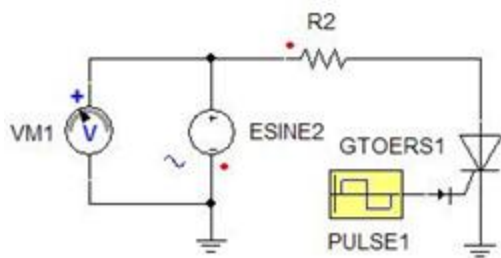


Figure 2. Application example of the GTO-Thyristor model

Table 4. System Parameters

Component	Parameter	Value [unit]
GTO-Thyristor (Equivalent Line) GTOERS1	CTRL	PULSE1.VAL
	VF	0.8 [V]
	RB	1m [Ohm]
	RR	100k [Ohm]
Resistor R2	R	1 [Ohm]
Voltage Source (Sine) ESINE2	AMPL	500 [V]
	FREQ	50 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [V]
Pulse Wave PULSE1	AMPL	1
	FREQ	200 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]

	OFF	0

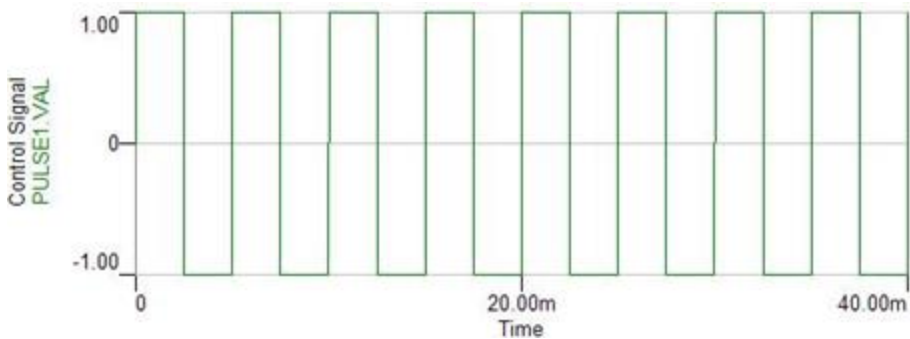


Figure 3. simulation result-control signal for GTOERS1

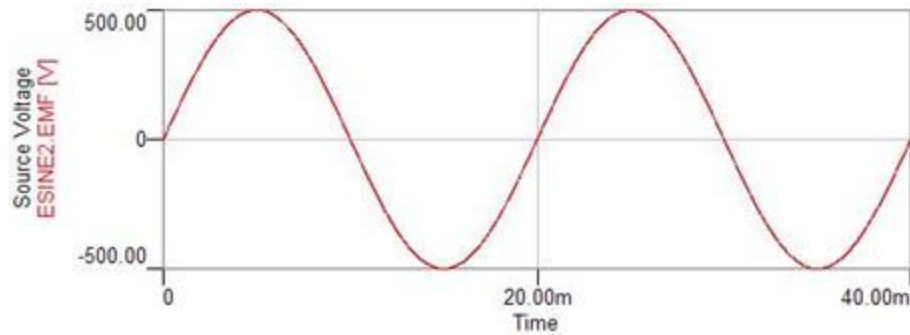


Figure 4. simulation result-output voltage of ESINE2

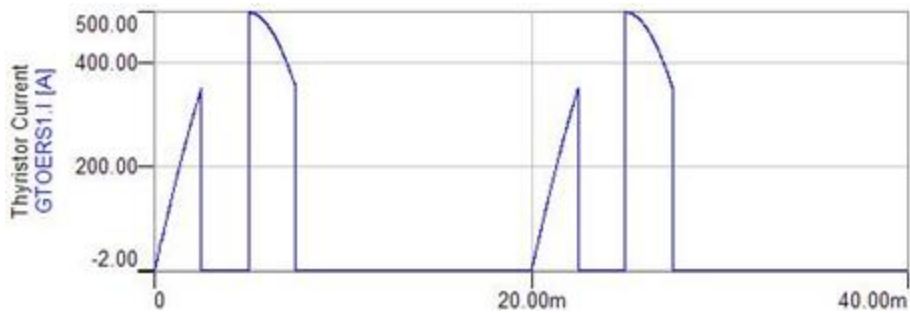


Figure 5. simulation result-current through GTOERS1

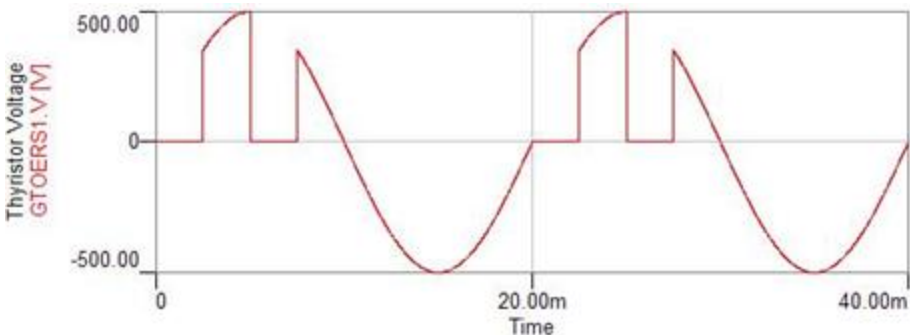


Figure 6. simulation result-voltage across GTOERS1

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References

[1] Ned Mohan, Tore M. Undeland, William P. Robbins, "Power Electronics: Converters, Applications, and Design". John Wiley & Sons, INC. New York, 1995.

IGBT

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

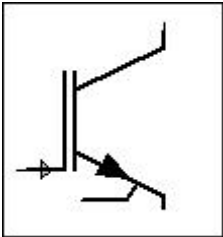


Figure 1. Component symbol

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Description

The System level IGBT (Insulated Gate Bipolar Transistor) model is used to simulate a static voltage-current-relation. Each voltage causes a corresponding current depending on the selected characteristic.

The predefined output characteristics defined in the component dialog guarantee a high calculation speed. Besides the predefined characteristic types (equivalent line, exponential function, lookup table) other user-defined characteristics can also be used. Usually an Equivalent line, Exponential function, Hyperbolic function, Polynom or the XY Lookup Table should be used. Characteristics based on XY-Data pairs allow simple access to measured curves for the switching behavior of the components.

To control the IGBT apply a logical signal. This signal can originate from any Twin Builder system variable.

Control Signal (Gate Voltage)	Component State
> 0	ON

≤ 0	OFF

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Assumptions and Limitations

This component models a static voltage-current-relation of the IGBT. Therefore, the dynamic behaviors are not taken into account.

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Mathematical Description

The static output voltage-current-relation of the IGBT model can be described as:

$$v(t) = f(i(t), [\text{control signal}])$$

where f is the characteristics specified by users.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
C	Collector	electrical
E	Emitter	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
CH	Characteristic; IGBT	Real	--

CTRL	Control Signal; All components	Real	0
VF	Forward Voltage; IGBTEQUL	Real	0.8 [V]
RB	Bulk Resistance; IGBTEQUL	Real	1m [Ohm]
RR	Reverse Resistance; IGBTEQUL/IGBTEXP	Real	100k [Ohm]
ISAT	Saturation Current; IGBTEXP	Real	1p [A]
VT	Thermal Voltage; IGBTEXP	Real	35m [V]
FILE	Characteristic; IGBTXY	File	--

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direciotn	Data Type
V	Voltage [V]	Output	real
I	Current [A]	Output	real
G	Conductivity [S]	Output	real
dV	Derivative of Voltage [V/s]	Output	real
dI	Derivative of Current [A/s]	Output	real

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Example

In this example, the characteristic of IGBT1 is defined by an external Exponential Function EXP2. The Triangular Wave TRIANG2 sends out control signal to IGBT1. The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the simulation results are shown in Figure 3-5.

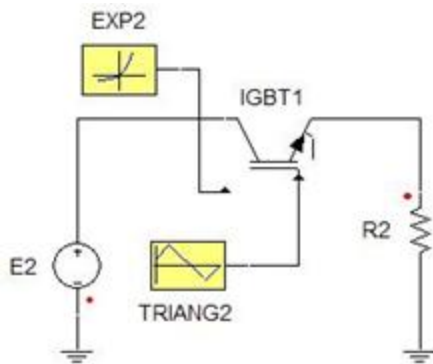


Figure 2. Application example of the System Level IGBT model

Table 4. System Parameters

Component	Parameter	Value [unit]
Triangular Wave TRIANG2	AMPL	0.311k
	FREQ	300 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [V]
Resistor R2	R	1k [Ohm]
Voltage Source E2	EMF	300 [V]
Exponential Function EXP2	VT	100m [V]
	ISAT	1p [A]
	RR	100 [Ohm]
IGBT (system level) IGBT1	CH	EXP2.VAL
	CTRL	TRIANG2.VAL

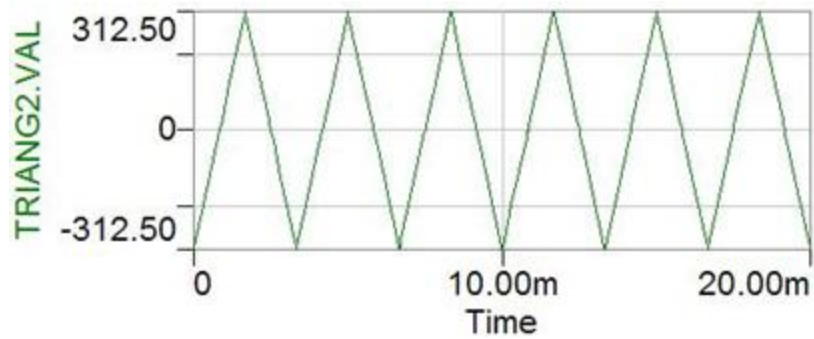


Figure 3. Simulation result-control signal for IGBT1

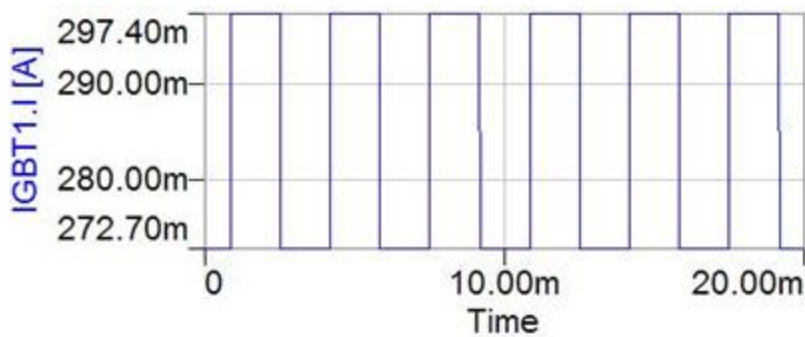


Figure 4. Simulation result-output current of IGBT1

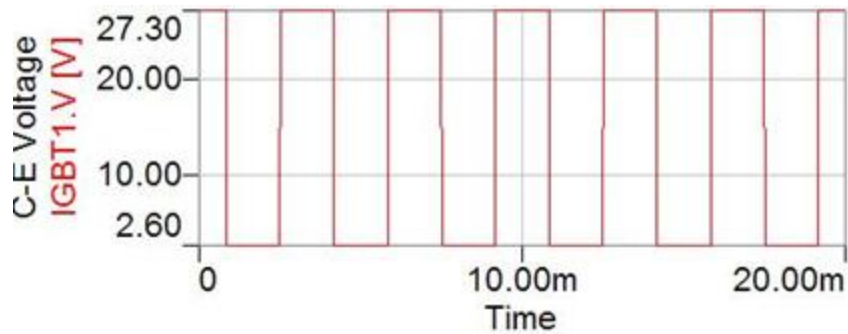


Figure 5. Simulation result-output voltage (v_{ce}) of IGBT1

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References

[1] Ned Mohan, Tore M. Undeland, William P. Robbins, "Power Electronics: Converters, Applications, and Design". John Wiley & Sons, INC. New York, 1995.

MOS Field Effect Transistor

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

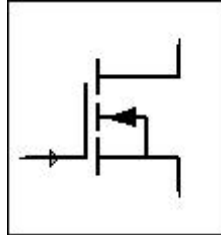


Figure 1. Component symbol

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Description

The system level MOS Field Effect Transistor (MOSFET) model is used to simulate a static voltage-current-relation. Each voltage causes a corresponding current depending on the selected characteristic.

The predefined output characteristics defined in the component dialog guarantee a high calculation speed. Besides the predefined characteristic types (equivalent line, exponential function, lookup table) other user-defined characteristics can also be used. Usually an Equivalent line, Exponential function, Hyperbolic function, Polynom or the XY Lookup Table should be used. Characteristics based on XY-Data pairs allow simple access to measured curves for the switching behavior of the components.

To control the MOSFET, a logical signal is applied. This signal can originate from any Twin Builder system variable.

Control Signal (Gate Voltage)	Component State
> 0	ON

≤ 0	OFF

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Assumptions and Limitations

This component models a static voltage-current-relation of the MOSFET. Therefore, the dynamic behaviors are not taken into account.

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Mathematical Description

The static output voltage-current-relation of the MOSFET model can be described as:

$$v(t) = f(i(t), [\text{control signal}])$$

where f is the characteristics specified by users.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
D	Drain	electrical
S	Source	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
CH	Characteristic; MOS	real	--

CTRL	Control Signal; All components	real	0
VF	Forward Voltage; MOSEQUL	real	0.8 [V]
RB	Bulk Resistance; MOSEQUL	real	1m [Ohm]
RR	Reverse Resistance; MOSEQUL/MOSEXP	real	100k [Ohm]
ISAT	Saturation Current; MOSEXP	real	1e-12 [A]
VT	Thermal Voltage; MOSEXP	real	35m [V]
FILE	Characteristic; MOSXY	file	--

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
V	Voltage [V]	Output	real
I	Current [A]	Output	real
	Conductivity [S]	Output	real
DV	Derivative of Voltage [V/s]	Output	real
DI	Derivative of Current [A/s]	Output	real

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Example

In this example, the characteristic of MOSEXP1 is defined by the internal exponential function. The Triangular Wave TRIANG3 sends out control signal to MOSEXP1. The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the simulation results are shown in Figure 3-5.

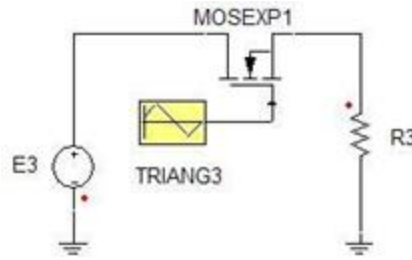


Figure 2. Application example of the System Level MOSFET model

Table 4. System Parameters

Component	Parameter	Value [unit]
Triangular Wave TRIANG3	AMPL	0.311k
	FREQ	300 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [V]
Resistor R3	R	1k [Ohm]
Voltage Source E2	EMF	300 [V]
MOSFET MOSEXP1	VT	100m [V]
	ISAT	1p [A]
	RR	100 [Ohm]

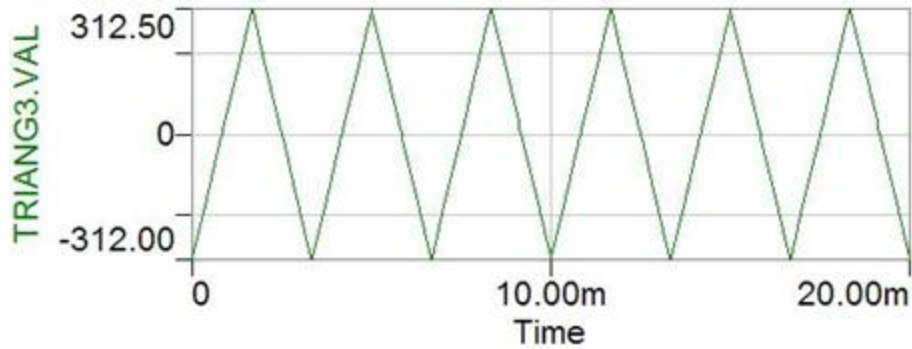


Figure 3. Simulation result-control signal for MOSEXP1

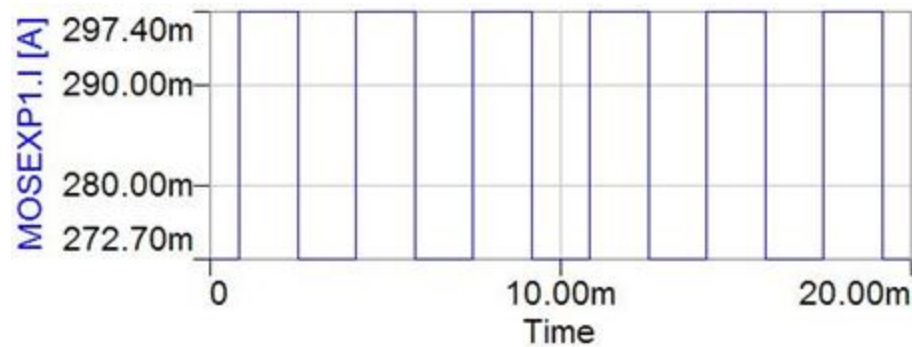


Figure 4. Simulation result-output current of MOSEXP1

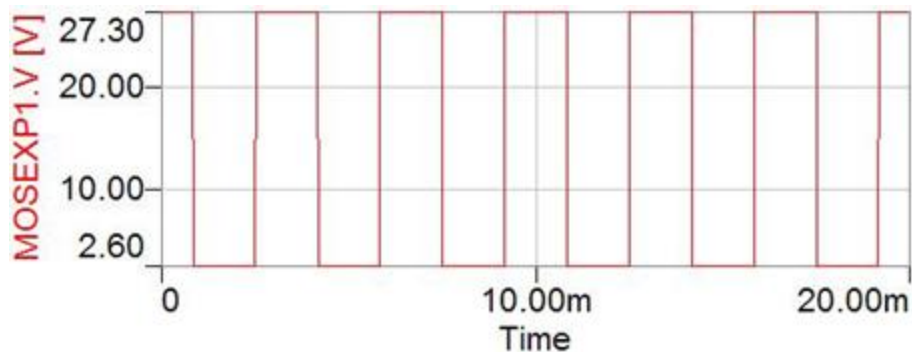


Figure 5. Simulation result-output voltage of MOSEXP1

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References

[1] Ned Mohan, Tore M. Undeland, William P. Robbins, "Power Electronics: Converters, Applications, and Design". John Wiley & Sons, INC. New York, 1995.

Thyristor

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

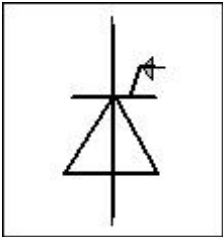


Figure 1. Component symbol

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- [Assumptions and Limitations](#)
- [Mathematical Description](#)
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Description

The System level Thyristor is used to simulate a static voltage-current-relation. Each voltage causes a corresponding current depending on the selected characteristic and the applied control signal. The predefined output characteristics defined in the component dialog guarantee a high calculation speed. Besides the predefined characteristic types (equivalent line, exponential function, lookup table) other user-defined characteristics can also be used. Usually an Equivalent line, Exponential function, Hyperbolic function, Polynom or the XY Lookup Table should be used. Characteristics based on XY-Data pairs allow simple access to measured curves for the switching behavior of the components.

To control the Thyristor, apply a logical signal. This signal can originate from any Twin Builder system variable.

Control Signal (Ignition Current)	Component State
> 0	ON, if $v(t) > V_F$

≤ 0	No Change. (the GTO turns off, when the current through the component becomes ≤ 0)

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Assumptions and Limitations

This component models a static voltage-current-relation of Thyristor. Therefore, the dynamic behaviors are not taken into account.

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Mathematical Description

The static output voltage-current-relation of the Thyristor model can be described as:

$$v(t) = f(i(t), [\text{control signal}])$$

where f is the characteristics specified by users.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
A	Anode	electrical
C	Cathode	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]

CH	Characteristic; TH	real	--
CTRL	Control Signal; All components	real	0
IH	Holding Current; All components	real	0 [A]
VF	Forward Voltage; THEQUL	real	0.8 [V]
RB	Bulk Resistance; THEQUL	real	1m [Ohm]
RR	Reverse Resistance; THEQUL/THEXP	real	100k [Ohm]
ISAT	Saturation Current; THEXP	real	1e-12 [A]
VT	Thermal Voltage; THEXP	real	35m [V]
FILE	Characteristic; THXY	file	--

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
V	Voltage [V]	Output	real
I	Current [A]	Output	real
	Conductivity [S]	Output	real
DV	Derivative of Voltage [V/s]	Output	real
DI	Derivative of Current [A/s]	Output	real

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Example

This example demonstrates the operation mechanism of Thyristor model through a simple example. The characteristic of the Thyristor THEQUL1 is defined by the internal equivalent lines. The control signal for THEQUL1 is decided by the Pulse Wave block PULSE1. The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the simulation results are shown in Figure 3-6.

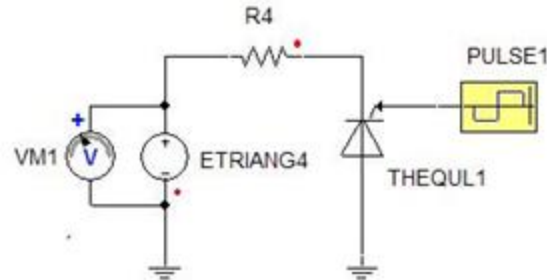


Figure 2. Application example of the Thyristor model

Table 4. System Parameters

Component	Parameter	Value [unit]
Thyristor (Equivalent Line)THEQUL1	CTRL	PULSE1.VAL
	VF	0.8 [V]
	RB	1m [Ohm]
	RR	100k [Ohm]
	IH	0 [A]
Resistor R4	R	1 [Ohm]
Voltage Source (Triangular) ETRIANG4	AMPL	300 [V]
	FREQ	50 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [V]

Pulse Wave PULSE1	AMPL	2
	FREQ	100 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0

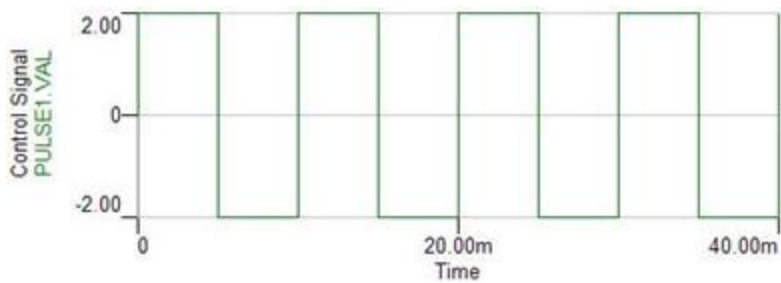


Figure 3. simulation result-control signal for THEQUL1

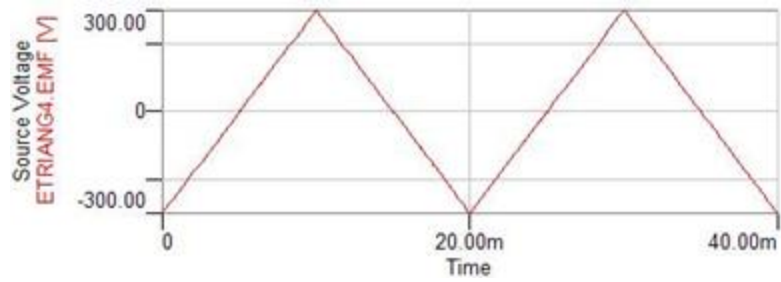


Figure 4. simulation result-output voltage of ETRIANG4

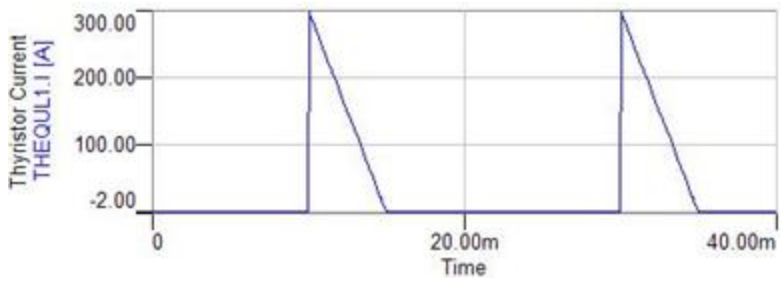
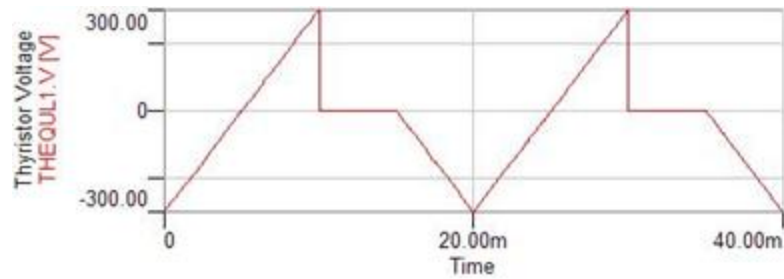


Figure 5. simulation result-current through THEQUL1**Figure 6. simulation result-voltage across THEQUL1**[Top](#)

References

[1] Ned Mohan, Tore M. Undeland, William P. Robbins, "Power Electronics: Converters, Applications, and Design". John Wiley & Sons, INC. New York, 1995.

TRIAC

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

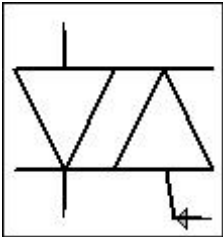


Figure 1. Component symbol

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- [Assumptions and Limitations](#)
- [Mathematical Description](#)
- [Netlist Syntax](#)
- [Conservative Pins](#)
- [Parameters](#)
- [Input/Output Quantities](#)
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Description

The System level TRIAC is used to simulate a static voltage-current-relation. Each voltage causes a corresponding current depending on the selected characteristic and the applied control signal. The predefined output characteristics defined in the component dialog guarantee a high calculation speed. Besides the predefined characteristic types (equivalent line, exponential function, lookup table) other user-defined characteristics can also be used. Usually an Equivalent line, Exponential function, Hyperbolic function, Polynom or the XY Lookup Table should be used. Characteristics based on XY-Data pairs allow simple access to measured curves for the switching behavior of the components.

To control the TRIAC, apply a logical signal. This signal can originate from any Twin Builder system variable.

Control Signal (Ignition Current)	Component State
> 0	ON, if $v(t) > V_F$

≤ 0	No Change.

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Assumptions and Limitations

This component models a static voltage-current-relation of TRIAC. Therefore, the dynamic behaviors are not taken into account.

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Mathematical Description

The static output voltage-current-relation of the TRIAC model can be described as:

$$v(t) = f(i(t), [\text{control signal}])$$

where f is the characteristics specified by users.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
N1	Pin 1	electrical
N2	Pin 2	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
CH	Characteristic; TRIAC	real	--
CTRL	Control Signal; All components	real	0
VF	Forward Voltage; TRIACEQUL	real	0.8 [V]
RB	Bulk Resistance; TRIACEQUL	real	1m [Ohm]
RR	Reverse Resistance; TRIACEQUL/TRIACEXP	real	100k [Ohm]
ISAT	Saturation Current; TRIACEXP	real	1e-12[A]
VT	Thermal Voltage; TRIACEXP	real	35m [V]
FILE	Characteristic; TRIACXY	file	--

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
V	Voltage [V]	Output	real
I	Current [A]	Output	real
	Conductivity [S]	Output	real
DV	Derivative of Voltage [V/s]	Output	real
DI	Derivative of Current [A/s]	Output	real

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Example

This example demonstrates the operation mechanism of Triac model through a simple example. The characteristic of the Triac TRIACERS1 is defined by the internal equivalent line. The control signal for TRIACERS1 is decided by the Pulse Wave block PULSE1. The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the simulation results are shown in Figure 3-6.

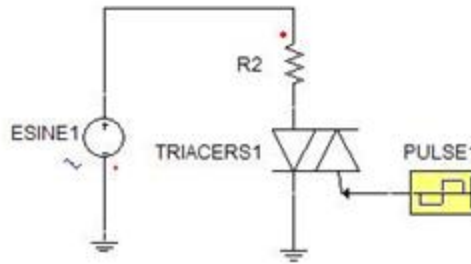


Figure 2. Application example of the Triac model

Table 4. System Parameters

Component	Parameter	Value [unit]
Thyristor (Equivalent Line) THEQUL1	CTRL	PULSE1.VAL
	VF	0.8 [V]
	RB	1m [Ohm]
	RR	100k [Ohm]
	IH	0 [A]
Resistor R2	R	1 [Ohm]
Voltage Source (Sine) ESINE1	AMPL	500 [V]
	FREQ	50 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [V]

Pulse Wave PULSE1	AMPL	311
	FREQ	200 [Hz]
	TDELAY	0 [s]
	PHASE	210 [degree]
	OFF	0

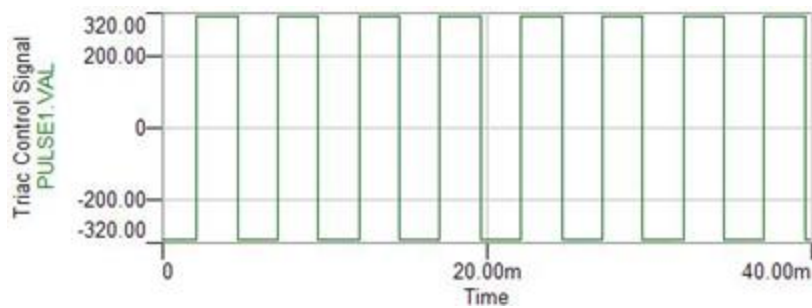


Figure 3. simulation result-control signal for TRIACERS1



Figure 4. simulation result-output voltage of TRIACERS1

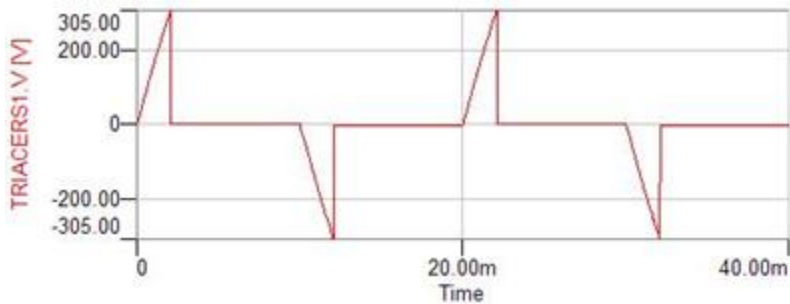


Figure 5. simulation result-current through TRIACERS1

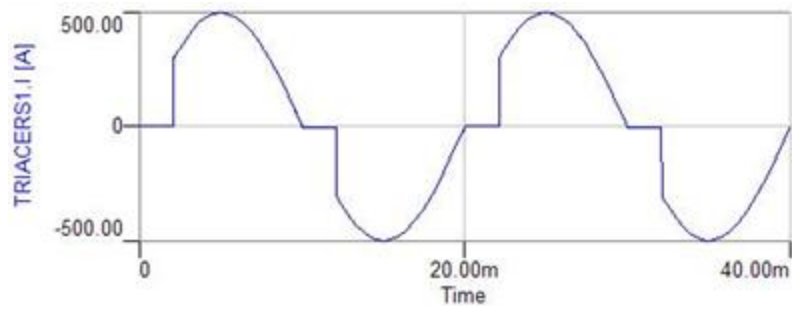


Figure 6. simulation result-voltage across TRIACERS1

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References

[1] Ned Mohan, Tore M. Undeland, William P. Robbins, "Power Electronics: Converters, Applications, and Design". John Wiley & Sons, INC. New York, 1995.

Sources

- Voltage Source(E)
- Controlled Voltage Source (EC)
- Fourier Source (Fourier)
- Current Source(I)
- Controlled Current Source (IC)
- Multidimensional Table Source (NDSRC)
- Polynomial Source (POLY/POLY)
- Power Source (PSRC)
- Voltage Controlled Oscillator (xVCO)

Voltage Source

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

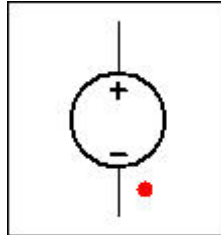


Figure 1. Component symbol

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The component represents an independent voltage source. In the dialog box, you can choose a constant, or the time-controlled sine, pulse, triangular, trapezoidal, saw-tooth rising, or saw-tooth falling type.

Linear Voltage Source

Description

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Assumptions and Limitations

This component represents an ideal voltage source, hence internal resistance is not considered.

Also, when providing an expression for a voltage source EMF parameter, any currents appearing in the expression should be ammeter or voltage source currents, for best numerical performance. The safest component types of currents to use are AM, E (including the time function forms), EI, and EV.

When voltage variables appear in the EMF expression, it is recommended to use a node voltage or a voltmeter (VM) voltage. However, voltage for most of the internal two-port electrical components (circuit components with a green dot) are also supported.

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Mathematical Description

The output voltage of the Linear Voltage Source model is defined as following:

$$v(t) = -EMF$$

where EMF is the electromotive force. The value of EMF is equivalent to the present value of the quantity specified in the text box. Usually a constant value, a time function, or a variable are chosen, or the value of the electromotive force is determined in a state graph. All system quantities and variables can be combined with mathematical and logical operators and constants.

Note: However, the expression must be technically meaningful. If it is not, numerical instability or completely wrong results are possible. In particular, sudden changes in the first derivation of the control quantity should be avoided.

Note also that the Twin Builder voltage sources have the opposite orientation compared to SPICE-like voltage sources.

[See also Twin Builder Reference Arrow System](#)

The current through an ideal voltage source can be arbitrary. Real voltage sources have always an internal resistance. If the internal resistance is essential for the simulation target, a corresponding resistance must be connected in series.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
N1	Pin 1 (with red point)	electrical
N2	Pin 2	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
EMF	EMF Value	real	1 [V]
PARTDERIV	Partial Derivation Flag	real	1*
AC_MAG	EMF Magnitude	real	0.1m [V]
AC_PHASE	EMF Phase Shift	real	0 [degree]

* 1: On; 0: Off

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
V	Voltage [V]	Output	real
I	Current [A]	Output	real
DV	Derivative of Voltage [V/s]	Output	real
DI	Derivative of Current [A/s]	Output	real

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Example

In this example, a Linear Voltage Source E1 is connected to a first-order RL load. The initial current of the inductor L1 is 0A. The current through the load increases exponentially from 0A at simulation time $t=0$, to 2A as the system reaches steady state, while the voltage across L1 decreases exponentially from 10V to 0V. The time constant of the circuit is decided by the ratio between the resistance of R1 to the inductance of L1, i.e., $\tau = L/R$. The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the simulation results are shown in Figure 3.

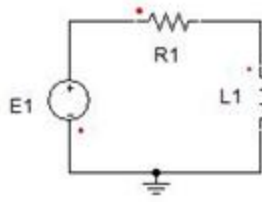


Figure 2. Application example of the Linear Voltage Source model

Table 4. System Parameters

Component	Parameter	Value [unit]
Voltage Source E1	EMF	10 [V]
Resistor R1	R	5 [Ohm]
Inductor L1	L	2m [H]
	I0	0 [A]

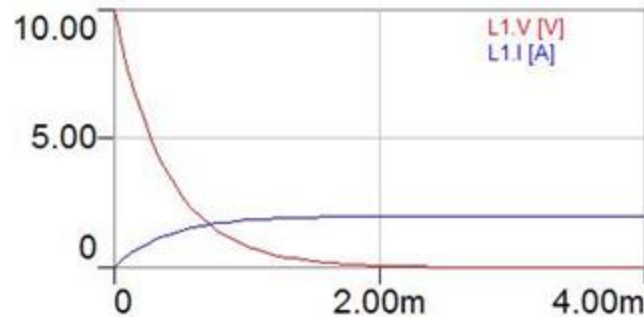


Figure 3. Simulation results-voltage across and current through the inductor L1

Time-Controlled Linear Voltage Source

Description

The time-controlled voltage sources have the same properties as the linear voltage source above; the current can be arbitrary and the sources have the opposite orientation compared to SPICE-like voltage sources. The value of the electromotive force instead is equivalent to the present value of the selected time function at each calculation step.

The simulator internal names of time-controlled voltage sources read as follows: Sine-ESINE; Pulse-EPULSE; Triangular-ETRIANG; Trapezoidal-ETRAPEZ; Saw-tooth Rising-ESZ_RISE;

Saw-tooth Falling-EST_FALL. The names are only relevant to simulation scripts in SML. Access to source parameters is carried out only by the component name.

Note: You should use Trapezoidal as the Time Control for creating a non-ideal pulse waveform (for example, rise time and fall time), with a correctly defined Period and the Periodical drop-down set to Yes.

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Assumptions and Limitations

This component represents an ideal voltage source, hence internal resistance is not considered.

Also, when providing an expression for a voltage source EMF parameter, any currents appearing in the expression should be ammeter or voltage source currents, for best numerical performance. The safest component types of currents to use are AM, E (including the time function forms), EI, and EV.

When voltage variables appear in the EMF expression, any node voltage or component voltage is safe to use.

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Mathematical Description

The output voltage of the Time-Controlled Linear Voltage Source model is defined as following:

$$v(t) = -f[\text{time function}]$$

where $f[\text{time function}]$ can be specified in the component dialog box.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
N1	Pin 1 (with red point)	electrical
N2	Pin 2	electrical

[Top](#)

Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
AMPL	Amplitude	real	0.326k [V]
FREQU	Frequency (no trapezoidal function parameter)	real	50 [Hz]
TPERIO	Period	real	0.02 [s]
TDELAY	Delay	real	0 [s]
PHASE	Phase	real	0 [degree]
OFF	Offset	real	0 [V]
PERIO	Periodic; PERIO=1, periodical function, PERIO=0; non-periodical function	real	1
TRISE	Rise Time (only trapezoidal function)	real	0.005 [s]
TFALL	Fall Time (only trapezoidal function)	real	0.01 [s]
PWIDTH	Pulse Width (only trapezoidal function)	real	0.005 [s]
AC_MAG	EMF Magnitude	real	0.001 [V]
AC_PHASE	EMF Phase Shift	real	0 [degree]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
V	Voltage [V]	Output	real
I	Current [A]	Output	real
EMF	EMF Value [V]	Output	real
DV	Derivative of Voltage [V/s]	Output	real
DI	Derivative of Current [A/s]	Output	real

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Example

In this example, usage of different types of Time-Controlled Linear Voltage Source is demonstrated. The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the waveforms of the output voltage of the voltage sources are shown in Figure 3-8.

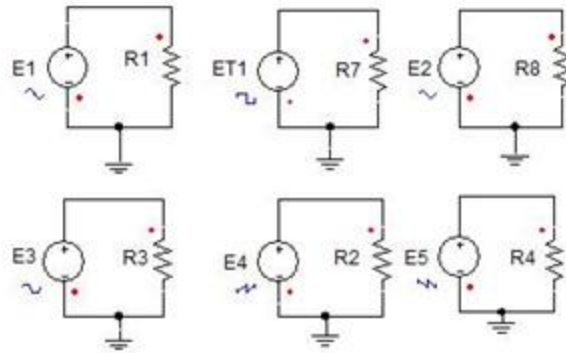


Figure 2. Application example of the Time-Controlled Linear Voltage Source models

Table 4. System Parameters

Component	Parameter	Value [unit]
Voltage Source (Sinusoidal) E1	AMPL	326 [V]
	FREQ	50 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [V]
Resistor (Linear) R1/R2/R3/R4/ R7/R8	R	1k [Ohm]
Voltage Source (Pulse) ET1 **	AMPL	326 [V]
	FREQ	50 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [V]
Voltage Source (Triangular) E2	AMPL	326 [V]
	FREQ	50 [Hz]

	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [V]
Voltage Source (Trapezoidal) E3	AMPL	326 [V]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [V]
	TRISE	5m [s]
	TFALL	10m [s]
	PWIDTH	5m [s]
Voltage Source (Saw-tooth Rising) E4	AMPL	326 [V]
	FREQ	50 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [V]
Voltage Source (Saw-tooth Falling) E5	AMPL	326 [V]
	FREQ	50 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [V]

** For the Time Controlled parameter, the duty ratio of the Pulse option is fixed and cannot be changed.

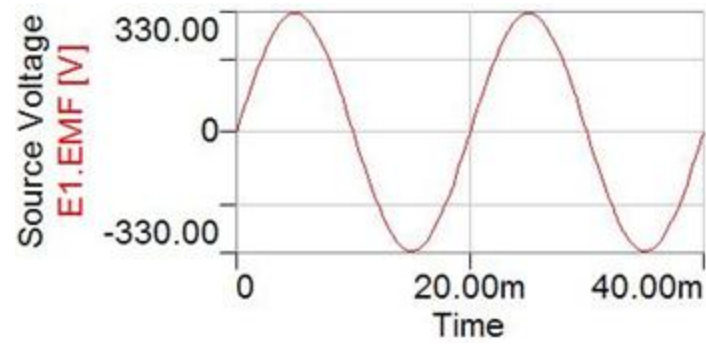


Figure 3. Simulation result-EMF of the Sinusoidal Voltage Source model E1

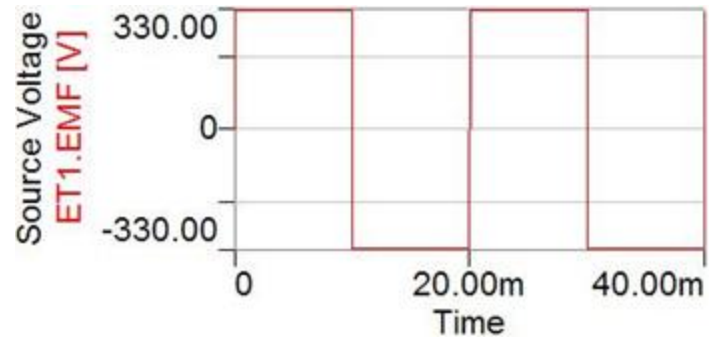


Figure 4. Simulation result-EMF of the Pulse Voltage Source model ET1

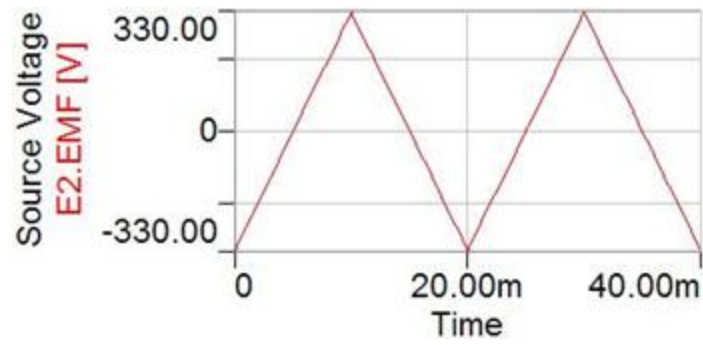


Figure 5. Simulation result-EMF of the Triangular Voltage Source model E2

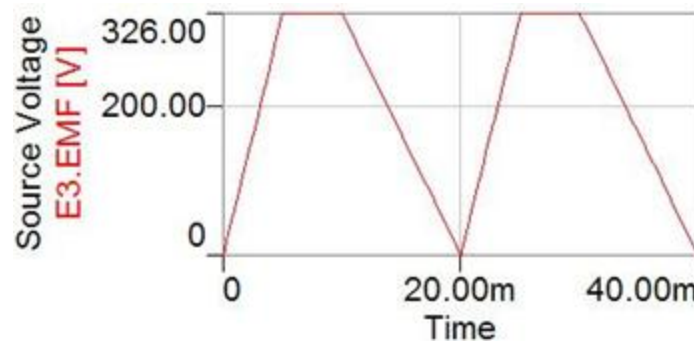


Figure 6. Simulation result-EMF of the Trapezoidal Voltage Source model E3

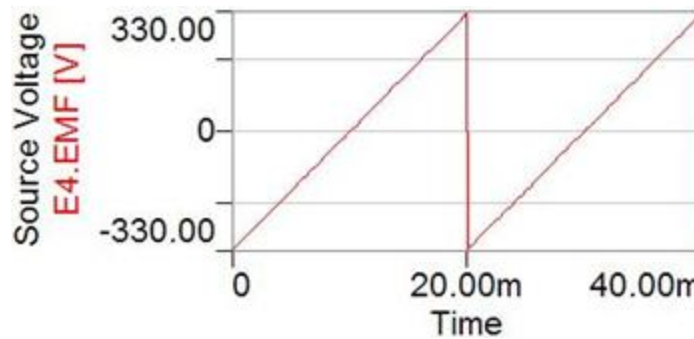


Figure 7. Simulation result-EMF of the Saw-Tooth Rising Voltage Source model E4

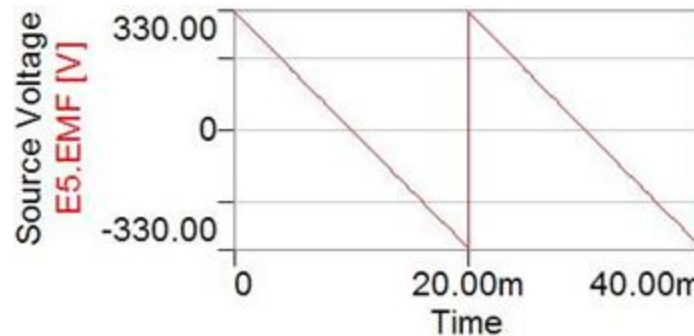


Figure 8. Simulation result-EMF of the Saw-Tooth Falling Voltage Source model E5

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References

[1] Roland E. Thomas, Albert J. Rosa. "The Analysis and Design of Linear Circuits." John Wiley & Sons, Inc., May, 2003.

Controlled Voltage Source

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

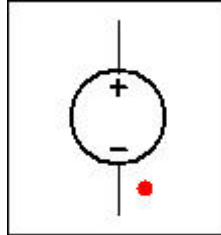


Figure 1. Component symbol

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The component represents a dependent voltage source. Within the dialog you can choose a voltage-controlled, current-controlled, nonlinear voltage-controlled, or nonlinear current-controlled type.

Linear voltage/current-controlled Voltage Source

Description

The value of the EMF of the Linear Voltage/Current-Controlled Voltage Source model is proportional to the input control voltage/current.

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Assumptions and Limitations

Internal loss is not considered in this model.

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Mathematical Description

The value of the EMF is calculated from the voltage/current of the controlling circuit component multiplied by an arbitrary control coefficient K.

$$v(t) = -K \cdot v[\text{control component}]$$

$$v(t) = -K \cdot i[\text{control component}]$$

Note: The Twin Builder voltage sources have the opposite orientation compared to SPICE-like voltage sources.

[See also Twin Builder Reference Arrow System](#)

In Twin Builder only voltage sources or ammeters are allowed as controlling components for current-controlled elements. These must be inserted properly in the controlling branch.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
N1	Pin 1 (with red point)	electrical
N2	Pin 2	electrical

[Top](#)

Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
QUANT	Control Quantity	Real	0 [V/A]
FACT	Factor	Real	1

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
V	Voltage [V]	Output	real
I	Current [A]	Output	real
dV	Derivative of Voltage [V/s]	Output	real
dI	Derivative of Current [A/s]	Output	real

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Example

Refer to the example in the following section.

Nonlinear voltage/current-controlled Voltage Source

Description

The value of the EMF of the Nonlinear Voltage/Current-Controlled Voltage Source model is calculated by user-specified nonlinear function of the input control voltage/current.

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Assumptions and Limitations

Internal loss is not considered in this model.

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Mathematical Description

The value of the EMF is calculated from the voltage/current of the controlling component corresponding to an arbitrary nonlinear function.

$$v(t) = -f(v[\text{control component}])$$

$$v(t) = -f(i[\text{control component}])$$

To describe the nonlinear relation, you must specify a name of an appropriate XY nonlinear characteristic function.

[See also Separate Component Characteristic](#)

To define characteristic data, you can do one of the following:

- **Use Pin** : connect the output of an XY component, connected to the pin to provide the characteristic
- Use the **Characteristic** Dialog: in the Characteristic dialog box, choose the following options
 - **Reference** : specify the output variable of an XY component, e.g. XY1.VAL
 - **Lookup Table** : there are two options if you want to use a lookup table to define the characteristic
 1. **File Reference** : the name in the text box specifies a variable which refers to a subsheet port specifying a characteristic file
 2. **Data Pairs** : enter sets of data to define the characteristics

Note: The Twin Builder voltage sources have the opposite orientation compared to SPICE-like voltage sources.

[See also Twin Builder Reference Arrow System](#)

In Twin Builder only voltage sources or ammeters are allowed as controlling components for current-controlled elements. These must be inserted properly in the controlling branch.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
N1	Pin 1 (with red point)	electrical
N2	Pin 2	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]

QUANT	Control Quantity	Real	0 [V/A]
CH	Characteristic	Real	[/]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
V	Voltage [V]	Output	real
I	Current [A]	Output	real
dV	Derivative of Voltage [V/s]	Output	real
dI	Derivative of Current [A/s]	Output	real

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Example

In this example, usage of different types of Controlled Voltage Source is demonstrated. The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the waveforms of the output voltage of the voltage sources are shown in Figure 3-6.

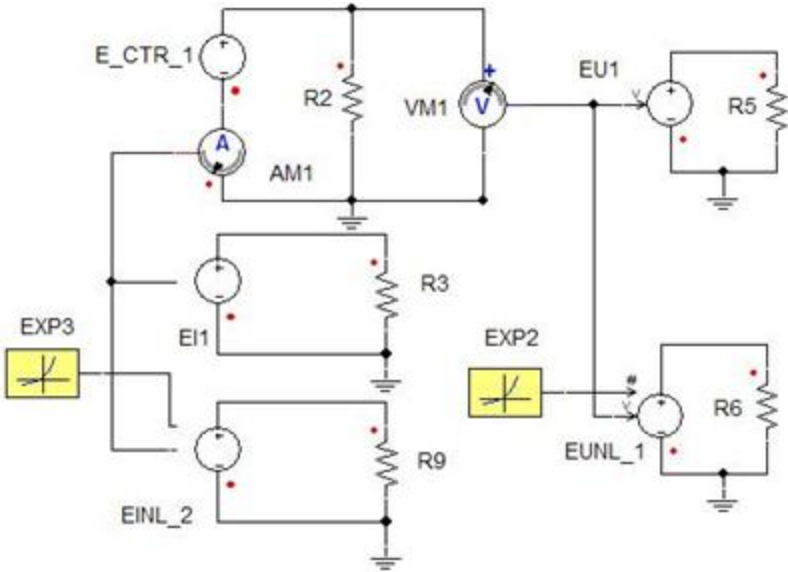


Figure 2. Application example of the Controlled Voltage Source models**Table 4. System Parameters**

Component	Parameter	Value [unit]
Voltage Source E_CTR_1	EMF	t*10 [V]
Resistor R2	R	10 [Ohm]
Resistor R3/R5/ R6/R9	R	1k [Ohm]
Controlled Voltage Source (Current Controlled) EI1	QUANT	AM1.I [A]
	FACT	2
Controlled Voltage Source (Voltage Controlled) EU1	QUANT	VM1.I [A]
	FACT	3
Controlled Voltage Source (Nonlinear Current Controlled) EINL_2	QUANT	AM1.I [A]
	CH	EXP3.VAL
Controlled Voltage Source (Nonlinear Voltage Controlled) EUNL_1	QUANT	VM1.I [A]
	CH	EXP2.VAL
Exponential Function EXP3	VT	35m [V]
	ISAT	5 [A]
	RR	0.1Meg [Ohm]
Exponential Function EXP2	VT	35m [V]
	ISAT	1p [A]
	RR	0.1Meg [Ohm]

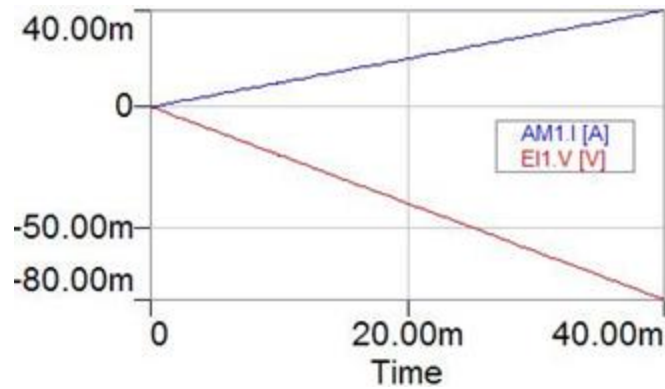


Figure 3. Simulation results-control current and voltage output of the Linear Current-Controlled Voltage Source EI1

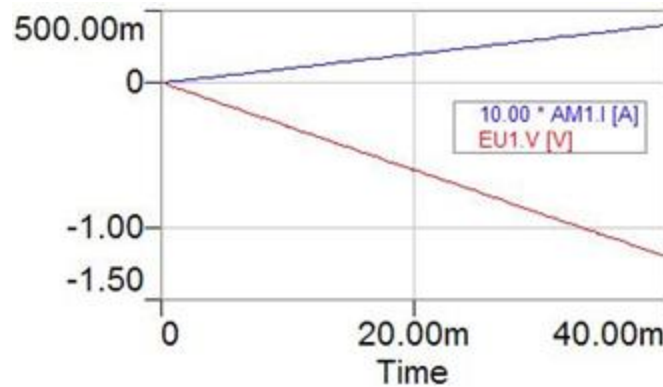


Figure 4. Simulation results-control voltage and voltage output of the Linear Voltage-Controlled Voltage Source EU1

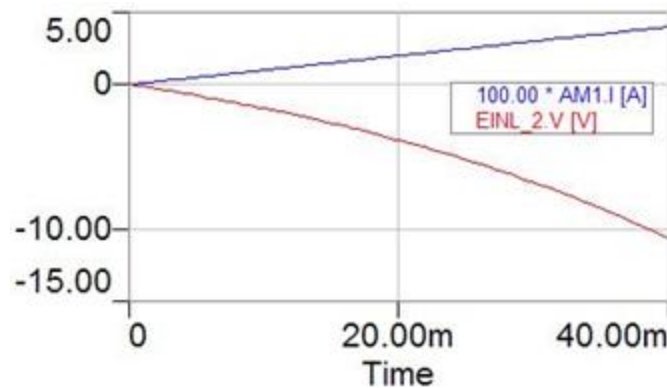


Figure 5. Simulation results-control current and voltage output of the Nonlinear voltage-Controlled Voltage Source EINL_2

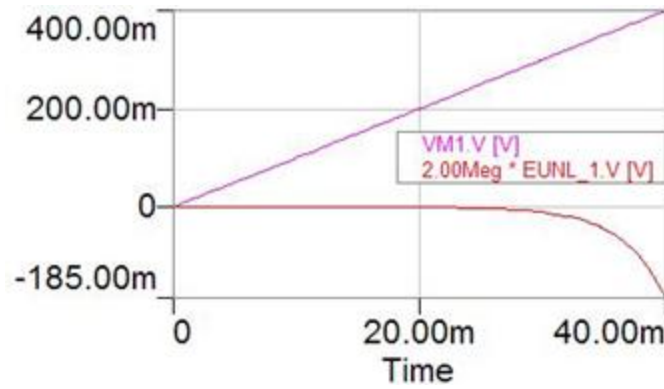


Figure 6. Simulation results-control voltage and voltage output of the Nonlinear Voltage-Controlled Voltage Source EUNL_1

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References

[1] Roland E. Thomas, Albert J. Rosa. "The Analysis and Design of Linear Circuits." John Wiley & Sons, Inc., May, 2003.

Fourier Source

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

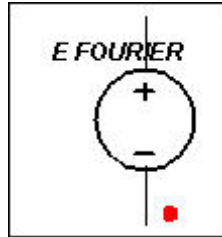


Figure 1. Component symbol

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Description

The component represents a Fourier source. You can choose to use it as either a voltage source or a current source. The EMF value of the Fourier voltage source or the source current of the Fourier current source result from the ripple amplitude of the defined sine waves. The values can be imported from a data file created through an FFT analysis. In addition, you can also define the fundamental harmonics and the number of sub harmonics in the component dialog box. In this dialog box, you can choose to use this component as a voltage or current source.

Note: The component cannot be used with AC and DC simulation.

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Assumptions and Limitations

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Mathematical Description

Fourier Voltage Source

When this component is used as a voltage source, and both the even and odd harmonic contents are considered, the EMF value of the Fourier voltage source is calculated as following:

$$\text{EMF}(t) = \sum_{v=1}^m A_v \cdot \sin(2\pi \cdot v \cdot f_1 \cdot t + \varphi_v)$$

where m is the total number of harmonics that are considered, f_1 is the base frequency, and A_v and φ_v are the amplitude and phase angle of the v^{th} harmonic, respectively.

If only even harmonics are considered, the EMF value is calculated as:

$$\text{EMF}(t) = A_1 \cdot \sin(2\pi \cdot f_1 \cdot t + \varphi_1) + \sum_{v=1}^k A_{2v} \cdot \sin(2\pi \cdot 2v \cdot f_1 \cdot t + \varphi_{2v})$$

where $k = \text{int}(m/2)$.

Likewise, if only odd harmonics are considered, the EMF value is calculated as:

$$\text{EMF}(t) = \sum_{v=0}^k A_{(2v+1)} \cdot \sin(2\pi \cdot (2v+1) \cdot f_1 \cdot t + \varphi_{(2v+1)})$$

Fourier Current Source

When this component is used as a current source, and both the even and odd harmonic contents are considered, the source current value of the Fourier current source is calculated as following:

$$i(t) = \sum_{v=1}^m A_v \cdot \sin(2\pi \cdot v \cdot f_1 \cdot t + \varphi_v)$$

where m is the total number of harmonics that are considered, f_1 is the base frequency, and A_v and φ_v are the amplitude and phase angle of the v^{th} harmonic, respectively.

If only even harmonics are considered, the source current value is calculated as:

$$i(t) = A_1 \cdot \sin(2\pi \cdot f_1 \cdot t + \varphi_1) + \sum_{v=1}^m A_{2v} \cdot \sin(2\pi \cdot 2v \cdot f_1 \cdot t + \varphi_{2v})$$

Likewise, if only odd harmonics are considered, the source current value is calculated as:

$$i(t) = \sum_{v=0}^m A_{(2v+1)} \cdot \sin(2\pi \cdot (2v+1) \cdot f_1 \cdot t + \varphi_{(2v+1)})$$

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
N1	Pin 1 (with red point)	electrical
N2	Pin 2	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
ORD	Maximum of Power	real	0
QUANT [n]	Control Components and Quantity	real	-- [V] / [A]
COEFF [n]	Coefficients	real	--

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data

			Type
V	Voltage [V]	Output	real
I	Current [A]	Output	real
EMF	EMF Value [V] (voltage source)	Output	real
IS	Source Current [A] (current source)	Output	real
DV	Derivative of Voltage [V/s]	Output	real
DI	Derivative of Current [A/s]	Output	real

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Example

Fourier Voltage Source

In this example, the Fourier Source is used as a voltage source. The fundamental frequency is 50Hz, and 4 odd harmonics are superimposed on the fundamental waveform. The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the waveform of the EMF of the voltage source is shown in Figure 3.

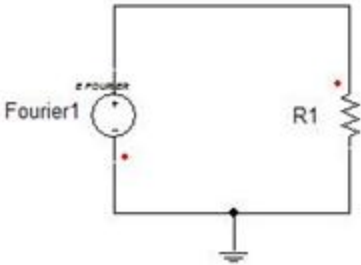


Figure 2. Application example of the Fourier Source as a voltage source

Table 4. System Parameters

Component	Parameter	Value [unit]
Fourier Source FOURIER1	Fundamental (50Hz)	12.7324
	3rd Harmonic (150Hz)	4.24401
	5th Harmonic (250Hz)	2.54627

	7th Harmonic (350Hz)	1.8186
Resistor R1	R	1000 [Ohm]

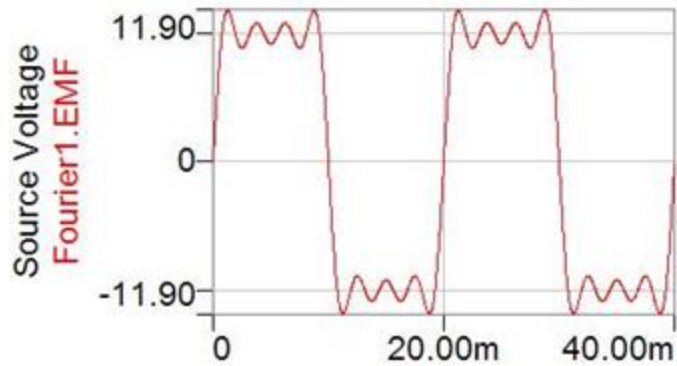


Figure 3. Simulation result-EMF of the Fourier Voltage Source

Fourier Current Source

In this example, the Fourier Source is used as a current source. The fundamental frequency is 500Hz, and 4 odd harmonics are superimposed on the fundamental waveform. The schematic of the example is shown in Figure 4, system parameters are listed in Table 5, and the waveforms of the source current of the current source is shown in Figure 5.

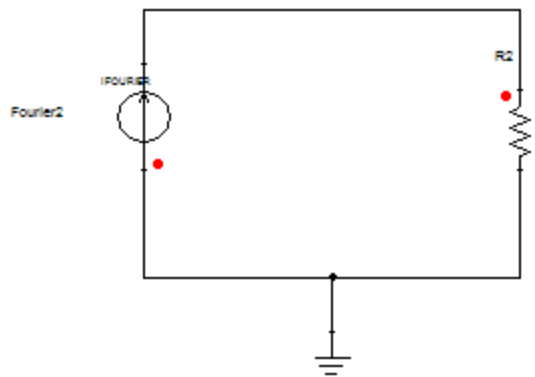


Figure 4. Application example of the Fourier Source as a current source

Table 5. System Parameters

Component	Parameter	Value [unit]
Fourier Source FOURIER2	Fundamental (500Hz)	12.7324
	3rd Harmonic (1500Hz)	4.24401

	5th Harmonic (2500Hz)	2.54627
	7th Harmonic (3500Hz)	1.81862
Resistor R2	R	1000 [Ohm]

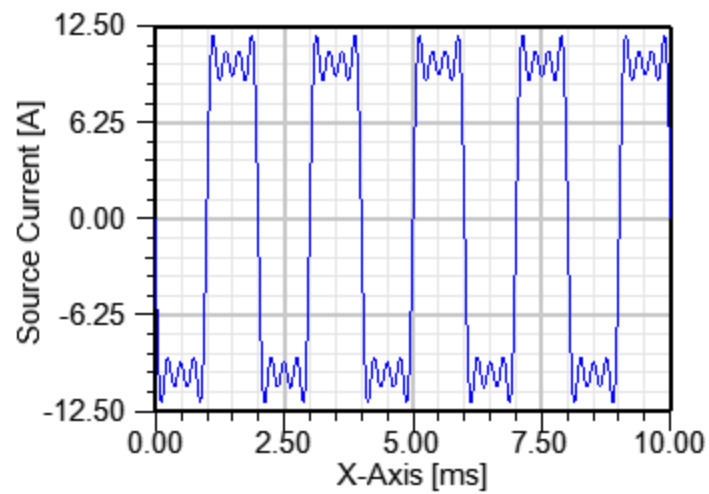


Figure 5. Simulation result-source current of the Fourier Current Source

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References

Current Source

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

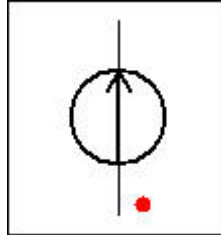


Figure 1. Component symbol

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The component represents an independent current source. Within the dialog you can choose a constant, or the time-controlled sine, pulse, triangular, trapezoidal, saw-tooth rising, or saw-tooth falling type.

Linear Current Source

Description

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Assumptions and Limitations

This component represents an ideal voltage source, hence internal resistance is not considered.

Also, when providing an expression for the source current parameter, any currents appearing in the expression should be ammeter or voltage source currents, for best numerical performance. The safest component types of currents to use are AM, E (including the time function forms), EI, and EV.

When voltage variables appear in the source current expression, it is recommended to use a node voltage or a voltmeter (VM) voltage. However, voltage for most of the internal two-port electrical components (circuit components with a green dot) are also supported

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Mathematical Description

The output current of the Linear Current Source model is defined as following:

$$i(t) = I$$

The value of the source current is equivalent to the present value of the quantity specified in the text box. Usually a constant value, a time function, or a variable are chosen, or the value is determined in a state graph. All system quantities and variables can be combined with mathematical and logical operators and constants.

Note: However, the expression must be technically meaningful. If it is not, numerical instability or completely wrong results are possible. In particular, sudden changes in the first derivation of the control quantity should be avoided.

The voltage of an ideal current source is arbitrary. Real current sources always have an internal resistance. If the internal resistance is essential for the simulation target, a corresponding resistance must be connected in parallel.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
N1	Pin 1 (with red point)	electrical
N2	Pin 2	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
IS	Source Current	real	1 [A]
PARTDERIV	Partial Derivation Flag	real	1*
AC_MAG	Source Current Magnitude (AC)	real	0.1m [A]
AC_PHASE	Phase Shift	real	0 [degree]

* 1: On; 0: Off

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
V	Voltage [V]	Output	real
I	Current [A]	Output	real
DV	Derivative of Voltage [V/s]	Output	real
DI	Derivative of Current [A/s]	Output	real

Time-Controlled Linear Current Source

Description

The time-controlled current sources have the same properties as the linear current source above; the current can be arbitrary and the sources have the opposite orientation compared to SPICE-like voltage sources. The value of the electromotive force instead is equivalent to the present value of the selected time function at each calculation step.

The simulator internal names of time-controlled current sources read as follows: Sine-ISINE; Pulse-IPULSE; Triangular-ITRIANG; Trapezoidal-ITRAPEZ; Saw-tooth Rising-ISZ_RISE; Saw-tooth Falling-IST_FALL. The names are only relevant to simulation scripts in SML. Access to source parameters is carried out only by the component name.

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Assumptions and Limitations

This component represents an ideal current source, hence internal resistance is not considered.

Also, when providing an expression for the source current parameter, any currents appearing in the expression should be ammeter or voltage source currents, for best numerical performance. The safest component types of currents to use are AM, E (including the time function forms), EI, and EV.

When voltage variables appear in the source current expression, any node voltage or component voltage is safe to use.

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Mathematical Description

The output current of the Time-Controlled Linear Current Source model is defined as following:

$$i(t) = f[\text{time function}]$$

where $f[\text{time function}]$ can be specified in the component dialog box.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
N1	Pin 1 (with red point)	electrical
N2	Pin 2	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]

AMPL	Amplitude	real	0.326k [A]
FREQU	Frequency (no trapezoidal function parameter)	real	50 [Hz]
TPERIO	Period	real	0.02 [s]
TDELAY	Delay	real	0 [s]
PHASE	Phase	real	0 [degree]
OFF	Offset	real	0 [A]
PERIO	Periodic; PERIO=1, periodical function, PERIO=0; non-periodical function	real	1
TRISE	Rise Time (only trapezoidal function)	real	0.005 [s]
TFALL	Fall Time (only trapezoidal function)	real	0.01 [s]
PWIDTH	Pulse Width (only trapezoidal function)	real	0.005 [s]
AC_MAG	Source Current Magnitude (AC)	real	0.001 [A]
AC_PHASE	Phase Shift	real	0 [degree]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
V	Voltage [V]	Output	real

I	Current [A]	Output	real
IS	Source Current [A]	Output	real
DV	Derivative of Voltage [V/s]	Output	real
DI	Derivative of Current [A/s]	Output	real

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Example

In this example, usage of different types of Time-Controlled Linear Current Source models is demonstrated. The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the waveforms of the output voltage of the voltage sources are shown in Figure 3-8.

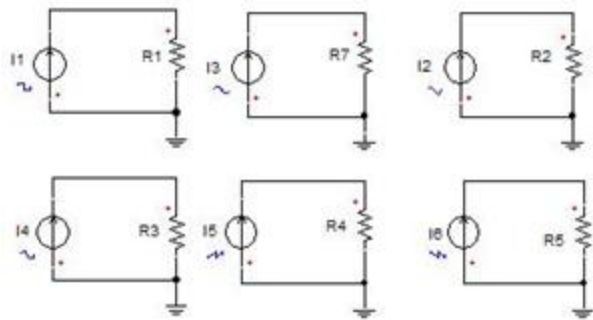


Figure 2. Application example of the Time-Controlled Current Source models

Table 4. System Parameters

Component	Parameter	Value [unit]
Current Source (Pulse) I1	AMPL	326 [A]
	FREQ	50 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [A]

Resistor (Linear) R1/R2/R3/R4/ R7/R8	R	1k [Ohm]
Current Source (Sinusiodal) I3	AMPL	326 [A]
	FREQ	50 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [A]
Current Source (Triangular) I2	AMPL	326 [A]
	FREQ	50 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [A]
Current Source (Trapezoidal) I4	AMPL	326 [A]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [A]
	TRISE	5m [s]
	TFALL	10m [s]
	PWIDTH	5m [s]
Current Source (Saw-tooth Rising) I5	AMPL	326 [A]
	FREQ	50 [Hz]
	TDELAY	0 [s]

Current Source (Saw-tooth Falling) I6	PHASE	0 [degree]
	OFF	0 [A]
	AMPL	326 [A]
	FREQ	50 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [A]

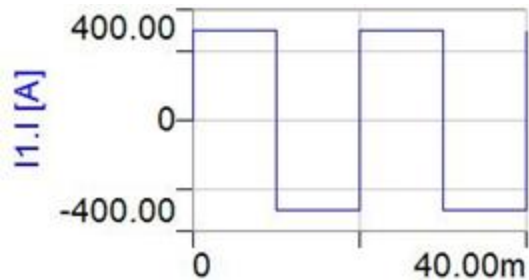


Figure 3. Simulation result-current of the Pulse Current Source model I1

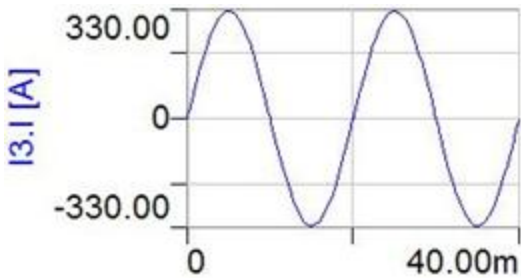


Figure 4. Simulation result- current of the Sinusoidal Current Source model I3

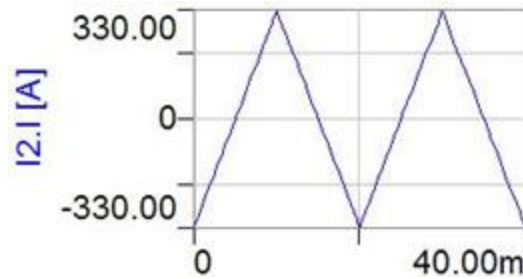


Figure 5. Simulation result- current of the Triangular Current Source model I2

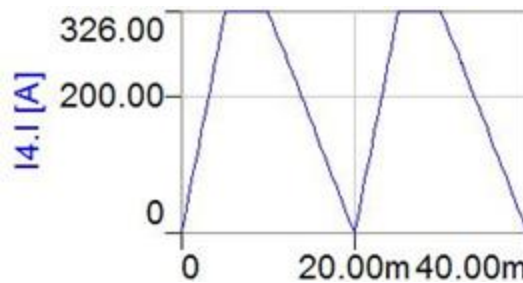


Figure 6. Simulation result- current of the Trapezoidal Current Source model I4

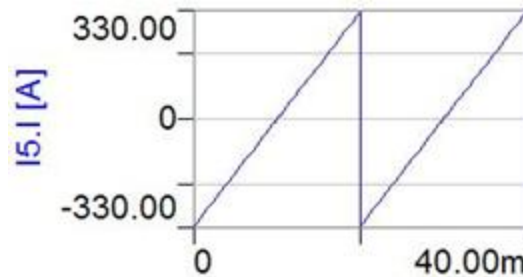


Figure 7. Simulation result- current of the Saw-Tooth Rising Current Source model I5

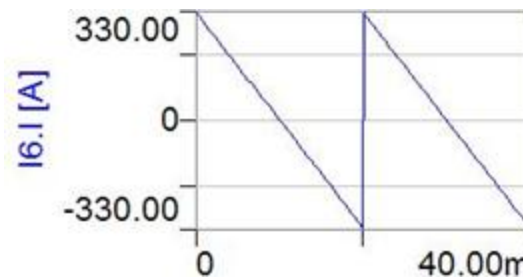


Figure 6. Simulation result- current of the Saw-Tooth Falling Current Source model I6

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References

[1] Roland E. Thomas, Albert J. Rosa. "The Analysis and Design of Linear Circuits." John Wiley & Sons, Inc., May, 2003.

Controlled Current Source

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

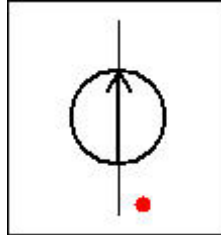


Figure 1. Component symbol

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The component represents a dependent current source. You can choose a voltage-controlled, current-controlled, nonlinear voltage-controlled, or nonlinear current-controlled type.

Linear Voltage/Current-Controlled Current Source

Description

The value of the source current of the Linear Voltage/Current-Controlled Current Source model is proportional to the input control voltage/current.

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Assumptions and Limitations

Internal loss is not considered in this model.

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Mathematical Description

The value of the source current is calculated from the voltage/current of the controlling circuit component multiplied by an arbitrary control coefficient K. For the control, any circuit component can be specified.

$$i(t) = K \cdot v[\text{control component}]$$

$$i(t) = K \cdot i[\text{control component}]$$

Note: Only voltage sources or ammeters can be the controlling components for current-controlled elements. These must be inserted properly in the controlling branch.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
N1	Pin 1 (with red point)	electrical
N2	Pin 2	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
QUANT	Control Quantity	Real	0 [V/A]
FACT	Factor	Real	1

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
V	Voltage [V]	Output	real
I	Current [A]	Output	real
dV	Derivative of Voltage [V/s]	Output	real
dI	Derivative of Current [A/s]	Output	real

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Example

Refer to the example in the following section.

Nonlinear voltage/current-controlled Current Source

Description

The value of the source current of the Nonlinear Voltage/Current-Controlled Current Source model is calculated by user-specified nonlinear function of the input control voltage/current.

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Assumptions and Limitations

Internal loss is not considered in this model.

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Mathematical Description

The value of the source current is calculated from the voltage/current of the controlling component corresponding to an arbitrary nonlinear function. The control can result from any component of the electrical circuit.

$$i(t) = f(v[\text{control component}])$$

$$i(t) = f(i[\text{control component}])$$

To describe the nonlinear relation, you must specify a name of an appropriate XY nonlinear characteristic function.

[See also Separate Component Characteristic](#)

- **Use Pin** : connect the output of an XY component, connected to the pin to provide the characteristic
 - Use the **Characteristic** Dialog: in the Characteristic dialog box, choose the following options
 - **Reference** : specify the output variable of an XY component, e.g. XY1.VAL
 - **Lookup Table** : there are two options if you want to use a lookup table to define the characteristic
1. **File Reference** : the name in the text box specifies a variable which refers to a subsheet port specifying a characteristic file
 2. **Data Pairs** : enter sets of data to define the characteristics

Note: Only voltage sources or ammeters can be the controlling components for current-controlled elements and must be inserted properly in the controlling branch.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
N1	Pin 1 (with red point)	electrical
N2	Pin 2	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
QUANT	Control Quantity	Real	0 [V/A]
CH	Characteristic	Real	[/]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
V	Voltage [V]	Output	real
I	Current [A]	Output	real
dV	Derivative of Voltage [V/s]	Output	real
dI	Derivative of Current [A/s]	Output	real

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Example

In this example, usage of different types of Controlled Current Source models is demonstrated. Notice that the control current and characteristic of IINL_1 is defined with variables from the schematic, while those of IINL_2 are connected directly through pin. The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the waveforms of the output voltage of the voltage sources are shown in Figure 3-6.

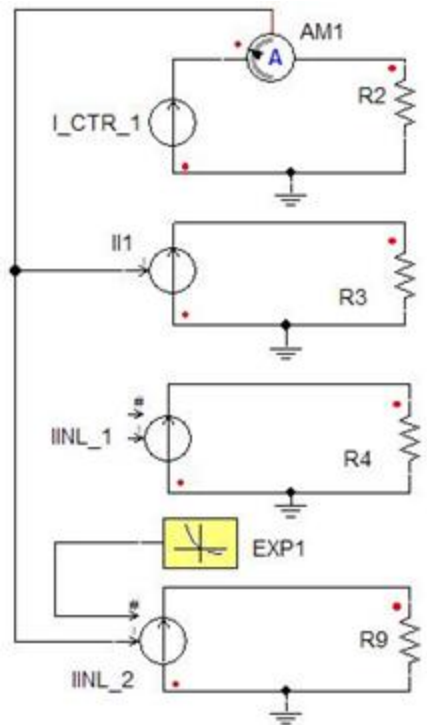


Figure 2. Application example of the Controlled Current Source models

Table 4. System Parameters

Component	Parameter	Value [unit]
Current Source I_CTR_1	EMF	t*10 [V]
Resistor R2/R3/R4/R9	R	1k [Ohm]
Controlled Current Source (Current Controlled) II1	QUANT	AM1.I [A]
	FACT	2
Controlled Current Source (Nonlinear Current Controlled) IINL_1	QUANT	AM1.I [A]
	CH	EXP1.VAL
Controlled Current Source (Nonlinear Current Controlled) IINL_2	QUANT	AM1.I [A]
	CH	EXP1.VAL
Exponential Function EXP1	VT	35m [V]

	ISAT	5p [A]
	RR	0.1Meg [Ohm]

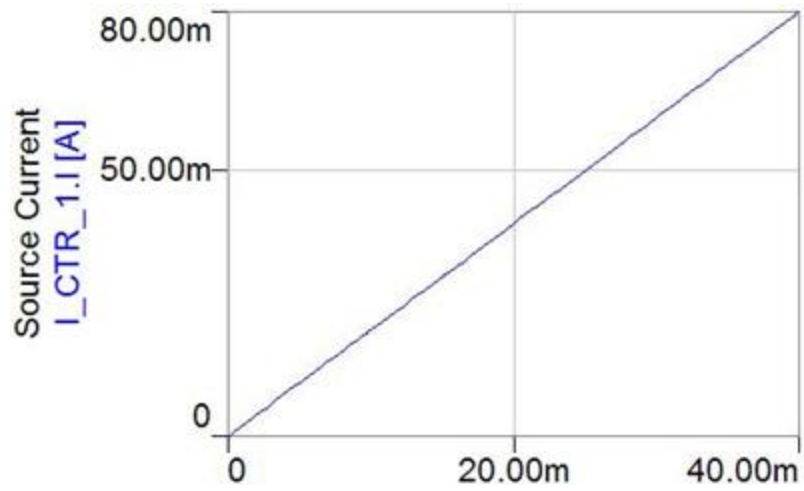


Figure 3. Simulation results- current output of the Linear Current Source I_CTR_1

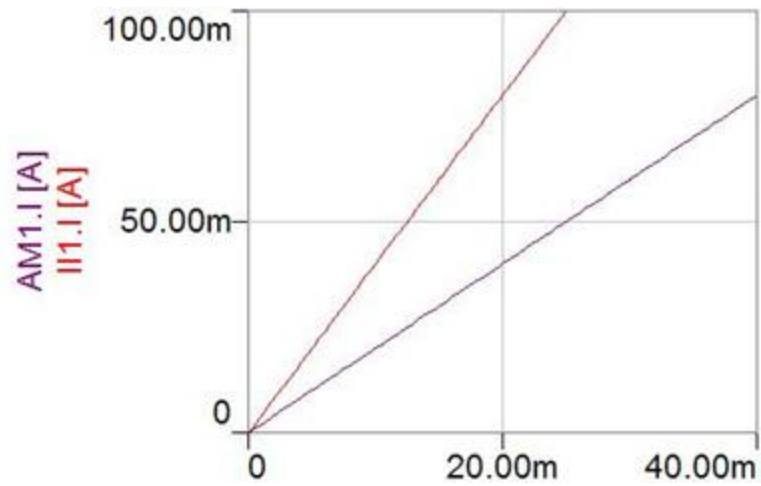


Figure 4. Simulation results- control current and current output of the Linear Current-Controlled Current Source I1

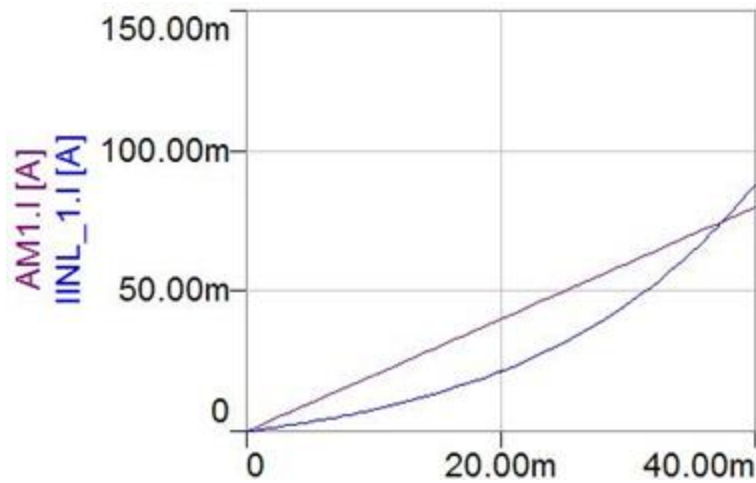


Figure 5. Simulation results-control current and current output of the Nonlinear current-Controlled Coltage Source I1NL_1

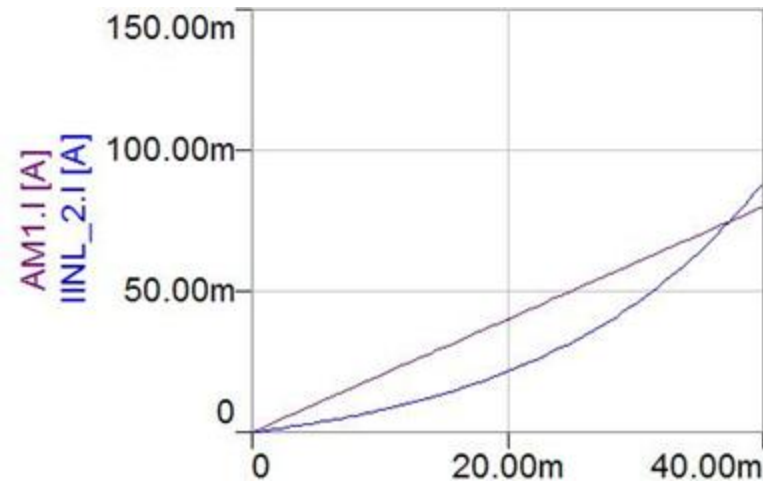


Figure 6. Simulation results-control current and current output of the Nonlinear current-Controlled Coltage Source I1NL_2

Collector Current Source

Description

The Nonlinear Collector Current Source model allows the static modeling of transistors (Early effect). The collector current depends via a nonlinear relation on both its own branch voltage ($v_{ce}(t)$) as well as the voltage of the controlling branch ($v_{be}(t)$).

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Assumptions and Limitations

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Mathematical Description

The output current of the Nonlinear Collector Current model is calculated as following:

$$i(t) = v_{be}(t) \cdot \ln \frac{v_{ce}(t) - VEA}{VCE - VEA}$$

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
N1	Pin 1 (with red point)	electrical
N2	Pin 2	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
VEA	Early Voltage	real	0 [V]
VCE	Collector-emitter reference potential	real	100 [V]
QUANT	Control Quantity	real	1 [V]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
V	Voltage [V]	Output	real
I	Current [A]	Output	real
dV	Derivative of Voltage [V/s]	Output	real
dI	Derivative of Current [A/s]	Output	real

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Example

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References

[1] Roland E. Thomas, Albert J. Rosa. "The Analysis and Design of Linear Circuits." John Wiley & Sons, Inc., May, 2003.

Multidimensional Table Source

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

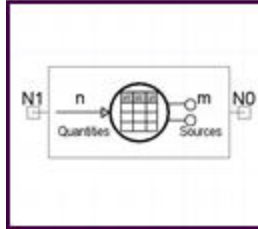


Figure 1. Component symbol

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Description

The multidimensional table source represents a table of controlled electrical sources (voltage and current), which depend on different, nonlinear input quantities. Each input quantity (node voltage or current of ammeter) has a specific characteristic with extrapolation type. The characteristics of input values can also be imported from an existing data file.

Note: The multidimensional table source component differs from V7 in that limited input/outputs are allowed. Each instance of the table source will have two complementary output terminals. Multiple output channels may be defined but only one can be assigned to the output terminals for each instance of the component, and any output channel selected will be shown as SRC_QUANT[0] for that instance. Multiple outputs now require the use of multiple instances of the table source component. In addition, each table source may have up to 6 inputs assigned to terminals. Additional inputs are allowed but cannot have terminals assigned. Connections to these inputs can be accomplished by editing the **Input** field in the Special Component Dialog or in the Properties dialog.

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Assumptions and Limitations

Note: The number of datasets in the multidimensional table is limited to 10000.

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Mathematical Description

If this component is used as a voltage source, the value of the n^{th} element of the output voltage vector can be expressed as:

$$v[n](t) = -f(v(\text{QUANT})[m], i(\text{QUANT})[m])$$

If this component is used as a current source, the value of the n^{th} element of the source current vector can be expressed as:

$$i[n](t) = f(v(\text{QUANT})[m], i(\text{QUANT})[m])$$

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
N0	First Source	electrical
N1	Second Source	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
P	Table File Name	Real	--
IP	Interpolation Type	Real	NONSPLINE
QUANT[n]	Control Input	Real	--
EP[n]	Extrapolation Type	Real	LINEAR
SRC[n]	Source Type	Real	VSRC

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
SRC_QUANT[0]	Output Vector	Output	real
dSRC_QUANT[0] [m]	Derivative of Output Vector	Output	real

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Example

In this example, the Multidimensional Table Source NDSRC2 is used as a voltage source. The input quantities are voltage of node N1 and N2. The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the input quantities and output voltage of NDSRC2 are shown in Figure 3 and 4.

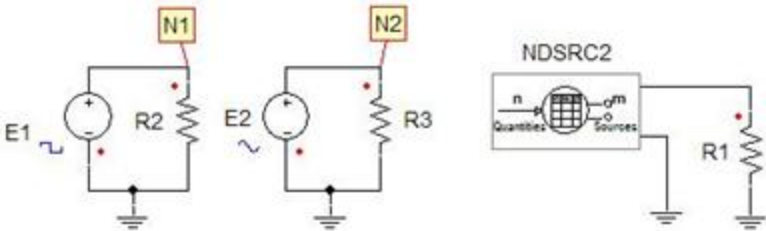


Figure 2. Application example of the Multidimensional Table as a voltage source

Table 4. System Parameters

Component	Parameter	Value [unit]
Voltage Source (sinusoidal) E1	AMPL	2 [V]
	FREQ	250 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	2 [V]
Resistor (Linear) R2/R3	R	1k [Ohm]
Resistor (Linear) R1	R	1 [Ohm]
Voltage Source (pulse) E1	AMPL	0.8 [V]
	FREQ	500 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0.8 [V]
Current Source (Triangular) I2	AMPL	326 [A]
	FREQ	50 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [A]
Multidimensional Table Source (voltage source) NDSRC2	P	NDSRC1_ssh_ NDSRC2.mdx
	IP	NONSPLINE

	QUANT[0]	N1.V
	QUANT[1]	N2.V
	EP[0]	LINEAR
	EP[1]	LINEAR
	SRC[0]	VSRC

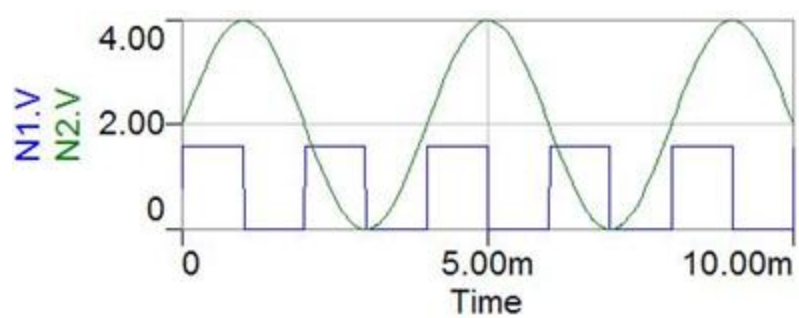


Figure 3. Simulation results-input quantities of NDSRC2

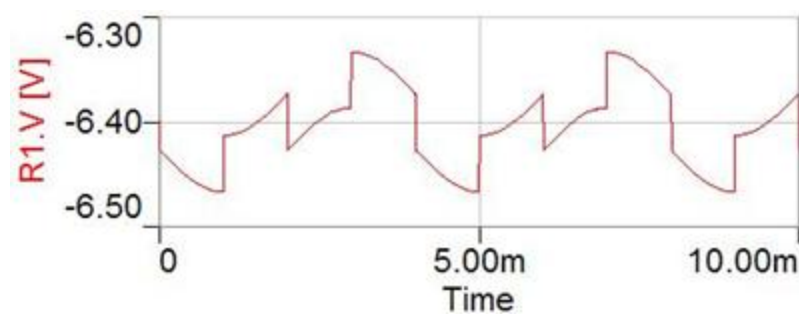


Figure 3. Simulation results-output voltage of NDSRC2

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References

Polynomial Source

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

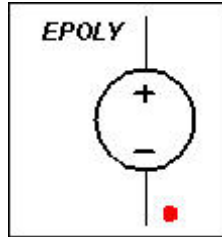


Figure 1. Component symbol

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- [Assumptions and Limitations](#)
- [Mathematical Description](#)
- [Netlist Syntax](#)
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- [Parameters](#)
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Description

The component represents a polynomial source. In this dialog box, you can choose to make it function as a voltage or current source. The function models polynomials of an order specified by the user. The meaning of the polynomial coefficients $\text{COEFF}[0]$, $\text{COEFF}[1]$, ..., $\text{COEFF}[n]$ depends on the order of the polynomial.

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Assumptions and Limitations

Internal losses are not considered in this component.

The polynomial functionality applies only to transient analysis.

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Mathematical Description

To illustrate how the output current/voltage are calculated, let's look at the cases when $m=1,2$ and 3. For ORD order of polynomial, the output current/voltage is calculated as:

$$\frac{i(t)}{v(t)} = \sum_{i=0}^{\text{ORD}} a_i x_1^i \quad (m = 1)$$

$$\frac{i(t)}{v(t)} = \sum_{\substack{i=0 \\ j \geq i}}^{\text{ORD}} a_{ij} x_1^i x_2^j \quad (m = 2)$$

$$\frac{i(t)}{v(t)} = \sum_{\substack{i=0 \\ j \geq i \\ k \geq j}}^{\text{ORD}} a_{ijk} x_1^i x_2^j x_3^k \quad (m = 3)$$

The same procedure can be applied to the case of m number of control quantities.

Note: the control quantities $x_1, x_2, \dots, x_m$ must be either voltage or current quantities. In addition, the coefficients a_i, a_{ij}, a_{ijk} used in the equations above are only for the purpose of demonstrating the calculation procedure. The actual polynomial coefficients COEFF[0], COEFF[1], ..., COEFF[n] are defined in the component dialog box. Since only the value of the control quantities are used for the calculation of the value of the output quantity, the polynomial coefficients doesn't have unit.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
N1	Pin 1 (with red point)	electrical
N2	Pin 2	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
ORD	Maximum of Power	real	0
QUANT [n]	Control Components and Quantity	real	-- [V] / [A]
COEFF [n]	Coefficients	real	0
AC_MAG	EMF Magnitude	real	1m [V] / [A]
AC_PHASE	EMF Phase Shift	real	0 [degree]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
V	Voltage [V]	Output	real
I	Current [A]	Output	real
EMF	EMF Value [V] (voltage source)	Output	real
IS	Source Current [A] (current source)	Output	real
dV	Derivative of Voltage [V/s]	Output	real
dI	Derivative of Current [A/s]	Output	real

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Example

In this example, the control quantities of the Polynomial Source E_POLY1 are the current measured by the Ammeter AM1-AM1.I and the voltage across the Resistor R1-R1.V. The output voltage of E_POLY1 is calculated as following:

$$v(t) = 0 + 1 \cdot x_1 + 1 \cdot x_2 + 1 \cdot x_1^2 + 2 \cdot x_1 \cdot x_2 + 0 \cdot x_2^2.$$

The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the waveforms of the output voltage of the voltage sources are shown in Figure 3-5.

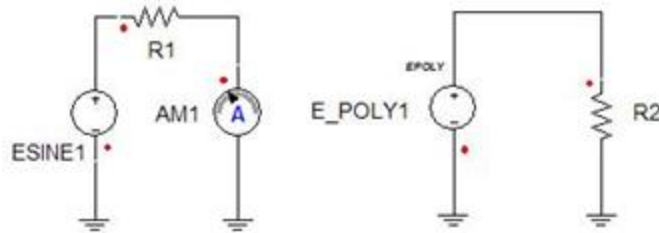


Figure 2. Application example of the Polynomial Source (voltage source) models**Table 4. System Parameters**

Component	Parameter	Value [unit]
Voltage Source (sinusoidal) ESINE1	AMPL	1 [V]
	FREQ	50 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [A]
Resistor R1/R2	R	1 [Ohm]
Polynomial Source (voltage source) E_ POLY1	ORD	2 [V]
	QUANT[0]	R1.V
	QUANT[0]	AM1.I
	COEFF[0]	0
	COEFF[1]	1
	COEFF[2]	1
	COEFF[3]	1
	COEFF[4]	2
	COEFF[5]	0

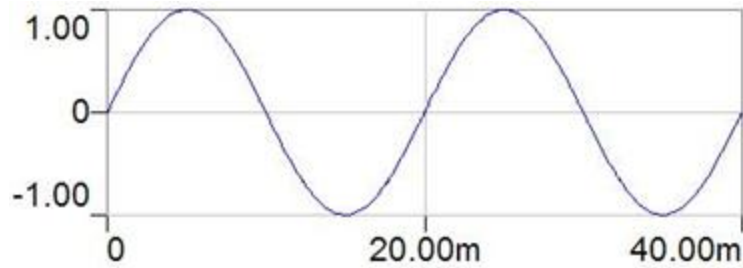


Figure 3. Simulation result-current through the Ammeter AM1

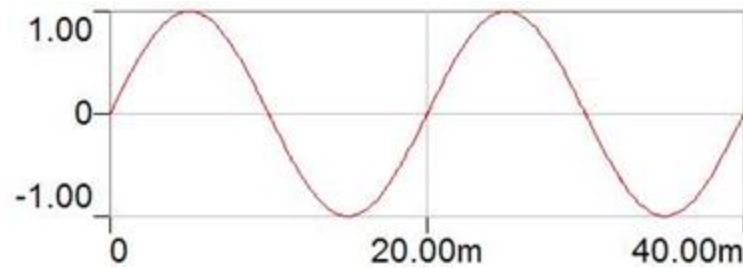


Figure 4. Simulation result-voltage across R1

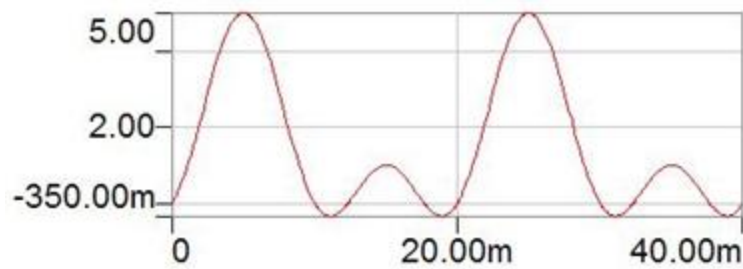


Figure 5. Simulation result-output voltage of E_POLY1

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References

Power Source

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

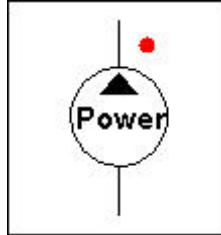


Figure 1. Component symbol

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Description

The component is able to work as either a power source (positive power) or power sink (negative power). However, the circuit must be technically meaningful. You cannot use the component as sink when it is connected only with a resistor. If you use the component as source (positive power) connected only with a resistor, two solutions with opposite current and voltage values exist.

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Assumptions and Limitations

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Mathematical Description

The power output P of this component is calculated as following:

$$\text{POWER}(t) = v(t) \cdot i(t)$$

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Netlist Syntax

INTERN PSRC ?InstanceName(@InstanceName):(@ (Refbase)@(ID)) N1:= %0 , N2:= %1 (P
:= @P , AC_PHASE := @AC_PHASE , AC_MAG := @AC_MAG);

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
N1	Pin 1 (with red point)	electrical
N2	Pin 2	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
P	Power	Real	1 [W]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
V	Voltage [V]	Output	real
I	Current [A]	Output	real
dV	Derivative of Voltage [V/s]	Output	real
dI	Derivative of Current [A/s]	Output	real

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Example

In this example, the power output of the Power Source P31 is decided by a Sine Wave block SINE2. The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the output voltage, current and power of P31 are shown in Figure 3.

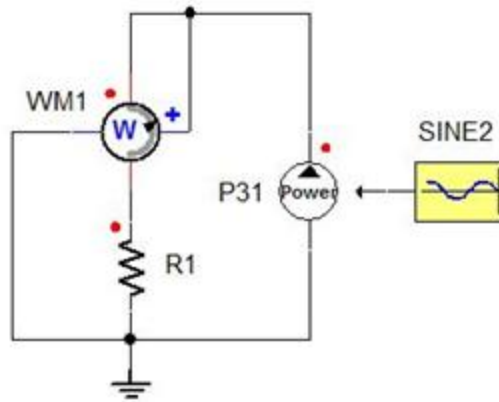


Figure 2. Application example of the Power Source model

Table 4. System Parameters

Component	Parameter	Value [unit]
Sine Wave SINE2	AMPL	25
	FREQ	50 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	50 [V]
Resistor (Linear) R1	R	1k [Ohm]
Power Source P31	P	SINE2.VAL [W]

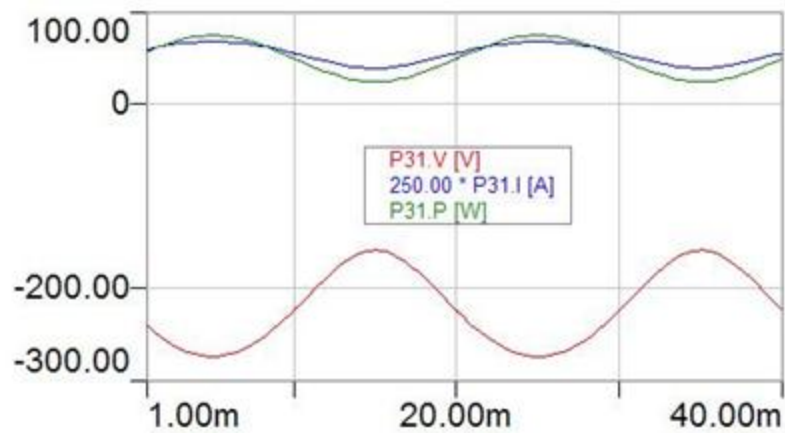


Figure 3. Simulation results-output voltage, current and power of the Power Source P31

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References

[1] Roland E. Thomas, Albert J. Rosa. "The Analysis and Design of Linear Circuits." John Wiley & Sons, Inc., May, 2003.

Voltage-Controlled Oscillator

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

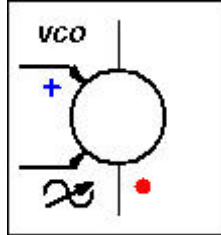


Figure 1. Component symbol

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Description

The component represents a voltage-controlled Oscillator. In this dialog box, you can choose to make this component a voltage or current source.

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Assumptions and Limitations

Internal losses are not considered in this component.

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Mathematical Description

The Voltage Controlled Oscillator provides a sine wave with a frequency dependent on the input voltage. The frequency/input voltage relation can be described as 1:1, e.g. $v_{\text{control}}=50\text{V} \rightarrow f=50\text{Hz}$. Furthermore you can define amplitude and phase shift of the output sine wave and limit of the control signal.

If this component is used as a voltage source, the output voltage is calculated as following:

$$v(t) = AMPL \cdot \sin \left(2\pi \int_0^t f(\tau) d\tau + PHASE \right)$$

If this component is used as a current source, the output current is calculated as following:

$$i(t) = AMPL \cdot \sin \left(2\pi \int_0^t f(\tau) d\tau + PHASE \right)$$

where the frequency f equals the value of V_{control} , i.e., $f = \text{value}(V_{\text{control}})$. If the Limit Input Voltage option is selected,

$$f = \begin{cases} \text{value}(V_{\text{control}}) & LL \leq V_{\text{control}} \leq UL \\ \text{value}(LL) & V_{\text{control}} < LL \\ \text{value}(UL) & V_{\text{control}} > UL \end{cases}$$

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Port/Terminal Description	Nature/Data Type
N1	Pin 1 (with red point)	electrical
N2	Pin 2	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
UL	Input Voltage Upper Limit	real	0 [V]

LL	Input Voltage Lower Limit	real	0 [V]
AMPL	Amplitude	real	0.326k [V]
PHASE	Phase	real	0 [deg]
AC_MAG	EMF Magnitude	real	1m [V]/[A]
AC_PHASE	EMF Phase Shift	real	0 [degree]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
V	Voltage [V]	Output	real
I	Current [A]	Output	real
FREQU	Frequency [Hz]	Output	real
dV	Derivative of Voltage [V/s]	Output	real
dI	Derivative of Current [A/s]	Output	real

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Example

Voltage Controlled Oscillator as a Current Source

In this example, the Voltage Controlled Oscillator is used as a current source. The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the waveforms of the output voltage of the voltage sources are shown in Figure 3 and 4.

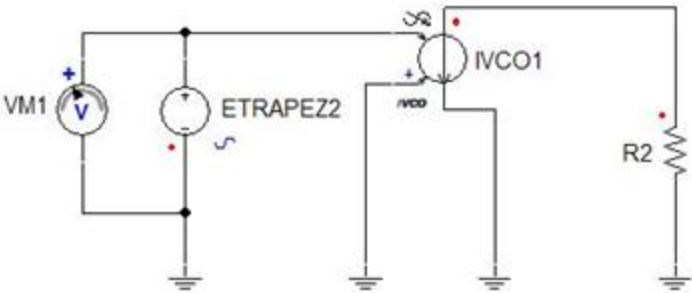


Figure 2. Application example of the Voltage Controlled Oscillator (current source) models

Table 4. System Parameters

Component	Parameter	Value [unit]
Voltage Source (Trapezoidal) ETRAPEZ2	AMPL	311 [A]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0 [A]
	TRISE	10m [s]
	TFALL	10m [s]
	PWIDTH	10m [s]
Resistor R2	R	1k [Ohm]
Voltage Controlled Oscillator (current source) IVCO1 (Input Voltage Limit is not set)	AMPL	10 [A]
	PHASE	0 [deg]
	AC_MAG	1m [A]
	AC_PHASE	0 [degree]

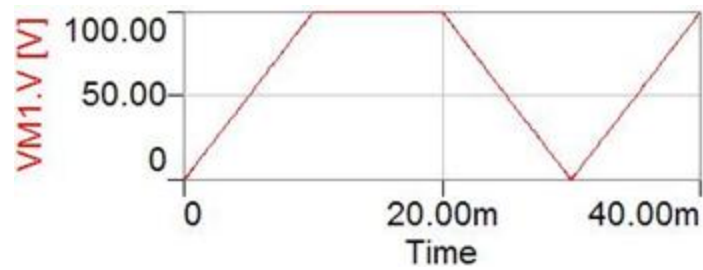


Figure 3. Simulation result-control voltage for IVC01

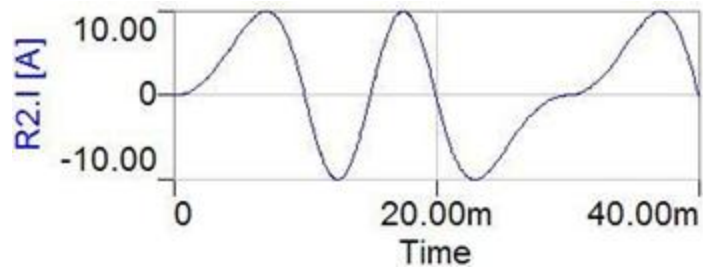


Figure 4. Simulation result-current output of IVC01

Voltage Controlled Oscillator as a Voltage Source

In this example, the Voltage Controlled Oscillator is used as a voltage source. The schematic of the example is shown in Figure 5, system parameters are listed in Table 5, and the waveforms of the output voltage of the voltage sources are shown in Figure 6 and 7.

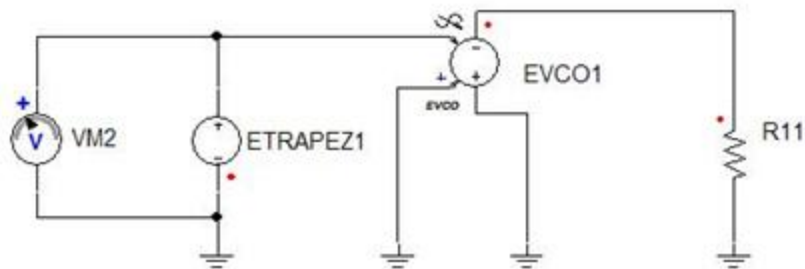


Figure 2. Application example of the Voltage Controlled Oscillator (voltage source) models

Table 4. System Parameters

Component	Parameter	Value [unit]
Voltage Source (Trapezoidal) ETRAPEZ1	AMPL	311 [V]
	TDELAY	0 [s]
	PHASE	0 [degree]

	OFF	0 [A]
	TRISE	10m [s]
	TFALL	10m [s]
	PWIDTH	10m [s]
Resistor R11	R	1k [Ohm]
Voltage Controlled Oscillator (voltage source) EVCO1 (Input Voltage Limit is not set)	AMPL	300 [V]
	PHASE	0 [deg]
	AC_MAG	1m [V]
	AC_PHASE	0 [degree]

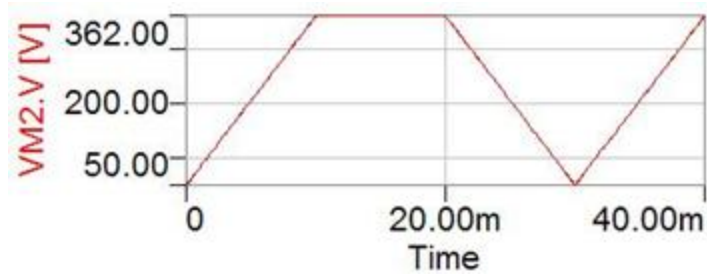


Figure 6. Simulation result-control voltage for EVC01

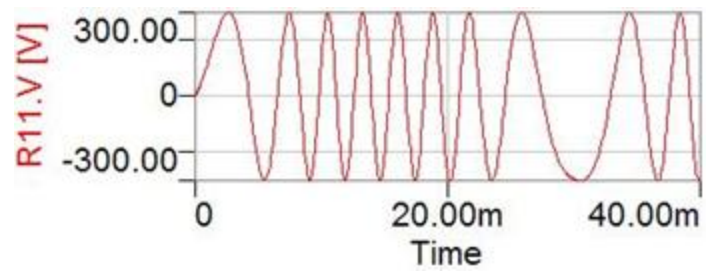


Figure 7. Simulation result-voltage output of EVC01

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References

[1] Roland E. Thomas, Albert J. Rosa. "The Analysis and Design of Linear Circuits." John Wiley & Sons, Inc., May, 2003.

Introduction to SPICE-Compatible Models

SPICE-compatible models in Twin Builder include all diode and transistor models provided in Berkeley SPICE 3f5, the lossy line model (LTRA), and the newest process-based MOSFET models (BSIM and EKV). A four-pin version of the BJT model is provided. The SPICE semiconductor capacitor and resistor models are not included. The models support both AC and DC analysis.

Model Implementation

Default Parameter Handling

Initial Conditions

Convergence Tolerances

Temperature Effects on SPICE Compatible Models

Model Implementation

SPICE-compatible models are basic components at the device level. They run code from Berkeley SPICE 3f5, with additions for the BSIM3, BSIM4, and EKV model. The library interface to Twin Builder mimics the SPICE circuit environment.

The device models in PSPICE, derived from an earlier version 2g6 of Berkeley SPICE, have evolved independently and they are comparable to those in SPICE 3f5, but they are not necessarily identical. A reference on these differences is *Semiconductor Device Modeling with SPICE*, 2nd ed., by Guiseppe Massobrio and Paulo Antognetti, McGraw-Hill, 1993. This book also describes the differences with HSPICE models.

Vendor-specific SPICE models are often implemented as a SPICE subcircuit composed of several basic components. The SPICE converter in Twin Builder can handle the conversion of both basic component models, and subcircuit models.

A small number of model parameter names were changed to conform to Twin Builder naming conventions. SPICE can sometimes accept two versions of a parameter name (for example VTO or VT0). Twin Builder models accept only the preferred name (VTO). For transistor models, SPICE accepts a vector of initial voltages (for example IC with 3 elements), Twin Builder models accept the alternative separate parameters for initial voltages (for example ICVDS, ICVGS, and ICVBS).

SPICE-compatible Twin Builder models combine model and instance parameters in one component, whereas SPICE manages these parameter sets separately. SPICE also handles default parameters differently.

[See also Default Parameter Handling](#)

SPICE-compatible Twin Builder models perform their own integration of charges and other state variables, always using the 2nd-order trapezoidal integration method. They also perform their own estimates of local truncation error, for use in limiting the time step. For these and other reasons, the SPICE-compatible models can behave differently than typical Twin Builder models.

[See also Initial Conditions](#)

[See also Convergence Tolerances](#)

Default Parameter Handling

For SPICE-compatible models, the default values were determined by creating a new instance of the device, and querying the library code for parameter values at the default temperature of 27 °C. A few of the default parameter values listed in the SPICE 3f5 documentation do not include the temperature adjustment. For example, the VTO parameter in MOS3, and the KP parameter in MOS2, both have default values of 20u listed in the SPICE 3f5 documentation. But Twin Builder will report these default values as 20.7189u.

SPICE has the concept of a *not given* parameter, and by default no parameters are *given*. These parameters will still return a value when queried. For example, the diode breakdown voltage (BV) returns '0' when queried for a default value, but during simulation SPICE knows that BV was not specified and hence does not use it. The same effect can be simulated by specifying *infinity* for BV, as listed in the SPICE 3f5 documentation. The new SPICE-compatible models will return zero as default values for diode breakdown voltages and some of the BJT voltage parameters. In SPICE5 (model library in Simplorer 5), these default values were *infinity*, but the simulation behavior has not changed.

The *not given* and the *infinity default* approaches are not always equivalent. Sometimes there are side effects when parameters are not given - it may trigger more pre-processing in the SPICE model code. One example is the default U0=600 value from the SPICE 3f5 documentation for MOS1. This only applies if TOX is given, while KC and U0 are not given. Therefore Twin Builder shows the default value as '0' instead of '600', because the simulation of a default MOS1 will behave as if TOX, KC, and U0 are all not given.

The Schematic passes all parameters to the SPICE-compatible model library, whether the user changed them or not. Internally, the library decides whether a parameter was given or not, by comparing to the default value. If you change a few parameters, there can be a discrepancy if the SPICE 3 pre-processing (side effects) are not correct. There is no way to specify a parameter equal to its default value. The library act as if it was not given and the pre-processing side effects may not be correct. This only applies to components dropped on the sheet and edited by the user. These problems do not occur with SML text in macros. If the macro specifies only a few parameters, the library should behave exactly as SPICE does. This would apply to any vendor-specific model converted by Twin Builder.

Initial Conditions

SPICE has device-level initial conditions that are sometimes used to assist convergence, or to choose between multiple stable states. These options are available, but they behave differently in Twin Builder than in SPICE:

1. Users can specify that a semiconductor device is *off* during the DC solution. This is mainly used to choose between multiple stable operating points. It is applicable to DC, AC, and TR analysis. The terminal voltages are still allowed to vary when the device is specified *off*. If SPICE cannot reach a converged DC solution, it will try a second time, ignoring the *off* specs. In Twin Builder, the second attempt would not occur.
2. Users can specify initial semiconductor terminal voltages, but only for transient analysis. They are ignored for AC and DC. In SPICE, the DC solution before transient analysis is then skipped; any voltages left unspecified are assumed to be zero. The behavior for Twin Builder is different – any model with a specified initial voltage will try to hold that voltage at the terminals. In other parts of the circuit, the initial voltages are not set to zero as in SPICE, instead, Twin Builder solves for them as usual.

To employ option #1, set the OFF parameter for a device equal to '1'.

The device initial voltages (option #2) work, but it is easy to enter bad values and get bad solutions at time zero. The user is better off specifying initial voltages on external capacitors in the circuit. That will push the DC solution in the right direction. Initial voltages can also be specified on the LTRA model, at least when C is not zero. Please note that the preferred method in SPICE is to set initial node voltages, rather than device voltages. This method also works in Twin Builder.

Convergence Tolerances

The library code adjusts the standard SPICE convergence options, based on the Twin Builder simulation parameters. When running under Twin Builder, SPICE-compatible models do not use these parameters for convergence testing, but they may use the parameters to reject a time step due to estimated local truncation error in the numerical integrations. The main SPICE parameter controlling this is RELTOL, which is directly comparable to the Twin Builder LDF parameter.

SPICE Convergence Parameters

This summarizes SPICE 3f5 convergence parameters, specified on a .OPTIONS card.

- RELTOL – the relative error to be allowed in device voltage or current. Defaults to 0.1%, but users are often advised to make RELTOL=1%, either for faster simulations, or to achieve convergence in power electronic circuits. The Twin Builder default for LDF is 1%.
- ABSTOL and VNTOL – minimum absolute error tolerances, sometimes called *best accuracy*, for current and voltage, respectively. These come into play when the voltages and currents approach zero, and RELTOL would produce a very low magnitude. Default values for SPICE are ABSTOL=1e-12 and VNTOL=1e-6. These must often be increased for power electronics, and users are advised to set values 8 or 9 orders of magnitude below the peak current or voltage expected. The Twin Builder defaults for similar parameters VEmax and IEmax are both 1e-3, but these parameters do not mean the same as ABSTOL and VNTOL.
- CHGTOL – the *best accuracy* for charge on junction capacitances, independent of ABSTOL and VNTOL. Default value is 1e-14, often increased for power electronics.
- TRTOL – in SPICE, the local truncation error function estimates a time step, which is then multiplied by TRTOL for comparison to the present time step. Default value is 7, and it seems like a pure fudge factor. In Georgia Tech XSPICE, the default was changed to '1'. Users are sometimes advised to increase TRTOL, up to 40, for faster simulations by allowing larger time steps. There is no apparent counterpart in Twin Builder.
- GMIN – the minimum conductance allowed in SPICE. Devices will not add matrix elements of lower magnitude than GMIN to the Jacobian. Defaults to 1e-12. There is no apparent counterpart in Twin Builder.
- Various Iteration Limits – Twin Builder takes care of the iteration limits for the SPICE models, so the SPICE iteration limits are not discussed here.

To assist convergence, SPICE users are often advised to loosen the tolerances, especially RELTOL. Increasing the iteration limits is also suggested.

Users are not often advised to tighten up the SPICE tolerances. An exception is with the voltage-controlled and current-controlled switches, where CHGTOL=1e-16 and TRTOL=1 has been suggested. The values should not be changed for this reason in Twin Builder, because it does not use the SPICE switch models.

Besides their use for error estimates, nearly all of the SPICE device models refer to some of the convergence parameters internally when loading the Jacobian and the right-hand side. Sometimes this is used to bypass some calculations, and other times to adjust the matrix elements.

SPICE Tolerances in Twin Builder

SPICE-compatible models set their convergence parameters from Twin Builder:

- RELTOL is taken from LDF on the Twin Builder TR parameters, scaling by 0.01 to convert LDF from percent. LDF is used even for the Twin Builder DC analysis, because the same code executes both DC and Transient analysis in the SPICE models.
- ABSTOL is the default value scaled by Twin Builder IEmax or Emax. For transient analysis, $ABSTOL = 1e-12 * IEmax / 1e-3$, because $1e-3$ is the Twin Builder default value for IEmax. For DC analysis, including that which precedes AC analysis, $ABSTOL = 1e-12 * EmaxDC / 1e-3$. For AC analysis, $ABSTOL = 1e-12 * EmaxAC / 1e-6$, but it has no effect in the SPICE model execution.
- VNTOL is also scaled by Twin Builder VEmax or Emax. For transient analysis, $VNTOL = 1e-6 * VEmax / 1e-3$. For DC analysis, $VNTOL = 1e-6 / EmaxDC / 1e-3$, and for AC analysis, $VNTOL = 1e-6 / EmaxAC / 1e-6$.
- CHGTOL is the default value scaled by the $ABSTOL * VNTOL$ product. $CHGTOL = 1e-14 * ABSTOL * VNTOL / 1e-18$.
- After getting ABSTOL, VNTOL, and CHGTOL, the minimum values are limited to 100 times less than their SPICE defaults. $ABSTOL_{min} = 1e-14$, $VNTOL_{min} = 1e-8$, and $CHGTOL_{min} = 1e-16$. There are no maximum values for ABSTOL, VNTOL, and CHGTOL.
- There are no minimum or maximum limits on RELTOL.
- GMIN is fixed at $1e-12$, and TRTOL is fixed at 7.

Recommendations

The main parameter for users to adjust would be LDF, just as the main SPICE parameter to adjust would be RELTOL. The suggested starting value is 1%, and later decreasing to 0.1% for more accuracy. The default behavior of the SPICE-compatible models will be $RELTOL=0.01$ instead of $RELTOL=0.001$, but all other default convergence parameters are the same as in SPICE 3f5.

The DC analysis of a SPICE-compatible model executes the same code as for a transient analysis, and it will use RELTOL (LDF) from the Twin Builder transient parameters. This value should be reviewed when running a DC analysis.

In most cases, the Twin Builder default values of $1e-3$ for IEmax and VEmax will work with the SPICE-compatible models. However, it may be necessary to reduce them for acceptable results in some cases.

SPICE 3f5 users are sometimes advised to allow up to 500 iterations for DC and transient analysis. If convergence becomes a problem, these higher limits can be set directly in the Twin Builder simulation parameter ITERATMAX.

Temperature Effects on SPICE-Compatible Models

SPICE semiconductor device parameters can be adjusted for temperature. If you define the component temperature different from the default value of 27 degC, that temperature is used. Otherwise the model ambient temperature, which is defined as simulation parameter, is used.

If you change the model ambient temperature in [Project]>[Design]>Analysis>Options>General>Ambient temperature (Cel) - Temp, but you want a component to stay at the default value of 27, then you must change that component temperature to a slightly different value, such as 27.01. This is necessary because of how the library must handle default values.

SPICE-Compatible Models

- [Bipolar Junction Transistors](#)
- [Diode](#)
- [Field-Effect Transistors](#)
- [Line Models](#)

SPICE-Compatible Bipolar Junction Transistors

The BJT components are implemented as C models. The models use the *MaxwellSpice.dll* file.

The simulation parameter Hmin (minimum time step) should be 0.1ns for the first simulation run. Then you can adjust the value for optimal simulation performance. For simulations of power electronics circuits, Hmin can be up to 100ns.

- [SPICE-Compatible NPN \(SPICE_NPN\)](#)
- [SPICE-Compatible NPN 4 Pins \(SPICE_NPN4\)](#)
- [SPICE-Compatible PNP \(SPICE_PNP\)](#)
- [SPICE-Compatible PNP 4 Pins \(SPICE_PNP4\)](#)

BJT Models - SPICE-Compatible NPN

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

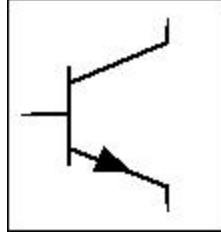


Figure 1. Component Symbol.

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- [Assumptions and Limitations](#)
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- [Netlist Syntax](#)
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- [Example](#)
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Description

The Spice-compatible BJT NPN-type, BJT PNP-type, BJT4 NPN-type, and BJT4 PNP-type models simulate the electrical and thermal behavior of a bipolar junction transistor using SPICE3 parameters and equations. Electrical characteristics and the temperature dependence of transistor behavior are calculated according to user-defined device parameters.

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Assumptions and Limitations

Figure 2 shows the current and voltage reference arrow system for this component.

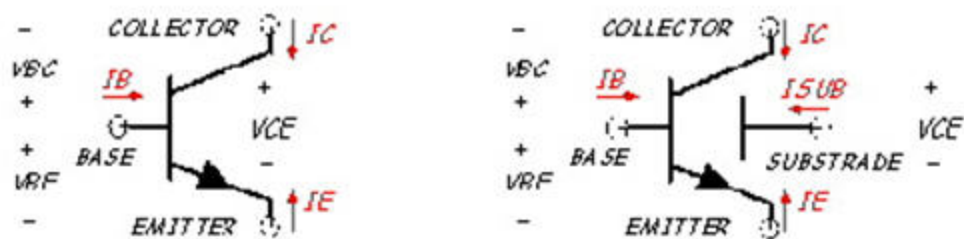


Figure 2. Current and Voltage Reference Arrow System

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Mathematical Description

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Netlist Syntax

UMODEL SPICE_NPN ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) COLLECTOR:= %0, BASE:= %1, EMITTER:= %2 (OFF:= @OFF, ICVBE:= @ICVBE, ICVCE:= @ICVCE, AREA:= @AREA, TEMP:= @TEMP, IS:= @IS, BF:= @BF, NF:= @NF, VAF:= @VAF, IKF:= @IKF, ISE:= @ISE, NE:= @NE, BR:= @BR, NR:= @NR, VAR:= @VAR, IKR:= @IKR, ISC:= @ISC, NC:= @NC, RB:= @RB, IRB:= @IRB, RBM:= @RBM, RE:= @RE, RC:= @RC, CJE:= @CJE, VJE:= @VJE, MJE:= @MJE, TF:= @TF, XTF:= @XTF, VTF:= @VTF, ITF:= @ITF \\\ , PTF:= @PTF, CJC:= @CJC, VJC:= @VJC, MJC:= @MJC, XCJC:= @XCJC, TR:= @TR, CJS:= @CJS, CCS:= @CCS, VJS:= @VJS, MJS:= @MJS, XTB:= @XTB, EG:= @EG, XTI:= @XTI, FC:= @FC, TNOM:= @TNOM, KF:= @KF, AF:= @AF) SRC: DB(Lib:=@ModellibraryName) ;

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
ANODE	Base	electrical
CATHODE	Emitter	electrical
COLLECTOR	Collector	electrical
SUBSTRATE	Substrate (4-pin models)	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value

			[Unit]
OFF	Device Initially Off	real	0
ICVBE	Initial Base-Emitter Voltage	real	0 [V]
ICVCE	Initial Collector-Emitter Voltage	real	0 [V]
AREA	Area Factor	real	1
TEMP	Instance Temperature	real	27 [°C]
IS	Saturation Current	real	0.1f [A]
BF	Ideal Forward Beta	real	0.1k [A/A]
NF	Forward Emission Coefficient	real	1
VAF	Forward Early Voltage	real	0 [V]
IKF	Forward Beta Roll-off Corner Current	real	0 [A]
ISE	Base-Emitter Leakage Saturation Current	real	0 [A]
NE	Base-Emitter Leakage Emission Coefficient	real	1.5
BR	Ideal Reverse Beta	real	1 [A/A]
NR	Reverse Emission Coefficient	real	1
VAR	Reverse Early Voltage	real	0 [V]
IKR	Reverse Beta Roll-off Corner Current	real	0 [A]
ISC	Base-Collector Leakage Saturation Current	real	0 [A]
NC	Base-Collector Leakage Emission Coefficient	real	2
RB	Zero-bias Base Resistance	real	0 [Ohm]
IRB	Current for Base Resistance Falling to 1/2 Minimum	real	0 [A]
RBM	Minimum Base Resistance	real	0 [Ohm]
RE	Emitter Resistance	real	0 [Ohm]
RC	Collector Resistance	real	0 [Ohm]
CJE	Zero-bias B-E Depletion Capacitance	real	0 [F]
VJE	Base-Emitter Built-in Potential	real	0.75 [V]
MJE	Base-Emitter Junction Grading Coefficient	real	0.33
TF	Ideal Forward Transit Time	real	0 [s]

XTF	Coefficient for Bias-dependence of TF	real	0
VTF	Voltage Giving VBC-dependence of TF	real	0 [V]
ITF	High-current Parameter for Effect on TF	real	0 [A]
PTF	Excess Phase	real	0 [deg]
CJC	Zero-bias BC Depletion Capacitance	real	0 [F]
VJC	BC Built-in Potential	real	0.75 [V]
MJC	BC Junction-grading Coefficient	real	0.33
XCJC	Fraction of BC Capacitance Connected to Internal Base	real	1
TR	Ideal Reverse Transit Time	real	0 [s]
CJS	Zero-bias CS Capacitance	real	0 [F]
CCS	Zero-bias CS Capacitance	real	0 [F]
VJS	Substrate Junction Built-in Potential	real	0.75 [V]
MJS	Substrate Junction Grading Coefficient	real	0
XTB	Forward and Reverse Beta Temperature Exponent	real	0
EG	Energy Gap for Saturation Current Temperature Dependency	real	1.11 [eV]
XTI	Temperature Exponent for Saturation Current	real	3
FC	Forward-bias Junction Fit Parameter	real	0.5
TNOM	Parameter Measurement Temperature	real	27 [°C]
KF	Flicker Noise Coefficient	real	0
AF	Flicker Noise Exponent	real	0

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
IC	Current at Collector Node [A]	Output	real
IB	Current at Base Node [A]	Output	real

IE	Emitter Current [A]	Output	real
ISUB	Substrate Current [A]	Output	real
VBE	Base-Emitter Voltage [V]	Output	real
VBC	Base-Collector Voltage [V]	Output	real
VCE	Collector-Emitter Voltage [V]	Output	real
P	Power Dissipation [W]	Output	real

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Example

Figure 3 shows application of the Spice-Compatible NPN-type and PNP-type BJT model. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 4.

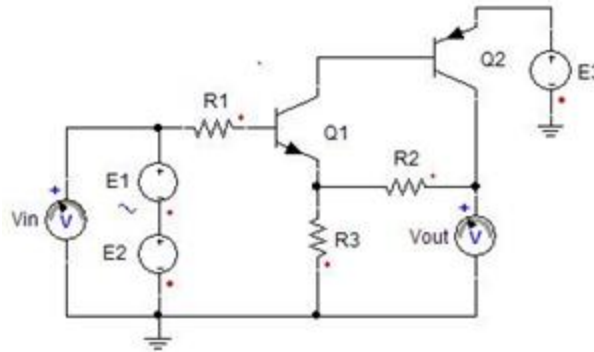


Figure 3. Application example of the Spice-Compatible BJT Model

Table 3

Component	Parameter	Value
Voltage Source (sinusoidal) E1	AMPL	0.1 [V]
	FREQ	15k [Hz]
	PHASE	0 [degree]
	OFF	0 [V]
	TDELAY	0 [s]
Voltage Source E2	EMF	0.58 [V]
Voltage Source E3	EMF	10 [V]
Resistor R1/R2	R	1k [Ohm]
Resistor R3	R	10 [Ohm]

Spice-Compatible NPN-Type BJT Q1	OFF	0

	ICVBE	0 [V]

	ICVCE	0 [V]

	AREA	1

TEMP	27 [°C]
IS	19f [A]
BF	150 [A/A]
NF	1
VAF	100 [V]
IKF	0.18 [A]
ISE	50p [A]
NE	2.5
BR	7.5 [A/A]
NR	1
VAR	6.4 [V]
IKR	12m [A]
ISC	8.7p [A]
NC	1.2
RB	50 [Ohm]
IRB	0 [A]
RBM	0 [Ohm]
RE	0.4[Ohm]
RC	0.3 [Ohm]
CJE	26p [F]
VJE	0.75 [V]
MJE	0.33
TF	0 [s]
XTF	0
VTF	0 [V]
ITF	0 [A]
PTF	0 [deg]
CJC	11p [F]
VJC	0.75 [V]
MJC	0.33

	XCJC	1
	TR	7n [s]
	CJS	0 [F]
	CCS	0 [F]
	VJS	0.75 [V]
	MJS	0
	XTB	1.5
	EG	1.11 [eV]
	XTI	3
	FC	0.5
	TNOM	27 [°C]
	KF	0.032f
	AF	1

Spice-Compatible PNP-Type BJT Q2	OFF	0

	ICVBE	0 [V]

	ICVCE	0 [V]

	AREA	1

TEMP	27 [°C]
IS	1.1p [A]
BF	200[A/A]
NF	1.2
VAF	50 [V]
IKF	0.1 [A]
ISE	13p [A]
NE	1.9
BR	6 [A/A]
NR	1
VAR	0 [V]
IKR	0 [A]
ISC	0 [A]
NC	2
RB	0 [Ohm]
IRB	0 [A]
RBM	0 [Ohm]
RE	0 [Ohm]
RC	0.6 [Ohm]
CJE	23p [F]
VJE	0.85 [V]
MJE	1.25
TF	0.5n [s]
XTF	0
VTF	0 [V]
ITF	0 [A]
PTF	0 [deg]
CJC	19p [F]
VJC	0.5 [V]
MJC	0.2

	XCJC	1
	TR	34n[s]
	CJS	0 [F]
	CCS	0 [F]
	VJS	0.75 [V]
	MJS	0
	XTB	1.5
	EG	1.11 [eV]
	XTI	3
	FC	0.5
	TNOM	27 [°C]
	KF	0
	AF	0

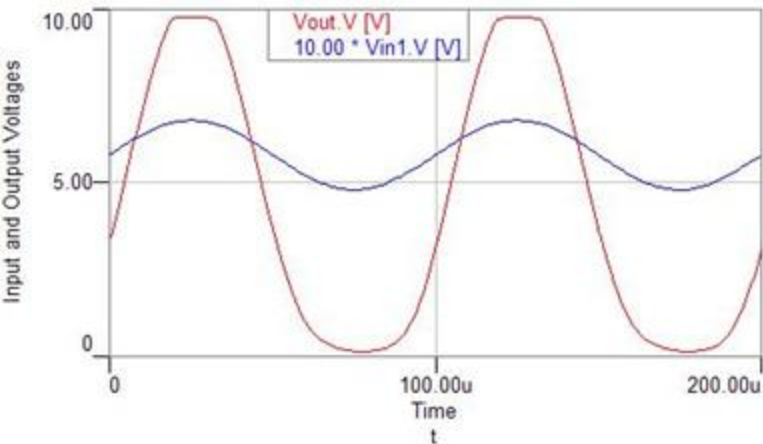


Figure 4. Simulation results-input and output voltage of Q1

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References

[1] Massobrio, Giueseppe, and Paolo Antognetti: *Semiconductor Device Modeling with SPICE*, New York: McGraw Hill, 1993

BJT Models - SPICE-Compatible 4-Pin NPN

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

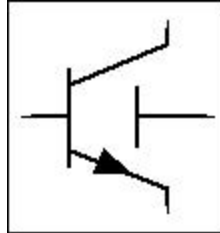


Figure 1. Component Symbol.

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- [Assumptions and Limitations](#)
- [Mathematical Description](#)
- [Netlist Syntax](#)
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- [Parameters](#)
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Description

The Spice-compatible BJT NPN-type, BJT PNP-type, BJT4 NPN-type, and BJT4 PNP-type models simulate the electrical and thermal behavior of a bipolar junction transistor using SPICE3 parameters and equations. Electrical characteristics and the temperature dependence of transistor behavior are calculated according to user-defined device parameters.

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Assumptions and Limitations

Figure 2 shows the current and voltage reference arrow system for this component.



Figure 2. Current and Voltage Reference Arrow System

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Mathematical Description

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Netlist Syntax

```

UMODEL SPICE_NPN4 ?InstanceName(@InstanceName):(@ (Refbase) @ (ID))
COLLECTOR:= %0, BASE:= %1, EMITTER:= %2, SUBSTRATE:= %3 ( OFF:= @OFF,
ICVBE:= @ICVBE, ICVCE:= @ICVCE, AREA:= @AREA, TEMP:= @TEMP, IS:= @IS, BF:=
@BF, NF:= @NF, VAF:= @VAF, IKF:= @IKF, ISE:= @ISE, NE:= @NE, BR:= @BR, NR:=
@NR, VAR:= @VAR, IKR:= @IKR, ISC:= @ISC, NC:= @NC, RB:= @RB, IRB:= @IRB, RBM:=
@RBM, RE:= @RE, RC:= @RC, CJE:= @CJE, VJE:= @VJE, MJE:= @MJE, TF:= @TF, XTF:=
@XTF, VTF:= @VTF, ITF:= @ITF \\\ , PTF:= @PTF, CJC:= @CJC, VJC:= @VJC, MJC:=
@MJC, XCJC:= @XCJC, TR:= @TR, CJS:= @CJS, CCS:= @CCS, VJS:= @VJS, MJS:=
@MJS, XTB:= @XTB, EG:= @EG, XTI:= @XTI, FC:= @FC, TNOM:= @TNOM, KF:= @KF,
AF:= @AF) SRC: DB(Lib:=@ModelLibraryName);

```

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
ANODE	Base	electrical
CATHODE	Emitter	electrical
COLLECTOR	Collector	electrical
SUBSTRATE	Substrate (4-pin models)	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
OFF	Device Initially Off	real	0
ICVBE	Initial Base-Emitter Voltage	real	0 [V]
ICVCE	Initial Collector-Emitter Voltage	real	0 [V]
AREA	Area Factor	real	1
TEMP	Instance Temperature	real	27 [°C]
IS	Saturation Current	real	0.1f [A]
BF	Ideal Forward Beta	real	0.1k [A/A]
NF	Forward Emission Coefficient	real	1
VAF	Forward Early Voltage	real	0 [V]
IKF	Forward Beta Roll-off Corner Current	real	0 [A]
ISE	Base-Emitter Leakage Saturation Current	real	0 [A]
NE	Base-Emitter Leakage Emission Coefficient	real	1.5
BR	Ideal Reverse Beta	real	1 [A/A]
NR	Reverse Emission Coefficient	real	1
VAR	Reverse Early Voltage	real	0 [V]
IKR	Reverse Beta Roll-off Corner Current	real	0 [A]
ISC	Base-Collector Leakage Saturation Current	real	0 [A]
NC	Base-Collector Leakage Emission Coefficient	real	2
RB	Zero-bias Base Resistance	real	0 [Ohm]
IRB	Current for Base Resistance Falling to 1/2 Minimum	real	0 [A]
RBM	Minimum Base Resistance	real	0 [Ohm]
RE	Emitter Resistance	real	0 [Ohm]
RC	Collector Resistance	real	0 [Ohm]
CJE	Zero-bias B-E Depletion Capacitance	real	0 [F]

VJE	Base-Emitter Built-in Potential	real	0.75 [V]
MJE	Base-Emitter Junction Grading Coefficient	real	0.33
TF	Ideal Forward Transit Time	real	0 [s]
XTF	Coefficient for Bias-dependence of TF	real	0
VTF	Voltage Giving VBC-dependence of TF	real	0 [V]
ITF	High-current Parameter for Effect on TF	real	0 [A]
PTF	Excess Phase	real	0 [deg]
CJC	Zero-bias BC Depletion Capacitance	real	0 [F]
VJC	BC Built-in Potential	real	0.75 [V]
MJC	BC Junction-grading Coefficient	real	0.33
XCJC	Fraction of BC Capacitance Connected to Internal Base	real	1
TR	Ideal Reverse Transit Time	real	0 [s]
CJS	Zero-bias CS Capacitance	real	0 [F]
CCS	Zero-bias CS Capacitance	real	0 [F]
VJS	Substrate Junction Built-in Potential	real	0.75 [V]
MJS	Substrate Junction Grading Coefficient	real	0
XTB	Forward and Reverse Beta Temperature Exponent	real	0
EG	Energy Gap for Saturation Current Temperature Dependency	real	1.11 [eV]
XTI	Temperature Exponent for Saturation Current	real	3
FC	Forward-bias Junction Fit Parameter	real	0.5
TNOM	Parameter Measurement Temperature	real	27 [°C]
KF	Flicker Noise Coefficient	real	0
AF	Flicker Noise Exponent	real	0

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
IC	Current at Collector Node [A]	Output	real
IB	Current at Base Node [A]	Output	real
IE	Emitter Current [A]	Output	real
ISUB	Substrate Current [A]	Output	real
VBE	Base-Emitter Voltage [V]	Output	real
VBC	Base-Collector Voltage [V]	Output	real
VCE	Collector-Emitter Voltage [V]	Output	real
P	Power Dissipation [W]	Output	real

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Example

Figure 3 shows application of the Spice-Compatible 4-Pin NPN-type BJT model. The parameters of the Spice-Compatible Diode models SPICE_D1, SPICE_D2, SPICE_D3 and those of the Spice-Compatible 4-Pin NPN-Type BJT model SPICE_NPN41 are set to their default values; the parameters of the rest of the system are listed in Table 4 and the simulation results shown in Figure 4 and 5.

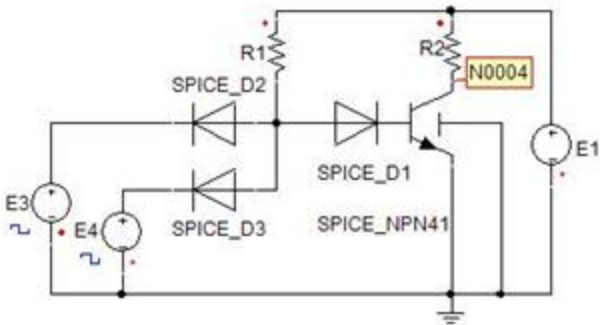


Figure 3. Application example of the Spice-Compatible 4-pin BJT Model

Table 3

Component	Parameter	Value

Voltage Source (pulse) E3	AMPL	2.5 [V]
	FREQ	100E+006 [Hz]
	PHASE	-180 [degree]
	OFF	2.5 [V]
	TDELAY	0 [s]
Voltage Source (pulse) E4	AMPL	2.5 [V]
	FREQ	200E+006 [Hz]
	PHASE	-180 [degree]
	OFF	2.5 [V]
	TDELAY	0 [s]
Voltage Source E1	EMF	5 [V]
Resistor R1/R2	R	1k [Ohm]

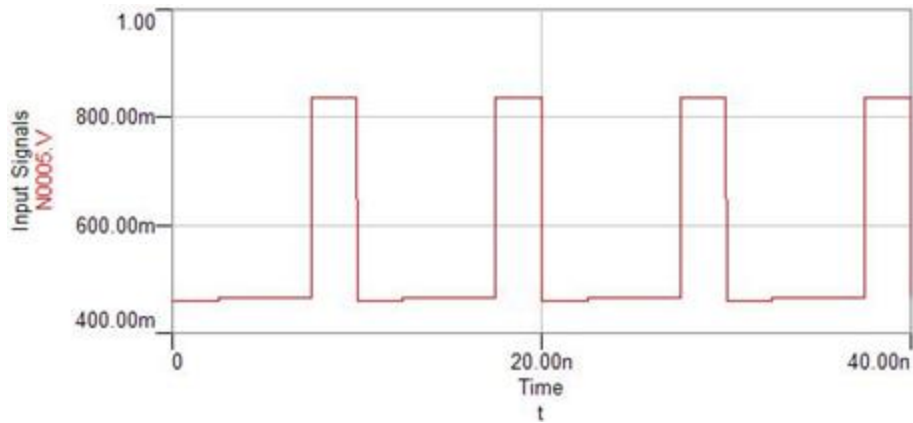


Figure 4. Simulation results-input voltage of SPICE_NPN41

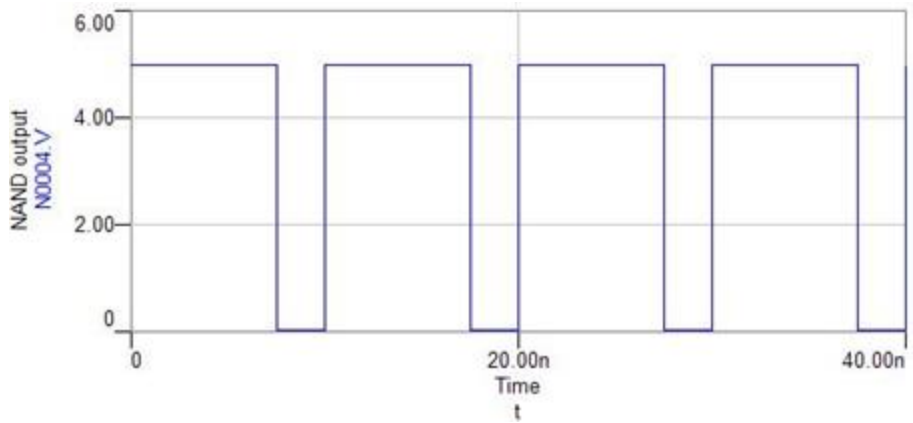


Figure 4. Simulation results-output collector voltage of SPICE_NPN41

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References

[1] Massobrio, Giuseppe, and Paolo Antognetti: *Semiconductor Device Modeling with SPICE*, New York: McGraw Hill, 1993

BJT Models - SPICE-Compatible PNP

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

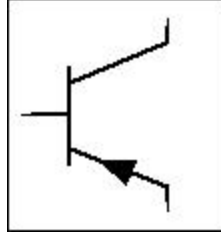


Figure 1. Component Symbol.

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Description

The Spice-compatible BJT NPN-type, BJT PNP-type, BJT4 NPN-type, and BJT4 PNP-type models simulate the electrical and thermal behavior of a bipolar junction transistor using SPICE3 parameters and equations. Electrical characteristics and the temperature dependence of transistor behavior are calculated according to user-defined device parameters.

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Assumptions and Limitations

Figure 2 shows the current and voltage reference arrow system for this component.



Figure 2. Current and Voltage Reference Arrow System

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Mathematical Description

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Netlist Syntax

```
UMODEL SPICE_PNP ?InstanceName(@InstanceName):(@Refbase@ID) COLLECTOR:=
%0, BASE:= %1, EMITTER:= %2 ( OFF:= @OFF, ICVBE:= @ICVBE, ICVCE:= @ICVCE,
AREA:= @AREA, TEMP:= @TEMP, IS:= @IS, BF:= @BF, NF:= @NF, VAF:= @VAF, IKF:=
@IKF, ISE:= @ISE, NE:= @NE, BR:= @BR, NR:= @NR, VAR:= @VAR, IKR:= @IKR, ISC:=
@ISC, NC:= @NC, RB:= @RB, IRB:= @IRB, RBM:= @RBM, RE:= @RE, RC:= @RC, CJE:=
@CJE, VJE:= @VJE, MJE:= @MJE, TF:= @TF, XTF:= @XTF, VTF:= @VTF, ITF:= @ITF \\\ ,
PTF:= @PTF, CJC:= @CJC, VJC:= @VJC, MJC:= @MJC, XCJC:= @XCJC, TR:= @TR, CJS:=
@CJS, CCS:= @CCS, VJS:= @VJS, MJS:= @MJS, XTB:= @XTB, EG:= @EG, XTI:= @XTI,
FC:= @FC, TNOM:= @TNOM, KF:= @KF, AF:= @AF) SRC: DB(Lib:=@ModelLibraryName) ;
```

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
ANODE	Base	electrical
CATHODE	Emitter	electrical
COLLECTOR	Collector	electrical
SUBSTRATE	Substrate (4-pin models)	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
OFF	Device Initially Off	real	0
ICVBE	Initial Base-Emitter Voltage	real	0 [V]
ICVCE	Initial Collector-Emitter Voltage	real	0 [V]
AREA	Area Factor	real	1
TEMP	Instance Temperature	real	27 [°C]
IS	Saturation Current	real	0.1f [A]
BF	Ideal Forward Beta	real	0.1k [A/A]
NF	Forward Emission Coefficient	real	1
VAF	Forward Early Voltage	real	0 [V]
IKF	Forward Beta Roll-off Corner Current	real	0 [A]
ISE	Base-Emitter Leakage Saturation Current	real	0 [A]
NE	Base-Emitter Leakage Emission Coefficient	real	1.5
BR	Ideal Reverse Beta	real	1 [A/A]
NR	Reverse Emission Coefficient	real	1
VAR	Reverse Early Voltage	real	0 [V]
IKR	Reverse Beta Roll-off Corner Current	real	0 [A]
ISC	Base-Collector Leakage Saturation Current	real	0 [A]
NC	Base-Collector Leakage Emission Coefficient	real	2
RB	Zero-bias Base Resistance	real	0 [Ohm]
IRB	Current for Base Resistance Falling to 1/2 Minimum	real	0 [A]
RBM	Minimum Base Resistance	real	0 [Ohm]
RE	Emitter Resistance	real	0 [Ohm]
RC	Collector Resistance	real	0 [Ohm]
CJE	Zero-bias B-E Depletion Capacitance	real	0 [F]

VJE	Base-Emitter Built-in Potential	real	0.75 [V]
MJE	Base-Emitter Junction Grading Coefficient	real	0.33
TF	Ideal Forward Transit Time	real	0 [s]
XTF	Coefficient for Bias-dependence of TF	real	0
VTF	Voltage Giving VBC-dependence of TF	real	0 [V]
ITF	High-current Parameter for Effect on TF	real	0 [A]
PTF	Excess Phase	real	0 [deg]
CJC	Zero-bias BC Depletion Capacitance	real	0 [F]
VJC	BC Built-in Potential	real	0.75 [V]
MJC	BC Junction-grading Coefficient	real	0.33
XCJC	Fraction of BC Capacitance Connected to Internal Base	real	1
TR	Ideal Reverse Transit Time	real	0 [s]
CJS	Zero-bias CS Capacitance	real	0 [F]
CCS	Zero-bias CS Capacitance	real	0 [F]
VJS	Substrate Junction Built-in Potential	real	0.75 [V]
MJS	Substrate Junction Grading Coefficient	real	0
XTB	Forward and Reverse Beta Temperature Exponent	real	0
EG	Energy Gap for Saturation Current Temperature Dependency	real	1.11 [eV]
XTI	Temperature Exponent for Saturation Current	real	3
FC	Forward-bias Junction Fit Parameter	real	0.5
TNOM	Parameter Measurement Temperature	real	27 [°C]
KF	Flicker Noise Coefficient	real	0
AF	Flicker Noise Exponent	real	0

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
IC	Current at Collector Node [A]	Output	real
IB	Current at Base Node [A]	Output	real
IE	Emitter Current [A]	Output	real
ISUB	Substrate Current [A]	Output	real
VBE	Base-Emitter Voltage [V]	Output	real
VBC	Base-Collector Voltage [V]	Output	real
VCE	Collector-Emitter Voltage [V]	Output	real
P	Power Dissipation [W]	Output	real

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Example

Figure 3 shows application of the Spice-Compatible NPN-type and PNP-type BJT model. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 4.

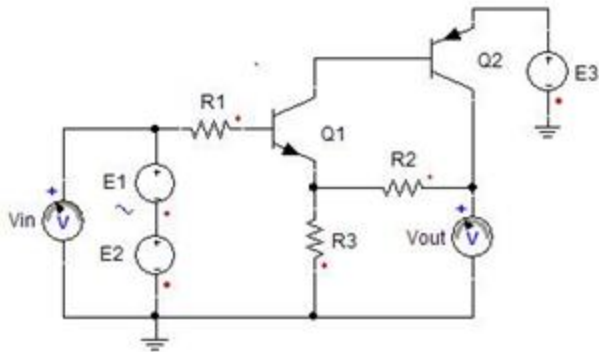


Figure 3. Application example of the Spice-Compatible BJT Model

Table 3

Component	Parameter	Value

Voltage Source (sinusoidal) E1	AMPL	0.1 [V]
	FREQ	15k [Hz]
	PHASE	0 [degree]
	OFF	0 [V]
	TDELAY	0 [s]
Voltage Source E2	EMF	0.58 [V]
Voltage Source E3	EMF	10 [V]
Resistor R1/R2	R	1k [Ohm]
Resistor R3	R	10 [Ohm]

Spice-Compatible NPN-Type BJT Q1	OFF	0

	ICVBE	0 [V]

	ICVCE	0 [V]

	AREA	1

TEMP	27 [°C]
IS	19f [A]
BF	150 [A/A]
NF	1
VAF	100 [V]
IKF	0.18 [A]
ISE	50p [A]
NE	2.5
BR	7.5 [A/A]
NR	1
VAR	6.4 [V]
IKR	12m [A]
ISC	8.7p [A]
NC	1.2
RB	50 [Ohm]
IRB	0 [A]
RBM	0 [Ohm]
RE	0.4[Ohm]
RC	0.3 [Ohm]
CJE	26p [F]
VJE	0.75 [V]
MJE	0.33
TF	0 [s]
XTF	0
VTF	0 [V]
ITF	0 [A]
PTF	0 [deg]
CJC	11p [F]
VJC	0.75 [V]
MJC	0.33

	XCJC	1
	TR	7n [s]
	CJS	0 [F]
	CCS	0 [F]
	VJS	0.75 [V]
	MJS	0
	XTB	1.5
	EG	1.11 [eV]
	XTI	3
	FC	0.5
	TNOM	27 [°C]
	KF	0.032f
	AF	1

Spice-Compatible PNP-Type BJT Q2	OFF	0

	ICVBE	0 [V]

	ICVCE	0 [V]

	AREA	1

TEMP	27 [°C]
IS	1.1p [A]
BF	200[A/A]
NF	1.2
VAF	50 [V]
IKF	0.1 [A]
ISE	13p [A]
NE	1.9
BR	6 [A/A]
NR	1
VAR	0 [V]
IKR	0 [A]
ISC	0 [A]
NC	2
RB	0 [Ohm]
IRB	0 [A]
RBM	0 [Ohm]
RE	0 [Ohm]
RC	0.6 [Ohm]
CJE	23p [F]
VJE	0.85 [V]
MJE	1.25
TF	0.5n [s]
XTF	0
VTF	0 [V]
ITF	0 [A]
PTF	0 [deg]
CJC	19p [F]
VJC	0.5 [V]
MJC	0.2

	XCJC	1
	TR	34n[s]
	CJS	0 [F]
	CCS	0 [F]
	VJS	0.75 [V]
	MJS	0
	XTB	1.5
	EG	1.11 [eV]
	XTI	3
	FC	0.5
	TNOM	27 [°C]
	KF	0
	AF	0

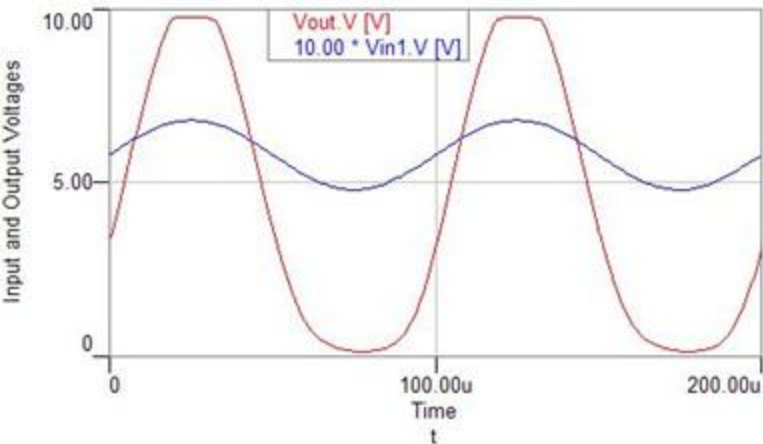


Figure 4. Simulation results-input and output voltage of Q1

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References

See also Massobrio, Giusseppe, and Paolo Antognetti: *Semiconductor Device Modeling with SPICE*, New York: McGraw Hill, 1993

BJT Models - SPICE-Compatible 4-Pin PNP

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

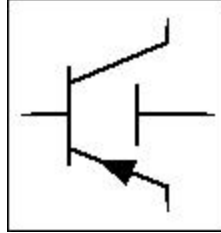


Figure 1. Component Symbol.

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- [Assumptions and Limitations](#)
- [Mathematical Description](#)
- [Netlist Syntax](#)
- [Conservative Pins](#)
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Description

The Spice-compatible BJT NPN-type, BJT PNP-type, BJT4 NPN-type, and BJT4 PNP-type models simulate the electrical and thermal behavior of a bipolar junction transistor using SPICE3 parameters and equations. Electrical characteristics and the temperature dependence of transistor behavior are calculated according to user-defined device parameters.

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Assumptions and Limitations

Figure 2 shows the current and voltage reference arrow system for this component.



Figure 2. Current and Voltage Reference Arrow System

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Mathematical Description

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Netlist Syntax

```

UMODEL SPICE_PNP4 ?InstanceName(@InstanceName):(@ (Refbase) @ (ID))
COLLECTOR:= %0, BASE:= %1, EMITTER:= %2, SUBSTRATE:= %3 ( OFF:= @OFF,
ICVBE:= @ICVBE, ICVCE:= @ICVCE, AREA:= @AREA, TEMP:= @TEMP, IS:= @IS, BF:=
@BF, NF:= @NF, VAF:= @VAF, IKF:= @IKF, ISE:= @ISE, NE:= @NE, BR:= @BR, NR:=
@NR, VAR:= @VAR, IKR:= @IKR, ISC:= @ISC, NC:= @NC, RB:= @RB, IRB:= @IRB, RBM:=
@RBM, RE:= @RE, RC:= @RC, CJE:= @CJE, VJE:= @VJE, MJE:= @MJE, TF:= @TF, XTF:=
@XTF, VTF:= @VTF, ITF:= @ITF \\\ , PTF:= @PTF, CJC:= @CJC, VJC:= @VJC, MJC:=
@MJC, XCJC:= @XCJC, TR:= @TR, CJS:= @CJS, CCS:= @CCS, VJS:= @VJS, MJS:=
@MJS, XTB:= @XTB, EG:= @EG, XTI:= @XTI, FC:= @FC, TNOM:= @TNOM, KF:= @KF,
AF:= @AF) SRC: DB(Lib:=@ModelLibraryName);

```

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
ANODE	Base	electrical
CATHODE	Emitter	electrical
COLLECTOR	Collector	electrical
SUBSTRATE	Substrate (4-pin models)	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
OFF	Device Initially Off	real	0
ICVBE	Initial Base-Emitter Voltage	real	0 [V]
ICVCE	Initial Collector-Emitter Voltage	real	0 [V]
AREA	Area Factor	real	1
TEMP	Instance Temperature	real	27 [°C]
IS	Saturation Current	real	0.1f [A]
BF	Ideal Forward Beta	real	0.1k [A/A]
NF	Forward Emission Coefficient	real	1
VAF	Forward Early Voltage	real	0 [V]
IKF	Forward Beta Roll-off Corner Current	real	0 [A]
ISE	Base-Emitter Leakage Saturation Current	real	0 [A]
NE	Base-Emitter Leakage Emission Coefficient	real	1.5
BR	Ideal Reverse Beta	real	1 [A/A]
NR	Reverse Emission Coefficient	real	1
VAR	Reverse Early Voltage	real	0 [V]
IKR	Reverse Beta Roll-off Corner Current	real	0 [A]
ISC	Base-Collector Leakage Saturation Current	real	0 [A]
NC	Base-Collector Leakage Emission Coefficient	real	2
RB	Zero-bias Base Resistance	real	0 [Ohm]
IRB	Current for Base Resistance Falling to 1/2 Minimum	real	0 [A]
RBM	Minimum Base Resistance	real	0 [Ohm]
RE	Emitter Resistance	real	0 [Ohm]
RC	Collector Resistance	real	0 [Ohm]
CJE	Zero-bias B-E Depletion Capacitance	real	0 [F]

VJE	Base-Emitter Built-in Potential	real	0.75 [V]
MJE	Base-Emitter Junction Grading Coefficient	real	0.33
TF	Ideal Forward Transit Time	real	0 [s]
XTF	Coefficient for Bias-dependence of TF	real	0
VTF	Voltage Giving VBC-dependence of TF	real	0 [V]
ITF	High-current Parameter for Effect on TF	real	0 [A]
PTF	Excess Phase	real	0 [deg]
CJC	Zero-bias BC Depletion Capacitance	real	0 [F]
VJC	BC Built-in Potential	real	0.75 [V]
MJC	BC Junction-grading Coefficient	real	0.33
XCJC	Fraction of BC Capacitance Connected to Internal Base	real	1
TR	Ideal Reverse Transit Time	real	0 [s]
CJS	Zero-bias CS Capacitance	real	0 [F]
CCS	Zero-bias CS Capacitance	real	0 [F]
VJS	Substrate Junction Built-in Potential	real	0.75 [V]
MJS	Substrate Junction Grading Coefficient	real	0
XTB	Forward and Reverse Beta Temperature Exponent	real	0
EG	Energy Gap for Saturation Current Temperature Dependency	real	1.11 [eV]
XTI	Temperature Exponent for Saturation Current	real	3
FC	Forward-bias Junction Fit Parameter	real	0.5
TNOM	Parameter Measurement Temperature	real	27 [°C]
KF	Flicker Noise Coefficient	real	0
AF	Flicker Noise Exponent	real	0

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
IC	Current at Collector Node [A]	Output	real
IB	Current at Base Node [A]	Output	real
IE	Emitter Current [A]	Output	real
ISUB	Substrate Current [A]	Output	real
VBE	Base-Emitter Voltage [V]	Output	real
VBC	Base-Collector Voltage [V]	Output	real
VCE	Collector-Emitter Voltage [V]	Output	real
P	Power Dissipation [W]	Output	real

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Example

Figure 3 shows application of the Spice-Compatible 4-Pin NPN-type BJT model. The parameters of the Spice-Compatible Diode models SPICE_D1, SPICE_D2, SPICE_D3 and those of the Spice-Compatible 4-Pin NPN-Type BJT model SPICE_NPN41 are set to their default values; the parameters of the rest of the system are listed in Table 4 and the simulation results shown in Figure 4.

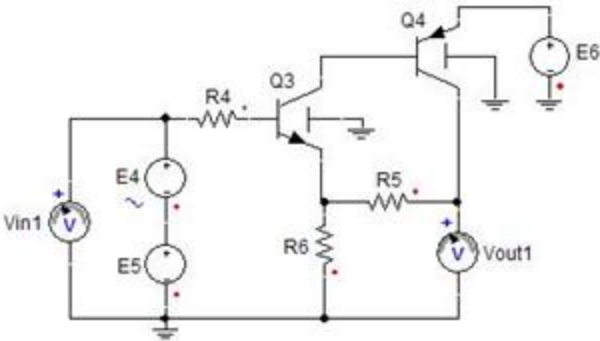


Figure 3. Application example of the Spice-Compatible 4-pin BJT Model

Table 3

Component	Parameter	Value

Voltage Source (pulse) E3	AMPL	2.5 [V]
	FREQ	100E+006 [Hz]
	PHASE	-180 [degree]
	OFF	2.5 [V]
	TDELAY	0 [s]
Voltage Source (pulse) E4	AMPL	2.5 [V]
	FREQ	200E+006 [Hz]
	PHASE	-180 [degree]
	OFF	2.5 [V]
	TDELAY	0 [s]
Voltage Source E1	EMF	5 [V]
Resistor R1/R2	R	1k [Ohm]

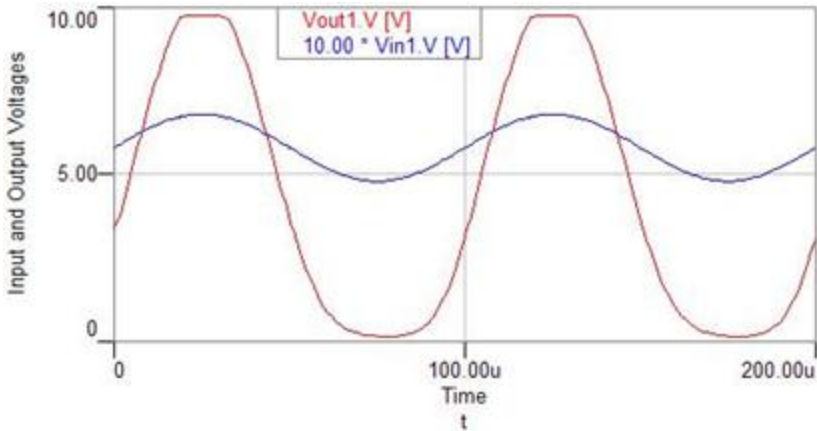


Figure 4. Simulation results-input voltage of Q3 and the collector voltage of Q4

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References

See also Massobrio, Giuseppe, and Paolo Antognetti: *Semiconductor Device Modeling with SPICE*, New York: McGraw Hill, 1993

SPICE-Compatible Diode Models

The diode components are implemented as C models. The models use the *MaxwellSpice.dll* file. The simulation parameter HMIN (minimum time step) should be 0.1ns for the first simulation run. Then you can adjust the value for optimal simulation performance. For simulations of power electronics circuits, HMIN can be up to 100ns.

- [Diode - SPICE-Compatible \(SPICE_D\)](#)

Diode - SPICE-Compatible

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

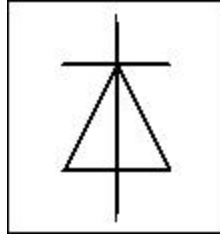


Figure 1. Component Symbol.

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Description

The Spice-Compatible Diode Model simulates the electrical and thermal behavior of a diode using SPICE3 parameters and equations. Electrical characteristics and the temperature dependence of diode behavior are calculated according to user-defined device parameters.

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Assumptions and Limitations

Figure 2 shows the current and voltage reference arrow system for this component.

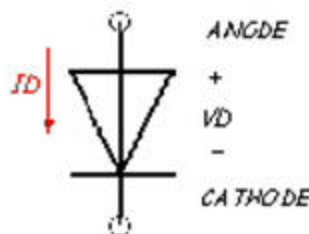


Figure 2. Current and Voltage Reference Arrow System[Top](#)**Mathematical Description****Basic static diode model (Shockley equation):****Forward Bias**

$$I_D = I_s \cdot \left[\exp\left(\frac{V_D}{N \cdot V_t}\right) - 1 + V_D \cdot GMIN \right]$$

Where I_s is the diode's reverse saturation current, V_t is the thermal voltage ($V_t = kT/q$), N is the emission coefficient (or ideality factor), and $GMIN$ is a parallel conductance served as a convergence aid in SPICE.

Reverse Bias

When $V_D < -5NV_t$, the leakage current through the p-n junction is set to I_s . The current through the diode is:

$$I_D = -I_s + V_D \cdot GMIN$$

The current after breakdown is modeled as an exponential function, the breakdown voltage is specified as BV in the model, with the current at the breakdown of IBV .

$$I_D = -I_s \cdot \left[\exp\left(\frac{-(BV + V_D)}{V_t}\right) - 1 + \frac{BV}{V_t} \right]$$

When $V_D = -BV$, I_D from the above equation is $-I_s(BV/V_t)$. So it's important to set IBV close to $-I_s(BV/V_t)$ for continuity of the diode characteristics.

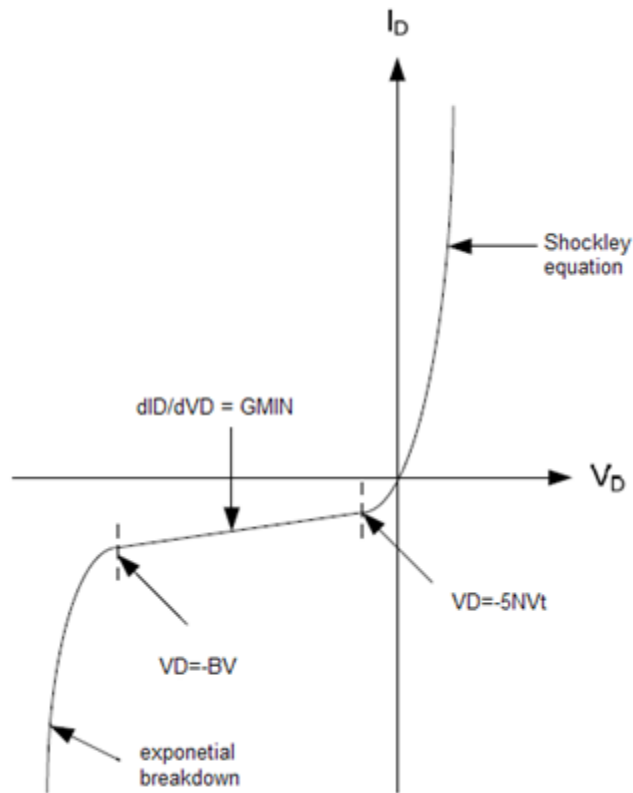


Figure 3. Static diode characteristic.

A series resistance R_S is added to the diode model to simulate the stray resistance.

Dynamic Effects:

Junction Capacitance

$$C_J = \frac{C_{J0}}{\sqrt{1 - \frac{V_D}{V_J}}}$$

Where C_{J0} is the junction capacitance at zero applied bias, and V_J is built-in junction voltage.

Diffusion Capacitance

$$C_d = \frac{e}{N \cdot k \cdot T} I_D \cdot TT$$

Where k is Boltzmann constant, T is junction temperature, and TT is the transit time.

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Netlist Syntax

UMODEL SPICE_D ?InstanceName(@InstanceName):(@ (Refbase)@(ID)) ANODE:= %0,
CATHODE:= %1 (OFF:= @OFF, TEMP:= @TEMP, IC:= @IC, AREA:= @AREA, IS:= @IS,
TNOM:= @TNOM, RS:= @RS, N:= @N, TT:= @TT, CJO:= @CJO, VJ:= @VJ, M:= @M, EG:=
@EG, XTI:= @XTI, KF:= @KF, AF:= @AF, FC:= @FC, BV:= @BV, IBV:= @IBV) SRC: DB(Lib:-
:=@ModelLibraryName);

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
ANODE	Anode	electrical
CATHODE	Cathode	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
OFF	Device Initially Off	real	0
TEMP	Instance Temperature	real	27 [°C]
IC	Initial Device Voltage	real	0 [V]
AREA	Area Factor	real	1
IS	Saturation Current	real	10f [A]
TNOM	Parameter Measurement Temperature	real	27 [°C]
RS	Ohmic Resistance	real	0 [Ohm]
N	Emission Coefficient	real	1
TT	Transit Time	real	0 [s]
CJO	Junction Capacitance	real	0 [F]
VJ	Junction Potential	real	1 [V]
M	Grading Coefficient	real	0.5
EG	Activation Energy	real	1.1 [eV]

XTI	Saturation Current Temperature Exponent	real	3
KF	Flicker Noise Coefficient	real	0
AF	Flicker Noise Exponent	real	1
FC	Forward-Bias Junction Fit Parameter	real	0.5
BV	Reverse Breakdown Voltage	real	0 [V] (See NOTE)
IBV	Current At Reverse Breakdown Voltage	real	1m [A]

NOTE: Per SPICE convention, an entered BV value of 0 is equivalent to infinity. Thus, there is no breakdown current when BV=0.

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Input/Output Quantities

Table 3

Name	Description[Unit]	Direction	Data Type
V	Diode voltage, not including voltage on stray resistance RS[V]	Output	real
I	Diode current[A]	Output	real
P	Diode power, not including power loss on stray resistance RS[W]	Output	real

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Example

Figure 3 shows application of the Spice-Compatible Diode Model. The parameters of the system are listed in Table 3 and the simulation results shown in Figure 4 and 5.

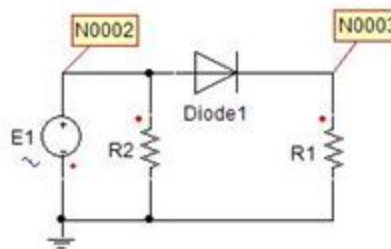


Figure 3. Application example of the Spice-Compatible Diode Model

Table 4

Component	Parameter	Value

Voltage Source (sinusoidal) E1	AMPL	50 [V]
	FREQ	15k [Hz]
	PHASE	0 [degree]
	OFF	0 [V]
	TDELAY	0 [s]
Resistor R1	R	10k [Ohm]
Resistor R2	R	1Meg [Ohm]
Spice-Compatible Diode Diode1	OFF	0
	TEMP	27 [°C]
	IC	0 [V]
	AREA	1
	IS	1.4n [A]
	TNOM	40 [°C]
	RS	100 [Ohm]
	N	1.7
	TT	5u [s]
	CJO	55p [F]
	VJ	0.2 [V]
	M	0.38
	EG	1.1 [eV]
	XTI	3
	KF	0
	AF	1
	FC	0.5
	BV	75 [V]
	IBV	1m [A]

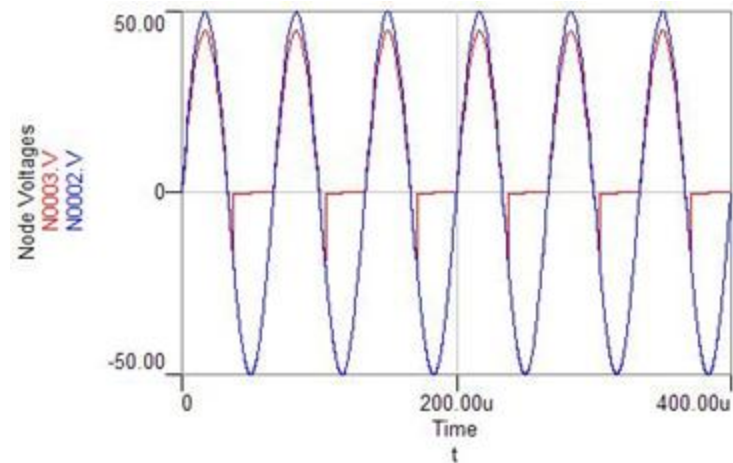


Figure 4. Simulation results – node voltages

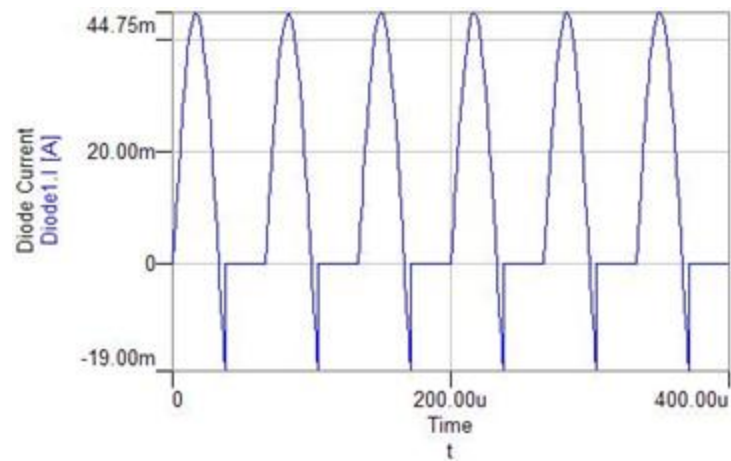


Figure 5. Simulation results – current through Diode1

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References

[1] Massobrio, Giuseppe, and Paolo Antognetti: *Semiconductor Device Modeling with SPICE*, New York: McGraw Hill, 1993

SPICE-Compatible Field-Effect Transistors

The field-effect transistor components are implemented as C models. The models use the *MaxwellSpice.dll* file. The simulation parameter HMIN (minimum time step) should be 0.1ns for the first simulation run. Then you can adjust the value for optimal simulation performance. For simulations of power electronics circuits, HMIN can be up to 100ns.

- [NMOS BSIM1 Model - SPICE-Compatible N-Channel \(BSIM1_N\)](#)
- [PMOS BSIM1 Model - SPICE-Compatible P-Channel \(BSIM1_P\)](#)
- [NMOS BSIM2 Model - SPICE-Compatible N-Channel \(BSIM2_N\)](#)
- [PMOS BSIM2 Model - SPICE-Compatible P-Channel \(BSIM2_P\)](#)
- [NMOS BSIM3 Model - SPICE-Compatible N-Channel \(BSIM3_N\)](#)
- [PMOS BSIM3 Model - SPICE-Compatible P-Channel \(BSIM3_P\)](#)
- [NMOS BSIM4 Model - SPICE-Compatible N-Channel \(BSIM4_N\)](#)
- [PMOS BSIM4 Model - SPICE-Compatible P-Channel \(BSIM4_P\)](#)
- [NMOS EKV Model - SPICE-Compatible N-Channel \(EKV_N\)](#)
- [PMOS EKV Model - SPICE-Compatible P-Channel \(EKV_P\)](#)
- [N-Channel JFET Model - SPICE-Compatible N-Channel \(SPICE_JFET_N\)](#)
- [P-Channel JFET Model - SPICE-Compatible P-Channel \(SPICE_JFET_P\)](#)
- [N-Channel MESFET Model - SPICE-Compatible N-Channel \(SPICE_MESFET_N\)](#)
- [P-Channel MESFET Model - SPICE-Compatible P-Channel \(SPICE_MESFET_P\)](#)
- [NMOS Level 1 MOS Model - SPICE-Compatible N-Channel \(SPICE_MOS1_N\)](#)
- [PMOS Level 1 MOS Model - SPICE-Compatible P-Channel \(SPICE_MOS1_P\)](#)
- [NMOS Level 2 MOS Model - SPICE-Compatible N-Channel \(SPICE_MOS2_N\)](#)
- [PMOS Level 2 MOS Model - SPICE-Compatible P-Channel \(SPICE_MOS2_P\)](#)
- [NMOS Level 3 MOS Model - SPICE-Compatible N-Channel \(SPICE_MOS3_N\)](#)
- [PMOS Level 3 MOS Model - SPICE-Compatible P-Channel \(SPICE_MOS3_P\)](#)
- [NMOS Level 6 MOS Model - SPICE-Compatible N-Channel \(SPICE_MOS6_N\)](#)
- [PMOS Level 6 MOS Model - SPICE-Compatible P-Channel \(SPICE_MOS6_P\)](#)

BSIM1 Model - SPICE-Compatible N-Channel

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

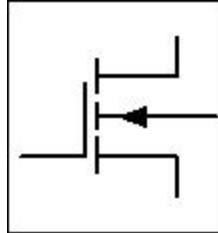


Figure 1. Component Symbol.

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- [Conservative Pins](#)
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Description

The Spice-Compatible Level1 BSIM N-channel and BSIM P-channel models simulate the electrical and thermal behavior of small-geometry MOSFETs using the parameters and equations of the SPICE3 BSIM1 MOSFET model. Electrical characteristics and the temperature dependence of MOSFET behavior are calculated according to user-defined device parameters that are obtained from MOSFET process characterization. This model is also referred to as MOS level 4.

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Assumptions and Limitations

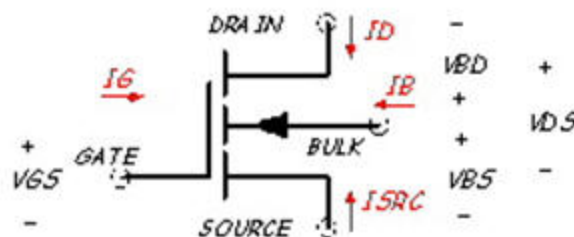


Figure 2. Current and Voltage Reference Arrow System[Top](#)**Mathematical Description**[Top](#)**Netlist Syntax**

```

UMODEL BSIM1_N ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) DRAIN:= %0,
GATE:= %1, SOURCE:= %2, BULK:= %3 ( L:= @L, W:= @W, AD:= @AD, AS:= @AS, PD:=
@PD, PS:= @PS, NRD:= @NRD, NRS:= @NRS, OFF:= @OFF, ICVDS:= @ICVDS, ICVGS:=
@ICVGS, ICVBS:= @ICVBS, VFB:= @VFB, LVFB:= @LVFB, WVFB:= @WVFB, PHI:= @PHI,
LPHI:= @LPHI, WPHI:= @WPHI, K1:= @K1, LK1:= @LK1, WK1:= @WK1, K2:= @K2, LK2:=
@LK2, WK2:= @WK2, ETA:= @ETA, LETA:= @LETA, WETA:= @WETA, X2E:= @X2E,
LX2E:= @LX2E, WX2E:= @WX2E \\\ , X3E:= @X3E, LX3E:= @LX3E, WX3E:= @WX3E, DL:=
@DL, DW:= @DW, MUZ:= @MUZ, X2MZ:= @X2MZ, LX2MZ:= @LX2MZ, WX2MZ:=
@WX2MZ, MUS:= @MUS, LMUS:= @LMUS, WMUS:= @WMUS, X2MS:= @X2MS, LX2MS:=
@LX2MS, WX2MS:= @WX2MS, X3MS:= @X3MS, LX3MS:= @LX3MS, WX3MS:= @WX3MS,
U0:= @U0, LU0:= @LU0, WU0:= @WU0, X2U0:= @X2U0, LX2U0:= @LX2U0, WX2U0:=
@WX2U0, U1:= @U1, LU1:= @LU1, WU1:= @WU1, X2U1:= @X2U1, LX2U1:= @LX2U1,
WX2U1:= @WX2U1 \\\ , X3U1:= @X3U1, LX3U1:= @LX3U1, WX3U1:= @WX3U1, N0:= @N0,
LN0:= @LN0, WN0:= @WN0, NB:= @NB, LNB:= @LNB, WNB:= @WNB, ND:= @ND, LND:=
@LND, WND:= @WND, TOX:= @TOX, TEMP:= @TEMP, VDD:= @VDD, CGSO:= @CGSO,
CGDO:= @CGDO, CGBO:= @CGBO, XPART:= @XPART, RSH:= @RSH, JS:= @JS, PB:=
@PB, MJ:= @MJ, PBSW:= @PBSW, MJSW:= @MJSW, CJ:= @CJ, CJSW:= @CJSW, WDF:=
@WDF, DELL:= @DELL) SRC: DB(Lib:=@ModelLibraryName);

```

[Top](#)**Conservative Pins****Table 1**

Name	Description	Nature/Data Type
GATE	Gate	electrical
SOURCE	Source	electrical
DRAIN	Drain	electrical
BULK	Bulk	electrical

[Top](#)**Parameters****Table 2**

Name	Description	Data Type	Default Value [Unit]

L	Length	real	5u [m]
W	Width	real	5u [m]
AD	Drain area	real	0 [m ²]
AS	Source area	real	0 [m ²]
PD	Drain perimeter	real	0 [m]
PS	Source perimeter	real	0 [m]
NRD	Number of squares in drain	real	1
NRS	Number of squares in source	real	1
OFF	Device is initially off	boolean	0
ICVDS	Initial D-S voltage	real	0 [V]
ICVGS	Initial G-S voltage	real	0 [V]
ICVBS	Initial B-S voltage	real	0 [V]
VFB	Flat band voltage	real	0 [V]
LVFB	Length dependence of vfb	real	0
WVFB	Width dependence of vfb	real	0
PHI	Strong inversion surface potential	real	0 [V]
LPHI	Length dependence of phi	real	0
WPHI	Width dependence of phi	real	0
K1	Bulk effect coefficient 1	real	0 [V ^{1/2}]
LK1	Length dependence of k1	real	0
WK1	Width dependence of k1	real	0
K2	Bulk effect coefficient 2	real	0
LK2	Length dependence of k2	real	0
WK2	Width dependence of k2	real	0
ETA	VDS dependence of threshold voltage	real	0
LETA	Length dependence of eta	real	0
WETA	Width dependence of eta	real	0
X2E	VBS dependence of eta	real	0 [V ⁻¹]

LX2E	Length dependence of x_{2e}	real	0
WX2E	Width dependence of x_{2e}	real	0
X3E	VDS dependence of η	real	0 [V ⁻¹]
LX3E	Length dependence of x_{3e}	real	0
WX3E	Width dependence of x_{3e}	real	0
DL	Channel length reduction in	real	0 [μm]
DW	Channel width reduction in	real	0 [μm]
MUZ	Zero field mobility at VDS=0 VGS=VTH	real	0 [cm ² /Vs]
X2MZ	VBS dependence of μ_{uz}	real	0 [cm ² /Vs]
LX2MZ	Length dependence of x_{2mz}	real	0
WX2MZ	Width dependence of x_{2mz}	real	0
MUS	Mobility at VDS=VDD VGS=VTH	real	0 [cm ² /Vs]
LMUS	Length dependence of μ_{us}	real	0
WMUS	Width dependence of μ_{us}	real	0
X2MS	VBS dependence of μ_{us}	real	0 [cm ² /Vs]
LX2MS	Length dependence of x_{2ms}	real	0
WX2MS	Width dependence of x_{2ms}	real	0
X3MS	VDS dependence of μ_{us}	real	0 [cm ² /Vs]
LX3MS	Length dependence of x_{3ms}	real	0
WX3MS	Width dependence of x_{3ms}	real	0
U0	VGS dependence of mobility	real	0 [V ⁻¹]
LU0	Length dependence of u_0	real	0
WU0	Width dependence of u_0	real	0
X2U0	VBS dependence of u_0	real	0 [V ⁻²]
LX2U0	Length dependence of x_{2u0}	real	0

WX2U0	Width dependence of $x2u0$	real	0
U1	VDS dependence of mobility, velocity saturation	real	0 [$\mu\text{m}/\text{V}^2$]
LU1	Length dependence of $u1$	real	0
WU1	Width dependence of $u1$	real	0
X2U1	VBS dependence of $u1$	real	0 [$\mu\text{m}/\text{V}^2$]
LX2U1	Length dependence of $x2u1$	real	0
WX2U1	Width dependence of $x2u1$	real	0
X3U1	VDS dependence of $u1$	real	0 [$\mu\text{m}/\text{V}^2$]
LX3U1	Length dependence of $x3u1$	real	0
WX3U1	Width dependence of $x3u1$	real	0
N0	Subthreshold slope	real	0
LN0	Length dependence of $n0$	real	0
WN0	Width dependence of $n0$	real	0
NB	VBS dependence of subthreshold slope	real	0
LNB	Length dependence of nb	real	0
WNB	Width dependence of nb	real	0
ND	VDS dependence of subthreshold slope	real	0
LND	Length dependence of nd	real	0
WND	Width dependence of nd	real	0
TOX	Gate oxide thickness in μm	real	0 [μm]
TEMP	Temperature in degree Celsius	real	0 [$^{\circ}\text{C}$]
VDD [V]	Supply voltage to specify μs	real	0 [V]
CGSO	Gate source overlap capacitance per unit channel width	real	0 [F/m]
CGDO	Gate drain overlap capacitance per unit channel width	real	0 [F/m]

CGBO	Gate bulk overlap capacitance per unit channel length	real	0 [F/m]
XPART	Flag for channel charge partitioning	real	0
RSH	Source drain diffusion sheet resistance	real	0 [Ohm/square]
JS	Source drain junction saturation current per unit area	real	0 [A/m ²]
PB	Source drain junction built in potential	real	0.1 [V]
MJ	Source drain bottom junction capacitance grading coefficient	real	0
PBSW	Source drain side junction capacitance built in potential	real	0.1 [V]
MJSW	Source drain side junction capacitance grading coefficient	real	0
CJ	Source drain bottom junction capacitance per unit area	real	0 [F/m ²]
CJSW	Source drain side junction capacitance per unit area	real	0 [F/m]
WDF	Default width of source drain diffusion in um	real	0 [m]
DELL	Length reduction of source drain diffusion	real	0 [m]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
VBS	Vbs [V]	Output	real
VGS	Vgs [V]	Output	real
VDS	Vds [V]	Output	real
VBD	Vbd [V]	Output	real
ID	Id (terminal) [A]	Output	real
IG	Ig (terminal) [A]	Output	real

IS	Is (terminal) [A]	Output	real
IB	Ib (terminal) [A]	Output	real
P	Power Dissipation [W]	Output	real

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Example

Figure 3 shows application of the Spice-Compatible Level1 BSIM N-channel and BSIM P-channel models. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 4.

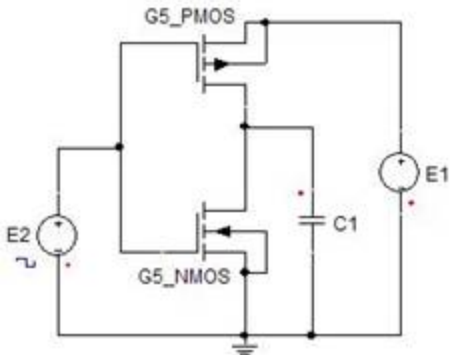


Figure 3. Application example of the Spice-Compatible Level1 BSIM N-channel and BSIM P-channel models

Table 4

Component	Parameter	Value
Capacitor C1	C	10p [F]
	V0	0 [V]
Voltage Source E1	EMF	5 [V]
Voltage Source (pulse) E2	AMPL	2.5 [V]
	FREQ	1e+006 [Hz]
	PHASE	0 [degree]
	OFF	2.5 [V]
	TDELAY	0 [s]

Spice-Compatible Level1 BSIM N-channel G5_NMOS	L	5u [m]

	W	5u [m]

AD	0 [m ²]
AS	0 [m ²]
PD	0 [m]
PS	0 [m]
NRD	1
NRS	1
OFF	0
ICVDS	0 [V]
ICVGS	0 [V]
ICVBS	0 [V]
VFB	-0.7 [V]
LVFB	4e-2
WVFB	5e-2
PHI	0.84 [V]
LPHI	0
WPHI	0
K1	0.78 [V ^{1/2}]
LK1	-8e-4
WK1	5e-2
K2	2.7e-2
LK2	5e-2
WK2	-3e-2
ETA	-2e-3
LETA	2e-2
WETA	-5e-3
X2E	4.4e-4 [V ⁻¹]
LX2E	-3e-3
WX2E	9e-4
X3E	-5e-15 [V ⁻¹]
LX3E	-2e-3

	WX3E	-1e-3

	DL	0.2 [μm]

	DW	0.5 [μm]

MUZ	600 [cm ² /Vs]
X2MZ	9.7 [cm ² /Vs]
LX2MZ	-6
WX2MZ	7
MUS	700 [cm ² /Vs]
LMUS	-50
WMUS	7
X2MS	-6e-2 [cm ² /Vs]
LX2MS	1
WX2MS	4
X3MS	9 [cm ² /Vs]
LX3MS	2
WX3MS	6
U0	0.33 [V ⁻¹]
LU0	0.1
WU0	0.1
X2U0	-1e-2 [V ⁻²]
LX2U0	-1e-3
WX2U0	5e-3
U1	3.3e-2 [μm/V ²]
LU1	3e-2
WU1	-1e-2
X2U1	-1e-3 [μm/V ²]
LX2U1	-1e-3
WX2U1	-7e-4
X3U1	9e-3 [μm/V ²]
LX3U1	2e-4
WX3U1	-5e-3
N0	1
LN0	0

WN0	0
NB	0
LNB	0
WNB	0
ND	0
LND	0
WND	0
TOX	1e-2 [μm]
TEMP	25 [°C]
VDD [V]	5 [V]
CGSO	3e-10 [F/m]
CGDO	3e-10 [F/m]
CGBO	4e-10 [F/m]
XPART	1
RSH	2.1 [Ohm/square]
JS	1e-8 [A/m ²]
PB	0.8 [V]
MJ	0.44
PBSW	0.8 [V]
MJSW	0.26
CJ	3.5e-4 [F/m ²]
CJSW	2.9e-10 [F/m]
WDF	0 [m]
DELL	0 [m]

Spice-Compatible Level1 BSIM N-channel G5_P MOS	L	5u [m]

	W	5u [m]

AD	0 [m ²]
AS	0 [m ²]
PD	0 [m]
PS	0 [m]
NRD	1
NRS	1
OFF	0
ICVDS	0 [V]
ICVGS	0 [V]
ICVBS	0 [V]
VFB	-0.2 [V]
LVFB	4e-2
WVFB	0.1
PHI	0.83 [V]
LPHI	0
WPHI	0
K1	0.35 [V ^{1/2}]
LK1	-7e-02
WK1	0.2
K2	-4.5e-2
LK2	9e-3
WK2	4e-2
ETA	-1e-2
LETA	2e-2
WETA	4e-4
X2E	5e-5 [V ⁻¹]
LX2E	-1e-3
WX2E	-2e-4
X3E	8e-4 [V ⁻¹]
LX3E	-2e-4

	WX3E	-1e-3

	DL	0.2 [μm]

	DW	0.5 [μm]

MUZ	140 [cm ² /Vs]
X2MZ	7 [cm ² /Vs]
LX2MZ	-2
WX2MZ	1
MUS	150 [cm ² /Vs]
LMUS	10
WMUS	4
X2MS	6 [cm ² /Vs]
LX2MS	-0.7
WX2MS	2
X3MS	-1E-2 [cm ² /Vs]
LX3MS	2
WX3MS	1
U0	0.2 [V ⁻¹]
LU0	6e-2
WU0	-6e-2
X2U0	9e-3 [V ⁻²]
LX2U0	-2E-3
WX2U0	2E-3
U1	1e-2 [μm/V ²]
LU1	1e-2
WU1	7e-4
X2U1	6E-4 [μm/V ²]
LX2U1	5E-4
WX2U1	3E-4
X3U1	-1e-3 [μm/V ²]
LX3U1	-5e-4
WX3U1	1e-3
N0	0
LN0	0

WN0	0
NB	0
LNB	0
WNB	0
ND	0
LND	0
WND	0
TOX	1E-2 [μm]
TEMP	25 [°C]
VDD [V]	5 [V]
CGSO	2.4E-10 [F/m]
CGDO	2.4E-10 [F/m]
CGBO	3.8E-10 [F/m]
XPART	1
RSH	2 [Ohm/square]
JS	1E-8 [A/m ²]
PB	0.85 [V]
MJ	0.44
PBSW	0.85 [V]
MJSW	0.24
CJ	9.5E-4 [F/m ²]
CJSW	2.5E-10 [F/m]
WDF	0 [m]
DELL	0 [m]

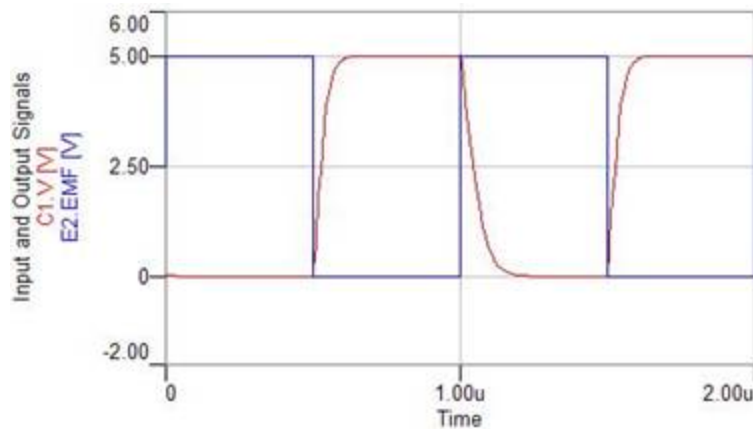


Figure 4. Simulation results-input and output voltage of G5_NMOS

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References

[1]Massobrio, Giuseppe, and Paolo Antognetti: *Semiconductor Device Modeling with SPICE*, New York: McGraw Hill, 1993

BSIM1 Model - SPICE-Compatible P-Channel

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

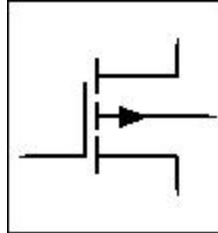


Figure 1. Component Symbol.

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Description

The Spice-Compatible BSIM1 N-channel and BSIM1 P-channel models simulate the electrical and thermal behavior of small-geometry MOSFETs using the parameters and equations of the SPICE3 BSIM1 MOSFET model. Electrical characteristics and the temperature dependence of MOSFET behavior are calculated according to user-defined device parameters that are obtained from MOSFET process characterization. This model is also referred to as MOS level 4.

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Assumptions and Limitations

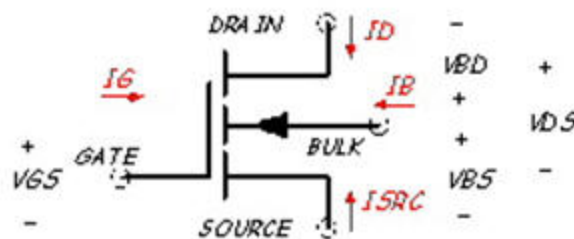


Figure 2. Current and Voltage Reference Arrow System[Top](#)**Mathematical Description**[Top](#)**Netlist Syntax**

```

UMODEL BSIM1_P ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) DRAIN:= %0,
GATE:= %1, SOURCE:= %2, BULK:= %3 ( L:= @L, W:= @W, AD:= @AD, AS:= @AS, PD:=
@PD, PS:= @PS, NRD:= @NRD, NRS:= @NRS, OFF:= @OFF, ICVDS:= @ICVDS, ICVGS:=
@ICVGS, ICVBS:= @ICVBS, VFB:= @VFB, LVFB:= @LVFB, WVFB:= @WVFB, PHI:= @PHI,
LPHI:= @LPHI, WPHI:= @WPHI, K1:= @K1, LK1:= @LK1, WK1:= @WK1, K2:= @K2, LK2:=
@LK2, WK2:= @WK2, ETA:= @ETA, LETA:= @LETA, WETA:= @WETA, X2E:= @X2E,
LX2E:= @LX2E, WX2E:= @WX2E \\\ , X3E:= @X3E, LX3E:= @LX3E, WX3E:= @WX3E, DL:=
@DL, DW:= @DW, MUZ:= @MUZ, X2MZ:= @X2MZ, LX2MZ:= @LX2MZ, WX2MZ:=
@WX2MZ, MUS:= @MUS, LMUS:= @LMUS, WMUS:= @WMUS, X2MS:= @X2MS, LX2MS:=
@LX2MS, WX2MS:= @WX2MS, X3MS:= @X3MS, LX3MS:= @LX3MS, WX3MS:= @WX3MS,
U0:= @U0, LU0:= @LU0, WU0:= @WU0, X2U0:= @X2U0, LX2U0:= @LX2U0, WX2U0:=
@WX2U0, U1:= @U1, LU1:= @LU1, WU1:= @WU1, X2U1:= @X2U1, LX2U1:= @LX2U1,
WX2U1:= @WX2U1 \\\ , X3U1:= @X3U1, LX3U1:= @LX3U1, WX3U1:= @WX3U1, N0:= @N0,
LN0:= @LN0, WN0:= @WN0, NB:= @NB, LNB:= @LNB, WNB:= @WNB, ND:= @ND, LND:=
@LND, WND:= @WND, TOX:= @TOX, TEMP:= @TEMP, VDD:= @VDD, CGSO:= @CGSO,
CGDO:= @CGDO, CGBO:= @CGBO, XPART:= @XPART, RSH:= @RSH, JS:= @JS, PB:=
@PB, MJ:= @MJ, PBSW:= @PBSW, MJSW:= @MJSW, CJ:= @CJ, CJSW:= @CJSW, WDF:=
@WDF, DELL:= @DELL) SRC: DB(Lib:=@ModelLibraryName);

```

[Top](#)**Conservative Pins****Table 1**

Name	Description	Nature/Data Type
GATE	Gate	electrical
SOURCE	Source	electrical
DRAIN	Drain	electrical
BULK	Bulk	electrical

[Top](#)**Parameters****Table 2**

Name	Description	Data Type	Default Value [Unit]

L	Length	real	5u [m]
W	Width	real	5u [m]
AD	Drain area	real	0 [m ²]
AS	Source area	real	0 [m ²]
PD	Drain perimeter	real	0 [m]
PS	Source perimeter	real	0 [m]
NRD	Number of squares in drain	real	1
NRS	Number of squares in source	real	1
OFF	Device is initially off	boolean	0
ICVDS	Initial D-S voltage	real	0 [V]
ICVGS	Initial G-S voltage	real	0 [V]
ICVBS	Initial B-S voltage	real	0 [V]
VFB	Flat band voltage	real	0 [V]
LVFB	Length dependence of vfb	real	0
WVFB	Width dependence of vfb	real	0
PHI	Strong inversion surface potential	real	0 [V]
LPHI	Length dependence of phi	real	0
WPHI	Width dependence of phi	real	0
K1	Bulk effect coefficient 1	real	0 [V ^{1/2}]
LK1	Length dependence of k1	real	0
WK1	Width dependence of k1	real	0
K2	Bulk effect coefficient 2	real	0
LK2	Length dependence of k2	real	0
WK2	Width dependence of k2	real	0
ETA	VDS dependence of threshold voltage	real	0
LETA	Length dependence of eta	real	0
WETA	Width dependence of eta	real	0
X2E	VBS dependence of eta	real	0 [V ⁻¹]

LX2E	Length dependence of x_{2e}	real	0
WX2E	Width dependence of x_{2e}	real	0
X3E	VDS dependence of η	real	0 [V ⁻¹]
LX3E	Length dependence of x_{3e}	real	0
WX3E	Width dependence of x_{3e}	real	0
DL	Channel length reduction in	real	0 [μm]
DW	Channel width reduction in	real	0 [μm]
MUZ	Zero field mobility at VDS=0 VGS=VTH	real	0 [cm ² /Vs]
X2MZ	VBS dependence of μ_{uz}	real	0 [cm ² /Vs]
LX2MZ	Length dependence of x_{2mz}	real	0
WX2MZ	Width dependence of x_{2mz}	real	0
MUS	Mobility at VDS=VDD VGS=VTH	real	0 [cm ² /Vs]
LMUS	Length dependence of μ_{us}	real	0
WMUS	Width dependence of μ_{us}	real	0
X2MS	VBS dependence of μ_{us}	real	0 [cm ² /Vs]
LX2MS	Length dependence of x_{2ms}	real	0
WX2MS	Width dependence of x_{2ms}	real	0
X3MS	VDS dependence of μ_{us}	real	0 [cm ² /Vs]
LX3MS	Length dependence of x_{3ms}	real	0
WX3MS	Width dependence of x_{3ms}	real	0
U0	VGS dependence of mobility	real	0 [V ⁻¹]
LU0	Length dependence of u_0	real	0
WU0	Width dependence of u_0	real	0
X2U0	VBS dependence of u_0	real	0 [V ⁻²]
LX2U0	Length dependence of x_{2u0}	real	0

WX2U0	Width dependence of $x2u0$	real	0
U1	VDS dependence of mobility, velocity saturation	real	0 [$\mu\text{m}/\text{V}^2$]
LU1	Length dependence of $u1$	real	0
WU1	Width dependence of $u1$	real	0
X2U1	VBS dependence of $u1$	real	0 [$\mu\text{m}/\text{V}^2$]
LX2U1	Length dependence of $x2u1$	real	0
WX2U1	Width dependence of $x2u1$	real	0
X3U1	VDS dependence of $u1$	real	0 [$\mu\text{m}/\text{V}^2$]
LX3U1	Length dependence of $x3u1$	real	0
WX3U1	Width dependence of $x3u1$	real	0
N0	Subthreshold slope	real	0
LN0	Length dependence of $n0$	real	0
WN0	Width dependence of $n0$	real	0
NB	VBS dependence of subthreshold slope	real	0
LNB	Length dependence of nb	real	0
WNB	Width dependence of nb	real	0
ND	VDS dependence of subthreshold slope	real	0
LND	Length dependence of nd	real	0
WND	Width dependence of nd	real	0
TOX	Gate oxide thickness in μm	real	0 [μm]
TEMP	Temperature in degree Celsius	real	0 [$^{\circ}\text{C}$]
VDD [V]	Supply voltage to specify μm s	real	0 [V]
CGSO	Gate source overlap capacitance per unit channel width	real	0 [F/m]
CGDO	Gate drain overlap capacitance per unit channel width	real	0 [F/m]

CGBO	Gate bulk overlap capacitance per unit channel length	real	0 [F/m]
XPART	Flag for channel charge partitioning	real	0
RSH	Source drain diffusion sheet resistance	real	0 [Ohm/square]
JS	Source drain junction saturation current per unit area	real	0 [A/m ²]
PB	Source drain junction built in potential	real	0.1 [V]
MJ	Source drain bottom junction capacitance grading coefficient	real	0
PBSW	Source drain side junction capacitance built in potential	real	0.1 [V]
MJSW	Source drain side junction capacitance grading coefficient	real	0
CJ	Source drain bottom junction capacitance per unit area	real	0 [F/m ²]
CJSW	Source drain side junction capacitance per unit area	real	0 [F/m]
WDF	Default width of source drain diffusion in um	real	0 [m]
DELL	Length reduction of source drain diffusion	real	0 [m]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
VBS	Vbs [V]	Output	real
VGS	Vgs [V]	Output	real
VDS	Vds [V]	Output	real
VBD	Vbd [V]	Output	real
ID	Id (terminal) [A]	Output	real
IG	Ig (terminal) [A]	Output	real

IS	Is (terminal) [A]	Output	real
IB	Ib (terminal) [A]	Output	real
P	Power Dissipation [W]	Output	real

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Example

Figure 3 shows application of the Spice-Compatible Level1 BSIM N-channel and BSIM P-channel models. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 4.

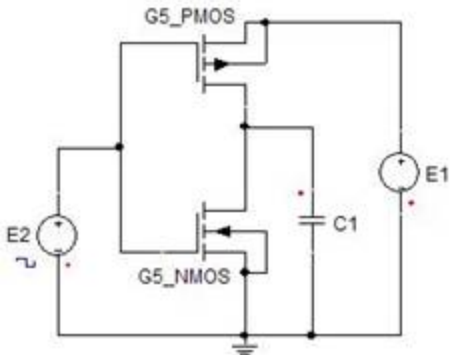


Figure 3. Application example of the Spice-Compatible Level1 BSIM N-channel and BSIM P-channel models

Table 4

Component	Parameter	Value
Capacitor C1	C	10p [F]
	V0	0 [V]
Voltage Source E1	EMF	5 [V]
Voltage Source (pulse) E2	AMPL	2.5 [V]
	FREQ	1e+006 [Hz]
	PHASE	0 [degree]
	OFF	2.5 [V]
	TDELAY	0 [s]

Spice-Compatible Level1 BSIM N-channel G5_NMOS	L	5u [m]

	W	5u [m]

AD	0 [m ²]
AS	0 [m ²]
PD	0 [m]
PS	0 [m]
NRD	1
NRS	1
OFF	0
ICVDS	0 [V]
ICVGS	0 [V]
ICVBS	0 [V]
VFB	-0.7 [V]
LVFB	4e-2
WVFB	5e-2
PHI	0.84 [V]
LPHI	0
WPHI	0
K1	0.78 [V ^{1/2}]
LK1	-8e-4
WK1	5e-2
K2	2.7e-2
LK2	5e-2
WK2	-3e-2
ETA	-2e-3
LETA	2e-2
WETA	-5e-3
X2E	4.4e-4 [V ⁻¹]
LX2E	-3e-3
WX2E	9e-4
X3E	-5e-15 [V ⁻¹]
LX3E	-2e-3

	WX3E	-1e-3

	DL	0.2 [μm]

	DW	0.5 [μm]

MUZ	600 [cm ² /Vs]
X2MZ	9.7 [cm ² /Vs]
LX2MZ	-6
WX2MZ	7
MUS	700 [cm ² /Vs]
LMUS	-50
WMUS	7
X2MS	-6e-2 [cm ² /Vs]
LX2MS	1
WX2MS	4
X3MS	9 [cm ² /Vs]
LX3MS	2
WX3MS	6
U0	0.33 [V ⁻¹]
LU0	0.1
WU0	0.1
X2U0	-1e-2 [V ⁻²]
LX2U0	-1e-3
WX2U0	5e-3
U1	3.3e-2 [μm/V ²]
LU1	3e-2
WU1	-1e-2
X2U1	-1e-3 [μm/V ²]
LX2U1	-1e-3
WX2U1	-7e-4
X3U1	9e-3 [μm/V ²]
LX3U1	2e-4
WX3U1	-5e-3
N0	1
LN0	0

WN0	0
NB	0
LNB	0
WNB	0
ND	0
LND	0
WND	0
TOX	1e-2 [μm]
TEMP	25 [°C]
VDD [V]	5 [V]
CGSO	3e-10 [F/m]
CGDO	3e-10 [F/m]
CGBO	4e-10 [F/m]
XPART	1
RSH	2.1 [Ohm/square]
JS	1e-8 [A/m ²]
PB	0.8 [V]
MJ	0.44
PBSW	0.8 [V]
MJSW	0.26
CJ	3.5e-4 [F/m ²]
CJSW	2.9e-10 [F/m]
WDF	0 [m]
DELL	0 [m]

Spice-Compatible Level1 BSIM N-channel G5_P MOS	L	5u [m]

	W	5u [m]

AD	0 [m ²]
AS	0 [m ²]
PD	0 [m]
PS	0 [m]
NRD	1
NRS	1
OFF	0
ICVDS	0 [V]
ICVGS	0 [V]
ICVBS	0 [V]
VFB	-0.2 [V]
LVFB	4e-2
WVFB	0.1
PHI	0.83 [V]
LPHI	0
WPHI	0
K1	0.35 [V ^{1/2}]
LK1	-7e-02
WK1	0.2
K2	-4.5e-2
LK2	9e-3
WK2	4e-2
ETA	-1e-2
LETA	2e-2
WETA	4e-4
X2E	5e-5 [V ⁻¹]
LX2E	-1e-3
WX2E	-2e-4
X3E	8e-4 [V ⁻¹]
LX3E	-2e-4

	WX3E	-1e-3

	DL	0.2 [μm]

	DW	0.5 [μm]

MUZ	140 [cm ² /Vs]
X2MZ	7 [cm ² /Vs]
LX2MZ	-2
WX2MZ	1
MUS	150 [cm ² /Vs]
LMUS	10
WMUS	4
X2MS	6 [cm ² /Vs]
LX2MS	-0.7
WX2MS	2
X3MS	-1E-2 [cm ² /Vs]
LX3MS	2
WX3MS	1
U0	0.2 [V ⁻¹]
LU0	6e-2
WU0	-6e-2
X2U0	9e-3 [V ⁻²]
LX2U0	-2E-3
WX2U0	2E-3
U1	1e-2 [μm/V ²]
LU1	1e-2
WU1	7e-4
X2U1	6E-4 [μm/V ²]
LX2U1	5E-4
WX2U1	3E-4
X3U1	-1e-3 [μm/V ²]
LX3U1	-5e-4
WX3U1	1e-3
N0	0
LN0	0

WN0	0
NB	0
LNB	0
WNB	0
ND	0
LND	0
WND	0
TOX	1E-2 [μm]
TEMP	25 [°C]
VDD [V]	5 [V]
CGSO	2.4E-10 [F/m]
CGDO	2.4E-10 [F/m]
CGBO	3.8E-10 [F/m]
XPART	1
RSH	2 [Ohm/square]
JS	1E-8 [A/m ²]
PB	0.85 [V]
MJ	0.44
PBSW	0.85 [V]
MJSW	0.24
CJ	9.5E-4 [F/m ²]
CJSW	2.5E-10 [F/m]
WDF	0 [m]
DELL	0 [m]

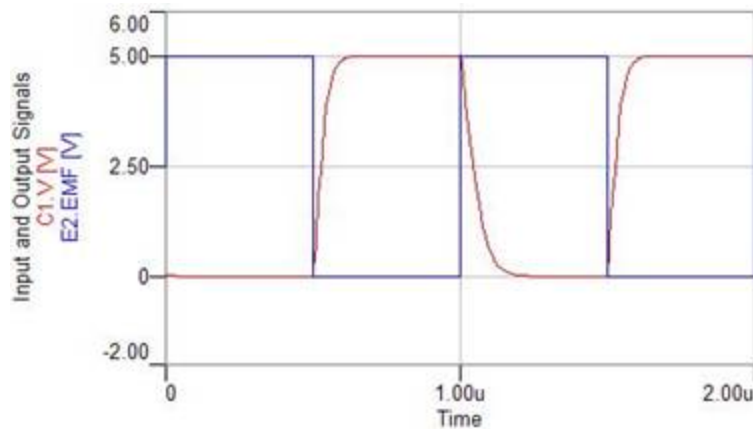


Figure 4. Simulation results-input and output voltage of G5_NMOS

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References

[1] Massobrio, Giuseppe, and Paolo Antognetti: *Semiconductor Device Modeling with SPICE*, New York: McGraw Hill, 1993

BSIM2 Model - SPICE-Compatible N-Channel

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

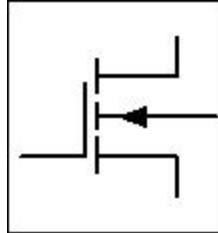


Figure 1. Component Symbol.

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Description

The Spice-Compatible BSIM2 N-channel and BSIM2 P-channel models simulate the electrical and thermal behavior of small-geometry MOSFETs using the parameters and equations of the BSIM2 MOSFET model. Electrical characteristics and the temperature dependence of MOSFET behavior are calculated according to user-defined device parameters that are obtained from MOSFET process characterization. This model is also referred to as MOS level 5.

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Assumptions and Limitations

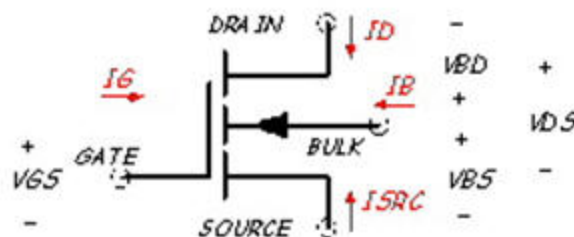


Figure 2. Current and Voltage Reference Arrow System[Top](#)**Mathematical Description**[Top](#)**Netlist Syntax**

```

UMODEL BSIM2_N ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) DRAIN:= %0,
GATE:= %1, SOURCE:= %2, BULK:= %3 ( L:= @L, W:= @W, AD:= @AD, AS:= @AS, PD:=
@PD, PS:= @PS, NRD:= @NRD, NRS:= @NRS, OFF:= @OFF, ICDVS:= @ICVDS, ICVGS:=
@ICVGS, ICVBS:= @ICVBS, VFB:= @VFB, LVFB:= @LVFB, WVFB:= @WVFB, PHI:= @PHI,
LPHI:= @LPHI, WPHI:= @WPHI, K1:= @K1, LK1:= @LK1, WK1:= @WK1, K2:= @K2, LK2:=
@LK2, WK2:= @WK2, ETA0:= @ETA0, LETA0:= @LETA0, WETA0:= @WETA0, ETAB:=
@ETAB, LETAB:= @LETAB, WETAB:= @WETAB \\\ , DL:= @DL, DW:= @DW, MU0:=
@MU0, MU0B:= @MU0B, LMU0B:= @LMU0B, WMU0B:= @WMU0B, MUS0:= @MUS0,
LMUS0:= @LMUS0, WMUS0:= @WMUS0, MUSB:= @MUSB, LMUSB:= @LMUSB, WMUSB:=
@WMUSB, MU20:= @MU20, LMU20:= @LMU20, WMU20:= @WMU20, MU2B:= @MU2B,
LMU2B:= @LMU2B, WMU2B:= @WMU2B, MU2G:= @MU2G, LMU2G:= @LMU2G, WMU2G:=
@WMU2G, MU30:= @MU30, LMU30:= @LMU30, WMU30:= @WMU30, MU3B:= @MU3B,
LMU3B:= @LMU3B, WMU3B:= @WMU3B, MU3G:= @MU3G, LMU3G:= @LMU3G, WMU3G:=
@WMU3G \\\ , MU40:= @MU40, LMU40:= @LMU40, WMU40:= @WMU40, MU4B:= @MU4B,
LMU4B:= @LMU4B, WMU4B:= @WMU4B, MU4G:= @MU4G, LMU4G:= @LMU4G, WMU4G:=
@WMU4G, UA0:= @UA0, LUA0:= @LUA0, WUA0:= @WUA0, UAB:= @UAB, LUAB:=
@LUAB, WUAB:= @WUAB, UB0:= @UB0, LUB0:= @LUB0, WUB0:= @WUB0, UBB:= @UBB,
LUBB:= @LUBB, WUBB:= @WUBB, U10:= @U10, LU10:= @LU10, WU10:= @WU10, U1B:=
@U1B, LU1B:= @LU1B, WU1B:= @WU1B, U1D:= @U1D, LU1D:= @LU1D, WU1D:= @WU1D
\\ , N0:= @N0, LN0:= @LN0, WN0:= @WN0, NB:= @NB, LNB:= @LNB, WNB:= @WNB, ND:=
@ND, LND:= @LND, WND:= @WND, VOF0:= @VOF0, LVOF0:= @LVOF0, WVOF0:=
@WVOF0, VOFB:= @VOFB, LVOFB:= @LVOFB, WVOFB:= @WVOFB, VOFD:= @VOFD,
LVOFD:= @LVOFD, WVOFD:= @WVOFD, AI0:= @AI0, LAI0:= @LAI0, WAI0:= @WAI0, AIB:=
@AIB, LAIB:= @LAIB, WAIB:= @WAIB, BI0:= @BI0, LBI0:= @LBI0, WBI0:= @WBI0, BIB:=
@BIB, LBIB:= @LBIB, WBIB:= @WBIB \\\ , VGHIGH:= @VGHIGH, LVGHIGH:= @LVGHIGH,
WVGHIGH:= @WVGHIGH, VGLOW:= @VGLOW, LVGLOW:= @LVGLOW, WVGLOW:=
@WVGLOW, TOX:= @TOX, TEMP:= @TEMP, VDD:= @VDD, VGG:= @VGG, VBB:= @VBB,
CGSO:= @CGSO, CGDO:= @CGDO, CGBO:= @CGBO, XPART:= @XPART, RSH:= @RSH,
JS:= @JS, PB:= @PB, MJ:= @MJ, PBSW:= @PBSW, MJSW:= @MJSW, CJ:= @CJ, CJSW:=
@CJSW, WDF:= @WDF, DELL:= @DELL) SRC: DB(Lib:=@ModelLibraryName);

```

[Top](#)**Conservative Pins****Table 1**

Name	Description	Nature/Data Type
GATE	Gate	electrical
SOURCE	Source	electrical

DRAIN	Drain	electrical
BULK	Bulk	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
L	Length	real	5u [m]
W	Width	real	5u [m]
AD	Drain area	real	0 [m ²]
AS	Source area	real	0 [m ²]
PD	Drain perimeter	real	0 [m]
PS	Source perimeter	real	0 [m]
NRD	Number of squares in drain	real	1
NRS	Number of squares in source	real	1
OFF	Device is initially off	boolean	0
ICVDS	Initial D-S voltage	real	0 [V]
ICVGS	Initial G-S voltage	real	0 [V]
ICVBS	Initial B-S voltage	real	0 [V]
VFB	Flat band voltage	real	-1 [V]
LVFB	Length dependence of vfb	real	0
WVFB	Width dependence of vfb	real	0
PHI	Strong inversion surface potential	real	0.75 [V]
LPHI	Length dependence of phi	real	0
WPHI	Width dependence of phi	real	0
K1	Bulk effect coefficient 1	real	0.8 [V ^{1/2}]
LK1	Length dependence of k1	real	0
WK1	Width dependence of k1	real	0
K2	Bulk effect coefficient 2	real	0
LK2	Length dependence of k2	real	0
WK2	Width dependence of k2	real	0
ETA0	VDS dependence of threshold voltage at	real	0

	VDD=0		
LETA0	Length dependence of eta0	real	0
WETA0	Width dependence of eta0	real	0
ETAB	VBS dependence of eta	real	0
LETAB	Length dependence of etab	real	0
WETAB	Width dependence of etab	real	0
DL	Channel length reduction in	real	0 [μm]
DW	Channel width reduction	real	0 [μm]
MU0	Low-field mobility, at VDS=0 VGS=VTH	real	0.4k [cm ² /V ² -s]
MU0B	VBS dependence of low-field mobility	real	0
LMU0B	Length dependence of mu0b	real	0
WMU0B	Width dependence of mu0b	real	0
MUS0	Mobility at VDS=VDD VGS=VTH	real	0.5k [cm ² /V ² -s]
LMUS0	Length dependence of mus0	real	0
WMUS0	Width dependence of mus	real	0
MUSB	VBS dependence of mus	real	0
LMUSB	Length dependence of musb	real	0
WMUSB	Width dependence of musb	real	0
MU20	VDS dependence of mu in tanh term	real	1.5
LMU20	Length dependence of mu20	real	0
WMU20	Width dependence of mu20	real	0
MU2B	VBS dependence of mu2	real	0
LMU2B	Length dependence of mu2b	real	0
WMU2B	Width dependence of mu2b	real	0
MU2G	VGS dependence of mu2	real	0

LMU2G	Length dependence of μ_{2g}	real	0
WMU2G	Width dependence of μ_{2g}	real	0
MU30	VDS dependence of μ in linear term	real	10
LMU30	Length dependence of μ_{30}	real	0
WMU30	Width dependence of μ_{30}	real	0
MU3B	VBS dependence of μ_3	real	0
LMU3B	Length dependence of μ_{3b}	real	0
WMU3B	Width dependence of μ_{3b}	real	0
MU3G	VGS dependence of μ_3	real	0
LMU3G	Length dependence of μ_{3g}	real	0
WMU3G	Width dependence of μ_{3g}	real	0
MU40	VDS dependence of μ in linear term	real	0
LMU40	Length dependence of μ_{40}	real	0
WMU40	Width dependence of μ_{40}	real	0
MU4B	VBS dependence of μ_4	real	0
LMU4B	Length dependence of μ_{4b}	real	0
WMU4B	Width dependence of μ_{4b}	real	0
MU4G	VGS dependence of μ_4	real	0
LMU4G	Length dependence of μ_{4g}	real	0
WMU4G	Width dependence of μ_{4g}	real	0
UA0	Linear VGS dependence of mobility	real	0.2
LUA0	Length dependence of μ_{a0}	real	0
WUA0	Width dependence of μ_{a0}	real	0
UAB	VBS dependence of μ_a	real	0
LUAB	Length dependence	real	0

	of uab		
WUAB	Width dependence of uab	real	0
UB0	Quadratic VGS dependence of mobility	real	0
LUB0	Length dependence of ub0	real	0
WUB0	Width dependence of ub0	real	0
UBB	VBS dependence of ub	real	0
LUBB	Length dependence of ubb	real	0
WUBB	Width dependence of ubb	real	0
U10	VDS dependence of mobility	real	0.1
LU10	Length dependence of u10	real	0
WU10	Width dependence of u10	real	0
U1B	VBS dependence of u1	real	0
LU1B	Length dependence of u1b	real	0
WU1B	Width dependence of u1b	real	0
U1D	VDS dependence of u1	real	0
LU1D	Length dependence of u1d	real	0
WU1D	Width dependence of u1d	real	0
N0	Subthreshold slope at VDS=0 VBS=0	real	1.4
LN0	Length dependence of n0	real	0
WN0	Width dependence of n0	real	0
NB	VBS dependence of n	real	0.5
LNB	Length dependence of nb	real	0
WNB	Width dependence of nb	real	0
ND	VDS dependence of n	real	0
LND	Length dependence of nd	real	0
WND	Width dependence of	real	0

	nd		
VOF0	Threshold voltage off-set AT $V_{DS}=0$ $V_{BS}=0$	real	1.8
LVOF0	Length dependence of vof0	real	0
WVOF0	Width dependence of vof0	real	0
VOFB	V_{BS} dependence of vof	real	0
LVOFB	Length dependence of vofb	real	0
WVOFB	Width dependence of vofb	real	0
VOFD	V_{DS} dependence of vof	real	0
LVOFD	Length dependence of vofd	real	0
WVOFD	Width dependence of vofd	real	0
AI0	Pre-factor of hot-electron effect	real	0
LAI0	Length dependence of ai0	real	0
WAI0	Width dependence of ai0	real	0
AIB	V_{BS} dependence of ai	real	0
LAIB	Length dependence of aib	real	0
WAIB	Width dependence of aib	real	0
BI0	Exponential factor of hot-electron effect	real	0
LBIO	Length dependence of bi0	real	0
WBIO	Width dependence of bi0	real	0
BIB	V_{BS} dependence of bi	real	0
LBIB	Length dependence of bib	real	0
WBIB	Width dependence of bib	real	0
VGHIGH	Upper bound of the cubic spline function	real	0.2
LVGHIGH	Length dependence of vghigh	real	0
WVGHIGH	Width dependence of vghigh	real	0

VGLOW	Lower bound of the cubic spline function	real	-0.15
LVGLOW	Length dependence of vglow	real	0
WVGLOW	Width dependence of vglow	real	0
TOX	Gate oxide thickness	real	30m [μm]
TEMP	Temperature in degree Celsius	real	27 [°C]
VDD	Maximum Vds	real	5 [V]
VGG	Maximum Vgs	real	5 [V]
VBB	Maximum Vbs	real	5 [V]
CGSO	Gate source overlap capacitance per unit channel width	real	0 [F/m]
CGDO	Gate drain overlap capacitance per unit channel width	real	0 [F/m]
CGBO	Gate bulk overlap capacitance per unit channel length	real	0 [F/m]
XPART	Flag for channel charge partitioning	real	0
RSH	Source drain diffusion sheet resistance in ohm per square	real	0 [Ohm/square]
JS	Source drain junction saturation current per unit area	real	0 [A/m ²]
PB	Source drain junction built in potential	real	0.1 [V]
MJ	Source drain bottom junction capacitance grading coefficient	real	0
PBSW	Source drain side junction capacitance built in potential	real	0.1 [V]
MJSW	Source drain side junction capacitance grading coefficient	real	0
CJ	Source drain bottom junction capacitance per unit area	real	0 [F/m ²]
CJSW	Source drain side junction capacitance per unit area	real	0 [F/m]
WDF	Default width of	real	10 [m]

	source drain diffusion in um		
DELL	Length reduction of source drain diffusion	real	0 [m]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
VBS	Vbs [V]	Output	real
VGS	Vgs [V]	Output	real
VDS	Vds [V]	Output	real
VBD	Vbd [V]	Output	real
ID	Id (terminal) [A]	Output	real
IG	Ig (terminal) [A]	Output	real
IS	Is (terminal) [A]	Output	real
IB	Ib (terminal) [A]	Output	real
P	Power Dissipation [W]	Output	real

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Example

Figure 3 shows application of the Spice-Compatible Level 2 BSIM N-channel and BSIM P-channel models. The parameters of BSIM2_P1 and BSIM2_N1 are set to their default values; the parameters of the rest of the system are listed in Table 4 and the simulation results shown in Figure 4.

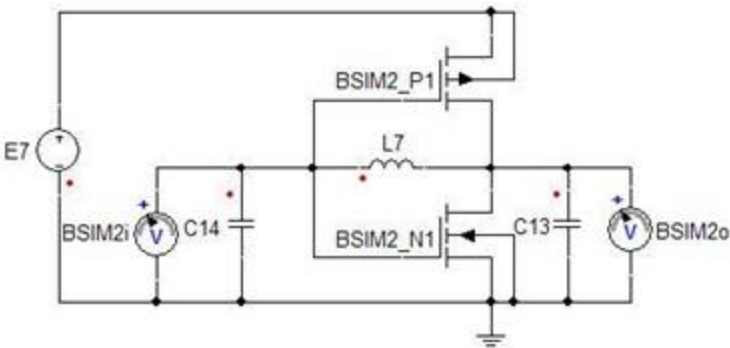


Figure 3. Application example of the Spice-Compatible Level 2 BSIM N-channel and BSIM P-channel models

Table 4

Component	Parameter	Value
Capacitor C14	C	100p [F]
	V0	7.5 [V]
Capacitor C13	C	100p [F]
	V0	0 [V]
Inductor L7	L	1m [H]
	I0	0 [A]
Voltage Source E7	EMF	15 [V]

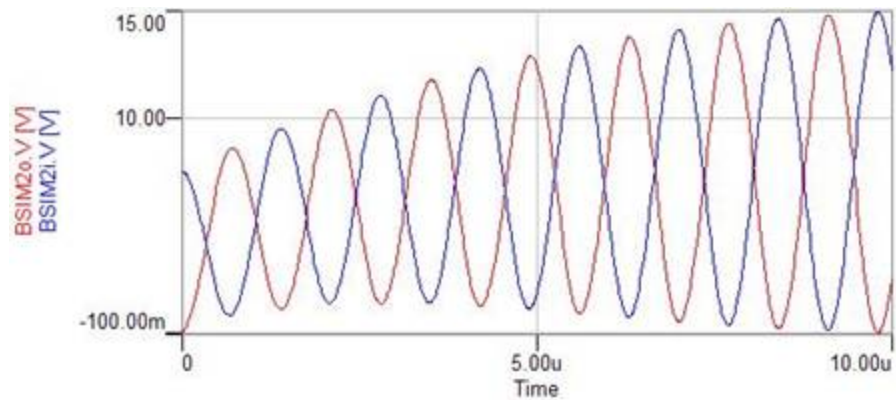


Figure 4. Simulation results-input and output voltage of BSIM2_N1

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References

[1]Massobrio, Giueseppe, and Paolo Antognetti: *Semiconductor Device Modeling with SPICE*, New York: McGraw Hill, 1993

BSIM2 Model - SPICE-Compatible P-Channel

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

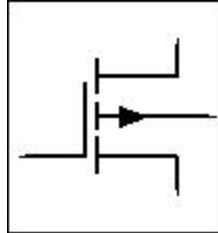


Figure 1. Component Symbol.

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Description

The Spice-Compatible BSIM2 N-channel and BSIM2 P-channel models simulate the electrical and thermal behavior of small-geometry MOSFETs using the parameters and equations of the BSIM2 MOSFET model. Electrical characteristics and the temperature dependence of MOSFET behavior are calculated according to user-defined device parameters that are obtained from MOSFET process characterization. This model is also referred to as MOS level 5.

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Assumptions and Limitations

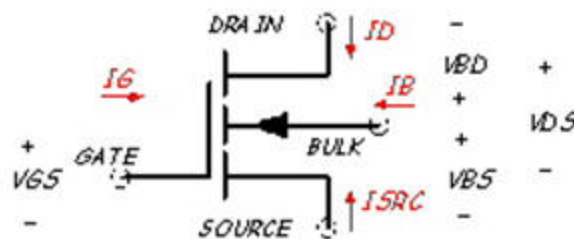


Figure 2. Current and Voltage Reference Arrow System[Top](#)**Mathematical Description**[Top](#)**Netlist Syntax**

```

UMODEL BSIM2_P ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) DRAIN:= %0,
GATE:= %1, SOURCE:= %2, BULK:= %3 ( L:= @L, W:= @W, AD:= @AD, AS:= @AS, PD:=
@PD, PS:= @PS, NRD:= @NRD, NRS:= @NRS, OFF:= @OFF, ICDVS:= @ICVDS, ICGVS:=
@ICVGS, ICVBS:= @ICVBS, VFB:= @VFB, LVFB:= @LVFB, WVFB:= @WVFB, PHI:= @PHI,
LPHI:= @LPHI, WPHI:= @WPHI, K1:= @K1, LK1:= @LK1, WK1:= @WK1, K2:= @K2, LK2:=
@LK2, WK2:= @WK2, ETA0:= @ETA0, LETA0:= @LETA0, WETA0:= @WETA0, ETAB:=
@ETAB, LETAB:= @LETAB, WETAB:= @WETAB \\\ , DL:= @DL, DW:= @DW, MU0:=
@MU0, MU0B:= @MU0B, LMU0B:= @LMU0B, WMU0B:= @WMU0B, MUS0:= @MUS0,
LMUS0:= @LMUS0, WMUS0:= @WMUS0, MUSB:= @MUSB, LMUSB:= @LMUSB, WMUSB:=
@WMUSB, MU20:= @MU20, LMU20:= @LMU20, WMU20:= @WMU20, MU2B:= @MU2B,
LMU2B:= @LMU2B, WMU2B:= @WMU2B, MU2G:= @MU2G, LMU2G:= @LMU2G, WMU2G:=
@WMU2G, MU30:= @MU30, LMU30:= @LMU30, WMU30:= @WMU30, MU3B:= @MU3B,
LMU3B:= @LMU3B, WMU3B:= @WMU3B, MU3G:= @MU3G, LMU3G:= @LMU3G, WMU3G:=
@WMU3G \\\ , MU40:= @MU40, LMU40:= @LMU40, WMU40:= @WMU40, MU4B:= @MU4B,
LMU4B:= @LMU4B, WMU4B:= @WMU4B, MU4G:= @MU4G, LMU4G:= @LMU4G, WMU4G:=
@WMU4G, UA0:= @UA0, LUA0:= @LUA0, WUA0:= @WUA0, UAB:= @UAB, LUAB:=
@LUAB, WUAB:= @WUAB, UB0:= @UB0, LUB0:= @LUB0, WUB0:= @WUB0, UBB:= @UBB,
LUBB:= @LUBB, WUBB:= @WUBB, U10:= @U10, LU10:= @LU10, WU10:= @WU10, U1B:=
@U1B, LU1B:= @LU1B, WU1B:= @WU1B, U1D:= @U1D, LU1D:= @LU1D, WU1D:= @WU1D
\\ , N0:= @N0, LN0:= @LN0, WN0:= @WN0, NB:= @NB, LNB:= @LNB, WNB:= @WNB, ND:=
@ND, LND:= @LND, WND:= @WND, VOF0:= @VOF0, LVOF0:= @LVOF0, WVOF0:=
@WVOF0, VOFB:= @VOFB, LVOFB:= @LVOFB, WVOFB:= @WVOFB, VOFD:= @VOFD,
LVOFD:= @LVOFD, WVOFD:= @WVOFD, AI0:= @AI0, LAI0:= @LAI0, WAI0:= @WAI0, AIB:=
@AIB, LAIB:= @LAIB, WAIB:= @WAIB, BI0:= @BI0, LBI0:= @LBI0, WBI0:= @WBI0, BIB:=
@BIB, LBIB:= @LBIB, WBIB:= @WBIB \\\ , VGHIGH:= @VGHIGH, LVGHIGH:= @LVGHIGH,
WVGHIGH:= @WVGHIGH, VGLOW:= @VGLOW, LVGLOW:= @LVGLOW, WVGLOW:=
@WVGLOW, TOX:= @TOX, TEMP:= @TEMP, VDD:= @VDD, VGG:= @VGG, VBB:= @VBB,
CGSO:= @CGSO, CGDO:= @CGDO, CGBO:= @CGBO, XPART:= @XPART, RSH:= @RSH,
JS:= @JS, PB:= @PB, MJ:= @MJ, PBSW:= @PBSW, MJSW:= @MJSW, CJ:= @CJ, CJSW:=
@CJSW, WDF:= @WDF, DELL:= @DELL) SRC: DB(Lib:=@ModelLibraryName);

```

[Top](#)**Conservative Pins****Table 1**

Name	Description	Nature/Data Type
GATE	Gate	electrical
SOURCE	Source	electrical

DRAIN	Drain	electrical
BULK	Bulk	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
L	Length	real	5u [m]
W	Width	real	5u [m]
AD	Drain area	real	0 [m ²]
AS	Source area	real	0 [m ²]
PD	Drain perimeter	real	0 [m]
PS	Source perimeter	real	0 [m]
NRD	Number of squares in drain	real	1
NRS	Number of squares in source	real	1
OFF	Device is initially off	boolean	0
ICVDS	Initial D-S voltage	real	0 [V]
ICVGS	Initial G-S voltage	real	0 [V]
ICVBS	Initial B-S voltage	real	0 [V]
VFB	Flat band voltage	real	-1 [V]
LVFB	Length dependence of vfb	real	0
WVFB	Width dependence of vfb	real	0
PHI	Strong inversion surface potential	real	0.75 [V]
LPHI	Length dependence of phi	real	0
WPHI	Width dependence of phi	real	0
K1	Bulk effect coefficient 1	real	0.8 [V ^{1/2}]
LK1	Length dependence of k1	real	0
WK1	Width dependence of k1	real	0
K2	Bulk effect coefficient 2	real	0
LK2	Length dependence of k2	real	0
WK2	Width dependence of k2	real	0
ETA0	VDS dependence of threshold voltage at	real	0

	VDD=0		
LETA0	Length dependence of eta0	real	0
WETA0	Width dependence of eta0	real	0
ETAB	VBS dependence of eta	real	0
LETAB	Length dependence of etab	real	0
WETAB	Width dependence of etab	real	0
DL	Channel length reduction in	real	0 [μm]
DW	Channel width reduction	real	0 [μm]
MU0	Low-field mobility, at VDS=0 VGS=VTH	real	0.4k [cm ² /V ² -s]
MU0B	VBS dependence of low-field mobility	real	0
LMU0B	Length dependence of mu0b	real	0
WMU0B	Width dependence of mu0b	real	0
MUS0	Mobility at VDS=VDD VGS=VTH	real	0.5k [cm ² /V ² -s]
LMUS0	Length dependence of mus0	real	0
WMUS0	Width dependence of mus	real	0
MUSB	VBS dependence of mus	real	0
LMUSB	Length dependence of musb	real	0
WMUSB	Width dependence of musb	real	0
MU20	VDS dependence of mu in tanh term	real	1.5
LMU20	Length dependence of mu20	real	0
WMU20	Width dependence of mu20	real	0
MU2B	VBS dependence of mu2	real	0
LMU2B	Length dependence of mu2b	real	0
WMU2B	Width dependence of mu2b	real	0
MU2G	VGS dependence of mu2	real	0

LMU2G	Length dependence of μ_{2g}	real	0
WMU2G	Width dependence of μ_{2g}	real	0
MU30	VDS dependence of μ in linear term	real	10
LMU30	Length dependence of μ_{30}	real	0
WMU30	Width dependence of μ_{30}	real	0
MU3B	VBS dependence of μ_3	real	0
LMU3B	Length dependence of μ_{3b}	real	0
WMU3B	Width dependence of μ_{3b}	real	0
MU3G	VGS dependence of μ_3	real	0
LMU3G	Length dependence of μ_{3g}	real	0
WMU3G	Width dependence of μ_{3g}	real	0
MU40	VDS dependence of μ in linear term	real	0
LMU40	Length dependence of μ_{40}	real	0
WMU40	Width dependence of μ_{40}	real	0
MU4B	VBS dependence of μ_4	real	0
LMU4B	Length dependence of μ_{4b}	real	0
WMU4B	Width dependence of μ_{4b}	real	0
MU4G	VGS dependence of μ_4	real	0
LMU4G	Length dependence of μ_{4g}	real	0
WMU4G	Width dependence of μ_{4g}	real	0
UA0	Linear VGS dependence of mobility	real	0.2
LUA0	Length dependence of μ_{a0}	real	0
WUA0	Width dependence of μ_{a0}	real	0
UAB	VBS dependence of μ_a	real	0
LUAB	Length dependence	real	0

	of uab		
WUAB	Width dependence of uab	real	0
UB0	Quadratic VGS dependence of mobility	real	0
LUB0	Length dependence of ub0	real	0
WUB0	Width dependence of ub0	real	0
UBB	VBS dependence of ub	real	0
LUBB	Length dependence of ubb	real	0
WUBB	Width dependence of ubb	real	0
U10	VDS dependence of mobility	real	0.1
LU10	Length dependence of u10	real	0
WU10	Width dependence of u10	real	0
U1B	VBS dependence of u1	real	0
LU1B	Length dependence of u1b	real	0
WU1B	Width dependence of u1b	real	0
U1D	VDS dependence of u1	real	0
LU1D	Length dependence of u1d	real	0
WU1D	Width dependence of u1d	real	0
N0	Subthreshold slope at VDS=0 VBS=0	real	1.4
LN0	Length dependence of n0	real	0
WN0	Width dependence of n0	real	0
NB	VBS dependence of n	real	0.5
LNB	Length dependence of nb	real	0
WNB	Width dependence of nb	real	0
ND	VDS dependence of n	real	0
LND	Length dependence of nd	real	0
WND	Width dependence of	real	0

	nd		
VOF0	Threshold voltage off-set AT $V_{DS}=0$ $V_{BS}=0$	real	1.8
LVOF0	Length dependence of vof0	real	0
WVOF0	Width dependence of vof0	real	0
VOFB	V_{BS} dependence of vof	real	0
LVOFB	Length dependence of vofb	real	0
WVOFB	Width dependence of vofb	real	0
VOFD	V_{DS} dependence of vof	real	0
LVOFD	Length dependence of vofd	real	0
WVOFD	Width dependence of vofd	real	0
AI0	Pre-factor of hot-electron effect	real	0
LAI0	Length dependence of ai0	real	0
WAI0	Width dependence of ai0	real	0
AIB	V_{BS} dependence of ai	real	0
LAIB	Length dependence of aib	real	0
WAIB	Width dependence of aib	real	0
BI0	Exponential factor of hot-electron effect	real	0
LBIO	Length dependence of bi0	real	0
WBIO	Width dependence of bi0	real	0
BIB	V_{BS} dependence of bi	real	0
LBIB	Length dependence of bib	real	0
WBIB	Width dependence of bib	real	0
VGHIGH	Upper bound of the cubic spline function	real	0.2
LVGHIGH	Length dependence of vghigh	real	0
WVGHIGH	Width dependence of vghigh	real	0

VGLOW	Lower bound of the cubic spline function	real	-0.15
LVGLOW	Length dependence of vglow	real	0
WVGLOW	Width dependence of vglow	real	0
TOX	Gate oxide thickness	real	30m [μm]
TEMP	Temperature in degree Celsius	real	27 [°C]
VDD	Maximum Vds	real	5 [V]
VGG	Maximum Vgs	real	5 [V]
VBB	Maximum Vbs	real	5 [V]
CGSO	Gate source overlap capacitance per unit channel width	real	0 [F/m]
CGDO	Gate drain overlap capacitance per unit channel width	real	0 [F/m]
CGBO	Gate bulk overlap capacitance per unit channel length	real	0 [F/m]
XPART	Flag for channel charge partitioning	real	0
RSH	Source drain diffusion sheet resistance in ohm per square	real	0 [Ohm/square]
JS	Source drain junction saturation current per unit area	real	0 [A/m ²]
PB	Source drain junction built in potential	real	0.1 [V]
MJ	Source drain bottom junction capacitance grading coefficient	real	0
PBSW	Source drain side junction capacitance built in potential	real	0.1 [V]
MJSW	Source drain side junction capacitance grading coefficient	real	0
CJ	Source drain bottom junction capacitance per unit area	real	0 [F/m ²]
CJSW	Source drain side junction capacitance per unit area	real	0 [F/m]
WDF	Default width of	real	10 [m]

	source drain diffusion in um		
DELL	Length reduction of source drain diffusion	real	0 [m]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
VBS	Vbs [V]	Output	real
VGS	Vgs [V]	Output	real
VDS	Vds [V]	Output	real
VBD	Vbd [V]	Output	real
ID	Id (terminal) [A]	Output	real
IG	Ig (terminal) [A]	Output	real
IS	Is (terminal) [A]	Output	real
IB	Ib (terminal) [A]	Output	real
P	Power Dissipation [W]	Output	real

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Example

Figure 3 shows application of the Spice-Compatible Level 2 BSIM N-channel and BSIM P-channel models. The parameters of BSIM2_P1 and BSIM2_N1 are set to their default values; the parameters of the rest of the system are listed in Table 4 and the simulation results shown in Figure 4.

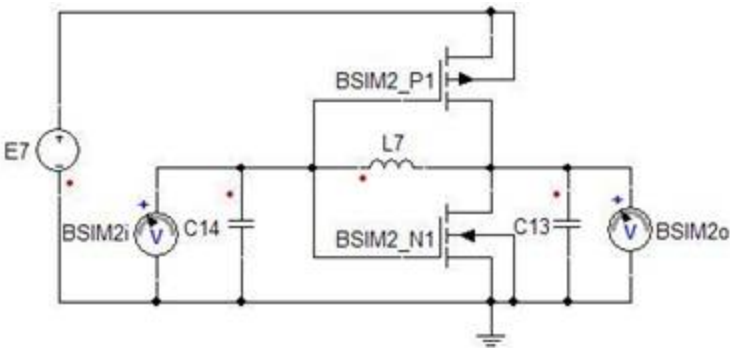


Figure 3. Application example of the Spice-Compatible Level 2 BSIM N-channel and BSIM P-channel models

Table 4

Component	Parameter	Value
Capacitor C14	C	100p [F]
	V0	7.5 [V]
Capacitor C13	C	100p [F]
	V0	0 [V]
Inductor L7	L	1m [H]
	I0	0 [A]
Voltage Source E7	EMF	15 [V]

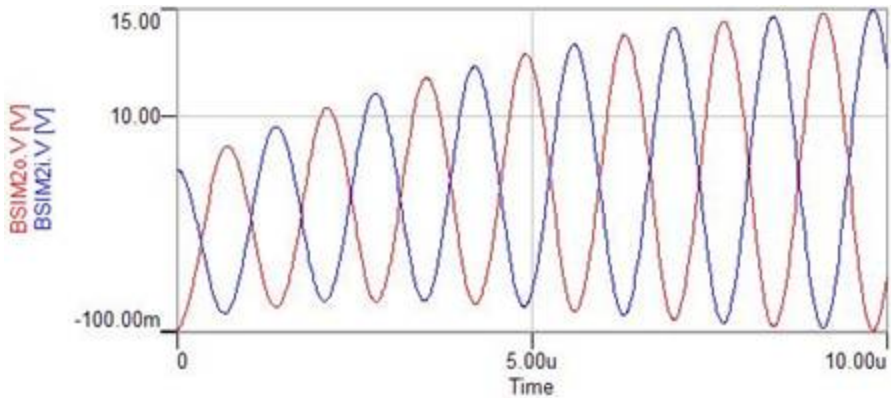


Figure 4. Simulation results-input and output voltage of BSIM2_N1

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References

[1]Massobrio, Giueseppe, and Paolo Antognetti: *Semiconductor Device Modeling with SPICE*, New York: McGraw Hill, 1993

BSIM3 Model - SPICE-Compatible N-Channel

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

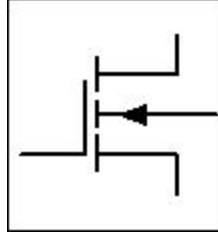


Figure 1. Component Symbol.

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Description

The Spice-Compatible BSIM3 N-channel and BSIM3 P-channel models simulate the electrical and thermal behavior of small-geometry MOSFETs using the parameters and equations of the BSIM3 MOSFET model. Electrical characteristics and the temperature dependence of MOSFET behavior are calculated according to user-input device parameters that are obtained from MOSFET process characterization.

BSIM3 and BSIM4 are developed by the Device Research Group of the Department of Electrical Engineering and Computer Science, University of California, Berkeley and copyrighted by the University of California.

Note: Only circuit-level temperatures can be used with these components, and no device-level temperatures can be used.

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Assumptions and Limitations

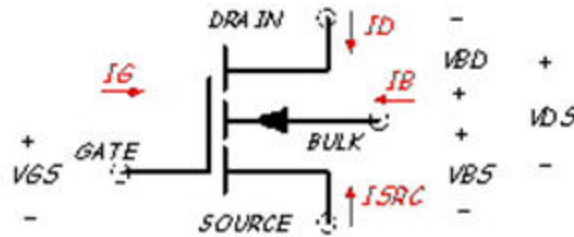


Figure 2. Current and Voltage Reference Arrow System

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Mathematical Description

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Netlist Syntax

```
UMODEL BSIM3_N ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) DRAIN:= %0,
GATE:= %1, SOURCE:= %2, BULK:= %3 ( L:= @L, W:= @W, AD:= @AD, AS:= @AS, PD:=
@PD, PS:= @PS, NRD:= @NRD, NRS:= @NRS, OFF:= @OFF, NQSMOD:= @NQSMOD,
ICVDS:= @ICVDS, ICVGS:= @ICVGS, ICVBS:= @ICVBS, CAPMOD:= @CAPMOD,
MOBMOD:= @MOBMOD, NOIMOD:= @NOIMOD, PARAMCHK:= @PARAMCHK, BINUNIT:=
@BINUNIT, TOX:= @TOX, TOXM:= @TOXM, CDSC:= @CDSC, CDSCB:= @CDSCB,
CDSCD:= @CDSCD, CIT:= @CIT, NFACTOR:= @NFACTOR, XJ:= @XJ, VSAT:= @VSAT,
AT:= @AT, A0:= @A0, AGS:= @AGS \\\ , A1:= @A1, A2:= @A2, KETA:= @KETA, NSUB:=
@NSUB, NCH:= @NCH, NGATE:= @NGATE, GAMMA1:= @GAMMA1, GAMMA2:=
@GAMMA2, VBX:= @VBX, VBM:= @VBM, XT:= @XT, K1:= @K1, KT1:= @KT1, KT1L:=
@KT1L, KT2:= @KT2, K2:= @K2, K3:= @K3, K3B:= @K3B, W0:= @W0, NLX:= @NLX,
DVT0:= @DVT0, DVT1:= @DVT1, DVT2:= @DVT2, DVT0W:= @DVT0W, DVT1W:=
@DVT1W, DVT2W:= @DVT2W, DROUT:= @DROUT, DSUB:= @DSUB, VTH0:= @VTH0,
VTHO:= @VTHO \\\ , UA:= @UA, UA1:= @UA1, UB:= @UB, UB1:= @UB1, UC:= @UC, UC1:=
@UC1, U0:= @U0, UTE:= @UTE, VOFF:= @VOFF, TNOM:= @TNOM, CGSO:= @CGSO,
CGDO:= @CGDO, CGBO:= @CGBO, XPART:= @XPART, ELM:= @ELM, DELTA:= @DELTA,
RSH:= @RSH, RDSW:= @RDSW, PRWG:= @PRWG, PRWB:= @PRWB, PRT:= @PRT,
ETA0:= @ETA0, ETAB:= @ETAB, PCLM:= @PCLM, PDIBLC1:= @PDIBLC1, PDIBLC2:=
@PDIBLC2, PDIBLCB:= @PDIBLCB, PSCBE1:= @PSCBE1, PSCBE2:= @PSCBE2, PVAG:=
@PVAG \\\ , JS:= @JS, JSW:= @JSW, PB:= @PB, NJ:= @NJ, XTI:= @XTI, MJ:= @MJ,
PBSW:= @PBSW, MJSW:= @MJSW, PBSWG:= @PBSWG, MJSWG:= @MJSWG, CJ:= @CJ,
```

VFBCV:= @VFBCV, VFB:= @VFB, CJSW:= @CJSW, CJSWG:= @CJSWG, TPB:= @TPB,
 TCJ:= @TCJ, TPBSW:= @TPBSW, TCJSW:= @TCJSW, TPBSWG:= @TPBSWG, TCJSWG:=
 @TCJSWG, ACDE:= @ACDE, MOIN:= @MOIN, NOFF:= @NOFF, VOFFCV:= @VOFFCV,
 LINT:= @LINT, LL:= @LL, LLC:= @LLC, LLN:= @LLN, LW:= @LW \\\, LWC:= @LWC, LWN:=
 @LWN, LWL:= @LWL, LWLC:= @LWLC, LMIN:= @LMIN, LMAX:= @LMAX, WR:= @WR,
 WINT:= @WINT, DWG:= @DWG, DWB:= @DWB, WL:= @WL, WLC:= @WLC, WLN:= @WLN,
 WW:= @WW, WWC:= @WWC, WWN:= @WWN, WWL:= @WWL, WWLC:= @WWLC,
 WMIN:= @WMIN, WMAX:= @WMAX, B0:= @B0, B1:= @B1, CGSL:= @CGSL, CGDL:=
 @CGDL, CKAPPA:= @CKAPPA, CF:= @CF, CLC:= @CLC, CLE:= @CLE, DWC:= @DWC,
 DLC:= @DLC \\\, ALPHA0:= @ALPHA0, ALPHA1:= @ALPHA1, BETA0:= @BETA0, IJTH:=
 @IJTH, LCDSC:= @LCDSC, LCDSCB:= @LCDSCB, LCDSCD:= @LCDSCD, LCIT:= @LCIT,
 LNFACTOR:= @LNFACTOR, LXJ:= @LXJ, LVSAT:= @LVSAT, LAT:= @LAT, LA0:= @LA0,
 LAGS:= @LAGS, LA1:= @LA1, LA2:= @LA2, LKETA:= @LKETA, LNSUB:= @LNSUB,
 LNCH:= @LNCH, LNGATE:= @LNGATE, LGAMMA1:= @LGAMMA1, LGAMMA2:=
 @LGAMMA2, LVBX:= @LVBX, LVBM:= @LVBM, LXT:= @LXT, LK1:= @LK1, LKT1:= @LKT1,
 LKT1L:= @LKT1L, LKT2:= @LKT2, LK2:= @LK2 \\\, LK3:= @LK3, LK3B:= @LK3B, LW0:=
 @LW0, LNLX:= @LNLX, LDVT0:= @LDVT0, LDVT1:= @LDVT1, LDVT2:= @LDVT2,
 LDVT0W:= @LDVT0W, LDVT1W:= @LDVT1W, LDVT2W:= @LDVT2W, LDROUT:=
 @LDROUT, LDSUB:= @LDSUB, LVTH0:= @LVTH0, LVTHO:= @LVTHO, LUA:= @LUA,
 LUA1:= @LUA1, LUB:= @LUB, LUB1:= @LUB1, LUC:= @LUC, LUC1:= @LUC1, LU0:=
 @LU0, LUTE:= @LUTE, LVOFF:= @LVOFF, LELM:= @LELM, LDELTA:= @LDELTA,
 LRDSW:= @LRDSW, LPRWG:= @LPRWG, LPRWB:= @LPRWB, LPRT:= @LPRT, LETA0:=
 @LETA0 \\\, LETAB:= @LETAB, LPCLM:= @LPCLM, LPDIBLC1:= @LPDIBLC1, LPDIBLC2:=
 @LPDIBLC2, LPDIBLCB:= @LPDIBLCB, LPSCBE1:= @LPSCBE1, LPSCBE2:= @LPSCBE2,
 LPVAG:= @LPVAG, LWR:= @LWR, LDWG:= @LDWG, LDWB:= @LDWB, LB0:= @LB0,
 LB1:= @LB1, LCGSL:= @LCGSL, LCGDL:= @LCGDL, LCKAPPA:= @LCKAPPA, LCF:=
 @LCF, LCLC:= @LCLC, LCLE:= @LCLE, LALPHA0:= @LALPHA0, LALPHA1:= @LALPHA1,
 LBETA0:= @LBETA0, LVFBCV:= @LVFBCV, LVFB:= @LVFB, LACDE:= @LACDE, LMOIN:=
 @LMOIN, LNOFF:= @LNOFF, LVOFFCV:= @LVOFFCV, WCDSC:= @WCDSC, WCDSCB:=
 @WCDSCB \\\, WCDSCD:= @WCDSCD, WCIT:= @WCIT, WNFACTOR:= @WNFACTOR,
 WXJ:= @WXJ, WVSAT:= @WVSAT, WAT:= @WAT, WA0:= @WA0, WAGS:= @WAGS,
 WA1:= @WA1, WA2:= @WA2, WKETA:= @WKETA, WNSUB:= @WNSUB, WNCH:=
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 @WGAMMA2, WVBX:= @WVBX, WVBM:= @WVBM, WXT:= @WXT, WK1:= @WK1, WKT1:=
 @WKT1, WKT1L:= @WKT1L, WKT2:= @WKT2, WK2:= @WK2, WK3:= @WK3, WK3B:=
 @WK3B, WW0:= @WW0, WNLX:= @WNLX, WDV0:= @WDV0, WDV1:= @WDV1 \\\,
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 @PNCH, PNGATE:= @PNGATE, PGAMMA1:= @PGAMMA1, PGAMMA2:= @PGAMMA2,
 PVBX:= @PVBX, PVBM:= @PVBM, PXT:= @PXT, PK1:= @PK1, PKT1:= @PKT1, PKT1L:=
 @PKT1L, PKT2:= @PKT2, PK2:= @PK2, PK3:= @PK3, PK3B:= @PK3B, PW0:= @PW0,
 PNLX:= @PNLX, PDVT0:= @PDVT0, PDVT1:= @PDVT1, PDVT2:= @PDVT2, PDVT0W:=
 @PDVT0W, PDVT1W:= @PDVT1W, PDVT2W:= @PDVT2W, PDROUT:= @PDROUT,
 PDSUB:= @PDSUB \\\ , PVTH0:= @PVTH0, PVTHO:= @PVTHO, PUA:= @PUA, PUA1:=
 @PUA1, PUB:= @PUB, PUB1:= @PUB1, PUC:= @PUC, PUC1:= @PUC1, PU0:= @PU0,
 PUTE:= @PUTE, PVOFF:= @PVOFF, PELM:= @PELM, PDELTA:= @PDELTA, PRDSW:=
 @PRDSW, PPRWG:= @PPRWG, PPRWB:= @PPRWB, PPRT:= @PPRT, PETA0:=
 @PETA0, PETAB:= @PETAB, PPCLM:= @PPCLM, PPDIBLC1:= @PPDIBLC1, PPDIBLC2:=
 @PPDIBLC2, PPDIBLCB:= @PPDIBLCB, PPSCBE1:= @PPSCBE1, PPSCBE2:=
 @PPSCBE2, PPVAG:= @PPVAG, PWR:= @PWR, PDWG:= @PDWG, PDWB:= @PDWB,
 PB0:= @PB0 \\\ , PB1:= @PB1, PCGSL:= @PCGSL, PCGDL:= @PCGDL, PCKAPPA:=
 @PCKAPPA, PCF:= @PCF, PCLC:= @PCLC, PCLE:= @PCLE, PALPHA0:= @PALPHA0,
 PALPHA1:= @PALPHA1, PBETA0:= @PBETA0, PVFBCV:= @PVFBCV, PVFB:= @PVFB,
 PACDE:= @PACDE, PMOIN:= @PMOIN, PNOFF:= @PNOFF, PVOFFCV:= @PVOFFCV,
 NOIA:= @NOIA, NOIB:= @NOIB, NOIC:= @NOIC, EM:= @EM, EF:= @EF, AF:= @AF, KF:=
 @KF) SRC: DB(Lib:=@ModelLibraryName);

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
GATE	Gate	electrical
SOURCE	Source	electrical
DRAIN	Drain	electrical
BULK	Bulk	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
L	Length	real	5u [m]
W	Width	real	5u [m]
AD	Drain area	real	0 [m ²]

AS	Source area	real	0 [m ²]
PD	Drain perimeter	real	0 [m]
PS	Source perimeter	real	0 [m]
NRD	Number of squares in drain	real	1
NRS	Number of squares in source	real	1
OFF	Device is initially off	boolean	0
NQSMOD	Non-quasi-static model selector	real	0
ICVDS	Initial D-S voltage	real	0 [V]
ICVGS	Initial G-S voltage	real	0 [V]
ICVBS	Initial B-S voltage	real	0 [V]
CAPMOD	Capacitance Model Selector	real	3
MOBMOD	Mobility model selector	real	1
NOIMOD	Noise model selector	real	1
PARAMCHK	Model parameter checking selector	real	0
BINUNIT	Bin unit selector	real	1
TOX	Gate oxide thickness in meters	real	15n [m]
TOXM	Gate oxide thickness used in extraction	real	15n [m]
CDSC	Drain/Source and channel coupling capacitance	real	0.24m [F/m ²]
CDSCB	Body-bias dependence of cdsc	real	0 [F/Vm ²]
CDSCD	Drain-bias dependence of cdsc	real	0 [F/Vm ²]

CIT	Interface state capacitance	real	0 [F/m ²]
NFACTOR	Subthreshold swing Coefficient	real	1
XJ	Junction depth in meters	real	0.15u [m]
VSAT	Saturation velocity at tnom	real	80k [m/s]
AT	Temperature coefficient of vsat	real	33k [m/s]
A0	Non-uniform depletion width effect coefficient	real	1
AGS	Gate bias coefficient of Abulk	real	0 [1/V]
A1	Non-saturation effect coefficient	real	0 [1/V]
A2	Non-saturation effect coefficient	real	1
KETA	Body-bias coefficient of non-uniform depletion width effect	real	-47m [1/V]
NSUB	Substrate doping concentration	real	6e+16 [cm ⁻³]
NCH	Channel doping concentration	real	1.7e+17 [cm ⁻³]
NGATE	Poly-gate doping concentration	real	0 [cm ⁻³]
GAMMA1	Vth body coefficient	real	0 [V ^{1/2}]
GAMMA2	Vth body coefficient	real	0 [V ^{1/2}]
VBX	Vth transition body Voltage	real	0 [V]
VBM	Maximum body voltage	real	-3 [V]
XT	Doping depth [m]	real	0.155u [m]
K1	Bulk effect coefficient	real	0 [V ^{1/2}]

	efficient 1		
KT1	Temperature coefficient of V_{th}	real	-0.11 [V]
KT1L	Temperature coefficient of V_{th}	real	0 [Vm]
KT2	Body-coefficient of k_{t1}	real	22m
K2	Bulk effect coefficient 2	real	0
K3	Narrow width effect coefficient	real	80
K3B	Body effect coefficient of k_3	real	0 [1/V]
W0	Narrow width effect parameter	real	2.5u [m]
NLX	Lateral non-uniform doping effect	real	0.174u [m]
DVT0	Short channel effect coeff. 0	real	2.2
DVT1	Short channel effect coeff. 1	real	0.53
DVT2	Short channel effect coeff. 2	real	-32m [1/V]
DVT0W	Narrow Width effect coeff. 0	real	0 [1/m]
DVT1W	Narrow Width effect coeff. 1	real	5.3Meg [1/m]
DVT2W	Narrow Width effect coeff. 2	real	-32m [1/V]
DROUT	DIBL coefficient of output resistance	real	0.56
DSUB	DIBL coefficient in the subthreshold region	real	0.56
VTH0	Threshold voltage	real	0.7 [V]
VTHO	Threshold voltage	real	0.7 [V]
UA	Linear gate dependence of mobility	real	2.25n [m/V]

UA1	Temperature coefficient of μ_a	real	4.31n [m/V]
UB	Quadratic gate dependence of mobility	real	5.87e-019 [m/V]
UB1	Temperature coefficient of μ_b	real	-7.61e-018 [m/V] ²
UC	Body-bias dependence of mobility	real	-46.5p [m/V]
UC1	Temperature coefficient of μ_c	real	-56p [MOBMOD=1,2: m/V ² ; MOBMOD=3: 1/V]
U0	Low-field mobility at T_{nom}	real	67m [cm ² /Vs]
UTE	Temperature coefficient of mobility	real	-1.5
VOFF	Threshold voltage offset	real	-80m [V]
TNOM	Parameter measurement temperature	real	0.30015k [K]
CGSO	Gate-source overlap capacitance per width	real	0.20718798n [F/m]
CGDO	Gate-drain overlap capacitance per width	real	0.20718798n [F/m]
CGBO	Gate-bulk overlap capacitance per length	real	0 [F/m]
XPART	Channel charge partitioning	real	0
ELM	Non-quasi-static Elmore Constant Parameter	real	5
DELTA	Effective V_{ds} parameter	real	10m [V]
RSH	Source-drain sheet resistance	real	0 [W/square]

RDSW	Source-drain resistance per width	real	0 [W-mmWr]
PRWG	Gate-bias effect on parasitic resistance	real	0 [1/V]
PRWB	Body-effect on parasitic resistance	real	0 [1/V ^{1/2}]
PRT	Temperature coefficient of parasitic resistance	real	0 [W-mm]
ETA0	Subthreshold region DIBL coefficient	real	80m
ETAB	Subthreshold region DIBL coefficient	real	-70m [1/V]
PCLM	Channel length modulation Coefficient	real	1.3
PDIBLC1	Drain-induced barrier lowering coefficient	real	0.39
PDIBLC2	Drain-induced barrier lowering coefficient	real	8.6m
PDIBLCB	Body-effect on drain-induced barrier lowering	real	0 [1/V]
PSCBE1	Substrate current body-effect coefficient	real	0.424G [V/m]
PSCBE2	Substrate current body-effect coefficient	real	10u [m/V]
PVAG	Gate dependence of output resistance parameter	real	0
JS	Source/drain junction reverse saturation current density	real	0.1m [A/m ²]

JSW	Sidewall junction reverse saturation current density	real	0 [A/m]
PB	Source/drain junction built-in potential	real	1 [V]
NJ	Source/drain junction emission coefficient	real	1
XTI	Junction current temperature exponent	real	3
MJ	Source/drain bottom junction capacitance grading coefficient	real	0.5
PBSW	Source/drain sidewall junction capacitance built in potential	real	1 [V]
MJSW	Source/drain sidewall junction capacitance grading coefficient	real	0.33
PBSWG	Source/drain (gate side) sidewall junction capacitance built in potential	real	1 [V]
MJSWG	Source/drain (gate side) sidewall junction capacitance grading coefficient	real	0.33
CJ	Source/drain bottom junction capacitance per unit area	real	0.5m [F/m ²]
VFBCV	Flat Band Voltage parameter for cap-mod=0 only	real	-1 [V]
VFB	Flat Band	real	0 [V]

	Voltage		
CJSW	Source/drain sidewall junction capacitance per unit periphery	real	0.5n [F/m]
CJSWG	Source/drain (gate side) sidewall junction capacitance per unit width	real	0.5n [F/m]
TPB	Temperature coefficient of pb	real	0 [V/K]
TCJ	Temperature coefficient of cj	real	0 [1/K]
TPBSW	Temperature coefficient of pbsw	real	0 [V/K]
TCJSW	Temperature coefficient of cjsw	real	0 [1/K]
TPBSWG	Temperature coefficient of pbswg	real	0 [V/K]
TCJSWG	Temperature coefficient of cjswg	real	0 [1/K]
ACDE	Exponential coefficient for finite charge thickness	real	1 [m/V]
MOIN	Coefficient for gate-bias dependent surface potential	real	15
NOFF	C-V turn-on/off parameter	real	1
VOFFCV	C-V lateral-shift parameter	real	0 [V]
LINT	Length reduction parameter	real	0 [m]
LL	Length reduction parameter	real	0 [mLLN]
LLC	Length reduction parameter for CV	real	0 [mLLN]
LLN	Length reduction parameter	real	1

LW	Length reduction parameter	real	0 [mLWN]
LWC	Length reduction parameter for CV	real	0 [mLWN]
LWN	Length reduction parameter	real	1
LWL	Length reduction parameter	real	0 [mLWN+LLN]
LWLC	Length reduction parameter for CV	real	0 [mLWN+LLN]
LMIN	Minimum length for the model	real	0 [m]
LMAX	Maximum length for the model	real	1 [m]
WR	Width dependence of rds	real	1
WINT	Width reduction parameter	real	0 [m]
DWG	Width reduction parameter	real	0 [m/V]
DWB	Width reduction parameter	real	0 [m/V ^{1/2}]
WL	Width reduction parameter	real	0 [mWLN]
WLC	Width reduction parameter for CV	real	0 [mWLN]
WLN	Width reduction parameter	real	1
WW	Width reduction parameter	real	0 [mWWN]
WWC	Width reduction parameter for CV	real	0 [mWWN]
WWN	Width reduction parameter	real	1
WWL	Width reduction parameter	real	0 [mWWN+WLN]
WWLC	Width reduction parameter for CV	real	0 [mWWN+WLN]
WMIN	Minimum width for the model	real	0 [m]
WMAX	Maximum width for the	real	1 [m]

	model		
B0	Abulk narrow width parameter	real	0 [m]
B1	Abulk narrow width parameter	real	0 [m]
CGSL	New C-V model parameter	real	0 [F/m]
CGDL	New C-V model parameter	real	0 [F/m]
CKAPPA	New C-V model parameter	real	0.6 [V]
CF	Fringe capacitance parameter	real	72.9896663192103p [F/m]
CLC	Vdsat parameter for C-V model	real	0.1u [m]
CLE	Vdsat parameter for C-V model	real	0.6
DWC	Delta W for C-V model	real	0 [m]
DLC	Delta L for C-V model	real	0 [m]
ALPHA0	substrate current model parameter	real	0 [m/V]
ALPHA1	substrate current model parameter	real	0 [1/V]
BETA0	substrate current model parameter	real	30 [V]
IJTH	Diode limiting current	real	0.1 [A]
LCDSC	Length dependence of cdsc	real	0
LCDSCB	Length dependence of cdsb	real	0
LCDSCD	Length dependence of cdsd	real	0
LCIT	Length dependence of cit	real	0
LNFACTOR	Length depend-	real	0

	ence of nfactor		
LXJ	Length depend- ence of xj	real	0
LVSAT	Length depend- ence of vsat	real	0
LAT	Length depend- ence of at	real	0
LA0	Length depend- ence of a0	real	0
LAGS	Length depend- ence of ags	real	0
LA1	Length depend- ence of a1	real	0
LA2	Length depend- ence of a2	real	0
LKETA	Length depend- ence of keta	real	0
LNSUB	Length depend- ence of nsub	real	0
LNCH	Length depend- ence of nch	real	0
LNGATE	Length depend- ence of ngate	real	0
LGAMMA1	Length depend- ence of gamma1	real	0
LGAMMA2	Length depend- ence of gamma2	real	0
LVBX	Length depend- ence of vbx	real	0
LVBM	Length depend- ence of vbm	real	0
LXT	Length depend- ence of xt	real	0
LK1	Length depend- ence of k1	real	0
LKT1	Length depend- ence of kt1	real	0
LKT1L	Length depend- ence of kt1l	real	0
LKT2	Length depend- ence of kt2	real	0
LK2	Length depend- ence of k2	real	0
LK3	Length depend- ence of k3	real	0
LK3B	Length depend- ence of k3b	real	0

LW0	Length dependence of w0	real	0
LNLX	Length dependence of nlx	real	0
LDVT0	Length dependence of dvt0	real	0
LDVT1	Length dependence of dvt1	real	0
LDVT2	Length dependence of dvt2	real	0
LDVT1W	Length dependence of dvt1w	real	0
LDVT2W	Length dependence of dvt2w	real	0
LDROUT	Length dependence of drout	real	0
LDSUB	Length dependence of dsub	real	0
LVTH0	Length dependence of vto	real	0
LVTHO	Length dependence of vto	real	0
LUA	Length dependence of ua	real	0
LUA1	Length dependence of ua1	real	0
LUB	Length dependence of ub	real	0
LUB1	Length dependence of ub1	real	0
LUC	Length dependence of uc	real	0
LUC1	Length dependence of uc1	real	0
LU0	Length dependence of u0	real	0
LUTE	Length dependence of ute	real	0
LVOFF	Length dependence of voff	real	0
LELM	Length dependence of elm	real	0
LDELTA	Length dependence of delta	real	0
LRDSW	Length dependence of rds	real	0
LPRWG	Length dependence of prwg	real	0
BLPRWB	Length dependence of prwb	real	0

	ence of prwb		
LPRT	Length depend- ence of prt	real	0
LETA0	Length depend- ence of eta0	real	0
LETAB	Length depend- ence of etab	real	0
LPCLM	Length depend- ence of pclm	real	0
LPDIBLC1	Length depend- ence of pdiblc1	real	0
LPDIBLC2	Length depend- ence of pdiblc2	real	0
LPDIBLCB	Length depend- ence of pdiblc b	real	0
LPSCBE1	Length depend- ence of pscbe1	real	0
LPSCBE2	Length depend- ence of pscbe2	real	0
LPVAG	Length depend- ence of pvag	real	0
LWR	Length depend- ence of wr	real	0
LDWG	Length depend- ence of dwg	real	0
LDWB	Length depend- ence of dwb	real	0
LB0	Length depend- ence of b0	real	0
LB1	Length depend- ence of b1	real	0
LCGSL	Length depend- ence of cgsl	real	0
LCGDL	Length depend- ence of cgdl	real	0
LCKAPPA	Length depend- ence of ckappa	real	0
LCF	Length depend- ence of cf	real	0
LCLC	Length depend- ence of clc	real	0
LCLE	Length depend- ence of cle	real	0
LALPHA0	Length depend- ence of alpha0	real	0
LALPHA1	Length depend- ence of alpha1	real	0
LBETA0	Length depend- ence of beta0	real	0

LVFBCV	Length dependence of vfbcv	real	0
LVFB	Length dependence of vfb	real	0
LACDE	Length dependence of acde	real	0
LMOIN	Length dependence of moin	real	0
LNOFF	Length dependence of noff	real	0
LVOFFCV	Length dependence of voffcv	real	0
WCDSC	Width dependence of cdsc	real	0
WCDSCB	Width dependence of cdsb	real	0
WCDSCD	Width dependence of cdsd	real	0
WCIT	Width dependence of cit	real	0
WNFACTOR	Width dependence of nfactor	real	0
WXJ	Width dependence of xj	real	0
WVSAT	Width dependence of vsat	real	0
WAT	Width dependence of at	real	0
WA0	Width dependence of a0	real	0
WAGS	Width dependence of ags	real	0
WA1	Width dependence of a1	real	0
WA2	Width dependence of a2	real	0
WKETA	Width dependence of keta	real	0
WNSUB	Width dependence of nsub	real	0
WNCH	Width dependence of nch	real	0
WNGATE	Width dependence of ngate	real	0
WGAMMA1	Width dependence of gamma1	real	0
WGAMMA2	Width dependence of	real	0

	gamma2		
WVBX	Width dependence of vbx	real	0
WVBM	Width dependence of vbm	real	0
WXT	Width dependence of xt	real	0
WK1	Width dependence of k1	real	0
WKT1	Width dependence of kt1	real	0
WKT1L	Width dependence of kt1l	real	0
WKT2	Width dependence of kt2	real	0
WK2	Width dependence of k2	real	0
WK3	Width dependence of k3	real	0
WK3B	Width dependence of k3b	real	0
WW0	Width dependence of w0	real	0
WNLX	Width dependence of nlx	real	0
WDVT0	Width dependence of dvt0	real	0
WDVT1	Width dependence of dvt1	real	0
WDVT2	Width dependence of dvt2	real	0
WDVT0W	Width dependence of dvt0w	real	0
WDVT1W	Width dependence of dvt1w	real	0
WDVT2W	Width dependence of dvt2w	real	0
WDROUT	Width dependence of drout	real	0
WDSUB	Width dependence of dsub	real	0
WVTH0	Width dependence of vto	real	0
WVTHO	Width dependence of vto	real	0
WUA	Width dependence of ua	real	0
WUA1	Width dependence of ua1	real	0

WUB	Width dependence of ub	real	0
WUB1	Width dependence of ub1	real	0
WUC	Width dependence of uc	real	0
WUC1	Width dependence of uc1	real	0
WU0	Width dependence of u0	real	0
WUTE	Width dependence of ute	real	0
WVOFF	Width dependence of voff	real	0
WELM	Width dependence of elm	real	0
WDELTA	Width dependence of delta	real	0
WRDSW	Width dependence of rds	real	0
WPRWG	Width dependence of prwg	real	0
WPRWB	Width dependence of prwb	real	0
WPRT	Width dependence of prt	real	0
WETA0	Width dependence of eta0	real	0
WETAB	Width dependence of etab	real	0
WPCLM	Width dependence of pclm	real	0
WPDIBLC1	Width dependence of pdiblc1	real	0
WPDIBLC2	Width dependence of pdiblc2	real	0
WPDIBLCB	Width dependence of pdiblc b	real	0
W PSCBE	Width dependence of pscbe1	real	0
WPSCBE2	Width dependence of pscbe2	real	0
WPVAG	Width dependence of pvag	real	0
WWR	Width dependence of wr	real	0
WDWG	Width dependence of dwg	real	0
WDWB	Width depend-	real	0

	ence of dwb		
WB0	Width dependence of b0	real	0
WB1	Width dependence of b1	real	0
WCGSL	Width dependence of cgsl	real	0
WCGDL	Width dependence of cgdl	real	0
WCKAPPA	Width dependence of ckappa	real	0
WCF	Width dependence of cf	real	0
WCLC	Width dependence of clc	real	0
WCLE	Width dependence of cle	real	0
WALPHA0	Width dependence of alpha0	real	0
WALPHA1	Width dependence of alpha1	real	0
WBETA0	Width dependence of beta0	real	0
WVFCV	Width dependence of vfbcv	real	0
WVFB	Width dependence of vfb	real	0
WACDE	Width dependence of acde	real	0
WMOIN	Width dependence of moin	real	0
WNOFF	Width dependence of noff	real	0
WVOFFCV	Width dependence of voffcv	real	0
PCDSC	Cross-term dependence of cdsc	real	0
PCDSCB	Cross-term dependence of cdsch	real	0
PCDSCD	Cross-term dependence of cdsd	real	0
PCIT	Cross-term dependence of cit	real	0
PNFACTOR	Cross-term dependence of	real	0

	nfactor		
PXJ	Cross-term dependence of xj	real	0
PVSAT	Cross-term dependence of vsat	real	0
PAT	Cross-term dependence of at	real	0
PA0	Cross-term dependence of a0	real	0
PAGS	Cross-term dependence of ags	real	0
PA1	Cross-term dependence of a1	real	0
PA2	Cross-term dependence of a2	real	0
PKETA	Cross-term dependence of keta	real	0
PNSUB	Cross-term dependence of nsub	real	0
PNCH	Cross-term dependence of nch	real	0
PNGATE	Cross-term dependence of ngate	real	0
PGAMMA1	Cross-term dependence of gamma1	real	0
PGAMMA2	Cross-term dependence of gamma2	real	0
PVBX	Cross-term dependence of vbx	real	0
PVBM	Cross-term dependence of vbm	real	0
PXT	Cross-term dependence of xt	real	0

PK1	Cross-term dependence of k1	real	0
PKT1	Cross-term dependence of kt1	real	0
PKT1L	Cross-term dependence of kt1l	real	0
PKT2	Cross-term dependence of kt2	real	0
PK2	Cross-term dependence of k2	real	0
PK3	Cross-term dependence of k3	real	0
PK3B	Cross-term dependence of k3b	real	0
PW0	Cross-term dependence of w0	real	0
PNLX	Cross-term dependence of nlx	real	0
PDVT0	Cross-term dependence of dvt0	real	0
PDVT1	Cross-term dependence of dvt1	real	0
PDVT2	Cross-term dependence of dvt2	real	0
PDVT0W	Cross-term dependence of dvt0w	real	0
PDVT1W	Cross-term dependence of dvt1w	real	0
PDVT2W	Cross-term dependence of dvt2w	real	0
PDROUT	Cross-term dependence of drout	real	0
PDSUB	Cross-term	real	0

	dependence of dsub		
PVTH0	Cross-term dependence of vto	real	0
PVTH0	Cross-term dependence of vto	real	0
PUA	Cross-term dependence of ua	real	0
PUA1	Cross-term dependence of ua1	real	0
PUB	Cross-term dependence of ub	real	0
PUB1	Cross-term dependence of ub1	real	0
PUC	Cross-term dependence of uc	real	0
PUC1	Cross-term dependence of uc1	real	0
PU0	Cross-term dependence of u0	real	0
PUTE	Cross-term dependence of ute	real	0
PVOFF	Cross-term dependence of voff	real	0
PELM	Cross-term dependence of elm	real	0
PDELTA	Cross-term dependence of delta	real	0
PRDSW	Cross-term dependence of rdsw	real	0
PPRWG	Cross-term dependence of prwg	real	0
PPRWB	Cross-term dependence of	real	0

	prwb		
PPRT	Cross-term dependence of prt	real	0
PETA0	Cross-term dependence of eta0	real	0
PETAB	Cross-term dependence of etab	real	0
PPCLM	Cross-term dependence of pclm	real	0
PPDIBLC1	Cross-term dependence of pdiblc1	real	0
PPDIBLC2	Cross-term dependence of pdiblc2	real	0
PPDIBLCB	Cross-term dependence of pdiblcb	real	0
PPSCBE1	Cross-term dependence of pscbe1	real	0
PPSCBE2	Cross-term dependence of pscbe2	real	0
PPVAG	Cross-term dependence of pvag	real	0
PWR	Cross-term dependence of wr	real	0
PDWG	Cross-term dependence of dwg	real	0
PDWB	Cross-term dependence of dwb	real	0
PB0	Cross-term dependence of b0	real	0
PB1	Cross-term dependence of b1	real	0
PCGSL	Cross-term dependence of cgsl	real	0

PCGDL	Cross-term dependence of cgdI	real	0
PCKAPPA	Cross-term dependence of ckappa	real	0
PCF	Cross-term dependence of cf	real	0
PCLC	Cross-term dependence of clc	real	0
PCLE	Cross-term dependence of cle	real	0
PALPHA0	Cross-term dependence of alpha0	real	0
PALPHA1	Cross-term dependence of alpha1	real	0
PBETA0	Cross-term dependence of beta0	real	0
PVFCV	Cross-term dependence of vfbcv	real	0
PVFB	Cross-term dependence of vfb	real	0
PACDE	Cross-term dependence of acde	real	0
PMOIN	Cross-term dependence of moin	real	0
PNOFF	Cross-term dependence of noff	real	0
PVOFFCV	Cross-term dependence of voffcv	real	0
NOIA	Flicker noise parameter	real	1e+020
NOIB	Flicker noise parameter	real	50k
NOIC	Flicker noise parameter	real	-1.4p
EM	Flicker noise	real	41Meg [V/m]

	parameter		
EF	Flicker noise frequency exponent	real	1
AF	Flicker noise exponent	real	1
KF	Flicker noise coefficient	real	0

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
VBS	Vbs [V]	Output	real
VGS	Vgs [V]	Output	real
VDS	Vds [V]	Output	real
VBD	Vbd [V]	Output	real
ID	Id (terminal) [A]	Output	real
IG	Ig (terminal) [A]	Output	real
IS	Is (terminal) [A]	Output	real
IB	Ib (terminal) [A]	Output	real
P	Power Dissipation [W]	Output	real

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Example

Figure 3 shows application of the Spice-Compatible Level 3 BSIM N-channel and BSIM P-channel models. The parameters of BSIM3_P1 and BSIM3_N1 are set to their default values; the parameters of the rest of the system are listed in Table 4 and the simulation results shown in Figure 4.

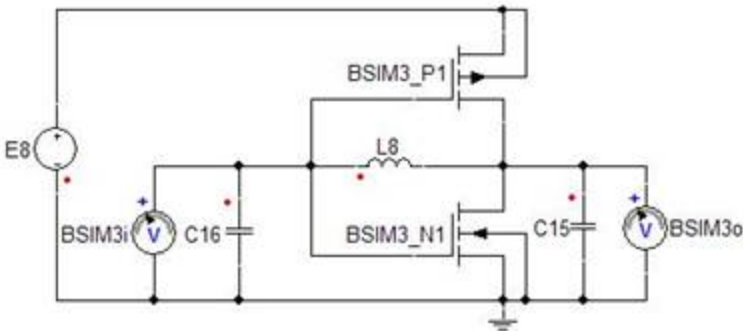


Figure 3. Application example of the Spice-Compatible Level 3 BSIM N-channel and BSIM P-channel models

Table 4

Component	Parameter	Value
Capacitor C16	C	100p [F]
	V0	7.5 [V]
Capacitor C15	C	100p [F]
	V0	0 [V]
Inductor L8	L	1m [H]
	I0	0 [A]
Voltage Source E8	EMF	15 [V]

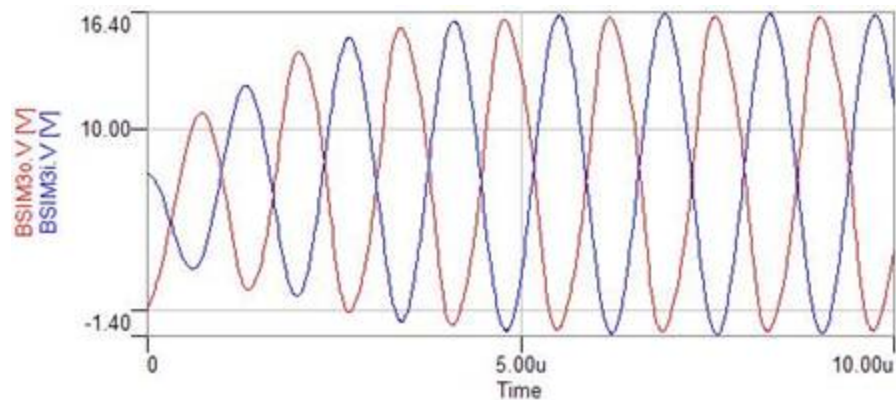


Figure 4. Simulation results-input and output voltage of BSIM3_N1

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References

[1] Information on the Web site of UC Berkeley Device Group at <http://www-device.eecs.berkeley.edu/~bsim3/>

BSIM3 Model - SPICE-Compatible P-Channel

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

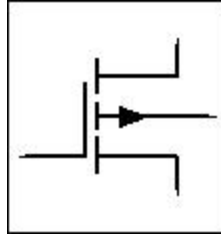


Figure 1. Component Symbol.

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Description

The Spice-Compatible BSIM3 N-channel and BSIM3 P-channel models simulate the electrical and thermal behavior of small-geometry MOSFETs using the parameters and equations of the BSIM3 MOSFET model. Electrical characteristics and the temperature dependence of MOSFET behavior are calculated according to user-input device parameters that are obtained from MOSFET process characterization.

BSIM3 and BSIM4 are developed by the Device Research Group of the Department of Electrical Engineering and Computer Science, University of California, Berkeley and copyrighted by the University of California.

Note: Only circuit-level temperatures can be used with these components, and no device-level temperatures can be used.

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Assumptions and Limitations

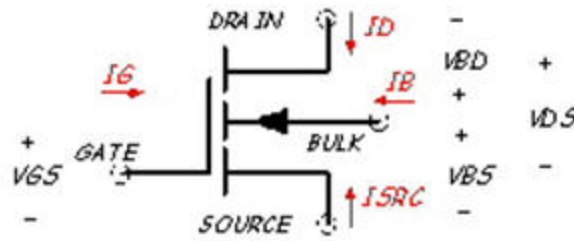


Figure 2. Current and Voltage Reference Arrow System

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Mathematical Description

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Netlist Syntax

```
UMODEL BSIM3_P ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) DRAIN:= %0,
GATE:= %1, SOURCE:= %2, BULK:= %3 ( L:= @L, W:= @W, AD:= @AD, AS:= @AS, PD:=
@PD, PS:= @PS, NRD:= @NRD, NRS:= @NRS, OFF:= @OFF, NQSMOD:= @NQSMOD,
ICVDS:= @ICVDS, ICVGS:= @ICVGS, ICVBS:= @ICVBS, CAPMOD:= @CAPMOD,
MOBMOD:= @MOBMOD, NOIMOD:= @NOIMOD, PARAMCHK:= @PARAMCHK, BINUNIT:=
@BINUNIT, TOX:= @TOX, TOXM:= @TOXM, CDSC:= @CDSC, CDSCB:= @CDSCB,
CDSCD:= @CDSCD, CIT:= @CIT, NFACTOR:= @NFACTOR, XJ:= @XJ, VSAT:= @VSAT,
AT:= @AT, A0:= @A0, AGS:= @AGS \\\ , A1:= @A1, A2:= @A2, KETA:= @KETA, NSUB:=
@NSUB, NCH:= @NCH, NGATE:= @NGATE, GAMMA1:= @GAMMA1, GAMMA2:=
@GAMMA2, VBX:= @VBX, VBM:= @VBM, XT:= @XT, K1:= @K1, KT1:= @KT1, KT1L:=
@KT1L, KT2:= @KT2, K2:= @K2, K3:= @K3, K3B:= @K3B, W0:= @W0, NLX:= @NLX,
DVT0:= @DVT0, DVT1:= @DVT1, DVT2:= @DVT2, DVT0W:= @DVT0W, DVT1W:=
@DVT1W, DVT2W:= @DVT2W, DROUT:= @DROUT, DSUB:= @DSUB, VTH0:= @VTH0,
VTHO:= @VTHO \\\ , UA:= @UA, UA1:= @UA1, UB:= @UB, UB1:= @UB1, UC:= @UC, UC1:=
@UC1, U0:= @U0, UTE:= @UTE, VOFF:= @VOFF, TNOM:= @TNOM, CGSO:= @CGSO,
CGDO:= @CGDO, CGBO:= @CGBO, XPART:= @XPART, ELM:= @ELM, DELTA:= @DELTA,
RSH:= @RSH, RDSW:= @RDSW, PRWG:= @PRWG, PRWB:= @PRWB, PRT:= @PRT,
ETA0:= @ETA0, ETAB:= @ETAB, PCLM:= @PCLM, PDIBLC1:= @PDIBLC1, PDIBLC2:=
@PDIBLC2, PDIBLCB:= @PDIBLCB, PSCBE1:= @PSCBE1, PSCBE2:= @PSCBE2, PVAG:=
@PVAG \\\ , JS:= @JS, JSW:= @JSW, PB:= @PB, NJ:= @NJ, XTI:= @XTI, MJ:= @MJ,
PBSW:= @PBSW, MJSW:= @MJSW, PBSWG:= @PBSWG, MJSWG:= @MJSWG, CJ:= @CJ,
VFBCV:= @VFBCV, VFB:= @VFB, CJSW:= @CJSW, CJSWG:= @CJSWG, TPB:= @TPB,
TCJ:= @TCJ, TPBSW:= @TPBSW, TCJSW:= @TCJSW, TPBSWG:= @TPBSWG, TCJSWG:=
@TCJSWG, ACDE:= @ACDE, MOIN:= @MOIN, NOFF:= @NOFF, VOFFCV:= @VOFFCV,
LINT:= @LINT, LL:= @LL, LLC:= @LLC, LLN:= @LLN, LW:= @LW \\\ , LWC:= @LWC, LWN:=
@LWN, LWL:= @LWL, LWLC:= @LWLC, LMIN:= @LMIN, LMAX:= @LMAX, WR:= @WR,
WINT:= @WINT, DWG:= @DWG, DWB:= @DWB, WL:= @WL, WLC:= @WLC, WLN:= @WLN,
WW:= @WW, WWC:= @WWC, WWN:= @WWN, WWL:= @WWL, WWLC:= @WWLC,
WMIN:= @WMIN, WMAX:= @WMAX, B0:= @B0, B1:= @B1, CGSL:= @CGSL, CGDL:=
```


@CGDL, CKAPPA:= @CKAPPA, CF:= @CF, CLC:= @CLC, CLE:= @CLE, DWC:= @DWC,
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 LNFACTOR:= @LNFACTOR, LXJ:= @LXJ, LVSAT:= @LVSAT, LAT:= @LAT, LA0:= @LA0,
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 @LW0, LNLX:= @LNLX, LDVT0:= @LDVT0, LDVT1:= @LDVT1, LDVT2:= @LDVT2,
 LDVT0W:= @LDVT0W, LDVT1W:= @LDVT1W, LDVT2W:= @LDVT2W, LDROUT:=
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 @PPDIBLC2, PPDIBLCB:= @PPDIBLCB, PPSCBE1:= @PPSCBE1, PPSCBE2:=
 @PPSCBE2, PPVAG:= @PPVAG, PWR:= @PWR, PDWG:= @PDWG, PDWB:= @PDWB,
 PB0:= @PB0 \\\ , PB1:= @PB1, PCGSL:= @PCGSL, PCGDL:= @PCGDL, PCKAPPA:=
 @PCKAPPA, PCF:= @PCF, PCLC:= @PCLC, PCLE:= @PCLE, PALPHA0:= @PALPHA0,
 PALPHA1:= @PALPHA1, PBETA0:= @PBETA0, PVFBCV:= @PVFBCV, PVFB:= @PVFB,
 PACDE:= @PACDE, PMOIN:= @PMOIN, PNOFF:= @PNOFF, PVOFFCV:= @PVOFFCV,
 NOIA:= @NOIA, NOIB:= @NOIB, NOIC:= @NOIC, EM:= @EM, EF:= @EF, AF:= @AF, KF:=
 @KF) SRC: DB(Lib:=@ModellibraryName);

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
GATE	Gate	electrical
SOURCE	Source	electrical
DRAIN	Drain	electrical
BULK	Bulk	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
L	Length	real	5u [m]
W	Width	real	5u [m]
AD	Drain area	real	0 [m ²]
AS	Source area	real	0 [m ²]
PD	Drain perimeter	real	0 [m]
PS	Source perimeter	real	0 [m]
NRD	Number of squares in drain	real	1
NRS	Number of squares in source	real	1
OFF	Device is initially off	boolean	0
NQSMOD	Non-quasi-static model selector	real	0
ICVDS	Initial D-S voltage	real	0 [V]
ICVGS	Initial G-S voltage	real	0 [V]
ICVBS	Initial B-S voltage	real	0 [V]
CAPMOD	Capacitance Model Selector	real	3
MOBMOD	Mobility model selector	real	1
NOIMOD	Noise model selector	real	1
PARAMCHK	Model parameter checking selector	real	0
BINUNIT	Bin unit selector	real	1
TOX	Gate oxide thickness in meters	real	15n [m]
TOXM	Gate oxide thickness used in extraction	real	15n [m]
CDSC	Drain/Source	real	0.24m [F/m ²]

	and channel coupling capacitance		
CDSCB	Body-bias dependence of cdsc	real	0 [F/Vm ²]
CDSCD	Drain-bias dependence of cdsc	real	0 [F/Vm ²]
CIT	Interface state capacitance	real	0 [F/m ²]
NFACTOR	Subthreshold swing Coefficient	real	1
XJ	Junction depth in meters	real	0.15u [m]
VSAT	Saturation velocity at tn timer	real	80k [m/s]
AT	Temperature coefficient of vsat	real	33k [m/s]
A0	Non-uniform depletion width effect coefficient	real	1
AGS	Gate bias coefficient of Abulk	real	0 [1/V]
A1	Non-saturation effect coefficient	real	0 [1/V]
A2	Non-saturation effect coefficient	real	1
KETA	Body-bias coefficient of non-uniform depletion width effect	real	-47m [1/V]
NSUB	Substrate doping concentration	real	6e+16 [cm ⁻³]
NCH	Channel doping concentration	real	1.7e+17 [cm ⁻³]
NGATE	Poly-gate doping concentration	real	0 [cm ⁻³]
GAMMA1	Vth body coefficient	real	0 [V ^{1/2}]

GAMMA2	Vth body coef- ficient	real	0 [V ^{1/2}]
VBX	Vth transition body Voltage	real	0 [V]
VBM	Maximum body voltage	real	-3 [V]
XT	Doping depth [m]	real	0.155u [m]
K1	Bulk effect coef- ficient 1	real	0 [V ^{1/2}]
KT1	Temperature coefficient of Vth	real	-0.11 [V]
KT1L	Temperature coefficient of Vth	real	0 [Vm]
KT2	Body-coef- ficient of kt1	real	22m
K2	Bulk effect coef- ficient 2	real	0
K3	Narrow width effect coef- ficient	real	80
K3B	Body effect coefficient of k3	real	0 [1/V]
W0	Narrow width effect para- meter	real	2.5u [m]
NLX	Lateral non-uni- form doping effect	real	0.174u [m]
DVT0	Short channel effect coeff. 0	real	2.2
DVT1	Short channel effect coeff. 1	real	0.53
DVT2	Short channel effect coeff. 2	real	-32m [1/V]
DVT0W	Narrow Width coeff. 0	real	0 [1/m]
DVT1W	Narrow Width effect coeff. 1	real	5.3Meg [1/m]
DVT2W	Narrow Width effect coeff. 2	real	-32m [1/V]
DROUT	DIBL coef- ficient of output resistance	real	0.56
DSUB	DIBL coef- ficient in the	real	0.56

	subthreshold region		
VTH0	Threshold voltage	real	0.7 [V]
VTHO	Threshold voltage	real	0.7 [V]
UA	Linear gate dependence of mobility	real	2.25n [m/V]
UA1	Temperature coefficient of ua	real	4.31n [m/V]
UB	Quadratic gate dependence of mobility	real	5.87e-019 [m/V]
UB1	Temperature coefficient of ub	real	-7.61e-018 [m/V] ²
UC	Body-bias dependence of mobility	real	-46.5p [m/V]
UC1	Temperature coefficient of uc	real	-56p [MOBMOD=1,2: m/V ² ; MOBMOD=3: 1/V]
U0	Low-field mobility at Tnom	real	67m [cm ² /Vs]
UTE	Temperature coefficient of mobility	real	-1.5
VOFF	Threshold voltage offset	real	-80m [V]
TNOM	Parameter measurement temperature	real	0.30015k [K]
CGSO	Gate-source overlap capacitance per width	real	0.20718798n [F/m]
CGDO	Gate-drain overlap capacitance per width	real	0.20718798n [F/m]
CGBO	Gate-bulk overlap capacitance per length	real	0 [F/m]
XPART	Channel charge partitioning	real	0

ELM	Non-quasi-static Elmore Constant Parameter	real	5
DELTA	Effective Vds parameter	real	10m [V]
RSH	Source-drain sheet resistance	real	0 [W/square]
RDSW	Source-drain resistance per width	real	0 [W-mmWr]
PRWG	Gate-bias effect on parasitic resistance	real	0 [1/V]
PRWB	Body-effect on parasitic resistance	real	0 [1/V ^{1/2}]
PRT	Temperature coefficient of parasitic resistance	real	0 [W-mm]
ETA0	Subthreshold region DIBL coefficient	real	80m
ETAB	Subthreshold region DIBL coefficient	real	-70m [1/V]
PCLM	Channel length modulation Coefficient	real	1.3
PDIBLC1	Drain-induced barrier lowering coefficient	real	0.39
PDIBLC2	Drain-induced barrier lowering coefficient	real	8.6m
PDIBLCB	Body-effect on drain-induced barrier lowering	real	0 [1/V]
PSCBE1	Substrate current body-effect coefficient	real	0.424G [V/m]
PSCBE2	Substrate current body-effect coefficient	real	10u [m/V]

PVAG	Gate dependence of output resistance parameter	real	0
JS	Source/drain junction reverse saturation current density	real	0.1m [A/m ²]
JSW	Sidewall junction reverse saturation current density	real	0 [A/m]
PB	Source/drain junction built-in potential	real	1 [V]
NJ	Source/drain junction emission coefficient	real	1
XTI	Junction current temperature exponent	real	3
MJ	Source/drain bottom junction capacitance grading coefficient	real	0.5
PBSW	Source/drain sidewall junction capacitance built in potential	real	1 [V]
MJSW	Source/drain sidewall junction capacitance grading coefficient	real	0.33
PBSWG	Source/drain (gate side) sidewall junction capacitance built in potential	real	1 [V]
MJSWG	Source/drain (gate side) sidewall junction capacitance grading coefficient	real	0.33

CJ	Source/drain bottom junction capacitance per unit area	real	0.5m [F/m ²]
VFBCV	Flat Band Voltage parameter for cap-mod=0 only	real	-1 [V]
VFB	Flat Band Voltage	real	0 [V]
CJSW	Source/drain sidewall junction capacitance per unit periphery	real	0.5n [F/m]
CJSWG	Source/drain (gate side) sidewall junction capacitance per unit width	real	0.5n [F/m]
TPB	Temperature coefficient of pb	real	0 [V/K]
TCJ	Temperature coefficient of cj	real	0 [1/K]
TPBSW	Temperature coefficient of pbsw	real	0 [V/K]
TCJSW	Temperature coefficient of cjsw	real	0 [1/K]
TPBSWG	Temperature coefficient of pbswg	real	0 [V/K]
TCJSWG	Temperature coefficient of cjswg	real	0 [1/K]
ACDE	Exponential coefficient for finite charge thickness	real	1 [m/V]
MOIN	Coefficient for gate-bias dependent surface potential	real	15
NOFF	C-V turn-on/off parameter	real	1
VOFFCV	C-V lateral-shift parameter	real	0 [V]

LINT	Length reduction parameter	real	0 [m]
LL	Length reduction parameter	real	0 [mLLN]
LLC	Length reduction parameter for CV	real	0 [mLLN]
LLN	Length reduction parameter	real	1
LW	Length reduction parameter	real	0 [mLWN]
LWC	Length reduction parameter for CV	real	0 [mLWN]
LWN	Length reduction parameter	real	1
LWL	Length reduction parameter	real	0 [mLWN+LLN]
LWLC	Length reduction parameter for CV	real	0 [mLWN+LLN]
LMIN	Minimum length for the model	real	0 [m]
LMAX	Maximum length for the model	real	1 [m]
WR	Width dependence of rds	real	1
WINT	Width reduction parameter	real	0 [m]
DWG	Width reduction parameter	real	0 [m/V]
DWB	Width reduction parameter	real	0 [m/V ^{1/2}]
WL	Width reduction parameter	real	0 [mWLN]
WLC	Width reduction parameter for CV	real	0 [mWLN]
WLN	Width reduction parameter	real	1
WW	Width reduction parameter	real	0 [mWWN]
WWC	Width reduction parameter for CV	real	0 [mWWN]
WWN	Width reduction parameter	real	1

WWL	Width reduction parameter	real	0 [mWWN+WLN]
WWLC	Width reduction parameter for CV	real	0 [mWWN+WLN]
WMIN	Minimum width for the model	real	0 [m]
WMAX	Maximum width for the model	real	1 [m]
B0	Abulk narrow width parameter	real	0 [m]
B1	Abulk narrow width parameter	real	0 [m]
CGSL	New C-V model parameter	real	0 [F/m]
CGDL	New C-V model parameter	real	0 [F/m]
CKAPPA	New C-V model parameter	real	0.6 [V]
CF	Fringe capacitance parameter	real	72.9896663192103p [F/m]
CLC	Vdsat parameter for C-V model	real	0.1u [m]
CLE	Vdsat parameter for C-V model	real	0.6
DWC	Delta W for C-V model	real	0 [m]
DLC	Delta L for C-V model	real	0 [m]
ALPHA0	substrate current model parameter	real	0 [m/V]
ALPHA1	substrate current model parameter	real	0 [1/V]
BETA0	substrate current model parameter	real	30 [V]
IJTH	Diode limiting current	real	0.1 [A]

LCDSC	Length dependence of cdsc	real	0
LCDSCB	Length dependence of cdsb	real	0
LCDSCD	Length dependence of cdsd	real	0
LCIT	Length dependence of cit	real	0
LNFACTOR	Length dependence of nfactor	real	0
LXJ	Length dependence of xj	real	0
LVSAT	Length dependence of vsat	real	0
LAT	Length dependence of at	real	0
LA0	Length dependence of a0	real	0
LAGS	Length dependence of ags	real	0
LA1	Length dependence of a1	real	0
LA2	Length dependence of a2	real	0
LKETA	Length dependence of keta	real	0
LNSUB	Length dependence of nsub	real	0
LNCH	Length dependence of nch	real	0
LNGATE	Length dependence of ngate	real	0
LGAMMA1	Length dependence of gamma1	real	0
LGAMMA2	Length dependence of gamma2	real	0
LVBX	Length dependence of vbx	real	0
LVBM	Length dependence of vbm	real	0
LXT	Length dependence of xt	real	0
LK1	Length dependence of k1	real	0
LKT1	Length dependence of kt1	real	0
LKT1L	Length depend-	real	0

	ence of kt1l		
LKT2	Length depend- ence of kt2	real	0
LK2	Length depend- ence of k2	real	0
LK3	Length depend- ence of k3	real	0
LK3B	Length depend- ence of k3b	real	0
LW0	Length depend- ence of w0	real	0
LNLX	Length depend- ence of nlx	real	0
LDVT0	Length depend- ence of dvt0	real	0
LDVT1	Length depend- ence of dvt1	real	0
LDVT2	Length depend- ence of dvt2	real	0
LDVT1W	Length depend- ence of dvt1w	real	0
LDVT2W	Length depend- ence of dvt2w	real	0
LDROUT	Length depend- ence of drout	real	0
LDSUB	Length depend- ence of dsub	real	0
LVTH0	Length depend- ence of vto	real	0
LVTHO	Length depend- ence of vto	real	0
LUA	Length depend- ence of ua	real	0
LUA1	Length depend- ence of ua1	real	0
LUB	Length depend- ence of ub	real	0
LUB1	Length depend- ence of ub1	real	0
LUC	Length depend- ence of uc	real	0
LUC1	Length depend- ence of uc1	real	0
LU0	Length depend- ence of u0	real	0
LUTE	Length depend- ence of ute	real	0
LVOFF	Length depend- ence of voff	real	0

LELM	Length dependence of elm	real	0
LDELTA	Length dependence of delta	real	0
LRDSW	Length dependence of rds	real	0
LPRWG	Length dependence of prwg	real	0
BLPRWB	Length dependence of prwb	real	0
LPRT	Length dependence of prt	real	0
LETA0	Length dependence of eta0	real	0
LETAB	Length dependence of etab	real	0
LPCLM	Length dependence of pclm	real	0
LPDIBLC1	Length dependence of pdiblc1	real	0
LPDIBLC2	Length dependence of pdiblc2	real	0
LPDIBLCB	Length dependence of pdiblcb	real	0
LPSCBE1	Length dependence of pscbe1	real	0
LPSCBE2	Length dependence of pscbe2	real	0
LPVAG	Length dependence of pvag	real	0
LWR	Length dependence of wr	real	0
LDWG	Length dependence of dwg	real	0
LDWB	Length dependence of dwb	real	0
LB0	Length dependence of b0	real	0
LB1	Length dependence of b1	real	0
LCGSL	Length dependence of cgsl	real	0
LCGDL	Length dependence of cgdl	real	0
LCKAPPA	Length dependence of ckappa	real	0
LCF	Length dependence of cf	real	0
LCLC	Length depend-	real	0

	ence of clc		
LCLE	Length depend- ence of cle	real	0
LALPHA0	Length depend- ence of alpha0	real	0
LALPHA1	Length depend- ence of alpha1	real	0
LBETA0	Length depend- ence of beta0	real	0
LVFBCV	Length depend- ence of vfbcv	real	0
LVFB	Length depend- ence of vfb	real	0
LACDE	Length depend- ence of acde	real	0
LMOIN	Length depend- ence of moin	real	0
LNOFF	Length depend- ence of noff	real	0
LVOFFCV	Length depend- ence of voffcv	real	0
WCDSC	Width depend- ence of cdsc	real	0
WCDSCB	Width depend- ence of cdsb	real	0
WCDSCD	Width depend- ence of cdsd	real	0
WCIT	Width depend- ence of cit	real	0
WNFACTOR	Width depend- ence of nfactor	real	0
WXJ	Width depend- ence of xj	real	0
WVSAT	Width depend- ence of vsat	real	0
WAT	Width depend- ence of at	real	0
WA0	Width depend- ence of a0	real	0
WAGS	Width depend- ence of ags	real	0
WA1	Width depend- ence of a1	real	0
WA2	Width depend- ence of a2	real	0
WKETA	Width depend- ence of keta	real	0
WNSUB	Width depend- ence of nsub	real	0

WNCH	Width dependence of nch	real	0
WNGATE	Width dependence of ngate	real	0
WGAMMA1	Width dependence of gamma1	real	0
WGAMMA2	Width dependence of gamma2	real	0
WVBX	Width dependence of vbx	real	0
WVBM	Width dependence of vbm	real	0
WXT	Width dependence of xt	real	0
WK1	Width dependence of k1	real	0
WKT1	Width dependence of kt1	real	0
WKT1L	Width dependence of kt1l	real	0
WKT2	Width dependence of kt2	real	0
WK2	Width dependence of k2	real	0
WK3	Width dependence of k3	real	0
WK3B	Width dependence of k3b	real	0
WW0	Width dependence of w0	real	0
WNLX	Width dependence of nlx	real	0
WDVT0	Width dependence of dvt0	real	0
WDVT1	Width dependence of dvt1	real	0
WDVT2	Width dependence of dvt2	real	0
WDVT0W	Width dependence of dvt0w	real	0
WDVT1W	Width dependence of dvt1w	real	0
WDVT2W	Width dependence of dvt2w	real	0
WDROUT	Width dependence of drout	real	0
WDSUB	Width depend-	real	0

	ence of dsub		
WVTH0	Width dependence of vto	real	0
WVTHO	Width dependence of vto	real	0
WUA	Width dependence of ua	real	0
WUA1	Width dependence of ua1	real	0
WUB	Width dependence of ub	real	0
WUB1	Width dependence of ub1	real	0
WUC	Width dependence of uc	real	0
WUC1	Width dependence of uc1	real	0
WU0	Width dependence of u0	real	0
WUTE	Width dependence of ute	real	0
WVOFF	Width dependence of voff	real	0
WELM	Width dependence of elm	real	0
WDELTA	Width dependence of delta	real	0
WRDSW	Width dependence of rds	real	0
WPRWG	Width dependence of prwg	real	0
WPRWB	Width dependence of prwb	real	0
WPRT	Width dependence of prt	real	0
WETA0	Width dependence of eta0	real	0
WETAB	Width dependence of etab	real	0
WPCLM	Width dependence of pclm	real	0
WPDIBLC1	Width dependence of pdiblc1	real	0
WPDIBLC2	Width dependence of pdiblc2	real	0
WPDIBLCB	Width dependence of pdiblcb	real	0
W PSCBE	Width dependence of pscbe1	real	0

WPSCBE2	Width dependence of pscbe2	real	0
WPVAG	Width dependence of pvag	real	0
WWR	Width dependence of wr	real	0
WDWG	Width dependence of dwg	real	0
WDWB	Width dependence of dwb	real	0
WB0	Width dependence of b0	real	0
WB1	Width dependence of b1	real	0
WCGSL	Width dependence of cgsI	real	0
WCGDL	Width dependence of cgdl	real	0
WCKAPPA	Width dependence of ckappa	real	0
WCF	Width dependence of cf	real	0
WCLC	Width dependence of clc	real	0
WCLE	Width dependence of cle	real	0
WALPHA0	Width dependence of alpha0	real	0
WALPHA1	Width dependence of alpha1	real	0
WBETA0	Width dependence of beta0	real	0
WVFCV	Width dependence of vfbcv	real	0
WVFB	Width dependence of vfb	real	0
WACDE	Width dependence of acde	real	0
WMOIN	Width dependence of moin	real	0
WNOFF	Width dependence of noff	real	0
WVOFFCV	Width dependence of voffcv	real	0
PCDSC	Cross-term dependence of cdsc	real	0
PCDSCB	Cross-term dependence of	real	0

	cdscb		
PCDSCD	Cross-term dependence of cdscd	real	0
PCIT	Cross-term dependence of cit	real	0
PNFACTOR	Cross-term dependence of nfactor	real	0
PXJ	Cross-term dependence of xj	real	0
PVSAT	Cross-term dependence of vsat	real	0
PAT	Cross-term dependence of at	real	0
PA0	Cross-term dependence of a0	real	0
PAGS	Cross-term dependence of ags	real	0
PA1	Cross-term dependence of a1	real	0
PA2	Cross-term dependence of a2	real	0
PKETA	Cross-term dependence of keta	real	0
PNSUB	Cross-term dependence of nsub	real	0
PNCH	Cross-term dependence of nch	real	0
PNGATE	Cross-term dependence of ngate	real	0
PGAMMA1	Cross-term dependence of gamma1	real	0
PGAMMA2	Cross-term dependence of gamma2	real	0

PVBX	Cross-term dependence of vbx	real	0
PVBM	Cross-term dependence of vbm	real	0
PXT	Cross-term dependence of xt	real	0
PK1	Cross-term dependence of k1	real	0
PKT1	Cross-term dependence of kt1	real	0
PKT1L	Cross-term dependence of kt1l	real	0
PKT2	Cross-term dependence of kt2	real	0
PK2	Cross-term dependence of k2	real	0
PK3	Cross-term dependence of k3	real	0
PK3B	Cross-term dependence of k3b	real	0
PW0	Cross-term dependence of w0	real	0
PNLX	Cross-term dependence of nlx	real	0
PDVT0	Cross-term dependence of dvt0	real	0
PDVT1	Cross-term dependence of dvt1	real	0
PDVT2	Cross-term dependence of dvt2	real	0
PDVT0W	Cross-term dependence of dvt0w	real	0
PDVT1W	Cross-term	real	0

	dependence of dvt1w		
PDVT2W	Cross-term dependence of dvt2w	real	0
PDROUT	Cross-term dependence of drout	real	0
PDSUB	Cross-term dependence of dsub	real	0
PVTH0	Cross-term dependence of vto	real	0
PVTHO	Cross-term dependence of vto	real	0
PUA	Cross-term dependence of ua	real	0
PUA1	Cross-term dependence of ua1	real	0
PUB	Cross-term dependence of ub	real	0
PUB1	Cross-term dependence of ub1	real	0
PUC	Cross-term dependence of uc	real	0
PUC1	Cross-term dependence of uc1	real	0
PU0	Cross-term dependence of u0	real	0
PUTE	Cross-term dependence of ute	real	0
PVOFF	Cross-term dependence of voff	real	0
PELM	Cross-term dependence of elm	real	0
PDELTA	Cross-term dependence of	real	0

	delta		
PRDSW	Cross-term dependence of rds w	real	0
PPRWG	Cross-term dependence of pr w g	real	0
PPRWB	Cross-term dependence of pr w b	real	0
PPRT	Cross-term dependence of prt	real	0
PETA0	Cross-term dependence of eta 0	real	0
PETAB	Cross-term dependence of eta b	real	0
PPCLM	Cross-term dependence of pcl m	real	0
PPDIBLC1	Cross-term dependence of pdiblc 1	real	0
PPDIBLC2	Cross-term dependence of pdiblc 2	real	0
PPDIBLCB	Cross-term dependence of pdiblc b	real	0
PPSCBE1	Cross-term dependence of pscbe 1	real	0
PPSCBE2	Cross-term dependence of pscbe 2	real	0
PPVAG	Cross-term dependence of pvag	real	0
PWR	Cross-term dependence of wr	real	0
PDWG	Cross-term dependence of dwg	real	0
PDWB	Cross-term dependence of dwb	real	0

PB0	Cross-term dependence of b0	real	0
PB1	Cross-term dependence of b1	real	0
PCGSL	Cross-term dependence of cgsl	real	0
PCGDL	Cross-term dependence of cgdl	real	0
PCKAPPA	Cross-term dependence of ckappa	real	0
PCF	Cross-term dependence of cf	real	0
PCLC	Cross-term dependence of clc	real	0
PCLE	Cross-term dependence of cle	real	0
PALPHA0	Cross-term dependence of alpha0	real	0
PALPHA1	Cross-term dependence of alpha1	real	0
PBETA0	Cross-term dependence of beta0	real	0
PVFCV	Cross-term dependence of vfbcv	real	0
PVFB	Cross-term dependence of vfb	real	0
PACDE	Cross-term dependence of acde	real	0
PMOIN	Cross-term dependence of moin	real	0
PNOFF	Cross-term dependence of noff	real	0
PVOFFCV	Cross-term	real	0

	dependence of voffcv		
NOIA	Flicker noise parameter	real	1e+020
NOIB	Flicker noise parameter	real	50k
NOIC	Flicker noise parameter	real	-1.4p
EM	Flicker noise parameter	real	41Meg [V/m]
EF	Flicker noise frequency exponent	real	1
AF	Flicker noise exponent	real	1
KF	Flicker noise coefficient	real	0

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
VBS	Vbs [V]	Output	real
VGS	Vgs [V]	Output	real
VDS	Vds [V]	Output	real
VBD	Vbd [V]	Output	real
ID	Id (terminal) [A]	Output	real
IG	Ig (terminal) [A]	Output	real
IS	Is (terminal) [A]	Output	real
IB	Ib (terminal) [A]	Output	real
P	Power Dissipation [W]	Output	real

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Example

Figure 3 shows application of the Spice-Compatible Level 3 BSIM N-channel and BSIM P-channel models. The parameters of BSIM3_P1 and BSIM3_N1 are set to their default values; the parameters of the rest of the system are listed in Table 4 and the simulation results shown in Figure 4.

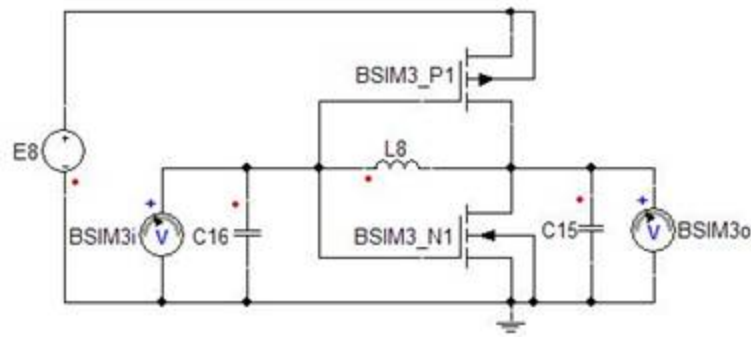


Figure 3. Application example of the Spice-Compatible Level 3 BSIM N-channel and BSIM P-channel models

Table 4

Component	Parameter	Value
Capacitor C16	C	100p [F]
	V0	7.5 [V]
Capacitor C15	C	100p [F]
	V0	0 [V]
Inductor L8	L	1m [H]
	I0	0 [A]
Voltage Source E8	EMF	15 [V]

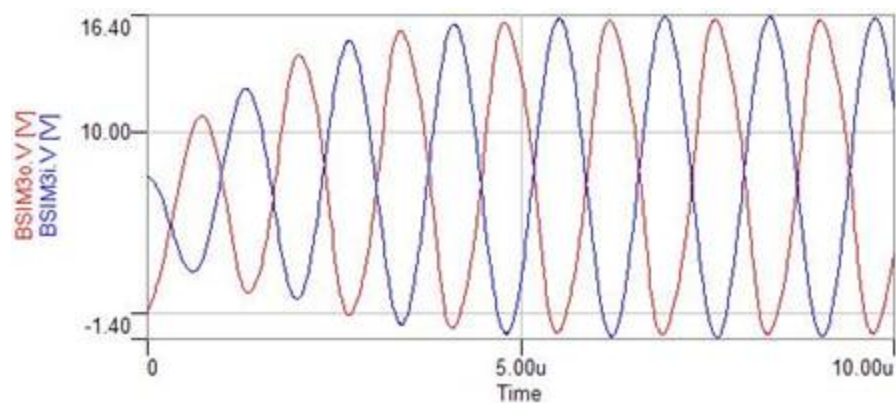


Figure 4. Simulation results-input and output voltage of BSIM3_N1

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References

[1] Information on the Web site of UC Berkeley Device Group at

<http://www-device.eecs.berkeley.edu/~bsim3/>

BSIM4 Model - SPICE-Compatible N-Channel

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

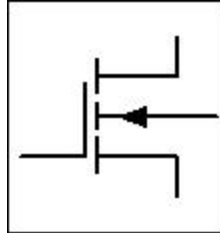


Figure 1. Component Symbol.

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Description

The Spice-Compatible BSIM4 N-channel and BSIM4 P-channel models simulate the electrical and thermal behavior of small-geometry MOSFETs using the parameters and equations of the BSIM4 MOSFET model. Electrical characteristics and the temperature dependence of MOSFET behavior are calculated according to user-defined device parameters that are obtained from MOSFET process characterization.

BSIM3 and BSIM4 are developed by the Device Research Group of the Department of Electrical Engineering and Computer Science, University of California, Berkeley and copyrighted by the University of California.

Note: Only circuit-level temperatures can be used with these components, and no device-level temperatures can be used.

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Assumptions and Limitations

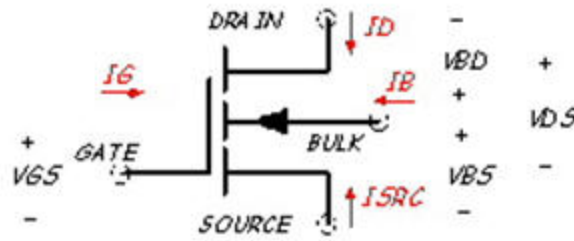


Figure 2. Current and Voltage Reference Arrow System

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Mathematical Description

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Netlist Syntax

```
UMODEL BSIM4_N ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) DRAIN:= %0,
GATE:= %1, SOURCE:= %2, BULK:= %3 ( L:= @L, W:= @W, NF:= @NF, MIN:= @MIN, AD:=
@AD, AS:= @AS, PD:= @PD, PS:= @PS, NRD:= @NRD, NRS:= @NRS, OFF:= @OFF,
RGEOMOD:= @RGEOMOD, ICDVS:= @ICVDS, ICDVS:= @ICVGS, ICDVS:= @ICVBS,
CAPMOD:= @CAPMOD, DIOMOD:= @DIOMOD, RDSMOD:= @RDSMOD, TRNQSMOD:=
@TRNQSMOD, ACNQSMOD:= @ACNQSMOD, MOBMOD:= @MOBMOD, RBODYMOD:=
@RBODYMOD, RGATEMOD:= @RGATEMOD, PERMOD:= @PERMOD, GEOMOD:=
@GEOMOD, FNOIMOD:= @FNOIMOD, TNOIMOD:= @TNOIMOD, IGCMOD:= @IGCMOD,
IGBMOD:= @IGBMOD, PARAMCHK:= @PARAMCHK \\\, BINUNIT:= @BINUNIT, TOXE:=
@TOXE, TOXP:= @TOXP, TOXM:= @TOXM, TOXREF:= @TOXREF, DTOX:= @DTOX,
EPSROX:= @EPSROX, CDSC:= @CDSC, CDSCB:= @CDSCB, CDSCD:= @CDSCD, CIT:=
@CIT, NFACTOR:= @NFACTOR, XJ:= @XJ, VSAT:= @VSAT, AT:= @AT, A0:= @A0, AGS:=
@AGS, A1:= @A1, A2:= @A2, KETA:= @KETA, NSUB:= @NSUB, NDEP:= @NDEP, NSD:=
@NSD, PHIN:= @PHIN, NGATE:= @NGATE, GAMMA1:= @GAMMA1, GAMMA2:=
@GAMMA2, VBX:= @VBX, VBM:= @VBM, XT:= @XT \\\, K1:= @K1, KT1:= @KT1, KT1L:=
@KT1L, KT2:= @KT2, K2:= @K2, K3:= @K3, K3B:= @K3B, W0:= @W0, DVTP0:= @DVTP0,
DVTP1:= @DVTP1, LPE0:= @LPE0, LPEB:= @LPEB, DVT0:= @DVT0, DVT1:= @DVT1,
DVT2:= @DVT2, DVT0W:= @DVT0W, DVT1W:= @DVT1W, DVT2W:= @DVT2W, DROUT:=
@DROUT, DSUB:= @DSUB, VTH0:= @VTH0, VTHO:= @VTHO, UA:= @UA, UA1:= @UA1,
UB:= @UB, UB1:= @UB1, UC:= @UC, UC1:= @UC1, U0:= @U0, EU:= @EU \\\, UTE:=
@UTE, VOFF:= @VOFF, MINV:= @MINV, VOFFL:= @VOFFL, TNOM:= @TNOM, CGSO:=
@CGSO, CGDO:= @CGDO, CGBO:= @CGBO, XPART:= @XPART, DELTA:= @DELTA,
RSH:= @RSH, RDSW:= @RDSW, RDSWMIN:= @RDSWMIN, RSW:= @RSW, RDW:=
@RDW, RDWMIN:= @RDWMIN, RSWMIN:= @RSWMIN, PRWG:= @PRWG, PRWB:=
@PRWB, PRT:= @PRT, ETA0:= @ETA0, ETAB:= @ETAB, PCLM:= @PCLM, PDIBLC1:=
@PDIBLC1, PDIBLC2:= @PDIBLC2, PDIBLCB:= @PDIBLCB, FPROUT:= @FPROUT,
PDITS:= @PDITS, PDITSL:= @PDITSL, PDITSD:= @PDITSD \\\, PSCBE1:= @PSCBE1,
PSCBE2:= @PSCBE2, PVAG:= @PVAG, JSS:= @JSS, JSWS:= @JSWS, JSWGS:=
@JSWGS, PBS:= @PBS, NJS:= @NJS, XTIS:= @XTIS, MJS:= @MJS, PBSWS:= @PBSWS,
```

MJSWS:= @MJSWS, PBSWGS:= @PBSWGS, MJSWGS:= @MJSWGS, CJS:= @CJS,
 CJSWS:= @CJSWS, CJSWGS:= @CJSWGS, JSD:= @JSD, JSWD:= @JSWD, JSWGD:=
 @JSWGD, PBD:= @PBD, NJD:= @NJD, XTID:= @XTID, MJD:= @MJD, PBSWD:= @PBSWD,
 MJSWD:= @MJSWD, PBSWGD:= @PBSWGD, MJSWGD:= @MJSWGD, CJD:= @CJD,
 CJSWD:= @CJSWD \\\ , CJSWGD:= @CJSWGD, VFBCV:= @VFBCV, VFB:= @VFB, TPB:=
 @TPB, TCJ:= @TCJ, TPBSW:= @TPBSW, TCJSW:= @TCJSW, TPBSWG:= @TPBSWG,
 TCJSWG:= @TCJSWG, ACDE:= @ACDE, MOIN:= @MOIN, NOFF:= @NOFF, VOFFCV:=
 @VOFFCV, DMCg:= @DMCg, DMCI:= @DMCI, DMDG:= @DMDG, DMCgt:= @DMCgt,
 XGW:= @XGW, XGL:= @XGL, RSHG:= @RSHG, NGCON:= @NGCON, XRCRG1:=
 @XRCRG1, XRCRG2:= @XRCRG2, LINT:= @LINT, LL:= @LL, LLC:= @LLC, LLN:= @LLN,
 LW:= @LW, LWC:= @LWC, LWN:= @LWN \\\ , LWL:= @LWL, LWLC:= @LWLC, LMIN:=
 @LMIN, LMAX:= @LMAX, WR:= @WR, WINT:= @WINT, DWG:= @DWG, DWB:= @DWB,
 WL:= @WL, WLC:= @WLC, WLN:= @WLN, WW:= @WW, WWC:= @WWC, WWN:= @WWN,
 WWL:= @WWL, WWLC:= @WWLC, WMIN:= @WMIN, WMAX:= @WMAX, B0:= @B0, B1:=
 @B1, CGSL:= @CGSL, CGDL:= @CGDL, CKAPPAS:= @CKAPPAS, CKAPPAD:=
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 @XW \\\ , XL:= @XL, DLCIG:= @DLCIG, DWJ:= @DWJ, ALPHA0:= @ALPHA0, ALPHA1:=
 @ALPHA1, BETA0:= @BETA0, AGIDL:= @AGIDL, BGIDL:= @BGIDL, CGIDL:= @CGIDL,
 EGIDL:= @EGIDL, AIGC:= @AIGC, BIGC:= @BIGC, CIGC:= @CIGC, AIGSD:= @AIGSD,
 BIGSD:= @BIGSD, CIGSD:= @CIGSD, AIGBACC:= @AIGBACC, BIGBACC:= @BIGBACC,
 CIGBACC:= @CIGBACC, AIGBINV:= @AIGBINV, BIGBINV:= @BIGBINV, CIGBINV:=
 @CIGBINV, NIGC:= @NIGC, NIGBINV:= @NIGBINV, NIGBACC:= @NIGBACC, NTOX:=
 @NTOX, EIGBINV:= @EIGBINV, PIGCD:= @PIGCD, POXEDGE:= @POXEDGE,
 IJTHDFWD:= @IJTHDFWD \\\ , IJTHSFWD:= @IJTHSFWD, IJTHDREV:= @IJTHDREV,
 IJTHSREV:= @IJTHSREV, XJBVD:= @XJBVD, XJBVS:= @XJBVS, BVD:= @BVD, BVS:=
 @BVS, GBMIN:= @GBMIN, RBDB:= @RBDB, RBPB:= @RBPB, RBSB:= @RBSB, RBPS:=
 @RBPS, RBPd:= @RBPd, LCDSC:= @LCDSC, LCDSCB:= @LCDSCB, LCDSCD:=
 @LCDSCD, LCIT:= @LCIT, LNFACTOR:= @LNFACTOR, LXJ:= @LXJ, LVSAT:= @LVSAT,
 LAT:= @LAT, LA0:= @LA0, LAGS:= @LAGS, LA1:= @LA1, LA2:= @LA2, LKETA:= @LKETA,
 LNSUB:= @LNSUB, LNDEP:= @LNDEP, LNSD:= @LNSD, LPHIN:= @LPHIN \\\ , LNGATE:=
 @LNGATE, LGAMMA1:= @LGAMMA1, LGAMMA2:= @LGAMMA2, LVBX:= @LVBX, LVBM:=
 @LVBM, LXT:= @LXT, LK1:= @LK1, LKT1:= @LKT1, LKT1L:= @LKT1L, LKT2:= @LKT2,
 LK2:= @LK2, LK3:= @LK3, LK3B:= @LK3B, LW0:= @LW0, LDVTP0:= @LDVTP0, LDVTP1:=
 @LDVTP1, LLPE0:= @LLPE0, LLPEB:= @LLPEB, LDVT0:= @LDVT0, LDVT1:= @LDVT1,
 LDVT2:= @LDVT2, LDVT0W:= @LDVT0W, LDVT1W:= @LDVT1W, LDVT2W:= @LDVT2W,
 LDROUT:= @LDROUT, LDSUB:= @LDSUB, LVTH0:= @LVTH0, LVTHO:= @LVTHO, LUA:=
 @LUA, LUA1:= @LUA1 \\\ , LUB:= @LUB, LUB1:= @LUB1, LUC:= @LUC, LUC1:= @LUC1,
 LU0:= @LU0, LUTE:= @LUTE, LVOFF:= @LVOFF, LMINV:= @LMINV, LDELTA:= @LDELTA,
 LRDSW:= @LRDSW, LRSW:= @LRSW, LRDW:= @LRDW, LPRWG:= @LPRWG, LPRWB:=
 @LPRWB, LPRT:= @LPRT, LETA0:= @LETA0, LETAB:= @LETAB, LPCLM:= @LPCLM,
 LPDIBLC1:= @LPDIBLC1, LPDIBLC2:= @LPDIBLC2, LPDIBLCB:= @LPDIBLCB, LFPROUT:=
 @LFPROUT, LPDITS:= @LPDITS, LPDITSd:= @LPDITSd, LPSCBE1:= @LPSCBE1,
 LPSCBE2:= @LPSCBE2, LPVAG:= @LPVAG, LWR:= @LWR, LDWG:= @LDWG, LDWB:=
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 LCLE:= @LCLE, LALPHA0:= @LALPHA0, LALPHA1:= @LALPHA1, LBETA0:= @LBETA0,
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 LPOXEDGE:= @LPOXEDGE, LVFBCV:= @LVFBCV, LVFB:= @LVFB, LACDE:= @LACDE,
 LMOIN:= @LMOIN, LNOFF:= @LNOFF, LVOFFCV:= @LVOFFCV, LXRCRG1:= @LXRCRG1,
 LXRCRG2:= @LXRCRG2, LEU:= @LEU, WCDSC:= @WCDSC, WCDSCB:= @WCDSCB,
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 @EF, AF:= @AF, KF:= @KF) SRC: DB(Lib:=@ModelLibraryName) ;

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
GATE	Gate	electrical
SOURCE	Source	electrical
DRAIN	Drain	electrical
BULK	Bulk	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
L	Length	real	5u [m]
W	Width	real	5u [m]
NF	Number of fingers	real	1
MIN	Minimize either D or S	integer	0
AD	Drain area	real	0 [m ²]
AS	Source area	real	0 [m ²]
PD	Drain perimeter	real	0 [m]
PS	Source perimeter	real	0 [m]
NRD	Number of squares in drain	real	1
NRS	Number of squares in source	real	1
OFF	Device is initially off	boolean	0
RGEOMOD	S/D resistance and contact model selector	integer	0
ICVDS	Initial D-S voltage	real	0 [V]
ICVGS	Initial G-S voltage	real	0 [V]
ICVBS	Initial B-S voltage	real	0 [V]
CAPMOD	Capacitance model selector	integer	2
DIOMOD	Diode IV model selector	integer	1
RDSMOD	Bias-dependent S/D resistance model selector	integer	0
TRNQSMOD	Transient NQS model selector	integer	0
ACNQSMOD	AC NQS model selector	integer	0
MOBMOD	Mobility model selector	integer	0

RBODYMOD	Distributed body R model selector	integer	0
RGATEMOD	Gate R model selector	integer	0
PERMOD	Pd and Ps model selector	integer	1
GEOMOD	Geometry dependent parasitics model selector	integer	0
FNOIMOD	Flicker noise model selector	integer	1
TNOIMOD	Thermal noise model selector	integer	0
IGCMOD	Gate-to-channel lg model selector	integer	0
IGBMOD	Gate-to-body lg model selector	integer	0
PARAMCHK	Model parameter checking selector	integer	1
BINUNIT	Bin unit selector	integer	1
TOXE	Electrical gate oxide thickness in meters	real	3n [m]
TOXP	Physical gate oxide thickness in meters	real	3n [m]
TOXM	Gate oxide thickness at which parameters are extracted	real	3n [m]
TOXREF	Target tox value	real	3n [m]
DTOX	Defined as (toxe - toxp)	real	0 [m]
EPSROX	Dielectric constant of the gate oxide relative to vacuum	real	3.9
CDSC	Drain/Source and channel coupling capa-	real	0.24m [F/m ²]

	citance		
CDSCB	Body-bias dependence of cdsc	real	0 [F/Vm ²]
CDSCD	Drain-bias dependence of cdsc	real	0 [F/Vm ²]
CIT	Interface state capacitance	real	0 [F/m ²]
NFACTOR	Subthreshold swing Coefficient	real	1
XJ	Junction depth in meters	real	0.15u [m]
VSAT	Saturation velocity at tnom	real	80k [m/s]
AT	Temperature coefficient of vsat	real	33k [m/s]
A0	Non-uniform depletion width effect coefficient.	real	1
AGS	Gate bias coefficient of Abulk	real	0 [V ⁻¹]
A1	Non-saturation effect coefficient	real	0 [V ⁻¹]
A2	Non-saturation effect coefficient	real	1
KETA	Body-bias coefficient of non-uniform depletion width effect	real	-47m [V ⁻¹]
NSUB	Substrate doping concentration	real	6e+016 [cm ⁻³]
NDEP	Channel doping concentration at the depletion edge	real	1.7e+017 [cm ⁻³]
NSD	S/D doping concentration	real	1e+020 [cm ⁻³]
PHIN	Adjusting parameter for sur-	real	0 [V]

	face potential due to non-uniform vertical doping		
NGATE	Poly-gate doping concentration	real	0 [cm ⁻³]
GAMMA1	Vth body coefficient	real	0 [V ^{1/2}]
GAMMA2	Vth body coefficient	real	0 [V ^{1/2}]
VBX	Vth transition body Voltage	real	0 [V]
VBM	Maximum body voltage	real	-3 [V]
XT	Doping depth	real	0.155u [m]
K1	Bulk effect coefficient 1	real	0 [V ^{1/2}]
KT1	Temperature coefficient of Vth	real	-0.11 [V]
KT1L	Temperature coefficient of Vth	real	0 [Vm]
KT2	Body-coefficient of kt1	real	22m
K2	Bulk effect coefficient 2	real	0
K3	Narrow width effect coefficient	real	80
K3B	Body effect coefficient of k3	real	0 [V ⁻¹]
W0	Narrow width effect parameter	real	2.5u [m]
DVTP0	First parameter for Vth shift due to pocket	real	0 [m]
DVTP1	Second parameter for Vth shift due to pocket	real	0 [V ⁻¹]
LPE0	Equivalent length of pocket region at zero bias	real	0.174u [m]

LPEB	Equivalent length of pocket region accounting for body bias	real	0 [m]
DVT0	Short channel effect coeff. 0	real	2.2
DVT1	Short channel effect coeff. 1	real	0.53
DVT2	Short channel effect coeff. 2	real	-32m [V ⁻¹]
DVT0W	Narrow Width effect coeff. 0	real	0
DVT1W	Narrow Width effect coeff. 1	real	5.3Meg [m ⁻¹]
DVT2W	Narrow Width effect coeff. 2	real	-32m [V ⁻¹]
DROUT	DIBL coefficient of output resistance	real	0.56
DSUB	DIBL coefficient in the subthreshold region	real	0.56
VTH0	Threshold voltage	real	0.7 [V]
VTHO	Threshold voltage	real	0.7 [V]
UA	Linear gate dependence of mobility	real	1n [m/V]
UA1	Temperature coefficient of ua	real	1n [m/V]
UB	Quadratic gate dependence of mobility	real	1e-019 [m ² /V ²]
UB1	Temperature coefficient of ub	real	-1e-018 [m/V ²]
UC	Body-bias dependence of mobility	real	-46.5p [MOBMOD = 1: V ⁻¹ MOBMOD = 0, 2: m/V ²]
UC1	Temperature coefficient of uc	real	-56p [MOBMOD = 1: V ⁻¹ MOBMOD = 0, 2: m/V ²]
U0	Low-field mobility at Tnom	real	67m [m ² /Vs]

EU	Mobility exponent	real	1.67
UTE	Temperature coefficient of mobility	real	-1.5
VOFF	Threshold voltage offset	real	-80m [V]
MINV	Fitting parameter for moderate inversion in Vgsteff	real	0
VOFFL	Length dependence parameter for Vth offset	real	0 [mV]
TNOM	Parameter measurement temperature	real	0.30015k [K]
CGSO	Gate-source overlap capacitance per width	real	1.03593906n [F/m]
CGDO	Gate-drain overlap capacitance per width	real	1.03593906n [F/m]
CGBO	Gate-bulk overlap capacitance per length	real	0 [F/m]
XPART	Channel charge partitioning	real	0
DELTA	Effective Vds parameter	real	10m [V]
RSH	Source-drain sheet resistance	real	0 [W/square]
RDSW	Source-drain resistance per width	real	0.2k [W(mmWR)]
RDSWMIN	Source-drain resistance per width at high Vg	real	0 [W(mmWR)]
RSW	Source resistance per width	real	0.1k [W(mmWR)]
RDW	Drain resistance	real	0.1k [W(mmWR)]

	istance per width		
RDWMIN	Drain resistance per width at high V_g	real	0 [W(mmWR)]
RSWMIN	Source resistance per width at high V_g	real	0 [W(mmWR)]
PRWG	Gate-bias effect on parasitic resistance	real	1 [V^{-1}]
PRWB	Body-effect on parasitic resistance	real	0 [$V^{-0.5}$]
PRT	Temperature coefficient of parasitic resistance	real	0 [W^{-m}]
ETA0	Subthreshold region DIBL coefficient	real	80m
ETAB	Subthreshold region DIBL coefficient	real	-70m [V^{-1}]
PCLM	Channel length modulation Coefficient	real	1.3
PDIBLC1	Drain-induced barrier lowering coefficient	real	0.39
PDIBLC2	Drain-induced barrier lowering coefficient	real	8.6m
PDIBLCB	Body-effect on drain-induced barrier lowering	real	0 [V^{-1}]
FPROUT	Rout degradation coefficient for pocket devices	real	0 [$V/m^{0.5}$]
PDITS	Coefficient for drain-induced V_{th} shifts	real	0 [V^{-1}]
PDITSL	Length dependence of	real	0 [m^{-1}]

	drain-induced Vth shifts		
PDITSD	Vds dependence of drain-induced Vth shifts	real	0 [V ⁻¹]
PSCBE1	Substrate current body-effect coefficient	real	0.424G [V/m]
PSCBE2	Substrate current body-effect coefficient	real	10u [m/V]
PVAG	Gate dependence of output resistance parameter	real	0
JSS	Bottom source junction reverse saturation current density	real	0.1m [A/m ²]
JSWS	Isolation edge sidewall source junction reverse saturation current density	real	0 [A/m]
JSWGS	Gate edge source junction reverse saturation current density	real	0 [A/m]
PBS	Source junction built-in potential	real	1 [V]
NJS	Source junction emission coefficient	real	1
XTIS	Source junction current temperature exponent	real	3
MJS	Source bottom junction capacitance grading coefficient	real	0.5
PBSWS	Source side-	real	1 [V]

	wall junction capacitance built in potential		
MJSWS	Source side-wall junction capacitance grading coefficient	real	0.33
PBSWGS	Source (gate side) sidewall junction capacitance built in potential	real	1
MJSWGS	Source (gate side) sidewall junction capacitance grading coefficient	real	0.33 [V]
CJS	Source bottom junction capacitance per unit area	real	0.5m [F/m ²]
CJSWS	Source side-wall junction capacitance per unit periphery	real	0.5n [F/m]
CJSWGS	Source (gate side) sidewall junction capacitance per unit width	real	0.5n [F/m]
JSD	Bottom drain junction reverse saturation current density	real	0.1m [A/m ²]
JSWD	Isolation edge sidewall drain junction reverse saturation current density	real	0 [A/m]
JSWGD	Gate edge drain junction reverse saturation current density	real	0 [A/m]

PBD	Drain junction built-in potential	real	1 [V]
NJD	Drain junction emission coefficient	real	1
XTID	Drain junction current temperature exponent	real	3
MJD	Drain bottom junction capacitance grading coefficient	real	0.5
PBSWD	Drain sidewall junction capacitance built in potential	real	1 [V]
MJSWD	Drain sidewall junction capacitance grading coefficient	real	0.33
PBSWGD	Drain (gate side) sidewall junction capacitance built in potential	real	1 [V]
MJSWGD	Drain (gate side) sidewall junction capacitance grading coefficient	real	0.33
CJD	Drain bottom junction capacitance per unit area	real	0.5m [F/m ²]
CJSWD	Drain sidewall junction capacitance per unit periphery	real	0.5n [F/m]
CJSWGD	Drain (gate side) sidewall junction capacitance per unit width	real	0.5n [F/m]
VFBCV	Flat Band Voltage parameter for cap-mod=0 only	real	-1 [V]

VFB	Flat Band Voltage	real	0 [V]
TPB	Temperature coefficient of pb	real	0 [V/K]
TCJ	Temperature coefficient of cj	real	0 [K ⁻¹]
TPBSW	Temperature coefficient of pbsw	real	0 [V/K]
TCJSW	Temperature coefficient of cjsw	real	0 [K ⁻¹]
TPBSWG	Temperature coefficient of pbswg	real	0 [V/K]
TCJSWG	Temperature coefficient of cjswg	real	0 [K ⁻¹]
ACDE	Exponential coefficient for finite charge thickness	real	1 [m/V]
MOIN	Coefficient for gate-bias dependent surface potential	real	15
NOFF	C-V turn-on/off parameter	real	1
VOFFCV	C-V lateral-shift parameter	real	0 [V]
DMCG	Distance of Mid-Contact to Gate edge	real	0 [m]
DMCI	Distance of Mid-Contact to Isolation	real	0 [m]
DMDG	Distance of Mid-Diffusion to Gate edge	real	0 [m]
DMCGT	Distance of Mid-Contact to Gate edge in Test structures	real	0 [m]
XGW	Distance from gate contact center to device edge	real	0 [m]
XGL	Variation in	real	0 [m]

	Ldrawn		
RSHG	Gate sheet resistance	real	0.1 [W/square]
NGCON	Number of gate contacts	real	1
XRCRG1	First fitting parameter the bias-dependent Rg	real	12
XRCRG2	Second fitting parameter the bias-dependent Rg	real	1
LINT	Length reduction parameter	real	0 [m]
LL	Length reduction parameter	real	0 [mLLN]
LLC	Length reduction parameter for CV	real	0 [mLLN]
LLN	Length reduction parameter	real	1
LW	Length reduction parameter	real	0 [mLWN]
LWC	Length reduction parameter for CV	real	0 [mLWN]
LWN	Length reduction parameter	real	1
LWL	Length reduction parameter	real	0 [mLWN+LLN]
LWLC	Length reduction parameter for CV	real	0 [mLWN+LLN]
LMIN	Minimum length for the model	real	0 [m]
LMAX	Maximum length for the model	real	1 [m]
WR	Width dependence of rds	real	1
WINT	Width reduction parameter	real	0 [m]
DWG	Width reduction parameter	real	0 [m/V]
DWB	Width reduction parameter	real	0 [m/V ^{1/2}]
WL	Width reduction parameter	real	0 [mWLN]

	tion parameter		
WLC	Width reduction parameter for CV	real	0 [mWLN]
WLN	Width reduction parameter	real	1
WW	Width reduction parameter	real	0 [mWWN]
WWC	Width reduction parameter for CV	real	0 [mWWN]
WWN	Width reduction parameter	real	1
WWL	Width reduction parameter	real	0 [mWWN+WLN]
WWLC	Width reduction parameter for CV	real	0 [mWWN+WLN]
WMIN	Minimum width for the model	real	0 [m]
WMAX	Maximum width for the model	real	1 [m]
B0	Abulk narrow width parameter	real	0 [m]
B1	Abulk narrow width parameter	real	0 [m]
CGSL	New C-V model parameter	real	0 [F/m]
CGDL	New C-V model parameter	real	0 [F/m]
CKAPPAS	S/G overlap C-V parameter	real	0.6 [V]
CKAPPAD	D/G overlap C-V parameter	real	0.6 [V]
CF	Fringe capacitance parameter	real	0.107725345717919n [F/m]
CLC	Vdsat parameter for C-V model	real	0.1u [m]
CLE	Vdsat parameter for C-V model	real	0.6
DWC	Delta W for C-	real	0 [m]

	V model		
DLC	Delta L for C-V model	real	0 [m]
XW	W offset for channel width due to mask/etch effect	real	0 [m]
XL	L offset for channel length due to mask/etch effect	real	0 [m]
DLCIG	Delta L for I _g model	real	0 [m]
DWJ	Delta W for S/D junctions	real	0 [m]
ALPHA0	substrate current model parameter	real	0 [A/m/V]
ALPHA1	substrate current model parameter	real	0 [A/V]
BETA0	substrate current model parameter	real	30 [V]
AGIDL	Pre-exponential constant for GIDL	real	0 [mho]
BGIDL	Exponential constant for GIDL	real	2.3G [V/m]
CGIDL	Parameter for body-bias dependence of GIDL	real	0.5 [V ³]
EGIDL	Fitting parameter for Band-bending	real	0.8 [V]
AIGC	Parameter for I _{gc}	real	0.43 [(Fs ² /g) ^{0.5} m ⁻¹]
BIGC	Parameter for I _{gc}	real	54m [(Fs ² /g) ^{0.5} m ⁻¹ V ⁻¹]
CIGC	Parameter for I _{gc}	real	75m [V ⁻¹]
AIGSD	Parameter for I _{gs,d}	real	0.43 [(Fs ² /g) ^{0.5} m ⁻¹]
BIGSD	Parameter for I _{gs,d}	real	54m [(Fs ² /g) ^{0.5} m ⁻¹ V ⁻¹]

CIGSD	Parameter for $I_{gs,d}$	real	75m [V ⁻¹]
AIGBACC	Parameter for I_{gb}	real	0.43 [(Fs ² /g) ^{0.5} m ⁻¹]
BIGBACC	Parameter for I_{gb}	real	54m [(Fs ² /g) ^{0.5} m ⁻¹ V ⁻¹]
CIGBACC	Parameter for I_{gb}	real	75m [V ⁻¹]
AIGBINV	Parameter for I_{gb}	real	0.35 [(Fs ² /g) ^{0.5} m ⁻¹]
BIGBINV	Parameter for I_{gb}	real	30m [(Fs ² /g) ^{0.5} m ⁻¹ V ⁻¹]
CIGBINV	Parameter for I_{gb}	real	6m [V ⁻¹]
NIGC	Parameter for I_{gc} slope	real	1
NIGBINV	Parameter for I_{gbinv} slope	real	3
NIGBACC	Parameter for I_{gbacc} slope	real	1
NTOX	Exponent for Tox ratio	real	1
EIGBINV	Parameter for the Si bandgap for I_{gbinv}	real	1.1
PIGCD	Parameter for I_{gc} partition	real	1
POXEDGE	Factor for the gate edge Tox	real	1
IJTHDFWD	Forward drain diode forward limiting current	real	0.1 [A]
IJTHSFWD	Forward source diode forward limiting current	real	0.1 [A]
IJTHDREV	Reverse drain diode forward limiting current	real	0.1 [A]
IJTHSREV	Reverse source diode forward limiting current	real	0.1 [A]
XJBVD	Fitting parameter for drain diode break-down current	real	1
XJBVS	Fitting parameter for	real	1

	source diode breakdown cur- rent		
BVD	Drain diode breakdown voltage	real	10 [V]
BVS	Source diode breakdown voltage	real	10 [V]
GBMIN	Minimum body conductance	real	1p [mho]
RBDB	Resistance between bNode and dbNode	real	50 [W]
RBPB	Resistance between bNodePrime and bNode	real	50 [W]
RBSB	Resistance between bNode and sbNode	real	50 [W]
RBPS	Resistance between bNodePrime and sbNode	real	50 [W]
RBPB	Resistance between bNodePrime and bNode	real	50 [W]
LCDSC	Length dependence of cdsc	real	0
LCDSCB	Length dependence of cdscb	real	0
LCDSCD	Length dependence of cdscd	real	0
LCIT	Length dependence of cit	real	0
LNFACTOR	Length dependence of nfactor	real	0
LXJ	Length dependence of xj	real	0

LVSAT	Length dependence of vsat	real	0
LAT	Length dependence of at	real	0
LA0	Length dependence of a0	real	0
LAGS	Length dependence of ags	real	0
LA1	Length dependence of a1	real	0
LA2	Length dependence of a2	real	0
LKETA	Length dependence of keta	real	0
LNSUB	Length dependence of nsub	real	0
LNDEP	Length dependence of ndep	real	0
LNSD	Length dependence of nsd	real	0
LPHIN	Length dependence of phin	real	0
LNGATE	Length dependence of ngate	real	0
LGAMMA1	Length dependence of gamma1	real	0
LGAMMA2	Length dependence of gamma2	real	0
LVBX	Length dependence of vbx	real	0
LVBM	Length dependence of vbm	real	0
LXT	Length	real	0

	dependence of x_t		
LK1	Length dependence of k_1	real	0
LKT1	Length dependence of kt_1	real	0
LKT1L	Length dependence of kt_{1l}	real	0
LKT2	Length dependence of kt_2	real	0
LK2	Length dependence of k_2	real	0
LK3	Length dependence of k_3	real	0
LK3B	Length dependence of k_{3b}	real	0
LW0	Length dependence of w_0	real	0
LDVTP0	Length dependence of dvt_{p0}	real	0
LDVTP1	Length dependence of dvt_{p1}	real	0
LLPE0	Length dependence of l_{pe0}	real	0
LLPEB	Length dependence of l_{peb}	real	0
LDVT0	Length dependence of dvt_0	real	0
LDVT1	Length dependence of dvt_1	real	0
LDVT2	Length dependence of dvt_2	real	0
LDVT0W	Length dependence of	real	0

	dvt0w		
LDVT1W	Length dependence of dvt1w	real	0
LDVT2W	Length dependence of dvt2w	real	0
LDROUT	Length dependence of drou	real	0
LDSUB	Length dependence of dsub	real	0
LVTH0	Length dependence of vto	real	0
LVTHO	Length dependence of vto	real	0
LUA	Length dependence of ua	real	0
LUA1	Length dependence of ua1	real	0
LUB	Length dependence of ub	real	0
LUB1	Length dependence of ub1	real	0
LUC	Length dependence of uc	real	0
LUC1	Length dependence of uc1	real	0
LU0	Length dependence of u0	real	0
LUTE	Length dependence of ute	real	0
LVOFF	Length dependence of voff	real	0
LMINV	Length dependence of minv	real	0

LDELTA	Length dependence of delta	real	0
LRDSW	Length dependence of rds w	real	0
LRSW	Length dependence of rsw	real	0
LRDW	Length dependence of rdw	real	0
LPRWG	Length dependence of prwg	real	0
LPRWB	Length dependence of prwb	real	0
LPRT	Length dependence of prt	real	0
LETA0	Length dependence of eta0	real	0
LETAB	Length dependence of etab	real	0
LPCLM	Length dependence of pclm	real	0
LPDIBLC1	Length dependence of pdiblc1	real	0
LPDIBLC2	Length dependence of pdiblc2	real	0
LPDIBLCB	Length dependence of pdiblc b	real	0
LFPROUT	Length dependence of pdiblc b	real	0
LPDITS	Length dependence of pdits	real	0
LPDITSD	Length dependence of pditsd	real	0
LPSCBE1	Length	real	0

	dependence of pscbe1		
LPSCBE2	Length dependence of pscbe2	real	0
LPVAG	Length dependence of pvag	real	0
LWR	Length dependence of wr	real	0
LDWG	Length dependence of dwg	real	0
LDWB	Length dependence of dwb	real	0
LB0	Length dependence of b0	real	0
LB1	Length dependence of b1	real	0
LCGSL	Length dependence of cgs1	real	0
LCGDL	Length dependence of cgdl	real	0
LCKAPPAS	Length dependence of ckappas	real	0
LCKAPPAD	Length dependence of ckappad	real	0
LCF	Length dependence of cf	real	0
LCLC	Length dependence of clc	real	0
LCLE	Length dependence of cle	real	0
LALPHA0	Length dependence of alpha0	real	0
LALPHA1	Length dependence of	real	0

	alpha1		
LBETA0	Length dependence of beta0	real	0
LAGIDL	Length dependence of agidl	real	0
LBGIDL	Length dependence of bgidl	real	0
LCGIDL	Length dependence of cgidl	real	0
LEGIDL	Length dependence of egidl	real	0
LAIGC	Length dependence of aigc	real	0
LBIGC	Length dependence of bigc	real	0
LCIGC	Length dependence of cigc	real	0
LAIGSD	Length dependence of aigsd	real	0
LBIGSD	Length dependence of bigsd	real	0
LCIGSD	Length dependence of cigsd	real	0
LAIGBACC	Length dependence of aigbacc	real	0
LBIGBACC	Length dependence of bigbacc	real	0
LCIGBACC	Length dependence of cigbacc	real	0
LAIGBINV	Length dependence of aigbinv	real	0
LBIGBINV	Length dependence of bigbinv	real	0

LCIGBINV	Length dependence of cigbinv	real	0
LNIGC	Length dependence of nigc	real	0
LNIGBINV	Length dependence of nigbinv	real	0
LNIGBACC	Length dependence of nigbacc	real	0
LNTOX	Length dependence of ntox	real	0
LEIGBINV	Length dependence for eigbinv	real	0
LPIGCD	Length dependence for pigcd	real	0
LPOXEDGE	Length dependence for poxedge	real	0
LVFBCV	Length dependence of vfbcv	real	0
LVFB	Length dependence of vfb	real	0
LACDE	Length dependence of acde	real	0
LMOIN	Length dependence of moin	real	0
LNOFF	Length dependence of noff	real	0
LVOFFCV	Length dependence of voffcv	real	0
LXRCRG1	Length dependence of xrcrg1	real	0
LXRCRG2	Length dependence of xrcrg2	real	0
LEU	Length	real	0

	dependence of eu		
SC	th dependence of cdsc	real	0
WCDSCB	Width dependence of cdscb	real	0
WCDSCD	Width dependence of cdsd	real	0
WCIT	Width dependence of cit	real	0
WNFACTOR	Width dependence of nfactor	real	0
WXJ	Width dependence of xj	real	0
WVSAT	Width dependence of vsat	real	0
WAT	Width dependence of at	real	0
WA0	Width dependence of a0	real	0
WAGS	Width dependence of ags	real	0
WA1	Width dependence of a1	real	0
WA2	Width dependence of a2	real	0
WKETA	Width dependence of keta	real	0
WNSUB	Width dependence of nsub	real	0
WNDEP	Width dependence of ndep	real	0
WNSD	Width dependence of nsd	real	0
WPHIN	Width dependence of phin	real	0
WNGATE	Width dependence of ngate	real	0
WGAMMA1	Width dependence of gamma1	real	0
WGAMMA2	Width dependence of gamma2	real	0
WVBX	Width dependence of vbx	real	0
WVBM	Width dependence of vbm	real	0
WXT	Width depend-	real	0

	ence of xt		
WK1	Width depend- ence of k1	real	0
WKT1	Width depend- ence of kt1	real	0
WKT1L	Width depend- ence of kt1l	real	0
WKT2	Width depend- ence of kt2	real	0
WK2	Width depend- ence of k2	real	0
WK3	Width depend- ence of k3	real	0
WK3B	Width depend- ence of k3b	real	0
WW0	Width depend- ence of w0	real	0
WDVTP0	Width depend- ence of dvtp0	real	0
WDVTP1	Width depend- ence of dvtp1	real	0
WLPE0	Width depend- ence of lpe0	real	0
WLPEB	Width depend- ence of lpeb	real	0
WDVT0	Width depend- ence of dvt0	real	0
WDVT1	Width depend- ence of dvt1	real	0
WDVT2	Width depend- ence of dvt2	real	0
WDVT0W	Width depend- ence of dvt0w	real	0
WDVT1W	Width depend- ence of dvt1w	real	0
WDVT2W	Width depend- ence of dvt2w	real	0
WDROUT	Width depend- ence of drout	real	0
WDSUB	Width depend- ence of dsub	real	0
WVTH0	Width depend- ence of vto	real	0
WVTHO	Width depend- ence of vto	real	0
WUA	Width depend- ence of ua	real	0
WUA1	Width depend- ence of ua1	real	0

WUB	Width dependence of ub	real	0
WUB1	Width dependence of ub1	real	0
WUC	Width dependence of uc	real	0
WUC1	Width dependence of uc1	real	0
WU0	Width dependence of u0	real	0
WUTE	Width dependence of ute	real	0
WVOFF	Width dependence of voff	real	0
WMINV	Width dependence of minv	real	0
WDELTA	Width dependence of delta	real	0
WRDSW	Width dependence of rds	real	0
WRSW	Width dependence of rsw	real	0
WRDW	Width dependence of rdw	real	0
WPRWG	Width dependence of prwg	real	0
WPRWB	Width dependence of prwb	real	0
WPRT	Width dependence of prt	real	0
WETA0	Width dependence of eta0	real	0
WETAB	Width dependence of etab	real	0
WPCLM	Width dependence of pclm	real	0
WPDIBLC1	Width dependence of pdiblc1	real	0
WPDIBLC2	Width dependence of pdiblc2	real	0
WPDIBLCB	Width dependence of pdiblc b	real	0
WFPROUT	Width dependence of pdiblc b	real	0
WPDITS	Width dependence of pdits	real	0
WPDITSD	Width dependence of pditsd	real	0
WPSCBE1	Width depend-	real	0

	ence of pscbe1		
WPSCBE2	Width depend- ence of pscbe2	real	0
WPVAG	Width depend- ence of pvag	real	0
WWR	Width depend- ence of wr	real	0
WDWG	Width depend- ence of dwg	real	0
WDWB	Width depend- ence of dwb	real	0
WB0	Width depend- ence of b0	real	0
WB1	Width depend- ence of b1	real	0
WCGSL	Width depend- ence of cgsl	real	0
WCGDL	Width depend- ence of cgdl	real	0
WCKAPPAS	Width depend- ence of ckappas	real	0
WCKAPPAD	Width depend- ence of ckappad	real	0
WCF	Width depend- ence of cf	real	0
WCLC	Width depend- ence of clc	real	0
WCLE	Width depend- ence of cle	real	0
WALPHA0	Width depend- ence of alpha0	real	0
WALPHA1	Width depend- ence of alpha1	real	0
WBETA0	Width depend- ence of beta0	real	0
WAGIDL	Width depend- ence of agidl	real	0
WBGIDL	Width depend- ence of bgidl	real	0
WCGIDL	Width depend- ence of cgidl	real	0
WEGIDL	Width depend- ence of egidl	real	0
WAIGC	Width depend- ence of aigc	real	0

WBIGC	Width dependence of bigc	real	0
WCIGC	Width dependence of cigc	real	0
WAIGSD	Width dependence of aigsd	real	0
WBIGSD	Width dependence of bigsd	real	0
WCIGSD	Width dependence of cigsd	real	0
WAIGBACC	Width dependence of aigbacc	real	0
WBIGBACC	Width dependence of bigbacc	real	0
WCIGBACC	Width dependence of cigbacc	real	0
WAIGBINV	Width dependence of aigbinv	real	0
WBIGBINV	Width dependence of bigbinv	real	0
WCIGBINV	Width dependence of cigbinv	real	0
WNIGC	Width dependence of nigc	real	0
WNIGBINV	Width dependence of nigbinv	real	0
WNIGBACC	Width dependence of nigbacc	real	0
WNTOX	Width dependence of ntox	real	0
WEIGBINV	Width dependence for eigbinv	real	0
WPIGCD	Width dependence for pigcd	real	0
WPOXEDGE	Width dependence for poxedge	real	0
WVFBCV	Width dependence of vfbcv	real	0
WVFB	Width dependence of vfb	real	0
WACDE	Width dependence of acde	real	0
WMOIN	Width depend-	real	0

	ence of moir		
WNOFF	Width dependence of noff	real	0
WVOFFCV	Width dependence of voffcv	real	0
WXRCRG1	Width dependence of xrcrg1	real	0
WXRCRG2	Width dependence of xrcrg2	real	0
WEU	Width dependence of eu	real	0
PCDSC	Cross-term dependence of cdsc	real	0
PCDSCB	Cross-term dependence of cdsb	real	0
PCDSCD	Cross-term dependence of cdsd	real	0
PCIT	Cross-term dependence of cit	real	0
PNFACTOR	Cross-term dependence of nfactor	real	0
PXJ	Cross-term dependence of xj	real	0
PVSAT	Cross-term dependence of vsat	real	0
PAT	Cross-term dependence of at	real	0
PA0	Cross-term dependence of a0	real	0
PAGS	Cross-term dependence of ags	real	0
PA1	Cross-term dependence of a1	real	0
PA2	Cross-term dependence of a2	real	0
PKETA	Cross-term dependence of	real	0

	keta		
PNSUB	Cross-term dependence of nsub	real	0
PNDEP	Cross-term dependence of ndep	real	0
PNSD	Cross-term dependence of nsd	real	0
PPHIN	Cross-term dependence of phin	real	0
PNGATE	Cross-term dependence of ngate	real	0
PGAMMA1	Cross-term dependence of gamma1	real	0
PGAMMA2	Cross-term dependence of gamma2	real	0
PVBX	Cross-term dependence of vbx	real	0
PVBM	Cross-term dependence of vbm	real	0
PXT	Cross-term dependence of xt	real	0
PK1	Cross-term dependence of k1	real	0
PKT1	Cross-term dependence of kt1	real	0
PKT1L	Cross-term dependence of kt1l	real	0
PKT2	Cross-term dependence of kt2	real	0
PK2	Cross-term dependence of k2	real	0
PK3	Cross-term dependence of k3	real	0

PK3B	Cross-term dependence of k3b	real	0
PW0	Cross-term dependence of w0	real	0
PDVTP0	Cross-term dependence of dvtp0	real	0
PDVTP1	Cross-term dependence of dvtp1	real	0
PLPE0	Cross-term dependence of lpe0	real	0
PLPEB	Cross-term dependence of lpeb	real	0
PDVT0	Cross-term dependence of dvt0	real	0
PDVT1	Cross-term dependence of dvt1	real	0
PDVT2	Cross-term dependence of dvt2	real	0
PDVT0W	Cross-term dependence of dvt0w	real	0
PDVT1W	Cross-term dependence of dvt1w	real	0
PDVT2W	Cross-term dependence of dvt2w	real	0
PDROUT	Cross-term dependence of drout	real	0
PDSUB	Cross-term dependence of dsub	real	0
PVTH0	Cross-term dependence of vto	real	0
PVTHO	Cross-term dependence of vto	real	0
PUA	Cross-term	real	0

	dependence of ua		
PUA1	Cross-term dependence of ua1	real	0
PUB	Cross-term dependence of ub	real	0
PUB1	Cross-term dependence of ub1	real	0
PUC	Cross-term dependence of uc	real	0
PUC1	Cross-term dependence of uc1	real	0
PU0	Cross-term dependence of u0	real	0
PUTE	Cross-term dependence of ute	real	0
PVOFF	Cross-term dependence of voff	real	0
PMINV	Cross-term dependence of minv	real	0
PDELTA	Cross-term dependence of delta	real	0
PRDSW	Cross-term dependence of rdsw	real	0
PRSW	Cross-term dependence of rsw	real	0
PRDW	Cross-term dependence of rdw	real	0
PPRWG	Cross-term dependence of prwg	real	0
PPRWB	Cross-term dependence of prwb	real	0
PPRT	Cross-term dependence of	real	0

	prt		
PETA0	Cross-term dependence of eta0	real	0
PETAB	Cross-term dependence of etab	real	0
PPCLM	Cross-term dependence of pclm	real	0
PPDIBLC1	Cross-term dependence of pdiblc1	real	0
PPDIBLC2	Cross-term dependence of pdiblc2	real	0
PPDIBLCB	Cross-term dependence of pdiblc b	real	0
PFPROUT	Cross-term dependence of pdiblc b	real	0
PPDITS	Cross-term dependence of pdits	real	0
PPDITSD	Cross-term dependence of pditsd	real	0
PPSCBE1	Cross-term dependence of pscbe1	real	0
PPSCBE2	Cross-term dependence of pscbe2	real	0
PPVAG	Cross-term dependence of pvag	real	0
PWR	Cross-term dependence of wr	real	0
PDWG	Cross-term dependence of dwg	real	0
PDWB	Cross-term dependence of dwb	real	0
PB0	Cross-term dependence of b0	real	0

PB1	Cross-term dependence of b1	real	0
PCGSL	Cross-term dependence of cgsl	real	0
PCGDL	Cross-term dependence of cgdl	real	0
PCKAPPAS	Cross-term dependence of ckappas	real	0
PCKAPPAD	Cross-term dependence of ckappad	real	0
PCF	Cross-term dependence of cf	real	0
PCLC	Cross-term dependence of clc	real	0
PCLE	Cross-term dependence of cle	real	0
PALPHA0	Cross-term dependence of alpha0	real	0
PALPHA1	Cross-term dependence of alpha1	real	0
PBETA0	Cross-term dependence of beta0	real	0
PAGIDL	Cross-term dependence of agidl	real	0
PBGIDL	Cross-term dependence of bgidl	real	0
PCGIDL	Cross-term dependence of cgidl	real	0
PEGIDL	Cross-term dependence of egidl	real	0
PAIGC	Cross-term dependence of aigc	real	0
PBIGC	Cross-term	real	0

	dependence of bigc		
PCIGC	Cross-term dependence of cigc	real	0
PAIGSD	Cross-term dependence of aigsd	real	0
PBIGSD	Cross-term dependence of bigsd	real	0
PCIGSD	Cross-term dependence of cigsd	real	0
PAIGBACC	Cross-term dependence of aigbacc	real	0
PBIGBACC	Cross-term dependence of bigbacc	real	0
PCIGBACC	Cross-term dependence of cigbacc	real	0
PAIGBINV	Cross-term dependence of aigbinv	real	0
PBIGBINV	Cross-term dependence of bigbinv	real	0
PCIGBINV	Cross-term dependence of cigbinv	real	0
PNIGC	Cross-term dependence of nigc	real	0
PNIGBINV	Cross-term dependence of nigbinv	real	0
PNIGBACC	Cross-term dependence of nigbacc	real	0
PNTOX	Cross-term dependence of ntox	real	0
PEIGBINV	Cross-term dependence for eigbinv	real	0
PPIGCD	Cross-term dependence	real	0

	for pigcd		
PPOXEDGE	Cross-term dependence for poxedge	real	0
PVFBCV	Cross-term dependence of vfbcv	real	0
PVFB	Cross-term dependence of vfb	real	0
PACDE	Cross-term dependence of acde	real	0
PMOIN	Cross-term dependence of moi	real	0
PNOFF	Cross-term dependence of noff	real	0
PVOFFCV	Cross-term dependence of voffcv	real	0
PXRCRG1	Cross-term dependence of xrcrg1	real	0
PXRCRG2	Cross-term dependence of xrcrg2	real	0
PEU	Cross-term dependence of eu	real	0
NOIA	Flicker noise parameter	real	$6.25e+041 [(eV)^{-1}s^{(1-EF)}m^{-3}]$
NOIB	Flicker noise parameter	real	$3.125e+026 [(eV)^{-1}s^{(1-EF)}m^{-1}]$
NOIC	Flicker noise parameter	real	$8.75G [(eV)^{-1}s^{(1-EF)}m]$
TNOIA	Thermal noise parameter	real	1.5
TNOIB	Thermal noise parameter	real	3.5
NTNOI	Thermal noise parameter	real	1
EM	Flicker noise parameter	real	41Meg [V/m]
EF	Flicker noise frequency exponent	real	1
AF	Flicker noise	real	1

	exponent		
KF	Flicker noise coefficient	real	$0 [A^{(2-EF)}s^{(1-EF)}F]$

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
VBS	Vbs [V]	Output	real
VGS	Vgs [V]	Output	real
VDS	Vds [V]	Output	real
VBD	Vbd [V]	Output	real
ID	Id (terminal) [A]	Output	real
IG	Ig (terminal) [A]	Output	real
IS	Is (terminal) [A]	Output	real
IB	Ib (terminal) [A]	Output	real
P	Power Dissipation [W]	Output	real

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Example

Figure 3 shows application of the Spice-Compatible Level 4 BSIM N-channel and BSIM P-channel models. The parameters of BSIM4_P1 and BSIM4_N1 are set to their default values; the parameters of the rest of the system are listed in Table 4 and the simulation results shown in Figure 4.

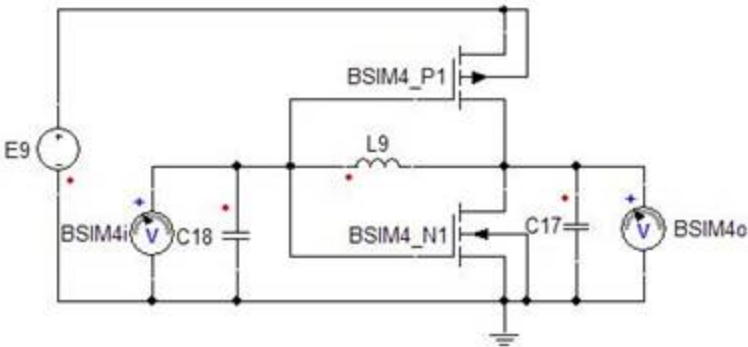


Figure 3. Application example of the Spice-Compatible Level 4 BSIM N-channel and BSIM P-channel models

Table 4

Component	Parameter	Value
Capacitor C18	C	100p [F]
	V0	7.5 [V]
Capacitor C17	C	100p [F]
	V0	0 [V]
Inductor L9	L	1m [H]
	I0	0 [A]
Voltage Source E9	EMF	15 [V]

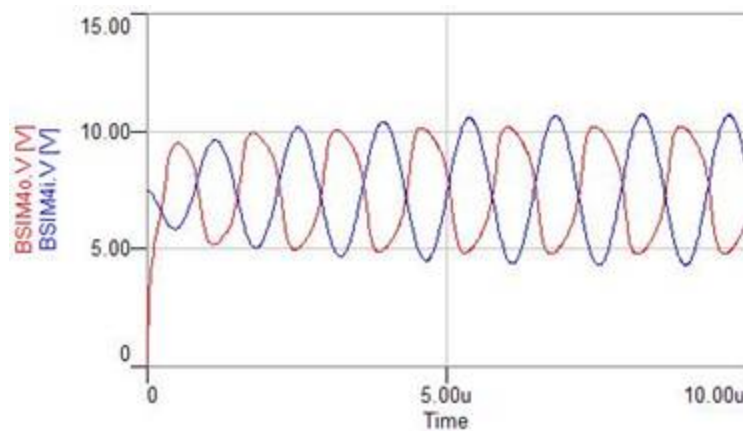


Figure 4. Simulation results-input and output voltage of BSIM4_N1

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References

[1] information on the Web site of UC Berkeley Device Group at <http://www-device.eecs.berkeley.edu/~bsim3/>

BSIM4 Model - SPICE-Compatible P-Channel

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

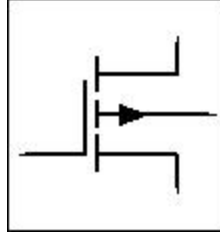


Figure 1. Component Symbol.

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- [Assumptions and Limitations](#)
- [Mathematical Description](#)
- [Netlist Syntax](#)
- [Conservative Pins](#)
- [Parameters](#)
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Description

The Spice-Compatible BSIM4 N-channel and BSIM4 P-channel models simulate the electrical and thermal behavior of small-geometry MOSFETs using the parameters and equations of the BSIM4 MOSFET model. Electrical characteristics and the temperature dependence of MOSFET behavior are calculated according to user-defined device parameters that are obtained from MOSFET process characterization.

BSIM3 and BSIM4 are developed by the Device Research Group of the Department of Electrical Engineering and Computer Science, University of California, Berkeley and copyrighted by the University of California.

Note: Only circuit-level temperatures can be used with these components, and no device-level temperatures can be used.

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Assumptions and Limitations

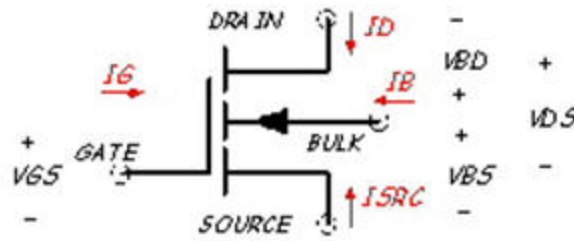


Figure 2. Current and Voltage Reference Arrow System

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Mathematical Description

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Netlist Syntax

```
UMODEL BSIM4_P ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) DRAIN:= %0,
GATE:= %1, SOURCE:= %2, BULK:= %3 ( L:= @L, W:= @W, NF:= @NF, MIN:= @MIN, AD:=
@AD, AS:= @AS, PD:= @PD, PS:= @PS, NRD:= @NRD, NRS:= @NRS, OFF:= @OFF,
RGEOMOD:= @RGEOMOD, ICDVS:= @ICVDS, ICDVS:= @ICVGS, ICDVS:= @ICVBS,
CAPMOD:= @CAPMOD, DIOMOD:= @DIOMOD, RDSMOD:= @RDSMOD, TRNQSMOD:=
@TRNQSMOD, ACNQSMOD:= @ACNQSMOD, MOBMOD:= @MOBMOD, RBODYMOD:=
@RBODYMOD, RGATEMOD:= @RGATEMOD, PERMOD:= @PERMOD, GEOMOD:=
@GEOMOD, FNOIMOD:= @FNOIMOD, TNOIMOD:= @TNOIMOD, IGCMOD:= @IGCMOD,
IGBMOD:= @IGBMOD, PARAMCHK:= @PARAMCHK \\\, BINUNIT:= @BINUNIT, TOXE:=
@TOXE, TOXP:= @TOXP, TOXM:= @TOXM, TOXREF:= @TOXREF, DTOX:= @DTOX,
EPSROX:= @EPSROX, CDSC:= @CDSC, CDSCB:= @CDSCB, CDSCD:= @CDSCD, CIT:=
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UB:= @UB, UB1:= @UB1, UC:= @UC, UC1:= @UC1, U0:= @U0, EU:= @EU \\\, UTE:=
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@PDIBLC1, PDIBLC2:= @PDIBLC2, PDIBLCB:= @PDIBLCB, FPROUT:= @FPROUT,
PDITS:= @PDITS, PDITSL:= @PDITSL, PDITSD:= @PDITSD \\\, PSCBE1:= @PSCBE1,
PSCBE2:= @PSCBE2, PVAG:= @PVAG, JSS:= @JSS, JSWS:= @JSWS, JSWGS:=
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 @EF, AF:= @AF, KF:= @KF) SRC: DB(Lib:=@ModelLibraryName) ;

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
GATE	Gate	electrical
SOURCE	Source	electrical
DRAIN	Drain	electrical
BULK	Bulk	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
L	Length	real	5u [m]
W	Width	real	5u [m]
NF	Number of fingers	real	1
MIN	Minimize either D or S	integer	0
AD	Drain area	real	0 [m ²]
AS	Source area	real	0 [m ²]
PD	Drain perimeter	real	0 [m]
PS	Source perimeter	real	0 [m]
NRD	Number of squares in drain	real	1
NRS	Number of squares in source	real	1
OFF	Device is initially off	boolean	0
RGEOMOD	S/D resistance and contact model selector	integer	0
ICVDS	Initial D-S voltage	real	0 [V]
ICVGS	Initial G-S voltage	real	0 [V]
ICVBS	Initial B-S voltage	real	0 [V]
CAPMOD	Capacitance model selector	integer	2
DIOMOD	Diode IV model selector	integer	1
RDSMOD	Bias-dependent S/D resistance model selector	integer	0
TRNQSMOD	Transient NQS model selector	integer	0
ACNQSMOD	AC NQS model selector	integer	0
MOBMOD	Mobility model selector	integer	0

RBODYMOD	Distributed body R model selector	integer	0
RGATEMOD	Gate R model selector	integer	0
PERMOD	Pd and Ps model selector	integer	1
GEOMOD	Geometry dependent parasitics model selector	integer	0
FNOIMOD	Flicker noise model selector	integer	1
TNOIMOD	Thermal noise model selector	integer	0
IGCMOD	Gate-to-channel lg model selector	integer	0
IGBMOD	Gate-to-body lg model selector	integer	0
PARAMCHK	Model parameter checking selector	integer	1
BINUNIT	Bin unit selector	integer	1
TOXE	Electrical gate oxide thickness in meters	real	3n [m]
TOXP	Physical gate oxide thickness in meters	real	3n [m]
TOXM	Gate oxide thickness at which parameters are extracted	real	3n [m]
TOXREF	Target tox value	real	3n [m]
DTOX	Defined as (toxe - toxp)	real	0 [m]
EPSROX	Dielectric constant of the gate oxide relative to vacuum	real	3.9
CDSC	Drain/Source and channel coupling capa-	real	0.24m [F/m ²]

	citance		
CDSCB	Body-bias dependence of cdsc	real	0 [F/Vm ²]
CDSCD	Drain-bias dependence of cdsc	real	0 [F/Vm ²]
CIT	Interface state capacitance	real	0 [F/m ²]
NFACTOR	Subthreshold swing Coefficient	real	1
XJ	Junction depth in meters	real	0.15u [m]
VSAT	Saturation velocity at tnom	real	80k [m/s]
AT	Temperature coefficient of vsat	real	33k [m/s]
A0	Non-uniform depletion width effect coefficient.	real	1
AGS	Gate bias coefficient of Abulk	real	0 [V ⁻¹]
A1	Non-saturation effect coefficient	real	0 [V ⁻¹]
A2	Non-saturation effect coefficient	real	1
KETA	Body-bias coefficient of non-uniform depletion width effect	real	-47m [V ⁻¹]
NSUB	Substrate doping concentration	real	6e+016 [cm ⁻³]
NDEP	Channel doping concentration at the depletion edge	real	1.7e+017 [cm ⁻³]
NSD	S/D doping concentration	real	1e+020 [cm ⁻³]
PHIN	Adjusting parameter for sur-	real	0 [V]

	face potential due to non-uniform vertical doping		
NGATE	Poly-gate doping concentration	real	0 [cm ⁻³]
GAMMA1	Vth body coefficient	real	0 [V ^{1/2}]
GAMMA2	Vth body coefficient	real	0 [V ^{1/2}]
VBX	Vth transition body Voltage	real	0 [V]
VBM	Maximum body voltage	real	-3 [V]
XT	Doping depth	real	0.155u [m]
K1	Bulk effect coefficient 1	real	0 [V ^{1/2}]
KT1	Temperature coefficient of Vth	real	-0.11 [V]
KT1L	Temperature coefficient of Vth	real	0 [Vm]
KT2	Body-coefficient of kt1	real	22m
K2	Bulk effect coefficient 2	real	0
K3	Narrow width effect coefficient	real	80
K3B	Body effect coefficient of k3	real	0 [V ⁻¹]
W0	Narrow width effect parameter	real	2.5u [m]
DVTP0	First parameter for Vth shift due to pocket	real	0 [m]
DVTP1	Second parameter for Vth shift due to pocket	real	0 [V ⁻¹]
LPE0	Equivalent length of pocket region at zero bias	real	0.174u [m]

LPEB	Equivalent length of pocket region accounting for body bias	real	0 [m]
DVT0	Short channel effect coeff. 0	real	2.2
DVT1	Short channel effect coeff. 1	real	0.53
DVT2	Short channel effect coeff. 2	real	-32m [V ⁻¹]
DVT0W	Narrow Width effect coeff. 0	real	0
DVT1W	Narrow Width effect coeff. 1	real	5.3Meg [m ⁻¹]
DVT2W	Narrow Width effect coeff. 2	real	-32m [V ⁻¹]
DROUT	DIBL coefficient of output resistance	real	0.56
DSUB	DIBL coefficient in the subthreshold region	real	0.56
VTH0	Threshold voltage	real	0.7 [V]
VTHO	Threshold voltage	real	0.7 [V]
UA	Linear gate dependence of mobility	real	1n [m/V]
UA1	Temperature coefficient of ua	real	1n [m/V]
UB	Quadratic gate dependence of mobility	real	1e-019 [m ² /V ²]
UB1	Temperature coefficient of ub	real	-1e-018 [m/V ²]
UC	Body-bias dependence of mobility	real	-46.5p [MOBMOD = 1: V ⁻¹ MOBMOD = 0, 2: m/V ²]
UC1	Temperature coefficient of uc	real	-56p [MOBMOD = 1: V ⁻¹ MOBMOD = 0, 2: m/V ²]
U0	Low-field mobility at Tnom	real	67m [m ² /Vs]

EU	Mobility exponent	real	1.67
UTE	Temperature coefficient of mobility	real	-1.5
VOFF	Threshold voltage offset	real	-80m [V]
MINV	Fitting parameter for moderate inversion in Vgsteff	real	0
VOFFL	Length dependence parameter for Vth offset	real	0 [mV]
TNOM	Parameter measurement temperature	real	0.30015k [K]
CGSO	Gate-source overlap capacitance per width	real	1.03593906n [F/m]
CGDO	Gate-drain overlap capacitance per width	real	1.03593906n [F/m]
CGBO	Gate-bulk overlap capacitance per length	real	0 [F/m]
XPART	Channel charge partitioning	real	0
DELTA	Effective Vds parameter	real	10m [V]
RSH	Source-drain sheet resistance	real	0 [W/square]
RDSW	Source-drain resistance per width	real	0.2k [W(mmWR)]
RDSWMIN	Source-drain resistance per width at high Vg	real	0 [W(mmWR)]
RSW	Source resistance per width	real	0.1k [W(mmWR)]
RDW	Drain resistance	real	0.1k [W(mmWR)]

	istance per width		
RDWMIN	Drain resistance per width at high V_g	real	0 [W(mmWR)]
RSWMIN	Source resistance per width at high V_g	real	0 [W(mmWR)]
PRWG	Gate-bias effect on parasitic resistance	real	1 [V^{-1}]
PRWB	Body-effect on parasitic resistance	real	0 [$V^{-0.5}$]
PRT	Temperature coefficient of parasitic resistance	real	0 [W^{-m}]
ETA0	Subthreshold region DIBL coefficient	real	80m
ETAB	Subthreshold region DIBL coefficient	real	-70m [V^{-1}]
PCLM	Channel length modulation Coefficient	real	1.3
PDIBLC1	Drain-induced barrier lowering coefficient	real	0.39
PDIBLC2	Drain-induced barrier lowering coefficient	real	8.6m
PDIBLCB	Body-effect on drain-induced barrier lowering	real	0 [V^{-1}]
FPROUT	Rout degradation coefficient for pocket devices	real	0 [$V/m^{0.5}$]
PDITS	Coefficient for drain-induced V_{th} shifts	real	0 [V^{-1}]
PDITSL	Length dependence of	real	0 [m^{-1}]

	drain-induced Vth shifts		
PDITSD	Vds dependence of drain-induced Vth shifts	real	0 [V ⁻¹]
PSCBE1	Substrate current body-effect coefficient	real	0.424G [V/m]
PSCBE2	Substrate current body-effect coefficient	real	10u [m/V]
PVAG	Gate dependence of output resistance parameter	real	0
JSS	Bottom source junction reverse saturation current density	real	0.1m [A/m ²]
JSWS	Isolation edge sidewall source junction reverse saturation current density	real	0 [A/m]
JSWGS	Gate edge source junction reverse saturation current density	real	0 [A/m]
PBS	Source junction built-in potential	real	1 [V]
NJS	Source junction emission coefficient	real	1
XTIS	Source junction current temperature exponent	real	3
MJS	Source bottom junction capacitance grading coefficient	real	0.5
PBSWS	Source side-	real	1 [V]

	wall junction capacitance built in potential		
MJSWS	Source side-wall junction capacitance grading coefficient	real	0.33
PBSWGS	Source (gate side) sidewall junction capacitance built in potential	real	1
MJSWGS	Source (gate side) sidewall junction capacitance grading coefficient	real	0.33 [V]
CJS	Source bottom junction capacitance per unit area	real	0.5m [F/m ²]
CJSWS	Source side-wall junction capacitance per unit periphery	real	0.5n [F/m]
CJSWGS	Source (gate side) sidewall junction capacitance per unit width	real	0.5n [F/m]
JSD	Bottom drain junction reverse saturation current density	real	0.1m [A/m ²]
JSWD	Isolation edge sidewall drain junction reverse saturation current density	real	0 [A/m]
JSWGD	Gate edge drain junction reverse saturation current density	real	0 [A/m]

PBD	Drain junction built-in potential	real	1 [V]
NJD	Drain junction emission coefficient	real	1
XTID	Drain junction current temperature exponent	real	3
MJD	Drain bottom junction capacitance grading coefficient	real	0.5
PBSWD	Drain sidewall junction capacitance built in potential	real	1 [V]
MJSWD	Drain sidewall junction capacitance grading coefficient	real	0.33
PBSWGD	Drain (gate side) sidewall junction capacitance built in potential	real	1 [V]
MJSWGD	Drain (gate side) sidewall junction capacitance grading coefficient	real	0.33
CJD	Drain bottom junction capacitance per unit area	real	0.5m [F/m ²]
CJSWD	Drain sidewall junction capacitance per unit periphery	real	0.5n [F/m]
CJSWGD	Drain (gate side) sidewall junction capacitance per unit width	real	0.5n [F/m]
VFBCV	Flat Band Voltage parameter for cap-mod=0 only	real	-1 [V]

VFB	Flat Band Voltage	real	0 [V]
TPB	Temperature coefficient of pb	real	0 [V/K]
TCJ	Temperature coefficient of cj	real	0 [K ⁻¹]
TPBSW	Temperature coefficient of pbsw	real	0 [V/K]
TCJSW	Temperature coefficient of cjsw	real	0 [K ⁻¹]
TPBSWG	Temperature coefficient of pbswg	real	0 [V/K]
TCJSWG	Temperature coefficient of cjswg	real	0 [K ⁻¹]
ACDE	Exponential coefficient for finite charge thickness	real	1 [m/V]
MOIN	Coefficient for gate-bias dependent surface potential	real	15
NOFF	C-V turn-on/off parameter	real	1
VOFFCV	C-V lateral-shift parameter	real	0 [V]
DMCG	Distance of Mid-Contact to Gate edge	real	0 [m]
DMCI	Distance of Mid-Contact to Isolation	real	0 [m]
DMDG	Distance of Mid-Diffusion to Gate edge	real	0 [m]
DMCGT	Distance of Mid-Contact to Gate edge in Test structures	real	0 [m]
XGW	Distance from gate contact center to device edge	real	0 [m]
XGL	Variation in	real	0 [m]

	Ldrawn		
RSHG	Gate sheet resistance	real	0.1 [W/square]
NGCON	Number of gate contacts	real	1
XRCRG1	First fitting parameter the bias-dependent Rg	real	12
XRCRG2	Second fitting parameter the bias-dependent Rg	real	1
LINT	Length reduction parameter	real	0 [m]
LL	Length reduction parameter	real	0 [mLLN]
LLC	Length reduction parameter for CV	real	0 [mLLN]
LLN	Length reduction parameter	real	1
LW	Length reduction parameter	real	0 [mLWN]
LWC	Length reduction parameter for CV	real	0 [mLWN]
LWN	Length reduction parameter	real	1
LWL	Length reduction parameter	real	0 [mLWN+LLN]
LWLC	Length reduction parameter for CV	real	0 [mLWN+LLN]
LMIN	Minimum length for the model	real	0 [m]
LMAX	Maximum length for the model	real	1 [m]
WR	Width dependence of rds	real	1
WINT	Width reduction parameter	real	0 [m]
DWG	Width reduction parameter	real	0 [m/V]
DWB	Width reduction parameter	real	0 [m/V ^{1/2}]
WL	Width reduction parameter	real	0 [mWLN]

	tion parameter		
WLC	Width reduction parameter for CV	real	0 [mWLN]
WLN	Width reduction parameter	real	1
WW	Width reduction parameter	real	0 [mWWN]
WWC	Width reduction parameter for CV	real	0 [mWWN]
WWN	Width reduction parameter	real	1
WWL	Width reduction parameter	real	0 [mWWN+WLN]
WWLC	Width reduction parameter for CV	real	0 [mWWN+WLN]
WMIN	Minimum width for the model	real	0 [m]
WMAX	Maximum width for the model	real	1 [m]
B0	Abulk narrow width parameter	real	0 [m]
B1	Abulk narrow width parameter	real	0 [m]
CGSL	New C-V model parameter	real	0 [F/m]
CGDL	New C-V model parameter	real	0 [F/m]
CKAPPAS	S/G overlap C-V parameter	real	0.6 [V]
CKAPPAD	D/G overlap C-V parameter	real	0.6 [V]
CF	Fringe capacitance parameter	real	0.107725345717919n [F/m]
CLC	Vdsat parameter for C-V model	real	0.1u [m]
CLE	Vdsat parameter for C-V model	real	0.6
DWC	Delta W for C-	real	0 [m]

	V model		
DLC	Delta L for C-V model	real	0 [m]
XW	W offset for channel width due to mask/etch effect	real	0 [m]
XL	L offset for channel length due to mask/etch effect	real	0 [m]
DLCIG	Delta L for I _g model	real	0 [m]
DWJ	Delta W for S/D junctions	real	0 [m]
ALPHA0	substrate current model parameter	real	0 [A/m/V]
ALPHA1	substrate current model parameter	real	0 [A/V]
BETA0	substrate current model parameter	real	30 [V]
AGIDL	Pre-exponential constant for GIDL	real	0 [mho]
BGIDL	Exponential constant for GIDL	real	2.3G [V/m]
CGIDL	Parameter for body-bias dependence of GIDL	real	0.5 [V ³]
EGIDL	Fitting parameter for Band-bending	real	0.8 [V]
AIGC	Parameter for I _{gc}	real	0.43 [(Fs ² /g) ^{0.5} m ⁻¹]
BIGC	Parameter for I _{gc}	real	54m [(Fs ² /g) ^{0.5} m ⁻¹ V ⁻¹]
CIGC	Parameter for I _{gc}	real	75m [V ⁻¹]
AIGSD	Parameter for I _{gs,d}	real	0.43 [(Fs ² /g) ^{0.5} m ⁻¹]
BIGSD	Parameter for I _{gs,d}	real	54m [(Fs ² /g) ^{0.5} m ⁻¹ V ⁻¹]

CIGSD	Parameter for $I_{gs,d}$	real	75m [V ⁻¹]
AIGBACC	Parameter for I_{gb}	real	0.43 [(Fs ² /g) ^{0.5} m ⁻¹]
BIGBACC	Parameter for I_{gb}	real	54m [(Fs ² /g) ^{0.5} m ⁻¹ V ⁻¹]
CIGBACC	Parameter for I_{gb}	real	75m [V ⁻¹]
AIGBINV	Parameter for I_{gb}	real	0.35 [(Fs ² /g) ^{0.5} m ⁻¹]
BIGBINV	Parameter for I_{gb}	real	30m [(Fs ² /g) ^{0.5} m ⁻¹ V ⁻¹]
CIGBINV	Parameter for I_{gb}	real	6m [V ⁻¹]
NIGC	Parameter for I_{gc} slope	real	1
NIGBINV	Parameter for I_{gbinv} slope	real	3
NIGBACC	Parameter for I_{gbacc} slope	real	1
NTOX	Exponent for Tox ratio	real	1
EIGBINV	Parameter for the Si bandgap for I_{gbinv}	real	1.1
PIGCD	Parameter for I_{gc} partition	real	1
POXEDGE	Factor for the gate edge Tox	real	1
IJTHDFWD	Forward drain diode forward limiting current	real	0.1 [A]
IJTHSFWD	Forward source diode forward limiting current	real	0.1 [A]
IJTHDREV	Reverse drain diode forward limiting current	real	0.1 [A]
IJTHSREV	Reverse source diode forward limiting current	real	0.1 [A]
XJBVD	Fitting parameter for drain diode break-down current	real	1
XJBVS	Fitting parameter for	real	1

	source diode breakdown cur- rent		
BVD	Drain diode breakdown voltage	real	10 [V]
BVS	Source diode breakdown voltage	real	10 [V]
GBMIN	Minimum body conductance	real	1p [mho]
RBDB	Resistance between bNode and dbNode	real	50 [W]
RBPB	Resistance between bNodePrime and bNode	real	50 [W]
RBSB	Resistance between bNode and sbNode	real	50 [W]
RBPS	Resistance between bNodePrime and sbNode	real	50 [W]
RBPD	Resistance between bNodePrime and bNode	real	50 [W]
LCDSC	Length dependence of cdsc	real	0
LCDSCB	Length dependence of cdscb	real	0
LCDSCD	Length dependence of cdscd	real	0
LCIT	Length dependence of cit	real	0
LNFACTOR	Length dependence of nfactor	real	0
LXJ	Length dependence of xj	real	0

LVSAT	Length dependence of vsat	real	0
LAT	Length dependence of at	real	0
LA0	Length dependence of a0	real	0
LAGS	Length dependence of ags	real	0
LA1	Length dependence of a1	real	0
LA2	Length dependence of a2	real	0
LKETA	Length dependence of keta	real	0
LNSUB	Length dependence of nsub	real	0
LNDEP	Length dependence of ndep	real	0
LNSD	Length dependence of nsd	real	0
LPHIN	Length dependence of phin	real	0
LNGATE	Length dependence of ngate	real	0
LGAMMA1	Length dependence of gamma1	real	0
LGAMMA2	Length dependence of gamma2	real	0
LVBX	Length dependence of vbx	real	0
LVBM	Length dependence of vbm	real	0
LXT	Length	real	0

	dependence of xt		
LK1	Length dependence of k1	real	0
LKT1	Length dependence of kt1	real	0
LKT1L	Length dependence of kt1l	real	0
LKT2	Length dependence of kt2	real	0
LK2	Length dependence of k2	real	0
LK3	Length dependence of k3	real	0
LK3B	Length dependence of k3b	real	0
LW0	Length dependence of w0	real	0
LDVTP0	Length dependence of dvtp0	real	0
LDVTP1	Length dependence of dvtp1	real	0
LLPE0	Length dependence of lpe0	real	0
LLPEB	Length dependence of lpeb	real	0
LDVT0	Length dependence of dvt0	real	0
LDVT1	Length dependence of dvt1	real	0
LDVT2	Length dependence of dvt2	real	0
LDVT0W	Length dependence of	real	0

	dvt0w		
LDVT1W	Length dependence of dvt1w	real	0
LDVT2W	Length dependence of dvt2w	real	0
LDROUT	Length dependence of drou	real	0
LDSUB	Length dependence of dsub	real	0
LVTH0	Length dependence of vto	real	0
LVTHO	Length dependence of vto	real	0
LUA	Length dependence of ua	real	0
LUA1	Length dependence of ua1	real	0
LUB	Length dependence of ub	real	0
LUB1	Length dependence of ub1	real	0
LUC	Length dependence of uc	real	0
LUC1	Length dependence of uc1	real	0
LU0	Length dependence of u0	real	0
LUTE	Length dependence of ute	real	0
LVOFF	Length dependence of voff	real	0
LMINV	Length dependence of minv	real	0

LDELTA	Length dependence of delta	real	0
LRDSW	Length dependence of rds w	real	0
LRSW	Length dependence of rsw	real	0
LRDW	Length dependence of rdw	real	0
LPRWG	Length dependence of prwg	real	0
LPRWB	Length dependence of prwb	real	0
LPRT	Length dependence of prt	real	0
LETA0	Length dependence of eta0	real	0
LETAB	Length dependence of etab	real	0
LPCLM	Length dependence of pclm	real	0
LPDIBLC1	Length dependence of pdiblc1	real	0
LPDIBLC2	Length dependence of pdiblc2	real	0
LPDIBLCB	Length dependence of pdiblcb	real	0
LFPROUT	Length dependence of pdiblcb	real	0
LPDITS	Length dependence of pdits	real	0
LPDITSD	Length dependence of pditsd	real	0
LPSCBE1	Length	real	0

	dependence of pscbe1		
LPSCBE2	Length dependence of pscbe2	real	0
LPVAG	Length dependence of pvag	real	0
LWR	Length dependence of wr	real	0
LDWG	Length dependence of dwg	real	0
LDWB	Length dependence of dwb	real	0
LB0	Length dependence of b0	real	0
LB1	Length dependence of b1	real	0
LCGSL	Length dependence of cgs1	real	0
LCGDL	Length dependence of cgdl	real	0
LCKAPPAS	Length dependence of ckappas	real	0
LCKAPPAD	Length dependence of ckappad	real	0
LCF	Length dependence of cf	real	0
LCLC	Length dependence of clc	real	0
LCLE	Length dependence of cle	real	0
LALPHA0	Length dependence of alpha0	real	0
LALPHA1	Length dependence of	real	0

	alpha1		
LBETA0	Length dependence of beta0	real	0
LAGIDL	Length dependence of agidl	real	0
LBGIDL	Length dependence of bgidl	real	0
LCGIDL	Length dependence of cgidl	real	0
LEGIDL	Length dependence of egidl	real	0
LAIGC	Length dependence of aigc	real	0
LBIGC	Length dependence of bigc	real	0
LCIGC	Length dependence of cigc	real	0
LAIGSD	Length dependence of aigsd	real	0
LBIGSD	Length dependence of bigsd	real	0
LCIGSD	Length dependence of cigsd	real	0
LAIGBACC	Length dependence of aigbacc	real	0
LBIGBACC	Length dependence of bigbacc	real	0
LCIGBACC	Length dependence of cigbacc	real	0
LAIGBINV	Length dependence of aigbinv	real	0
LBIGBINV	Length dependence of bigbinv	real	0

LCIGBINV	Length dependence of cigbinv	real	0
LNIGC	Length dependence of nigc	real	0
LNIGBINV	Length dependence of nigbinv	real	0
LNIGBACC	Length dependence of nigbacc	real	0
LNTOX	Length dependence of ntox	real	0
LEIGBINV	Length dependence for eigbinv	real	0
LPIGCD	Length dependence for pigcd	real	0
LPOXEDGE	Length dependence for poxedge	real	0
LVFBCV	Length dependence of vfbcv	real	0
LVFB	Length dependence of vfb	real	0
LACDE	Length dependence of acde	real	0
LMOIN	Length dependence of moin	real	0
LNOFF	Length dependence of noff	real	0
LVOFFCV	Length dependence of voffcv	real	0
LXRCRG1	Length dependence of xrcrg1	real	0
LXRCRG2	Length dependence of xrcrg2	real	0
LEU	Length	real	0

	dependence of eu		
SC	th dependence of cdsc	real	0
WCDSCB	Width dependence of cdscb	real	0
WCDSCD	Width dependence of cdsd	real	0
WCIT	Width dependence of cit	real	0
WNFACTOR	Width dependence of nfactor	real	0
WXJ	Width dependence of xj	real	0
WVSAT	Width dependence of vsat	real	0
WAT	Width dependence of at	real	0
WA0	Width dependence of a0	real	0
WAGS	Width dependence of ags	real	0
WA1	Width dependence of a1	real	0
WA2	Width dependence of a2	real	0
WKETA	Width dependence of keta	real	0
WNSUB	Width dependence of nsub	real	0
WNDEP	Width dependence of ndep	real	0
WNSD	Width dependence of nsd	real	0
WPHIN	Width dependence of phin	real	0
WNGATE	Width dependence of ngate	real	0
WGAMMA1	Width dependence of gamma1	real	0
WGAMMA2	Width dependence of gamma2	real	0
WVBX	Width dependence of vbx	real	0
WVBM	Width dependence of vbm	real	0
WXT	Width depend-	real	0

	ence of xt		
WK1	Width depend- ence of k1	real	0
WKT1	Width depend- ence of kt1	real	0
WKT1L	Width depend- ence of kt1l	real	0
WKT2	Width depend- ence of kt2	real	0
WK2	Width depend- ence of k2	real	0
WK3	Width depend- ence of k3	real	0
WK3B	Width depend- ence of k3b	real	0
WW0	Width depend- ence of w0	real	0
WDVTP0	Width depend- ence of dvtp0	real	0
WDVTP1	Width depend- ence of dvtp1	real	0
WLPE0	Width depend- ence of lpe0	real	0
WLPEB	Width depend- ence of lpeb	real	0
WDVT0	Width depend- ence of dvt0	real	0
WDVT1	Width depend- ence of dvt1	real	0
WDVT2	Width depend- ence of dvt2	real	0
WDVT0W	Width depend- ence of dvt0w	real	0
WDVT1W	Width depend- ence of dvt1w	real	0
WDVT2W	Width depend- ence of dvt2w	real	0
WDROUT	Width depend- ence of drout	real	0
WDSUB	Width depend- ence of dsub	real	0
WVTH0	Width depend- ence of vto	real	0
WVTHO	Width depend- ence of vto	real	0
WUA	Width depend- ence of ua	real	0
WUA1	Width depend- ence of ua1	real	0

WUB	Width dependence of ub	real	0
WUB1	Width dependence of ub1	real	0
WUC	Width dependence of uc	real	0
WUC1	Width dependence of uc1	real	0
WU0	Width dependence of u0	real	0
WUTE	Width dependence of ute	real	0
WVOFF	Width dependence of voff	real	0
WMINV	Width dependence of minv	real	0
WDELTA	Width dependence of delta	real	0
WRDSW	Width dependence of rds	real	0
WRSW	Width dependence of rsw	real	0
WRDW	Width dependence of rdw	real	0
WPRWG	Width dependence of prwg	real	0
WPRWB	Width dependence of prwb	real	0
WPRT	Width dependence of prt	real	0
WETA0	Width dependence of eta0	real	0
WETAB	Width dependence of etab	real	0
WPCLM	Width dependence of pclm	real	0
WPDIBLC1	Width dependence of pdiblc1	real	0
WPDIBLC2	Width dependence of pdiblc2	real	0
WPDIBLCB	Width dependence of pdiblc b	real	0
WFPROUT	Width dependence of pdiblc b	real	0
WPDITS	Width dependence of pdits	real	0
WPDITSD	Width dependence of pditsd	real	0
WPSCBE1	Width depend-	real	0

	ence of pscbe1		
WPSCBE2	Width depend- ence of pscbe2	real	0
WPVAG	Width depend- ence of pvag	real	0
WWR	Width depend- ence of wr	real	0
WDWG	Width depend- ence of dwg	real	0
WDWB	Width depend- ence of dwb	real	0
WB0	Width depend- ence of b0	real	0
WB1	Width depend- ence of b1	real	0
WCGSL	Width depend- ence of cgsl	real	0
WCGDL	Width depend- ence of cgdl	real	0
WCKAPPAS	Width depend- ence of ckappas	real	0
WCKAPPAD	Width depend- ence of ckappad	real	0
WCF	Width depend- ence of cf	real	0
WCLC	Width depend- ence of clc	real	0
WCLE	Width depend- ence of cle	real	0
WALPHA0	Width depend- ence of alpha0	real	0
WALPHA1	Width depend- ence of alpha1	real	0
WBETA0	Width depend- ence of beta0	real	0
WAGIDL	Width depend- ence of agidl	real	0
WBGIDL	Width depend- ence of bgidl	real	0
WCGIDL	Width depend- ence of cgidl	real	0
WEGIDL	Width depend- ence of egidl	real	0
WAIGC	Width depend- ence of aigc	real	0

WBIGC	Width dependence of bigc	real	0
WCIGC	Width dependence of cigc	real	0
WAIGSD	Width dependence of aigsd	real	0
WBIGSD	Width dependence of bigsd	real	0
WCIGSD	Width dependence of cigsd	real	0
WAIGBACC	Width dependence of aigbacc	real	0
WBIGBACC	Width dependence of bigbacc	real	0
WCIGBACC	Width dependence of cigbacc	real	0
WAIGBINV	Width dependence of aigbinv	real	0
WBIGBINV	Width dependence of bigbinv	real	0
WCIGBINV	Width dependence of cigbinv	real	0
WNIGC	Width dependence of nigc	real	0
WNIGBINV	Width dependence of nigbinv	real	0
WNIGBACC	Width dependence of nigbacc	real	0
WNTOX	Width dependence of ntox	real	0
WEIGBINV	Width dependence for eigbinv	real	0
WPIGCD	Width dependence for pigcd	real	0
WPOXEDGE	Width dependence for poxedge	real	0
WVFCV	Width dependence of vfbcv	real	0
WVFB	Width dependence of vfb	real	0
WACDE	Width dependence of acde	real	0
WMOIN	Width depend-	real	0

	ence of moir		
WNOFF	Width dependence of noff	real	0
WVOFFCV	Width dependence of voffcv	real	0
WXRCRG1	Width dependence of xrcrg1	real	0
WXRCRG2	Width dependence of xrcrg2	real	0
WEU	Width dependence of eu	real	0
PCDSC	Cross-term dependence of cdsc	real	0
PCDSCB	Cross-term dependence of cdsb	real	0
PCDSCD	Cross-term dependence of cdsd	real	0
PCIT	Cross-term dependence of cit	real	0
PNFACTOR	Cross-term dependence of nfactor	real	0
PXJ	Cross-term dependence of xj	real	0
PVSAT	Cross-term dependence of vsat	real	0
PAT	Cross-term dependence of at	real	0
PA0	Cross-term dependence of a0	real	0
PAGS	Cross-term dependence of ags	real	0
PA1	Cross-term dependence of a1	real	0
PA2	Cross-term dependence of a2	real	0
PKETA	Cross-term dependence of	real	0

	keta		
PNSUB	Cross-term dependence of nsub	real	0
PNDEP	Cross-term dependence of ndep	real	0
PNSD	Cross-term dependence of nsd	real	0
PPHIN	Cross-term dependence of phin	real	0
PNGATE	Cross-term dependence of ngate	real	0
PGAMMA1	Cross-term dependence of gamma1	real	0
PGAMMA2	Cross-term dependence of gamma2	real	0
PVBX	Cross-term dependence of vbx	real	0
PVBM	Cross-term dependence of vbm	real	0
PXT	Cross-term dependence of xt	real	0
PK1	Cross-term dependence of k1	real	0
PKT1	Cross-term dependence of kt1	real	0
PKT1L	Cross-term dependence of kt1l	real	0
PKT2	Cross-term dependence of kt2	real	0
PK2	Cross-term dependence of k2	real	0
PK3	Cross-term dependence of k3	real	0

PK3B	Cross-term dependence of k3b	real	0
PW0	Cross-term dependence of w0	real	0
PDVTP0	Cross-term dependence of dvtp0	real	0
PDVTP1	Cross-term dependence of dvtp1	real	0
PLPE0	Cross-term dependence of lpe0	real	0
PLPEB	Cross-term dependence of lpeb	real	0
PDVT0	Cross-term dependence of dvt0	real	0
PDVT1	Cross-term dependence of dvt1	real	0
PDVT2	Cross-term dependence of dvt2	real	0
PDVT0W	Cross-term dependence of dvt0w	real	0
PDVT1W	Cross-term dependence of dvt1w	real	0
PDVT2W	Cross-term dependence of dvt2w	real	0
PDROUT	Cross-term dependence of drout	real	0
PDSUB	Cross-term dependence of dsub	real	0
PVTH0	Cross-term dependence of vto	real	0
PVTHO	Cross-term dependence of vto	real	0
PUA	Cross-term	real	0

	dependence of ua		
PUA1	Cross-term dependence of ua1	real	0
PUB	Cross-term dependence of ub	real	0
PUB1	Cross-term dependence of ub1	real	0
PUC	Cross-term dependence of uc	real	0
PUC1	Cross-term dependence of uc1	real	0
PU0	Cross-term dependence of u0	real	0
PUTE	Cross-term dependence of ute	real	0
PVOFF	Cross-term dependence of voff	real	0
PMINV	Cross-term dependence of minv	real	0
PDELTA	Cross-term dependence of delta	real	0
PRDSW	Cross-term dependence of rdsw	real	0
PRSW	Cross-term dependence of rsw	real	0
PRDW	Cross-term dependence of rdw	real	0
PPRWG	Cross-term dependence of prwg	real	0
PPRWB	Cross-term dependence of prwb	real	0
PPRT	Cross-term dependence of	real	0

	prt		
PETA0	Cross-term dependence of eta0	real	0
PETAB	Cross-term dependence of etab	real	0
PPCLM	Cross-term dependence of pclm	real	0
PPDIBLC1	Cross-term dependence of pdiblc1	real	0
PPDIBLC2	Cross-term dependence of pdiblc2	real	0
PPDIBLCB	Cross-term dependence of pdiblc b	real	0
PFPROUT	Cross-term dependence of pdiblc b	real	0
PPDITS	Cross-term dependence of pdits	real	0
PPDITSD	Cross-term dependence of pditsd	real	0
PPSCBE1	Cross-term dependence of pscbe1	real	0
PPSCBE2	Cross-term dependence of pscbe2	real	0
PPVAG	Cross-term dependence of pvag	real	0
PWR	Cross-term dependence of wr	real	0
PDWG	Cross-term dependence of dwg	real	0
PDWB	Cross-term dependence of dwb	real	0
PB0	Cross-term dependence of b0	real	0

PB1	Cross-term dependence of b1	real	0
PCGSL	Cross-term dependence of cgsl	real	0
PCGDL	Cross-term dependence of cgdl	real	0
PCKAPPAS	Cross-term dependence of ckappas	real	0
PCKAPPAD	Cross-term dependence of ckappad	real	0
PCF	Cross-term dependence of cf	real	0
PCLC	Cross-term dependence of clc	real	0
PCLE	Cross-term dependence of cle	real	0
PALPHA0	Cross-term dependence of alpha0	real	0
PALPHA1	Cross-term dependence of alpha1	real	0
PBETA0	Cross-term dependence of beta0	real	0
PAGIDL	Cross-term dependence of agidl	real	0
PBGIDL	Cross-term dependence of bgidl	real	0
PCGIDL	Cross-term dependence of cgidl	real	0
PEGIDL	Cross-term dependence of egidl	real	0
PAIGC	Cross-term dependence of aigc	real	0
PBIGC	Cross-term	real	0

	dependence of bigc		
PCIGC	Cross-term dependence of cigc	real	0
PAIGSD	Cross-term dependence of aigsd	real	0
PBIGSD	Cross-term dependence of bigsd	real	0
PCIGSD	Cross-term dependence of cigsd	real	0
PAIGBACC	Cross-term dependence of aigbacc	real	0
PBIGBACC	Cross-term dependence of bigbacc	real	0
PCIGBACC	Cross-term dependence of cigbacc	real	0
PAIGBINV	Cross-term dependence of aigbinv	real	0
PBIGBINV	Cross-term dependence of bigbinv	real	0
PCIGBINV	Cross-term dependence of cigbinv	real	0
PNIGC	Cross-term dependence of nigc	real	0
PNIGBINV	Cross-term dependence of nigbinv	real	0
PNIGBACC	Cross-term dependence of nigbacc	real	0
PNTOX	Cross-term dependence of ntox	real	0
PEIGBINV	Cross-term dependence for eigbinv	real	0
PPIGCD	Cross-term dependence	real	0

	for pigcd		
PPOXEDGE	Cross-term dependence for poxedge	real	0
PVFBCV	Cross-term dependence of vfbcv	real	0
PVFB	Cross-term dependence of vfb	real	0
PACDE	Cross-term dependence of acde	real	0
PMOIN	Cross-term dependence of moi	real	0
PNOFF	Cross-term dependence of noff	real	0
PVOFFCV	Cross-term dependence of voffcv	real	0
PXRCRG1	Cross-term dependence of xrcrg1	real	0
PXRCRG2	Cross-term dependence of xrcrg2	real	0
PEU	Cross-term dependence of eu	real	0
NOIA	Flicker noise parameter	real	$6.25e+041 [(eV)^{-1}s^{(1-EF)}m^{-3}]$
NOIB	Flicker noise parameter	real	$3.125e+026 [(eV)^{-1}s^{(1-EF)}m^{-1}]$
NOIC	Flicker noise parameter	real	$8.75G [(eV)^{-1}s^{(1-EF)}m]$
TNOIA	Thermal noise parameter	real	1.5
TNOIB	Thermal noise parameter	real	3.5
NTNOI	Thermal noise parameter	real	1
EM	Flicker noise parameter	real	41Meg [V/m]
EF	Flicker noise frequency exponent	real	1
AF	Flicker noise	real	1

	exponent		
KF	Flicker noise coefficient	real	$0 [A^{(2-EF)}s^{(1-EF)}F]$

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
VBS	Vbs [V]	Output	real
VGS	Vgs [V]	Output	real
VDS	Vds [V]	Output	real
VBD	Vbd [V]	Output	real
ID	Id (terminal) [A]	Output	real
IG	Ig (terminal) [A]	Output	real
IS	Is (terminal) [A]	Output	real
IB	Ib (terminal) [A]	Output	real
P	Power Dissipation [W]	Output	real

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Example

Figure 3 shows application of the Spice-Compatible Level 4 BSIM N-channel and BSIM P-channel models. The parameters of BSIM4_P1 and BSIM4_N1 are set to their default values; the parameters of the rest of the system are listed in Table 4 and the simulation results shown in Figure 4.

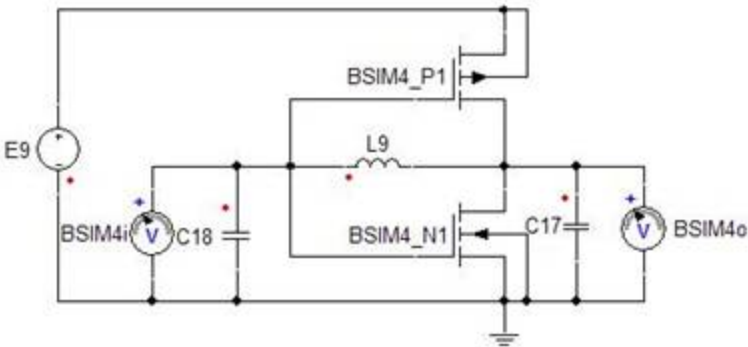


Figure 3. Application example of the Spice-Compatible Level 4 BSIM N-channel and BSIM P-channel models

Table 4

Component	Parameter	Value
Capacitor C18	C	100p [F]
	V0	7.5 [V]
Capacitor C17	C	100p [F]
	V0	0 [V]
Inductor L9	L	1m [H]
	I0	0 [A]
Voltage Source E9	EMF	15 [V]

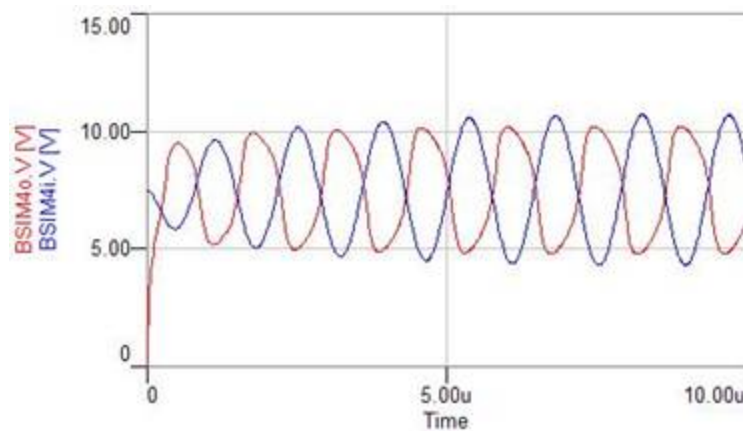


Figure 4. Simulation results-input and output voltage of BSIM4_N1

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References

[1] information on the Web site of UC Berkeley Device Group at <http://www-device.eecs.berkeley.edu/~bsim3/>

EKV Model - SPICE-Compatible N-Channel

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

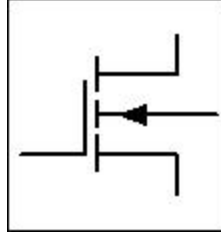


Figure 1. Component Symbol.

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- [Netlist Syntax](#)
- [Conservative Pins](#)
- [Parameters](#)
- [Input/Output Quantities](#)
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Description

The Spice-Compatible EKV N-channel and EKV P-channel models simulate the electrical and thermal behavior of submicron MOSFETs used in low-voltage, low-current analog and mixed signal circuits. The Spice-Compatible EKV models use the parameters and equations of the EKV MOSFET model. Electrical characteristics and the temperature dependence of MOSFET behavior are calculated according to user-defined device parameters that are based on fundamental physical properties of the MOS structure.

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Assumptions and Limitations

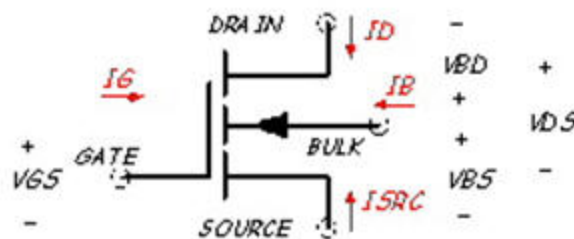


Figure 2. Current and Voltage Reference Arrow System[Top](#)**Mathematical Description**[Top](#)**Netlist Syntax**

```

UMODEL EKV_N ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) DRAIN:= %0,
GATE:= %1, SOURCE:= %2, BULK:= %3 ( TEMP:= @TEMP, L:= @L, W:= @W, AD:= @AD,
AS:= @AS, PD:= @PD, PS:= @PS, NRD:= @NRD, NRS:= @NRS, OFF:= @OFF, ICVDS:=
@ICVDS, ICVGS:= @ICVGS, ICVBS:= @ICVBS, EKVINT:= @EKVINT, VTO:= @VTO, KP:=
@KP, GAMMA:= @GAMMA, PHI:= @PHI, COX:= @COX, XJ:= @XJ, THETA:= @THETA,
E0:= @E0, UCRIT:= @UCRIT, DW:= @DW, DL:= @DL, LAMBDA:= @LAMBDA, WETA:=
@WETA, LETA:= @LETA, IBA:= @IBA, IBB:= @IBB \\\ , IBN:= @IBN, Q0:= @Q0, LK:= @LK,
TCV:= @TCV, BEX:= @BEX, UCX:= @UCX, IBBT:= @IBBT, NQS:= @NQS, SATLIM:=
@SATLIM, KF:= @KF, AF:= @AF, IS:= @IS, JS:= @JS, JSW:= @JSW, N:= @N, CBD:=
@CBD, CBS:= @CBS, CJ:= @CJ, CJSW:= @CJSW, MJ:= @MJ, MJSW:= @MJSW, FC:=
@FC, PB:= @PB, PBSW:= @PBSW, TT:= @TT, CGSO:= @CGSO, CGDO:= @CGDO,
CGBO:= @CGBO, RS:= @RS, RD:= @RD \\\ , RSH:= @RSH, RSC:= @RSC, RDC:= @RDC,
XTI:= @XTI, TR1:= @TR1, TR2:= @TR2, NLEVEL:= @NLEVEL, TNOM:= @TNOM) SRC: DB
(Lib:=@ModelLibraryName) ;

```

[Top](#)**Conservative Pins****Table 1**

Name	Description	Nature/Data Type
GATE	Gate	electrical
SOURCE	Source	electrical
DRAIN	Drain	electrical
BULK	Bulk	electrical

[Top](#)**Parameters****Table 2**

Name	Description	Data Type	Default Value [Unit]
L	Length	real	0.1m [m]
W	Width	real	0.1m [m]
AD	Drain area	real	0 [m ²]

AS	Source area	real	0 [m ²]
PD	Drain perimeter	real	0 [m]
PS	Source perimeter	real	0 [m]
NRD	Drain squares	real	1
NRS	Source squares	real	1
OFF	Device initially off	boolean	0
ICVDS	Initial D-S voltage	real	0 [V]
ICVGS	Initial G-S voltage	real	0 [V]
ICVBS	Initial B-S voltage	real	0 [V]
TEMP	Instance temperature	real	27 [°C]
EKVINT	interpolation function selector	real	0
VTO	Nominal threshold voltage	real	0.5 [V]
KP	Transconductance parameter	real	50u [A/V ²]
GAMMA	Body effect parameter	real	1 [V ^{1/2}]
PHI	Bulk Fermi potential	real	0.7 [V]
COX	Gate oxide capacitance	real	0.7m [F/m ²]
XJ	Junction depth	real	0.1u [m]
THETA	Mobility reduction coefficient	real	0 [V ⁻¹]
E0	NEW Mobility reduction coefficient	real	1T [V/m]
UCRIT	Longitudinal critical field	real	0.1G [V/m]
DW	Channel width correction	real	0 [m]
DL	Channel length correction	real	0 [m]
LAMBDA	Depletion length coefficient	real	0.5
WETA	Narrow channel effect coefficient	real	0.25
LETA	Short channel coefficient	real	0.1
IBA	First impact ionization coefficient	real	0 [m ⁻¹]
IBB	Second impact ion-	real	0.3G [V/m]

	ization coefficient		
IBN	Saturation voltage factor for impact ionization	real	1
Q0	RSCE excess charge	real	0 [As/m ²]
LK	RSCE characteristic length	real	0.29u [m]
TCV	Threshold voltage temperature coefficient	real	1m [V/K]
BEX	Mobility temperature exponent	real	-1.5
UCEX	Longitudinal critical field temperature coefficient	real	0.8
IBBT	Temperature coefficient for ibb	real	0.9m [1/K]
NQS	Non-Quasi-Static operation switch	real	0
SATLIM	Ratio defining the saturation limit	real	54.5981500331442
KF	Flicker noise coefficient	real	0
AF	Flicker noise exponent	real	1
IS	Bulk p-n saturation current	real	10f [A]
JS	Bulk p-n bottom saturation current per area	real	0 [A/m ²]
JSW	Bulk p-n sidewall saturation current per length	real	0 [A/m]
N	Emission coefficient	real	1
CBD	B-D p-n capacitance	real	0 [F]
CBS	B-S p-n capacitance	real	0 [F]
CJ	Bottom p-n capacitance per area	real	0 [F/m ²]
CJSW	Sidewall p-n capacitance per length	real	0 [F/m]
MJ	Bottom p-n grading coefficient	real	0.5
in	Sidewall p-n grading coefficient	real	0.33
FC	Forward p-n capa-	real	0.5

	capacitance coefficient		
PB	Bulk p-n junction potential	real	0.8 [V]
PBSW	Bulk sidewall p-n junction potential	real	0.8 [V]
TT	Bulk p-n transit time	real	0 [s]
CGSO	Gate-source overlap capacitance	real	0 [F/m]
CGDO	Gate-drain overlap capacitance	real	0 [F/m]
CGBO	Gate-bulk overlap capacitance	real	0 [F/m]
RS	Source ohmic resistance	real	0 [W]
RD	Drain ohmic resistance	real	0 [W]
RSH	Drain, source sheet resistance	real	0 [W/square]
RSC	Source contact resistance	real	0 [W]
RDC	Drain contact resistance	real	0 [W]
XTI	Junction current temperature exponent	real	3
TR1	1st-order temperature coefficient	real	0
TR2	2nd-order temperature coefficient	real	0
NLEVEL	Noise level selector	real	1
TNOM	Parameter measurement temperature	real	27 [°C]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
VBS	Vbs [V]	Output	real
VGS	Vgs [V]	Output	real
VDS	Vds [V]	Output	real
VBD	Vbd [V]	Output	real

ID	Id (terminal) [A]	Output	real
IG	Ig (terminal) [A]	Output	real
IB	Ib (terminal) [A]	Output	real
ISRC	Source current [A]	Output	real
ISUB	Substrate current [A]	Output	real
POWER	Instantaneous power [W]	Output	real

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Example

Figure 3 shows application of the Spice-Compatible EKV N-channel and Spice-Compatible EKV P-channel models. The parameters of EKV_P1 and EKV_N1 are set to their default values; the parameters of the rest of the system are listed in Table 4 and the simulation results shown in Figure 4.

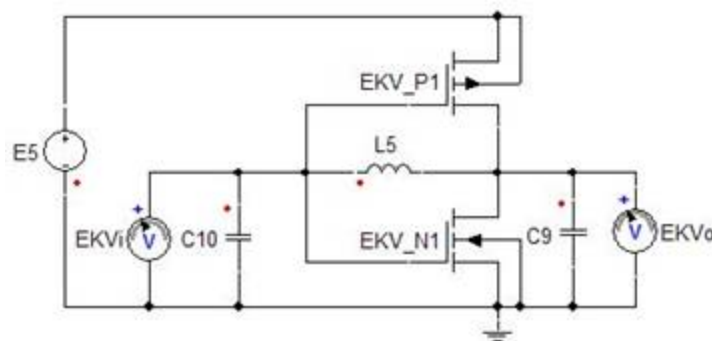


Figure 3. Application example of the Spice-Compatible EKV N-channel and P-channel models

Table 4

Component	Parameter	Value
Capacitor C10	C	100p [F]
	V0	7.5 [V]
Capacitor C9	C	100p [F]
	V0	0 [V]
Inductor L5	L	1m [H]
	I0	0 [A]
Voltage Source E5	EMF	15 [V]

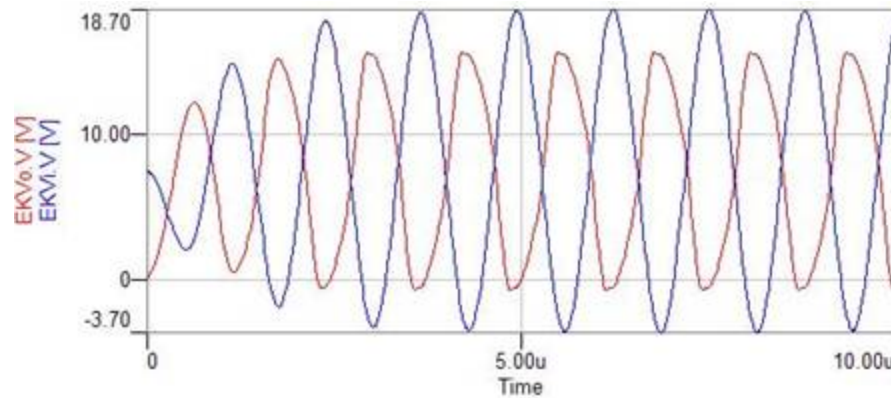


Figure 4. Simulation results-input and output voltage of EKV_N1

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References

[1] EKV 2.6 Documentation information on the Web site of Electronics Laboratory of EPFL (Lausanne) at <http://legwww.epfl.ch/ekv/model.html>

EKV Model - SPICE-Compatible P-Channel

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

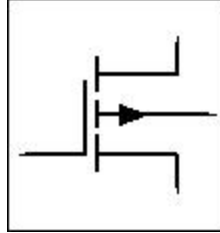


Figure 1. Component Symbol.

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- [Netlist Syntax](#)
- [Conservative Pins](#)
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Description

The Spice-Compatible EKV N-channel and EKV P-channel models simulate the electrical and thermal behavior of submicron MOSFETs used in low-voltage, low-current analog and mixed signal circuits. The Spice-Compatible EKV models use the parameters and equations of the EKV MOSFET model. Electrical characteristics and the temperature dependence of MOSFET behavior are calculated according to user-defined device parameters that are based on fundamental physical properties of the MOS structure.

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Assumptions and Limitations

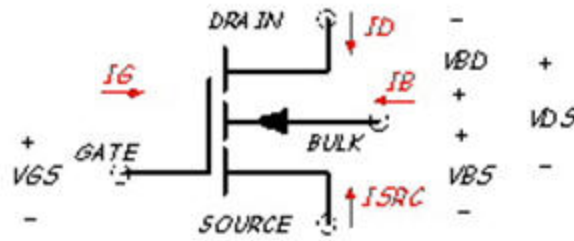


Figure 2. Current and Voltage Reference Arrow System

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Mathematical Description

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Netlist Syntax

```
UMODEL EKV_P ?InstanceName(@InstanceName):(@ (Refbase)@(ID)) DRAIN:= %0,
GATE:= %1, SOURCE:= %2, BULK:= %3 ( TEMP:= @TEMP, L:= @L, W:= @W, AD:= @AD,
AS:= @AS, PD:= @PD, PS:= @PS, NRD:= @NRD, NRS:= @NRS, OFF:= @OFF, ICDVS:=
@ICVDS, ICDVS:= @ICVGS, ICDVS:= @ICVBS, EKVINT:= @EKVINT, VTO:= @VTO, KP:=
@KP, GAMMA:= @GAMMA, PHI:= @PHI, COX:= @COX, XJ:= @XJ, THETA:= @THETA,
E0:= @E0, UCRIT:= @UCRIT, DW:= @DW, DL:= @DL, LAMBDA:= @LAMBDA, WETA:=
@WETA, LETA:= @LETA, IBA:= @IBA, IBB:= @IBB \\\ , IBN:= @IBN, Q0:= @Q0, LK:= @LK,
TCV:= @TCV, BEX:= @BEX, UCX:= @UCX, IBBT:= @IBBT, NQS:= @NQS, SATLIM:=
@SATLIM, KF:= @KF, AF:= @AF, IS:= @IS, JS:= @JS, JSW:= @JSW, N:= @N, CBD:=
@CBD, CBS:= @CBS, CJ:= @CJ, CJSW:= @CJSW, MJ:= @MJ, MJSW:= @MJSW, FC:=
@FC, PB:= @PB, PBSW:= @PBSW, TT:= @TT, CGSO:= @CGSO, CGDO:= @CGDO,
CGBO:= @CGBO, RS:= @RS, RD:= @RD \\\ , RSH:= @RSH, RSC:= @RSC, RDC:= @RDC,
XTI:= @XTI, TR1:= @TR1, TR2:= @TR2, NLEVEL:= @NLEVEL, TNOM:= @TNOM) SRC: DB
(Lib:=@ModelLibraryName);
```

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
GATE	Gate	electrical
SOURCE	Source	electrical
DRAIN	Drain	electrical
BULK	Bulk	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
L	Length	real	0.1m [m]
W	Width	real	0.1m [m]
AD	Drain area	real	0 [m ²]
AS	Source area	real	0 [m ²]
PD	Drain perimeter	real	0 [m]
PS	Source perimeter	real	0 [m]
NRD	Drain squares	real	1
NRS	Source squares	real	1
OFF	Device initially off	boolean	0
ICVDS	Initial D-S voltage	real	0 [V]
ICVGS	Initial G-S voltage	real	0 [V]
ICVBS	Initial B-S voltage	real	0 [V]
TEMP	Instance temperature	real	27 [°C]
EKVINT	interpolation function selector	real	0
VTO	Nominal threshold voltage	real	0.5 [V]
KP	Transconductance parameter	real	50u [A/V ²]
GAMMA	Body effect parameter	real	1 [V ^{1/2}]
PHI	Bulk Fermi potential	real	0.7 [V]
COX	Gate oxide capacitance	real	0.7m [F/m ²]
XJ	Junction depth	real	0.1u [m]
THETA	Mobility reduction coefficient	real	0 [V ⁻¹]
E0	NEW Mobility reduction coefficient	real	1T [V/m]
UCRIT	Longitudinal critical field	real	0.1G [V/m]
DW	Channel width correction	real	0 [m]

DL	Channel length correction	real	0 [m]
LAMBDA	Depletion length coefficient	real	0.5
WETA	Narrow channel effect coefficient	real	0.25
LETA	Short channel coefficient	real	0.1
IBA	First impact ionization coefficient	real	0 [m ⁻¹]
IBB	Second impact ionization coefficient	real	0.3G [V/m]
IBN	Saturation voltage factor for impact ionization	real	1
Q0	RSCE excess charge	real	0 [As/m ²]
LK	RSCE characteristic length	real	0.29u [m]
TCV	Threshold voltage temperature coefficient	real	1m [V/K]
BEX	Mobility temperature exponent	real	-1.5
UCEX	Longitudinal critical field temperature coefficient	real	0.8
IBBT	Temperature coefficient for ibb	real	0.9m [1/K]
NQS	Non-Quasi-Static operation switch	real	0
SATLIM	Ratio defining the saturation limit	real	54.5981500331442
KF	Flicker noise coefficient	real	0
AF	Flicker noise exponent	real	1
IS	Bulk p-n saturation current	real	10f [A]
JS	Bulk p-n bottom saturation current per area	real	0 [A/m ²]
JSW	Bulk p-n sidewall saturation current per length	real	0 [A/m]
N	Emission coefficient	real	1
CBD	B-D p-n capacitance	real	0 [F]
CBS	B-S p-n capa-	real	0 [F]

	citance		
CJ	Bottom p-n capacitance per area	real	0 [F/m ²]
CJSW	Sidewall p-n capacitance per length	real	0 [F/m]
MJ	Bottom p-n grading coefficient	real	0.5
in	Sidewall p-n grading coefficient	real	0.33
FC	Forward p-n capacitance coefficient	real	0.5
PB	Bulk p-n junction potential	real	0.8 [V]
PBSW	Bulk sidewall p-n junction potential	real	0.8 [V]
TT	Bulk p-n transit time	real	0 [s]
CGSO	Gate-source overlap capacitance	real	0 [F/m]
CGDO	Gate-drain overlap capacitance	real	0 [F/m]
CGBO	Gate-bulk overlap capacitance	real	0 [F/m]
RS	Source ohmic resistance	real	0 [W]
RD	Drain ohmic resistance	real	0 [W]
RSH	Drain, source sheet resistance	real	0 [W/square]
RSC	Source contact resistance	real	0 [W]
RDC	Drain contact resistance	real	0 [W]
XTI	Junction current temperature exponent	real	3
TR1	1st-order temperature coefficient	real	0
TR2	2nd-order temperature coefficient	real	0
NLEVEL	Noise level selector	real	1
TNOM	Parameter measurement temperature	real	27 [°C]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
VBS	Vbs [V]	Output	real
VGS	Vgs [V]	Output	real
VDS	Vds [V]	Output	real
VBD	Vbd [V]	Output	real
ID	Id (terminal) [A]	Output	real
IG	Ig (terminal) [A]	Output	real
IB	Ib (terminal) [A]	Output	real
ISRC	Source current [A]	Output	real
ISUB	Substrate current [A]	Output	real
POWER	Instantaneous power [W]	Output	real

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Example

Figure 3 shows application of the Spice-Compatible EKV N-channel and Spice-Compatible EKV P-channel models. The parameters of EKV_P1 and EKV_N1 are set to their default values; the parameters of the rest of the system are listed in Table 4 and the simulation results shown in Figure 4.

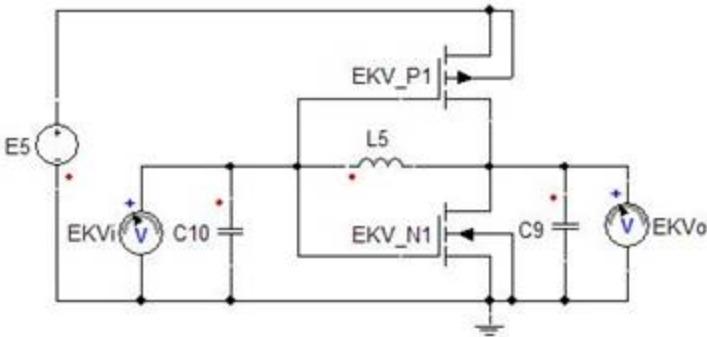


Figure 3. Application example of the Spice-Compatible EKV N-channel and P-channel models

Table 4

Component	Parameter	Value

Capacitor C10	C	100p [F]
	V0	7.5 [V]
Capacitor C9	C	100p [F]
	V0	0 [V]
Inductor L5	L	1m [H]
	I0	0 [A]
Voltage Source E5	EMF	15 [V]

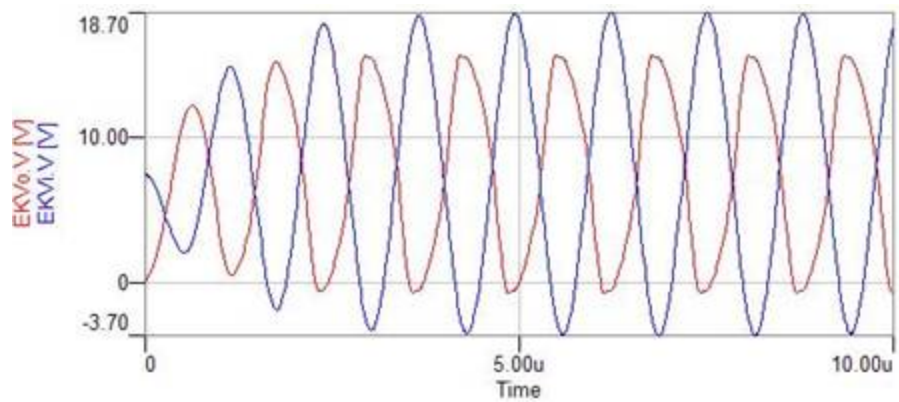


Figure 4. Simulation results-input and output voltage of EKV_N1

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References

[1] EKV 2.6 Documentation information on the Web site of Electronics Laboratory of EPFL (Lausanne) at <http://legwww.epfl.ch/ekv/model.html>

JFET Model - SPICE-Compatible N-Channel

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

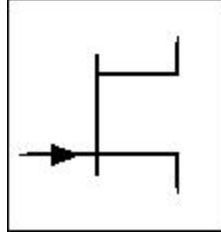


Figure 1. Component Symbol.

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Description

The Spice-compatible JFET N-channel and JFET P-channel models simulate the electrical and thermal behavior of a JFET using SPICE3 parameters and equations. Electrical characteristics and the temperature dependence of JFET behavior are calculated according to user-defined device parameters.

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Assumptions and Limitations

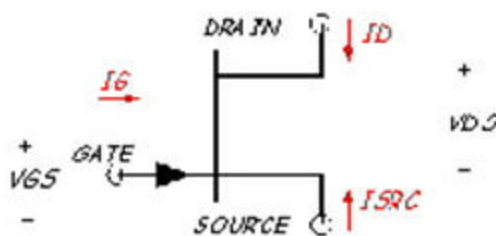


Figure 2. Current and Voltage Reference Arrow System[Top](#)**Mathematical Description**[Top](#)**Netlist Syntax**

```

UMODEL SPICE_JFET_N ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) DRAIN:=
%0, GATE:= %1, SOURCE:= %2 ( OFF:= @OFF, AREA:= @AREA, ICDVS:= @ICVDS,
ICVGS:= @ICVGS, TEMP:= @TEMP, VTO:= @VTO, BETA:= @BETA, LAMBDA:=
@LAMBDA, RD:= @RD, RS:= @RS, CGS:= @CGS, CGD:= @CGD, PB:= @PB, IS:= @IS,
FC:= @FC, B:= @B, TNOM:= @TNOM, KF:= @KF, AF:= @AF) SRC: DB(Lib:-
:=@ModelLibraryName);

```

[Top](#)**Conservative Pins****Table 1**

Name	Description	Nature/Data Type
GATE	Gate	electrical
SOURCE	Source	electrical
DRAIN	Drain	electrical

[Top](#)**Parameters****Table 2**

Name	Description	Data Type	Default Value [Unit]
OFF	Device initially off	boolean	0
AREA	Area factor	real	1
ICVDS	Initial Drain-Source voltage	real	0 [V]
ICVGS	Initial Gate-Source voltage	real	0 [V]
TEMP	Instance temperature	real	27 [°C]
VTO	Threshold voltage	real	-2 [V]
BETA	Transconductance parameter	real	0.1m [A/V ²]
LAMBDA	Channel length modulation parameter	real	0 [1/V]

RD	Drain ohmic resistance	real	0 [W]
RS	Source ohmic resistance	real	0 [W]
CGS	G-S junction capacitance	real	0 [F]
CGD	G-D junction capacitance	real	0 [F]
PB	Gate junction potential	real	1 [V]
IS	Gate junction saturation current	real	10f [A]
FC	Forward bias junction fit parameter	real	0.5
B	Doping tail parameter	real	1
TNOM	Parameter measurement temperature	real	27 [°C]
KF	Flicker Noise Coefficient	real	0
AF	Flicker Noise Exponent	real	0

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
VGS	Voltage Gate-Source [V]	Output	real
VGD	Voltage Gate-Drain [V]	Output	real
VDS	Voltage Drain-Source [V]	Output	real
ID	Current at drain node [A]	Output	real
IG	Current at gate node [A]	Output	real
ISRC	Source current [A]	Output	real
P	Power dissipation [W]	Output	real

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Example

Figure 3 shows application of the Spice-Compatible P-Channel and N-Channel JFET models. The parameters of J1 and J2 are set to their default values; the parameters of the rest of the system are listed in Table 4 and the simulation results shown in Figure 4.

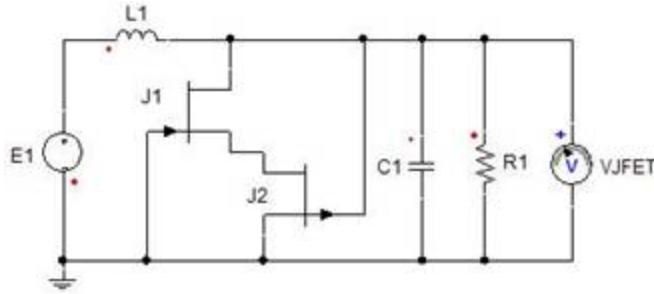


Figure 3. Application example of the Spice-Compatible N-channel and P-channel MESFET models

Table 4

Component	Parameter	Value
Voltage Source E1	EMF	2.4 [V]
Inductor L1	L	1 [H]
	I0	0 [A]
Capacitor C1	C	1u [F]
	V0	2.4 [V]
Resistor R1	R	100meg [Ohm]

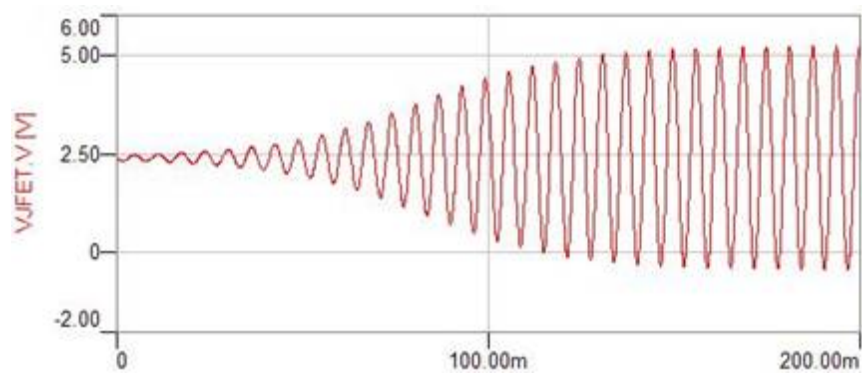


Figure 4. Simulation result

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References

[1] Massobrio, Giuseppe, and Paolo Antognetti: *Semiconductor Device Modeling with SPICE*, New York: McGraw Hill, 1993

JFET Model - SPICE-Compatible P-Channel

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

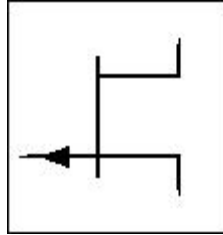


Figure 1. Component Symbol.

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Description

The Spice-compatible JFET N-channel and JFET P-channel models simulate the electrical and thermal behavior of a JFET using SPICE3 parameters and equations. Electrical characteristics and the temperature dependence of JFET behavior are calculated according to user-defined device parameters.

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Assumptions and Limitations

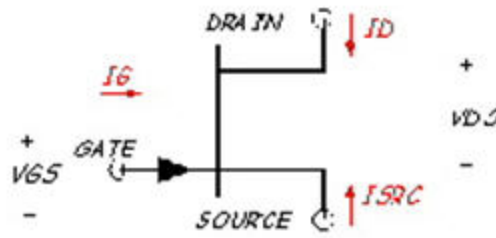


Figure 2. Current and Voltage Reference Arrow System

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Mathematical Description

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Netlist Syntax

```
UMODEL SPICE_JFET_P ?InstanceName(@InstanceName):(@ (Refbase)@(ID)) DRAIN:=
%0, GATE:= %1, SOURCE:= %2 ( OFF:= @OFF, AREA:= @AREA, ICVDS:= @ICVDS,
ICVGS:= @ICVGS, TEMP:= @TEMP, VTO:= @VTO, BETA:= @BETA, LAMBDA:=
@LAMBDA, RD:= @RD, RS:= @RS, CGS:= @CGS, CGD:= @CGD, PB:= @PB, IS:= @IS,
FC:= @FC, B:= @B, TNOM:= @TNOM, KF:= @KF, AF:= @AF) SRC: DB(Lib:-
:=@ModelLibraryName);
```

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
GATE	Gate	electrical
SOURCE	Source	electrical
DRAIN	Drain	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]

OFF	Device initially off	boolean	0
AREA	Area factor	real	1
ICVDS	Initial Drain-Source voltage	real	0 [V]
ICVGS	Initial Gate-Source voltage	real	0 [V]
TEMP	Instance temperature	real	27 [°C]
VTO	Threshold voltage	real	-2 [V]
BETA	Transconductance parameter	real	0.1m [A/V ²]
LAMBDA	Channel length modulation parameter	real	0 [1/V]
RD	Drain ohmic resistance	real	0 [W]
RS	Source ohmic resistance	real	0 [W]
CGS	G-S junction capacitance	real	0 [F]
CGD	G-D junction capacitance	real	0 [F]
PB	Gate junction potential	real	1 [V]
IS	Gate junction saturation current	real	10f [A]
FC	Forward bias junction fit parameter	real	0.5
B	Doping tail parameter	real	1
TNOM	Parameter measurement temperature	real	27 [°C]
KF	Flicker Noise Coefficient	real	0
AF	Flicker Noise Exponent	real	0

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
VGS	Voltage Gate-Source [V]	Output	real
VGD	Voltage Gate-Drain [V]	Output	real
VDS	Voltage Drain-Source [V]	Output	real
ID	Current at drain node [A]	Output	real

IG	Current at gate node [A]	Output	real
ISRC	Source current [A]	Output	real
P	Power dissipation [W]	Output	real

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Example

Figure 3 shows application of the Spice-Compatible P-Channel and N-Channel JFET models. The parameters of J1 and J2 are set to their default values; the parameters of the rest of the system are listed in Table 4 and the simulation results shown in Figure 4.

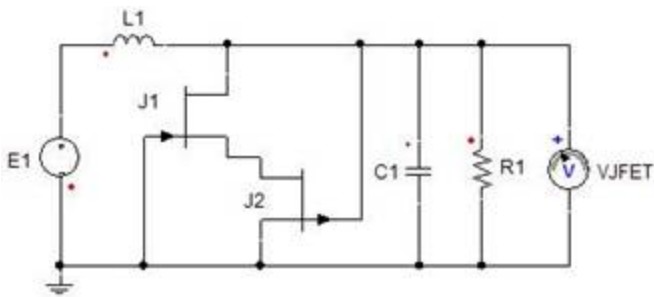


Figure 3. Application example of the Spice-Compatible N-channel and P-channel MESFET models

Table 4

Component	Parameter	Value
Voltage Source E1	EMF	2.4 [V]
Inductor L1	L	1 [H]
	I0	0 [A]
Capacitor C1	C	1u [F]
	V0	2.4 [V]
Resistor R1	R	100meg [Ohm]

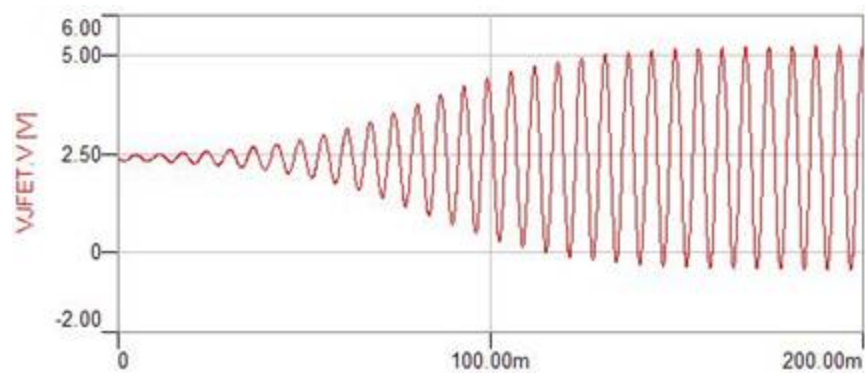


Figure 4. Simulation result

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References

[1]Massobrio, Giueseppe, and Paolo Antognetti: *Semiconductor Device Modeling with SPICE*, New York: McGraw Hill, 1993

MESFET Model - SPICE-Compatible N-Channel

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

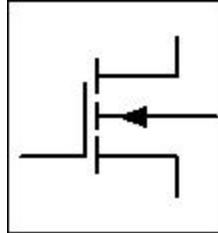


Figure 1. Component Symbol.

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Description

The Spice-compatible MESFET N-channel and MESFET P-channel models simulate the electrical and thermal behavior of a JFET using SPICE3 parameters and equations. Electrical characteristics and the temperature dependence of MESFET behavior are calculated according to user-defined device parameters.

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Assumptions and Limitations

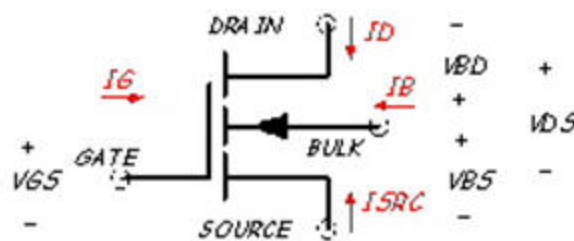


Figure 2. Current and Voltage Reference Arrow System[Top](#)**Mathematical Description**[Top](#)**Netlist Syntax**

```

UMODEL SPICE_MESFET_N ?InstanceName(@InstanceName):(@Refbase)@(ID))
DRAIN:= %0, GATE:= %1, SOURCE:= %2 ( OFF:= @OFF, AREA:= @AREA, ICVDS:=
@ICVDS, ICVGS:= @ICVGS, VTO:= @VTO, ALPHA:= @ALPHA, BETA:= @BETA,
LAMBDA:= @LAMBDA, B:= @B, RD:= @RD, RS:= @RS, CGS:= @CGS, CGD:= @CGD, PB:=
@PB, IS:= @IS, FC:= @FC, KF:= @KF, AF:= @AF) SRC: DB(Lib:=@ModelLibraryName) ;

```

[Top](#)**Conservative Pins****Table 1**

Name	Description	Nature/Data Type
GATE	Gate	electrical
SOURCE	Source	electrical
DRAIN	Drain	electrical
BULK	Bulk	electrical

[Top](#)**Parameters****Table 2**

Name	Description	Data Type	Default Value [Unit]
OFF	Device initially off	boolean	0
AREA	Area factor	real	1
ICVDS	Initial D-S voltage	real	0 [V]
ICVGS	Initial G-S voltage	real	0 [V]
VTO	Pinch-off voltage	real	-2 [V]
ALPHA	Saturation voltage parameter	real	2 [1/V]
BETA	Transconductance parameter	real	2.5m [A/V ²]
LAMBDA	Channel length modulation parameter	real	0 [1/V]

B	Doping tail extending parameter	real	0.3 [1/V]
RD	Drain ohmic resistance	real	0 [Ohm]
RS	Source ohmic resistance	real	0 [Ohm]
CGS	G-S junction capacitance	real	0 [F]
CGD	G-D junction capacitance	real	0
PB	Gate junction potential	real	1 [V]
IS	Junction saturation current	real	10f [A]
FC	Forward bias junction fit parm.	real	0.5
KF	Flicker noise coefficient	real	0
AF	Flicker noise exponent	real	0

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
VGS	Gate-Source voltage [V]	Output	real
VGD	Gate-Drain voltage [V]	Output	real
VDS	Drain-Source voltage [V]	Output	real
ID	Drain current [A]	Output	real
IG	Gate current [A]	Output	real
ISRC	Source current [A]	Output	real
P	Power dissipated by the mesfet [W]	Output	real

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Example

Figure 3 shows application of the Spice-Compatible N-channel MESFET model. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 4.

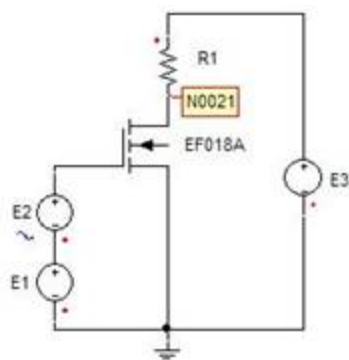


Figure 3. Application example of the Spice-Compatible EKV N-channel and P-channel models

Table 4

Component	Parameter	Value
Voltage Source (sinusoidal) E2	AMPL	[V]
	FREQ	[Hz]
	PHASE	[degree]
	OFF	[V]
	TDELAY	[s]
Voltage Source E1	EMF	[V]
Voltage Source E3	EMF	[V]
Resistor R1	R	1m [Ohm]

Spice-Compatible N-channel MESFET EF018A	OFF	0
	AREA	1
	ICVDS	0 [V]
	ICVGS	0 [V]
	VT0	-1.7 [V]
	ALPHA	2 [1/V]
	BETA	23.4m [A/V ²]
	LAMBDA	0 [1/V]
	B	0.3 [1/V]
	RD	1.3 [Ohm]
	RS	4.3 [Ohm]
	CGS	1.63E-013 [F]
	CGD	1.80E-14 [F]
	PB	1 [V]
	IS	1.4E-014 [A]
	FC	0.5
	KF	0
	AF	0

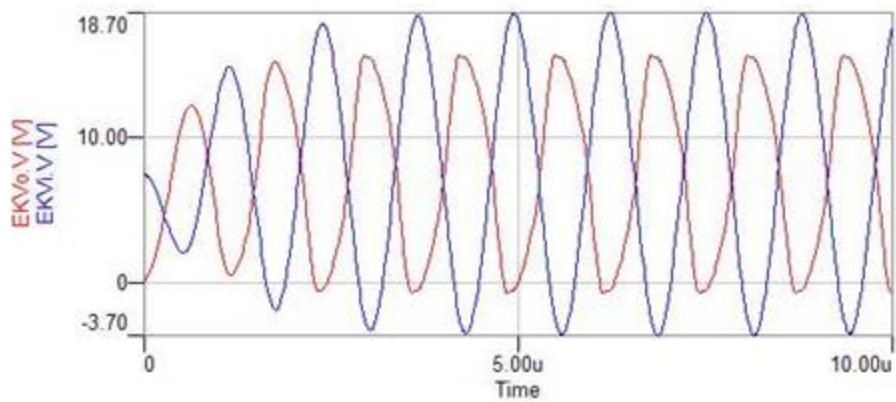


Figure 4. Simulation results-input and output voltage of EKV_N1

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References

[1]Massobrio, Giueseppe, and Paolo Antognetti: *Semiconductor Device Modeling with SPICE*, New York: McGraw Hill, 1993

MESFET Model - SPICE-Compatible P-Channel

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

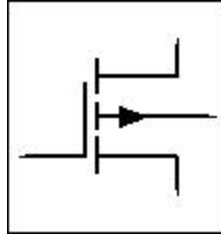


Figure 1. Component Symbol.

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Description

The Spice-compatible MESFET N-channel and MESFET P-channel models simulate the electrical and thermal behavior of a JFET using SPICE3 parameters and equations. Electrical characteristics and the temperature dependence of MESFET behavior are calculated according to user-defined device parameters.

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Assumptions and Limitations

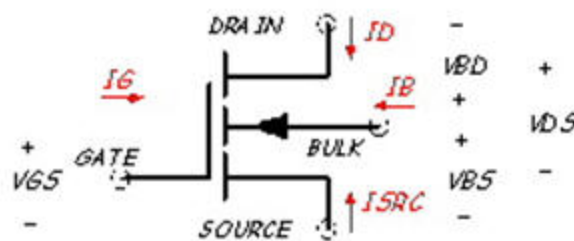


Figure 2. Current and Voltage Reference Arrow System[Top](#)**Mathematical Description**[Top](#)**Netlist Syntax**

```
UMODEL SPICE_MESFET_P ?InstanceName(@InstanceName):(@Refbase)@ID)) DRAIN:=
%0, GATE:= %1, SOURCE:= %2 ( OFF:= @OFF, AREA:= @AREA, ICDVS:= @ICVDS,
ICVGS:= @ICVGS, VTO:= @VTO, ALPHA:= @ALPHA, BETA:= @BETA, LAMBDA:=
@LAMBDA, B:= @B, RD:= @RD, RS:= @RS, CGS:= @CGS, CGD:= @CGD, PB:= @PB, IS:=
@IS, FC:= @FC, KF:= @KF, AF:= @AF) SRC: DB(Lib:=@ModelLibraryName) ;
```

[Top](#)**Conservative Pins****Table 1**

Name	Description	Nature/Data Type
GATE	Gate	electrical
SOURCE	Source	electrical
DRAIN	Drain	electrical
BULK	Bulk	electrical

[Top](#)**Parameters****Table 2**

Name	Description	Data Type	Default Value [Unit]
OFF	Device initially off	boolean	0
AREA	Area factor	real	1
ICVDS	Initial D-S voltage	real	0 [V]
ICVGS	Initial G-S voltage	real	0 [V]
VTO	Pinch-off voltage	real	-2 [V]
ALPHA	Saturation voltage parameter	real	2 [1/V]
BETA	Transconductance parameter	real	2.5m [A/V ²]
LAMBDA	Channel length modulation parameter	real	0 [1/V]

B	Doping tail extending parameter	real	0.3 [1/V]
RD	Drain ohmic resistance	real	0 [W]
RS	Source ohmic resistance	real	0 [W]
CGS	G-S junction capacitance	real	0 [F]
CGD	G-D junction capacitance	real	0
PB	Gate junction potential	real	1 [V]
IS	Junction saturation current	real	10f [A]
FC	Forward bias junction fit parm.	real	0.5
KF	Flicker noise coefficient	real	0
AF	Flicker noise exponent	real	0

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
VGS	Gate-Source voltage [V]	Output	real
VGD	Gate-Drain voltage [V]	Output	real
VDS	Drain-Source voltage [V]	Output	real
ID	Drain current [A]	Output	real
IG	Gate current [A]	Output	real
ISRC	Source current [A]	Output	real
P	Power dissipated by the mesfet [W]	Output	real

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Example

Figure 3 shows application of the Spice-Compatible P-Channel and N-Channel MESFET models. The parameters of Z1 and Z2 are set to their default values; the parameters of the rest of the system are listed in Table 4 and the simulation results shown in Figure 4.

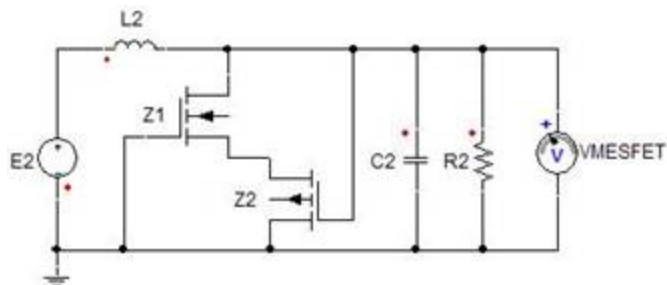


Figure 3. Application example of the Spice-Compatible N-channel and P-channel MESFET models

Table 4

Component	Parameter	Value
Voltage Source E2	EMF	-2.4 [V]
Inductor L2	L	1 [H]
	I0	0 [A]
Capacitor C2	C	1u [F]
	V0	2.4 [V]
Resistor R2	R	1m [Ohm]

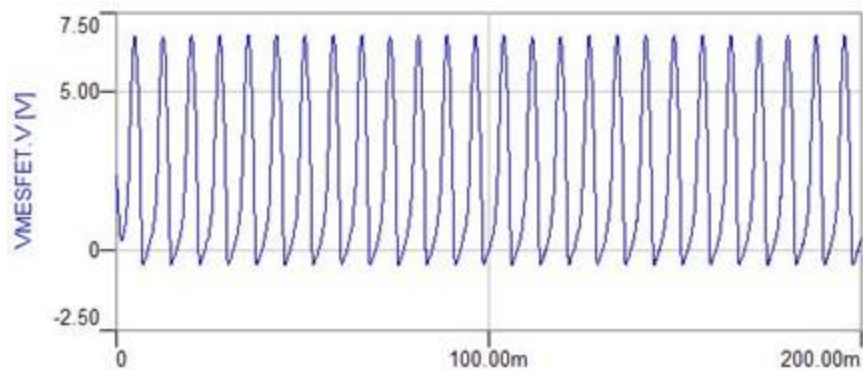


Figure 4. Simulation result

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References

[1] Massobrio, Gieseppe, and Paolo Antognetti: *Semiconductor Device Modeling with SPICE*, New York: McGraw Hill, 1993

Level 1 MOS Model - SPICE-Compatible N-Channel

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

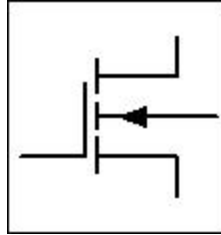


Figure 1. Component Symbol.

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Description

The Spice-Compatible Level 1 MOS N-channel and MOS P-channel models simulate the electrical and thermal behavior of MOSFETs using the parameters and equations of the SPICE3 Level 1 MOSFET model. Electrical characteristics and the temperature dependence of MOSFET behavior are calculated according to user-defined device parameters.

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Assumptions and Limitations

Figure 2 shows the current and voltage reference arrow system for this component.

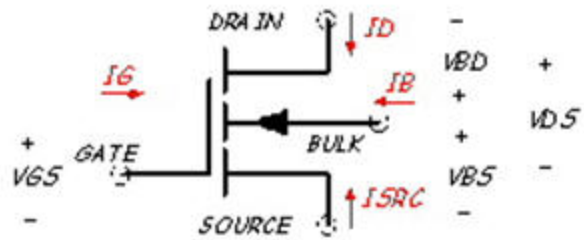


Figure 2. Current and Voltage Reference Arrow System

Mathematical Description

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Netlist Syntax

```
UMODEL SPICE_MOS1_N ?InstanceName(@InstanceName):(@ (Refbase)@(ID)) DRAIN:=
%0, GATE:= %1, SOURCE:= %2, BULK:= %3 ( L:= @L, W:= @W, AD:= @AD, AS:= @AS,
PD:= @PD, PS:= @PS, NRD:= @NRD, NRS:= @NRS, OFF:= @OFF, ICVDS:= @ICVDS,
ICVGS:= @ICVGS, ICVBS:= @ICVBS, TEMP:= @TEMP, VTO:= @VTO, KP:= @KP,
GAMMA:= @GAMMA, PHI:= @PHI, LAMBDA:= @LAMBDA, RD:= @RD, RS:= @RS, CBD:=
@CBD, CBS:= @CBS, IS:= @IS, PB:= @PB, CGSO:= @CGSO, CGDO:= @CGDO, CGBO:=
@CGBO, RSH:= @RSH, CJ:= @CJ, MJ:= @MJ \\\ , CJSW:= @CJSW, MJSW:= @MJSW, JS:=
@js, TOX:= @TOX, LD:= @LD, U0:= @U0, FC:= @FC, NSUB:= @NSUB, TPG:= @TPG,
NSS:= @NSS, TNOM:= @TNOM, KF:= @KF, AF:= @AF) SRC: DB(Lib:=@ModelLibraryName)
;
```

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
GATE	Gate	electrical
SOURCE	Source	electrical
DRAIN	Drain	electrical
BULK	Bulk	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
L	Length	real	0.1 [m]
W	Width	real	0.1 [m]
AD	Drain Area	real	0 [m ²]
AS	Source Area	real	0 [m ²]
PD	Drain Perimeter	real	0 [m]
PS	Source Perimeter	real	0 [m]
NRD	Drain squares	real	1
NRS	Source squares	real	1
OFF	Device initially off	boolean	0
ICVDS	Initial D-S voltage	real	0 [V]
ICVGS	Initial G-S voltage	real	0 [V]
ICVBS	Initial B-S voltage	real	0 [V]
TEMP	Instance temperature	real	27 [°C]
VTO	Threshold voltage	real	0 [V]
KP	Transconductance parameter	real	20u[A/V ²]
GAMMA	Bulk threshold parameter	real	0 [V ^{1/2}]
PHI	Surface potential	real	0.6 [V]
LAMBDA	Channel length modulation parameter	real	0 [V ⁻¹]
RD	Drain ohmic resistance	real	0 [Ohm]
RS	Source ohmic resistance	real	0 [Ohm]
CBD	B-D junction capacitance	real	0 [F]
CBS	B-S junction capacitance	real	0 [F]
IS	Bulk junction sat. current	real	10f [A]
PB	Bulk junction potential	real	0.8 [V]
CGSO	Gate-source overlap capacitance	real	0 [F/m]
CGDO	Gate-drain overlap capacitance	real	0 [F/m]

CGBO	Gate-bulk overlap capacitance	real	0 [F/m]
RSH	Sheet resistance	real	0 [Ohm/square]
CJ	Bottom junction capacitance per area	real	0 [F/m ²]
MJ	Bottom grading coefficient	real	0.5
CJSW	Side junction capacitance per area	real	0 [F/m]
MJSW	Side grading coefficient	real	0.5
JS	Bulk junction saturation current density	real	0 [A/m ²]
TOX	Oxide thickness	real	0 [m]
LD	Lateral diffusion	real	0 [m]
U0	Surface mobility	real	0 [cm ² /Vs]
FC	Forward bias junction fit parameter	real	0.5
NSUB	Substrate doping	real	0 [1/cm ³]
TPG	Gate type	integer	0
NSS	Surface state density	real	0 [1/cm ²]
TNOM	Parameter measurement temperature	real	27 [°C]
KF	Flicker noise coefficient	real	0
AF	Flicker noise exponent	real	0

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
ID	Drain current [A]	Output	real
ISRC	Source current [A]	Output	real
IG	Gate current [A]	Output	real
IB	Bulk current [A]	Output	real
VGS	Gate-Source voltage [V]	Output	real

VDS	Drain-Source voltage [V]	Output	real
VBS	Bulk-Source voltage [V]	Output	real
VBD	Bulk-Drain voltage [V]	Output	real
P	Instantaneous power [W]	Output	real

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Example

Figure 3 shows application of the Spice-Compatible Level 1 MOS N-channel and MOS P-channel models. The parameters of SPICE_MOS1_P1 and SPICE_MOS_N1 are set to their default values; the parameters of the rest of the system are listed in Table 4 and the simulation results shown in Figure 4.

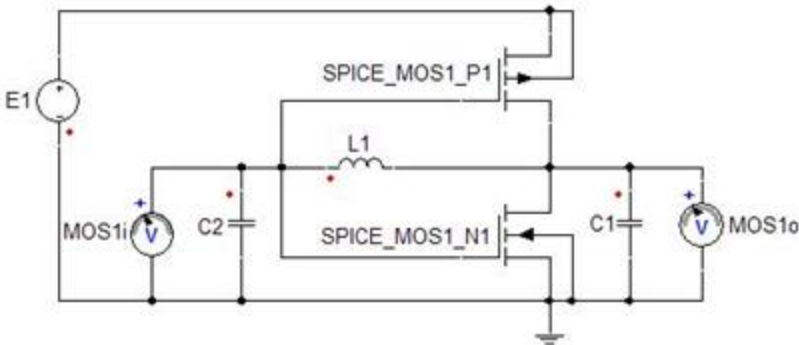


Figure 3. Application example of the Level 1 MOS N-channel and MOS P-channel models

Table 3

Component	Parameter	Value
Capacitor C2	C	100p [F]
	V0	7.5 [V]
Capacitor C1	C	100p [F]
	V0	0 [V]
Inductor L1	L	1m [H]
	I0	0 [A]
Voltage Source E1	EMF	15 [V]

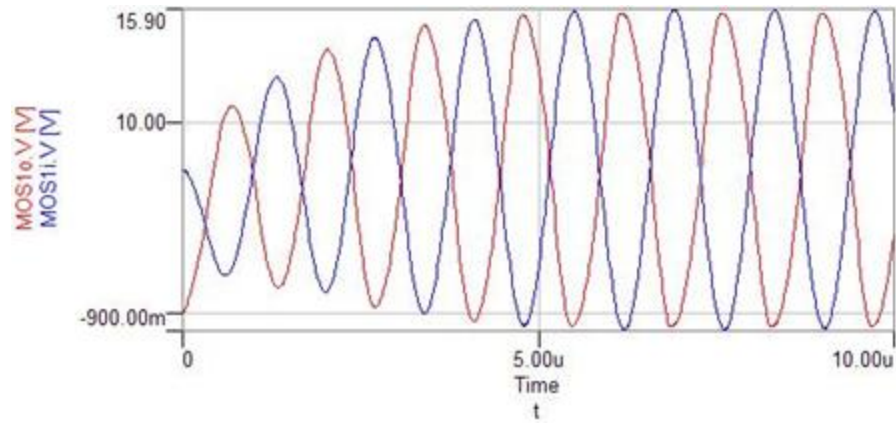


Figure 4. Simulation results-input and output voltage of SPICE_MOS_N1

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References

See also Massobrio, Giuseppe, and Paolo Antognetti: *Semiconductor Device Modeling with SPICE*, New York: McGraw Hill, 1993

Level 1 MOS Model - SPICE-Compatible P-Channel

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

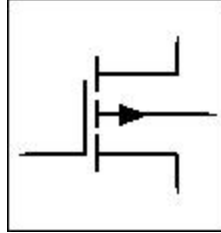


Figure 1. Component Symbol.

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Description

The Spice-Compatible MOS1 N-channel and MOS1 P-channel models simulate the electrical and thermal behavior of MOSFETs using the parameters and equations of the SPICE3 Level 1 MOSFET model. Electrical characteristics and the temperature dependence of MOSFET behavior are calculated according to user-defined device parameters.

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Assumptions and Limitations

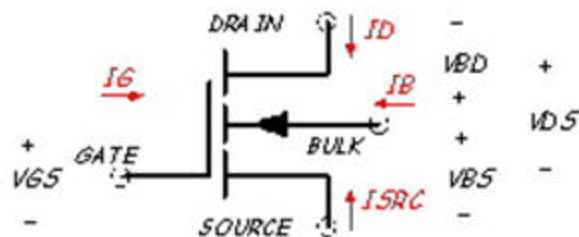


Figure 2. Current and Voltage Reference Arrow System[Top](#)**Mathematical Description**[Top](#)**Netlist Syntax**

```

UMODEL SPICE_MOS1_P ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) DRAIN:=
%0, GATE:= %1, SOURCE:= %2, BULK:= %3 ( L:= @L, W:= @W, AD:= @AD, AS:= @AS,
PD:= @PD, PS:= @PS, NRD:= @NRD, NRS:= @NRS, OFF:= @OFF, ICDVS:= @ICVDS,
ICVGS:= @ICVGS, ICDVS:= @ICVBS, TEMP:= @TEMP, VTO:= @VTO, KP:= @KP,
GAMMA:= @GAMMA, PHI:= @PHI, LAMBDA:= @LAMBDA, RD:= @RD, RS:= @RS, CBD:=
@CBD, CBS:= @CBS, IS:= @IS, PB:= @PB, CGSO:= @CGSO, CGDO:= @CGDO, CGBO:=
@CGBO, RSH:= @RSH, CJ:= @CJ, MJ:= @MJ \\\ , CJSW:= @CJSW, MJSW:= @MJSW, JS:=
@JS, TOX:= @TOX, LD:= @LD, U0:= @U0, FC:= @FC, NSUB:= @NSUB, TPG:= @TPG,
NSS:= @NSS, TNOM:= @TNOM, KF:= @KF, AF:= @AF) SRC: DB(Lib:=@ModelLibraryName)
;

```

[Top](#)**Conservative Pins****Table 1**

Name	Description	Nature/Data Type
GATE	Gate	electrical
SOURCE	Source	electrical
DRAIN	Drain	electrical
BULK	Bulk	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
L	Length	real	0.1 [m]
W	Width	real	0.1 [m]
AD	Drain Area	real	0 [m ²]
AS	Source Area	real	0 [m ²]
PD	Drain Perimeter	real	0 [m]
PS	Source Perimeter	real	0 [m]
NRD	Drain squares	real	1
NRS	Source squares	real	1
OFF	Device initially off	boolean	0
ICVDS	Initial D-S voltage	real	0 [V]
ICVGS	Initial G-S voltage	real	0 [V]
ICVBS	Initial B-S voltage	real	0 [V]
TEMP	Instance temperature	real	27 [°C]
VTO	Threshold voltage	real	0 [V]
KP	Transconductance parameter	real	20u[A/V ²]
GAMMA	Bulk threshold parameter	real	0 [V ^{1/2}]
PHI	Surface potential	real	0.6 [V]
LAMBDA	Channel length modulation parameter	real	0 [V ⁻¹]
RD	Drain ohmic resistance	real	0 [Ohm]
RS	Source ohmic resistance	real	0 [Ohm]
CBD	B-D junction capacitance	real	0 [F]
CBS	B-S junction capacitance	real	0 [F]
IS	Bulk junction sat. current	real	10f [A]
PB	Bulk junction potential	real	0.8 [V]
CGSO	Gate-source overlap capacitance	real	0 [F/m]
CGDO	Gate-drain overlap capacitance	real	0 [F/m]

CGBO	Gate-bulk overlap capacitance	real	0 [F/m]
RSH	Sheet resistance	real	0 [Ohm/square]
CJ	Bottom junction capacitance per area	real	0 [F/m ²]
MJ	Bottom grading coefficient	real	0.5
CJSW	Side junction capacitance per area	real	0 [F/m]
MJSW	Side grading coefficient	real	0.5
JS	Bulk junction saturation current density	real	0 [A/m ²]
TOX	Oxide thickness	real	0 [m]
LD	Lateral diffusion	real	0 [m]
U0	Surface mobility	real	0 [cm ² /Vs]
FC	Forward bias junction fit parameter	real	0.5
NSUB	Substrate doping	real	0 [1/cm ³]
TPG	Gate type	integer	0
NSS	Surface state density	real	0 [1/cm ²]
TNOM	Parameter measurement temperature	real	27 [°C]
KF	Flicker noise coefficient	real	0
AF	Flicker noise exponent	real	0

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
ID	Drain current [A]	Output	real
ISRC	Source current [A]	Output	real
IG	Gate current [A]	Output	real
IB	Bulk current [A]	Output	real
VGS	Gate-Source voltage [V]	Output	real

VDS	Drain-Source voltage [V]	Output	real
VBS	Bulk-Source voltage [V]	Output	real
VBD	Bulk-Drain voltage [V]	Output	real
P	Instantaneous power [W]	Output	real

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Example

Figure 3 shows application of the Spice-Compatible Level 1 MOS N-channel and MOS P-channel models. The parameters of SPICE_MOS1_P1 and SPICE_MOS1_N1 are set to their default values; the parameters of the rest of the system are listed in Table 4 and the simulation results shown in Figure 4.

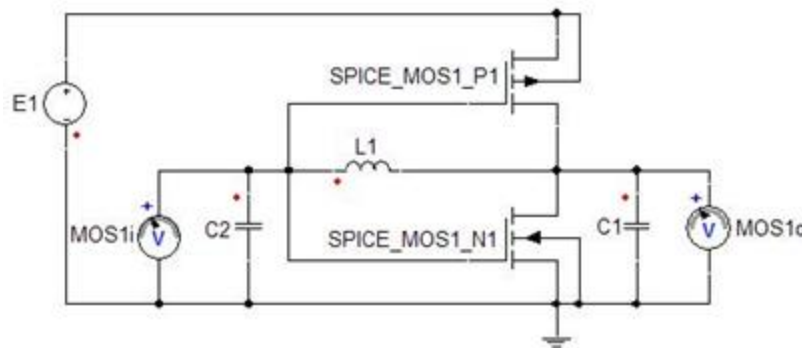


Figure 3. Application example of the Level 1 MOS N-channel and MOS P-channel models

Table 3

Component	Parameter	Value
Capacitor C2	C	100p [F]
	V0	7.5 [V]
Capacitor C1	C	100p [F]
	V0	0 [V]
Inductor L1	L	1m [H]
	I0	0 [A]
Voltage Source E1	EMF	15 [V]

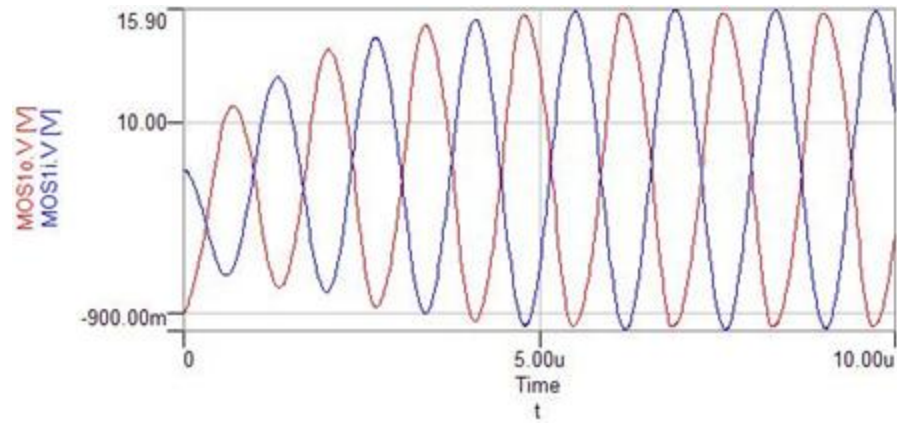


Figure 4. Simulation results-input and output voltage of SPICE_MOS1_N1

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References

See also Massobrio, Giuseppe, and Paolo Antognetti: *Semiconductor Device Modeling with SPICE*, New York: McGraw Hill, 1993

Level 2 MOS Model - SPICE-Compatible N-Channel

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

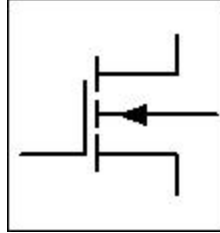


Figure 1. Component Symbol.

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- [Assumptions and Limitations](#)
- [Mathematical Description](#)
- [Netlist Syntax](#)
- [Conservative Pins](#)
- [Parameters](#)
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Description

The Spice-Compatible MOS2 N-channel and MOS2 P-channel models simulate the electrical and thermal behavior of MOSFETs using the parameters and equations of the SPICE3 Level 2 MOSFET model. Electrical characteristics and the temperature dependence of MOSFET behavior are calculated according to user-defined device parameters.

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Assumptions and Limitations

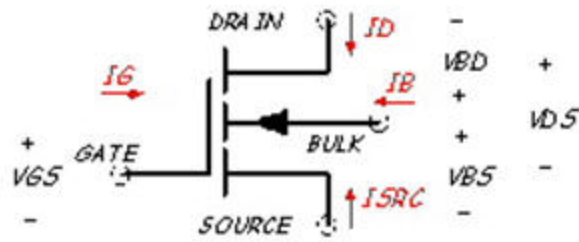


Figure 2. Current and Voltage Reference Arrow System

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Mathematical Description

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Netlist Syntax

```
UMODEL SPICE_MOS2_N ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) DRAIN:=
%0, GATE:= %1, SOURCE:= %2, BULK:= %3 ( L:= @L, W:= @W, AD:= @AD, AS:= @AS,
PD:= @PD, PS:= @PS, NRD:= @NRD, NRS:= @NRS, OFF:= @OFF, ICDVS:= @ICVDS,
ICVGS:= @ICVGS, ICDVS:= @ICVBS, TEMP:= @TEMP, VTO:= @VTO, KP:= @KP,
GAMMA:= @GAMMA, PHI:= @PHI, LAMBDA:= @LAMBDA, RD:= @RD, RS:= @RS, CBD:=
@CBD, CBS:= @CBS, IS:= @IS, PB:= @PB, CGSO:= @CGSO, CGDO:= @CGDO, CGBO:=
@CGBO, RSH:= @RSH, CJ:= @CJ, MJ:= @MJ \\\ , CJSW:= @CJSW, MJSW:= @MJSW, JS:=
@JS, TOX:= @TOX, LD:= @LD, U0:= @U0, FC:= @FC, NSUB:= @NSUB, TPG:= @TPG,
NSS:= @NSS, DELTA:= @DELTA, UEXP:= @UEXP, UCRIT:= @UCRIT, VMAX:= @VMAX,
XJ:= @XJ, NEFF:= @NEFF, NFS:= @NFS, TNOM:= @TNOM, KF:= @KF, AF:= @AF) SRC:
DB(Lib:=@ModelLibraryName) ;
```

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
GATE	Gate	electrical
SOURCE	Source	electrical
DRAIN	Drain	electrical
BULK	Bulk	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
L	Length	real	0.1 [m]
W	Width	real	0.1 [m]
AD	Drain Area	real	0 [m ²]
AS	Source Area	real	0 [m ²]
PD	Drain Perimeter	real	0 [m]
PS	Source Perimeter	real	0 [m]
NRD	Drain squares	real	1
NRS	Source squares	real	1
OFF	Device initially off	boolean	0
ICVDS	Initial D-S voltage	real	0 [V]
ICVGS	Initial G-S voltage	real	0 [V]
ICVBS	Initial B-S voltage	real	0 [V]
TEMP	Instance temperature	real	27 [°C]
VTO	Threshold voltage	real	0 [V]
KP	Transconductance parameter	real	20.71886279814u [A/V ²]
GAMMA	Bulk threshold parameter	real	0 [V ^{1/2}]
PHI	Surface potential	real	0.6 [V]
LAMBDA	Channel length modulation parameter	real	0 [V ⁻¹]
RD	Drain ohmic resistance	real	0 [Ohm]
RS	Source ohmic resistance	real	0 [Ohm]
CBD	B-D junction capacitance	real	0 [F]
CBS	B-S junction capacitance	real	0 [F]
IS	Bulk junction sat. current	real	10f [A]
PB	Bulk junction potential	real	0.8 [V]

CGSO	Gate-source overlap cap.	real	0 [F/m]
CGDO	Gate-drain overlap cap.	real	0 [F/m]
CGBO	Gate-bulk overlap cap.	real	0 [F/m]
RSH	Sheet resistance	real	0 [Ohm/square]
CJ	Bottom junction cap per area	real	0 [F/m ²]
MJ	Bottom grading coefficient	real	0.5
CJSW	Side junction cap per area	real	0 [F/m]
MJSW	Side grading coefficient	real	0.33
JS	Bulk junction saturation current density	real	0 [A/m ²]
TOX	Oxide thickness	real	0.1u [m]
LD	Lateral diffusion	real	0 [m]
U0	Surface mobility	real	0.6k [cm ² /Vs]
FC	Forward bias junction fit parameter	real	0.5
NSUB	Substrate doping	real	0 [1/cm ³]
TPG	Gate type	integer	0
NSS	Surface state density	real	0 [1/cm ²]
DELTA	Width Effect on Threshold	real	0
UEXP	Critical Field Exponent in Mobility Degradation	real	0
UCRIT	Critical Field for Mobility Degradation	real	10k [V/cm]
VMAX	Maximum Carrier Drift Velocity	real	0 [m/s]
XJ	Junction Depth	real	0 [m]
NEFF	Total Channel Charge Coefficient	real	1
NFS	Fast Surface State Density	real	0 [1/cm ²]
TNOM	Parameter measurement temperature	real	27 [°C]

KF	Flicker noise coefficient	real	0
AF	Flicker noise exponent	real	1

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
ID	Drain current [A]	Output	real
ISRC	Source current [A]	Output	real
IG	Gate current [A]	Output	real
IB	Bulk current [A]	Output	real
VGS	Gate-Source voltage [V]	Output	real
VDS	Drain-Source voltage [V]	Output	real
VBS	Bulk-Source voltage [V]	Output	real
VBD	Bulk-Drain voltage [V]	Output	real
P	Instantaneous power [W]	Output	real

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Example

Figure 3 shows application of the Spice-Compatible Level 2 MOS N-channel and MOS P-channel models. The parameters of SPICE_MOS2_P1 and SPICE_MOS2_N1 are set to their default values; the parameters of the rest of the system are listed in Table 4 and the simulation results shown in Figure 4.

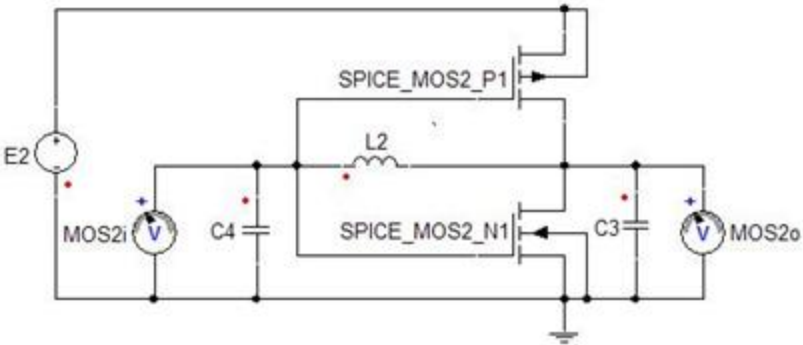


Figure 3. Application example of the Level 2 MOS N-channel and MOS P-channel models

Table 3

Component	Parameter	Value
Capacitor C4	C	100p [F]
	V0	7.5 [V]
Capacitor C3	C	100p [F]
	V0	0 [V]
Inductor L2	L	1m [H]
	I0	0 [A]
Voltage Source E2	EMF	15 [V]

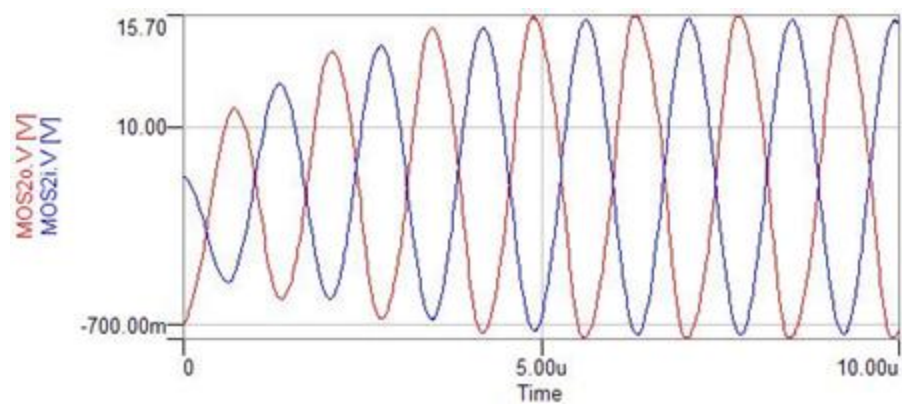


Figure 4. Simulation results-input and output voltage of SPICE_MOS2_N1

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References

See also Massobrio, Giuseppe, and Paolo Antognetti: *Semiconductor Device Modeling with SPICE*, New York: McGraw Hill, 1993

Level 2 MOS Model - SPICE-Compatible P-Channel

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

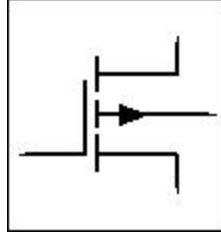


Figure 1. Component Symbol.

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- [Mathematical Description](#)
- [Netlist Syntax](#)
- [Conservative Pins](#)
- [Parameters](#)
- [Input/Output Quantities](#)
- [Example](#)
- [References](#)

Description

The Spice-Compatible MOS2 N-channel and MOS2 P-channel models simulate the electrical and thermal behavior of MOSFETs using the parameters and equations of the SPICE3 Level 2 MOSFET model. Electrical characteristics and the temperature dependence of MOSFET behavior are calculated according to user-defined device parameters.

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Assumptions and Limitations

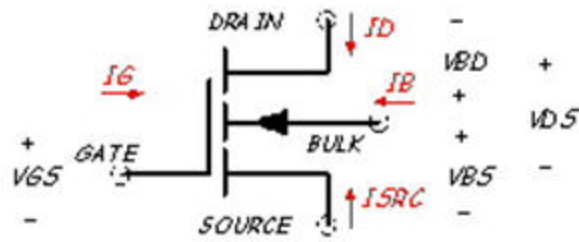


Figure 2. Current and Voltage Reference Arrow System

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Mathematical Description

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Netlist Syntax

```
UMODEL SPICE_MOS2_P ?InstanceName(@InstanceName):(@ (Refbase)@(ID)) DRAIN:=
%0, GATE:= %1, SOURCE:= %2, BULK:= %3 ( L:= @L, W:= @W, AD:= @AD, AS:= @AS,
PD:= @PD, PS:= @PS, NRD:= @NRD, NRS:= @NRS, OFF:= @OFF, ICDVS:= @ICVDS,
ICVGS:= @ICVGS, ICDVS:= @ICVBS, TEMP:= @TEMP, VTO:= @VTO, KP:= @KP,
GAMMA:= @GAMMA, PHI:= @PHI, LAMBDA:= @LAMBDA, RD:= @RD, RS:= @RS, CBD:=
@CBD, CBS:= @CBS, IS:= @IS, PB:= @PB, CGSO:= @CGSO, CGDO:= @CGDO, CGBO:=
@CGBO, RSH:= @RSH, CJ:= @CJ, MJ:= @MJ \\\ , CJSW:= @CJSW, MJSW:= @MJSW, JS:=
@JS, TOX:= @TOX, LD:= @LD, U0:= @U0, FC:= @FC, NSUB:= @NSUB, TPG:= @TPG,
NSS:= @NSS, DELTA:= @DELTA, UEXP:= @UEXP, UCRIT:= @UCRIT, VMAX:= @VMAX,
XJ:= @XJ, NEFF:= @NEFF, NFS:= @NFS, TNOM:= @TNOM, KF:= @KF, AF:= @AF) SRC:
DB(Lib:=@ModelLibraryName) ;
```

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
GATE	Gate	electrical
SOURCE	Source	electrical
DRAIN	Drain	electrical
BULK	Bulk	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
L	Length	real	0.1 [m]
W	Width	real	0.1 [m]
AD	Drain Area	real	0 [m ²]
AS	Source Area	real	0 [m ²]
PD	Drain Perimeter	real	0 [m]
PS	Source Perimeter	real	0 [m]
NRD	Drain squares	real	1
NRS	Source squares	real	1
OFF	Device initially off	boolean	0
ICVDS	Initial D-S voltage	real	0 [V]
ICVGS	Initial G-S voltage	real	0 [V]
ICVBS	Initial B-S voltage	real	0 [V]
TEMP	Instance temperature	real	27 [°C]
VTO	Threshold voltage	real	0 [V]
KP	Transconductance parameter	real	20.71886279814u [A/V ²]
GAMMA	Bulk threshold parameter	real	0 [V ^{1/2}]
PHI	Surface potential	real	0.6 [V]
LAMBDA	Channel length modulation parameter	real	0 [V ⁻¹]
RD	Drain ohmic resistance	real	0 [Ohm]
RS	Source ohmic resistance	real	0 [Ohm]
CBD	B-D junction capacitance	real	0 [F]
CBS	B-S junction capacitance	real	0 [F]
IS	Bulk junction sat. current	real	10f [A]
PB	Bulk junction potential	real	0.8 [V]

CGSO	Gate-source overlap cap.	real	0 [F/m]
CGDO	Gate-drain overlap cap.	real	0 [F/m]
CGBO	Gate-bulk overlap cap.	real	0 [F/m]
RSH	Sheet resistance	real	0 [Ohm/square]
CJ	Bottom junction cap per area	real	0 [F/m ²]
MJ	Bottom grading coefficient	real	0.5
CJSW	Side junction cap per area	real	0 [F/m]
MJSW	Side grading coefficient	real	0.33
JS	Bulk junction saturation current density	real	0 [A/m ²]
TOX	Oxide thickness	real	0.1u [m]
LD	Lateral diffusion	real	0 [m]
U0	Surface mobility	real	0.6k [cm ² /Vs]
FC	Forward bias junction fit parameter	real	0.5
NSUB	Substrate doping	real	0 [1/cm ³]
TPG	Gate type	integer	0
NSS	Surface state density	real	0 [1/cm ²]
DELTA	Width Effect on Threshold	real	0
UEXP	Critical Field Exponent in Mobility Degradation	real	0
UCRIT	Critical Field for Mobility Degradation	real	10k [V/cm]
VMAX	Maximum Carrier Drift Velocity	real	0 [m/s]
XJ	Junction Depth	real	0 [m]
NEFF	Total Channel Charge Coefficient	real	1
NFS	Fast Surface State Density	real	0 [1/cm ²]
TNOM	Parameter measurement temperature	real	27 [°C]

KF	Flicker noise coef- ficient	real	0
AF	Flicker noise expo- nent	real	1

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
ID	Drain current [A]	Output	real
ISRC	Source current [A]	Output	real
IG	Gate current [A]	Output	real
IB	Bulk current [A]	Output	real
VGS	Gate-Source voltage [V]	Output	real
VDS	Drain-Source voltage [V]	Output	real
VBS	Bulk-Source voltage [V]	Output	real
VBD	Bulk-Drain voltage [V]	Output	real
P	Instantaneous power [W]	Output	real

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Example

Figure 3 shows application of the Spice-Compatible Level 2 MOS N-channel and MOS P-channel models. The parameters of SPICE_MOS2_P1 and SPICE_MOS2_N1 are set to their default values; the parameters of the rest of the system are listed in Table 4 and the simulation results shown in Figure 4.

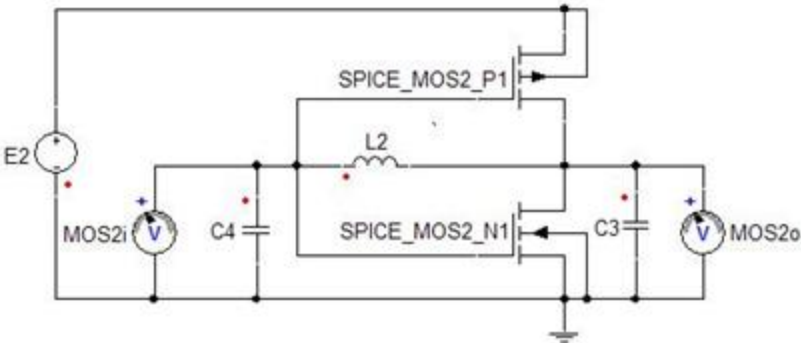


Figure 3. Application example of the Level 2 MOS N-channel and MOS P-channel models

Table 3

Component	Parameter	Value
Capacitor C4	C	100p [F]
	V0	7.5 [V]
Capacitor C3	C	100p [F]
	V0	0 [V]
Inductor L2	L	1m [H]
	I0	0 [A]
Voltage Source E2	EMF	15 [V]

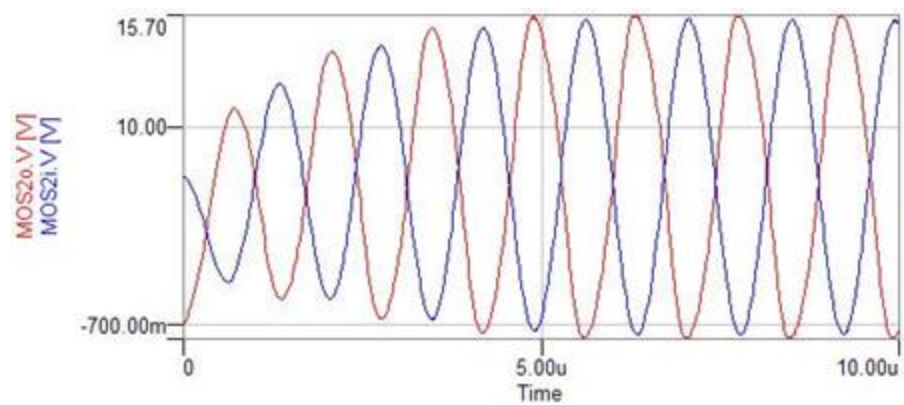


Figure 4. Simulation results-input and output voltage of SPICE_MOS2_N1

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References

See also Massobrio, Giuseppe, and Paolo Antognetti: *Semiconductor Device Modeling with SPICE*, New York: McGraw Hill, 1993

Level 3 MOS Model - SPICE-Compatible N-Channel

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

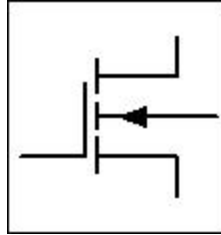


Figure 1. Component Symbol.

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- [Netlist Syntax](#)
- [Conservative Pins](#)
- [Parameters](#)
- [Input/Output Quantities](#)
- [Example](#)
- [References](#)

Description

The Spice-Compatible MOS3 N-channel and MOS3 P-channel models simulate the electrical and thermal behavior of MOSFETs using the parameters and equations of the SPICE3 Level 3 MOSFET model. Electrical characteristics and the temperature dependence of MOSFET behavior are calculated according to user-defined device parameters.

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Assumptions and Limitations

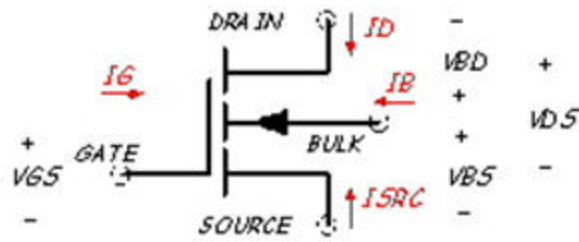


Figure 2. Current and Voltage Reference Arrow System

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Mathematical Description

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Netlist Syntax

```
UMODEL SPICE_MOS3_N ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) DRAIN:=
%0, GATE:= %1, SOURCE:= %2, BULK:= %3 ( L:= @L, W:= @W, AD:= @AD, AS:= @AS,
PD:= @PD, PS:= @PS, NRD:= @NRD, NRS:= @NRS, OFF:= @OFF, ICDVS:= @ICVDS,
ICVGS:= @ICVGS, ICDVS:= @ICVBS, TEMP:= @TEMP, VTO:= @VTO, KP:= @KP,
GAMMA:= @GAMMA, PHI:= @PHI, RD:= @RD, RS:= @RS, CBD:= @CBD, CBS:= @CBS,
IS:= @IS, PB:= @PB, CGSO:= @CGSO, CGDO:= @CGDO, CGBO:= @CGBO, RSH:= @RSH,
CJ:= @CJ, MJ:= @MJ, CJSW:= @CJSW \\\ , MJSW:= @MJSW, JS:= @JS, TOX:= @TOX,
LD:= @LD, U0:= @U0, FC:= @FC, NSUB:= @NSUB, TPG:= @TPG, NSS:= @NSS, VMAX:=
@VMAX, XJ:= @XJ, NFS:= @NFS, XD:= @XD, ALPHA:= @ALPHA, ETA:= @ETA, DELTA:=
@DELTA, THETA:= @THETA, KAPPA:= @KAPPA, TNOM:= @TNOM, KF:= @KF, AF:= @AF)
SRC: DB(Lib:=@ModelLibraryName) ;
```

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
GATE	Gate	electrical
SOURCE	Source	electrical
DRAIN	Drain	electrical
BULK	Bulk	electrical

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Table 2

Name	Description	Data Type	Default Value [Unit]
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PS	Source Perimeter	real	0 [m]
NRD	Drain squares	real	1
NRS	Source squares	real	1
OFF	Device initially off	boolean	0
ICVDS	Initial D-S voltage	real	0 [V]
ICVGS	Initial G-S voltage	real	0 [V]
ICVBS	Initial B-S voltage	real	0 [V]
TEMP	Instance temperature	real	27 [°C]
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KP	Transconductance parameter	real	20.71886279814u [A/V ²]
GAMMA	Bulk threshold parameter	real	0 [V ^{1/2}]
PHI	Surface potential	real	0.6 [V]
RD	Drain ohmic resistance	real	0 [Ohm]
RS	Source ohmic resistance	real	0 [Ohm]
CBD	B-D junction capacitance	real	0 [F]
CBS	B-S junction capacitance	real	0 [F]
IS	Bulk junction sat. current	real	10f [A]
PB	Bulk junction potential	real	0.8 [V]
CGSO	Gate-source overlap capacitance	real	0 [F/m]

CGDO	Gate-drain overlap capacitance	real	0 [F/m]
CGBO	Gate-bulk overlap capacitance	real	0 [F/m]
RSH	Sheet resistance	real	0 [Ohm/square]
CJ	Bottom junction capacitance per area	real	0 [F/m ²]
MJ	Bottom grading coefficient	real	0.5
CJSW	Side junction cap per area	real	0 [F/m]
MJSW	Side grading coefficient	real	0.33
JS	Bulk junction saturation current density	real	0 [A/m ²]
TOX	Oxide thickness	real	0.1u [m]
LD	Lateral diffusion	real	0 [m]
U0	Surface mobility	real	0.6k [cm ² /Vs]
FC	Forward bias junction fit parameter	real	0.5
NSUB	Substrate doping	real	0 [1/cm ³]
TPG	Gate type	integer	0
NSS	Surface state density	real	0 [1/cm ²]
VMAX	Maximum Carrier Drift Velocity	real	0 [m/s]
XJ	Junction Depth	real	0 [m]
NFS	Fast Surface State Density	real	0 [1/cm ²]
XD	Depletion Layer Width	real	0 [m]
ALPHA	Alpha	real	0
ETA	Static Feedback	real	0 [V]
DELTA	Width Effect on Threshold Voltage	real	0
THETA	Mobility Modulation	real	0 [V ⁻¹]
KAPPA	Saturation Field Factor	real	0.2
TNOM	Parameter measurement temperature	real	27 [°C]

KF	Flicker noise coefficient	real	0
AF	Flicker Noise Exponent	real	0

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
ID	Drain current [A]	Output	real
ISRC	Source current [A]	Output	real
IG	Gate current [A]	Output	real
IB	Bulk current [A]	Output	real
VGS	Gate-Source voltage [V]	Output	real
VDS	Drain-Source voltage [V]	Output	real
VBS	Bulk-Source voltage [V]	Output	real
VBD	Bulk-Drain voltage [V]	Output	real
P	Instantaneous power [W]	Output	real

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Example

Figure 3 shows application of the Spice-Compatible Level 3 MOS N-channel and MOS P-channel models. The parameters of SPICE_MOS3_P1 and SPICE_MOS3_N1 are set to their default values; the parameters of the rest of the system are listed in Table 4 and the simulation results shown in Figure 4.

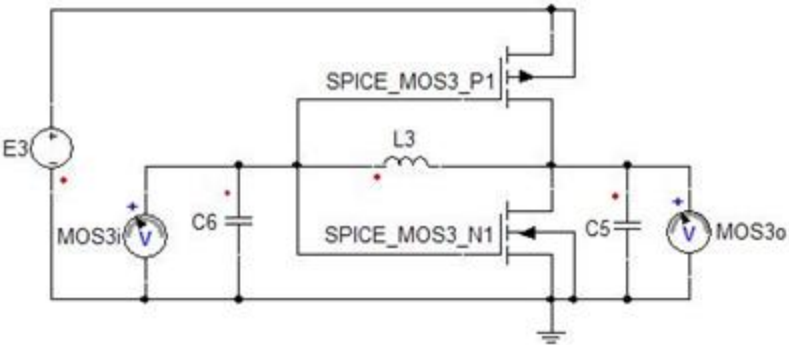


Figure 3. Application example of the Level 3 MOS N-channel and MOS P-channel models

Table 3

Component	Parameter	Value
Capacitor C6	C	100p [F]
	V0	7.5 [V]
Capacitor C5	C	100p [F]
	V0	0 [V]
Inductor L3	L	1m [H]
	I0	0 [A]
Voltage Source E3	EMF	15 [V]

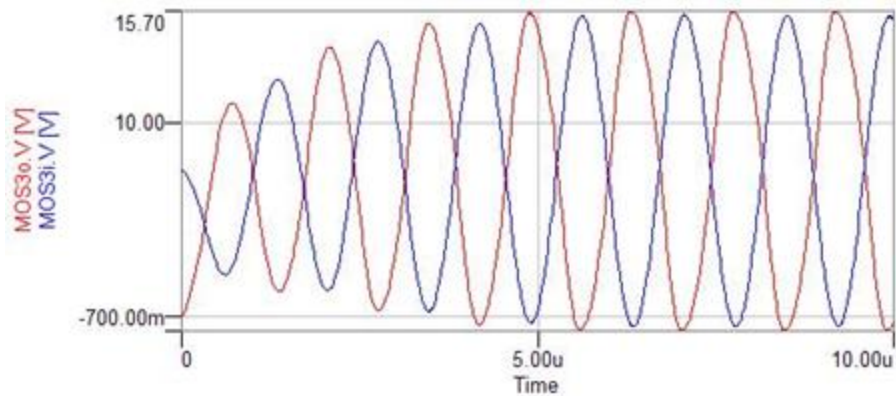


Figure 4. Simulation results-input and output voltage of SPICE_MOS3_N1

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References

See also Massobrio, Giusseppe, and Paolo Antognetti: *Semiconductor Device Modeling with SPICE*, New York: McGraw Hill, 1993

Level 3 MOS Model - SPICE-Compatible P-Channel

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

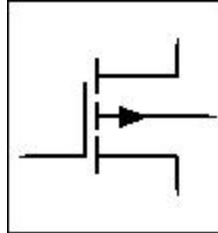


Figure 1. Component Symbol.

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- [Assumptions and Limitations](#)
- [Mathematical Description](#)
- [Netlist Syntax](#)
- [Conservative Pins](#)
- [Parameters](#)
- [Input/Output Quantities](#)
- [Example](#)
- [References](#)

Description

The Spice-Compatible MOS3 N-channel and MOS3 P-channel models simulate the electrical and thermal behavior of MOSFETs using the parameters and equations of the SPICE3 Level 3 MOSFET model. Electrical characteristics and the temperature dependence of MOSFET behavior are calculated according to user-defined device parameters.

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Assumptions and Limitations

Figure 2 shows the current and voltage reference arrow system for this component.

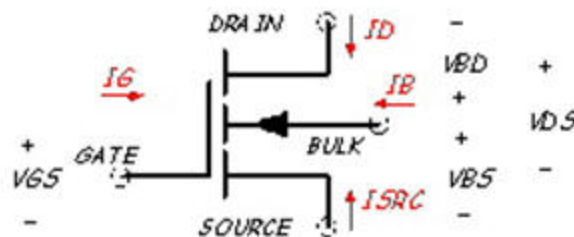


Figure 2. Current and Voltage Reference Arrow System[Top](#)**Mathematical Description**[Top](#)**Netlist Syntax**

```

UMODEL SPICE_MOS3_P ?InstanceName(@InstanceName):(@Refbase)@(ID)) DRAIN:=
%0, GATE:= %1, SOURCE:= %2, BULK:= %3 ( L:= @L, W:= @W, AD:= @AD, AS:= @AS,
PD:= @PD, PS:= @PS, NRD:= @NRD, NRS:= @NRS, OFF:= @OFF, ICVDS:= @ICVDS,
ICVGS:= @ICVGS, ICVBS:= @ICVBS, TEMP:= @TEMP, VTO:= @VTO, KP:= @KP,
GAMMA:= @GAMMA, PHI:= @PHI, RD:= @RD, RS:= @RS, CBD:= @CBD, CBS:= @CBS,
IS:= @IS, PB:= @PB, CGSO:= @CGSO, CGDO:= @CGDO, CGBO:= @CGBO, RSH:= @RSH,
CJ:= @CJ, MJ:= @MJ, CJSW:= @CJSW \\\ , MJSW:= @MJSW, JS:= @JS, TOX:= @TOX,
LD:= @LD, U0:= @U0, FC:= @FC, NSUB:= @NSUB, TPG:= @TPG, NSS:= @NSS, VMAX:=
@VMAX, XJ:= @XJ, NFS:= @NFS, XD:= @XD, ALPHA:= @ALPHA, ETA:= @ETA, DELTA:=
@DELTA, THETA:= @THETA, KAPPA:= @KAPPA, TNOM:= @TNOM, KF:= @KF, AF:= @AF)
SRC: DB(Lib:=@ModelLibraryName) ;

```

[Top](#)**Conservative Pins****Table 1**

Name	Description	Nature/Data Type
GATE	Gate	electrical
SOURCE	Source	electrical
DRAIN	Drain	electrical
BULK	Bulk	electrical

[Top](#)**Parameters****Table 2**

Name	Description	Data Type	Default Value [Unit]
L	Length	real	0.1 [m]
W	Width	real	0.1 [m]
AD	Drain Area	real	0 [m ²]
AS	Source Area	real	0 [m ²]
PD	Drain Perimeter	real	0 [m]

PS	Source Perimeter	real	0 [m]
NRD	Drain squares	real	1
NRS	Source squares	real	1
OFF	Device initially off	boolean	0
ICVDS	Initial D-S voltage	real	0 [V]
ICVGS	Initial G-S voltage	real	0 [V]
ICVBS	Initial B-S voltage	real	0 [V]
TEMP	Instance temperature	real	27 [°C]
VTO	Threshold voltage	real	0 [V]
KP	Transconductance parameter	real	20.71886279814u [A/V ²]
GAMMA	Bulk threshold parameter	real	0 [V ^{1/2}]
PHI	Surface potential	real	0.6 [V]
RD	Drain ohmic resistance	real	0 [Ohm]
RS	Source ohmic resistance	real	0 [Ohm]
CBD	B-D junction capacitance	real	0 [F]
CBS	B-S junction capacitance	real	0 [F]
IS	Bulk junction sat. current	real	10f [A]
PB	Bulk junction potential	real	0.8 [V]
CGSO	Gate-source overlap capacitance	real	0 [F/m]
CGDO	Gate-drain overlap capacitance	real	0 [F/m]
CGBO	Gate-bulk overlap capacitance	real	0 [F/m]
RSH	Sheet resistance	real	0 [Ohm/square]
CJ	Bottom junction capacitance per area	real	0 [F/m ²]
MJ	Bottom grading coefficient	real	0.5
CJSW	Side junction cap per area	real	0 [F/m]
MJSW	Side grading coefficient	real	0.33

JS	Bulk junction saturation current density	real	0 [A/m ²]
TOX	Oxide thickness	real	0.1u [m]
LD	Lateral diffusion	real	0 [m]
U0	Surface mobility	real	0.6k [cm ² /Vs]
FC	Forward bias junction fit parameter	real	0.5
NSUB	Substrate doping	real	0 [1/cm ³]
TPG	Gate type	integer	0
NSS	Surface state density	real	0 [1/cm ²]
VMAX	Maximum Carrier Drift Velocity	real	0 [m/s]
XJ	Junction Depth	real	0 [m]
NFS	Fast Surface State Density	real	0 [1/cm ²]
XD	Depletion Layer Width	real	0 [m]
ALPHA	Alpha	real	0
ETA	Static Feedback	real	0 [V]
DELTA	Width Effect on Threshold Voltage	real	0
THETA	Mobility Modulation	real	0 [V ⁻¹]
KAPPA	Saturation Field Factor	real	0.2
TNOM	Parameter measurement temperature	real	27 [°C]
KF	Flicker noise coefficient	real	0
AF	Flicker Noise Exponent	real	0

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
ID	Drain current [A]	Output	real

ISRC	Source current [A]	Output	real
IG	Gate current [A]	Output	real
IB	Bulk current [A]	Output	real
VGS	Gate-Source voltage [V]	Output	real
VDS	Drain-Source voltage [V]	Output	real
VBS	Bulk-Source voltage [V]	Output	real
VBD	Bulk-Drain voltage [V]	Output	real
P	Instantaneous power [W]	Output	real

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Example

Figure 3 shows application of the Spice-Compatible Level 3 MOS N-channel and MOS P-channel models. The parameters of SPICE_MOS3_P1 and SPICE_MOS3_N1 are set to their default values; the parameters of the rest of the system are listed in Table 4 and the simulation results shown in Figure 4.

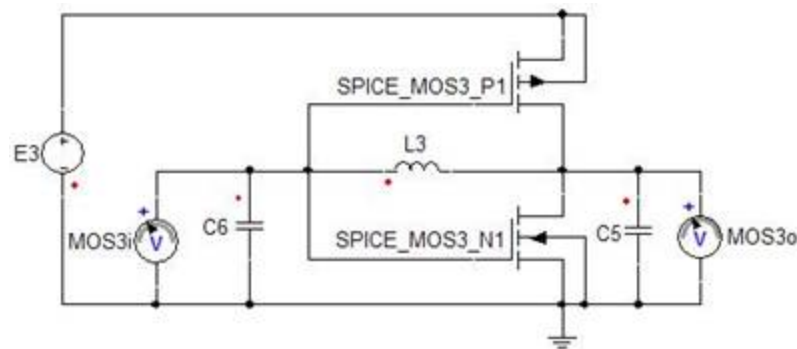


Figure 3. Application example of the Level 3 MOS N-channel and MOS P-channel models

Table 4

Component	Parameter	Value
Capacitor C6	C	100p [F]
	V0	7.5 [V]
Capacitor C5	C	100p [F]
	V0	0 [V]
Inductor L3	L	1m [H]
	I0	0 [A]
Voltage Source E3	EMF	15 [V]

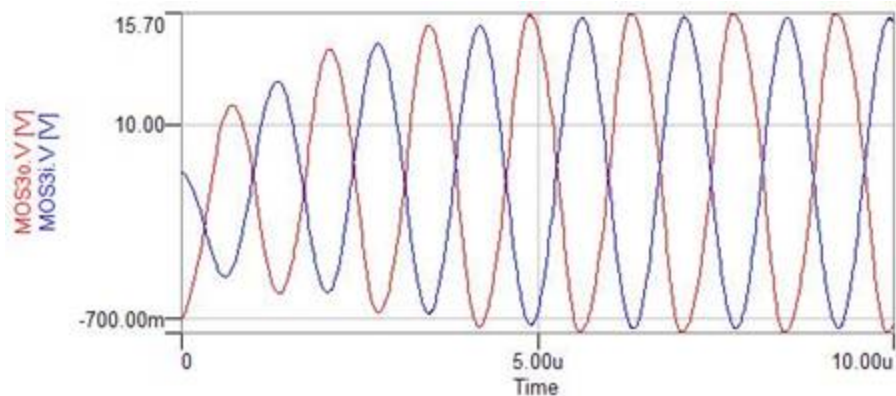


Figure 4. Simulation results-input and output voltage of SPICE_MOS3_N1

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References

[1]Massobrio, Giueseppe, and Paolo Antognetti: *Semiconductor Device Modeling with SPICE*, New York: McGraw Hill, 1993

Level 6 MOS Model - SPICE-Compatible N-Channel

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

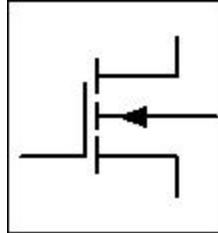


Figure 1. Component Symbol.

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- [Netlist Syntax](#)
- [Conservative Pins](#)
- [Parameters](#)
- [Input/Output Quantities](#)
- [Example](#)
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Description

The Spice-Compatible MOS6 N-channel and MOS6 P-channel models simulate the electrical and thermal behavior of MOSFETs using the parameters and equations of the SPICE3 Level 6 MOSFET model. Electrical characteristics and the temperature dependence of MOSFET behavior are calculated according to user-defined device parameters.

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Assumptions and Limitations

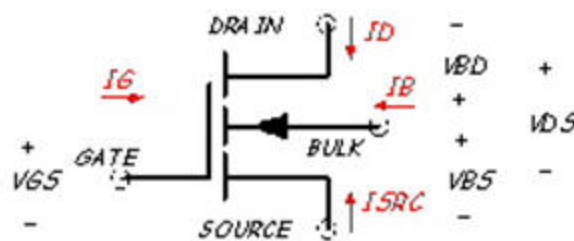


Figure 2. Current and Voltage Reference Arrow System[Top](#)**Mathematical Description**[Top](#)**Netlist Syntax**

```

UMODEL SPICE_MOS6_N ?InstanceName(@InstanceName):(@Refbase)@(ID)) DRAIN:=
%0, GATE:= %1, SOURCE:= %2, BULK:= %3 ( L:= @L, W:= @W, AD:= @AD, AS:= @AS,
PER_D:= @PER_D, PER_S:= @PER_S, NRD:= @NRD, NRS:= @NRS, OFF:= @OFF,
ICVDS:= @ICVDS, ICVGS:= @ICVGS, ICVBS:= @ICVBS, TEMP:= @TEMP, VTO:= @VTO,
KV:= @KV, NV:= @NV, KC:= @KC, NC:= @NC, NVTH:= @NVTH, PS:= @PS, GAMMA:=
@GAMMA, GAMMA1:= @GAMMA1, SIGMA:= @SIGMA, PHI:= @PHI, LAMBDA:=
@LAMBDA, LAMBDA0:= @LAMBDA0, LAMBDA1:= @LAMBDA1, RD:= @RD, RS:= @RS,
CBD:= @CBD \\\ , CBS:= @CBS, IS:= @IS, PB:= @PB, CGSO:= @CGSO, CGDO:= @CGDO,
CGBO:= @CGBO, RSH:= @RSH, CJ:= @CJ, MJ:= @MJ, CJSW:= @CJSW, MJSW:=
@MJSW, JS:= @JS, LD:= @LD, TOX:= @TOX, U0:= @U0, FC:= @FC, TPG:= @TPG,
NSUB:= @NSUB, NSS:= @NSS, TNOM:= @TNOM) SRC: DB(Lib:=@ModelLibraryName) ;

```

[Top](#)**Conservative Pins****Table 1**

Name	Description	Nature/Data Type
GATE	Gate	electrical
SOURCE	Source	electrical
DRAIN	Drain	electrical
BULK	Bulk	electrical

[Top](#)**Parameters****Table 2**

Name	Description	Data Type	Default Value [Unit]
L	Length	real	0.1 [m]
W	Width	real	0.1 [m]
AD	Drain Area	real	0 [m ²]
AS	Source Area	real	0 [m ²]
PER_D	Drain Perimeter	real	0 [m]

PER_S	Source Perimeter	real	0 [m]
NRD	Drain squares	real	0
NRS	Source squares	real	0
OFF	Device initially off	boolean	0
ICVDS	Initial D-S voltage	real	0 [V]
ICVGS	Initial G-S voltage	real	0 [V]
ICVBS	Initial B-S voltage	real	0 [V]
TEMP	Instance temperature	real	27 [°C]
VTO	Threshold voltage	real	0 [V]
KV	Saturation Voltage Factor	real	2
NV	Saturation Voltage Coefficient	real	0.5
KC	Saturation Current Factor	real	50u
NC	Saturation Current Coefficient	real	1
NVTH	Threshold Voltage Coefficient	real	0.5
GAMMA	Bulk threshold parameter	real	0 [V ^{1/2}]
GAMMA1	Bulk threshold parameter 1	real	0
PHI	Surface potential	real	0.6 [V]
LAMBDA	Channel length modulation parameter	real	0 [V ⁻¹]
LAMBDA0	Channel length modulation parameter 0	real	0
LAMBDA1	Channel length modulation parameter 1	real	0
RD	Drain ohmic resistance	real	0 [Ohm]
RS	Source ohmic resistance	real	0 [Ohm]
CBD	B-D junction capacitance	real	0 [F]
CBS	B-S junction capacitance	real	0 [F]
IS	Bulk junction saturation current	real	10f
PB	Bulk junction potential	real	0.8
CGSO	Gate-source overlap capacitance	real	0 [F/m]
CGDO	Gate-drain overlap capacitance	real	0 [F/m]

CGBO	Gate-bulk overlap capacitance	real	0 [F/m]
RSH	Sheet resistance	real	0 [W/m ²]
CJ	Bottom junction capacitance per area	real	0 [F/m ²]
MJ	Bottom grading coefficient	real	0.5
CJSW	Side junction capacitance per area	real	0 [F/m]
MJSW	Side grading coefficient	real	0.5
JS	Bulk junction saturation current density	real	0 [A/m ²]
TOX	Oxide thickness	real	0 [m]
LD	Lateral diffusion	real	0 [m]
U0	Surface mobility	real	0 [cm ² /Vs]
FC	Forward bias junction fit parameter	real	0.5
NSUB	Substrate doping	real	0 [1/cm ³]
TPG	Gate type	integer	0
NSS	Surface state density	real	0 [1/cm ²]
TNOM	Parameter measurement temperature	real	0.30015k [°C]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
ID	Drain current [A]	Output	real
ISRC	Source current [A]	Output	real
IG	Gate current [A]	Output	real
IB	Bulk current [A]	Output	real
VGS	Gate-Source voltage [V]	Output	real
VDS	Drain-Source voltage [V]	Output	real
VBS	Bulk-Source voltage [V]	Output	real
VBD	Bulk-Drain voltage [V]	Output	real
P	Instantaneous power [W]	Output	real

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Example

Figure 3 shows application of the Spice-Compatible Level 6 MOS N-channel and MOS P-channel models. The parameters of SPICE_MOS6_P1 and SPICE_MOS6_N1 are set to their default values; the parameters of the rest of the system are listed in Table 4 and the simulation results shown in Figure 4.

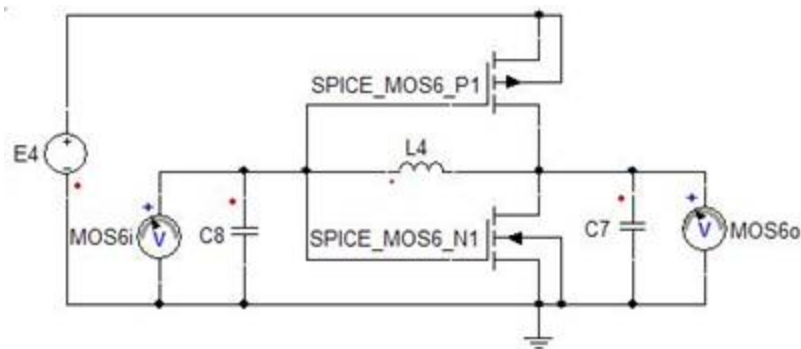


Figure 3. Application example of the Level 6 MOS N-channel and MOS P-channel models

Table 4

Component	Parameter	Value
Capacitor C8	C	100p [F]
	V0	7.5 [V]
Capacitor C7	C	100p [F]
	V0	0 [V]
Inductor L4	L	1m [H]
	I0	0 [A]
Voltage Source E3	EMF	15 [V]

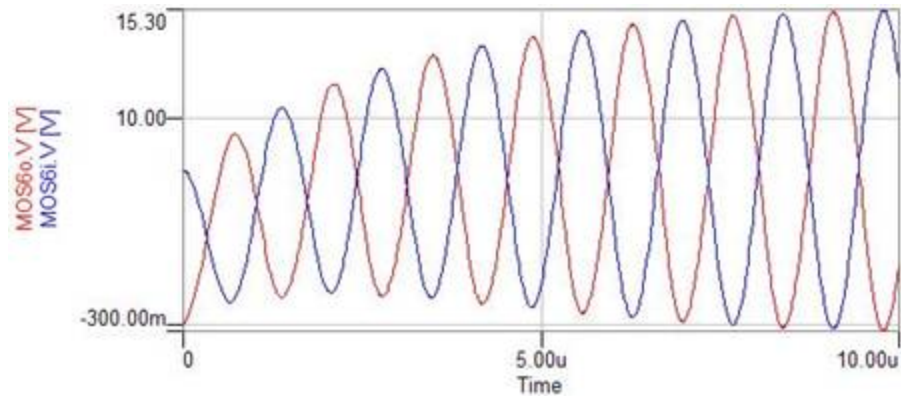


Figure 4. Simulation results-input and output voltage of SPICE_MOS6_N1

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References

[1]Massobrio, Giueseppe, and Paolo Antognetti: *Semiconductor Device Modeling with SPICE*, New York: McGraw Hill, 1993

Level 6 MOS Model - SPICE-Compatible P-Channel

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

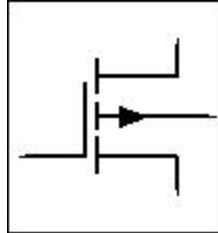


Figure 1. Component Symbol.

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- [Mathematical Description](#)
- [Netlist Syntax](#)
- [Conservative Pins](#)
- [Parameters](#)
- [Input/Output Quantities](#)
- [Example](#)
- [References](#)

Description

The Spice-Compatible MOS6 N-channel and MOS6 P-channel models simulate the electrical and thermal behavior of MOSFETs using the parameters and equations of the SPICE3 Level 6 MOSFET model. Electrical characteristics and the temperature dependence of MOSFET behavior are calculated according to user-defined device parameters.

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Assumptions and Limitations

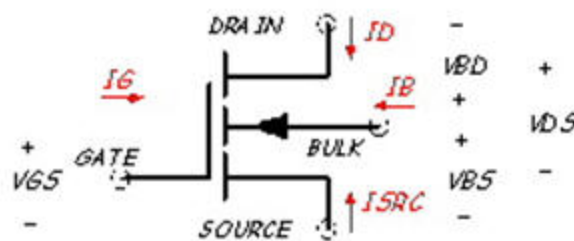


Figure 2. Current and Voltage Reference Arrow System[Top](#)**Mathematical Description**[Top](#)**Netlist Syntax**

```

UMODEL SPICE_MOS6_P ?InstanceName(@InstanceName):(@Refbase)@(ID)) DRAIN:=
%0, GATE:= %1, SOURCE:= %2, BULK:= %3 ( L:= @L, W:= @W, AD:= @AD, AS:= @AS,
PER_D:= @PER_D, PER_S:= @PER_S, NRD:= @NRD, NRS:= @NRS, OFF:= @OFF,
ICVDS:= @ICVDS, ICVGS:= @ICVGS, ICVBS:= @ICVBS, TEMP:= @TEMP, VTO:= @VTO,
KV:= @KV, NV:= @NV, KC:= @KC, NC:= @NC, NVTH:= @NVTH, PS:= @PS, GAMMA:=
@GAMMA, GAMMA1:= @GAMMA1, SIGMA:= @SIGMA, PHI:= @PHI, LAMBDA:=
@LAMBDA, LAMBDA0:= @LAMBDA0, LAMBDA1:= @LAMBDA1, RD:= @RD, RS:= @RS,
CBD:= @CBD \\\ , CBS:= @CBS, IS:= @IS, PB:= @PB, CGSO:= @CGSO, CGDO:= @CGDO,
CGBO:= @CGBO, RSH:= @RSH, CJ:= @CJ, MJ:= @MJ, CJSW:= @CJSW, MJSW:=
@MJSW, JS:= @JS, LD:= @LD, TOX:= @TOX, U0:= @U0, FC:= @FC, TPG:= @TPG,
NSUB:= @NSUB, NSS:= @NSS, TNOM:= @TNOM) SRC: DB(Lib:=@ModelLibraryName) ;

```

[Top](#)**Conservative Pins****Table 1**

Name	Description	Nature/Data Type
GATE	Gate	electrical
SOURCE	Source	electrical
DRAIN	Drain	electrical
BULK	Bulk	electrical

[Top](#)**Parameters****Table 2**

Name	Description	Data Type	Default Value [Unit]
L	Length	real	0.1 [m]
W	Width	real	0.1 [m]
AD	Drain Area	real	0 [m ²]
AS	Source Area	real	0 [m ²]
PER_D	Drain Perimeter	real	0 [m]

PER_S	Source Perimeter	real	0 [m]
NRD	Drain squares	real	0
NRS	Source squares	real	0
OFF	Device initially off	boolean	0
ICVDS	Initial D-S voltage	real	0 [V]
ICVGS	Initial G-S voltage	real	0 [V]
ICVBS	Initial B-S voltage	real	0 [V]
TEMP	Instance temperature	real	27 [°C]
VTO	Threshold voltage	real	0 [V]
KV	Saturation Voltage Factor	real	2
NV	Saturation Voltage Coefficient	real	0.5
KC	Saturation Current Factor	real	50u
NC	Saturation Current Coefficient	real	1
NVTH	Threshold Voltage Coefficient	real	0.5
GAMMA	Bulk threshold parameter	real	0 [V ^{1/2}]
GAMMA1	Bulk threshold parameter 1	real	0
PHI	Surface potential	real	0.6 [V]
LAMBDA	Channel length modulation parameter	real	0 [V ⁻¹]
LAMBDA0	Channel length modulation parameter 0	real	0
LAMBDA1	Channel length modulation parameter 1	real	0
RD	Drain ohmic resistance	real	0 [Ohm]
RS	Source ohmic resistance	real	0 [Ohm]
CBD	B-D junction capacitance	real	0 [F]
CBS	B-S junction capacitance	real	0 [F]
IS	Bulk junction saturation current	real	10f
PB	Bulk junction potential	real	0.8
CGSO	Gate-source overlap capacitance	real	0 [F/m]
CGDO	Gate-drain overlap capacitance	real	0 [F/m]

CGBO	Gate-bulk overlap capacitance	real	0 [F/m]
RSH	Sheet resistance	real	0 [W/m ²]
CJ	Bottom junction capacitance per area	real	0 [F/m ²]
MJ	Bottom grading coefficient	real	0.5
CJSW	Side junction capacitance per area	real	0 [F/m]
MJSW	Side grading coefficient	real	0.5
JS	Bulk junction saturation current density	real	0 [A/m ²]
TOX	Oxide thickness	real	0 [m]
LD	Lateral diffusion	real	0 [m]
U0	Surface mobility	real	0 [cm ² /Vs]
FC	Forward bias junction fit parameter	real	0.5
NSUB	Substrate doping	real	0 [1/cm ³]
TPG	Gate type	integer	0
NSS	Surface state density	real	0 [1/cm ²]
TNOM	Parameter measurement temperature	real	0.30015k [°C]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
ID	Drain current [A]	Output	real
ISRC	Source current [A]	Output	real
IG	Gate current [A]	Output	real
IB	Bulk current [A]	Output	real
VGS	Gate-Source voltage [V]	Output	real
VDS	Drain-Source voltage [V]	Output	real
VBS	Bulk-Source voltage [V]	Output	real
VBD	Bulk-Drain voltage [V]	Output	real
P	Instantaneous power [W]	Output	real

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Example

Figure 3 shows application of the Spice-Compatible Level 6 MOS N-channel and MOS P-channel models. The parameters of SPICE_MOS6_P1 and SPICE_MOS6_N1 are set to their default values; the parameters of the rest of the system are listed in Table 4 and the simulation results shown in Figure 4.

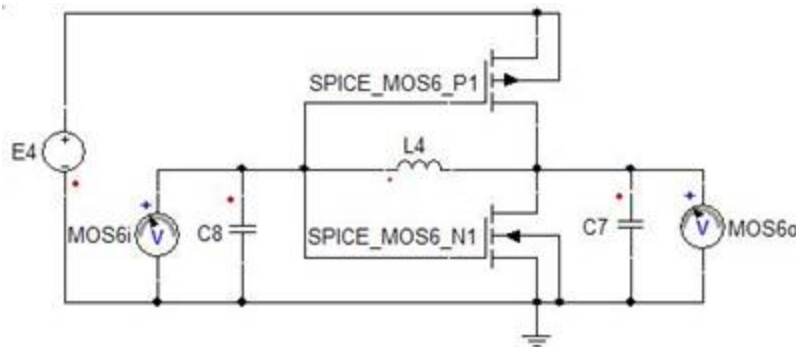


Figure 3. Application example of the Level 6 MOS N-channel and MOS P-channel models

Table 4

Component	Parameter	Value
Capacitor C8	C	
	V0	7.5 [V]
Capacitor C7	C	100p [F]
	V0	0 [V]
Inductor L4	L	1m [H]
	I0	0 [A]
Voltage Source E3	EMF	15 [V]

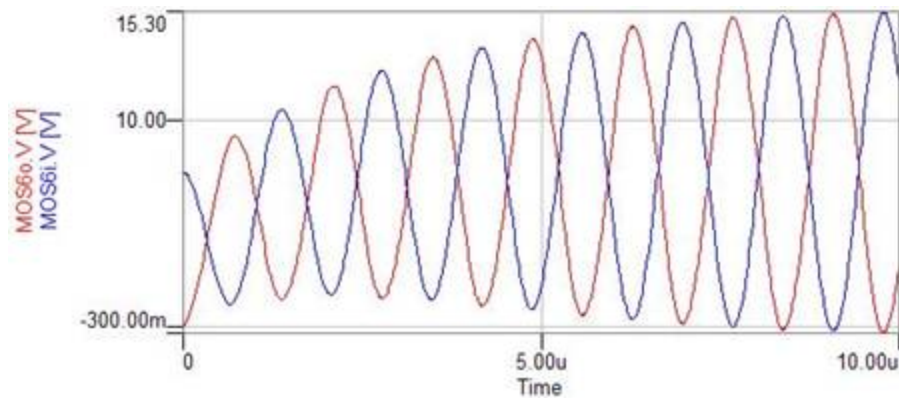


Figure 4. Simulation results-input and output voltage of SPICE_MOS6_N1

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References

[1]Massobrio, Giueseppe, and Paolo Antognetti: *Semiconductor Device Modeling with SPICE*, New York: McGraw Hill, 1993

SPICE-Compatible Line Models

The line components are implemented as C models. The models use the *MaxwellSpice.dll* file.

The simulation parameter HMIN (minimum time step) should be 0.1ns for the first simulation run. Then you can adjust the value for optimal simulation performance. For simulations of power electronics circuits, HMIN can be up to 100ns. Large values of HMIN can be used for long lines.

- [Lossy Transmission Line \(LTRA\)](#)

Lossy Transmission Line

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

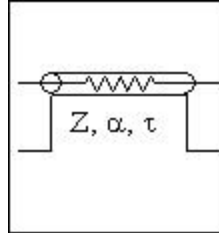


Figure 1. Component Symbol.

- [Description](#)
- [Assumptions and Limitations](#)
- [Mathematical Description](#)
- [Netlist Syntax](#)
- [Conservative Pins](#)
- [Parameters](#)
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- [Example](#)
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Description

The Spice-compatible lossy transmission line model simulates the electrical behavior of a lossy transmission line using SPICE3 LTRA parameters and equations. Line electrical characteristics are calculated according to user-defined line parameters.

The example shows all four supported modes of the LTRA model. The line is 0.2m long, and it has a characteristic impedance given by $\sqrt{L/C} = 50 \text{ Ohm}$. The wave velocity is given by $1/\sqrt{LC} = 2e8 \text{ m/s}$, and the line's travel time is 1ns. With a series resistance of 100 Ω/m , the total series resistance is 20 Ohm, or 40% of the characteristic impedance, so the line is very lossy.

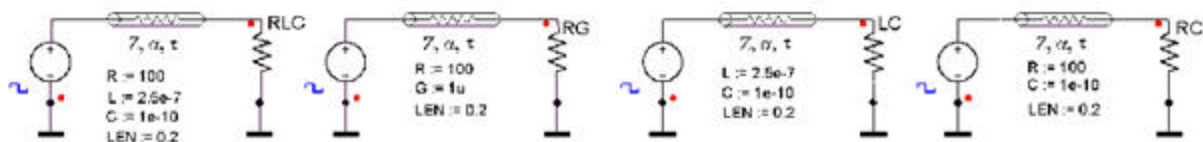


Figure 2. LTRA model in RLC, RG, LC, and RC modes.

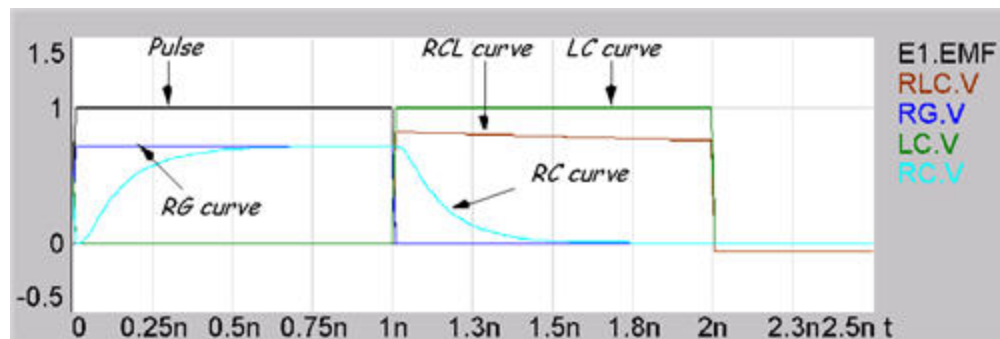


Figure 3. LTRA model waveforms in various modes.

The input voltage is a 1V pulse, 1ns wide. For the case of $R=0$, the input appears at the far end, delayed by 1ns (LC curve). There is no attenuation because the line R is zero. There is no reflection because the terminating resistance is equal to the characteristic impedance.

With high series resistance, the input is delayed 1ns as before, but distortion and attenuation occur (RLC curve). With only series resistance and a very low shunt conductance, there is no delay or distortion, but the output is attenuated (RG curve). Finally, with $L=0$ there is a delay from the RC time constant, but the delay is not 1-ns (RC curve).

When the input pulse is very narrow compared to the line's travel time, and the time step increases during simulation, it is possible for the pulse to become *lost*. It never appears at the far end. The *breakpoint* mechanism in the LTRA model does not fully address this problem, even when running in SPICE itself. A very small resistance value (for example $R=1\mu$) usually solves this problem.

Line Model Applications

SPICE 3f5 implements three different line models:

- LTRA - the lossy transmission line model, implemented with convolution of the impulse response.
- T - the lossless transmission line, implementing an idealized traveling wave behavior.
- URC - the uniform RC line, sometimes useful in low-frequency applications.

For the lossless case, LTRA is typically more accurate and efficient than the older T model. The URC model automatically creates an internal lumped RC network for SPICE, which is rather inefficient, and again, less accurate than the truly distributed-parameter LTRA model. Therefore, only the LTRA model has been provided for Twin Builder. All instances of the T and URC model should be converted to use the LTRA model.

Converting Lossless T Components to LTRA

The basic T component parameters are the characteristic impedance, and the line travel or delay time. To derive LTRA parameters, it's necessary to assume a wave velocity. For example, $3e8$ m/s (speed of light) will be assumed here. A different velocity may be assumed, and the derived parameters would be different but produce the same results in circuit simulation.

The characteristic impedance is directly available as Z0. The travel time may be input directly as TD, or indirectly as a frequency and normalized line length. If necessary, obtain the travel time as:

- $TD = NRMLLEN / \text{FREQ}$

If not specified, NRMLLEN = 0.25 for a quarter wavelength.

Next, obtain the length and the other LTRA parameters as:

- $LEN = 3e8 * TD$

- $L = Z0 / 3e8$

- $C = 1 / (Z0 * 3e8)$

- $R = G = 0$

For example, given $Z0 = 50$ and $TD = 1n$, we would obtain $LEN = 0.3$, $L = 1.667e-7$, and $C = 6.667e-11$. Assuming a velocity of $2e8$ instead of $3e8$, we would obtain $LEN = 0.2$, $L = 2.5e-7$, and $C = 1e-10$ as in the previous example. Both parameter sets would give the same results in Twin Builder.

Converting Uniform RC Components to LTRA

The LTRA parameters should be:

- LEN = LEN from the URC instance
- R = RPERL from the URC model
- C = CPERL from the URC model
- L = G = 0

Other parameters of the URC model should be ignored. The diode mode of URC, which employs ISPERL and RSPERL parameters, is not supported for Twin Builder.

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Assumptions and Limitations

The direction of the current and voltage references are shown as follows:

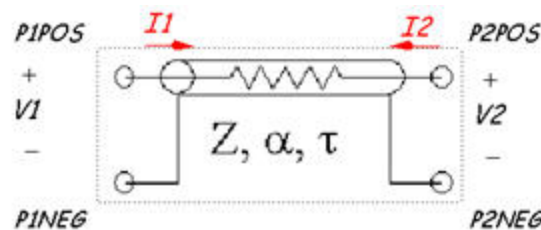


Figure 4. Current and Voltage Reference Arrow System

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Mathematical Description

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Netlist Syntax

```
UMODEL LTRA ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) P1POS:= %0,
P1NEG:= %1, P2POS:= %2, P2NEG:= %3 ( V1:= @V1, V2:= @V2, I1:= @I1, I2:= @I2, R:= @R,
L:= @L, G:= @G, C:= @C, LEN:= @LEN, NOCONTROL:= @NOCONTROL, STEPLIMIT:=
@STEPLIMIT, NOSTEPLIMIT:= @NOSTEPLIMIT, LININTERP:= @LININTERP,
QUADINTERP:= @QUADINTERP, MIXEDINTERP:= @MIXEDINTERP, TRUNCNR:=
@TRUNCNR, TRUNCNONTCUT:= @TRUNCNONTCUT, COMPACTREL:=
@COMPACTREL, COMPACTABS:= @COMPACTABS) SRC: DB(Lib:=@ModelLibraryName) ;
```

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
P1POS	P1 positive pin	electrical
P1NEG	P1 negative pin	electrical
P2POS	P2 positive pin	electrical
P2NEG	P2 negative pin	electrical

[Top](#)

Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
V1	Initial voltage at end 1	real	0 [V]
V2	Initial voltage at end 2	real	0 [V]
I1	Initial current at end 1	real	0 [A]
I2	Initial current at end 2	real	0 [A]
R	Resistance per meter	real	0 [Ohm/m]
L	Inductance per meter	real	0 [H/m]
G	Conductance per meter	real	0 [S/m]
C	Capacitance per meter	real	0 [F/m]
LEN	Length of line	real	0 [m]
NOCONTROL	No time step control	real	1
STEPLIMIT	Always limit time step to 0.8*(delay of line)	real	1
NOSTEPLIMIT	Don't always limit time step to 0.8*(delay of line)	real	0
LININTERP	Use linear interpolation	real	0
QUADINTERP	Use quadratic interpolation	real	1
MIXEDINTERP	Use linear interpolation if quadratic	real	0

	results look unacceptable		
TRUNCNR	Use N-R iterations for step calculation in LTRAt trunc	real	0
TRUNCNONTCUT	Don't limit time step to keep impulse response calculation errors low	real	0
COMPACTREL	Special reltol for straight line checking	real	1m
COMPACTABS	Special abstol for straight line checking	real	1p

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
I PORT1	Port current at end 1 [A]	Output	real
I PORT2	Port current at end 2 [A]	Output	real
V PORT1	Port voltage at end 1 [V]	Output	real
V PORT2	Port voltage at end 2 [V]	Output	real
P	Power Dissipation [W]	Output	real

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Example

Figure 5 shows application of the Spice-Compatible Lossy Transmission Line model. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 6 and 7.

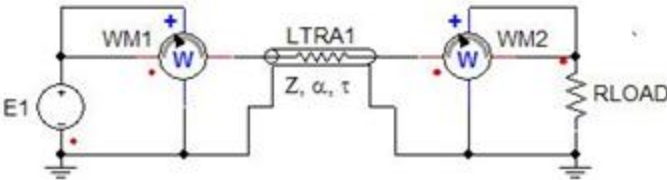


Figure 5. Application example of the Spice-Compatible Lossy Transmission Line model

Table 4

Component	Parameter	Value

Voltage Source (trapezoidal) E1	AMPL	1 [V]
	TRISE	0.1n [s]
	TFALL	0.1n [s]
	PWIDTH	1N [s]
	PHASE	0 [degree]
	OFF	0 [V]
	TDELAY	0 [s]
Resistor RLOAD	R	50 [Ohm]
Spice-Compatible Lossy Transmission Line LTRA1	V1	0 [V]
	V2	0 [V]
	I1	0 [A]
	I2	0 [A]
	R	100 [Ohm/m]
	L	2.5e-7 [H/m]
	G	0 [S/m]
	C	1e-10 [F/m]
	LEN	0.2 [m]
	NOCONTROL	1
	STEPLIMIT	1
	NOSTEPLIMIT	0
	LININTERP	0
	QUADINTERP	1
	MIXEDINTERP	0
	TRUNCNR	0
	TRUNCDONT CUT	0
	COMPACTREL	1m
	COMPACTABS	1p

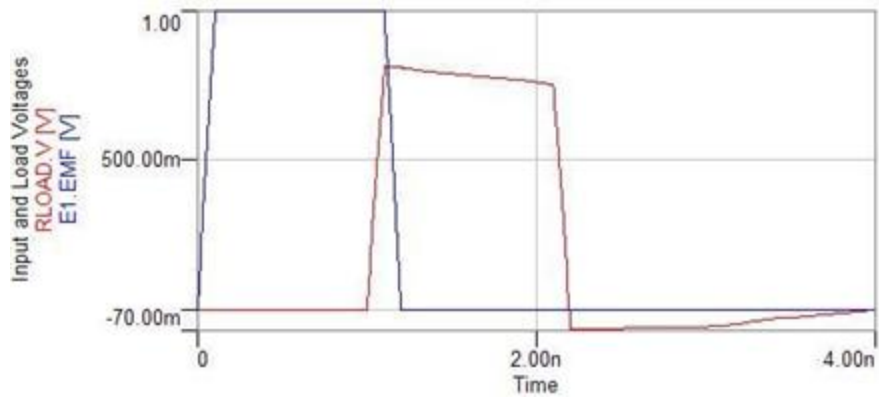


Figure 6. Simulation results-input and load voltages

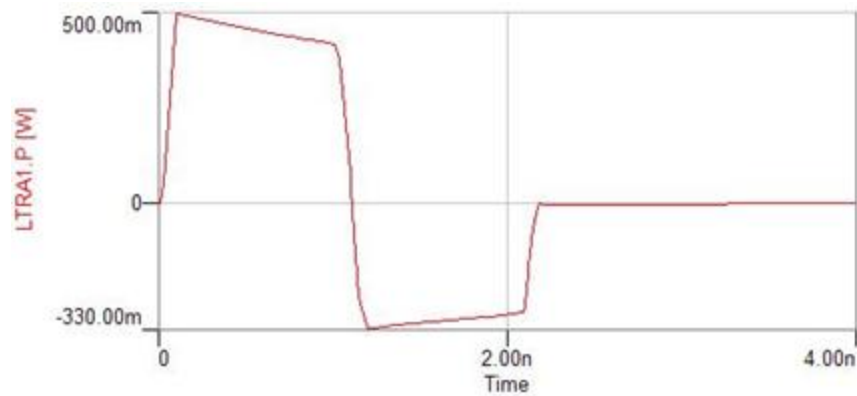


Figure 7. Simulation results-line losses

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References

[1] Roychowdhury, J. S., and D. O. Pederson: *Efficient Transient Simulation of Lossy Interconnect*, San Francisco, CA: ACM/IEEE Design Automation Conference, June 17-21, 1991

PSPICE-Compatible Models

- [Diode Models](#)
- [Field-Effect Transistors](#)

PSPICE-Compatible Diode Models

- [Diode PSPICE-Compatible](#)

Diode - PSPICE-Compatible

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

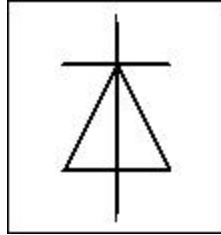


Figure 1. Component Symbol.

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- [Assumptions and Limitations](#)
- [Mathematical Description](#)
- [Netlist Syntax](#)
- [Conservative Pins](#)
- [Parameters](#)
- [Input/Output Quantities](#)

Description

The PSPICE-Compatible Diode Model simulates the electrical and thermal behavior of a diode using PSPICE parameters and equations. Electrical characteristics and the temperature dependence of diode behavior are calculated according to user-defined device parameters.

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Assumptions and Limitations

Figure 2 shows the current and voltage reference arrow system for this component.

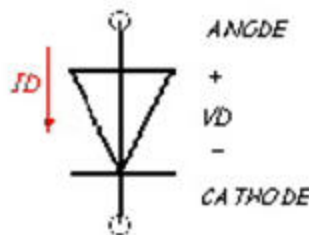


Figure 2. Current and Voltage Reference Arrow System

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Mathematical Description

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Netlist Syntax

```
UMODEL PSPICE_D ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) ANODE:= %0,
CATHODE:= %1 ( OFF:= @OFF, TEMP:= @TEMP, IC:= @IC, AREA:= @AREA, IS:= @IS,
TNOM:= @TNOM, RS:= @RS, N:= @N, TT:= @TT, CJO:= @CJO, VJ:= @VJ, M:= @M, EG:=
@EG, XTI:= @XTI, KF:= @KF, AF:= @AF, FC:= @FC, BV:= @BV, IBV:= @IBV, IBVL:-
=@IBVL, IKF-
:=@IKF, ISR-
:=@ISR, NBV-
:=@NBV, NBVL-
:=@NBVL, NR-
R:=@NR, TBV1:=@TBV1, TBV2:=@TBV2, TIKF:=@TIKF, TRS1:=@TRS1, TRS2:=@TRS2)
SRC: DB(Lib:=@ModelLibraryName) ;
```

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
ANODE	Anode	electrical
CATHODE	Cathode	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
OFF	Device Initially Off	real	0
TEMP	Instance Temperature	real	27 [°C]
IC	Initial Device Voltage	real	0 [V]
AREA	Area Factor	real	1
IS	Saturation Current	real	10f [A]
TNOM	Parameter Measurement Temperature	real	27 [°C]
RS	Ohmic Resistance	real	0 [Ohm]
N	Emission Coefficient	real	1

TT	Transit Time	real	0 [s]
CJO	Junction Capacitance	real	0 [F]
VJ	Junction Potential	real	1 [V]
M	Grading Coefficient	real	0.5
EG	Activation Energy	real	1.1 [eV]
XTI	Saturation Current Temperature Exponent	real	3
KF	Flicker Noise Coefficient	real	0
AF	Flicker Noise Exponent	real	1
FC	Forward-Bias Junction Fit Parameter	real	0.5
BV	Reverse Breakdown Voltage	real	Inf [V]
IBV	Current At Reverse Breakdown Voltage	real	1e-10 [A]
IBVL	Low Level Reverse Breakdown Knee Current	real	0 [A]
IKF	High-Injection Knee Current	real	1e-14 [A]
ISR	Recombination Current Parameter	real	0 [A]
NBV	Reverse Breakdown Ideality Factor	real	1
NBVL	Low-Level Reverse Breakdown Ideality Factor	real	1
NR	Emission Coefficient For Isr	real	2
TBV1	BV Temperature Coefficient, Linear	real	0 [°C ⁻¹]
TBV2	BV Temperature Coefficient, Quadratic	real	0 [°C ⁻²]
TIKF	IKF Temperature Coefficient, Linear	real	0 [°C ⁻¹]
TRS1	RS Temperature Coefficient, Linear	real	0 [°C ⁻¹]
TRS2	RS Temperature Coefficient, Quadratic	real	0 [°C ⁻²]

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Input/Output Quantities

Table 3

Name	Description[Unit]	Direction	Data Type
V	Diode voltage, not including voltage on stray resistance RS[V]	Output	real
I	Diode current[A]	Output	real
P	Diode power, not including power loss on stray resistance RS[W]	Output	real

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Field Effect Transistors

- [N-Channel/P-Channel JFET Model \(PSPICE-Compatible\)](#)

JFET Model - PSPICE-Compatible N-Channel/P-Channel

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

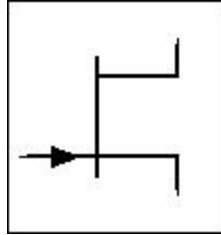


Figure 1. Component Symbol.

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- [Conservative Pins](#)
- [Parameters](#)
- [Input/Output Quantities](#)

Description

The PSPICE-compatible JFET N-channel and JFET P-channel models simulate the electrical and thermal behavior of a JFET using PSPICE parameters and equations. Electrical characteristics and the temperature dependence of JFET behavior are calculated according to user-defined device parameters.

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Assumptions and Limitations

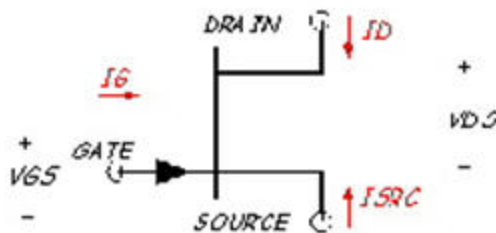


Figure 2. Current and Voltage Reference Arrow System

PSPICE parameters for temperature setting: T_MEASURED, T_ABS, T_REL_GLOBAL and T_REL_LOCAL, are currently not supported.

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Mathematical Description

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Netlist Syntax

```
UMODEL PSPICE_JFET_N ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) DRAIN:=
%0, GATE:= %1, SOURCE:= %2 ( OFF:= @OFF, AREA:= @AREA, ICVDS:= @ICVDS,
ICVGS:= @ICVGS, TEMP:= @TEMP, VTO:= @VTO, BETA:= @BETA, LAMBDA:=
@LAMBDA, RD:= @RD, RS:= @RS, CGS:= @CGS, CGD:= @CGD, PB:= @PB, IS:= @IS,
FC:= @FC, B:= @B, TNOM:= @TNOM, KF:= @KF, AF:= @AF, ALPHA:=@ ALPHA,
BETATCE:=@ BETATCE, ISR:= @ISR, M:=@M, N:=@N, NR:=@NR, VK:=@VK, VTOTC:-
:=@VTOTC, XTI:=@XTI) SRC: DB(Lib:=@ModelLibraryName) ;
```

```
UMODEL PSPICE_JFET_P ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) DRAIN:=
%0, GATE:= %1, SOURCE:= %2 ( OFF:= @OFF, AREA:= @AREA, ICVDS:= @ICVDS,
ICVGS:= @ICVGS, TEMP:= @TEMP, VTO:= @VTO, BETA:= @BETA, LAMBDA:=
@LAMBDA, RD:= @RD, RS:= @RS, CGS:= @CGS, CGD:= @CGD, PB:= @PB, IS:= @IS,
FC:= @FC, B:= @B, TNOM:= @TNOM, KF:= @KF, AF:= @AF, ALPHA:=@ ALPHA,
BETATCE:=@ BETATCE, ISR:= @ISR, M:=@M, N:=@N, NR:=@NR, VK:=@VK, VTOTC:-
:=@VTOTC, XTI:=@XTI) SRC: DB(Lib:=@ModelLibraryName) ;
```

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
GATE	Gate	electrical
SOURCE	Source	electrical
DRAIN	Drain	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
OFF	Device initially off	boolean	0
AREA	Area factor	real	1

ICVDS	Initial Drain-Source voltage	real	0 [V]
ICVGS	Initial Gate-Source voltage	real	0 [V]
TEMP	Instance temperature	real	27 [°C]
VTO	Threshold voltage	real	-2 [V]
BETA	Transconductance parameter	real	0.1m [A/V ²]
LAMBDA	Channel length modulation parameter	real	0 [1/V]
RD	Drain ohmic resistance	real	0 [W]
RS	Source ohmic resistance	real	0 [W]
CGS	G-S junction capacitance	real	0 [F]
CGD	G-D junction capacitance	real	0 [F]
PB	Gate junction potential	real	1 [V]
IS	Gate junction saturation current	real	10f [A]
FC	Forward bias junction fit parameter	real	0.5
TNOM	Parameter measurement temperature	real	27 [°C]
KF	Flicker Noise Coefficient	real	0
AF	Flicker Noise Exponent	real	0
ALPHA	Ionization coefficient	real	0[1/V]
BETATCE	BETA exponential temperature coefficient	real	0 [%°C]
ISR	Gate p-n recombination current parameter	real	0[A]
M	Gate p-n grading coefficient	real	0.5
N	Gate p-n emission coefficient	real	1
NR	Emission coefficient for ISR	real	2
VK	Ionization knee voltage	real	0[V]
VTOTC	VTO temperature coefficient	real	0 [V/°C]
XTI	IS temperature coefficient	real	3

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Input/Output Quantities**Table 3**

Name	Description [Unit]	Direction	Data Type
VGS	Voltage Gate-Source [V]	Output	real
VGD	Voltage Gate-Drain [V]	Output	real
VDS	Voltage Drain-Source [V]	Output	real
ID	Current at drain node [A]	Output	real
IG	Current at gate node [A]	Output	real
ISRC	Source current [A]	Output	real
P	Power dissipation [W]	Output	real

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Level 1-3 MOS Model - PSPICE-Compatible N-Channel / P-Channel

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

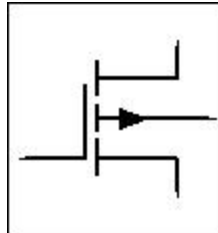


Figure 1. Component Symbol.

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- [Mathematical Description](#)
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- [Conservative Pins](#)
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Description

The PSPICE-Compatible Level 1-3 MOS N-channel and MOS2 P-channel models simulate the electrical and thermal behavior of MOSFETs using the parameters and equations of the PSPICE and Level 1-3 MOSFET model. Electrical characteristics and the temperature dependence of MOSFET behavior are calculated according to user-defined device parameters.

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Assumptions and Limitations

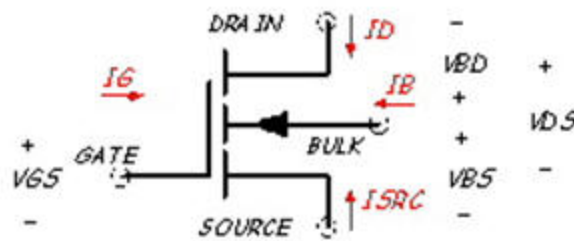


Figure 2. Current and Voltage Reference Arrow System[Top](#)**Mathematical Description**[Top](#)**Netlist Syntax**

Level 1 MOS N-channel

```

UMODEL PSPICE_MOS1_N ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) DRAIN:=
%0, GATE:= %1, SOURCE:= %2, BULK:= %3 ( L:= @L, W:= @W, AD:= @AD, AS:= @AS,
PD:= @PD, PS:= @PS, NRD:= @NRD, NRS:= @NRS, NRG:=@NRG, NRB:=@NRB, OFF:=
@OFF, ICDVS:= @ICVDS, ICDVS:= @ICVGS, ICDVS:= @ICVBS, TEMP:= @TEMP, VTO:=
@VTO, KP:= @KP, GAMMA:= @GAMMA, PHI:= @PHI, LAMBDA:= @LAMBDA, RD:= @RD,
RS:= @RS, CBD:= @CBD, CBS:= @CBS, IS:= @IS, PB:= @PB, CGSO:= @CGSO, CGDO:=
@CGDO, CGBO:= @CGBO, RSH:= @RSH, CJ:= @CJ, MJ:= @MJ \\\, CJSW:= @CJSW,
MJSW:= @MJSW, JS:= @JS, TOX:= @TOX, LD:= @LD, U0:= @U0, FC:= @FC, NSUB:=
@NSUB, TPG:= @TPG, NSS:= @NSS, TNOM:= @TNOM, KF:= @KF, AF:= @AF, JSSW:-
:=@JSSW, N:=@N, PBSW:=@PBSW, RB:=@RB, RDS:=@RDS, RG:=@RG, TT:=@TT, WD:-
:=@WD, NFS:=@NFS, VMAX:=@VMAX, DELTA:=@DELTA, UTRA:=@UTRA, XJ:=@XJ,
XQC:=@XQC, GDSNOI:=@GDSNOI, NLEV:=@NLEV) SRC: DB(Lib:=@ModelLibraryName) ;

```

Level 1 MOS P-channel

```

UMODEL PSPICE_MOS1_P ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) DRAIN:=
%0, GATE:= %1, SOURCE:= %2, BULK:= %3 ( L:= @L, W:= @W, AD:= @AD, AS:= @AS,
PD:= @PD, PS:= @PS, NRD:= @NRD, NRS:= @NRS, NRG:=@NRG, NRB:=@NRB, OFF:=
@OFF, ICDVS:= @ICVDS, ICDVS:= @ICVGS, ICDVS:= @ICVBS, TEMP:= @TEMP, VTO:=
@VTO, KP:= @KP, GAMMA:= @GAMMA, PHI:= @PHI, LAMBDA:= @LAMBDA, RD:= @RD,
RS:= @RS, CBD:= @CBD, CBS:= @CBS, IS:= @IS, PB:= @PB, CGSO:= @CGSO, CGDO:=
@CGDO, CGBO:= @CGBO, RSH:= @RSH, CJ:= @CJ, MJ:= @MJ \\\, CJSW:= @CJSW,
MJSW:= @MJSW, JS:= @JS, TOX:= @TOX, LD:= @LD, U0:= @U0, FC:= @FC, NSUB:=
@NSUB, TPG:= @TPG, NSS:= @NSS, TNOM:= @TNOM, KF:= @KF, AF:= @AF, JSSW:-
:=@JSSW, N:=@N, PBSW:=@PBSW.8, RB:=@RB, RDS:=@RDS, RG:=@RG, TT:=@TT,
WD:=@WD, NFS:=@NFS, VMAX:=@VMAX, DELTA:=@DELTA, UTRA:=@UTRA, XJ:=@XJ,
XQC:=@XQC, GDSNOI:=@GDSNOI, NLEV:=@NLEV) SRC: DB(Lib:=@ModelLibraryName) ;

```

Level 2 MOS N-channel

```

UMODEL PSPICE_MOS2_N ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) DRAIN:=
%0, GATE:= %1, SOURCE:= %2, BULK:= %3 ( L:= @L, W:= @W, AD:= @AD, AS:= @AS,
PD:= @PD, PS:= @PS, NRD:= @NRD, NRS:= @NRS, NRG:=@NRG, NRB:=@NRB, OFF:=
@OFF, ICDVS:= @ICVDS, ICDVS:= @ICVGS, ICDVS:= @ICVBS, TEMP:= @TEMP, VTO:=
@VTO, KP:= @KP, GAMMA:= @GAMMA, PHI:= @PHI, LAMBDA:= @LAMBDA, RD:= @RD,
RS:= @RS, CBD:= @CBD, CBS:= @CBS, IS:= @IS, PB:= @PB, CGSO:= @CGSO, CGDO:=
@CGDO, CGBO:= @CGBO, RSH:= @RSH, CJ:= @CJ, MJ:= @MJ \\\, CJSW:= @CJSW,
MJSW:= @MJSW, JS:= @JS, TOX:= @TOX, LD:= @LD, U0:= @U0, FC:= @FC, NSUB:=
@NSUB, TPG:= @TPG, NSS:= @NSS, DELTA:= @DELTA, UEXP:= @UEXP, UCRIT:=

```

@UCRIT, VMAX:= @VMAX, XJ:= @XJ, NEFF:= @NEFF, NFS:= @NFS, TNOM:= @TNOM, KF:= @KF, AF:= @AF, JSSW:=@JSSW, N:=@N, PBSW:=@PBSW.8, RB:=@RB, RDS:-:=@RDS, RG:=@RG, TT:=@TT, WD:=@WD, UTRA:=@UTRA, XQC:=@XQC, GDSNOI:-:=@GDSNOI, NLEV:=@NLEV) SRC: DB(Lib:=@ModelLibraryName) ;

Level 2 MOS P-channel

UMODEL PSPICE_MOS2_P ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) DRAIN:= %0, GATE:= %1, SOURCE:= %2, BULK:= %3 (L:= @L, W:= @W, AD:= @AD, AS:= @AS, PD:= @PD, PS:= @PS, NRD:= @NRD, NRS:= @NRS, NRG:=@NRG, NRB:=@NRB, OFF:= @OFF, ICDVS:= @ICVDS, ICDVS:= @ICVGS, ICDVS:= @ICVBS, TEMP:= @TEMP, VTO:= @VTO, KP:= @KP, GAMMA:= @GAMMA, PHI:= @PHI, LAMBDA:= @LAMBDA, RD:= @RD, RS:= @RS, CBD:= @CBD, CBS:= @CBS, IS:= @IS, PB:= @PB, CGSO:= @CGSO, CGDO:= @CGDO, CGBO:= @CGBO, RSH:= @RSH, CJ:= @CJ, MJ:= @MJ \\\ , CJSW:= @CJSW, MJSW:= @MJSW, JS:= @JS, TOX:= @TOX, LD:= @LD, U0:= @U0, FC:= @FC, NSUB:= @NSUB, TPG:= @TPG, NSS:= @NSS, DELTA:= @DELTA, UEXP:= @UEXP, UCRIT:= @UCRIT, VMAX:= @VMAX, XJ:= @XJ, NEFF:= @NEFF, NFS:= @NFS, TNOM:= @TNOM, KF:= @KF, AF:= @AF, JSSW:=@JSSW, N:=@N, PBSW:=@PBSW.8, RB:=@RB, RDS:-:=@RDS, RG:=@RG, TT:=@TT, WD:=@WD, UTRA:=@UTRA, XQC:=@XQC, GDSNOI:-:=@GDSNOI, NLEV:=@NLEV) SRC: DB(Lib:=@ModelLibraryName) ;

Level 3 MOS N-channel

UMODEL SPICE_MOS3_N ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) DRAIN:= %0, GATE:= %1, SOURCE:= %2, BULK:= %3 (L:= @L, W:= @W, AD:= @AD, AS:= @AS, PD:= @PD, PS:= @PS, NRD:= @NRD, NRS:= @NRS, NRG:=@NRG, NRB:=@NRB, OFF:= @OFF, ICDVS:= @ICVDS, ICDVS:= @ICVGS, ICDVS:= @ICVBS, TEMP:= @TEMP, VTO:= @VTO, KP:= @KP, GAMMA:= @GAMMA, PHI:= @PHI, RD:= @RD, RS:= @RS, CBD:= @CBD, CBS:= @CBS, IS:= @IS, PB:= @PB, CGSO:= @CGSO, CGDO:= @CGDO, CGBO:= @CGBO, RSH:= @RSH, CJ:= @CJ, MJ:= @MJ, CJSW:= @CJSW \\\ , MJSW:= @MJSW, JS:= @JS, TOX:= @TOX, LD:= @LD, U0:= @U0, FC:= @FC, NSUB:= @NSUB, TPG:= @TPG, NSS:= @NSS, VMAX:= @VMAX, XJ:= @XJ, NFS:= @NFS, XD:= @XD, ALPHA:= @ALPHA, ETA:= @ETA, DELTA:= @DELTA, THETA:= @THETA, KAPPA:= @KAPPA, TNOM:= @TNOM, KF:= @KF, AF:= @AF, JSSW:=@JSSW, N:=@N, PBSW:=@PBSW.8, RB:=@RB, RDS:=@RDS, RG:=@RG, TT:=@TT, WD:=@WD, UTRA:=@UTRA, XQC:=@XQC, GDSNOI:-:=@GDSNOI, NLEV:=@NLEV) SRC: DB(Lib:=@ModelLibraryName) ;

Level 3 MOS P-channel

UMODEL SPICE_MOS3_P ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) DRAIN:= %0, GATE:= %1, SOURCE:= %2, BULK:= %3 (L:= @L, W:= @W, AD:= @AD, AS:= @AS, PD:= @PD, PS:= @PS, NRD:= @NRD, NRS:= @NRS, NRG:=@NRG, NRB:=@NRB, OFF:= @OFF, ICDVS:= @ICVDS, ICDVS:= @ICVGS, ICDVS:= @ICVBS, TEMP:= @TEMP, VTO:= @VTO, KP:= @KP, GAMMA:= @GAMMA, PHI:= @PHI, RD:= @RD, RS:= @RS, CBD:= @CBD, CBS:= @CBS, IS:= @IS, PB:= @PB, CGSO:= @CGSO, CGDO:= @CGDO, CGBO:= @CGBO, RSH:= @RSH, CJ:= @CJ, MJ:= @MJ, CJSW:= @CJSW \\\ , MJSW:= @MJSW, JS:= @JS, TOX:= @TOX, LD:= @LD, U0:= @U0, FC:= @FC, NSUB:= @NSUB, TPG:= @TPG, NSS:= @NSS, VMAX:= @VMAX, XJ:= @XJ, NFS:= @NFS, XD:= @XD, ALPHA:= @ALPHA, ETA:= @ETA, DELTA:= @DELTA, THETA:= @THETA, KAPPA:= @KAPPA, TNOM:= @TNOM, KF:= @KF, AF:= @AF, JSSW:=@JSSW, N:=@N, PBSW:=@PBSW.8, RB:=@RB,

RDS:=@RDS, RG:=@RG, TT:=@TT, WD:=@WD, UTRA:=@UTRA, XQC:=@XQC, GDSNOI:-
:=@GDSNOI, NLEV:=@NLEV) SRC: DB(Lib:=@ModelLibraryName) ;

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
GATE	Gate	electrical
SOURCE	Source	electrical
DRAIN	Drain	electrical
BULK	Bulk	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
L	Length	real	0.1 [m]
W	Width	real	0.1 [m]
AD	Drain Area	real	0 [m ²]
AS	Source Area	real	0 [m ²]
PD	Drain Perimeter	real	0 [m]
PS	Source Perimeter	real	0 [m]
NRD	Relative drain resistivity (in squares)	real	0
NRS	Relative drain resistivity (in squares)	real	0
NRG	Relative gate resistivity (in squares)	real	0
NRB	Relative substrate resistivity (in squares)	real	0
OFF	Device initially off	boolean	0
ICVDS	Initial D-S voltage	real	0 [V]

ICVGS	Initial G-S voltage	real	0 [V]
ICVBS	Initial B-S voltage	real	0 [V]
TEMP	Instance temperature	real	27 [°C]
VTO	Threshold voltage	real	0 [V]
KP	Transconductance parameter	real	20.71886279814u [A/V ²]
GAMMA	Bulk threshold parameter	real	0 [V ^{1/2}]
PHI	Surface potential	real	0.6 [V]
LAMBDA	Channel length modulation parameter	real	0 [V ⁻¹]
RD	Drain ohmic resistance	real	0 [Ohm]
RS	Source ohmic resistance	real	0 [Ohm]
CBD	B-D junction capacitance	real	0 [F]
CBS	B-S junction capacitance	real	0 [F]
IS	Bulk junction sat. current	real	10f [A]
PB	Bulk junction potential	real	0.8 [V]
CGSO	Gate-source overlap cap.	real	0 [F/m]
CGDO	Gate-drain overlap cap.	real	0 [F/m]
CGBO	Gate-bulk overlap cap.	real	0 [F/m]
RSH	Sheet resistance	real	0 [Ohm/square]
CJ	Bottom junction cap per area	real	0 [F/m ²]
MJ	Bottom grading coefficient	real	0.5
CJSW	Side junction cap per area	real	0 [F/m]
MJSW	Side grading coefficient	real	0.33
JS	Bulk junction saturation current density	real	0 [A/m ²]
TOX	Oxide thickness	real	0.1u [m]
LD	Lateral diffusion	real	0 [m]
U0	Surface mobility	real	0.6k [cm ² /Vs]

FC	Forward bias junction fit parameter	real	0.5
NSUB	Substrate doping	real	0 [1/cm ³]
TPG	Gate type	integer	0
NSS	Surface state density	real	0 [1/cm ²]
DELTA	Width Effect on Threshold (Levels 2 and 3)	real	0
UEXP	Critical Field Exponent in Mobility Degradation	real	0
UCRIT	Critical Field for Mobility Degradation	real	10k [V/cm]
VMAX	Maximum Carrier Drift Velocity (Levels 2 and 3)	real	0 [m/s]
XJ	Junction Depth (Levels 2 and 3)	real	0 [m]
NEFF	Total Channel Charge Coefficient	real	1
NFS	Fast Surface State Density (Levels 2 and 3)	real	0 [1/cm ²]
TNOM	Parameter measurement temperature	real	27 [°C]
KF	Flicker noise coefficient	real	0
AF	Flicker noise exponent	real	1
JSSW	Bulk p-n saturation sidewall current/length	real	0 [A/m]
N	Bulk p-n emission coefficient	real	1
PBSW	Bulk p-n sidewall potential	real	PB [V]
RB	Bulk ohmic resistance	real	0 [Ohm]
RDS	Drain-source shunt resistance	real	0 [Ohm]
RG	Gate ohmic resistance	real	0 [Ohm]
TT	Bulk p-n transit time	real	0 [s]
WD	Lateral diffusion (width)	real	0 [m]

UTRA	(not used) Mobility degradation transverse field coefficient	real	0
XQC	(not used) Fraction of channel charge attributed to drain	real	1
GDSNOI	(not used) Channel shot noise coefficient (use with NLEV=3)	real	1
NLEV	(not used) Noise equation selector	real	2

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
ID	Drain current [A]	Output	real
ISRC	Source current [A]	Output	real
IG	Gate current [A]	Output	real
IB	Bulk current [A]	Output	real
VGS	Gate-Source voltage [V]	Output	real
VDS	Drain-Source voltage [V]	Output	real
VBS	Bulk-Source voltage [V]	Output	real
VBD	Bulk-Drain voltage [V]	Output	real
P	Instantaneous power [W]	Output	real

PSPICE-Compatible Switches

- [Current Controlled Switch \(PSPICE compatible\)](#)
- [Voltage Controlled Switch \(PSPICE compatible\)](#)

Current Controlled Switch (PSPICE compatible)

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

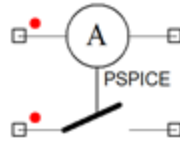


Figure 1. Component Symbol.

- [Description](#)
- [Assumptions and Limitations](#)
- [Mathematical Description](#)
- [Netlist Syntax](#)
- [Conservative Pins](#)
- [Parameters](#)
- [Input Quantities](#)
- [Output Quantities](#)
- [Example](#)
- [References](#)

Description

The component represents a non-ideal electrical switch. It is equivalent to the current-controlled switch from PSPICE when it is used as a variable-resistance switch. The resistance between the switch nodes N1 and N2 depends on the current flowing from the control node NC1 to the control node NC2. The resistance varies continuously between RON and ROFF during the switching transition.

Note: In order to model a switch equivalent to the PSPICE current-controlled switch as a short-transition switch, use the switch with hysteresis in Twin Builder (parameter TD is not available in Twin Builder).

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Assumptions and Limitations

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Mathematical Description

In the following equations:

Ic = control current

Lm = log-mean of resistor values = $\ln((RON \cdot ROFF)^{1/2})$

Lr = log-ratio of resistor values = $\ln(ROFF/ROFF)$

Im = mean of control current = $(ION + IOFF)/2$

Id = difference of control currents = $ION - IOFF$

Ss = switch state

Rs = switch resistance

For: $VON > VOFF$

if: $Ic > ION$ then:

Rs = RON

Ss = 1 (on)

if: $Ic < IOFF$ then:

Rs = ROFF

Ss = 0 (off)

if: $IOFF < Ic < ION$ then:

Rs = $\exp(Lm + 3 \cdot Lr \cdot (Ic - Im) / (2 \cdot Id) - 2 \cdot Lr \cdot (Ic - Im)^3 / Id^3)$

Ss = 2 (in transition)

For: $ION < IOFF$

if: $Ic < ION$ then:

Rs = RON

Ss = 1 (on)

if: $Ic > IOFF$ then:

Rs = ROFF

Ss = 0 (off)

if: $IOFF > Ic > ION$ then:

Rs = $\exp(Lm - 3 \cdot Lr \cdot (Ic - Im) / (2 \cdot Id) + 2 \cdot Lr \cdot (Ic - Im)^3 / Id^3)$

Ss = 2 (in transition)

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Netlist Syntax

```
UMODEL CSV_PSpice ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) N1:= %0, N2:= %1, NC1:= %2, NC2:= %3Â (Â RON:= @RON, ROFF:= @ROFF, ION:= @ION, IOFF:= @IOFF) SRC: DB(Lib:=@ModelLibraryName);
```

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Conservative Pins

Table 1

Name	Terminal Description	Nature
N1	Switch Pin 1 (red dot)	electrical
N2	Switch Pin 2	electrical

NC1	Control Pin 1 (red dot)	electrical
NC2	Control Pin 2	electrical

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Parameters

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Input Quantities

Table 2

Name	Description	Data Type	Data Value [Unit]
RON	On State Resistance Table Cell Outside Table: real Table Cell Outside Table: 1 [Ohm]		
ROFF	Off State Resistance	real	1e6 [Ohm]
ION	Control Current for On State	real	1e-3 [A]
IOFF	Control Current for Off State	real	0.0 [A]

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Output Quantities

Table 3

Name	Description [Unit]	Data Type
V	Voltage [V] Table Cell Outside Table: real	
dV	Derivative of Voltage [V/s]	real
I	Current [A]	real

dl	Derivative of Current [A/s]	real
STATE	Switching State (0=OFF; 1=ON; 2=in trans- ition)	real
IC	Control Current [A]	real

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Example

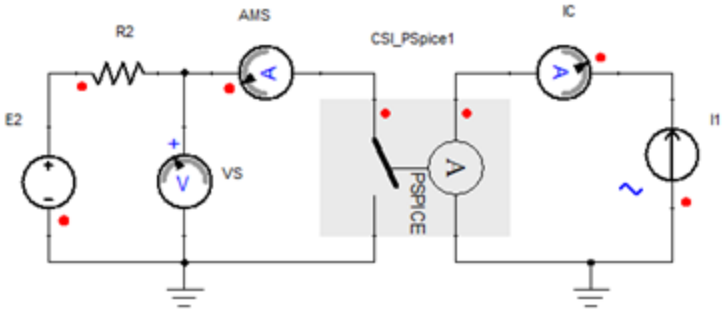


Figure 2. Application example of the I-controlled switch

Table 4. Component Parameters

Component	Parameter	Value [Unit]
Voltage Source E2	EMF	10 [V]
Resistor R2	R	1 [Ohm]
Current Source (Triangular) I1	AMPL	1 [A]
	FREQ	50 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0.5 [A]
Voltage Controlled Switch CSI_PSpice1	RON	1e-3 [Ohm]
	ROF	1e6 [Ohm]
	ION	1 [A]
	IOFF	0 [A]

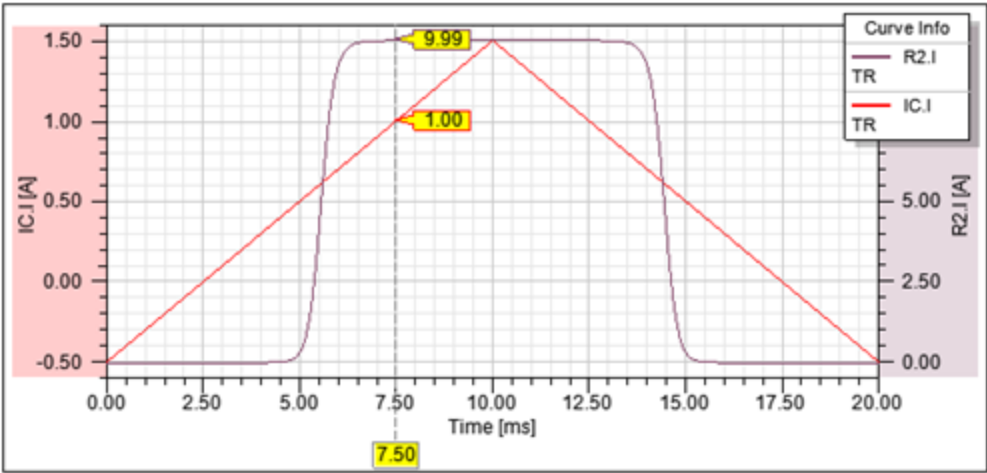


Figure 3. Simulation results

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References

Voltage Controlled Switch (PSPICE compatible)

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

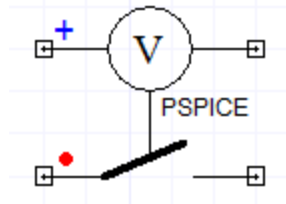


Figure 1. Component Symbol

- [Description](#)
- [Assumptions and Limitations](#)
- [Mathematical Description](#)
- [Netlist Syntax](#)
- [Conservative Pins](#)
- [Parameters](#)
- [Input Quantities](#)
- [Output Quantities](#)
- [Example](#)
- [References](#)

Description

The component represents a non-ideal electrical switch. It is equivalent to the voltage-controlled switch from PSPICE when it is used as a variable-resistance switch. The resistance between the switch nodes N1 and N2 depends on the voltage between the control nodes NC1 and NC2. The resistance varies continuously between RON and ROFF during the switching transition.

Note: In order to model a switch equivalent to the PSPICE voltage-controlled switch as a short-transition switch, use the switch with hysteresis in Twin Builder (parameter TD is not available in Twin Builder).

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Assumptions and Limitations

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Mathematical Description

In the following equations:

V_c = voltage across control nodes = $V(\text{NC1}) - V(\text{NC2})$

$L_m = \text{log-mean of resistor values} = \ln((R_{ON} \cdot R_{OFF})^{1/2})$

$L_r = \text{log-ratio of resistor values} = \ln(R_{ON}/R_{OFF})$

$V_m = \text{mean of control voltages} = (V_{ON} + V_{OFF})/2$

$V_d = \text{difference of control voltages} = V_{ON} - V_{OFF}$

$S_s = \text{switch state}$

$R_s = \text{switch resistance}$

For: $V_{ON} > V_{OFF}$

if: $V_c > V_{ON}$ then:

$R_s = R_{ON}$

$S_s = 1$ (on)

if: $V_c < V_{OFF}$ then:

$R_s = R_{OFF}$

$S_s = 0$ (off)

if: $V_{OFF} < V_c < V_{ON}$ then:

$R_s = \exp(L_m + 3 \cdot L_r \cdot (V_c - V_m) / (2 \cdot V_d) - 2 \cdot L_r \cdot (V_c - V_m)^3 / V_d^3)$

$S_s = 2$ (in transition)

For: $V_{ON} < V_{OFF}$

if: $V_c < V_{ON}$ then:

$R_s = R_{ON}$

$S_s = 1$ (on)

if: $V_c > V_{OFF}$ then:

$R_s = R_{OFF}$

$S_s = 0$ (off)

if: $V_{OFF} > V_c > V_{ON}$ then:

$R_s = \exp(L_m - 3 \cdot L_r \cdot (V_c - V_m) / (2 \cdot V_d) + 2 \cdot L_r \cdot (V_c - V_m)^3 / V_d^3)$

$S_s = 2$ (in transition)

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Netlist Syntax

UMODEL CSV_PSpice ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) N1:= %0, N2:= %1, NC1:= %2, NC2:= %3 (RON:= @RON, ROFF:= @ROFF, VON:= @VON, VOFF:= @VOFF) SRC: DB(Lib:=@ModelLibraryName);

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Conservative Pins

Table 1

Name	Terminal Description	Nature
N1	Switch Pin 1 (red dot)	electrical
N2	Switch Pin 2	electrical
NC1	Control Voltage Pin 1 (blue +)	electrical
NC2	Control Voltage Pin 2	electrical

[Top](#)**Parameters**[Top](#)**Input Quantities****Table 2**

Name	Description	Data Type	Data Value [Unit]
RON	On State Resistance	real	1 [Ohm]
ROFF	Off State Resistance	real	1e6 [Ohm]
VION	Control Voltage for On State	real	0.0 [V]
VIOFF	Control Voltage for Off State	real	1.0 [V]

[Top](#)**Output Quantities****Table 3**

Name	Description [Unit]	Data Type
V	Voltage [V]	real
dV	Derivative of Voltage [V/s]	real
I	Current [A]	real
dI	Derivative of Current [A/s]	real
STATE	Switching State (0=OFF; 1=ON; 2=in transition)	real
VC	Control Voltage [V]	real

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Example

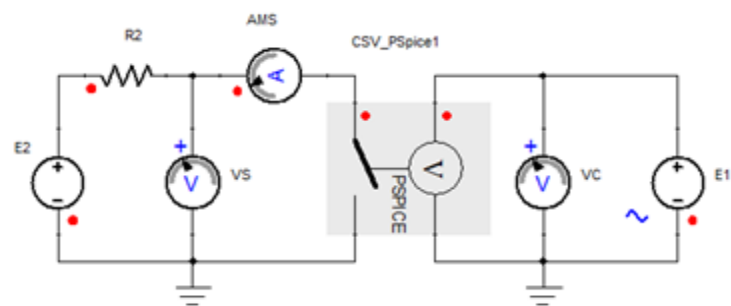


Figure 2. Application example of the V-controlled switch

Table 4. Component Parameters

Component	Parameter	Value [Unit]
Voltage Source E2	EMF	10 [V]
Resistor R2	R	1 [Ohm]
Current Source (Triangular) I1	AMPL	1 [V]
	FREQ	50 [Hz]
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0.5 [V]
Voltage Controlled Switch CSV_PSpice1	RON	1e-3 [Ohm]
	ROF	1e6 [Ohm]
	ION	1 [V]
	IOFF	0 [V]

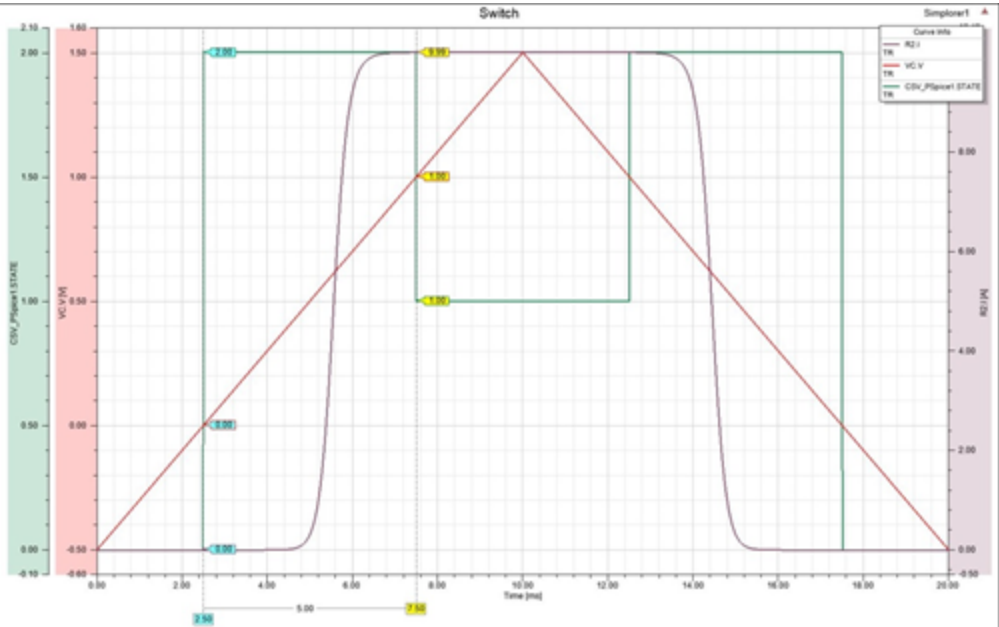


Figure 3. Simulation results

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References

Transformers

- [Single-Phase Systems](#)
- [Three-Phase Systems](#)

Twin Builder Transformer Models According to Spiro

Transformer components, available in the Basic Elements Library, are based on the *Spiro* model, which is characterized by any energy flow direction, a free number of galvanically separate windings, the exclusion of DC-current transmission and the consideration of losses.

In the Spiro model, every limb of the transformer is represented by one inductance. Each winding, that influences the flux through the limb, contributes to the current flowing through the inductance. Usually the ratio flux/current is different for the winding of the limb because of different numbers of turns or, in the case of a three-phase transformer, different positions of the windings. The current of only one winding can flow directly through the inductance. The other windings contribute by coupling factors.

Single Phase

The circuit shows the equivalent circuit for a single phase transformer. The current through the primary winding contributes directly to the current through the main inductance. Therefore the main inductance is calculated with respect to the primary winding.

Because of primary and secondary side stray inductances coupling factors are introduced. The coupling factor for the secondary side is determined by the ratio of the number of turns only. Therefore the current through the secondary winding controls the current source at the primary side with the control factor KTR which is the number-of-turns ratio.

The same relationships apply for the voltage induced at primary and secondary side respectively. Since the main inductance is calculated for the primary winding and its current is calculated with respect to the primary side, the induced voltage at the primary side equals the voltage across the main inductance. The induced voltage at the secondary side equals the voltage across the main inductance multiplied by the number-of-turns ratio KTR.

Model Extension for Three-Phase Systems

To model a three-phase system, the coupling between all six windings has to be considered. The model for the single-phase transformer has to be used three times. For every phase the influence of two more primary windings and two more secondary windings has to be modeled. This influence is modeled as for the single-phase transformer using controlled current and voltage sources.

Assuming the same number of turns for all primary windings the coupling between the primary windings depends on the geometry only. The coupling of a secondary winding to the primary winding of the same phase depends on the number-of-turns ratio again (as for single-phase transformers). The coupling from a secondary side to a primary side of another phase depends on geometry and number-of-turns ratio.

Three-Phase Transformer Twin Builder Models

Twin Builder provides separate models for primary and secondary windings, which can be adjusted to your needs individually. The coupling factors can be determined by a FEM-analysis or by an estimation of the magnetic resistances based on the core geometry.

There are also two parameterized models for three-phase transformers of *small* and *large* power. The parameters were determined by analyzing existing transformers with so-called EI-core.

[See also Six-Winding Transformer \(small and large Power\)](#)

See also Spiro, Hans: *Simulation integrierter Schaltungen durch universelle Rechenprogramme*, Verfahren und Praxis der rechnergestützten Simulation nichtlinearer Schaltungen, R. Oldenbourg Verlag München Wien, 1985

Single-Phase Systems

- [Transformer Primary Side of a Two-Winding-Transformer \(TFR1P1\)](#)
- [Transformer Secondary Side of a Two-Winding-Transformer \(TFR1P2\)](#)
- [Linear Two-Winding Transformer \(TFR1P2W\)](#)
- [Nonlinear Two-Winding Transformer \(TFRNL1P2W\)](#)
- [Ideal Two-Winding Transformer \(TWT\)](#)

Primary Side of a Two-Winding Transformer

Library: Basic Elements

Modeling Language: SML

Version Number: Twin Builder 2025.2

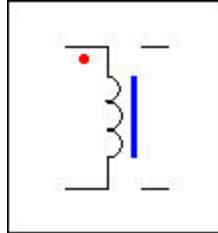


Figure 1. Component Symbol

- Description
- Assumptions and Limitations
- Mathematical Description
- Netlist Syntax
- Conservative Pins
- Parameters
- Input/Output Quantities
- Example
- References

Description

The component represents the primary side of a transformer based on the *Spiro* model, and its equivalent circuit is shown in Figure 2. For each coil, make sure a network path exists to the ground node. Within the dialog box, you can define the main and leakage inductances, the equivalent resistances for iron losses, the winding resistances for each side, and the initial values of the current. To define the parameter values, enter a numerical value, a variable, or expression in the corresponding field of parameter list.

Note: The terms primary and secondary are not intended in the strict sense. It simply means to combine exactly one macro of the primary side with at least one macro of the secondary side.

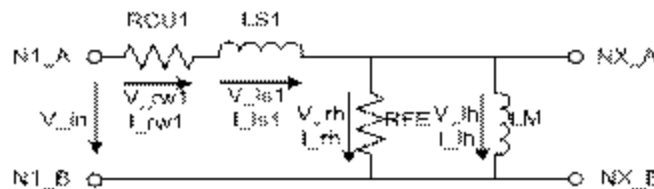


Figure 2. Equivalent Circuit of Primary Side of A Linear Transformer[Top](#)**Assumptions and Limitations**

This model does not take into account the magnetizing characteristics of the core.

[Top](#)**Mathematical Description**

Equations that are used to describe the linear two-winding transformer primary side are listed as follows:

$$V_{-rw1} = I_{-rw1} \cdot R_{cu1}$$

$$P_{si-ls1} = I_{-ls1} \cdot L_{ls1}$$

$$V_{-ls1} = \frac{d P_{si-ls1}}{d t}$$

$$P_{si-lh} = I_{-lh} \cdot L_M$$

$$V_{-lh} = \frac{d P_{si-lh}}{d t}$$

[Top](#)**Netlist Syntax**

Netlist generated by [Special Component Dialog](#).

[Top](#)**Conservative Pins****Table 1**

Name	Description	Nature/Data Type
N1_A	Positive Node on the Primary Side	electrical
N1_B	Negative Node on the Primary Side	electrical
NX_A	Positive Node at the Connection Point	electrical
NX_B	Negative Node at the Connection Point	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
LM	Magnetizing Inductance	real	0.1 [H]
LS1	Leakage Inductance Primary Side	real	1m [H]
RFE	Equivalent Resistance for Iron Losses	real	1.0e+018 [Ohm]
RCU1	Winding Resistance Primary Side	real	1u [Ohm]
I0	Initial Current	real	0 [A]

Note: Entering "_EMPTY" in the Initial Current field will allow the initial current to be set based on the simulation.

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
I1	Current Primary Side [A]	Output	real
V1	Voltage Primary Side [V]	Output	real

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Example

Figure 3 shows application of the primary and secondary side of linear two-winding transformers. The parameters of the voltage source are listed in Table 4. The simulation results in Figure 4 shows the simulation results.

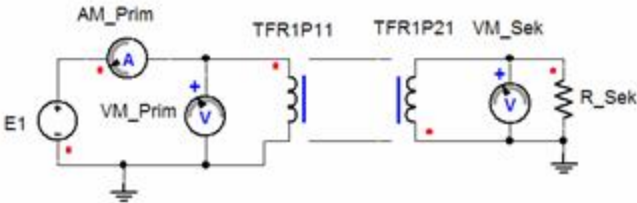
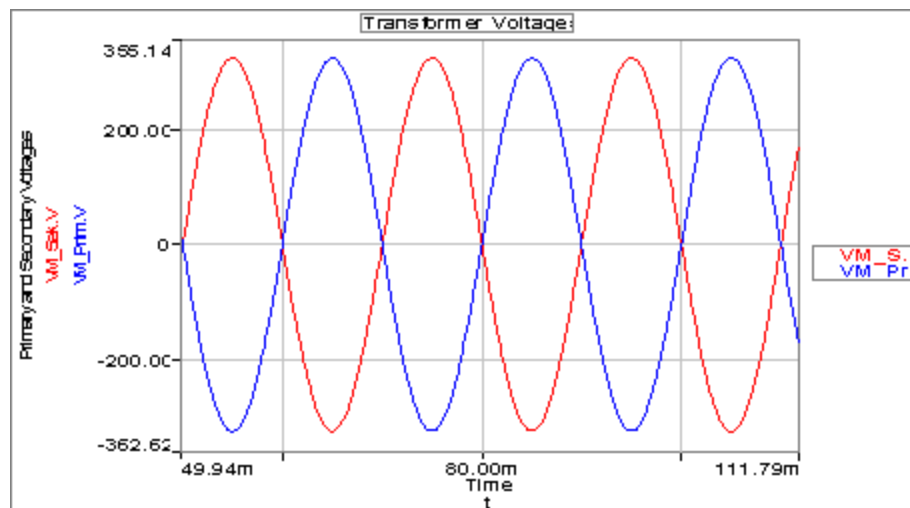


Figure 3. Application example of the primary and secondary side of linear two-winding transformers**Table 3**

Component	Parameter	Value
Voltage Source E1	AMPL	326 [V]
	FREQ	50 [Hz]
	PHASE	0 [degree]
	OFF	0 [V]
	TDELAY	0 [s]
Load R_sek	R	1 [ohm]
TFR1P11	LM	0.1 [H]
	LS1	1m [H]
	RFE	1.0e+018 [Ohm]
	RCU1	1u [Ohm]
TFR1P21	LS2	1m [H]
	RCU2	1u [Ohm]
	KTR	2 [/]

**Figure 4. Simulation results-voltages on the primary and secondary side of the transformer**[Top](#)

References

Secondary Side of a Two-Winding Transformer

Library: Basic Elements

Modeling Language: SML

Version Number: Twin Builder 2025.2

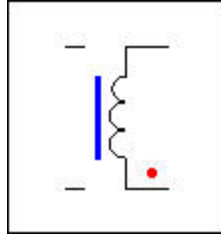


Figure 1. Component Symbol

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- Netlist Syntax
- Conservative Pins
- Parameters
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Description

The component represents the secondary side of a transformer based on the *Spiro* model, and its equivalent circuit is shown in Figure 2. For each coil make sure a network path exists to the ground node. Within the dialog users can define the main and leakage inductances, the equivalent resistances for iron losses, the winding resistances for each side, and the initial values of the current. To define the parameter values, enter a numerical value, a variable, or expression in the corresponding field of parameter list.

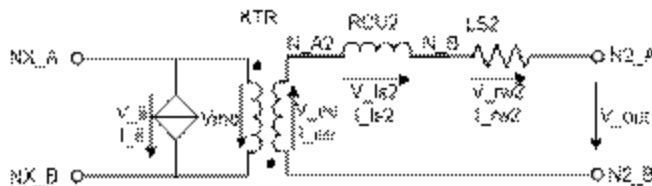


Figure 2. Equivalent circuit of the linear two-winding transformer secondary side

Note: The terms primary and secondary are not intended in the strict sense. It simply means to combine exactly one macro of the primary side with at least one macro of the secondary side.

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Assumptions and Limitations

This model does not take into account the magnetizing characteristics of the core.

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Mathematical Description

Equations that are used to describe the linear two-winding transformer secondary side are listed as follows:

$$I_{_n} = K_{TR} \cdot I_{_eu} = K_{TR} \cdot I_{_ls2}$$

$$V_{_eu} = V_{m0} \cdot K_{TR}$$

$$P_{si\_ls2} = I_{_ls2} \cdot L_{ls2}$$

$$V_{_ls2} = \frac{d P_{si\_ls2}}{d t}$$

$$V_{_rw2} = I_{_rw2} \cdot R_{cu2}$$

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
NX_A	Positive Node at the Connection Point	electrical
NX_B	Negative Node at the Connection Point	electrical
N2_A	Positive Node Secondary Side	electrical
N2_B	Negative Node Secondary Side	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
LS2	Leakage Inductance Secondary Side	real	1m [H]
RCU2	Winding Resistance Secondary Side	real	1u [Ohm]
KTR	Winding Ratio	real	1 [/]
I0	Initial Current	real	0 [A]

Note: Entering "_EMPTY" in the Initial Current field will allow the initial current to be set based on the simulation.

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
I2	Current Secondary Side [A]	Output	real
V2	Voltage Secondary Side [V]	Output	real

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Example

Figure 3 shows application of the primary and secondary side of linear two-winding transformers. The parameters of the voltage source are listed in Table 4. The simulation results in Figure 4 shows the simulation results.

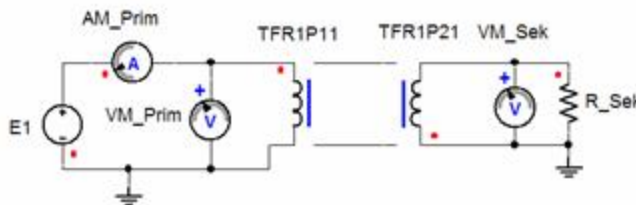


Figure 3. Application example of the primary and secondary side of linear two-winding transformers

Table 3

Component	Parameter	Value

Voltage Source E1	AMPL	326 [V]
	FREQ	50 [Hz]
	PHASE	0 [degree]
	OFF	0 [V]
	TDELAY	0 [s]
Resistor R_sek	R	1 [ohm]
TFR1P11	LM	0.1 [H]
	LS1	1m [H]
	RFE	1.0e+018 [Ohm]
	RCU1	1u [Ohm]
TFR1P21	LS2	1m [H]
	RCU2	1u [Ohm]
	KTR	2 [/]

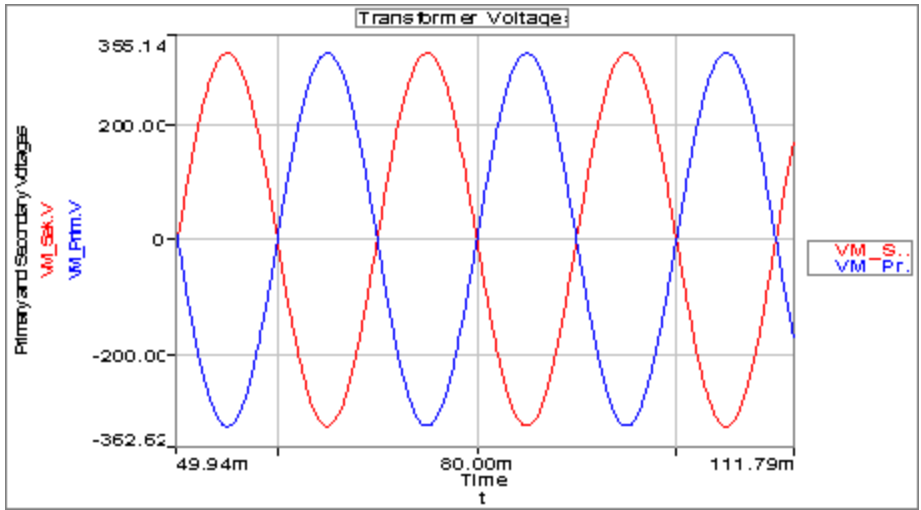


Figure 4. Simulation results-voltages on the primary and secondary side of the transformer

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References

Linear Two-Winding Transformer

Library: Basic Elements

Modeling Language: SML

Version Number: Twin Builder 2025.2

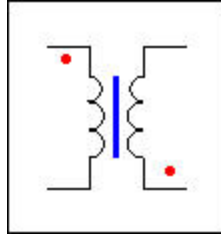


Figure 1. Component Symbol

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Description

The component represents a transformer based on the *Spiro* model, and the equivalent circuit is shown in Figure 2.. For each coil make sure a network path exists to the ground node. Within the dialog users can define the main and leakage inductances, the equivalent resistances for iron losses, the winding resistances for each side, and the initial values of the current. To define the parameter values, enter a numerical value, a variable, or expression in the corresponding field of parameter list.

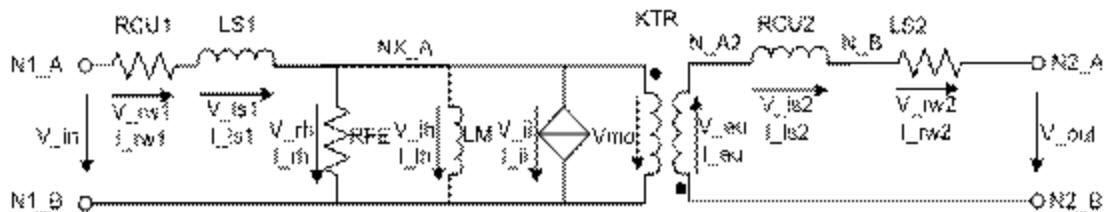


Figure 2. Equivalent circuit of the Linear Two-Winding Transformer

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Assumptions and Limitations

This model doesn't take into account the magnetizing characteristics of the core.

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Mathematical Description

Equations that are used to describe the linear two-winding transformer are listed as follows:

$$V_{rw1} = I_{rw1} \cdot R_{cu1}$$

$$P_{si\_ls1} = I_{ls1} \cdot L_{ls1}$$

$$V_{ls1} = \frac{d P_{si\_ls1}}{d t}$$

$$P_{si\_lh} = I_{lh} \cdot L_M$$

$$V_{lh} = \frac{d P_{si\_lh}}{d t}$$

$$V_{rh} = I_{rh} \cdot R_{FE}$$

$$I_{si} = K_{TR} \cdot I_{eu} = K_{TR} \cdot I_{ls2}$$

$$V_{eu} = v_{m0} \cdot K_{TR}$$

$$P_{si\_ls2} = I_{ls2} \cdot L_{ls2}$$

$$V_{ls2} = \frac{d P_{si\_ls2}}{d t}$$

$$V_{rw2} = I_{rw2} \cdot R_{cu2}$$

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
N1_A	Positive Node on the Primary Side	electrical

N1_B	Negative Node on the Primary Side	electrical
N2_A	Positive Node on the Secondary Side	electrical
N2_B	Negative Node on the Primary Side	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
LM	Main Inductance	real	0.1 [H]
LS1	Leakage Inductance Primary Side	real	1m [H]
LS2	Leakage Inductance Secondary Side	real	1m [H]
RFE	Equivalent Resistance for Iron Losses	real	1e+018 [Ohm]
RCU1	Winding Resistance Primary Side	real	1u [Ohm]
RCU2	Winding Resistance Secondary Side	real	1u [Ohm]
KTR	Coupling Factor	real	1 [/]
IP0	Initial Current Primary Side	real	0 [A]
IS0	Initial Current Secondary Side	real	0 [A]

Note: Entering "_EMPTY" in the Initial Current field will allow the initial current to be set based on the simulation.

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
V1	Voltage Primary Side [V]	Output	real
V2	Voltage Secondary Side [V]	Output	real

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Example

Fig 3 shows application of the linear two-winding transformer; the parameters of the system are listed in Table 4 and the simulation results in Figure 4.

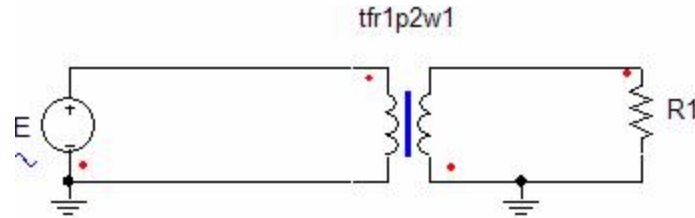


Figure 3. Application example of the linear two-winding transformer

Table 4

Component	Parameter	Value
Two-Winding Transformer tfr1p2w1	L_{s1}	0.001 [H]
	L_{s2}	0.001 [H]
	R_{FE}	1e18 [Ohm]
	K_{TR}	1
	L_m	0.1 [H]
	R_{cu1}	1e-6 [Ohm]
	R_{cu2}	1e-6 [Ohm]
	$I_0 - I_{s1}$	0.0 [A]
	$I_0 - I_{s2}$	0.0 [A]
Voltage Source (sinusoidal) E	AMPL	100 [V]
	FREQ	50 [Hz]
	PHASE	0 [degree]
	TDELAY	0 [s]
	OFF	0 [V]
Load R1	R	1K [Ohm]

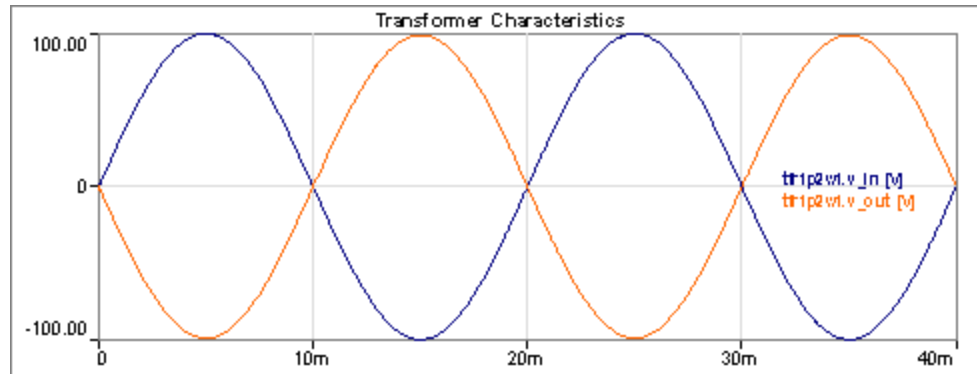


Figure 4. Simulation results – voltages on the primary and secondary side of the transformer

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References

Nonlinear Two-Winding Transformer

Library: Basic Elements

Modeling Language: SML

Version Number: Twin Builder 2025.2

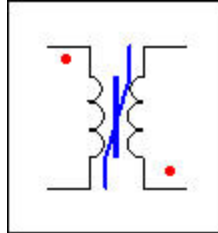


Figure 1. Component Symbol.

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Description

The component represents a transformer based on the *Spiro* model, and its equivalent circuit is shown in Figure 2. The characteristic describes the nonlinear mutual inductance without hysteresis ($L_M = f(I_h)$). L_M has to be >0 within the characteristic.

For each coil make sure a network path exists to the ground node. The macro does not provide an access to the initial value of the currents; these are assumed to be zero. Within the dialog you can define the main and leakage inductances, the equivalent resistances for iron losses and the winding resistances for each side.

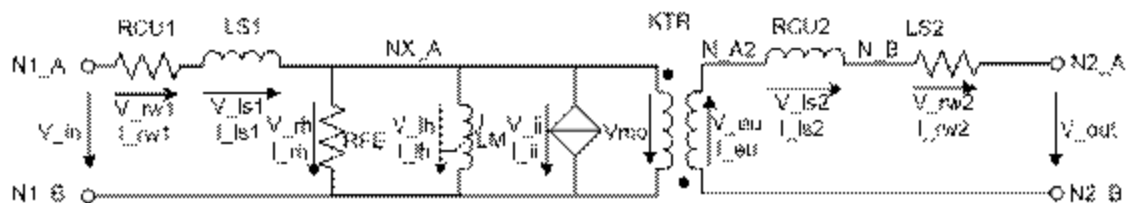


Figure 2. Equivalent circuit of the Nonlinear Two-Winding Transformer[Top](#)**Assumptions and Limitations**

This model doesn't take into account the magnetizing characteristics of the core.

[Top](#)**Mathematical Description**

Equations that are used to describe the linear two-winding transformer are listed as follows:

$$V_{rw1} = I_{rw1} \cdot R_{cu1}$$

$$P_{si\_ls1} = I_{ls1} \cdot L_{ls1}$$

$$V_{ls1} = \frac{d P_{si\_ls1}}{d t}$$

$$P_{si\_lh} = I_{lh} \cdot L_M$$

$$V_{lh} = \frac{d P_{si\_lh}}{d t}$$

$$V_{rh} = I_{rh} \cdot R_{FE}$$

$$I_{si} = K_{TR} \cdot I_{eu} = K_{TR} \cdot I_{ls2}$$

$$V_{eu} = V_{m0} \cdot K_{TR}$$

$$P_{si\_ls2} = I_{ls2} \cdot L_{ls2}$$

$$V_{ls2} = \frac{d P_{si\_ls2}}{d t}$$

$$V_{rw2} = I_{rw2} \cdot R_{cu2}$$

where L_M is nonlinear, and $L_M = f(I_{lh})$.

[Top](#)**Netlist Syntax**

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
N1_A, N1_B	Primary Side Node A and B	electrical
N2_A, N2_B	Secondary Side Node A and B	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
LS1	Leakage Inductance Primary Side	real	0.2u [H]
LS2	Leakage Inductance Secondary Side	real	0.2u [H]
RFE	Equivalent Resistance for Iron Losses	real	1Meg [Ohm]
RCU1	Winding Resistance Primary Side	real	0.3 [Ohm]
RCU2	Winding Resistance Secondary Side	real	0.3 [Ohm]
KTR	Coupling Factor	real	1 [/]
IP0	Initial current primary side	real	0 [A]
IS0	Initial current secondary side	real	0 [A]
CH	Characteristic	real	0

Note: Entering "_EMPTY" in the Initial Current field will allow the initial current to be set based on the simulation.

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
V1	Voltage Primary Side [V]	Output	real
V2	Voltage Secondary Side [V]	Output	real
I1	Current Primary Side [A]	Output	real
I2	Current Secondary Side [A]	Output	real

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Example

Fig 3 shows application of the nonlinear two-winding transformer; the parameters of the system are listed in Table 4 and the simulation results in Figure 4 and 5.

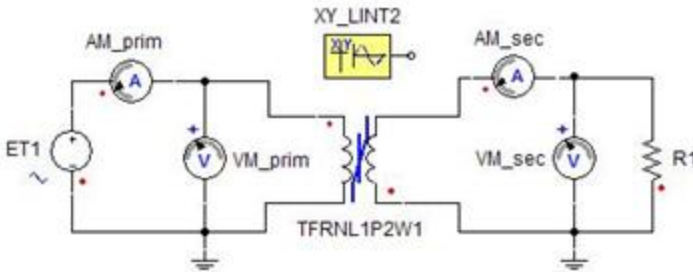


Figure 3. Application example of the nonlinear two-winding transformer

Table 4

Component	Parameter	Value
Two-Winding Nonlinear Transformer TFRNL1P2W1	LS1	0.2u [H]
	LS2	0.2u [H]
	RFE	1Meg [Ohm]
	RCU1	0.3 [Ohm]
	RCU2	0.3 [Ohm]
	KTR	2 [/]
	IP0	0 [A]
	ISO	0 [A]
	CH	XY_LINT2*

Voltage Source (sinusoidal) E	AMPL	1 [V]
	FREQ	100 [Hz]
	PHASE	0 [degree]
	TDELAY	0 [s]
	OFF	0 [V]
Resistor R1	R	10 [Ohm]

* Nonlinear characteristics of L_M is defined by the 2D Lookup Table XY_LINT2.

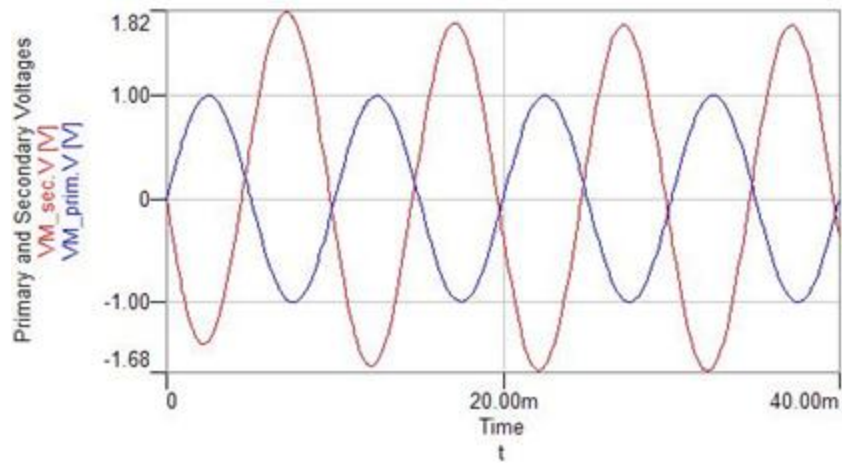


Figure 4. Simulation results – voltages on the primary and secondary side of the transformer

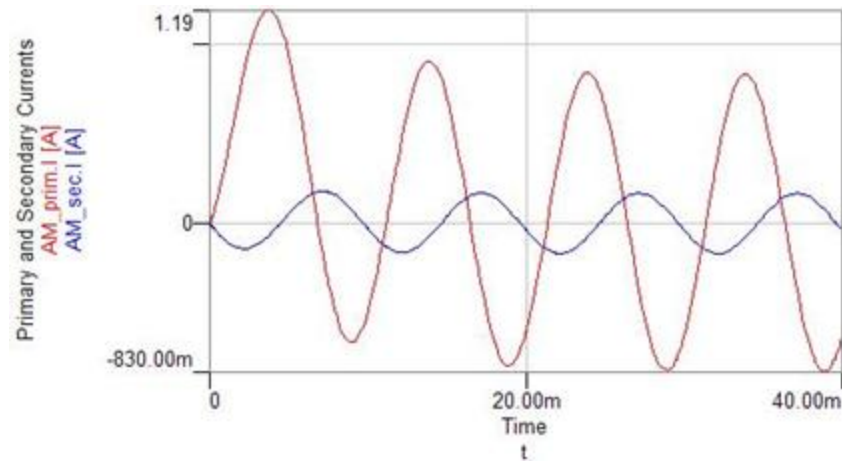


Figure 5. Simulation results – current thorough the primary and secondary side of the transformer

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References

Ideal Two-Winding Transformer

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

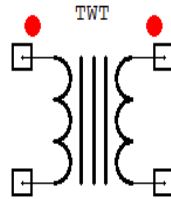


Figure 1. Component Symbol

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Description

The component represents an ideal transformer, characterized by the turns ratio, n . The ideal two-winding transformer is an internal component which is not based on the *Spiro* model.

NOTE: An alternative is to use the [mutual inductance model](#) which allows the user to model a transformer between two inductors, $L1$ and $L2$, quantitatively determined by the factor k .

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Assumptions and Limitations

This model doesn't take into account the magnetizing characteristics of the core, or the losses.

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Mathematical Description

The ideal linear two-winding transformer can be described as follows:

$$V2 = n \cdot V1$$

$$I1 = -n \cdot I2$$

where V1 and V2 are the voltage across the primary and the secondary side, respectively; I1 and I2 are the current through the primary and the secondary side; N1 and N2 are the number of turns used in the windings on the primary and the secondary; and $n = N2/N1$ is the turns ratio.

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Netlist Syntax

INTERN TWT ?InstanceName(@InstanceName):(@ (Rebase)@ (ID)) N1L1:= %0 , N2L1:= %1 , N1L2:= %2 , N2L2:= %3 (n:=@ (n)) ;

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
N1L1, N2L1	Inductor 1 – Node N1 and N2	electrical
N1L2, N2L2	Inductor 2 – Node N1 and N2	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
n	Turns Ratio	real	1 [none]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
V1	Voltage L1 [V]	Output	real
V2	Voltage L2 [V]	Output	real
I1	Current L1 [A]	Output	real
I2	Current L2 [A]	Output	real

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Example

Figure 2 shows an application example of the Ideal Linear Two-Winding Transformer. The parameters of the voltage sources are listed in Table 4 and the simulation results shown in Figure 3 and 4.

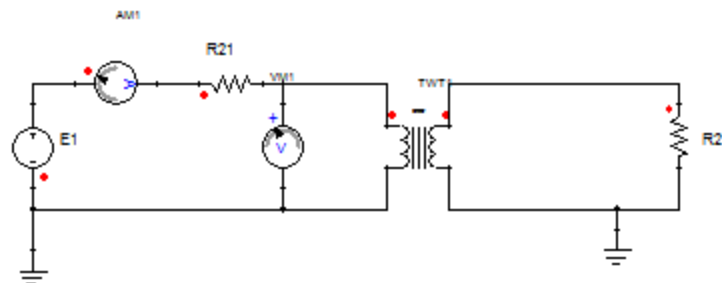


Figure 2. Application example of the linear two-winding transformer

Table 4

Component	Parameter	Value
Ideal Linear Two-Winding Transformer TWT1	n	2
Voltage Source (sinusoidal) E	AMPL	326 [V]
	FREQ	50 [Hz]
	PHASE	0 [degree]
	TDELAY	0 [s]
	OFF	0 [V]
Resistors R2/R21	R	10 [Ohm]

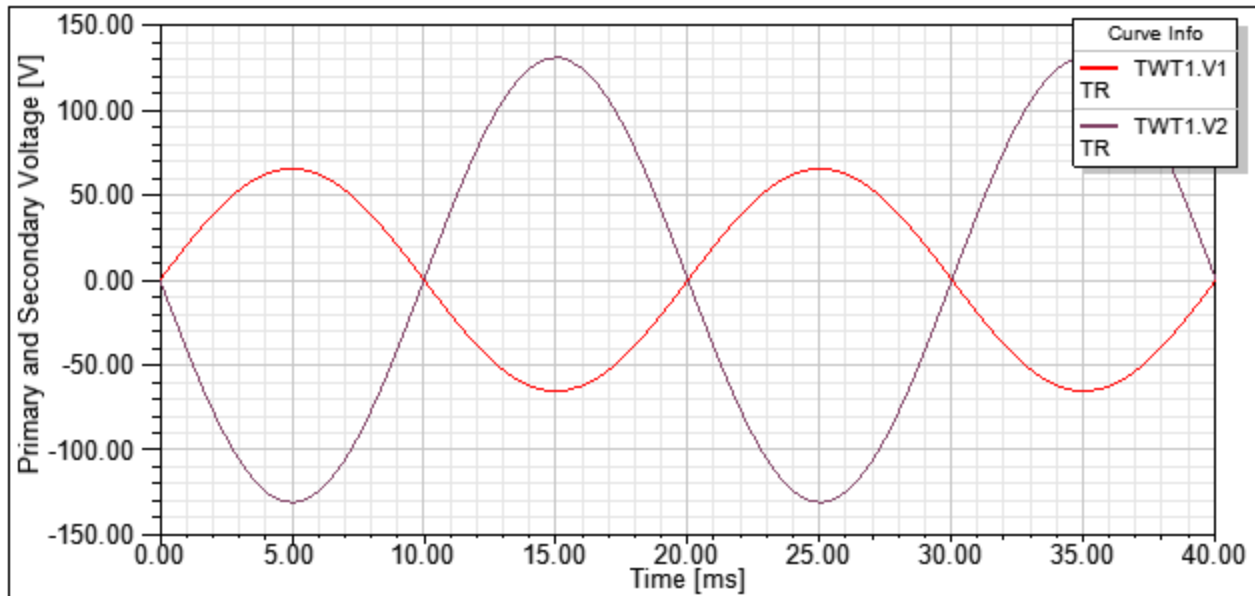


Figure 3. Simulation results for primary and secondary voltage of TWT1

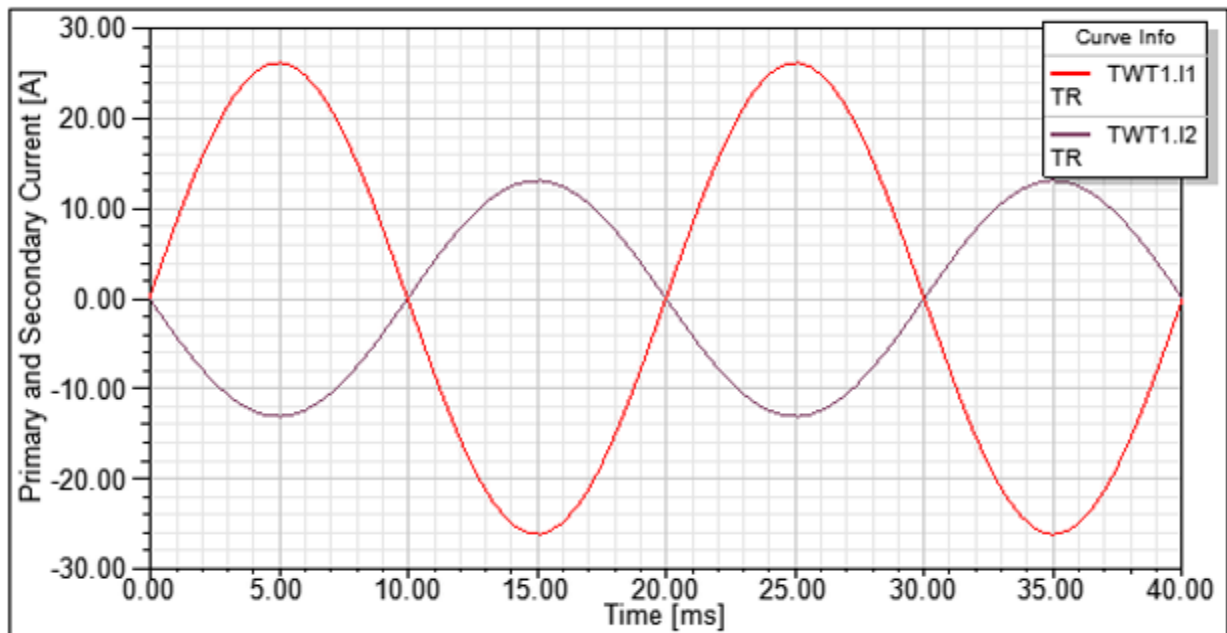


Figure 4. Simulation results for primary and secondary current of TWT1

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References

Three-Phase Systems

- [Transformer Primary Side of a Six-Winding-Transformer \(TFR3P1\)](#)
- [Transformer Secondary Side of a Six-Winding-Transformer \(TFR3P2\)](#)
- [Linear Three-Phase Six-Winding Transformer \(Large Power\) \(TFR3P6WL\)](#)
- [Linear Three-Phase Six-Winding Transformer \(Small Power\) \(TFR3P6WS\)](#)

Primary Side of a Six-Winding Transformer

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

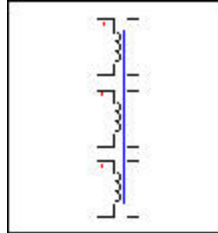


Figure 1. Component Symbol.

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- [Mathematical Description](#)
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Description

The component represents the primary side of linear six-winding transformers based on the *Spiro* model, and its equivalent circuit is shown in Figure 2. The use of this macro makes only sense with at least one macro of the secondary side. Using the Primary Side and Secondary Side of a Six-winding-Transformer allows a simple construction of a Three-Phase Transformer with more windings.

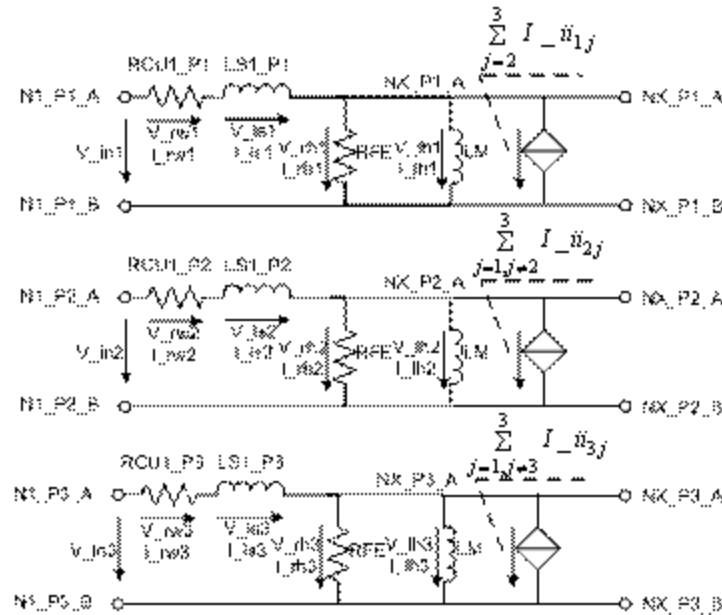


Figure 2. Equivalent circuit of the linear two-winding transformer primary side

Note: The terms primary and secondary are not intended in the strict sense. It simply means to combine exactly one macro of the primary side with at least one macro of the secondary side.

For each coil make sure a network path exists to the ground node. Within the dialog users can define the main and leakage inductances, the equivalent resistances for iron losses, the winding resistances for each side, and the initial values of the current. To define the parameter values, enter a numerical value, a variable, or expression in the corresponding field of parameter list.

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Assumptions and Limitations

This model does not take into account the magnetizing characteristics of the core.

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Mathematical Description

Equations that are used to describe the linear two-winding transformer primary side are listed as follows:

Phase 1	Phase 2	Phase 3
$V_{-rw1} = I_{-rw1} \cdot R_{cul\_p1}$	$V_{-rw2} = I_{-rw2} \cdot R_{cul\_p2}$	$V_{-rw3} = I_{-rw3} \cdot R_{cul\_p3}$
$P_{si\_ls1} = I_{-ls1} \cdot L_{ls1\_p1}$	$P_{si\_ls2} = I_{-ls2} \cdot L_{ls1\_p2}$	$P_{si\_ls3} = I_{-ls3} \cdot L_{ls1\_p3}$
$V_{-ls1} = \frac{d P_{si\_ls1}}{d t}$	$V_{-ls2} = \frac{d P_{si\_ls2}}{d t}$	$V_{-ls3} = \frac{d P_{si\_ls3}}{d t}$
$P_{si\_lh1} = I_{-lh1} \cdot L_M$	$P_{si\_lh2} = I_{-lh2} \cdot L_M$	$P_{si\_lh3} = I_{-lh3} \cdot L_M$

$V_{_lh1} = \frac{d P_{si\_lh1}}{d t}$	$V_{_lh2} = \frac{d P_{si\_lh2}}{d t}$	$V_{_lh3} = \frac{d P_{si\_lh3}}{d t}$
$V_{_rh1} = I_{_rh1} \cdot R_{FE}$	$V_{_rh2} = I_{_rh2} \cdot R_{FE}$	$V_{_rh3} = I_{_rh3} \cdot R_{FE}$
$I_{_ii12} = K_{TR1} \cdot I_{_rw2}$	$I_{_ii21} = K_{TR3} \cdot I_{_rw1}$	$I_{_ii31} = K_{TR2} \cdot I_{_rw1}$
$I_{_ii12} = K_{TR2} \cdot I_{_rw3}$	$I_{_ii23} = K_{TR3} \cdot I_{_rw3}$	$I_{_ii32} = K_{TR1} \cdot I_{_rw2}$

Where $K_{TR1} = 0.5$, $K_{TR2} = 0.25$, $K_{TR3} = 0.75$ for small-power transformers, and $K_{TR1} = 0.5$, $K_{TR2} = 0.333$, $K_{TR3} = 0.667$ for large-power transformers.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
N1_P1_A	Positive node on the primary side of phase 1	electrical
N1_P1_B	Negative node on the primary side of phase 1	electrical
N1_P2_A	Positive node on the primary side of phase 2	electrical
N1_P2_B	Negative node on the primary side of phase 2	electrical
N1_P3_A	Positive node on the primary side of phase 3	electrical
N1_P3_B	Negative node on the primary side of phase 3	electrical
NX_P1_A	Positive node at the connection point of phase 1	electrical
NX_P1_B	Negative node at the connection point of phase 1	electrical
NX_P2_A	Positive node at the connection point of phase 2	electrical
NX_P2_B	Negative node at the connection point of phase 2	electrical
NX_P3_A	Positive node at the connection point of phase 3	electrical
NX_P3_B	Negative node at the connection point of phase 3	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
LS1_P1	Leakage Inductance Primary Side of Phase 1	real	1m [H]
LS1_P2	Leakage Inductance Primary Side of Phase 2	real	1m [H]
LS1_P3	Leakage Inductance Primary Side of Phase 3	real	1m [H]
RCU1_P1	Winding Resistance Primary Side of Phase 1	real	1m [Ohm]
RCU1_P2	Winding Resistance Primary Side of Phase 2	real	1m [Ohm]
RCU1_P3	Winding Resistance Primary Side of Phase 3	real	1m [Ohm]
LM	Magnetizing Inductance	real	0.1 [H]
RFE	Equivalent Resistance for Iron Losses	real	1.0e+018 [Ohm]
KTR1	Coupling factor middle to outer limb	real	0.5
KTR2	Coupling factor outer to outer limb	real	0.25
KTR3	Coupling factor outer to middle limb	real	0.75
I0_IS1	Initial Current Primary Side of Phase 1	real	0 [A]
I0_IS2	Initial Current Primary Side of Phase 2	real	0 [A]
I0_IS3	Initial Current Primary Side of Phase 3	real	0 [A]

Note: Entering "_EMPTY" in the Initial Current field will allow the initial current to be set based on the simulation.

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Example

Figure 3 shows application of the linear six-winding transformer primary and secondary side (large power); the parameters of the transformer are set to the default values, and the parameters of the voltage sources are listed in Table 4 and the simulation results shown in Figure 4.

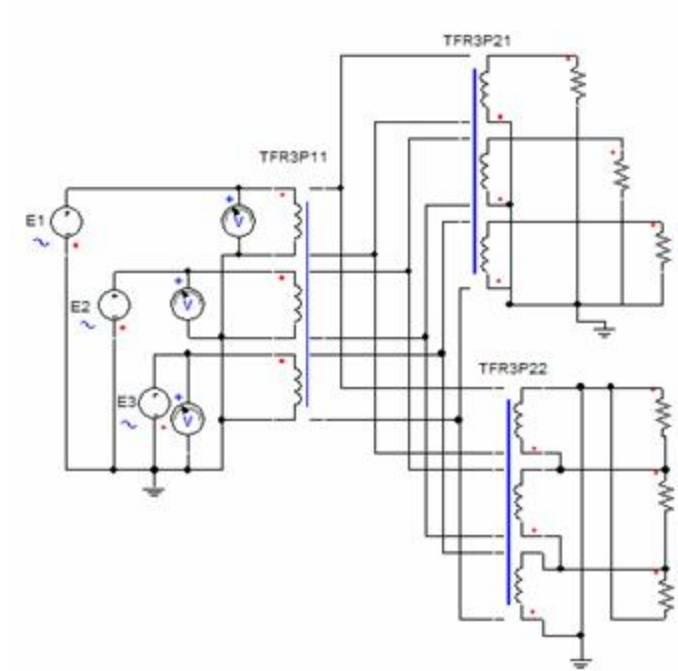


Figure 3. Application example of the primary and secondary sides of the linear six-winding transformer (small power)

Table 3

Component	Parameter	Value
Voltage Source (sinusoidal) E1/E2/E3	AMPL	500 [V]
	FREQ	50 [Hz]
	PHASE	0/-120/-240 [degree]
	OFF	0 [V]
	TDELAY	0 [s]

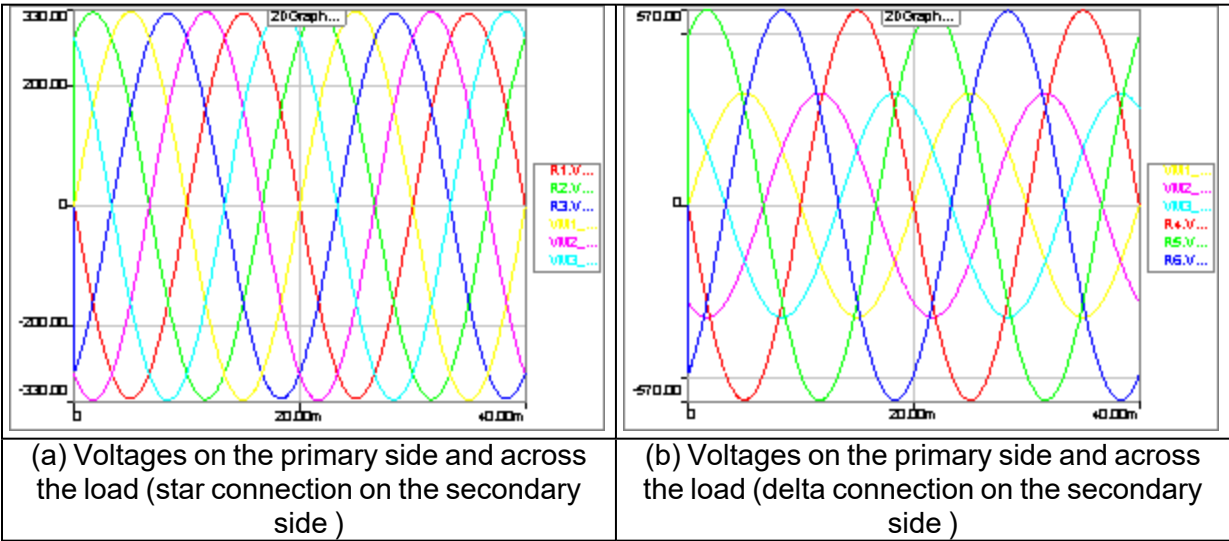


Figure 4. Simulation results-voltages on the primary and secondary sides of the transformer

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References

Secondary Side of a Six-Winding Transformer

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

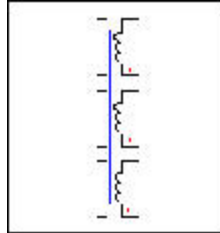


Figure 1. Component Symbol.

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Description

The component represents the secondary side of linear six-winding transformers based on the *Spiro* model. The equivalent circuit that is used to model linear six-winding transformers is shown in Fig 2. The use of this macro makes only sense with at least one macro of the secondary side. Using the Primary Side and Secondary Side of a Six-winding-Transformer allows a simple construction of a Three-Phase Transformer with more windings.

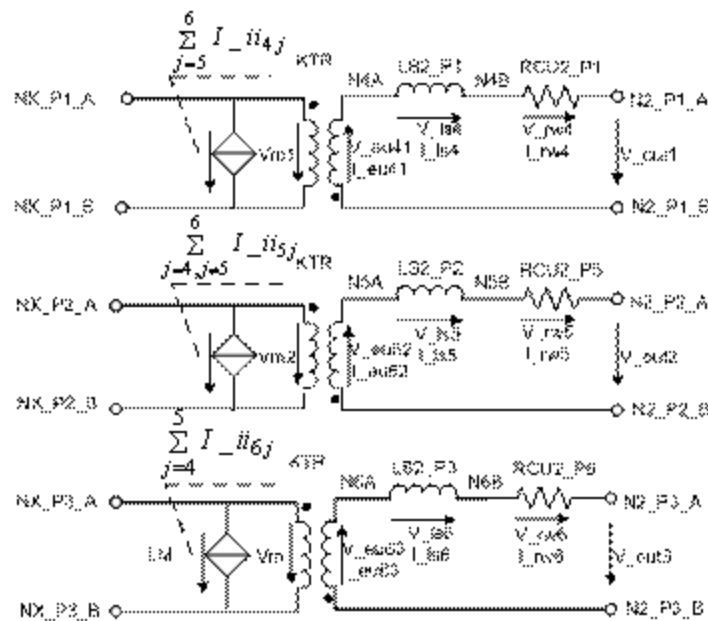


Figure 2. Equivalent circuit of the linear two-winding transformer secondary side

Note: The terms primary and secondary are not intended in the strict sense. It simply means to combine exactly one macro of the primary side with at least one macro of the secondary side.

For each coil make sure a network path exists to the ground node. Within the dialog users can define the main and leakage inductances, the equivalent resistances for iron losses, the winding resistances for each side, and the initial values of the current. To define the parameter values, enter a numerical value, a variable, or expression in the corresponding field of parameter list.

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Assumptions and Limitations

This model does not take into account the magnetizing characteristics of the core.

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Mathematical Description

Equations that are used to describe the linear two-winding transformer secondary side are listed as follows:

Phase 1	Phase 2	Phase 3
$I_{n14} = K_{TR} \cdot I_{rw4}$	$I_{n24} = K_{TR23} \cdot I_{rw4}$	$I_{n34} = K_{TR22} \cdot I_{rw4}$
$I_{n15} = K_{TR21} \cdot I_{rw5}$	$I_{n25} = K_{TR} \cdot I_{rw5}$	$I_{n35} = K_{TR21} \cdot I_{rw5}$
$I_{n16} = K_{TR22} \cdot I_{rw6}$	$I_{n26} = K_{TR23} \cdot I_{rw6}$	$I_{n36} = K_{TR} \cdot I_{rw6}$
$V_{eu41} = v_{m1} \cdot K_{TR}$	$V_{eu52} = v_{m2} \cdot K_{TR}$	$V_{eu63} = v_{m3} \cdot K_{TR}$

$P_{si\_ls4} = I_{ls4} \cdot L_{ls2\_p1}$	$P_{si\_ls5} = I_{ls5} \cdot L_{ls2\_p2}$	$P_{si\_ls6} = I_{ls6} \cdot L_{ls2\_p3}$
$V_{ls4} = \frac{d P_{si\_ls4}}{d t}$	$V_{ls5} = \frac{d P_{si\_ls5}}{d t}$	$V_{ls6} = \frac{d P_{si\_ls6}}{d t}$
$V_{rw4} = I_{rw4} \cdot R_{cu2\_p1}$	$V_{rw5} = I_{rw5} \cdot R_{cu2\_p2}$	$V_{rw6} = I_{rw6} \cdot R_{cu2\_p3}$
$I_{ii14} = K_{TR} \cdot I_{rw4}$	$I_{ii24} = K_{TR23} \cdot I_{rw4}$	$I_{ii34} = K_{TR22} \cdot I_{rw4}$

Where $K_{TR21} = 0.5 \cdot K_{TR}$, $K_{TR22} = 0.25 \cdot K_{TR}$, $K_{TR21} = 0.75 \cdot K_{TR}$ for small-power transformers, and $K_{TR21} = 0.5 \cdot K_{TR}$, $K_{TR22} = 0.333 \cdot K_{TR}$, $K_{TR21} = 0.667 \cdot K_{TR}$ for large-power transformers.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
N1_P1_A	Positive node on the primary side of phase 1	electrical
N1_P1_B	Negative node on the primary side of phase 1	electrical
N2_P1_A	Positive node on the secondary side of phase 1	electrical
N2_P1_B	Negative node on the secondary side of phase 1	electrical
N1_P2_A	Positive node on the primary side of phase 2	electrical
N1_P2_B	Negative node on the primary side of phase 2	electrical
N2_P2_A	Positive node on the secondary side of phase 2	electrical
N2_P2_B	Negative node on the secondary side of phase 2	electrical
N1_P3_A	Positive node on the primary side of phase 3	electrical
N1_P3_B	Negative node on the primary side of phase 3	electrical
N2_P3_A	Positive node on the secondary side of phase 3	electrical
N2_P3_B	Negative node on the secondary side of phase 3	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
LS2_P1	Leakage Inductance Secondary Side of Phase 1	real	1m [H]
LS2_P2	Leakage Inductance Secondary Side of Phase 2	real	1m [H]
LS2_P3	Leakage Inductance Secondary Side of Phase 3	real	1m [H]
RCU2_P1	Winding Resistance Secondary Side of Phase 1	real	1m [Ohm]
RCU2_P2	Winding Resistance Secondary Side of Phase 2	real	1m [Ohm]
RCU2_P3	Winding Resistance Secondary Side of Phase 3	real	1m [Ohm]
KTR0	Winding Ratio	real	1
KTR1	Coupling factor middle to outer limb	real	0.5
KTR2	Coupling factor outer to outer limb	real	0.25
KTR3	Coupling factor outer to middle limb	real	0.75
I0_P1	Initial Current Secondary Side of Phase 1	real	0 [A]
I0_P2	Initial Current Secondary Side of Phase 2	real	0 [A]
I0_P3	Initial Current Secondary Side of Phase 3	real	0 [A]

Note: Entering "_EMPTY" in the Initial Current field will allow the initial current to be set based on the simulation.

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Example

Figure 3 shows application of the linear six-winding transformer primary and secondary side (large power); the parameters of the transformer are set to the default values, and the parameters of the voltage sources are listed in Table 4 and the simulation results shown in Figure 4.

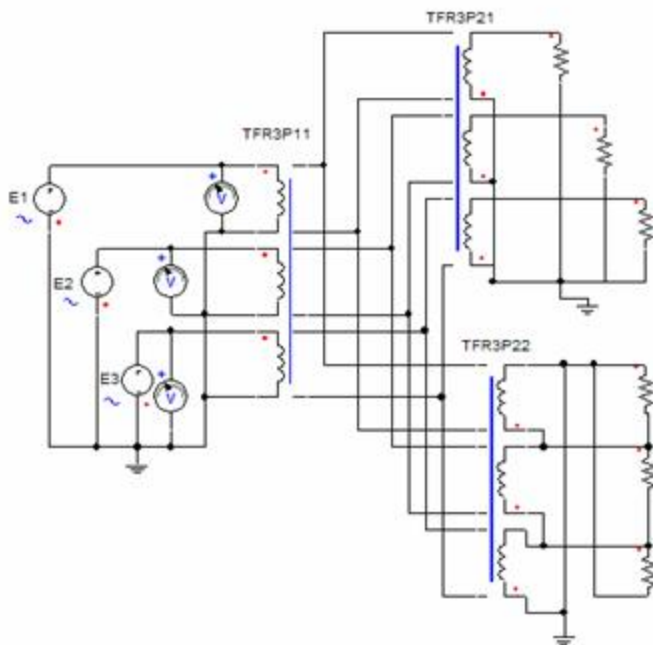
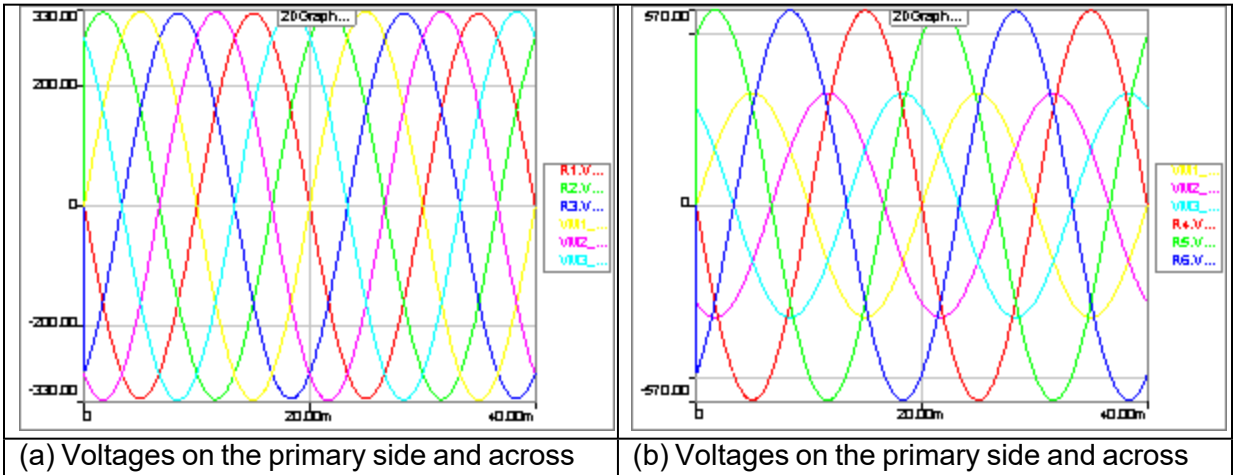


Figure 3. Application example of the primary and secondary side of the linear six-winding transformer (small power)

Table 3

Component	Parameter	Value
Voltage Source (sinusoidal) E1/E2/E3	AMPL	500 [V]
	FREQ	50 [Hz]
	PHASE	0/-120/-240 [degree]
	OFF	0 [V]
	TDELAY	0 [s]



the load (star connection on the secondary side)	the load (delta connection on the secondary side)

Figure 4. Simulation results-voltages on the primary and secondary side of the transformer

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References

Six-Winding Transformer (Large Power)

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

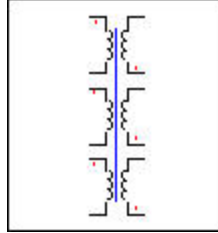


Figure 1. Component Symbol.

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Description

The component represents linear six-winding transformers (large power/small power) based on the *Spiro* model. For each coil, make sure a network path exists to the ground node. Within the dialog box, you can define the main and leakage inductances, the equivalent resistances for iron losses, the winding resistances for each side, and the initial values of the current. To define the parameter values, enter a numerical value, a variable, or expression in the corresponding field of parameter list. The six-winding large-power and small-power transformers differ in the core structure, as described in detail in the Mathematical Description of the Model section.

The equivalent circuit that is used to model linear six-winding transformers is shown in Figure 2. The Iron core structure of the large-power transformers is shown in Figure 3.

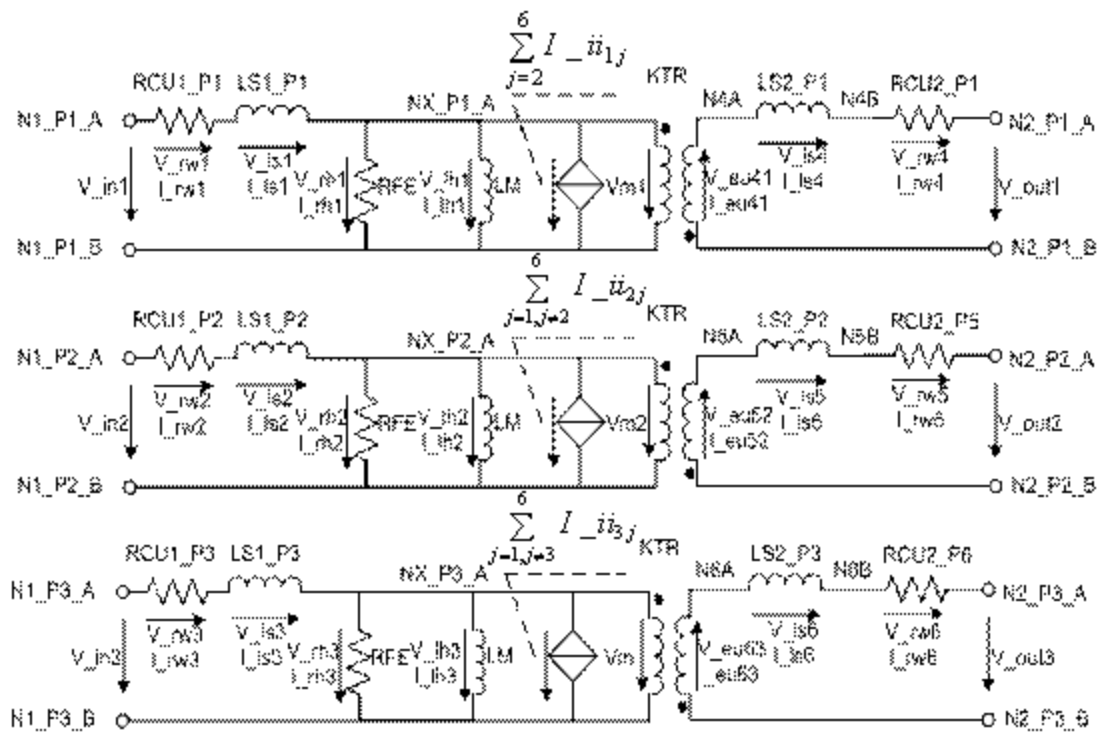


Figure 2. Equivalent circuit of the linear two-winding transformer

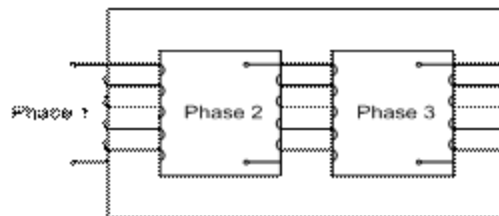


Figure 3. Structure of the iron core of the six-winding transformer (large power)

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Assumptions and Limitations

This model does not take into account the magnetizing characteristics of the core.

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Mathematical Description

Equations that are used to describe the linear two-winding transformer are listed as follows:

Phase 1	Phase 2	Phase 3

Primary Side	$V_{rw1} = I_{rw1} \cdot R_{cu1\_p1}$	$V_{rw2} = I_{rw2} \cdot R_{cu1\_p2}$	$V_{rw1} = I_{rw1} \cdot R_{cu1\_p3}$
	$P_{si\_ls1} = I_{ls1} \cdot L_{ls1\_p1}$	$P_{si\_ls2} = I_{ls2} \cdot L_{ls1\_p2}$	$P_{si\_ls5} = I_{ls5} \cdot L_{ls1\_p3}$
	$V_{ls1} = \frac{d P_{si\_ls1}}{d t}$	$V_{ls2} = \frac{d P_{si\_ls2}}{d t}$	$V_{ls5} = \frac{d P_{si\_ls5}}{d t}$
	$P_{si\_lh1} = I_{lh1} \cdot L_M$	$P_{si\_lh2} = I_{lh2} \cdot L_M$	$P_{si\_lh3} = I_{lh3} \cdot L_M$
	$V_{lh1} = \frac{d P_{si\_lh1}}{d t}$	$V_{lh2} = \frac{d P_{si\_lh2}}{d t}$	$V_{lh3} = \frac{d P_{si\_lh3}}{d t}$
	$V_{rh1} = I_{rh1} \cdot R_{FE}$	$V_{rh2} = I_{rh2} \cdot R_{FE}$	$V_{rh3} = I_{rh3} \cdot R_{FE}$
	$I_{ii12} = K_{TR11} \cdot I_{rw2}$	$I_{ii21} = K_{TR13} \cdot I_{rw1}$	$I_{ii31} = K_{TR12} \cdot I_{rw1}$
	$I_{ii12} = K_{TR12} \cdot I_{rw3}$	$I_{ii23} = K_{TR13} \cdot I_{rw3}$	$I_{ii32} = K_{TR11} \cdot I_{rw2}$
	$I_{ii14} = K_{TR} \cdot I_{rw4}$	$I_{ii24} = K_{TR23} \cdot I_{rw4}$	$I_{ii34} = K_{TR22} \cdot I_{rw4}$
	$I_{ii15} = K_{TR21} \cdot I_{rw5}$	$I_{ii25} = K_{TR} \cdot I_{rw5}$	$I_{ii35} = K_{TR21} \cdot I_{rw5}$
Secondary Side	$I_{ii16} = K_{TR22} \cdot I_{rw6}$	$I_{ii26} = K_{TR23} \cdot I_{rw6}$	$I_{ii36} = K_{TR} \cdot I_{rw6}$
	$V_{eu41} = v_{m1} \cdot K_{TR}$	$V_{eu52} = v_{m2} \cdot K_{TR}$	$V_{eu63} = v_{m3} \cdot K_{TR}$
	$P_{si\_ls4} = I_{ls4} \cdot L_{ls2\_p1}$	$P_{si\_ls5} = I_{ls5} \cdot L_{ls2\_p2}$	$P_{si\_ls6} = I_{ls6} \cdot L_{ls2\_p3}$
	$V_{ls4} = \frac{d P_{si\_ls4}}{d t}$	$V_{ls5} = \frac{d P_{si\_ls5}}{d t}$	$V_{ls6} = \frac{d P_{si\_ls6}}{d t}$
	$V_{rw4} = I_{rw4} \cdot R_{cu2\_p1}$	$V_{rw5} = I_{rw5} \cdot R_{cu2\_p2}$	$V_{rw6} = I_{rw6} \cdot R_{cu2\_p3}$

Where $K_{TR11} = 0.5$, $K_{TR12} = 0.333$, $K_{TR13} = 0.667$, $K_{TR21} = 0.5 \cdot K_{TR}$, $K_{TR22} = 0.333 \cdot K_{TR}$,
 $K_{TR21} = 0.667 \cdot K_{TR}$ for large-power transformers.

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Netlist Syntax

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
N1_P1_A	Positive node on the primary side of phase 1	Electrical
N1_P1_B	Negative node on the primary side of phase 1	Electrical
N2_P1_A	Positive node on the secondary side of phase 1	Electrical
N2_P1_B	Negative node on the secondary side of phase 1	Electrical
N1_P2_A	Positive node on the primary side of phase 2	Electrical
N1_P2_B	Negative node on the primary side of phase 2	Electrical
N2_P2_A	Positive node on the secondary side of phase 2	Electrical
N2_P2_B	Negative node on the secondary side of phase 2	Electrical
N1_P3_A	Positive node on the primary side of phase 3	Electrical
N1_P3_B	Negative node on the primary side of phase 3	Electrical
N2_P3_A	Positive node on the secondary side of phase 3	Electrical
N2_P3_B	Negative node on the secondary side of phase 3	Electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
LS1_P1	Leakage Inductance Primary Side of Phase 1	real	1m [H]
LS2_P1	Leakage Inductance Secondary Side of Phase 1	real	1m [H]
LS1_P2	Leakage Inductance Primary Side of Phase 2	real	1m [H]
LS2_P2	Leakage Inductance Secondary Side of Phase 2	real	1m [H]
LS1_P3	Leakage Inductance Primary Side of Phase 3	real	1m [H]

LS2_P3	Leakage Inductance Secondary Side of Phase 3	real	1m [H]
RCU1_P1	Winding Resistance Primary Side of Phase 1	real	1m [Ohm]
RCU2_P1	Winding Resistance Secondary Side of Phase 1	real	1m [Ohm]
RCU1_P2	Winding Resistance Primary Side of Phase 2	real	1m [Ohm]
RCU2_P2	Winding Resistance Secondary Side of Phase 2	real	1m [Ohm]
RCU1_P3	Winding Resistance Primary Side of Phase 3	real	1m [Ohm]
RCU2_P3	Winding Resistance Secondary Side of Phase 3	real	1m [Ohm]
LM	Magnetizing Inductance	real	0.1 [H]
RFE	Equivalent Resistance for Iron Losses	real	1.0e+018 [Ohm]
KTR	Winding Ratio (default value 1)	real	1
I0_P1	Initial Current Primary Side of Phase 1	real	0.0 [A]
I0_P2	Initial Current Primary Side of Phase 2	real	0.0 [A]
I0_P3	Initial Current Primary Side of Phase 3	real	0.0 [A]
I0_S1	Initial Current Secondary Side of Phase 1	real	0.0 [A]
I0_S2	Initial Current Secondary Side of Phase 2	real	0.0 [A]
I0_S3	Initial Current Secondary Side of Phase 3	real	0.0 [A]

Note: Entering "_Empty" in the Initial Current field will allow the initial current to be set based on the simulation.

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Example

Figure 4 shows application of the linear six-winding transformer (large power); the parameters of the transformer are set to the default values, and the parameters of the voltage sources are listed in Table 4 and the simulation results shown in Figure 5.

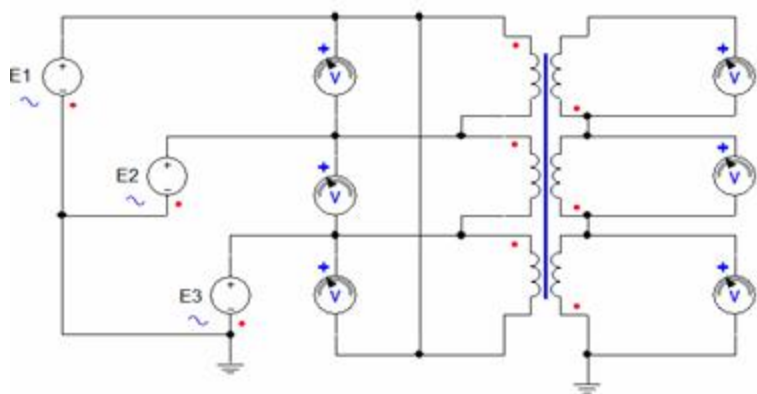


Figure 4. Application example of the linear six-winding transformer (large power)

Table 3

Component	Parameter	Value
Voltage Source (sinusoidal) E1/E2/E3	AMPL	500 [V]
	FREQ	50 [Hz]
	PHASE	0/-120/-240 [degree]
	OFF	0 [V]
	TDELAY	0 [s]



Figure 5. Simulation results – voltages on the primary and secondary sides of the transformer

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References

Six-Winding Transformer (Small Power)

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

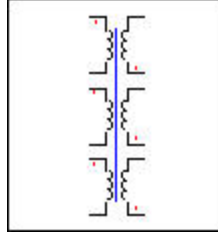


Figure 1. Component Symbol.

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Description

The component represents linear six-winding transformers (large power/small power) based on the *Spiro* model. For each coil, make sure a network path exists to the ground node. Within the dialog box, you can define the main and leakage inductances, the equivalent resistances for iron losses, the winding resistances for each side, and the initial values of the current. To define the parameter values, enter a numerical value, a variable, or expression in the corresponding field of parameter list. The six-winding large-power and small-power transformers differ in the core structure, as described in detail in the Mathematical Description of the Model section.

The equivalent circuit that is used to model linear six-winding transformers is shown in Figure 2. The Iron core structure of the large-power transformers is shown in Figure 3.

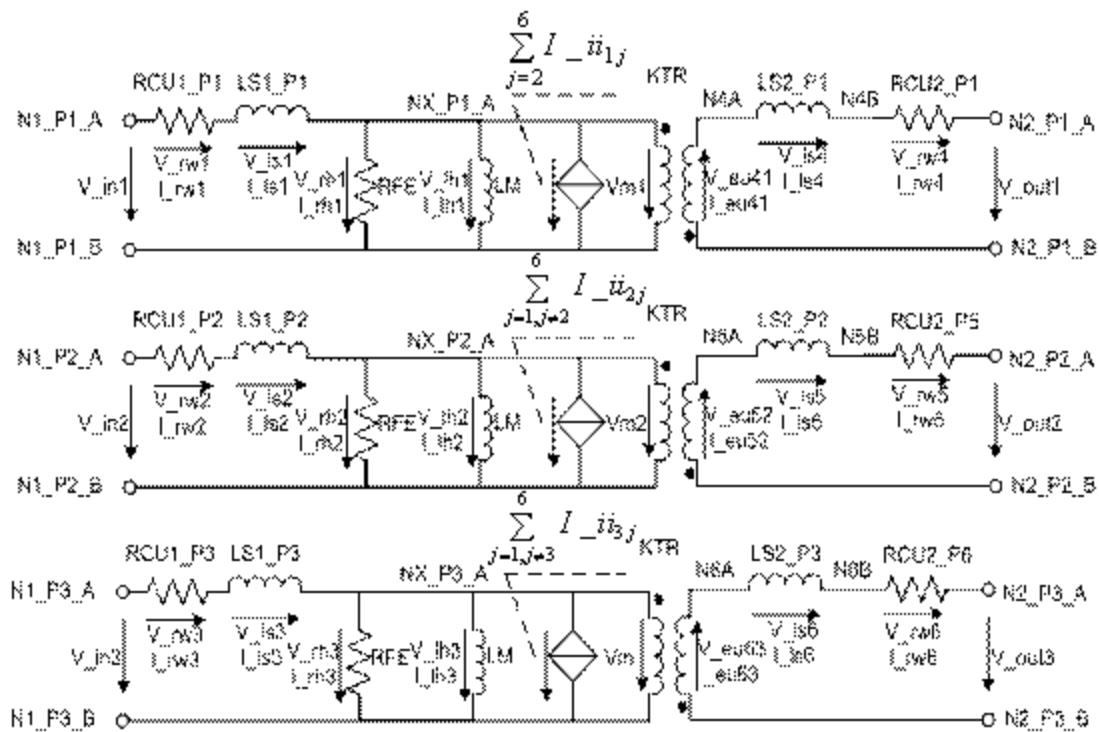


Figure 2. Equivalent circuit of the linear two-winding transformer

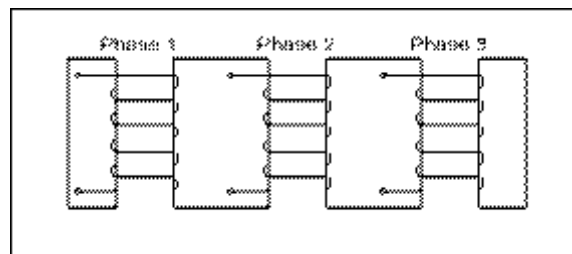


Figure 3 Structure of the iron core of the six-winding transformer (small power)

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Assumptions and Limitations

This model does not take into account the magnetizing characteristics of the core.

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Mathematical Description

Equations that are used to describe the linear two-winding transformer are listed as follows:

Phase 1	Phase 2	Phase 3

Primary Side	$V_{rw1} = I_{rw1} \cdot R_{cu1\_p1}$	$V_{rw2} = I_{rw2} \cdot R_{cu1\_p2}$	$V_{rw1} = I_{rw1} \cdot R_{cu1\_p3}$
	$P_{si\_ls1} = I_{ls1} \cdot L_{ls1\_p1}$	$P_{si\_ls2} = I_{ls2} \cdot L_{ls1\_p2}$	$P_{si\_ls5} = I_{ls5} \cdot L_{ls1\_p3}$
	$V_{ls1} = \frac{d P_{si\_ls1}}{d t}$	$V_{ls2} = \frac{d P_{si\_ls2}}{d t}$	$V_{ls5} = \frac{d P_{si\_ls5}}{d t}$
	$P_{si\_lh1} = I_{lh1} \cdot L_M$	$P_{si\_lh2} = I_{lh2} \cdot L_M$	$P_{si\_lh3} = I_{lh3} \cdot L_M$
	$V_{lh1} = \frac{d P_{si\_lh1}}{d t}$	$V_{lh2} = \frac{d P_{si\_lh2}}{d t}$	$V_{lh3} = \frac{d P_{si\_lh3}}{d t}$
	$V_{rh1} = I_{rh1} \cdot R_{FE}$	$V_{rh2} = I_{rh2} \cdot R_{FE}$	$V_{rh3} = I_{rh3} \cdot R_{FE}$
	$I_{ii12} = K_{TR11} \cdot I_{rw2}$	$I_{ii21} = K_{TR13} \cdot I_{rw1}$	$I_{ii31} = K_{TR12} \cdot I_{rw1}$
	$I_{ii12} = K_{TR12} \cdot I_{rw3}$	$I_{ii23} = K_{TR13} \cdot I_{rw3}$	$I_{ii32} = K_{TR11} \cdot I_{rw2}$
	$I_{ii14} = K_{TR} \cdot I_{rw4}$	$I_{ii24} = K_{TR23} \cdot I_{rw4}$	$I_{ii34} = K_{TR22} \cdot I_{rw4}$
	$I_{ii15} = K_{TR21} \cdot I_{rw5}$	$I_{ii25} = K_{TR} \cdot I_{rw5}$	$I_{ii35} = K_{TR21} \cdot I_{rw5}$
Secondary Side	$I_{ii16} = K_{TR22} \cdot I_{rw6}$	$I_{ii26} = K_{TR23} \cdot I_{rw6}$	$I_{ii36} = K_{TR} \cdot I_{rw6}$
	$V_{eu41} = v_{m1} \cdot K_{TR}$	$V_{eu52} = v_{m2} \cdot K_{TR}$	$V_{eu63} = v_{m3} \cdot K_{TR}$
	$P_{si\_ls4} = I_{ls4} \cdot L_{ls2\_p1}$	$P_{si\_ls5} = I_{ls5} \cdot L_{ls2\_p2}$	$P_{si\_ls6} = I_{ls6} \cdot L_{ls2\_p3}$
	$V_{ls4} = \frac{d P_{si\_ls4}}{d t}$	$V_{ls5} = \frac{d P_{si\_ls5}}{d t}$	$V_{ls6} = \frac{d P_{si\_ls6}}{d t}$
	$V_{rw4} = I_{rw4} \cdot R_{cu2\_p1}$	$V_{rw5} = I_{rw5} \cdot R_{cu2\_p2}$	$V_{rw6} = I_{rw6} \cdot R_{cu2\_p3}$

Where $K_{TR11} = 0.5$, $K_{TR12} = 0.25$, $K_{TR13} = 0.75$, $K_{TR21} = 0.5 \cdot K_{TR}$, $K_{TR22} = 0.25 \cdot K_{TR}$, $K_{TR23} = 0.75 \cdot K_{TR}$ for small-power transformers.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
N1_P1_A	Positive node on the primary side of phase 1	electrical
N1_P1_B	Negative node on the primary side of phase 1	electrical
N2_P1_A	Positive node on the secondary side of phase 1	electrical
N2_P1_B	Negative node on the secondary side of phase 1	electrical
N1_P2_A	Positive node on the primary side of phase 2	electrical
N1_P2_B	Negative node on the primary side of phase 2	electrical
N2_P2_A	Positive node on the secondary side of phase 2	electrical
N2_P2_B	Negative node on the secondary side of phase 2	electrical
N1_P3_A	Positive node on the primary side of phase 3	electrical
N1_P3_B	Negative node on the primary side of phase 3	electrical
N2_P3_A	Positive node on the secondary side of phase 3	electrical
N2_P3_B	Negative node on the secondary side of phase 3	electrical

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
LS1_P1	Leakage Inductance Primary Side of Phase 1	real	1m [H]
LS2_P1	Leakage Inductance Secondary Side of Phase 1	real	1m [H]
LS1_P2	Leakage Inductance Primary Side of Phase 2	real	1m [H]
LS2_P2	Leakage Inductance Secondary Side of Phase 2	real	1m [H]
LS1_P3	Leakage Inductance Primary Side of Phase 3	real	1m [H]
LS2_P3	Leakage Inductance Secondary Side of Phase 3	real	1m [H]
RCU1_P1	Winding Resistance Primary Side of Phase 1	real	1m [Ohm]
RCU2_P1	Winding Resistance Secondary Side of Phase 1	real	1m [Ohm]
RCU1_P2	Winding Resistance Primary Side of Phase 2	real	1m [Ohm]
RCU2_P2	Winding Resistance Secondary Side of Phase 2	real	1m [Ohm]
RCU1_P3	Winding Resistance Primary Side of Phase 3	real	1m [Ohm]
RCU2_P3	Winding Resistance Secondary Side of Phase 3	real	1m [Ohm]
LM	Magnetizing Inductance	real	0.1 [H]
RFE	Equivalent Resistance for Iron Losses	real	1.0e+018 [Ohm]
KTR	Winding Ratio (default value 1)	real	1
I0_P1	Initial Current Primary Side of Phase 1	real	0.0 [A]
I0_P2	Initial Current Primary Side of Phase 2	real	0.0 [A]
I0_P3	Initial Current Primary Side of Phase 3	real	0.0 [A]
I0_S1	Initial Current Secondary Side of Phase 1	real	0.0 [A]
I0_S2	Initial Current Secondary Side of Phase 2	real	0.0 [A]
I0_S3	Initial Current Secondary Side of Phase 3	real	0.0 [A]

Note: Entering "_Empty" in the Initial Current field will allow the initial current to be set based on the simulation.

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Example

Figure 4 shows application of the linear six-winding transformer (small power); the parameters of the transformer are set to the default values, and the parameters of the voltage sources are listed in Table 4 and the simulation results shown in Figure 5 and 6.

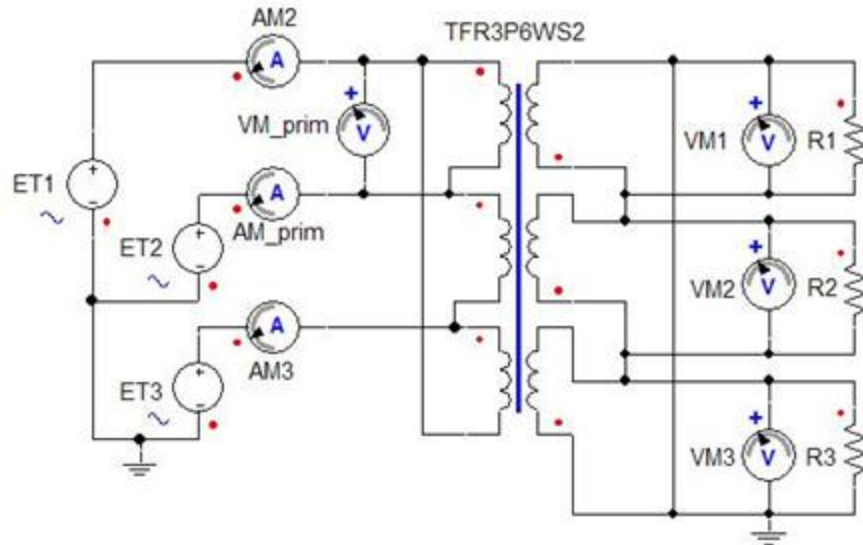


Figure 4. Application example of the linear six-winding transformer (small power)

Table 3

Component	Parameter	Value
Voltage Source (sinusoidal) E1/E2/E3	AMPL	326 [V]
	FREQ	50 [Hz]
	PHASE	0/-120/-240 [degree]
	OFF	0 [V]
	TDELAY	0 [s]
Resistor R1/R2/R3	R	10 [Ohm]

Linear Six-Winding Transformer
(Small Power) TFR3P6WS2

LS1_P1	1m [H]
LS2_P1	1m [H]
LS1_P2	1m [H]
LS2_P2	1m [H]
LS1_P3	1m [H]
LS2_P3	1m [H]
RCU1_P1	1m [Ohm]
RCU2_P1	1m [Ohm]
RCU1_P2	1m [Ohm]
RCU2_P2	1m [Ohm]
RCU1_P3	1m [Ohm]
RCU2_P3	1m [Ohm]
LM	0.1 [H]
RFE	1.0e+018 [Ohm]
KTR	2
I0_IS1	0.0 [A]
I0_IS2	0.0 [A]
I0_IS3	0.0 [A]
I0_IS4	0.0 [A]
I0_IS5	0.0 [A]
I0_IS6	0.0 [A]

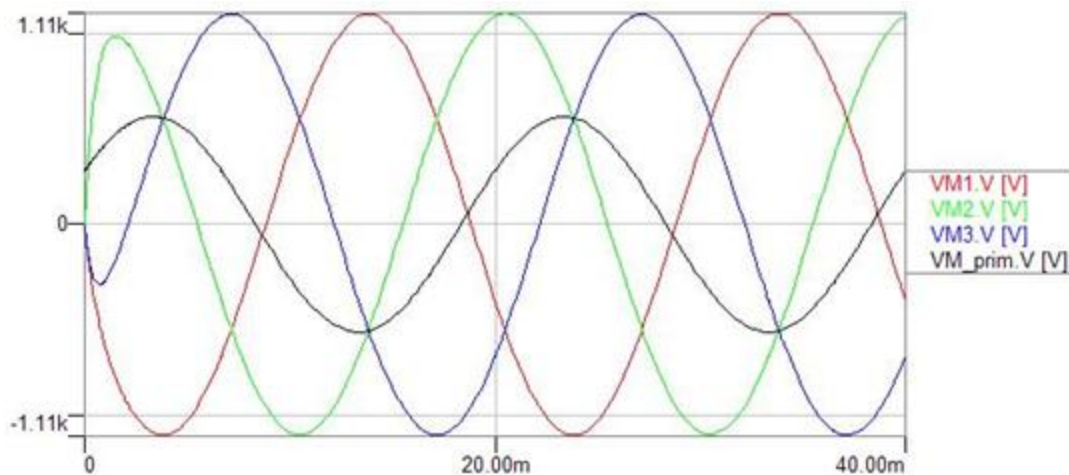


Figure 5. Simulation results – linear voltages on the primary side and three phase voltage on the secondary sides of the transformer

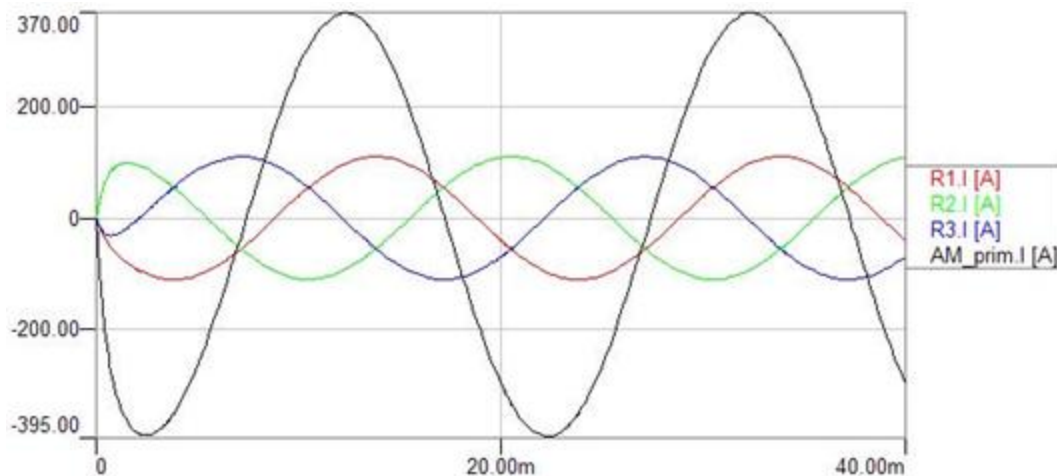


Figure 6. Simulation results – phase B current on the primary side and three phase current on the secondary sides of the transformer

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References

Using Measuring Instruments

Twin Builder provides measuring instruments for different physical domains. These meters provide **through** and **across** quantities as well as **power** for every physical domain used in a simulation model. All meters are ideal components, that means, no relevant quantities are assumed to be '0'.

Except for the position sensors of the velocity-force representation, meters have no user-defined parameters. They have at least one conservative node and are connected with a specific physical domain circuit.

The meters can provide the measured value at a special output pin, which can be connected with input parameters in the Schematic.

Measuring instruments can be used for modeling in several ways.

- For physical domain components, measuring instruments can provide through, across, and power quantities for controlled sources and components.
- For blocks, measuring instruments can provide setpoints, disturbances and reference values.
- For state graphs, measuring instruments can provide values to define comparison functions and synchronization signals.
- For semiconductor devices, the measurement tool can provide characteristic values, specific time and accuracy values.

Meters for following domains are available:

- [Electrical](#)
- [Fluidic](#)
- [Magnetic](#)
- [Mechanical](#)
- [Thermal](#)

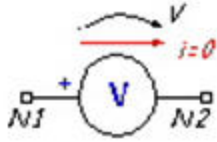
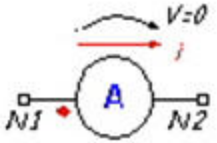
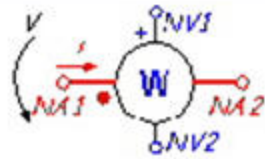
Special Measurement Tools

- [Semiconductor Devices](#)

Measuring instruments appear in the *Measurement* folder of the Basic Elements library. Select the folder *Measurement*, open one of the physical domain folders, and choose a meter for the corresponding quantity.

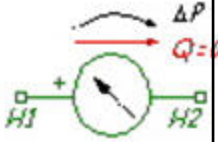
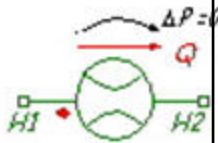
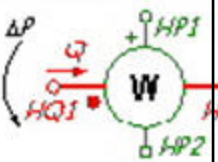
Electrical Meters

Electrical meters provide voltage (across quantity), current (through quantity), and power for electrical domain components.

Name/Equation	Symbol and Nodes	Outputs	Netlist
Voltmeter (VM) $i(t) = 0, R_i = \infty$		V [V]... Voltage dV [V/s]... Derivative of Voltage	INTERN VM ? InstanceName (@InstanceName):(@ (Refbase)@(ID)) N1:= %0 , N2:= %1 () ;
Ammeter (AM) $Dv(t) = 0, R_i = 0$		I[A]... Current dI [A/s]... Derivative of Current	INTERN AM ? InstanceName (@InstanceName):(@ (Refbase)@(ID)) N1:= %0 , N2:= %1 () ;
Wattmeter (WM) $POWER(t) = v(t) * i(t)$		P[W]... Power V [V]... Voltage I[A]... Current dV [V/s]... Derivative of Voltage dI [A/s]... Derivative of Current	INTERN WM ? InstanceName (@InstanceName):(@ (Refbase)@(ID)) NV1:= %2 , NV2:= %3 , NA1:= %0 , NA2:= %1 () ;

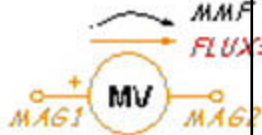
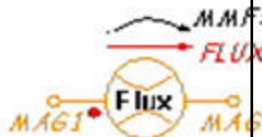
Fluidic Meters

Fluidic meters provide pressure (across quantity), flow rate (through quantity), and power for fluidic domain components. The flow meter symbol shows the direction of the flow rate with an arrow (animated symbol function).

Name/Equation	Symbol and Nodes	Outputs	Netlist
Manometer (PM) $Q(t) = 0$		P [Pa]...Differential Pressure	UMODEL PM ? InstanceName(@InstanceName):(@ (Refbase)@ (ID)) H1:= %0, H2:= %1 () SRC: DB(Lib:- =@ModelLibraryName);
Flow Meter (QM) $DP(t) = 0$		Q [m³/s]...Flow Rate	UMODEL QM ? InstanceName(@InstanceName):(@ (Refbase)@ (ID)) H1:= %0, H2:= %1 () SRC: DB(Lib:- =@ModelLibraryName);
Wattmeter (WM_HYD) $POWER(t) = Q(t) * P(t)$		P [Pa]...Differential Pressure Q [m³/s]...Flow Rate POWER [W]...Power	UMODEL WM_HYD ? InstanceName (@InstanceName): (@ (Refbase)@ (ID)) HP1:= %0, HP2:= %1, HQ1:= %2, HQ2:= %3 () SRC: DB(Lib:- =@ModelLibraryName);

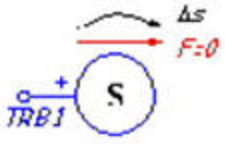
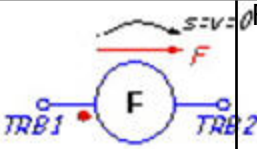
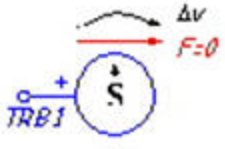
Magnetic Meters

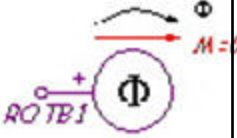
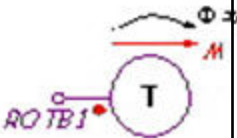
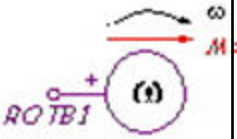
Magnetic meters provide magnetic voltage (across quantity), magnetic flux (through quantity), and power for magnetic domain components.

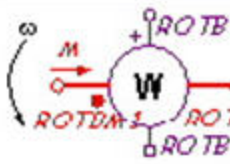
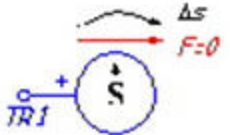
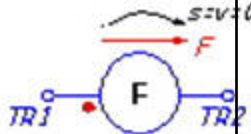
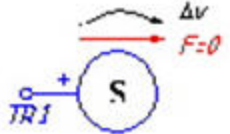
Name/Equation	Symbol and Nodes	Outputs	Netlist
Magnetic Voltmeter (VM_MAG) $FLUX(t) = 0$		MMF [A]...Magnetic Voltage	UMODEL VM_MAG ? InstanceName (@InstanceName): (@(Refbase)@(ID)) MAG1:= %0, MAG2:= %1 () SRC: DB(Lib:- =@ModelLibraryName);
Flux Sensor (FLUXM) $DMMF(t) = 0$		FLUX [Vs]...Magnetic Flux	UMODEL FLUXM ? InstanceName (@InstanceName): (@(Refbase)@(ID)) MAG1:= %0, MAG2:= %1 () SRC: DB(Lib:- =@ModelLibraryName);
Wattmeter (WM_MAG) $POWER(t) = FLUX(t) * MMF(t)$		MMF [A]...Magnetic Voltage FLUX [Vs]...Magnetic Flux POWER [W]...Power	UMODEL WM_MAG ? InstanceName (@InstanceName): (@(Refbase)@(ID)) MAGV1:= %0, MAGV2:= %1, MAGF1:= %2, MAGF2:= %3 () SRC: DB(Lib:- =@ModelLibraryName);

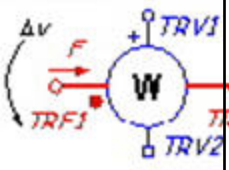
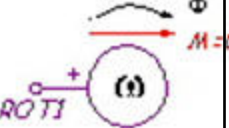
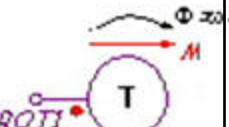
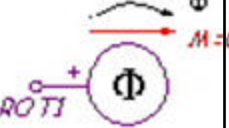
Mechanical Meters

Mechanical meters provide position (across quantity), velocity (across quantity), force (through quantity), and power for mechanical domain components. There are meters for Displacement-Force and Velocity-Force representation. Each representation form has components for translational and rotational systems.

Name/Equation	Symbol and Nodes	Inputs and Outputs	Netlist
Displacement-Force-Representation—Translational			
Position Sensor (SM_TRB) $F(t) = 0$		S [m]...Displacement	UMODEL SM_TRB ? InstanceName (@InstanceName): (@(Refbase)@ (ID)) TRB1:= %0, TRB2:= GND () SRC: DB(Lib:= "Simplorer Ele- ments\\\\Basic Ele- ments\\\\Basic Elements");
Force Sensor (FM_TRB) $Ds(t) = 0,$ $Dv(t) = 0$		F [N]...Force	UMODEL FM_TRB ? InstanceName (@InstanceName): (@(Refbase)@ (ID)) TRB1:= %0, TRB2:= %1 () SRC: DB(Lib:- =@ModelLibraryN- ame);
Velocity Sensor (VM_TRB) $F(t) = 0$		V [m/s]...Velocity	UMODEL VM_TRB ? InstanceName (@InstanceName): (@(Refbase)@ (ID)) TRB1:= %0, TRB2:= GND () SRC: DB(Lib:= "Simplorer Ele- ments\\\\\\\\\\\\\\\\Basic Ele- ments\\\\\\\\\\\\\\\\Basic Elements");

Wattmeter (WM_ TRB) $POWER(t) = F(t) * v(t)$		V [m/s]...Velocity F [N]...Force POWER [W]...Power	UMODEL WM_ TRB ? InstanceName (@InstanceName): (@ (Refbase)@ (ID)) TRBV1:= %0, TRBV2:= %1, TRBF1:= %2, TRBF2:= %3 () SRC: DB(Lib:- =@ModelLibraryN- ame) ;
Displacement-Force-Representation—Rotational			
Angle Sensor (SM_ ROTB) $M(t) = 0$		PHI [rad]...Angle	UMODEL SM_ ROTB ? InstanceName (@InstanceName): (@ (Refbase)@ (ID)) ROTB1:= %0, ROTB2:= GND () SRC: DBLib:= "Sim- plorer Ele- ments\\\\Basic Elements\\\\Basic Elements") ;
Torque Sensor (FM_ ROTB) $PHI(t) = 0,$ $OMEGA(t) = 0$		M [Nm]...Torque	UMODEL FM_ ROTB ? InstanceName (@InstanceName): (@ (Refbase)@ (ID)) ROTB1:= %0, ROTB2:= %1 () SRC: DB(Lib:- =@ModelLibraryN- ame) ;
Angular Velocity Sensor (VM_ ROTB) $M(t) = 0$		OMEGA [rad/s]...Angular Velocity	UMODEL VM_ ROTB ? InstanceName (@InstanceName): (@ (Refbase)@ (ID)) ROTB1:= %0, ROTB2:= GND () SRC: DB(Lib:= "Simplorer Ele- ments\\\\Basic Ele- ments\\\\Basic Elements") ;

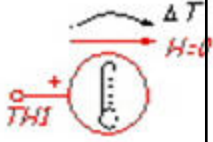
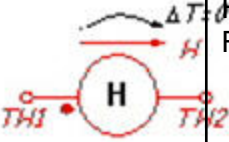
Wattmeter (WM_ ROTB) POWER(t) = M(t) * OMEGA(t)		OMEGA [rad/s]...An- gular Velocity M [Nm]...Torqu- e POWER [W]...Power	UMODEL WM_ ROTB ? InstanceName (@InstanceName): (@ (Refbase)@ (ID)) ROTBV1:= %0, ROTBV2:= %1, ROTBM1:= %2, ROTBM2:= %3 () SRC: DB(Lib:- =@ModelLibraryN- ame) ;
Velocity-Force-Representation—Translational_V			
Velocity Sensor (VM_TR) F(t) = 0		V [m/s]...Ve- locity	UMODEL VM_TR ? InstanceName (@InstanceName): (@ (Refbase)@ (ID)) TR1:= %0, TR2:= GND () SRC: DB(Lib:= "Simplorer Ele- ments\\\\Basic Ele- ments\\\\Basic Elements") ;
Force Sensor (FM_TR) Ds(t) = 0, Dv(t) = 0		F [N]...Force	UMODEL FM_TR ? InstanceName (@InstanceName): (@ (Refbase)@ (ID)) TR1:= %0, TR2:= %1 () SRC: DB(Lib:- =@ModelLibraryN- ame) ;
Position Sensor (SM_TR) F(t) = 0, s (t=0) = S0		S0 [m]...Ini- tial Position S [m]...Pos- ition	UMODEL SM_TR ? InstanceName (@InstanceName): (@ (Refbase)@ (ID)) TR1:= %0, TR2:= GND (S0:= @S0) SRC: DB (Lib:= "Simplorer Elements\\\\Basic Elements\\\\Basic Elements") ;

Wattmeter (WM_TR) $POWER(t) = F(t) v(t)$		V [m/s]... Velocity F [N]... Force POWER [W]... Power	UMODEL WM_TR ? InstanceName (@InstanceName): (@(Refbase)@ (ID)) TRV1:= %0, TRV2:= %1, TRF1:= %2, TRF2:= %3 () SRC: DB(Lib:-=@ModelLibraryName);
Velocity-Force-Representation—Rotational_V			
Angular Velocity Sensor (FM_ROT) $M(t) = 0$		OMEGA [rad/s]... Angular Velocity	UMODEL VM_ROT ? InstanceName (@InstanceName): (@(Refbase)@ (ID)) ROT1:= %0, ROT2:= GND () SRC: DB(Lib:="Simplorer Elements\\\\Basic Elements\\\\Basic Elements");
Torque Sensor (VM_ROT) $PHI(t) = 0, OMEGA(t) = 0$		M [Nm]... Torque	UMODEL FM_ROT ? InstanceName (@InstanceName): (@(Refbase)@ (ID)) ROT1:= %0, ROT2:= %1 () SRC: DB(Lib:-=@ModelLibraryName);
Angle Sensor (SM_ROT) $M(t) = 0, PHI(t=0) = PHI0$		PHI0 [rad]... Initial Angle PHI [rad]... Angle	UMODEL SM_ROT ? InstanceName (@InstanceName): (@(Refbase)@ (ID)) ROT1:= %0, ROT2:= GND (PHI0:= @PHI0) SRC: DB(Lib:="Simplorer Elements\\\\Basic Elements\\\\Basic Elements");

Wattmeter (WM_ ROT) POWER(t) = M(t) * OMEGA(t)		OMEGA [rad/s]...An- gular Velocity M [Nm]...Torqu- e POWER [W]...Power	UMODEL WM_ ROT ? InstanceName (@InstanceName): (@ (Refbase)@ (ID)) ROTV1:= %0, ROTV2:= %1, ROTM1:= %2, ROTM2:= %3 () SRC: DB(Lib:- =@ModelLibraryN- ame) ;

Thermal Meters

Thermal meters provide temperature (across quantity) and heat flow (through quantity) for thermal domain components.

Name/Equation	Symbol and Nodes	Outputs	Netlist
Thermometer (THM) $H(t) = 0$		T [K]...Temperature	UMODEL THM ? InstanceName(@InstanceName):(@ (Refbase)@(ID)) TH1:= %0, TH2:= %1 () SRC: DB(Lib:- =@ModelLibraryName);
Heat Flow Sensor (HFM) $DT(t) = 0$		H [J/s]...Heat Flow	UMODEL HFM ? InstanceName(@InstanceName):(@ (Refbase)@(ID)) TH1:= %0, TH2:= %1 () SRC: DB(Lib:- =@ModelLibraryName);

Semiconductor Measurement Device

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

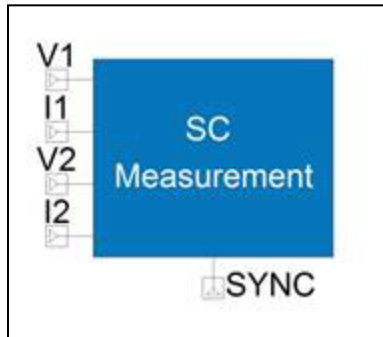


Figure 1. Component symbols

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- [Assumptions and Limitations](#)
- [Mathematical Description](#)
- [Netlist Syntax](#)
- [Conservative Pins](#)
- [Parameters](#)
- [Example](#)
- [References](#)

Description

The Semiconductor measurement device is an advanced component to perform comprehensive measurements on the input and output waveforms of inverting dynamic semiconductor switching devices like the Basic and Advanced Dynamic IGBTs and the Power MOSFET.

Controlled semiconductor devices such as IGBTs, MOSFETs, and in general all 4- pole devices normally have an input port with the terminal values voltage $V1(t)$ and current $I1(t)$ and an output port with $V2(t)$ and $I2(t)$ as shown in Figure 1. Those wave forms can be used to calculate all characteristics of a switching device. Besides the measurement of characteristic values of semiconductor device outputs, the measurement tool can be used for the comparison of given (measured) output wave forms of semiconductor devices with simulated output wave forms and to calculate accuracy characteristics.

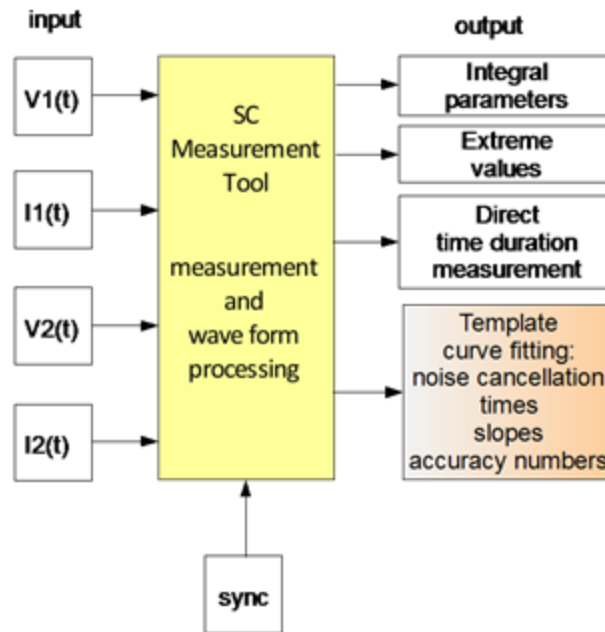


Figure 2. Semiconductor Measurement Device

As mentioned above, a 4-pole or 2-gate device can be characterized in the time domain no matter if this device is voltage or current controlled.

Measurement of curve characteristic

For an inverting switching device each of the four measurement input wave forms exhibits a rising and falling edge. From these eight switching edges all characteristic values of a device can be derived, such as the switching loss energy, the rise and fall times, the switching delays, overshoot values and integral parameters such as charges and stray flux.

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Assumptions and Limitations

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Mathematical Description

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Netlist Syntax

```

UMODEL SC_Measurement ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) ( V1:=
@V1, I1:= @I1, V2:= @V2, I2:= @I2, SYNC:= @SYNC, FIT_FLAG:= @FIT_FLAG, TYPE_
SEMICON:= @TYPE_SEMICON, MEASUREMENT_TON:= @MEASUREMENT_TON,
MEASUREMENT_TOFF:= @MEASUREMENT_TOFF, MEASUREMENT_EON:=
@MEASUREMENT_EON, MEASUREMENT_EOFF:= @MEASUREMENT_EOFF,
MEASUREMENT_ERR:= @MEASUREMENT_ERR, TYPE_REPORT:= @TYPE_REPORT,
VNOM:= @VNOM, INOM:= @INOM, V1MIN:= @V1MIN, V1MAX:= @V1MAX, HON:= @HON,
HOFF:= @HOFF, TOS:= @TOS, p_V10L:= @p_V10L, p_V10H:= @p_V10H, p_V20L:= @p_
V20L, p_V20H:= @p_V20H, p_I20L:= @p_I20L, p_I20H:= @p_I20H, p_V11L:= @p_V11L, p_

```

V11H:= @p_V11H, p_V21L:= @p_V21L, p_V21H:= @p_V21H, p_I21L:= @p_I21L, p_I21H:=
@p_I21H, T_MEASURE:= @T_MEASURE) SRC: DB(Lib:=@ModelLibraryName);

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Conservative Pins

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Input Parameters

Name	Description	Default Value
V1	Input voltage waveform	
I1	Input current waveform	
V2	Output voltage waveform	
I2	Output current waveform	
SYNC	Zero-crossing synchronization signal (trigger)	
FIT_FLAG	Data processing control 1:Sampling 2:Interpolation	1
TYPE_SEMICON	Semiconductor type	2
TYPE_REPORT	Report content selection	0
VNOM	Nominal blocking voltage in Off state	600 [V]
INOM	Nominal load current in On state	600 [A]
V1MIN	Input voltage low level	-15 [V]
V1MAX	Input voltage high level	15 [V]
HON	On-switch acquisition time	0 [s]
HOFF	Off-switch acquisition time	0 [s]
TOS	Measurement time offset	0 [s]
MEASUREMENT_TON	Measurement condition: TON	0403
MEASUREMENT_TOFF	Measurement condition: TOFF	0205
MEASUREMENT_EON	Measurement condition: EON	0502
MEASUREMENT_EOFF	Measurement condition: EOFF	0203
p_V10L	V1, off switch, low level percentage	10 [%]
p_V10H	V1, off switch, high level percentage	90 [%]
p_V20L	V2, off switch, low level percentage	10 [%]
p_V20H	V2, off switch, high level percentage	90 [%]
p_I20L	I2, off switch, low level percentage	10 [%]
p_I20H	I2, off switch, high level percentage	90 [%]

p_V11L	V1, on switch, low level percentage	10 [%]
p_V11H	V1, on switch, high level percentage	90 [%]
p_V21L	V2, on switch, low level percentage	10 [%]
p_V21H	V2, on switch, high level percentage	90 [%]
p_I21L	I2, on switch, low level percentage	10 [%]
p_I21H	I2, on switch, high level percentage	90 [%]

I1, V1, I2, and V2: The input and output wave forms must be provided with the time functions. Any current through and voltage across a component can be used, preferably ampere and volt meters.

SYNC: Synchronization signal that defines the start of time related processes and measurements at the switching points. Use the same signal that is used for the synchronization of transistor device.

FIT_FLAG: Defines the pre-treatment of the input data.

0: ignore device

1: use sampled data

2: interpolation of sampled data

TYPE_SEMICON:

1: Diode

2: n-channel MOSFET / IGBT;

-2: p-channel MOSFET / IGBT;

TYPE_REPORT: Defines the content of the report that is generated.

0: Silent, no report file is generated

1: Report wave forms

2: Additional report of the parameter convergence during the fitting

3: Additional fitting messages to detect problems

VNOM, INOM: Settled values of the blocking voltage and load current. Both values are the steady state or the quasi DC values and are used as 100% reference.

V1MIN, V1MAX: Minimum and maximum values of the input voltage. Both values are the steady state or the quasi DC values and are used as 100% reference for the input signal. Usual ranges of the values are 0 and (10V...20V) or (-20V...-10V) and (10V...20V).

HON, HOFF: Wave form acquisition time for the on and off switch. Before the data pre-processing can start the transients V1(t), I1(t), V2(t) and I2(t) must be read in. The user can provide the appropriate acquisition time. Especially the input voltage V1(t) must be acquired up to 80..90% of the total signal change. Generally HON and HOFF should be no longer than necessary to acquire data points which are meaningful for the wave form fitting. Providing Zero to HON

or HOFF causes an automatic internal calculation of the data acquisition times. Then the duration of HON is from the on switch trigger edge to 90% of the input voltage V1 and the duration of HOFF is from the off switch trigger edge to 3% of the load current. The number of the internally used data points is different from the number of simulated data points because of a sampling grid used for the data acquisition.

TOS: This time offset is simply subtracted from all measured times after the curve fitting. It is useful for more convenient time display and increases the accuracy of subsequent calculations.

MEASUREMENT_xxx: Definitions for time and energy measurements that correspond with the measurement conditions of the device characterization tool for that device. Each measurement condition includes 4 digits which represent a combination of start condition and a stop condition. The first 2 digits represent the start condition and the last 2 digits the stop condition of the measurement. For transistor devices (MOSFET, IGBT) measurement conditions need to be specified for ton, toff, Eon, and Eoff. The condition for Err is currently not used. For diode devices measurement conditions need to be specified for ton, toff and Eon.

MOSFET and IGBT Measurements

- **MEASUREMENT_TON**

Start t_on:

- 00xx: no measurement
- 01xx: zero crossing of rising external sync signal
- 02xx: 10% rising V1
- 03xx: zero crossing rising V1
- 04xx: 10% rising V1 after zero crossing

Stop t_on:

- xx00: no measurement
- xx01: 10% rising I2
- xx02: 90% rising I2
- xx03: 10% falling V2

- **MEASUREMENT_TOFF**

Start t_off:

- 00xx: no measurement
- 01xx: zero crossing of falling external sync signal
- 02xx: 90% falling V1 to zero
- 03xx: 90% falling V1 to V1min

Stop t_off:

xx00: no measurement

xx01: 10% rising V2

xx02: 90% rising V2

xx03: 90% falling I2

xx04: 50% falling I2

xx05: 10% falling I2 on current tail

xx06: 05% falling I2 on current tail (or next on trigger)

xx07: 03% falling I2 on current tail (or next on trigger)

xx08: 01% falling I2 on current tail (or next on trigger)

using secant extrapolation to get the values:

xx09: 10% falling I2 (extrapolated)

xx10: from 80% over 50% to 10% falling I2

xx11: from 80% over 60% to 10% falling I2

xx12: from 90% over 40% to 10% falling I2

xx13: from 90% over 50% to 10% falling I2

xx14: from 90% over 60% to 10% falling I2

- MEASUREMENT_EON

Start E_on:

00xx: no measurement

01xx: zero crossing of rising external sync signal

02xx: 10% rising V1 to V1 min

03xx: zero crossing rising V1

04xx: 10% rising V1 after zero crossing

05xx: 10% rising I2

Stop E_on:

xx00: no measurement

xx01: 90% rising I2

xx02: 10% falling V2

xx03: 5% falling V2

xx04: 3% falling V2 (or next off trigger)

xx05: 1% falling V2 (or next off trigger)

xx06: 50% falling V2

xx07: 90% falling V2

- MEASUREMENT_EOFF

Start E_off:

00xx: no measurement

01xx: zero crossing of falling external sync signal

02xx: 90% falling V1 to zero

03xx: 90% falling V1 to V1min

04xx: 10% rising V2

Stop E_off:

xx00: no measurement

xx01: 90% falling I2

xx02: 50% falling I2

xx03: 10% falling I2 on current tail

xx04: 5% falling I2 on current tail (or next on trigger)

xx05: 3% falling I2 on current tail (or next on trigger)

xx06: 1% falling I2 on current tail (or next on trigger)

Diode Measurement

- MEASUREMENT_TON

Start t_on:

00xx: no measurement

20xx: zero crossing of rising Irr

Stop t_on:

Xx00: no measurement

Xx20: 25% rising I2 (Irr before Irrm)

Xx21: 50% rising I2 (Irr before Irrm)

Xx22: 90% rising I2 (Irr before Irrm)

Xx23: 100% rising I2 Irr =Irrm)

- MEASUREMENT_TOFF

Start t_off:

00xx: no measurement

20xx: 95% falling I2 (Irr after Irrm)

21xx: 90% falling I2 (Irr after Irrm)

22xx: 85% falling I2 (Irr after Irrm)

23xx: 80% falling I2 (Irr after Irrm)

24xx: 75% falling I2 (Irr after Irrm)

Stop t_off:

xx00: no measurement

xx20: Extrapol 0-crossing from 50% falling I2

xx21: Extrapol 0-crossing from 40% falling I2

xx22: Extrapol 0-crossing from 30% falling I2

xx23: Extrapol 0-crossing from 25% falling I2

xx24: Extrapol 0-crossing from 20% falling I2

xx25: Extrapol 0-crossing from 10% falling I2

xx26: Extrapol 0-crossing from 5% falling I2

- MEASUREMENT_EON

Start E_on:

00xx: no measurement

20xx: zero crossing of rising I2

Stop E_on:

xx00: no measurement

xx20: Extrapol 0-crossing from 50% falling I2

xx21: Extrapol 0-crossing from 40% falling I2

xx22: Extrapol 0-crossing from 30% falling I2

xx23: Extrapol 0-crossing from 25% falling I2

xx24: Extrapol 0-crossing from 20% falling I2

xx25: Extrapol 0-crossing from 10% falling I2)

xx26: Extrapol 0-crossing from 5% falling I2

p_XXXX: Level definition in percent – Those values allow to define custom time measurements. The percentage value relates to the values V1MIN, V1MAX, VNOM, or INOM. The level values for I2, V2 are restricted between 0 and 100 [%]. The level values for V1 has the range –100 ... 100 [%] if the inputs for V1MIN and V1MAX are bipolar ($V1MIN \cdot V1MAX < 0$). Otherwise the level values for V1 also range from 0 and 100 [%] ($V1MIN \cdot V1MAX > 0$).

By setting these percentage levels, every measurement definition for delay times can be reproduced.

V: voltage

I: current

10: input, falling edge

11: input, rising edge

20: output, falling edge

21: output, rising edge

H,L: high or low level

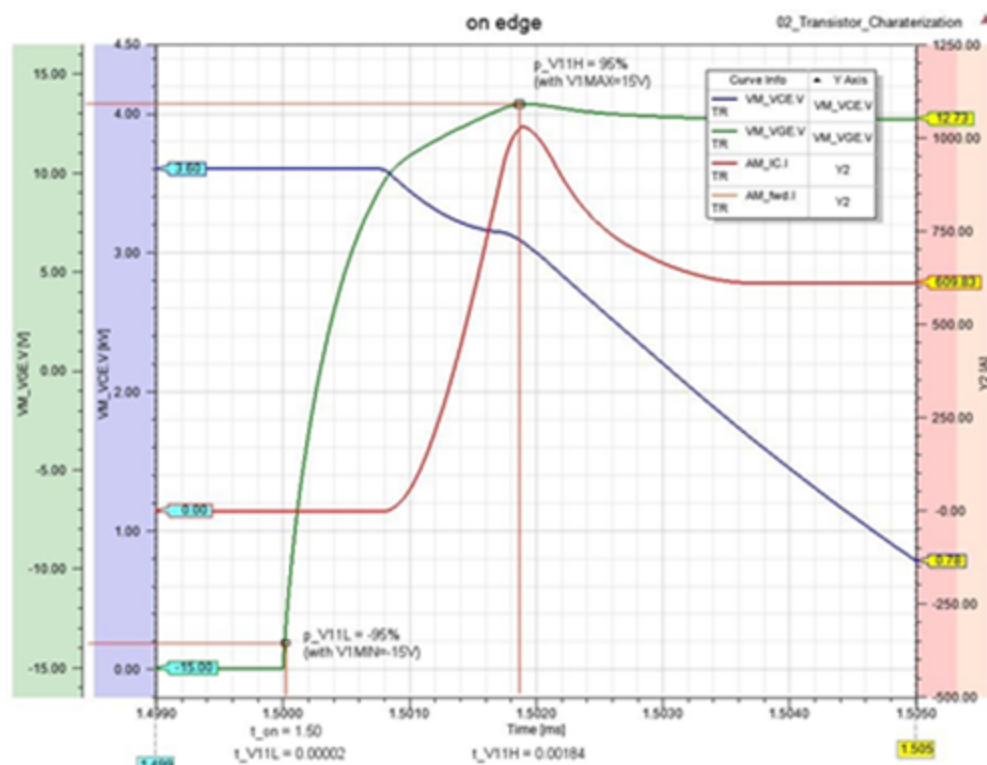


Figure 3. Example - Level definition for p_V11L and p_V11H

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Output Quantities

Name	Description	Unit
t_ON	on switch delay time	s
t_OFF	off switch delay time	s
E_ON	on switch loss energy	J
E_OFF	off switch loss energy	J
V1_MIN	sampled DC V1 minimum	V
V1_MAX	sampled DC V1 maximum	V
V2_MIN	sampled DC V2 minimum	V
V2_MAX	sampled DC V2 maximum	V
I2_MIN	sampled DC I2 minimum	A
I2_MAX	sampled DC I2 maximum	A
dV2	voltage slope $dV2/dt$	V/s
dI2	current slope $dI2/dt$	A/s
I2_PEAK	I2 peak	A
V2_PEAK	V2 peak	V
P1	input power loss time function	W
P2	output power loss time function	W
P1_MEAN	average input power loss	W
P2_MEAN	average output power loss	W
Q1_TOT	input charge = input current integral	As
Q2_TOT	output charge = load current overshoot integral	As
F2_TOT	linkage flux = output voltage overshoot integral	Vs
E1_TOT	input loss energy = input power integral per switch	Ws
E2_TOT	output loss energy = output power integral per switch	Ws
t_V10L	Time for off-switch low level of V1	s
t_V10H	Time for off-switch high level of V1	s

t_V20L	Time for off-switch low level of V2	s
t_V20H	Time for off-switch high level of V2	s
t_I20L	Time for off-switch low level of I2	s
t_I20H	Time for off-switch high level of I2	s
t_V11L	Time for on-switch low level of V1	s
t_V11H	Time for on-switch high level of V1	s
t_V21L	Time for on-switch low level of V2	s
t_V21H	Time for on-switch high level of V2	s
t_I21L	Time for on-switch low level of I2	s
t_I21H	Time for on-switch high level of I2	s
d_V10L	Slope for off-switch low level of V1	V/s
d_V10H	Slope for off-switch high level of V1	V/s
d_V20L	Slope for off-switch low level of V2	V/s
d_V20H	Slope for off-switch high level of V2	V/s
d_I20L	Slope for off-switch low level of I2	A/s
d_I20H	Slope for off-switch high level of I2	A/s
d_V11L	Slope for on-switch low level of V1	V/s
d_V11H	Slope for on-switch high level of V1	V/s
d_V21L	Slope for on-switch low level of V2	V/s
d_V21H	Slope for on-switch high level of V2	V/s
d_I21L	Slope for on-switch low level of I2	A/s
d_I21H	Slope for on-switch high level of I2	A/s

t_ON, t_OFF, E_ON and E_OFF: Time and energy measurements depending on the MEASUREMENT_XXX input parameters. Sampled measurements are performed directly on the input wave forms and may include one HMIN uncertainty. Interpolated measurements don't depend much on the step size setting. The integral output values such as E_ON and E_OFF are usually very robust and accurate for changing step size.

V1_MIN, V1_MAX: Actual minimum and maximum values of the input signal V1. These values may differ from the expected values V1_MIN and V1_MAX. This mismatch can occur when the switching cycle is too short for a complete recharging of the input capacitance of the device. In V1 sweep mode V1_MIN and V1_MAX return the actual drive voltage. The values are sampled

just before the start of on or off switch and can be used for working point depended device parameter control.

V2_MIN, V2_MAX, I2_MIN, I2_MAX: Actual values of the output voltage V2 and output current I2 which are sampled just before the switching transients (quasi DC values). These values are not the overall extreme values. Usually the MIN values are close to zero and the MAX values can be used for working point depended parameter control. V2_MAX should be equal the bus bar voltage and I2_MAX equals the load current.

dV2, dI2: The d/dt values for the output voltage and the output current. In contrast the other parameters these are time functions. Because internally state values like node voltages are used for the I2(t) and V2(t) input, the states return the built in first derivative which is simply provided for user access. This may be useful for EMI considerations.

I2_PEAK, V2_PEAK: The absolute maximum of load current and load voltage during one period. These values may change stepwise from one period to another.

P1, P2: Input and output loss power time functions. The products of current and voltage are calculated directly from the input wave forms. Both values don't have any impact on the step size control and therefore don't slow down the simulation, even for extraordinarily high power pulses. P1 and P2 can be injected in an external thermal network for the calculation of the maximum die temperature.

P1_MEAN, P2_MEAN: These are integral values having high accuracy and return the average power loss per period. The values may change stepwise from period to period. P1_MEAN and P2_MEAN can be injected into a simplified external thermal network to calculate for the average die temperature.

Q1_TOT: The total input charge of the device $\int I_1(t) dt$ for the on switch edge. This value is helpful to calculate for the on switch delay and to design the gate driver.

Q2_TOT: The integral of the load current overshoot for the on switch transient

$\int_{I2 > I\_MAX}^{off\ switch} (I2(t) - I\_MAX) dt$. Q2_TOT is the sum of the stored semiconductor excess charge of the upper free wheel diode and all lumped and distributed capacities at the collector terminal of the lower switch in a half bridge configuration.

F2_TOT: Integral of the load voltage overshoots for the off switch transient. It is caused by the sum of the stray inductances and has the meaning of a magnetic flux. It can be used to calculate for the stray inductance.

The naming convention for the t_ and d_ output parameters is analogous to the convention for the p_ input parameters:

V: voltage

I: current

10: input, falling edge

11: input, rising edge

20: output, falling edge

21: output, rising edge

H,L: high or low level

t_XXXX: According to the percentage inputs p_ the t_ values are the times belonging to the given percentages. The t_ outputs are affected by the time offset TOS and are calculated from the inverse template function $t = aw - 1(\text{value})$.

d_XXXX: According to the percentage inputs p_ the d_ values are the slopes belonging to the given percentages.

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Example

Transistor Validation inductive load (current source)

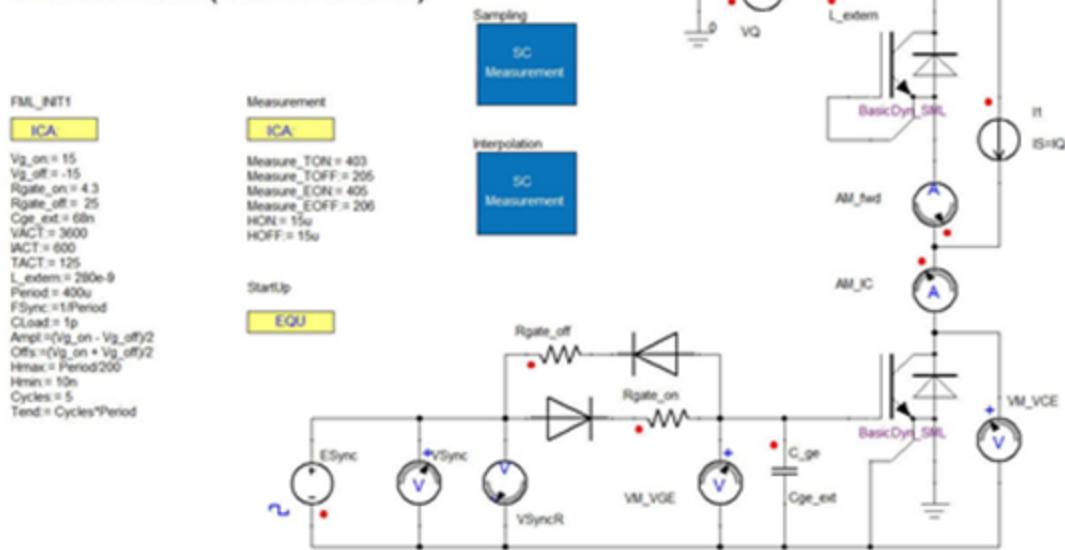


Figure 4. Example circuit

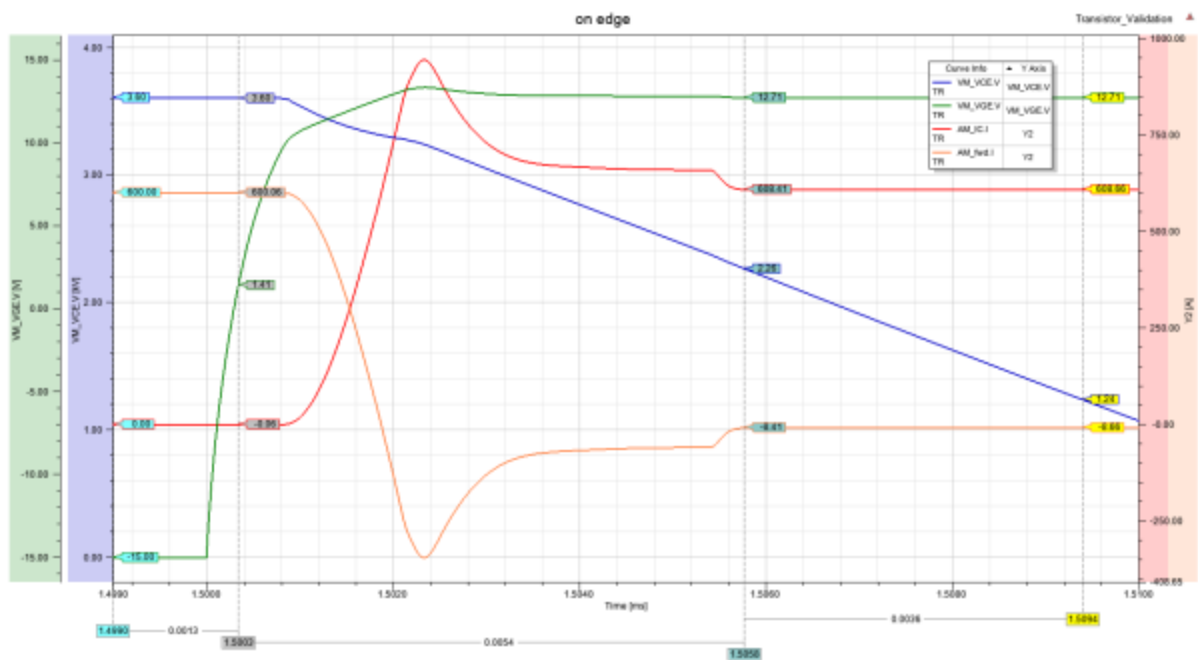


Figure 5. Simulation result - Switching ON waveforms

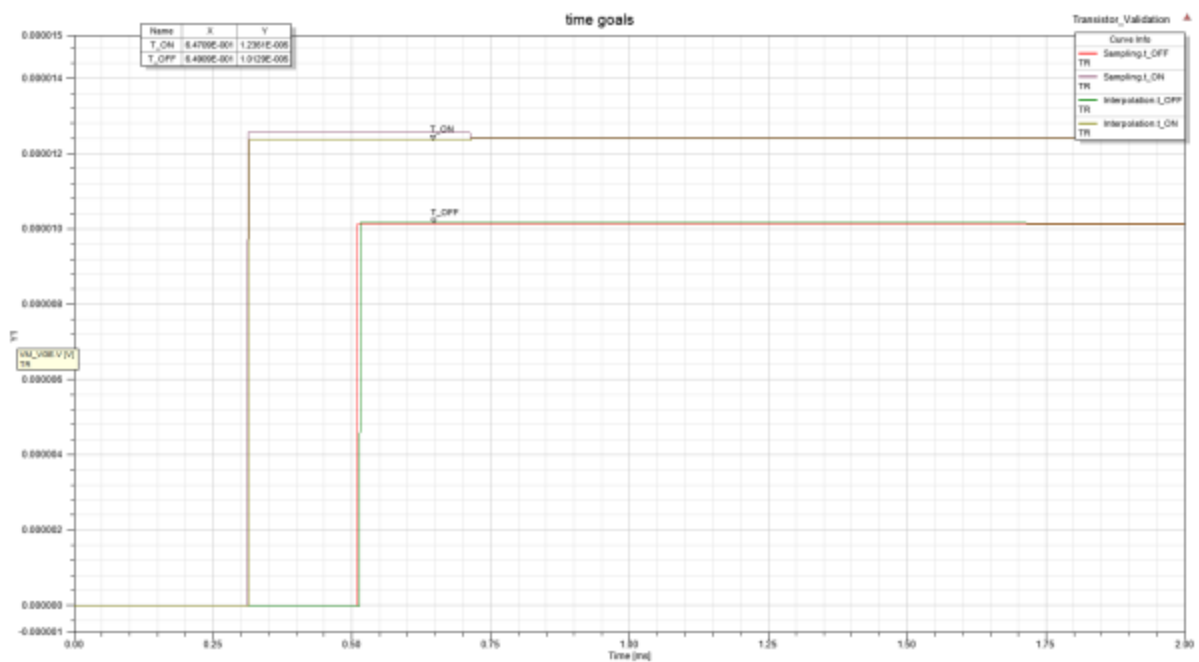


Figure 6. Simulation result - Time measurement values (TON, TOFF)

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References

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Modeling with Physical Domains Components

Physical Domain components appear in the *Physical Domains* folder of the Basic Elements library. The folder is subdivided into Fluidic, Magnetic, Mechanical, and Thermal domains. Select the folder *Physical Domains*, open one of the folders, click a name, drag the component onto the sheet and release the mouse button.

Along with electrical domain components you can model and simulate physical domain systems for different engineering applications. Each domain has its own relation for across and through quantities. In addition, components and wires of a domain are represented by an identical color in the graphical representation of the Schematic. To change the settings of nature colors, choose Tools\Options\Schematic Editor Options, click on the *Colors* tab, select *Wires* as the object type, and the color of wires for different domains can be edited. Please note: You can only change the wiring color, not the color of component symbols.

All models are implemented as C models.

The *Physical Domains* folder provides components for the following domains:

- [Fluidic Components](#)
- [Magnetic Components](#)
- [Mechanical Components](#)
- [Thermal Components](#)

Note: Mechanical components are subdivided into two categories: Displacement Force Representation, and Velocity Force Representation. Each of these two categories in-turn have two sub-categories: Rotational and Translational.

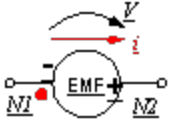
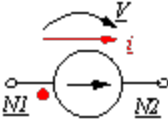
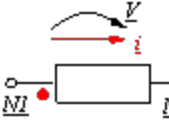
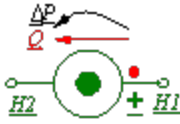
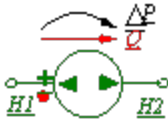
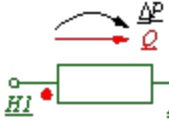
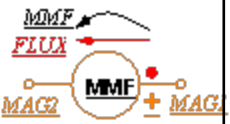
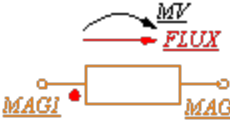
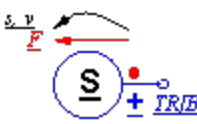
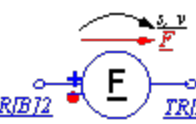
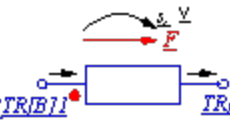
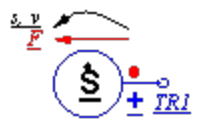
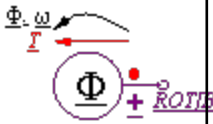
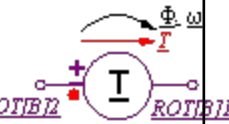
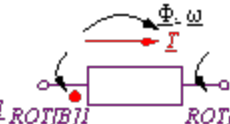
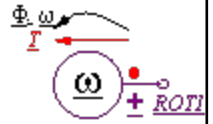
Reference Arrow System of Physical Domains

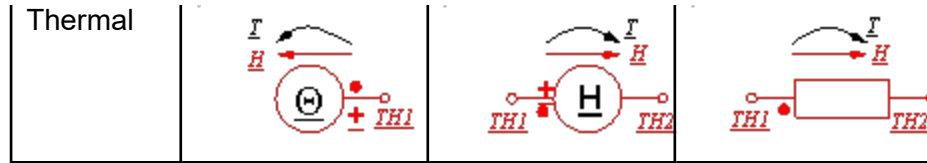
The table shows the reference arrow system for all available physical domains in Twin Builder.

The counting direction is marked by the red point at the component symbol. The red point is always at pin 1 of a component.

Across quantities: Value=Value at Pin1 – Value at Pin 2.

Through quantities: Value is positive if the quantity flows at the red point **into** the component.

	Difference Sources	Flow Sources	Passive Components
Electrical			
Fluidic			
Magnetic			
Mechanic Translational			
			
Mechanic Rotational			
			



Nature Types of Components

Nature types are properties from conservative nodes (ports) of components. At least one specific nature exists for each domain. The mechanical domain has four nature types.

In the Schematic, you can connect conservative nodes only if they have the same nature type. By way of contrast, other quantities (non-conservative nodes) can be changed between all domains.

The Physical Domains folder of the Basic Elements library contains components with the following nature types:

- electrical
- fluidic
- magnetic
- translational
- translational_v
- rotational
- rotational_v
- thermal

Connecting Components

Connections between components are created in the wire mode (CTRL+W or Draw > Wire). Place the cross wire on a component pin on the sheet, and set the beginning, corners, and end of the wire with the mouse. Press ESC to finish the wire mode.

Conservative component nodes must always be connected with a node of the same nature type. To connect conservative nodes of different nature types you must use the D2D (domain to domain) component.

Schematic tests the pins during the routing and will not allow invalid connections (for example between an electrical and magnetic nature).

After the simulator starts, Schematic tests the complete simulation model. If connections are missing, an error message or warning is displayed in the **Message Manager** area of the Information window.

Fluidic Components

- Hydraulic Capacitance (CHYD)
- Hydraulic Inductance (LHYD)
- Pressure Source (P)
- Flow Source (Q)
- Linear Orifice (RHYD)

Across and Through Quantity of the Fluidic Domain

Table 1

Across	Through	Equation
Pressure [Pa]	Flow Rate [m ³ /s]	$q(t) = K \cdot p(t)$

The fluidic domain components appear in the *Fluidic* folder of *Physical Domains* in the **Basic Elements** library. The folder provides fluidic basic components to model simple fluidic equivalent circuits. The fluidic domain uses the pressure as across and the flow rate as through quantities.

By default, components and wires of the fluidic domain are represented in green in the graphical representation of the Schematic. To change the settings of nature colors, choose Tools\Options\Schematic Editor Options, click on the *color* tab, select *Wires* as the object type, and the color of wires for different domains can be edited.

Hydraulic Capacitance

Library: Basic Elements

Modeling Language: SML

Version Number: Twin Builder 2025.2

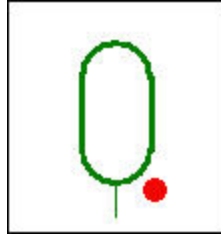


Figure 1. Component Symbol.

- [Description](#)
- [Assumptions and Limitations](#)
- [Mathematical Description](#)
- [Netlist Syntax](#)
- [Conservative Pins](#)
- [Parameters](#)
- [Input/Output Quantities](#)
- [Example](#)
- [References](#)

Description

The component represents the effects of fluid compressibility or hydraulic capacitance. When reaching the critical pressure level of $-1E5$ Pa the volume internally increases its capacitance (and the charge) to avoid dropping below that level.

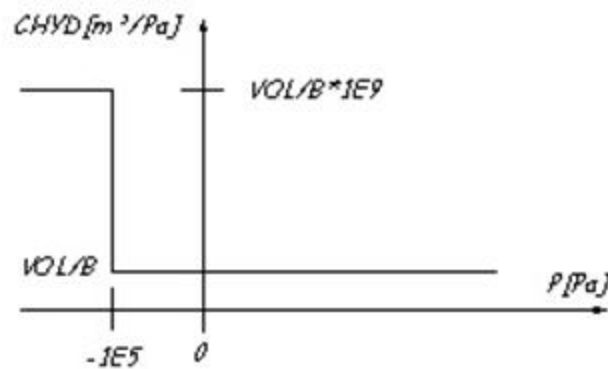


Figure 2.[Top](#)

Assumptions and Limitations

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Mathematical Description

The Hydraulic Capacitance model can be described as:

$$q(t) = C_{HYD} \cdot \frac{d}{dt}p(t) \quad C_{HYD} = \frac{VOL}{B}$$

where C_{HYD} is the equivalent hydraulically capacitance.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
H1	Pin 1 (with red point)	fluidic

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
VOL	Fluid Volume	real	0.1m [m ³]
B	Bulk Modulus	real	1G [Pa]
P0	Initial Pressure	real	0 [Pa]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
P	Differential Pressure [Pa]	Output	real
Q	Flow Rate [m³/s]	Output	real

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Example

Figure 2 shows application of the Hydraulic Capacitance model. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3.

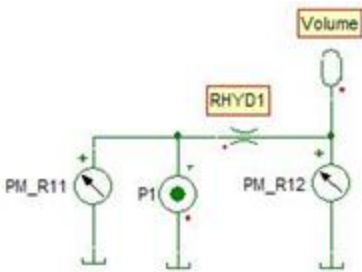


Figure 3. Application example of the Hydraulic Capacitance model

Table 4

Component	Parameter	Value
Pressure Source P1	VALUE	1Meg [Pa]
Linear Orifice RHYD2	K	1n (m³/(Pa·s))
Hydraulic Capacitance Volume	VOL	1m [m³]
	B	1G [Pa]
	P0	0 [Pa]

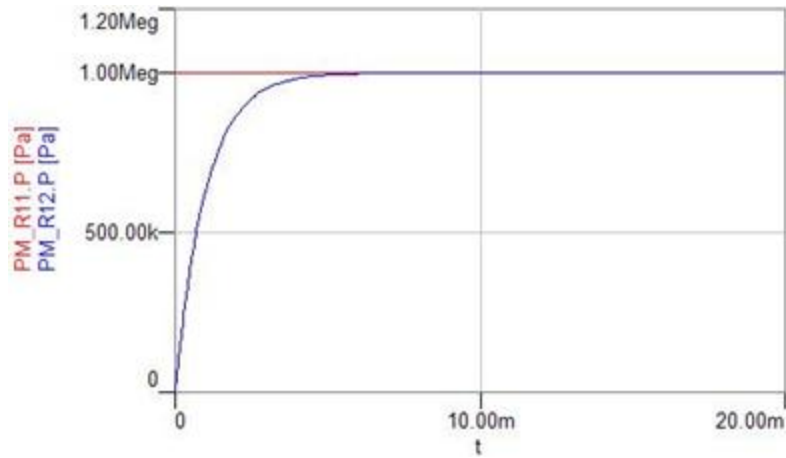


Figure 3. Simulation results-measurement results of PM_R11 and PM_R12

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References

Hydraulic Inductance

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

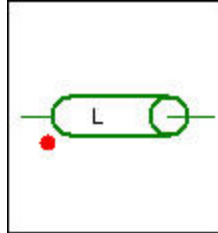


Figure 1. Component Symbol.

- [Description](#)
- [Assumptions and Limitations](#)
- [Mathematical Description](#)
- [Netlist Syntax](#)
- [Conservative Pins](#)
- [Parameters](#)
- [Input/Output Quantities](#)
- [Example](#)
- [References](#)

Description

The component represents a hydraulic resistance that also includes the effects of fluid inertia, or hydraulic inductance. The characteristics are based on equations for laminar and turbulent flow through a smooth round pipe supplemented with the differential equation for effect of fluid mass and acceleration.

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Assumptions and Limitations

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Mathematical Description

The Hydraulic Capacitance model can be described as:

$$P(t) = L_{HYD} \cdot \frac{d}{dt} q(t) \quad L_{HYD} = \frac{RHO \cdot LEN}{A} \quad A = \frac{\pi \cdot DIA^2}{4}$$

where L_{HYD} is the equivalent hydraulic inductance.

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Netlist Syntax

UMODEL LHYD ?InstanceName(@InstanceName):(@ (Refbase)@(ID)) H1:= %0, H2:= %1 (
RHO:= @RHO, DIA:= @DIA, LEN:= @LEN, Q0:= @Q0) SRC: DB(Lib:=@ModelLibraryName);

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
H1	Pin 1 (with red point)	fluidic
H2	Pin 2	fluidic

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
RHO	Fluid Density	real	900 [kg/m ³]
DIA	Diameter	real	10m [m]
LEN	Length	real	1 [m]
Q0	Initial Flow Rate	real	0 [m ³ /s]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
P	Differential Pressure [Pa]	Output	real
Q	Flow Rate [m ³ /s]	Output	real

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Example

Figure 2 shows application of the Hydraulic Inductance model. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3.

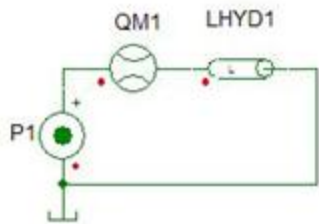


Figure 2. Application example of the Hydraulic Inductance model

Table 4

Component	Parameter	Value
Pressure Source P1	VALUE	100k*t [Pa]
Hydraulic Inductance LHYD1	RHO	1k [kg/m³]
	DIA	1m [m]
	LEN	1m [m]
	Q0	0 [m³/s]

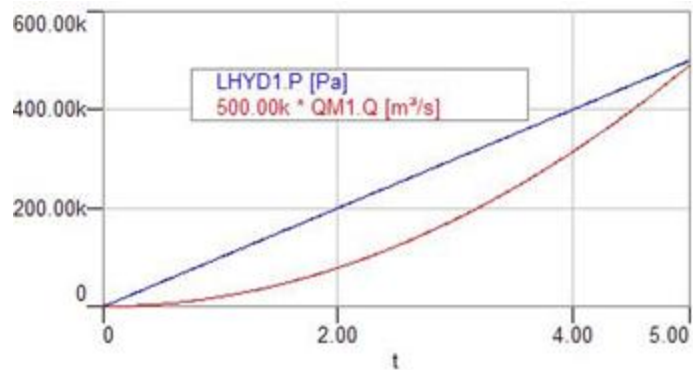


Figure 3. Simulation results-pressure across and flow through LHYD1

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References

Pressure Source

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

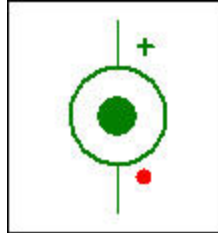


Figure 1. Component Symbol.

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Description

The component represents an ideal pressure source which supplies the defined pressure differential for an arbitrary flow rate. Within the dialog you can choose a constant or the time-controlled type.

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Mathematical Description

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

Linear Pressure Source

The pressure is equivalent to the present value of the quantity specified in the text box, which can be a constant value, a time function, a variable, or a value determined in a state graph. All system quantities and variables can be combined with mathematical and logical operators and constants.

$$\Delta p(t) = P = \text{VALUE}$$

The flow through an ideal pressure source can be arbitrary. Real pressure sources have always an internal resistance. If the internal resistance is essential for the simulation target, a corresponding resistance must be connected in series.

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Conservative Pins

Table 1

Name	Description	Nature Type
H1	Node with high potential (with red point)	fluidic
H2	Node with low potential	fluidic

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
VALUE	Pressure Differential	real	1Meg [Pa]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
P	Pressure Differential [Pa]	Output	real
Q	Flow Rate [m ³ /s]	Output	real

Time-Controlled Pressure Source

The time-controlled pressure sources have the same properties as the linear pressure source above; the flow rate can be arbitrary and the internal resistance is zero (ideal source). The value of the pressure differential instead is equivalent to the present value of the selected time function at each calculation step.

$$\Delta p(t) = f[\text{time function}]$$

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Conservative Pins

Table 4

Name	Description	Nature/Data Type
H1	Node with high potential (with red point)	fluidic
H2	Node with low potential	fluidic

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Parameters

Table 5

Name	Description	Data Type	Default Value [Unit]
AMPL	Amplitude	real	100k [Pa]
FREQ	Frequency (no trapezoidal function parameter)	real	1 [Hz]
TPERIO	Period	real	1 [s]
TDELAY	Delay	real	0 [s]
PHASE	Phase	real	0 [deg]
n/a	Angular Dimension	real	
OFF	Offset	real	900k
PERIO	Periodic; PERIO=1, periodical function, PERIO=0; non-periodical function	real	1
DAMPING	Damping factor (only sine function) DAMPING>0, amplitude is exponentially decreasing (damped). DAMPING<0, amplitude is exponentially increasing, DAMPING=0, no damping	real	0 [1/s]
TRISE	Rise Time (only trapezoidal function)	real	250m [s]
TFALL	Fall Time (only trapezoidal function)	real	250m [s]
PWIDTH	Pulse Width (only trapezoidal function)	real	900m [s]

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Input/Output Quantities

Table 6

Name	Description [Unit]	Direction	Data Type
P	Pressure Differential [Pa]	Output	real
Q	Flow Rate [m ³ /s]	Output	real

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Example

Figure 2 shows application of the Pressure Source model. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3.

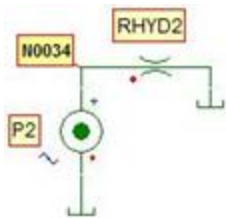


Figure 3. Application example of the Pressure Source model

Table 4

Component	Parameter	Value
Pressure Source (sinusoidal) P2	AMPL	1Meg [Pa]
	FREQ	5 [Hz]
	PHASE	0 [degree]
	OFF	2meg [Pa]
	TDELAY	0 [s]
Linear Orifice RHYD2	K	5n (m ³ /(Pa·s))

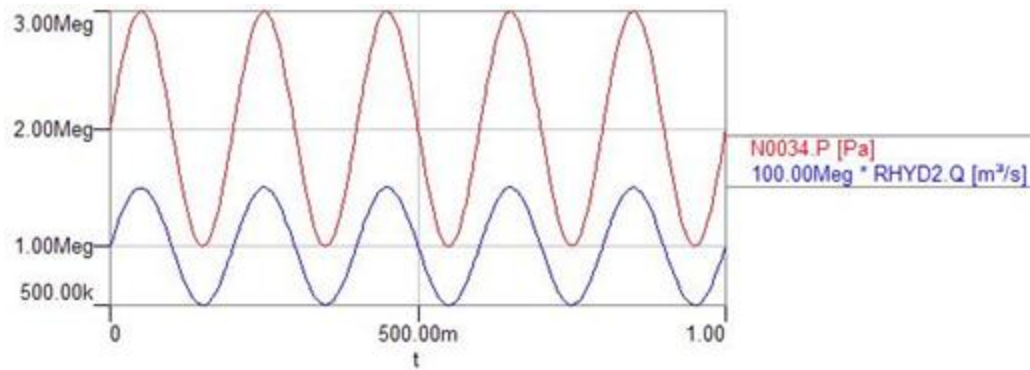


Figure 3. Simulation results-pressure output of P2 and flow through RHYD2

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References

Flow Source

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

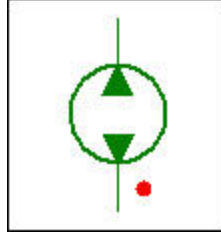


Figure 1. Component Symbol.

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Description

The component represents an ideal flow source which supplies the defined flow rate for an arbitrary pressure differential. Within the dialog you can choose a constant or the time-controlled type.

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Assumptions and Limitations

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Mathematical Description

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

Linear Flow Source

The flow rate is equivalent to the present value of the quantity specified in the input field, which can be a constant value, a time function, a variable, or a value determined in a state graph. All system quantities and variables can be combined with mathematical and logical operators and constants.

$$q(t) = \text{VALUE}$$

The pressure of an ideal flow source can be arbitrary. Real flow sources have always an internal resistance. If the internal resistance is essential for the simulation target, a corresponding resistance must be connected in parallel.

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
H1	Pin 1 (with red point)	fluidic
H2	Pin 2	fluidic

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
VALUE	Flow Rate	real	100u [m ³ /s]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
P	Pressure Differential [Pa]	Output	real
Q	Flow Rate [m ³ /s]	Output	real

Time-Controlled Flow Source

The time-controlled flow sources have the same properties as the linear flow source above; the pressure can be arbitrary and the internal resistance is zero (ideal source). The value of the flow rate instead is equivalent to the present value of the selected time function at each calculation step.

$$q(t) = f[\text{time function}]$$

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Conservative Pins

Table 4

Name	Description	Nature/Data Type
H1	Pin 1 (with red point)	fluidic
H2	Pin 2	fluidic

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Parameters

Table 5

Name	Description	Data Type	Default Value [Unit]
AMPL	Amplitude	real	10u [m ³ /s ²]
FREQU	Frequency (no trapezoidal function parameter)	real	1 [Hz]
TPERIO	Period	real	1 [s]
TDELAY	Delay	real	0 [s]
PHASE	Phase	real	0 [deg]
n/a	Angular Dimension		
OFF	Offset	real	100u
PERIO	Periodic; PERIO=1, periodical function, PERIO=0; non-periodical function	real	1
DAMPING	Damping factor (only sine function) DAMPING>0, amplitude is exponentially decreasing (damped).	real	0 [1/s]

	DAMPING<0, amplitude is exponentially increasing, DAMPING=0, no damping		
TRISE	Rise Time (only trapezoidal function)	real	250m [s]
TFALL	Fall Time (only trapezoidal function)	real	250m [s]
PWIDTH	Pulse Width (only trapezoidal function)	real	500m [s]

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Input/Output Quantities

Table 6

Name	Description [Unit]	Direction	Data Type
P	Pressure Differential [Pa]	Output	real
Q	Flow Rate [m ³ /s]	Output	real

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Example

Figure 2 shows application of the Flow Source model. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3.

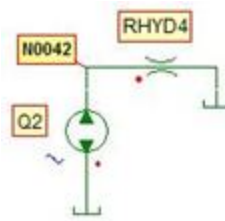


Figure 3. Application example of the Flow Source model

Table 4

Component	Parameter	Value
Flow Source (sinusoidal) Q2	AMPL	100u [m³/s]
	FREQ	5 [Hz]
	PHASE	0 [degree]
	OFF	0 [m³/s]
	TDELAY	0 [s]
Linear Orifice RHYD4	K	5n (m³/(Pa·s))

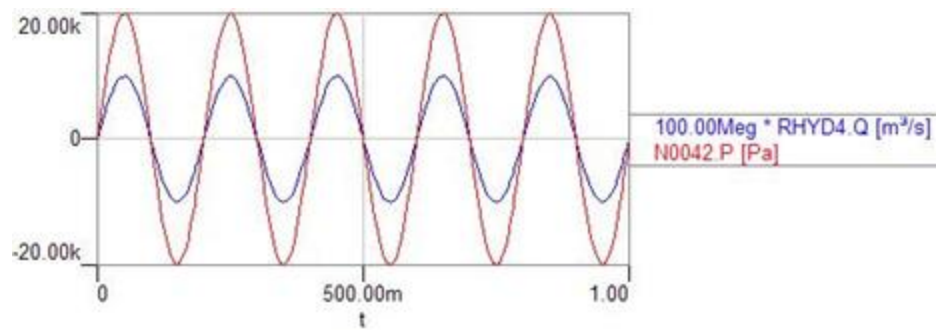


Figure 3. Simulation results-pressure at Node N0042 and flow through RHYD4

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References

Linear Orifice

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

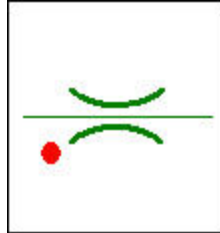


Figure 1. Component Symbol.

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Description

The component represents a simple fluid resistance with laminar flow (linear flow characteristic curve). The conductance K describes the flow for very small reynolds numbers. The Linear Orifice is used for long lines, leakage in valves, hydrostatic slipper bearings, etc.

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Assumptions and Limitations

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Mathematical Description

The Linear Orifice can be described as a linear hydraulic conductance block where flow rate is directly proportional to pressure differential.

$$q(t) = K \cdot p(t)$$

where K is the Hydraulic Conductance.

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Netlist Syntax

UMODEL RHYD ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) H1:= %0, H2:= %1 (
K:= @K) SRC: DB(Lib:=@ModelLibraryName) ;

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
H1	Pin 1 (with red point)	fluidic
H2	Pin 2	fluidic

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
K	Hydraulic Conductance	real	1n [m ³ /(s*Pa)]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
P	Differential Pressure [Pa]	Output	real
Q	Flow Rate [m ³ /s]	Output	real

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Example

Figure 2 shows application of the Linear Orifice model. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3.

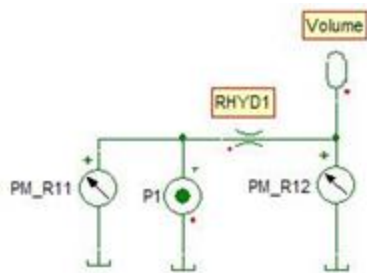


Figure 3. Application example of the Linear Orifice model

Table 4

Component	Parameter	Value
Pressure Source P1	VALUE	1Meg [Pa]
Linear Orifice RHYD2	K	1n (m ³ /(Pa·s))
Hydraulic Capacitance Volume	VOL	1m [m ³]
	B	1G [Pa]
	P0	0 [Pa]

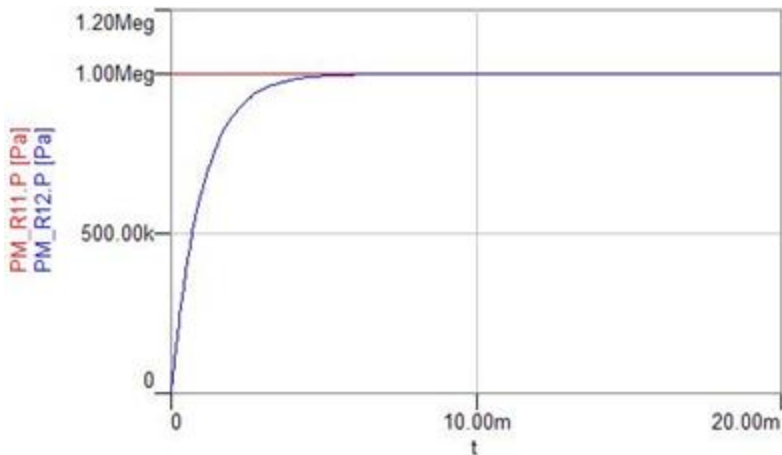


Figure 3. Simulation results-measurement results of PM_R11 and PM_R12

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References

Magnetic Components

- [Winding \(ELTOMAG\)](#)
- [Flux Source \(FLUX\)](#)
- [Jiles-Atherton Model for Magnetic Core Material \(JACore\)](#)
- [Magneto-Motive Force Source \(MMF\)](#)
- [Magneto-Resistor \(RMAG\)](#)

Across and Through Quantity of the Magnetic Domain

Across	Through	Equation
Magneto-Motive Force [A]	Magnetic Flux [Vs]	$MV(t) = K \cdot FLUX(t)$

The magnetic domain components appear in the *Magnetic* folder of *Physical Domains* in the **Basic Element** library. The folder provides magnetic basic components to model simple magnetic equivalent circuits. The magnetic domain uses the magneto-motive force as across and the magnetic flux as through quantity.

By default, components and wires of the magnetic domain are represented in orange in the graphical representation of the Schematic. To change the settings of nature colors, choose Tools\Options\Schematic Editor Options, click on the *color* tab, select *Wires* as the object type, and the color of wires for different domains can be edited.

Winding

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

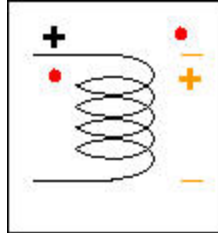


Figure 1. Component Symbol.

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Description

The component represents a coupling element between electric and magnetic circuit. It converts electrical energy into magnetic energy and vice versa (bidirectional energy flow). The component has electrical pins, N1 and N2 (across: v, through: i) and magnetic pins, MAG1 and MAG2. You can specify the number of turns (coupling quantity between magnetic and electric domain) and the ohmic winding resistance.

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Mathematical Description

The Winding model can be described as following:

$$v(t) = -W \cdot \frac{d}{dt} \text{FLUX} + R \cdot i(t) \quad \text{MV}(t) = W \cdot i(t)$$

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Netlist Syntax

UMODEL ELTOMAG ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) N1:= %0, N2:= %1, MAG1:= %2, MAG2:= %3 (R:= @R, W:= @W, FLUX0:= @FLUX0) SRC: DB(Lib:- :=@ModelLibraryName);

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
N1	Positive node Pin 1 (with red point)	electrical
N2	Pin 2	electrical
MAG1	Positive node Pin 1 (with red point)	magnetic
MAG2	Pin 2	magnetic

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
R	Resistance [Ohm]	real	1u [Ohm]
W	Number of Turns	real	1

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
V	Voltage [V]	Output	real
I	Current [A]	Output	real
MV	Magnetic Voltage [A]	Output	real
FLUX	Magnetic Flux [V*s]	Output	real

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Example

Figure 2 shows application of the Winding model. In this example, a sinusoidal magnetic flux causes voltage induction within the winding. The magnetic power provided by the flux source is converted into heat by the resistor. Due to the ohmic losses at the winding the power consumption of the resistor is lower than the power output of the flux source. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3.

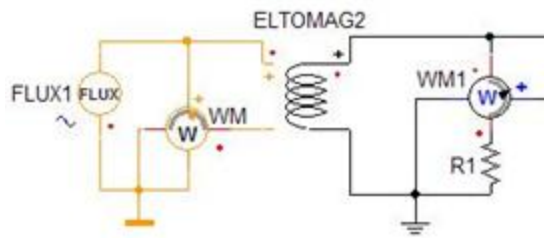


Figure 2. Application example of the Winding model

Table 4

Component	Parameter	Value
Resistor R1	R	1 [Ohm]
Flux Source (sinusoidal) FLUX1	AMPL	4.5m [Web]
	FREQU	50 [Hz]
	OFF	0 [Web]
	TDELAY	0 [s]
	PHASE	0 [deg]
Winding ELTOMAG2	R	50m [Ohm]
	W	1000
	FLUX0	0 [Vs]

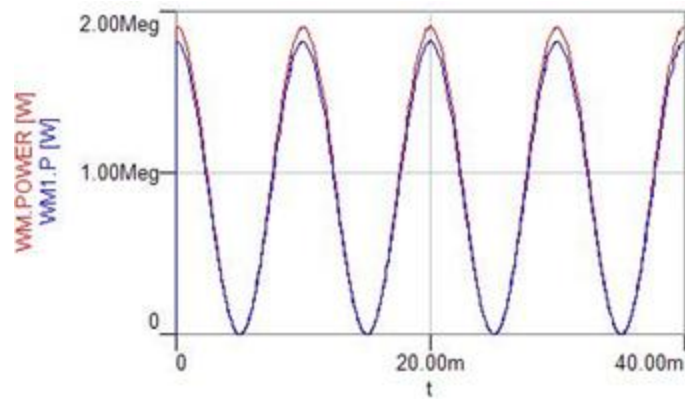


Figure 3. Simulation results

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References

Magnetic Flux Source

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2



Figure 1. Component Symbol.

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Description

The component represents an ideal magnetic flux source which supplies the defined magnetic flux for an arbitrary magneto-motive force. Within the dialog you can choose a constant or time-controlled source.

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Mathematical Description

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

Linear Magnetic Flux Source

The magnetic flux is equivalent to the present value of the quantity specified in the text box, which can be a constant value, a time function, a variable, or a value determined in a state graph. All system quantities and variables can be combined with mathematical and logical operators and constants.

$$\text{FLUX}(t) = \text{VALUE}$$

The magneto-motive force of an ideal flux source can be arbitrary. Real flux sources have always an internal resistance. If the internal resistance is essential for the simulation target, a corresponding resistance must be connected in parallel.

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
MAG1	Pin 1 (with red point)	magnetic
MAG2	Pin 2	magnetic

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
VALUE	Magnetic Flux [Vs]	real	4.5m [Vs]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
MV	Magnetic Voltage [A]	Output	real
FLUX	Magnetic Flux [Vs]	Output	real

Time-Controlled Magnetic Flux Source

The time-controlled flux sources have the same properties as the linear flux source above; the force can be arbitrary and the internal resistance is zero (ideal source). The value of the flux rate instead is equivalent to the present value of the selected time function at each calculation step.

$$\text{FLUX}(t) = f[\text{time function}]$$

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Conservative Pins

Table 4

Name	Description	Nature/Data Type
MAG1	Pin 1 (with red point)	magnetic
MAG2	Pin 2	magnetic

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Parameters

Table 5

Name	Description	Data Type	Default Value [Unit]
AMPL	Amplitude	real	4.5m [Vs]
FREQU	Frequency (no trapezoidal function parameter)	real	50 [Hz]
TPERIO	Period	real	20m [s]
TDELAY	Delay	real	0 [s]
PHASE	Phase	real	0 [deg]
n/a	Angular Dimension		
OFF	Offset	real	0
PERIO	Periodic; PERIO=1, periodical function, PERIO=0; non-periodical function	real	1
DAMPING	Damping factor (only sine function) DAMPING>0, amplitude is exponentially decreasing (damped). DAMPING<0, amplitude is expo-	real	0 [1/s]

	nentially increasing, DAMPING=0, no damping		
TRISE	Rise Time (only trapezoidal func- tion)	real	5m [s]
TFALL	Fall Time (only trapezoidal func- tion)	real	10m [s]
PWIDTH	Pulse Width (only trapezoidal function)	real	5m [s]

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Input/Output Quantities

Table 6

Name	Description [Unit]	Direction	Data Type
MV	Magnetic Voltage [A]	Output	real
FLUX	Magnetic Flux [Vs]	Output	real

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Example

Figure 2 shows application of the Flux Source model. In this example, a sinusoidal magnetic flux causes voltage induction within the winding. The magnetic power provided by the flux source is converted into heat by the resistor. Due to the ohmic losses at the winding the power consumption of the resistor is lower than the power output of the flux source. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3.

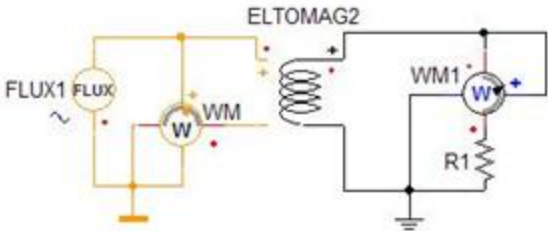


Figure 2. Application example of the Flux Source

Table 4

Component	Parameter	Value
Resistor R1	R	1 [Ohm]

Flux Source (sinusoidal) FLUX1	AMPL	4.5m [Web]
	FREQU	50 [Hz]
	OFF	0 [Web]
	TDELAY	0 [s]
	PHASE	0 [deg]
Winding ELTOMAG2	R	50m [Ohm]
	W	1000
	FLUX0	0 [Vs]

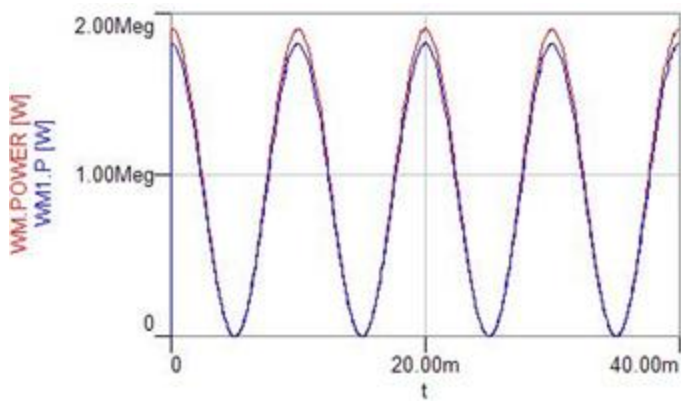


Figure 3. Simulation results

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References

Jiles-Atherton Model

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

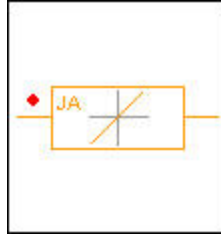


Figure 1. Component Symbol.

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Description

The component provides static and dynamic properties of ferromagnetic core materials for magnetic domain components in 5 different modeling levels. All model levels can represent eddy current losses, which are produced by currents induced inside the core. If $\rho \rightarrow \infty$, eddy current losses are '0'.

Table 1

Level	Description
0	Linear model
1	Anhysteretic model. Saturation is represented by a hyperbola (no hysteresis).
2	Anhysteretic model. Saturation is represented by a Langevin function (no hysteresis).
3	Jiles-Atherton hysteresis model. Saturation is represented by a hyperbola.
4	Jiles-Atherton hysteresis model. Saturation is represented by a Langevin function.

The Jiles-Atherton model takes into account all necessary static and dynamic characteristics of ferromagnetic materials. The effort for model calibration is small and the model equation has an acceptable numerical characteristic. The limits of the Jiles-Atherton model are:

- Unsatisfactory recognition of impulse magnetization, caused by steep current peaks
- Complex mathematical algorithms for calibration
- Temperature behavior, magnetic anisotropic behavior and the influence of mechanical load are poorly modeled

The Jiles-Atherton model gives acceptable results if the correlation between magnetic field force (magnetic flux density) and magnetization (induction) in ferromagnetic materials under normal conditions is taken into account, and a continuous control function with a frequency limit of 500 kHz is used. Therefore, this model is most often used for transformers, normal converters and commutation inductors. The model is not appropriate for switching processes, as in switching power supplies or pulse transducers.

All parameters must be positive real numbers using SI units.

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Assumptions and Limitations

Linear Jiles-Atherton Model (Level 0)

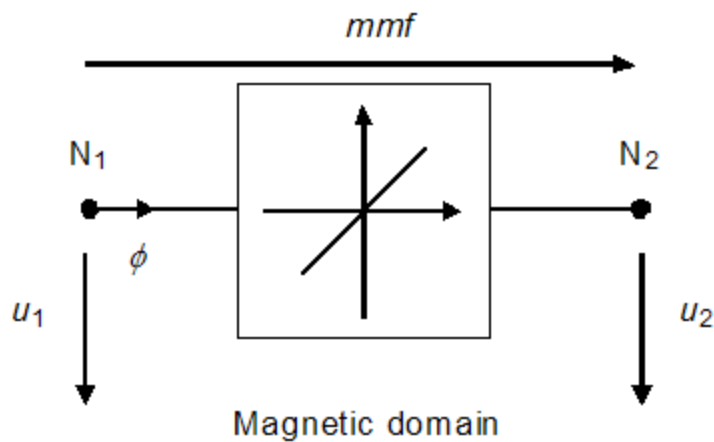


Fig. 2: Electrical representation of level 0 model.

This model is valid for TR, DC and AC simulations.

The characteristic equation is a linear magnetization:

$$\mathbf{M} = \chi \cdot \mathbf{H}$$

To take into account the effect of frequency on eddy current losses (only for AC simulations), the following expression is used to modify the electrical resistivity of the core material:

$$\rho(\omega) = \rho \cdot (1 + k_{w1} \cdot \omega + k_{w2} \cdot \omega^2) \quad \omega = 2 \cdot \pi \cdot f$$

NOTE:

If ρ approaches infinity, eddy current losses are zero.

$k_{w1} = 0$ and $k_{w2} = 0$ imply that the core resistivity is constant.

k_{w1} and k_{w2} cannot be negative in order to avoid a negative value of the core resistivity.

Anhyseretic Jiles-Atherton Model (Level 1 and 2)

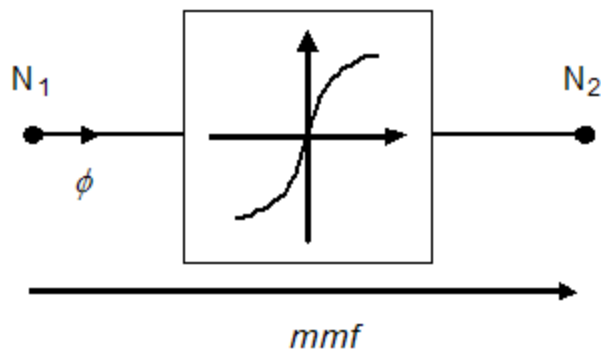


Fig. 3: Electrical representation of level 1 and 2 model.

These models are valid for TR and DC simulations. They cannot be used in AC simulations because of their nonlinear characteristic.

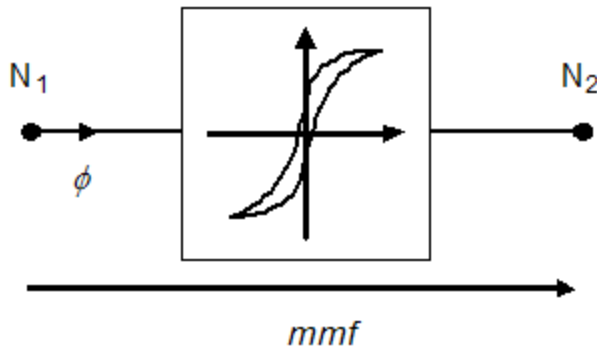
- The characteristic equation for level 1 is a hyperbola:

$$M = M_S \cdot \frac{H}{|H| + A}$$

- The characteristic equation for level 2 is a Langevin function:

$$M = M_S \cdot \left(\coth\left(\frac{H + \alpha \cdot M}{A}\right) - \frac{A}{H + \alpha \cdot M} \right)$$

Anhyseretic Jiles-Atherton Model (Level 3 and 4)

**Fig. 3: Electrical representation of level 3 and 4 model.**

These models are valid for TR and DC simulations. They cannot be used in AC simulations because their nonlinear characteristic.

- The characteristic equation for level 3 is a modified Jiles-Atherton hysteresis model:

$$\frac{dM}{dH} = (1 - C) \cdot \frac{M_{an} - M}{\delta K} + C \cdot \frac{dM_{an}}{dH} \quad \delta = \operatorname{sgn}\left(\frac{dH}{dt}\right)$$

The anhyseretic magnetization for level 3 is described by an hyperbola:

$$M_{\text{an}} = M_S \cdot \frac{H}{|H| + A}$$

- The characteristic equation for level 4 is the original Jiles-Atherton hysteresis model:

$$\frac{dM}{dH} = (1 - C) \cdot \frac{M_{\text{an}} - M}{\delta K - \alpha \cdot (M_{\text{an}} - M)} + C \cdot \frac{dM_{\text{an}}}{dH} \quad \delta = \text{sgn}\left(\frac{dH}{dt}\right)$$

The anhysteretic magnetization for level 4 is described by a Langevin function:

$$M = M_S \cdot \left(\coth\left(\frac{H + \alpha \cdot M}{A}\right) - \frac{A}{H + \alpha \cdot M} \right)$$

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Mathematical Description

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Conservative Pins

Table 2

Name	Description	Nature/Data Type
MAG1	Pin 1	magnetic
MAG2	Pin 2	magnetic

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Parameters

Table 3
Linear Jiles-Atherton Model (Level 0)

Name	Description	Data Type	Default Value [Unit]
M0	Initial Magnetization; $ M0 \geq 1$	real	0 [A/m]
RHO	Electrical Resistivity of Core Material	real	1T [Ohm*m] (See NOTES)
KW1	Coefficient 1 for Electrical Resistivity in AC Simulation	real	0 [s/rad] (See NOTES)
KW2	Coefficient 2 for Electrical Resistivity in AC Simulation	real	0 [s ² /rad ²] (See NOTES)
AE	Effective Area of Core Material	real	28.6u [m ²]
LE	Effective Length of Core	real	29m [m]
MUE	Effective relative Permeability of Core; $MUE > 1$	real	2k [Tám/A]

***NOTES:**

1. If RHO approaches infinity, eddy current losses are zero.
2. KW1 = 0 and KW2 = 0 imply that the core resistivity is constant.
3. KW1 and KW2 cannot be negative in order to avoid a negative value of the core resistivity.

Table 4
Anhysteretic Jiles-Atherton Model (Level 1 and 2)

Name	Description	Data Type	Default Value [Unit]
MSHYP	Saturation Magnetization (Level 1 only)	real	313680 [A/m]
MSLAN	Saturation Magnetization (Level 2 only)	real	313680 [A/m]
ALPHALAN	Interdomain Coupling Coefficient (Level 2 only)	real	5.33333e-005
AHYP	Thermal Energy Parameter (Level 1 only)	real	21.7276 [A/m]
ALAN	Thermal Energy Parameter (Level 2 only)	real	16.0868 [A/m]
M0	Initial Magnetization; $ M0 \geq 1$	real	0 [A/m]
RHO	Electrical Resistivity of Core Material	real	1T [Ohm*m] (see NOTE)
AE	Effective Area of Core Material	real	28.6u [m ²]
LE	Effective Length of Core	real	0.029m [m]

***NOTE:**

If RHO approaches infinity, eddy current losses are zero.

Table 5
Anhysteretic Jiles-Atherton Model (Level 3 and 4)

Name	Description	Data Type	Default Value [Unit]
MSHYP	Saturation Magnetization (Level 3 only)	real	31368 [A/m]
MSLAN	Saturation Magnetization (Level 3 only)	real	31368 [A/m]
ALPHALAN	Interdomain Coupling Coefficient (Level 4 only)	real	5.33333e-005
AHYP	Thermal Energy Parameter (Level 3 only)	real	21.7276 [A/m]
ALAN	Thermal Energy Parameter (Level 4 only)	real	16.0868 [A/m]
CHYP	Reversible Magnetization Coefficient; $0 \leq C < 1$ (Level 3 only)	real	0.138465
CLAN	Reversible Magnetization Coefficient; $0 \leq C < 1$ (Level 4 only)	real	0.102517
KHYP	Pinning Energy Parameter (Level 3 only)	real	11.75 [A/m]
KLAN	Pinning Energy Parameter (Level 4 only)	real	10 [A/m]
M0	Initial Magnetization; $ M0 \geq 1$	real	0 [A/m]
H0	Initial Magnetic Field	real	0 [A/m]
RHO	Electrical Resistivity of Core Material	real	1T [Ohm*m]
AE	Effective Area of Core Material	real	28.6u [m ²]
LE	Effective Length of Core	real	29m [m]

***NOTE:**

If RHO approaches infinity, eddy current losses are zero.

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Input/Output Quantities**Table 6**

Name	Description [Unit]	Direction	Data Type
MMF	Magnetomotive Force Across Magnetic Pins [A]	Output	real
FLUX	Core Flux [Wb]	Output	real

B	Magnetic Flux Density [T]	Output	real
H	Magnetic Field strength [A/m]	Output	real
M	Magnetization [A/m]	Output	real
PTOTAL	Total Power Losses [W]	Output	real
PHYST	Magnetic Hysteresis Power Losses [W]	Output	real
PEDDY	Eddy Current Power Losses [W]	Output	real

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Example

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References

[1] Jiles, DC; Atherton, DL: *Theory of Ferromagnetic Hysteresis*. J. Mag. Mag. Mater., 61 (1986) 1/2, pp:48-60

Magneto-Motive Force Source

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2



Figure 1. Component Symbol.

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Description

The component represents an ideal magneto-motive force source which supplies the defined magnetic force for an arbitrary magnetic flux. Within the dialog you can choose a constant or time-controlled source.

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Assumptions and Limitations

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Mathematical Description

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

Linear Magneto-Motive Force Source

The magneto-motive force is equivalent to the present value of the quantity specified in the text box, which can be a constant value, a time function, a variable, or a value determined in a state graph. All system quantities and variables can be combined with mathematical and logical operators and constants.

$$MV(t) = \text{VALUE}$$

The magnetic flux of an ideal force source can be arbitrary. Real force sources have always an internal resistance. If the internal resistance is essential for the simulation target, a corresponding resistance must be connected in parallel.

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
MAG1	Pin 1 (with red point)	magnetic
MAG2	Pin 2	magnetic

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
VALUE	Magneto-Motive Force	real	1e4 [A]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
MMF	Magneto-Motive Force [A]	Output	real
FLUX	Magnetic Flux [Vs]	Output	real

Time-Controlled Magneto-Motive Force Source

The time-controlled force sources have the same properties as the linear force source above; the flux can be arbitrary and the internal resistance is zero (ideal source). The value of the force instead is equivalent to the present value of the selected time function at each calculation step.

$$MV(t) = f[\text{time function}]$$

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Conservative Pins

Table 4

Name	Description	Nature/Data Type
MAG1	Pin 1 (with red point)	magnetic
MAG2	Pin 2	magnetic

[Top](#)

Parameters

Table 5

Name	Description	Data Type	Default Value [Unit]
AMPL	Amplitude	real	1e4 [A]
FREQU	Frequency (no trapezoidal function parameter)	real	50 [Hz]
TPERIO	Period	real	20m [s]
TDELAY	Delay	real	0 [s]
PHASE	Phase	real	0 [deg]
n/a	Angular Dimension		
OFF	Offset	real	0
PERIO	Periodic; PERIO=1, periodical function, PERIO=0; non-periodical function	real	1
DAMPING	Damping factor (only sine function) DAMPING>0, amplitude is exponentially decreasing (damped). DAMPING<0, amplitude is expo-	real	0 [1/s]

	nentially increasing, DAMPING=0, no damping		
TRISE	Rise Time (only trapezoidal func- tion)	real	5m [s]
TFALL	Fall Time (only trapezoidal func- tion)	real	10m [s]
PWIDTH	Pulse Width (only trapezoidal function)	real	5m [s]

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Input/Output Quantities

Table 6

Name	Description [Unit]	Direction	Data Type
MMF	Magneto-Motive Force [A]	Output	real
FLUX	Magnetic Flux [Vs]	Output	real

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Example

Figure 2 shows application of the Magneto-Motive Force Source model. In this example, the magnetic circuit of a three-phase system (e.g. transformer with open secondary side) is modeled. Magnetic flux and mmf are measured at one particular point of the core. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3.

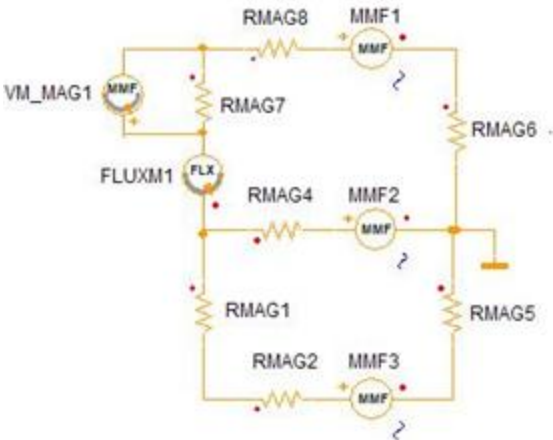


Figure 2. Application example of the Magneto-Motive Force Source

Table 4

Component	Parameter	Value
Magneto-Resistor RMAG1/RMAG5/RMAG6/RMAG7	K	5e7 [A/Web]
Magneto-Resistor RMAG2/ RMAG4/RMAG8	K	1e8 [A/Web]
Magneto-Motive Force Source (sinusoidal) MMF1	AMPL	1e4 [A]
	FREQU	50 [Hz]
	OFF	0 [A]
	TDELAY	0 [s]
	PHASE	0 [deg]
Magneto-Motive Force Source (sinusoidal) MMF2	AMPL	1e4 [A]
	FREQU	50 [Hz]
	OFF	0 [A]
	TDELAY	0 [s]
	PHASE	120 [deg]
Magneto-Motive Force Source (sinusoidal) MMF3	AMPL	1e4 [A]
	FREQU	50 [Hz]
	OFF	0 [A]
	TDELAY	0 [s]
	PHASE	240 [deg]

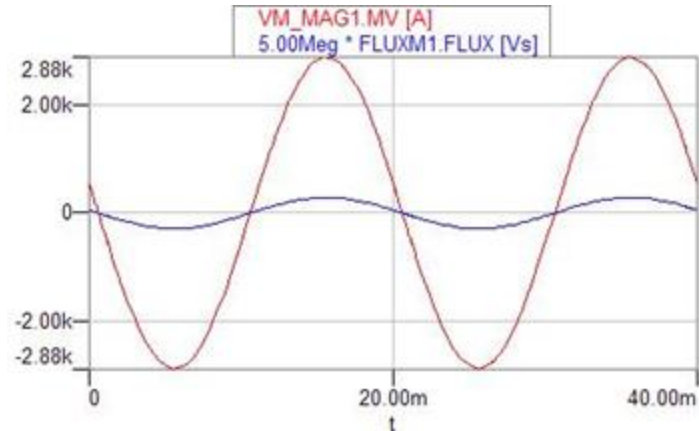


Figure 3. Simulation results

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References

Magneto-Resistor

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

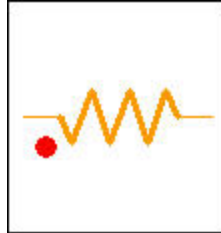


Figure 1. Component Symbol.

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Description

The component represents a magneto-resistor that means, a homogeneous distributed magnetic field within a media of proportional B-H-relation to model air gaps and leakage paths.

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Assumptions and Limitations

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Mathematical Description

The Magneto-Resistor mode can be described as:

$$MV(t) = K \cdot FLUX(t)$$

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Netlist Syntax

UMODEL RMAG ?InstanceName(@InstanceName):(@ (Refbase)@(ID)) MAG1:= %0, MAG2:= %1 (K:= @K) SRC: DB(Lib:=@ModelLibraryName) ;

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
MAG1	Pin 1 (with red point)	magnetic
MAG2	Pin 2	magnetic

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
K	Linear Coefficient	real	1e9 [A/(V*s)]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
MV	Magnetic Voltage [A]	Output	real
FLUX	Magnetic Flux [V*s]	Output	real

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Example

Figure 2 shows application of the Magneto-Resistor model. In this example, the magnetic circuit of a three-phase system (e.g. transformer with open secondary side) is modeled. Magnetic flux and mmf are measured at one particular point of the core. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3.

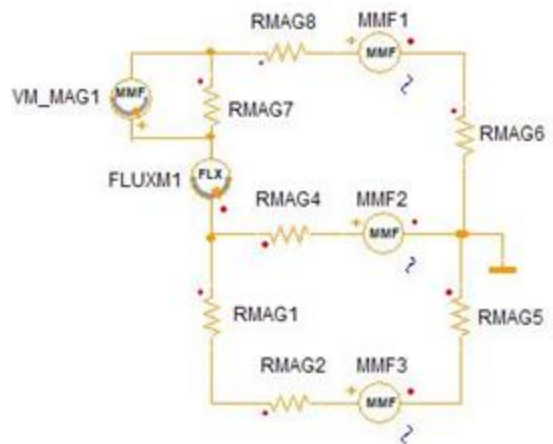


Figure 2. Application example of the Magnetoresistor model

Table 4

Component	Parameter	Value
Magneto-Resistor RMAG1/RMAG5/RMAG6/RMAG7	K	5e7 [A/Web]
Magneto-Resistor RMAG2/ RMAG4/RMAG8	K	1e8 [A/Web]
Magneto-Motive Force Source (sinusoidal) MMF1	AMPL	1e4 [A]
	FREQU	50 [Hz]
	OFF	0 [A]
	TDELAY	0 [s]
	PHASE	0 [deg]
Magneto-Motive Force Source (sinusoidal) MMF2	AMPL	1e4 [A]
	FREQU	50 [Hz]
	OFF	0 [A]
	TDELAY	0 [s]
	PHASE	120 [deg]
Magneto-Motive Force Source (sinusoidal) MMF3	AMPL	1e4 [A]
	FREQU	50 [Hz]
	OFF	0 [A]
	TDELAY	0 [s]
	PHASE	240 [deg]

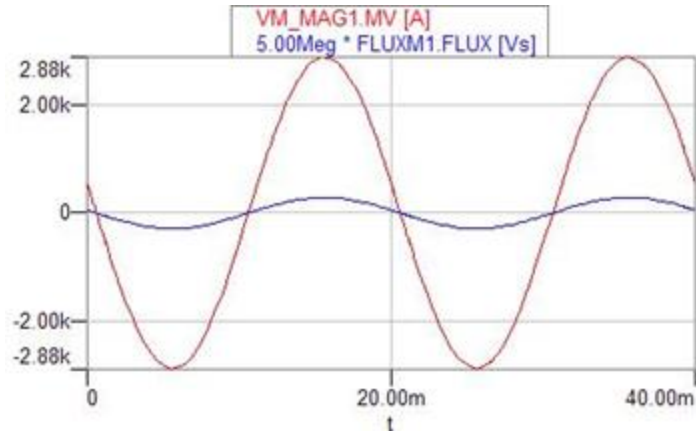


Figure 3. Simulation results

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References

Mechanical Components

The mechanical domain components appear in the *Mechanical* folder of *Physical Domains* in the **Basic Elements** library. The folder provides mechanical basic components to model simple mechanical equivalent circuits. There are two representation forms:

- [Displacement-Force](#)
- [Velocity-Force](#)

The following table shows the across and through quantities used of the representation forms.

By default, components and wires of the mechanical domain are represented in blue for translational systems and in lilac for rotational systems. The velocity-force components and wires are represented by a darker coloring compared to the displacement-force components. To change the settings of nature colors, choose Tools\Options\Schematic Editor Options, click on the *color* tab, select *Wires* as the object type, and the color of wires for different domains can be edited.

Across and Through Quantities of Mechanical Domains

Table 1

Representation	System	Across	Through	Equation
Displacement-Force	Translational	s [m]	F [N]	$v(t) = \frac{ds}{dt}$
	Rotational	φ [rad]	M [Nm]	$\omega(t) = \frac{d\varphi}{dt}$
Velocity-Force	Translational	v [m/s]	F [N]	$s(t) = \int v dt$
	Rotational	ω [rad/s]	M [Nm]	$\varphi(t) = \int \omega dt$

Displacement-Force Representation

The displacement-force representation consists of:

- [Rotational Components](#)
- [Translational Components](#)

Rotational Components

- [Damper \(DAMP_ROT\)](#)
- [Torque Source \(F_ROT\)](#)
- [Limit Stop \(LIMIT_ROT\)](#)
- [Ideal Rotational Limit Stop \(LIMIT_STOP_IDEAL_ROT\)](#)
- [Mass \(MASS_ROT\)](#)
- [Angle Source \(S_ROT\)](#)
- [Spacer \(SPACER_ROT\)](#)
- [Spring \(SPRING_ROT\)](#)
- [Angular Velocity Source \(V_ROT\)](#)

Damper

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

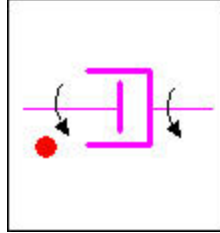


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Description

The component represents a simple damper specified by a linear damping coefficient.

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Assumptions and Limitations

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Mathematical Description

The Damper model can be described as:

$$M(t) = \text{DAMPING} \cdot \dot{\omega}(t)$$

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Netlist Syntax

UMODEL DAMP_ROTB ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) ROTB1:= %0,
ROTB2:= %1 (DAMPING:= @DAMPING) SRC: DB(Lib:=@ModelLibraryName) ;

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
ROTB1	Pin1	rotational
ROTB2	Pin2	rotational

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
DAMPING	Damping Coefficient	real	1 [Nm*s/rad]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
PHI	Angle [rad]	Output	real
M	Torque [Nm]	Output	real
OMEGA	Angular Velocity [rad/s]	Output	real

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Example

Figure 2 shows application of the Damper model. In this example, a constant angular velocity is applied to the system. Due to the damping of the system, the force applied to the mass

sinusoidally decays with time. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3 and 4.

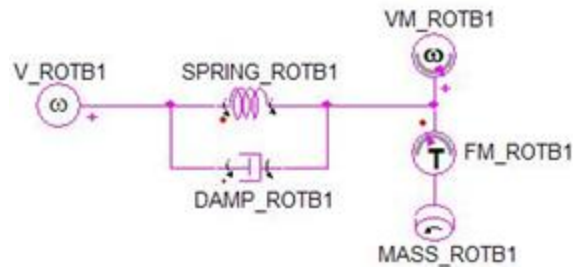


Figure 2. Application example of the Damper model

Table 4

Component	Parameter	Value
Spring SPRING_ROT B1	C	10 [Nm/rad]
Damper DAMPER_ROT B1	DUMPING	0.05 [Nms/rad]
Angular Velocity Source V_ROT B1	VALUE	10 [rad/s]
Mass MASS_ROT B1	J	1 [Kg m ²]
	PHI0	0 [rad]
	OMEGA0	0 [rad/s]

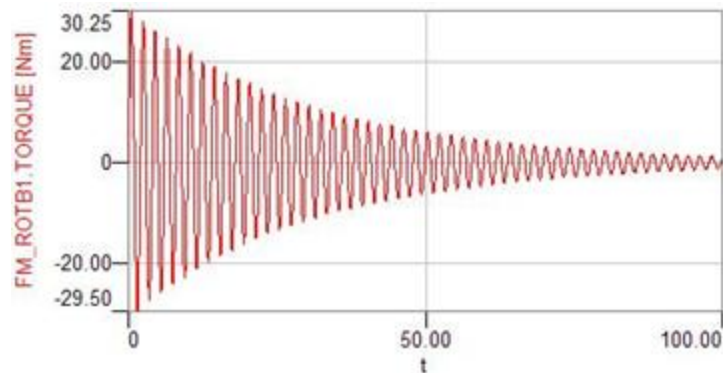


Figure 3. Simulation result-torque applied to MASS_ROT B1

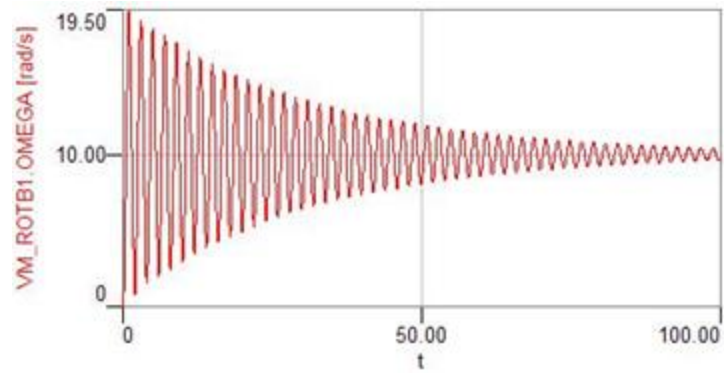


Figure 4. Simulation result-angular velocity of MASS_ROT B1

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References

Torque Source

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

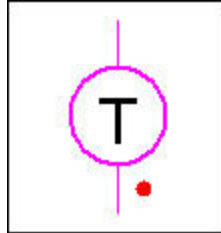


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Description

The component represents an ideal mechanical torque source which supplies the defined torque for an arbitrary position.

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Assumptions and Limitations

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Mathematical Description

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

Linear Torque Source

The torque is equivalent to the present value of the quantity specified in the input field, which can be a constant value, a time function, a variable, or a value determined in a state graph. All system quantities and variables can be combined with mathematical and logical operators and constants.

$$M(t) = \text{VALUE}$$

The position of an ideal torque source can be arbitrary. Real flow sources have always an internal resistance. If the internal resistance is essential for the simulation target, a corresponding resistance must be connected in parallel.

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
ROTB1	Pin1	rotational
ROTB2	Pin2	rotational

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
VALUE	Torque [Nm]	real	1

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
PHI	Angle [rad]	Output	real
M	Torque [Nm]	Output	real
OMEGA	Angular Velocity [rad/s]	Output	real

Time-Controlled Torque Source

The time-controlled torque sources have the same properties as the linear torque source above; the position can be arbitrary and the internal resistance is zero (ideal source). The value of torque instead is equivalent to the present value of the selected time function at each calculation step.

$$M(t) = f[\text{time function}]$$

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Conservative Pins

Table 4

Name	Description	Nature/Data Type
ROTB1	Pin1	rotational
ROTB2	Pin2	rotational

[Top](#)

Parameters

Table 5

Name	Description	Data Type	Default Value [Unit]
AMPL	Amplitude	real	1 [Nm]
FREQU	Frequency (no trapezoidal function parameter)	real	50 [Hz]
TPERIO	Period	real	20m [s]
TDELAY	Delay	real	0 [s]
PHASE	Phase	real	0 [deg]
n/a	Angular Dimension		
OFF	Offset	real	0
PERIO	Periodic; PERIO=1, periodical function, PERIO=0; non-periodical function	real	1
DAMPING	Damping factor (only sine function) DAMPING>0, amplitude is exponentially decreasing (damped). DAMPING<0, amplitude is exponentially increasing, DAMPING=0, no damping	real	0 [1/s]
TRISE	Rise Time (only trapezoidal function)	real	5m [s]
TFALL	Fall Time (only trapezoidal function)	real	10m [s]
PWIDTH	Pulse Width (only trapezoidal function)	real	5m [s]

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Input/Output Quantities

Table 6

Name	Description [Unit]	Direction	Data Type
PHI	Angle [rad]	Output	real
M	Torque [Nm]	Output	real
OMEGA	Angular Velocity [rad/s]	Output	real

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Example

Figure 2 shows application of the Toque Source model. In this example, The mass is accel-
erated by a constant Torque. The acceleration is limited due to the Limit Stop. The Limit stop rep-
resents a spring-damper combination which causes the mass to stop at the defined upper angle
limit. The parameters of the system are listed in Table 4 and the simulation results shown in Fig-
ure 3 and 4.

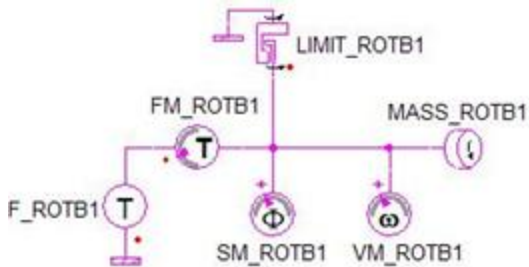


Figure 2. Application example of the Torque Source model

Table 4

Component	Parameter	Value
Limit Stop LIMIT_ROT B1	C	1.0e5 [Nm/rad]
	DUMPING	1.0e5 [Nms/rad]
	PHIU	1 [rad]
	PHIL	0 [rad]
Torque Source F_ROT B1	VALUE	10 [Nm]
Mass MASS_ROT B1	J	3 [Kg m ²]
	PHI0	0.1 [rad]
	OMEGA0	0 [rad/s]

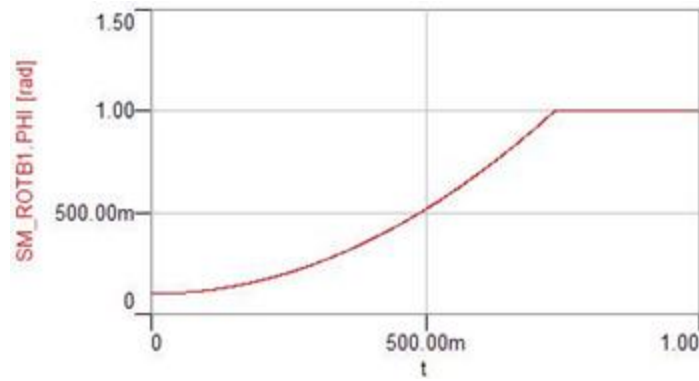


Figure 3. Simulation result-angle of MASS_ROT B1

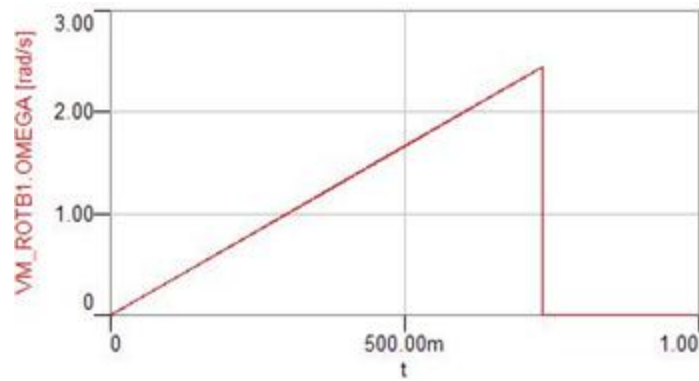


Figure 4. Simulation result-angular velocity of MASS_ROT B1

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References

Limit Stop

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

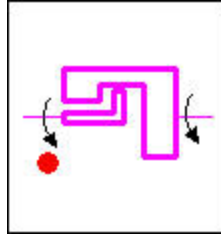


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Description

The component represents a parallel damper and spring combination within defined limits (upper and lower limit).

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Assumptions and Limitations

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Mathematical Description

The Limit Stop can be described as:

```

if  $\varphi(t) > \text{PHIUL}$ 
 $M(t) = C \cdot (\varphi(t) - \text{PHIUL}) + \text{DAMPING} \cdot \omega(t)$ 
if  $\varphi(t) < \text{PHILL}$ 
 $M(t) = C \cdot (\varphi(t) - \text{PHILL}) + \text{DAMPING} \cdot v(t)$ 
else  $M(t) = 0$ 

```

[Top](#)**Netlist Syntax**

```

UMODEL LIMIT_ROT ?InstanceName(@InstanceName):(@Refbase)@(ID)) ROTB1:= %0,
ROTB2:= %1 ( C:= @C, DAMPING:= @DAMPING, PHIUL:= @PHIUL, PHILL:= @PHILL) SRC:
DB(Lib:=@ModelLibraryName);

```

[Top](#)**Conservative Pins****Table 1**

Name	Description	Nature/Data Type
ROTB1	Pin1	rotational
ROTB2	Pin2	rotational

[Top](#)**Parameters****Table 2**

Name	Description	Data Type	Default Value [Unit]
C	Spring Rate	real	1.0e+006 [Nm/rad]
DAMPING	Damping Coefficient	real	1.0e+006 [Nm*s/rad]
PHIUL	Upper Angle Limit	real	1 [rad]
PHILL	Lower Angle Limit	real	0 [rad]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
PHI	Angle [rad]	Output	real
M	Torque [Nm]	Output	real
OMEGA	Angular Velocity [rad/s]	Output	real

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Example

Figure 2 shows application of the Limit Stop model. In this example, the mass is accelerated by a constant Torque. The acceleration is limited due to the Limit Stop. The Limit stop represents a spring-damper combination which causes the mass to stop at the defined upper angle limit. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3 and 4.

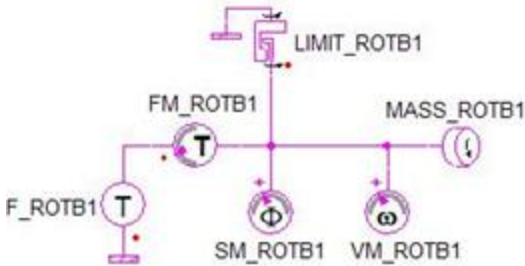


Figure 2. Application example of the Limit Stop model

Table 4

Component	Parameter	Value
Limit Stop LIMIT_ROT B1	C	1.0e5 [Nm/rad]
	DUMPING	1.0e5 [Nms/rad]
	PHIU	1 [rad]
	PHIL	0 [rad]
Torque Source F_ROT B1	VALUE	10 [Nm]
Mass MASS_ROT B1	J	3 [Kg m ²]

	PHI0	0.1 [rad]
	OMEGA0	0 [rad/s]

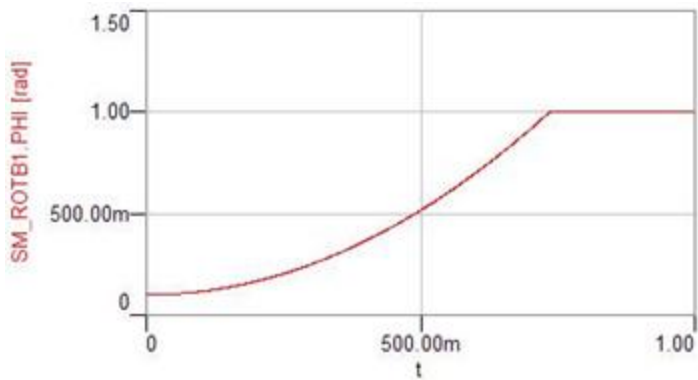


Figure 3. Simulation result-angle of MASS_ROTBT1

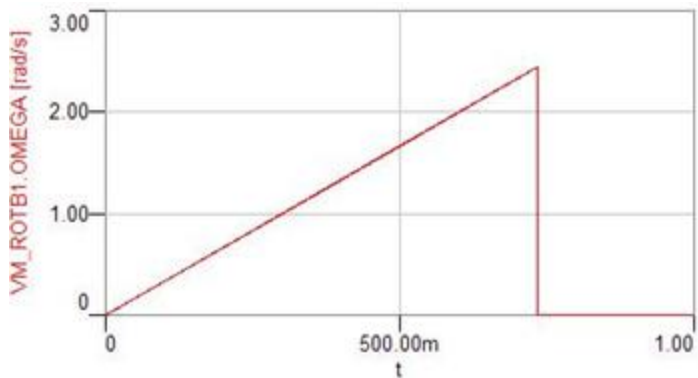


Figure 4. Simulation result-angular velocity of MASS_ROTBT1

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References

Ideal Limit Stop

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

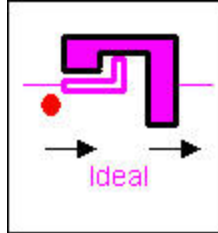


Figure 1. Component Symbol.

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Description

The component models an ideal mechanical Limit Stop. It will prevent a mass model connected to node 1 to exceed the upper limit setting and to undershoot the lower limit with respect to the angle at the other node.

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Assumptions and Limitations

This model may cause numerical problems when used with trapezoidal integration algorithm. In case of problems switch to the Euler method.

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Mathematical Description

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Netlist Syntax

```
MODEL LIMIT_STOP_IDEAL_ROT ?InstanceName(@InstanceName):(@Refbase)@(ID))
ROTB1:= %0, ROTB2:= %1 ( UPPER_LIM:= @UPPER_LIM, LOWER_LIM:= @LOWER_LIM)
SRC: DB(Lib:=@ModelLibraryName);
```

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
ROTB1	Pin1	rotational
ROTB2	Pin2	rotational

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
UPPER_LIM	Upper Angle Limit	real	1
LOWER_LIM	Lower Angle Limit	real	0

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
DELTA_PHI	Angle [rad]	Output	real
TORQUE	Torque [Nm]	Output	real

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Example

Figure 2 shows application of the Ideal Limit Stop model. In this example, the mass is accelerated by a constant Torque. The acceleration is limited due to the defined upper angle limit of

the Ideal Limit Stop LIMIT_STOP_IDEAL_ROTB1. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3 and 4.

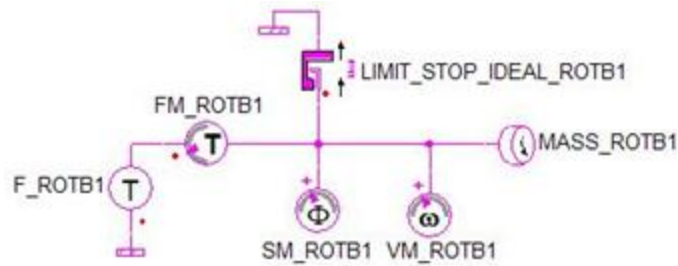


Figure 2. Application example of the Ideal Limit Stop model

Table 4

Component	Parameter	Value
Ideal Limit Stop LIMIT_STOP_IDEAL_ROT B1	PHIU	1 [rad]
	PHIL	0 [rad]
Torque Source F_ROT B1	VALUE	10 [Nm]
Mass MASS_ROT B1	J	3 [Kg m ²]
	PHI0	0.1 [rad]
	OMEGA0	0 [rad/s]

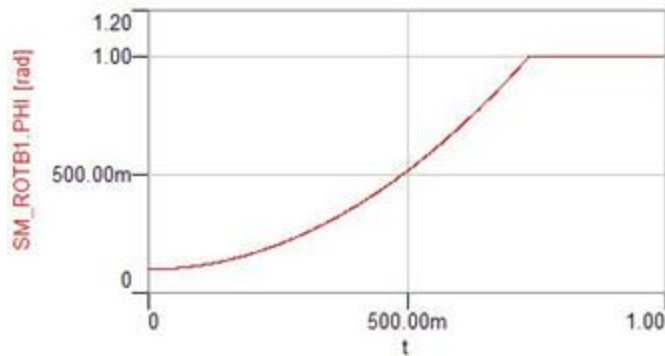


Figure 3. Simulation result-angle of MASS_ROT B1

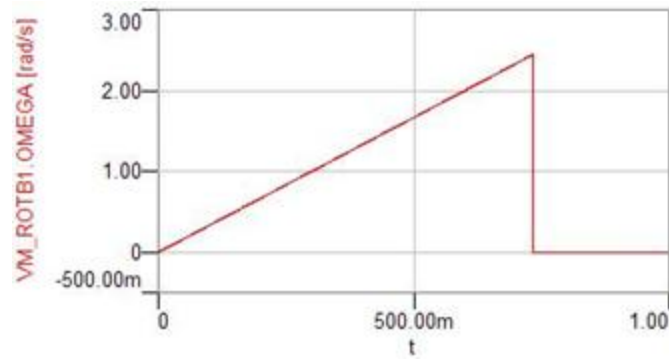


Figure 4. Simulation result-angular velocity of MASS_ROT B1

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References

Mass

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

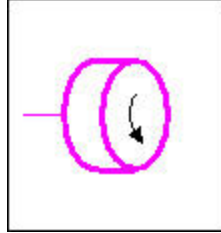


Figure 1. Component Symbol.

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Description

The component represents a mass specified by an inertia and initial velocity.

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Assumptions and Limitations

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Mathematical Description

The Mass model can be described as:

$$M(t) = J \cdot a(t) \quad \varphi(t) = \int \omega dt + \varphi_0 \quad \omega(t) = \int a dt + \omega_0$$

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Netlist Syntax

UMODEL MASS_ROTB ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) ROTB1:= %0 (
J:= @J, PHI0:= @PHI0, OMEGA0:= @OMEGA0) SRC: DB(Lib:=@ModelLibraryName) ;

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
ROTB1	Pin1	rotational
ROTB2	Pin2	rotational

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
J	Mass Moment of Inertia	real	1 [kg*m ²]
PHI0	Initial Angle	real	0 [rad]
OMEGA0	Initial Angular Velocity	real	0 [rad/s]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
PHI	Angle [rad]	Output	real
M	Torque [Nm]	Output	real
OMEGA	Angular Velocity [rad/s]	Output	real
ACC	Acceleration [rad/s ²]	Output	real

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Example

Figure 2 shows application of the Mass model. In this example, a constant angular velocity is applied to the system. Due to the damping of the system, the force applied to the mass sinusoidally decays with time. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3 and 4.

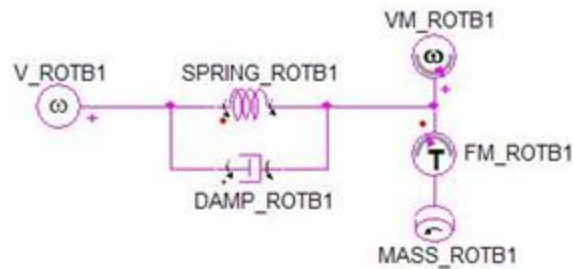


Figure 2. Application example of the Mass model

Table 4

Component	Parameter	Value
Spring SPRING_ROT B1	C	10 [Nm/rad]
Damper DAMPER_ROT B1	DUMPING	0.05 [Nms/rad]
Angular Velocity Source V_ROT B1	VALUE	10 [rad/s]
Mass MASS_ROT B1	J	1 [Kg m ²]
	PHI0	0 [rad]
	OMEGA0	0 [rad/s]

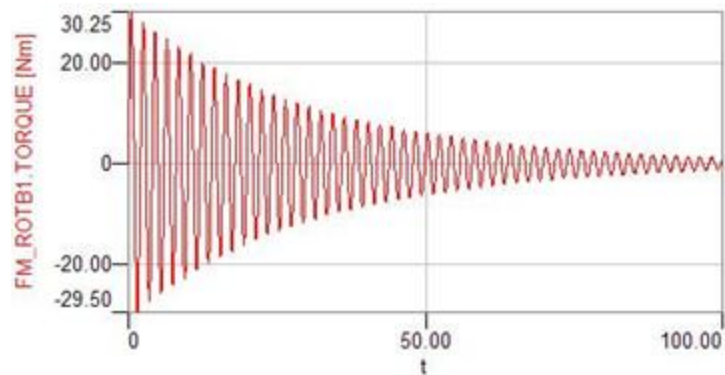


Figure 3. Simulation result-torque applied to MASS_ROT B1

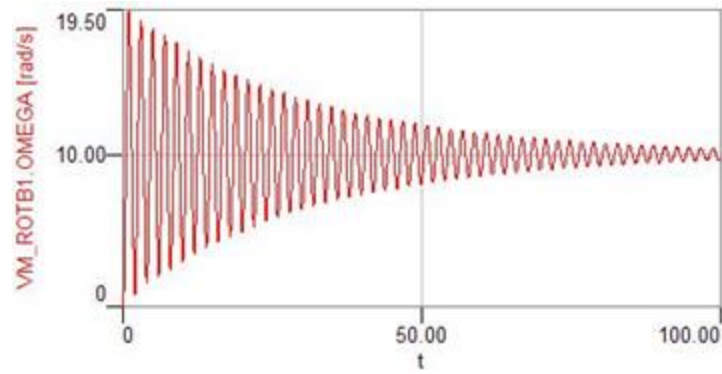


Figure 4. Simulation result-angular velocity of MASS_ROT B1

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References

Angle Source

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

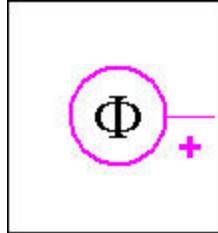


Figure 1. Component Symbol.

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Description

The component represents an ideal mechanical position source which supplies the defined position for an arbitrary torque.

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Assumptions and Limitations

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Mathematical Description

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

Linear Angle Source

The angle is equivalent to the present value of the quantity specified in the text box, which can be a constant value, a time function, a variable, or a value determined in a state graph. All system quantities and variables can be combined with mathematical and logical operators and constants.

$$\varphi(t) = \text{VALUE}$$

The torque through an ideal angle source can be arbitrary. Real torque sources have always an internal resistance. If the internal resistance is essential for the simulation target, a corresponding resistance must be connected in series.

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
ROTB1	Pin Angle Source	rotational

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
VALUE	Angle	real	0 [rad]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
PHI	Angle [rad]	Output	real

M	Torque [Nm]	Output	real
OMEGA	Angular Velocity [rad/s]	Output	real

Time-Controlled Angle Source

The time-controlled angle sources have the same properties as the linear angle source above; the torque flow can be arbitrary and the internal resistance is zero (ideal source). The value of the angle instead is equivalent to the present value of the selected time function at each calculation step.

$$\varphi(t) = f[\text{time function}]$$

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Conservative Pins

Table 4

Name	Description	Nature/Data Type
ROTB1	Pin Angle Source	rotational

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Parameters

Table 5

Name	Description	Data Type	Default Value [Unit]
AMPL	Amplitude	real	6.28 [rad]
FREQU	Frequency (no trapezoidal function parameter)	real	50 [Hz]
TPERIO	Period	real	20m [s]
TDELAY	Delay	real	0 [s]
PHASE	Phase	real	0 [deg]

n/a	Angular Dimension		
OFF	Offset	real	0
PERIO	Periodic; PERIO=1, periodical function, PERIO=0; non-periodical function	real	1
DAMPING	Damping factor (only sine function) DAMPING>0, amplitude is exponentially decreasing (damped). DAMPING<0, amplitude is exponentially increasing, DAMPING=0, no damping	real	0 [1/s]
TRISE	Rise Time (only trapezoidal function)	real	5m [s]
TFALL	Fall Time (only trapezoidal function)	real	10m [s]
PWIDTH	Pulse Width (only trapezoidal function)	real	5m [s]

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Input/Output Quantities

Table 6

Name	Description [Unit]	Direction	Data Type
PHI	Angle [rad]	Output	real
M	Torque [Nm]	Output	real
OMEGA	Angular Velocity [rad/s]	Output	real

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Example

Figure 2 shows application of the Angle Source model. In this example, a sinusoidal displacement is applied to a mass. The offset is removed with the Spacer SPACER_ROT B1. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3 ~ 5.

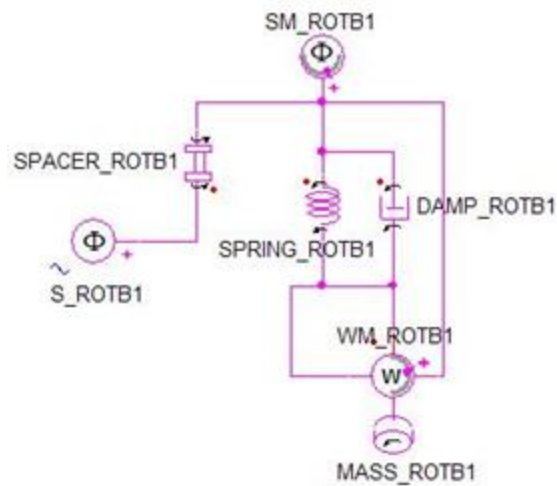


Figure 2. Application example of the Angle Source model

Table 4

Component	Parameter	Value
Spacer SPACER_ROT B1	LEN	0.2 [rad]
Spring SPRING_ROT B1	C	10 [Nm/rad]
Damper DAMPER_ROT B1	DUMPING	0.05 [Nms/rad]
Angle Source (sinusoidal) S_ROT B1	AMPL	1.5 [rad]
	FREQ	1
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0.2 [rad]
Mass MASS_ROT B1	J	1 [Kg m ²]
	PHI0	0 [rad]
	OMEGA0	0 [rad/s]

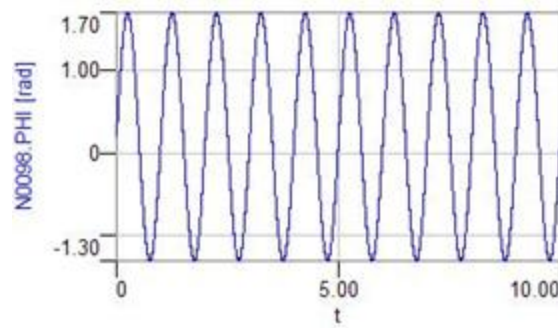


Figure 3. Simulation result-output angle of S_ROTb1

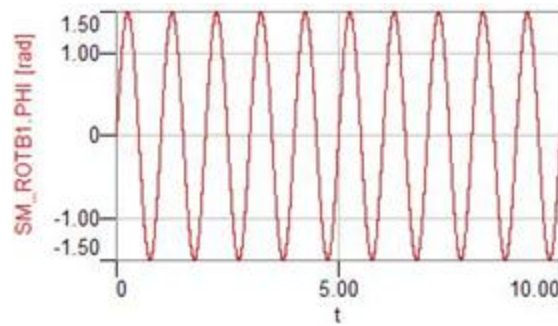


Figure 4. Simulation result-measured angle of SM_ROTb1

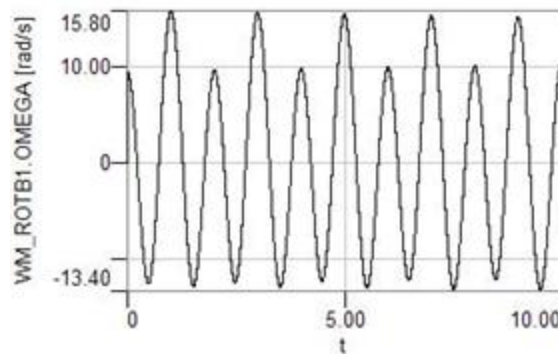


Figure 5. Simulation result-angular speed of MASS_ROTb1

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References

Spacer

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

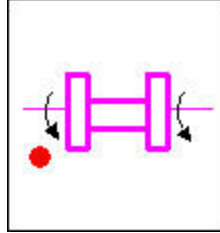


Figure 1. Component Symbol.

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Description

The component represents a constant displacement between two components in a mechanical system specified by a length.

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Assumptions and Limitations

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Mathematical Description

The Spacer model can be described as:

$$\omega(t) = \frac{d\varphi}{dt} \quad \varphi = \text{LEN}$$

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Netlist Syntax

UMODEL SPACER_ROTB ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) ROTB1:= %0, ROTB2:= %1 (LEN:= @LEN) SRC: DB(Lib:=@ModelLibraryName);

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
ROTB1	Pin1	rotational
ROTB2	Pin2	rotational

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
LEN	Length	real	0 [rad]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
PHI	Angle [rad]	Output	real
M	Torque [Nm]	Output	real
OMEGA	Angular Velocity [rad/s]	Output	real

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Example

Figure 2 shows application of the Spacer model. In this example, a sinusoidal displacement is applied to a mass. The offset is removed with the Spacer SPACER_ROTB1. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3 ~ 5.

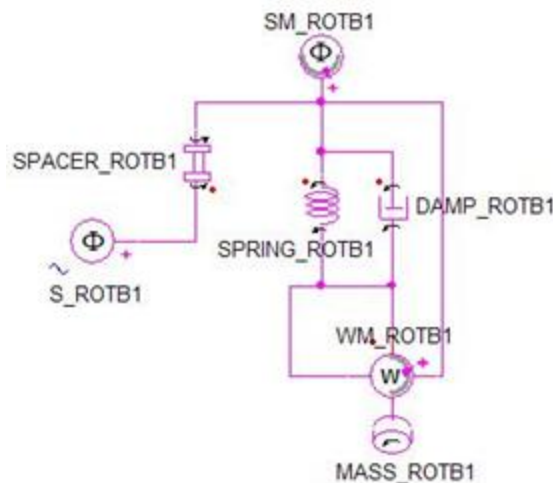


Figure 2. Application example of the Spacer model

Table 4

Component	Parameter	Value
Spacer SPACER_ROT1	LEN	0.2 [rad]
Spring SPRING_ROT1	C	10 [Nm/rad]
Damper DAMPER_ROT1	DUMPING	0.05 [Nms/rad]
Angle Source (sinusoidal) S_ROT1	AMPL	1.5 [rad]
	FREQ	1
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	0.2 [rad]
Mass MASS_ROT1	J	1 [Kg m ²]
	PHI0	0 [rad]
	OMEGA0	0 [rad/s]

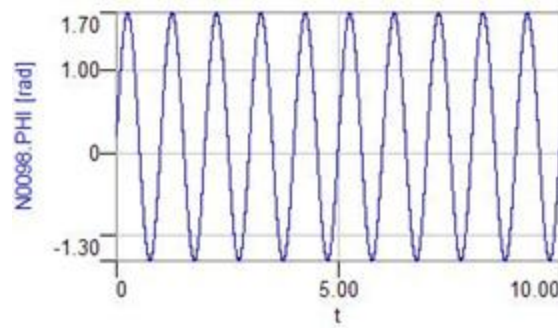


Figure 3. Simulation result-output angle of S_ROT B1

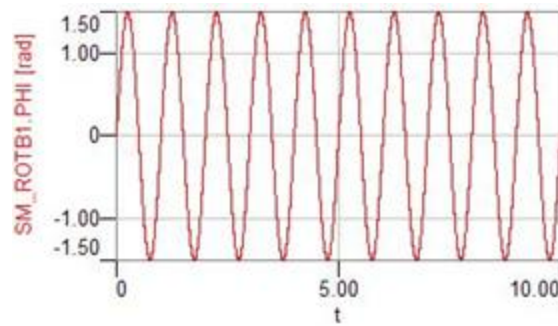


Figure 4. Simulation result-measured angle of SM_ROT B1

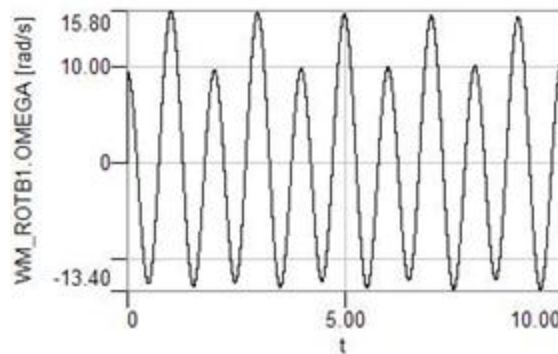


Figure 5. Simulation result-angular speed of MASS_ROT B1

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References

Spring

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

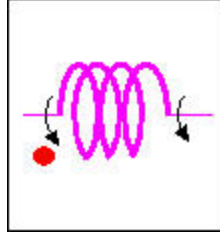


Figure 1. Component Symbol.

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Description

The component represents a simple spring specified by a spring rate.

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Assumptions and Limitations

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Mathematical Description

The Spring model can be described as:

$$M(t) = C \cdot \varphi(t)$$

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Netlist Syntax

UMODEL SPRING_ROTB ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) ROTB1:= %0, ROTB2:= %1 (C:= @C) SRC: DB(Lib:=@ModelLibraryName) ;

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
ROTB1	Pin1	rotational
ROTB2	Pin2	rotational

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
C	Spring Rate	real	1 [Nm/rad]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
PHI	Angle [rad]	Output	real
M	Torque [Nm]	Output	real
OMEGA	Angular Velocity [rad/s]	Output	real

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Example

Figure 2 shows application of the Spring model. In this example, a constant angular velocity is applied to the system. Due to the damping of the system, the force applied to the mass sinus-

odially decays with time. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3 and 4.

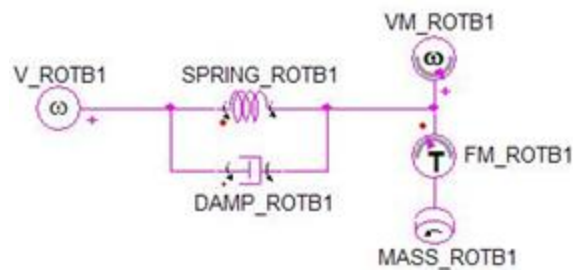


Figure 2. Application example of the Spring model

Table 4

Component	Parameter	Value
Spring SPRING_ROT B1	C	10 [Nm/rad]
Damper DAMPER_ROT B1	DUMPING	0.05 [Nms/rad]
Angular Velocity Source V_ROT B1	VALUE	10 [rad/s]
Mass MASS_ROT B1	J	1 [Kg m ²]
	PHI0	0 [rad]
	OMEGA0	0 [rad/s]

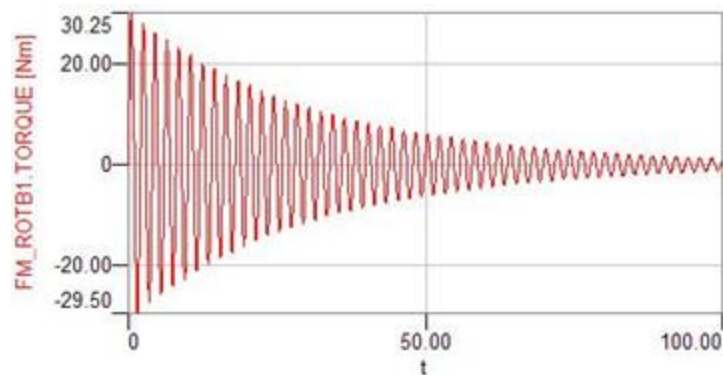


Figure 3. Simulation result-torque applied to MASS_ROT B1

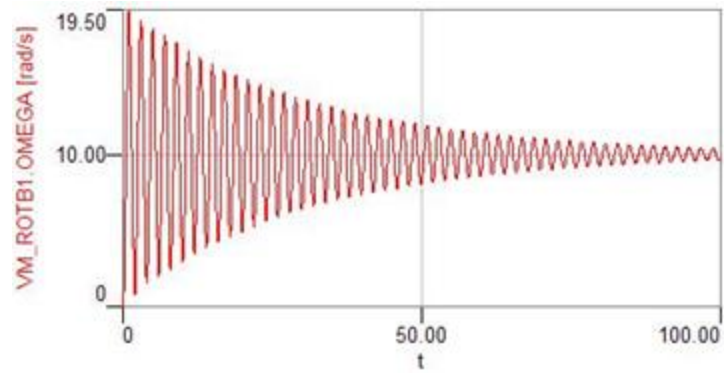


Figure 4. Simulation result-angular velocity of MASS_ROT B1

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References

Angular Velocity Source

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

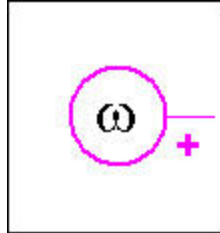


Figure 1. Component Symbol.

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Description

The component represents an ideal mechanical velocity source which supplies the defined velocity for an arbitrary torque.

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Assumptions and Limitations

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Mathematical Description

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

Linear Angular Velocity Source

The velocity is equivalent to the present value of the quantity specified in the text box, which can be a constant value, a time function, a variable, or a value determined in a state graph. All system quantities and variables can be combined with mathematical and logical operators and constants.

The torque through an ideal angle source can be arbitrary. Real torque sources have always an internal resistance. If the internal resistance is essential for the simulation target, a corresponding resistance must be connected in series.

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
ROTB1	Pin Angular Velocity Source	rotational

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
VALUE	Angular Velocity	real	1 [rad/s]
PHI0	Initial Angle	real	0 [rad]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
PHI	Angle [rad]	Output	real
M	Torque [Nm]	Output	real

OMEGA	Angular Velocity [rad/s]	Output	real

Time-Controlled Angular Velocity Source

The time-controlled velocity sources have the same properties as the linear velocity source above; the torque flow can be arbitrary and the internal resistance is zero (ideal source). The value of the angle instead is equivalent to the present value of the selected time function at each calculation step.

$$\frac{d\varphi}{dt} = \omega(t) = f[\text{time function}]$$

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Conservative Pins

Table 4

Name	Description	Nature/Data Type
ROTB1	Pin Angular Velocity Source	rotational

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Parameters

Table 5

Name	Description	Data Type	Default Value [Unit]
AMPL	Amplitude	real	1 [rad/s]
PHI0	Initial Angle	real	0 [rad]
FREQU	Frequency (no trapezoidal function parameter)	real	50 [Hz]
TPERIO	Period	real	20m [s]
TDELAY	Delay	real	0 [s]
PHASE	Phase	real	0 [deg]
n/a	Angular Dimension		
OFF	Offset	real	0
PERIO	Periodic; PERIO=1, periodical function, PERIO=0; non-periodical function	real	1
DAMPING	Damping factor (only sine function) DAMPING>0, amplitude is exponentially decreasing (damped). DAMPING<0, amplitude is exponentially increasing, DAMPING=0, no damping	real	0 [1/s]
TRISE	Rise Time (only trapezoidal function)	real	5m [s]
TFALL	Fall Time (only trapezoidal function)	real	10m [s]
PWIDTH	Pulse Width (only trapezoidal function)	real	5m [s]

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Input/Output Quantities

Table 6

Name	Description [Unit]	Direction	Data Type
PHI	Angle [rad]	Output	real

M	Torque [Nm]	Output	real
OMEGA	Angular Velocity [rad/s]	Output	real

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Example

Figure 2 shows application of the Angular Velocity Source model. In this example, a constant angular velocity is applied to the system. Due to the damping of the system, the force applied to the mass sinusoidally decays with time. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3 and 4.

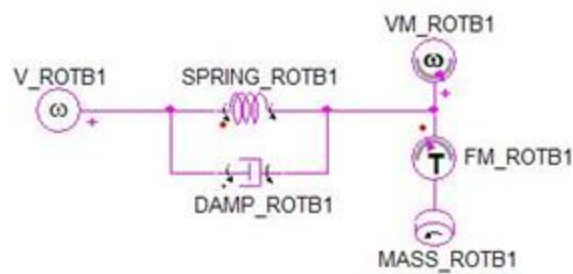


Figure 2. Application example of the Angular Velocity Source model

Table 4

Component	Parameter	Value
Spring SPRING_ROT B1	C	10 [Nm/rad]
Damper DAMPER_ROT B1	DUMPING	0.05 [Nms/rad]
Angular Velocity Source V_ROT B1	VALUE	10 [rad/s]
Mass MASS_ROT B1	J	1 [Kg m ²]
	PHI0	0 [rad]
	OMEGA0	0 [rad/s]

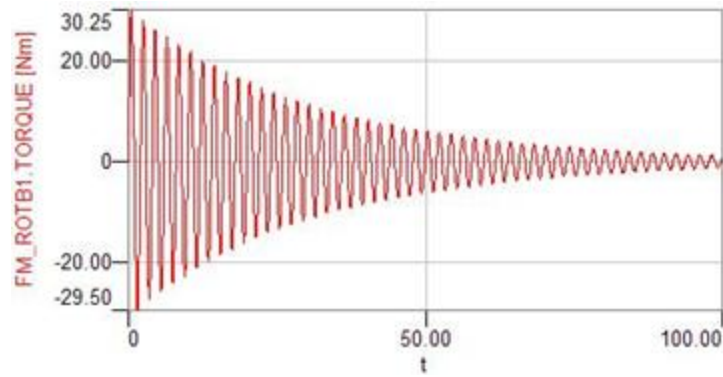


Figure 3. Simulation result-torque applied to MASS_ROT B1

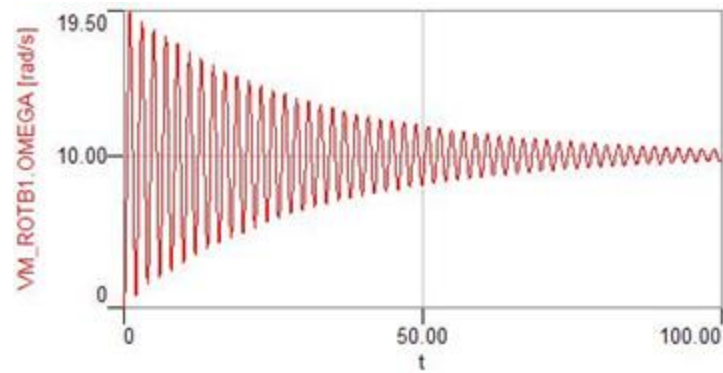


Figure 4. Simulation result-angular velocity of MASS_ROT B1

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References

Translational Components

- Damper (DAMP_TRB)
- Force Source (F_TRB)
- Ideal Translational Limit Stop (LIMIT_STOP_IDEAL_TRB)
- Limit Stop (LIMIT_TRB)
- Mass (MASS_TRB)
- Position Source (S_TRB)
- Solenoid (SOLENOID_TRB)
- Spacer (SPACER_TRB)
- Spring (SPRING_TRB)
- Velocity Source (V_TRB)

Damper

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

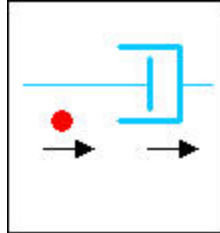


Figure 1. Component Symbol.

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Description

The component represents a simple damper specified by a linear damping coefficient.

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Assumptions and Limitations

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Mathematical Description

The Damper model can be described as:

$$F(t) = \text{DAMPING} \cdot v(t)$$

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Netlist Syntax

UMODEL DAMP_TRB ?InstanceName(@InstanceName):(@Refbase)@(ID)) TRB1:= %0,
TRB2:= %1 (DAMPING:= @DAMPING) SRC: DB(Lib:=@ModelLibraryName);

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
TRB1	Pin1	translational
TRB2	Pin2	translational

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
DAMPING	Damping Coefficient	real	1 [N*s/m]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
S	Displacement [m]	Output	real
F	Force [N]	Output	real
V	Velocity [m/s]	Output	real

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Example

Figure 2 shows application of the Damper model. In this example, a constant velocity (10m/s) is applied to the system. Due to the damping element, the force applied to the mass sinusoidally

decays with time. The parameters of the system are listed in Table 4 and the simulation results shown in Figures 3, 4, and 5.

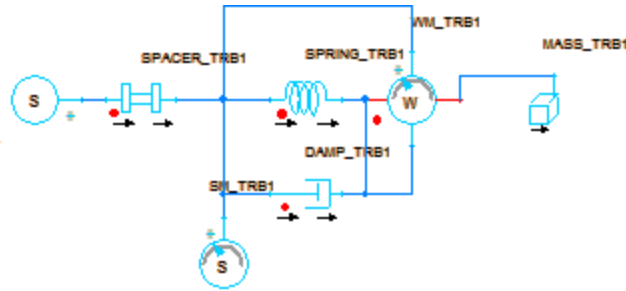


Figure 2. Application example of the Damper model

Table 4

Component	Parameter	Value
Spring SPRING_TRB1	C	10k [N/m]
Damper DAMP_TRB1	DAMPING	5 [Ns/m]
Velocity Source V_TRB1	VALUE	10 [m/s]
	S0	0 [m]
Mass MASS_TRB1	M	500 [Kg]
	S0	0 [m]
	V0	0 [m/s]

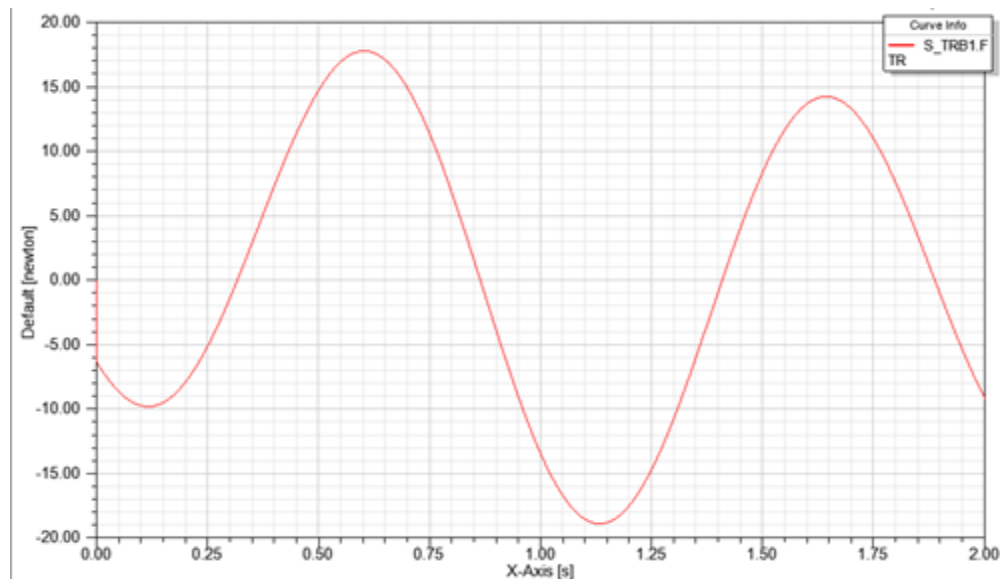


Figure 3. Simulation result-force applied to the spacer

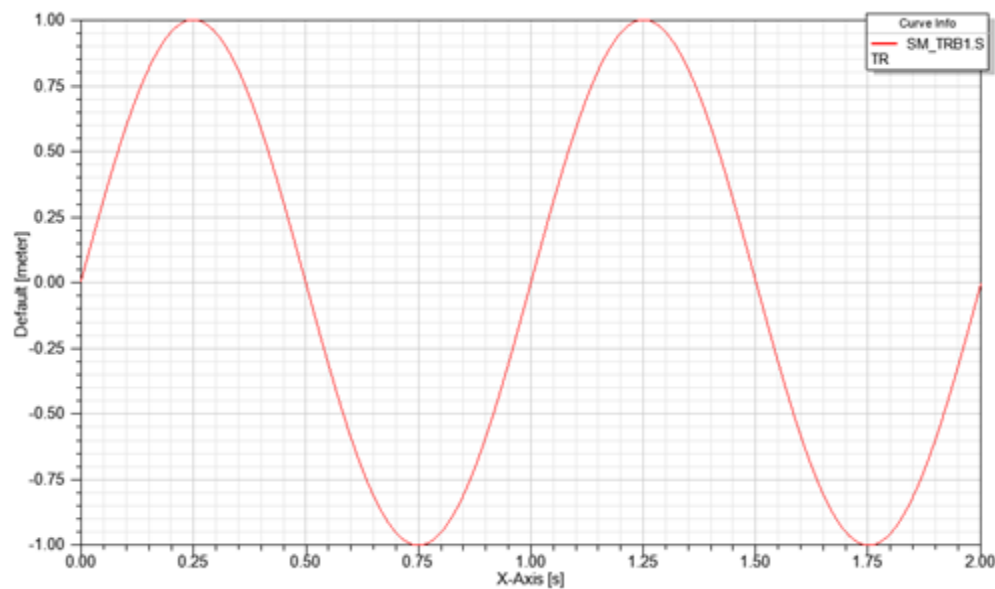


Figure 4. Simulation result-displacement of the mass

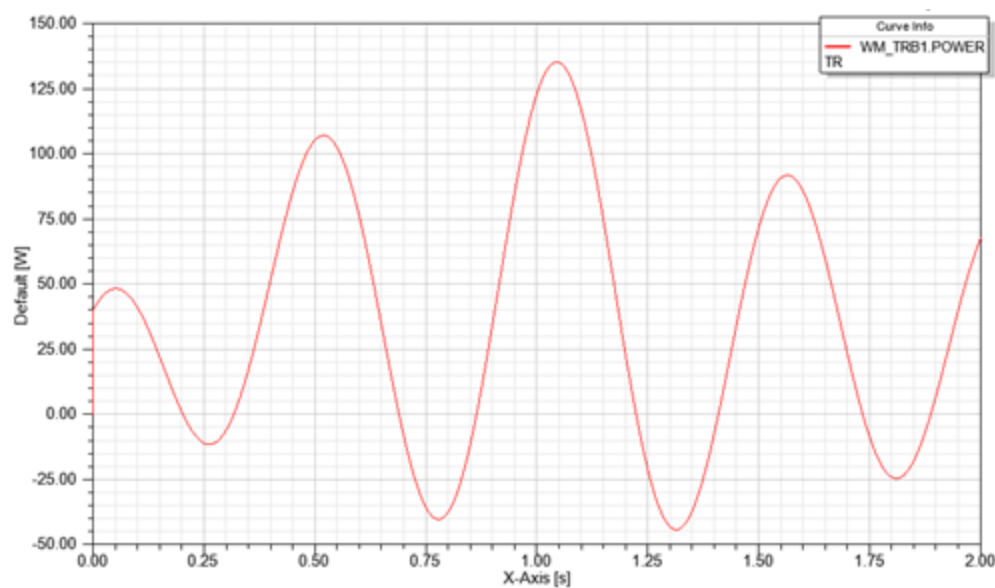


Figure 4. Simulation result-power of the system

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References

Force Source

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

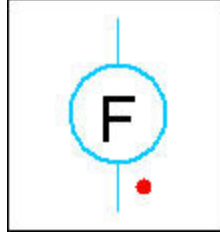


Figure 1. Component Symbol.

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Description

The component represents an ideal mechanical force source which supplies the defined force for an arbitrary position.

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Assumptions and Limitations

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Mathematical Description

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

Linear Force Source

The force is equivalent to the present value of the quantity specified in the input field, which can be a constant value, a time function, a variable, or a value determined in a state graph. All system quantities and variables can be combined with mathematical and logical operators and constants.

$$F(t) = \text{VALUE}$$

The position of an ideal force source can be arbitrary. Real flow sources have always an internal resistance. If the internal resistance is essential for the simulation target, a corresponding resistance must be connected in parallel.

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
TRB1	Pin1	translational
TRB2	Pin2	translational

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
VALUE	Force	real	10 [N]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
S	Displacement [m]	Output	real
F	Force [N]	Output	real
V	Velocity [m/s]	Output	real

Time-Controlled Force Source

The time-controlled force/torque sources have the same properties as the linear force/torque source above; the position can be arbitrary and the internal resistance is zero (ideal source). The value of force/torque instead is equivalent to the present value of the selected time function at each calculation step.

$$F(t) = f[\text{time function}]$$

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Conservative Pins

Table 4

Name	Description	Nature/Data Type
TRB1	Pin1	translational
TRB2	Pin2	translational

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Parameters

Table 5

Name	Description	Data Type	Default Value [Unit]
AMPL	Amplitude	real	10 [N]
FREQU	Frequency (no trapezoidal function parameter)	real	50 [Hz]
TPERIO	Period	real	20m [s]
TDELAY	Delay	real	0 [s]
PHASE	Phase	real	0 [deg]
n/a	Angular Dimension		
OFF	Offset	real	0
PERIO	Periodic; PERIO=1, periodical function, PERIO=0; non-periodical function	real	1
DAMPING	Damping factor (only sine function) DAMPING>0, amplitude is exponentially decreasing (damped). DAMPING<0, amplitude is exponentially increasing, DAMPING=0, no damping	real	0 [1/s]
TRISE	Rise Time (only trapezoidal function)	real	5m [s]
TFALL	Fall Time (only trapezoidal function)	real	10m [s]
PWIDTH	Pulse Width (only trapezoidal function)	real	5m [s]

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Input/Output Quantities

Table 6

Name	Description [Unit]	Direction	Data Type
S	Displacement [m]	Output	real
F	Force [N]	Output	real
V	Velocity [m/s]	Output	real

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Example

Figure 2 shows application of the Force Source model. In this example, the mass is accelerated by a constant Force (10 N). The acceleration is limited due to the Limit Stop. The Limit stop represents a spring-damper combination which causes the mass to stop at the defined upper position (sul). The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3 and 4.

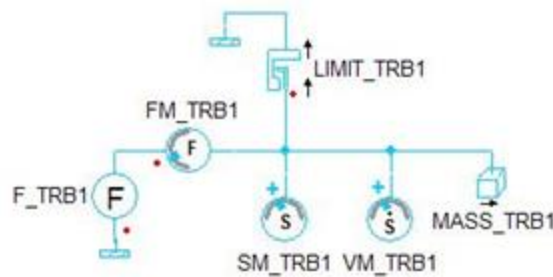


Figure 2. Application example of the Force Source model

Table 4

Component	Parameter	Value
Force Source	F_TRB1	10 [N]
Limit Stop LIMIT_TRB1	DAMPING	1.0e5 [Ns/m]
	C	1.0e5 [N/m]
	SU	1 [m]
	SL	0 [m]
Mass MASS_TRB1	M	3 [Kg]
	S0	0 [m]
	V0	0 [m/s]

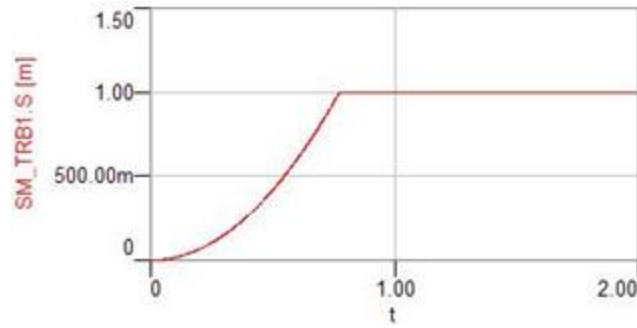


Figure 3. Simulation result-displacement of MASS_TRB1

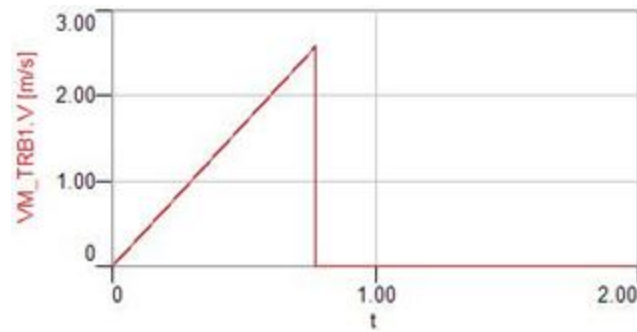


Figure 4. Simulation result-velocity of MASS_TRB1

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References

Ideal Limit Stop

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

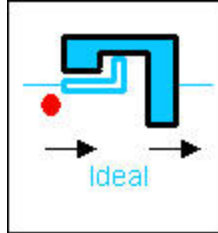


Figure 1. Component Symbol.

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Description

The component models an ideal mechanical Limit Stop. It will prevent a mass model connected to node 1 to exceed the upper limit setting and to undershoot the lower limit with respect to the position at the other node.

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Assumptions and Limitations

This model may cause numerical problems when used with trapezoidal integration algorithm. In case of problems switch to the Euler method.

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Mathematical Description

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Netlist Syntax

```
MODEL LIMIT_STOP IDEAL_TRB ?InstanceName(@InstanceName):(@Refbase)@(ID))  
TRB1:= %0, TRB2:= %1 ( UPPER_LIM:= @UPPER_LIM, LOWER_LIM:= @LOWER_LIM)  
SRC: DB(Lib:=@ModelLibraryName);
```

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
TRB1	Pin1	translational
TRB2	Pin2	translational

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
UPPER_LIM	Upper Position Limit	real	1
LOWER_LIM	Lower Position Limit	real	0

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
DELTA_S	Displacement [m]	Output	real
F	Force [N]	Output	real

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Example

Figure 2 shows application of the Ideal Limit Stop model. In this example, the mass is accelerated by a constant Force (10 Nm). The acceleration is limited due to the ideal Limit Stop. The Limit stop causes the mass to stop at the defined upper position limit. This component might be sensitive on the selected integration algorithm. In case of problems please set it to 'Euler'. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3 and 4.

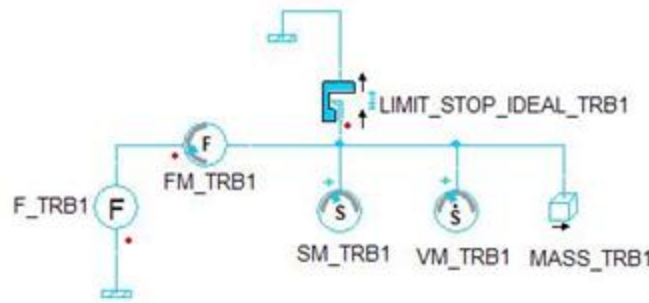


Figure 2. Application example of the Mass model

Table 4

Component	Parameter	Value
Force Source F_TRB1	VALUE	10 [N]
Limit Stop LIMIT_TRB1	SU	1 [m]
	SL	0 [m]
Mass MASS_TRB1	M	3 [Kg]
	S0	0 [m]
	V0	0 [m/s]

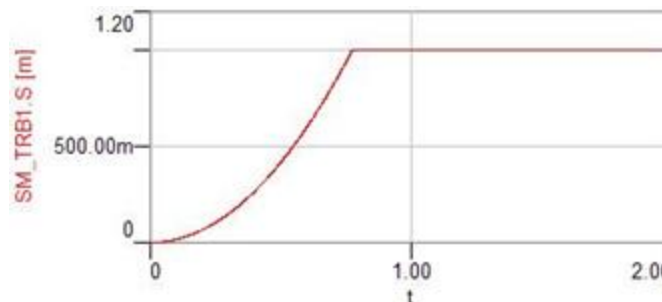


Figure 3. Simulation result-displacement of MASS_TRB1

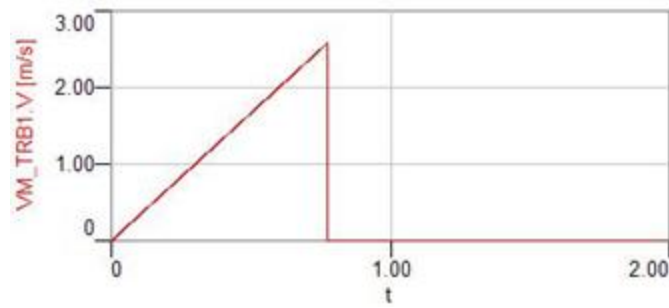


Figure 4. Simulation result-velocity of MASS_TRB1

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References

Limit Stop

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

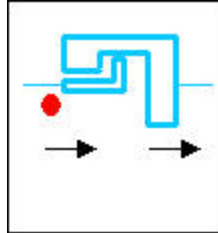


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Description

The component represents a parallel damper and spring combination within defined limits (upper and lower limit).

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Assumptions and Limitations

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Mathematical Description

The Limit Stop can be described as:

```
if  $s(t) > SUL$   
 $F(t) = C \cdot (s(t) - SUL) + DAMPING \cdot v(t)$   
if  $\overline{s(t)} < SLL$   
 $F(t) = C \cdot (s(t) - SLL) + DAMPING \cdot v(t)$   
else  $F(t) = 0$ 
```

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Netlist Syntax

```
UMODEL LIMIT_TRB ?InstanceName(@InstanceName):(@Refbase@ID)) TRB1:= %0,  
TRB2:= %1 ( C:= @C, DAMPING:= @DAMPING, SUL:= @SUL, SLL:= @SLL) SRC: DB(Lib:-  
:=@ModelLibraryName);
```

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
TRB1	Pin1	translational
TRB2	Pin2	translational

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
C	Spring Rate	real	1.0e6 [N/m]
DAMPING	Damping Coefficient	real	1.0e6 [N*s/m]
SUL	Upper Position Limit	real	1 [m]
SLL	Lower Position Limit	real	0 [m]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
S	Displacement [m]	Output	real
F	Force [N]	Output	real
V	Velocity [m/s]	Output	real

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Example

Figure 2 shows application of the Limit Stop model. In this example, the mass is accelerated by a constant Force (10 N). The acceleration is limited due to the Limit Stop. The Limit stop represents a spring-damper combination which causes the mass to stop at the defined upper position (sul). The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3 and 4.

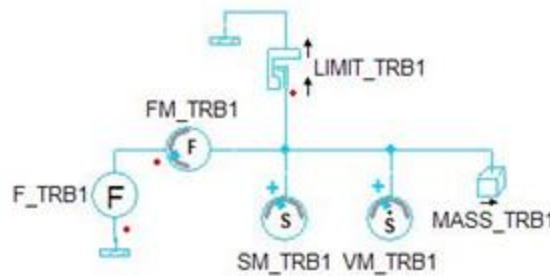


Figure 2. Application example of the Mass model

Table 4

Component	Parameter	Value
Force Source	F_TRB1	10 [N]
Limit Stop LIMIT_TRB1	DAMPING	1.0e5 [Ns/m]
	C	1.0e5 [N/m]
	SU	1 [m]
	SL	0 [m]

Mass MASS_TRB1	M	3 [Kg]
	S0	0 [m]
	V0	0 [m/s]

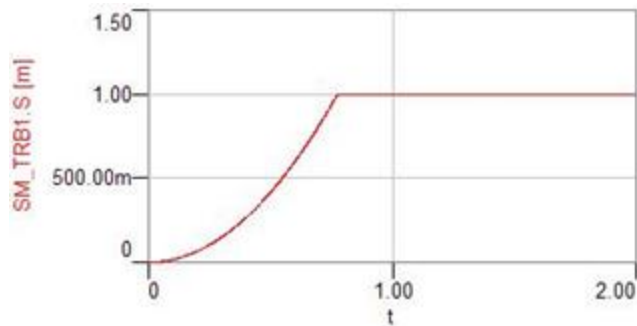


Figure 3. Simulation result-displacement of MASS_TRB1

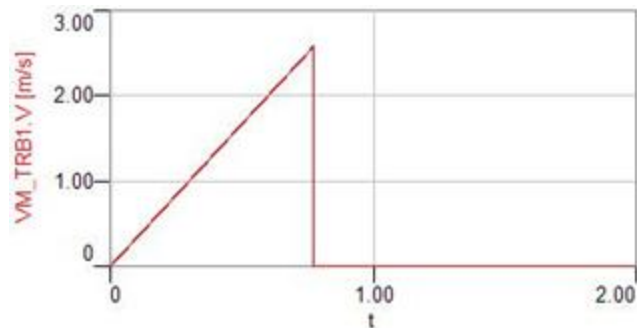


Figure 4. Simulation result-velocity of MASS_TRB1

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References

Mass

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

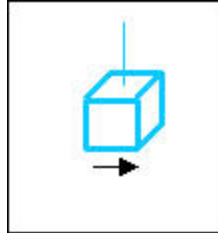


Figure 1. Component Symbol.

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Description

The component represents a mass specified by a mass and initial position.

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Assumptions and Limitations

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Mathematical Description

The Mass model can be described as:

$$F(t) = M \cdot a(t) \quad s(t) = \int v dt + s_0 \quad v(t) = \int a dt + v_0$$

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Netlist Syntax

```
UMODEL MASS_TRB ?InstanceName(@InstanceName):(@Refbase)@(ID)) TRB1:= %0 (  
M:= @M, S0:= @S0, V0:= @V0) SRC: DB(Lib:=@ModelLibraryName) ;
```

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
TRB1	Pin1	translational
TRB2	Pin2	translational

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
M	Mass	real	1 [kg]
S0	Initial Position	real	0 [m]
V0	Initial Velocity	real	0 [m/s]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
S	Displacement [m]	Output	real
F	Force [N]	Output	real
V	Velocity [m/s]	Output	real
ACC	Acceleration [m/s ²]	Output	real

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Example

Figure 2 shows application of the Mass model. In this example, the mass is accelerated by a constant Force (10 N). The acceleration is limited due to the Limit Stop. The Limit stop represents a spring-damper combination which causes the mass to stop at the defined upper position (sul). The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3 and 4.

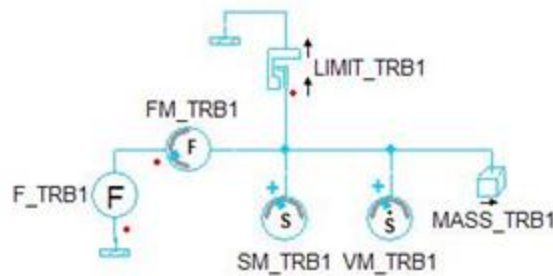


Figure 2. Application example of the Mass model

Table 4

Component	Parameter	Value
Force Source	F_TRB1	10 [N]
Limit Stop LIMIT_TRB1	DAMPING	1.0e5 [Ns/m]
	C	1.0e5 [N/m]
	SU	1 [m]
	SL	0 [m]
Mass MASS_TRB1	M	3 [Kg]
	S0	0 [m]
	V0	0 [m/s]

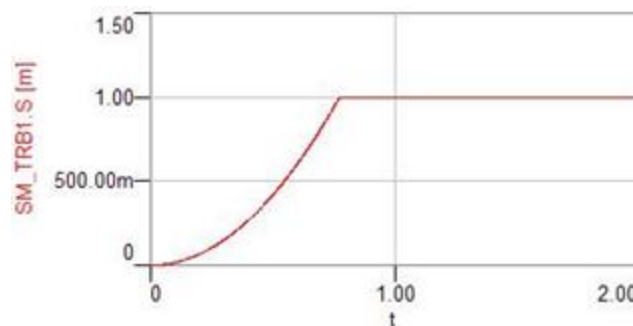


Figure 3. Simulation result-displacement of MASS_TRB1

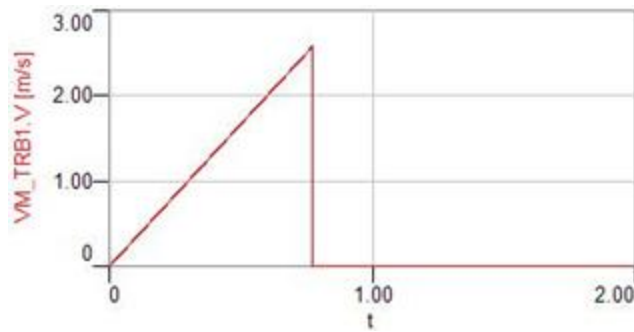


Figure 4. Simulation result-velocity of MASS_TRB1

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References

Position Source

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

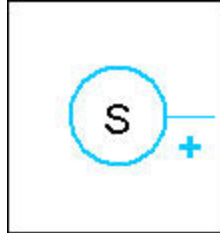


Figure 1. Component Symbol.

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Description

The component represents an ideal mechanical position source which supplies the defined position for an arbitrary force.

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Assumptions and Limitations

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Mathematical Description

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

Linear Position Source

The displacement is equivalent to the present value of the quantity specified in the text box, which can be a constant value, a time function, a variable, or a value determined in a state graph. All system quantities and variables can be combined with mathematical and logical operators and constants.

$$s(t) = \text{VALUE}$$

The force through an ideal position source can be arbitrary. Real force sources have always an internal resistance. If the internal resistance is essential for the simulation target, a corresponding resistance must be connected in series.

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
TRB1	Pin Position Source	Translational

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
VALUE	Displacement	real	1.0 [m]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
S	Displacement [m]	Output	real

F	Force [N]	Output	real
V	Velocity [m/s]	Output	real

Time-Controlled Position Source

The time-controlled position/angle sources have the same properties as the linear position source above; the force flow can be arbitrary and the internal resistance is zero (ideal source). The value of the position instead is equivalent to the present value of the selected time function at each calculation step.

$$s(t) = f[\text{time function}]$$

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Conservative Pins

Table 4

Name	Description	Nature/Data Type
TRB1	Pin Position Source	translational

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Parameters

Table 5

Name	Description	Data Type	Default Value [Unit]
AMPL	Amplitude	real	1 [m]
FREQU	Frequency (no trapezoidal function parameter)	real	50 [Hz]
TPERIO	Period	real	20m [s]
TDELAY	Delay	real	0 [s]
PHASE	Phase	real	0 [deg]

n/a	Angular Dimension		
OFF	Offset	real	0
PERIO	Periodic; PERIO=1, periodical function, PERIO=0; non-periodical function	real	1
DAMPING	Damping factor (only sine function) DAMPING>0, amplitude is exponentially decreasing (damped). DAMPING<0, amplitude is exponentially increasing, DAMPING=0, no damping	real	0 [1/s]
TRISE	Rise Time (only trapezoidal function)	real	5m [s]
TFALL	Fall Time (only trapezoidal function)	real	10m [s]
PWIDTH	Pulse Width (only trapezoidal function)	real	5m [s]

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Input/Output Quantities

Table 6

Name	Description [Unit]	Direction	Data Type
S	Displacement [m]	Output	real
F	Force [N]	Output	real
V	Velocity [m/s]	Output	real

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Example

Figure 2 shows application of the Position Source model. In this example, a sinusoidal displacement is applied to a mass. The offset is removed with a spacer. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3 ~ 5.

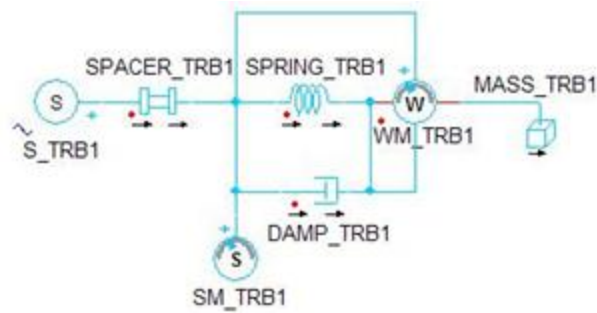


Figure 2. Application example of the Position Source model

Table 4

Component	Parameter	Value
Spring SPRING_TRB1	C	10 [N/m]
Damper DAMP_TRB1	DAMPING	1 [Ns/m]
Spacer SPACER_TRB1	LEN	1 [m]
Position Source (sinusoidal) S_TRB1	AMPL	1 [m]
	FREQU	1 [Hz]
	OFF	1 [m]
	TDELAY	0 [s]
	PHASE	0 [deg]
Mass MASS_TRB1	M	1 [Kg]
	S0	0 [m]
	V0	0 [m/s]

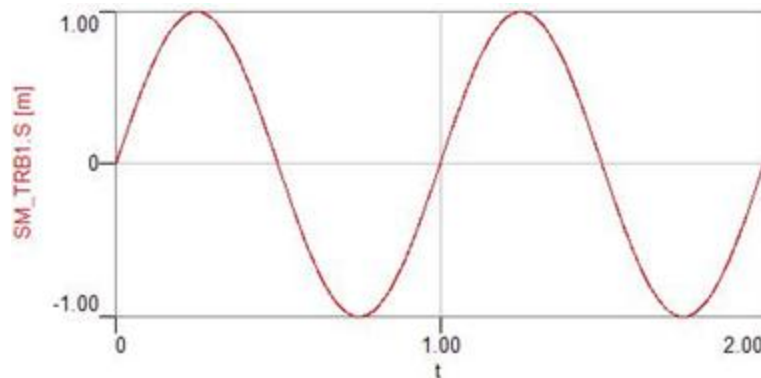


Figure 3. Simulation result

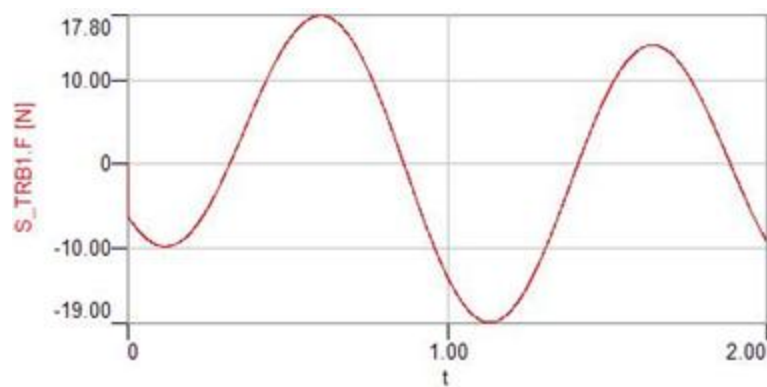


Figure 4. Simulation result

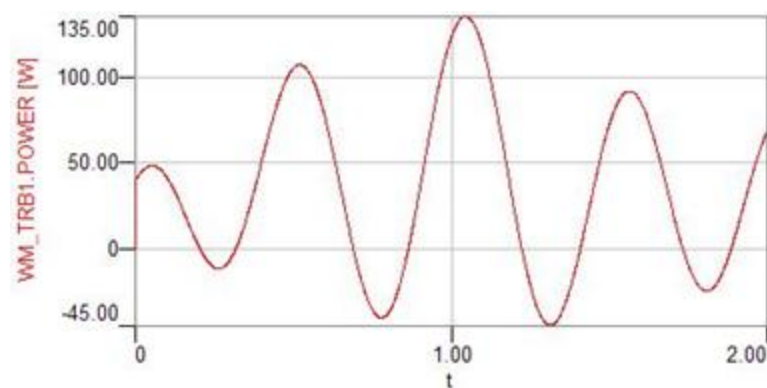


Figure 5. Simulation result

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References

Solenoid

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

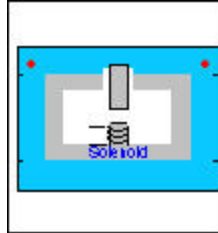


Figure 1. Component Symbol.

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Description

The Solenoid component is an ideal behavioral model of a linear actuator.

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Assumptions and Limitations

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Mathematical Description

The inductance and generated force of the solenoid are described by the following equations:

$$L(x) = N^2 \times \left(\frac{L_0}{1 + K \times x} \right)$$

$$F = \frac{-(N^2 \times L_0 \times K \times I^2)}{2 \times (1 + K \times x)^2}$$

where x is the plunger gap, L_0 is the maximum inductance per turn, K is the inductance coefficient, N is the number of coil turns, and I is the solenoid current.

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Netlist Syntax

```
MODEL SOLENOID_TRB ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) P:= %0, M:= %1, POS1:= %2, POS2:= %3 ( L0:= @L0, K:= @K, N:= @N) SRC: DB(Lib:- :=@ModelLibraryName);
```

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
P	Positive electrical terminal	electrical
M	Negative electrical terminal	electrical
POS1	Postive mechanical terminal	translational
POS2	Negative mechanical terminal	translational

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
L0	Maximum inductance per turn at the minimum gap	real	125n [H]
K	Inductance coefficient	real	197.735 [1/m]
N	Number of coil turns	real	1

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type

F	Generated force [N]	Output	real
V	Solenoid voltage [V]	Output	real
I	Solenoid current [A]	Output	real
dV	Solenoid voltage derivative [V/s]	Output	real
dI	Solenoid current derivative [A/s]	Output	real

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Example

Figure 2 shows application of the Solenoid model. In this example, the generated force by the Solenoid SOLENOID_TRB1 acts to decrease the plunger gap. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3 and 4.

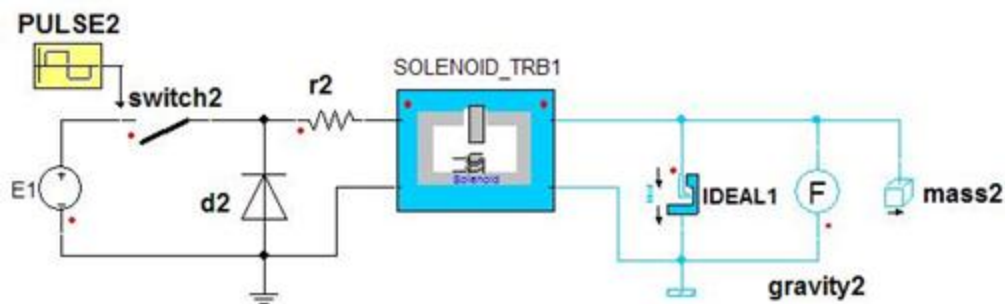


Figure 2. Application example of the Solenoid model

Table 4

Component	Parameter	Value
Force Source F_TRB1	VALUE	$9.8 \cdot \text{mass2.m}$ [N]
Voltage Source E1	EMF	12 [V]
Resistor r2	R	103 [Ohm]
Diode d2	isat	1p [A]
	vt	35m [V]
	rr	100k [Ohm]
	vf	0.8 [v]
	rb	1m [Ohm]

Pulse Wave PULSE2	AMPL	0.5
	FREQ	0.5
	TDELAY	0 [s]
	PHASE	0 [degree]
	OFF	-0.1
Mass mass2	m	0.0545 [Kg]
	s0	0.0127 [m]
	v0	0 [m/s]
Ideal Limit Stop IDEAL1	SU	0.0127 [m]
	SL	0 [m]
Solenoid SOLENOID_TRB1	L0	125n [H]
	K	197.735 [1/m]
	N	12500

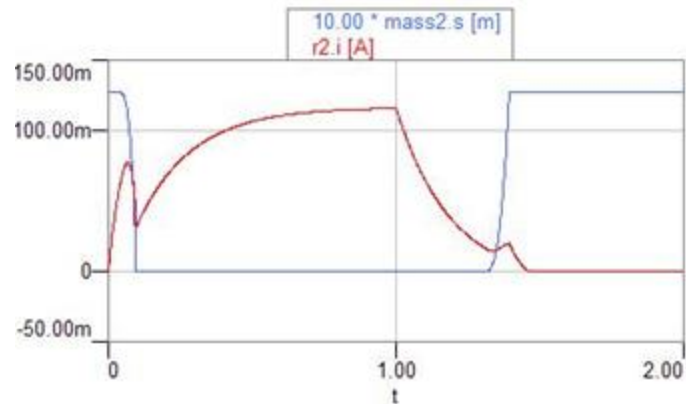


Figure 3. Simulation result-displacement of mass2 and current input of the SOLENOID_TRB1

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References

Spacer

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

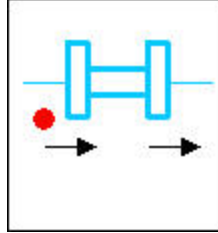


Figure 1. Component Symbol.

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Description

The component represents a constant displacement between two components in a mechanical system specified by a length.

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Assumptions and Limitations

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Mathematical Description

The Spacer model can be described as:

$$v(t) = \frac{ds}{dt} \quad s = \text{LEN}$$

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Netlist Syntax

UMODEL SPACER_TRB ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) TRB1:= %0,
TRB2:= %1 (LEN:= @LEN) SRC: DB(Lib:=@ModelLibraryName);

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
TRB1	Pin1	translational
TRB2	Pin2	translational

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
LEN	Length	real	0 [m]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
S	Displacement [m]	Output	real
F	Force [N]	Output	real
V	Velocity [m/s]	Output	real

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Example

Figure 2 shows application of the Spacer model. In this example, a sinusoidal displacement is applied to a mass. The offset is removed with a spacer. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3 ~ 5.

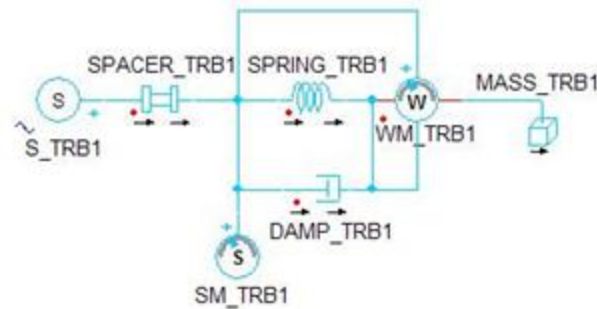


Figure 2. Application example of the Position Source model

Table 4

Component	Parameter	Value
Spring SPRING_TRB1	C	10 [N/m]
Damper DAMP_TRB1	DAMPING	1 [Ns/m]
Spacer SPACER_TRB1	LEN	1 [m]
Position Source (sinusoidal) S_TRB1	AMPL	1 [m]
	FREQU	1 [Hz]
	OFF	1 [m]
	TDELAY	0 [s]
	PHASE	0 [deg]
Mass MASS_TRB1	M	1 [Kg]
	S0	0 [m]
	V0	0 [m/s]

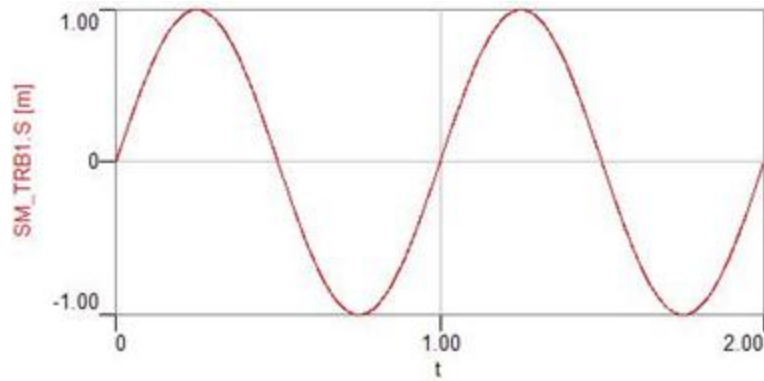


Figure 3. Simulation result

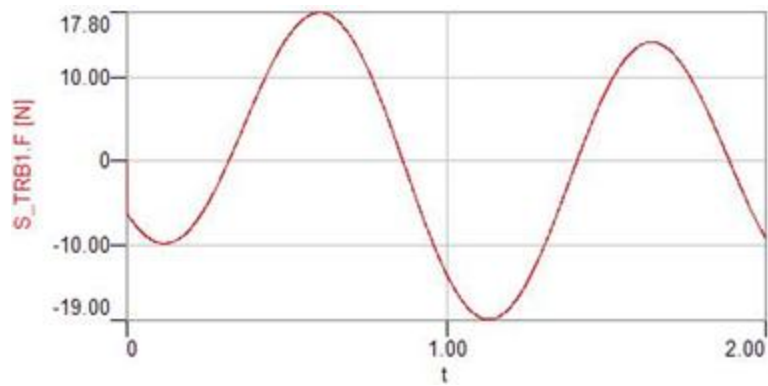


Figure 4. Simulation result

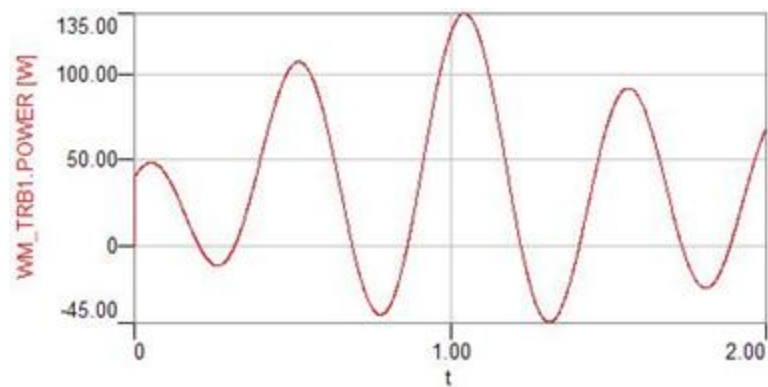


Figure 5. Simulation result

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References

Spring

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

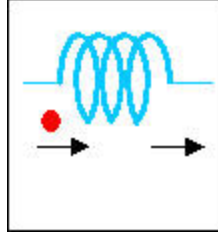


Figure 1. Component Symbol.

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Description

The component represents a simple spring specified by a spring rate.

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Assumptions and Limitations

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Mathematical Description

The Spring model can be described as:

$$F(t) = C \cdot s(t)$$

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Netlist Syntax

UMODEL SPRING_TRB ?InstanceName(@InstanceName):(@ (Refbase)@(ID)) TRB1:= %0,
TRB2:= %1 (C:= @C) SRC: DB(Lib:=@ModelLibraryName) ;

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
TRB1	Pin1	translational
TRB2	Pin2	translational

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
C	Spring Rate	real	100 [N/m]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
S	Displacement [m]	Output	real
F	Force [N]	Output	real
V	Velocity [m/s]	Output	real

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Example

Figure 2 shows application of the Spring model. In this example, a constant velocity (10m/s) is applied to the system. Due to the damping element, the force applied to the mass sinusoidally

decays with time. The parameters of the system are listed in Table 4 and the simulation results shown in Figures 3, 4, and 5.

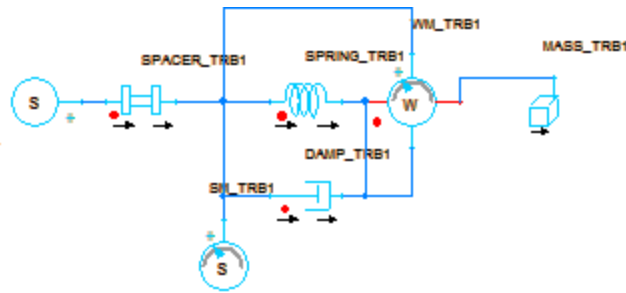


Figure 2. Application example of the Spring model

Table 4

Component	Parameter	Value
Spring SPRING_TRB1	C	10k [N/m]
Damper DAMP_TRB1	DAMPING	5 [Ns/m]
Velocity Source V_TRB1	VALUE	10 [m/s]
	S0	0 [m]
Mass MASS_TRB1	M	500 [Kg]
	S0	0 [m]
	V0	0 [m/s]

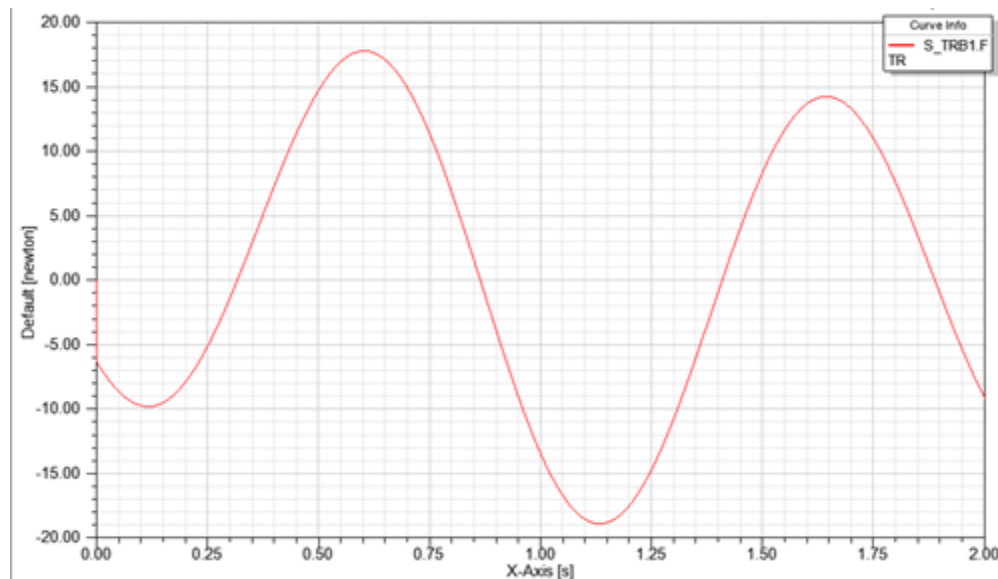


Figure 3. Simulation result-force applied to the spacer

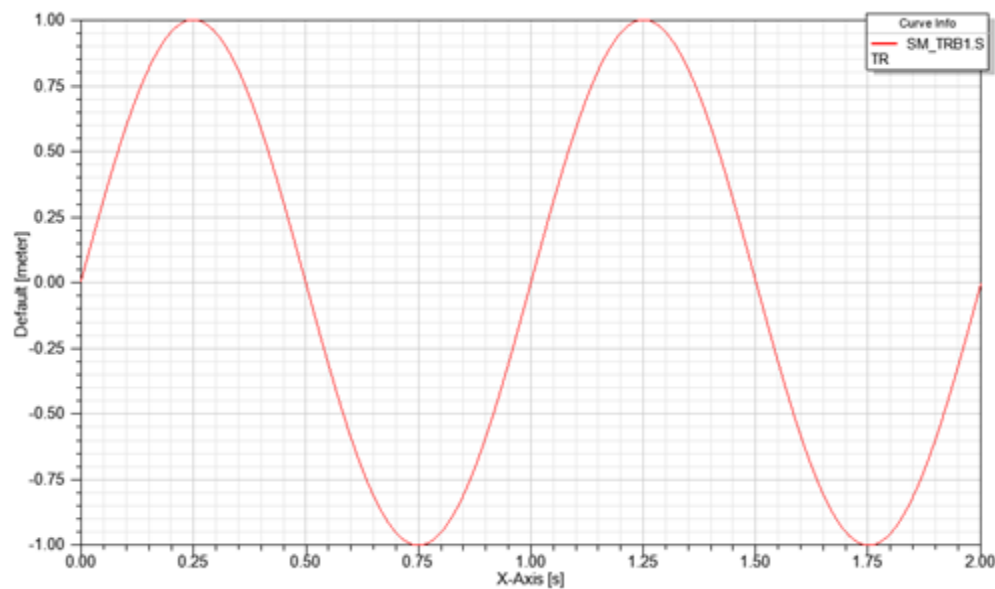


Figure 4. Simulation result-displacement of the mass

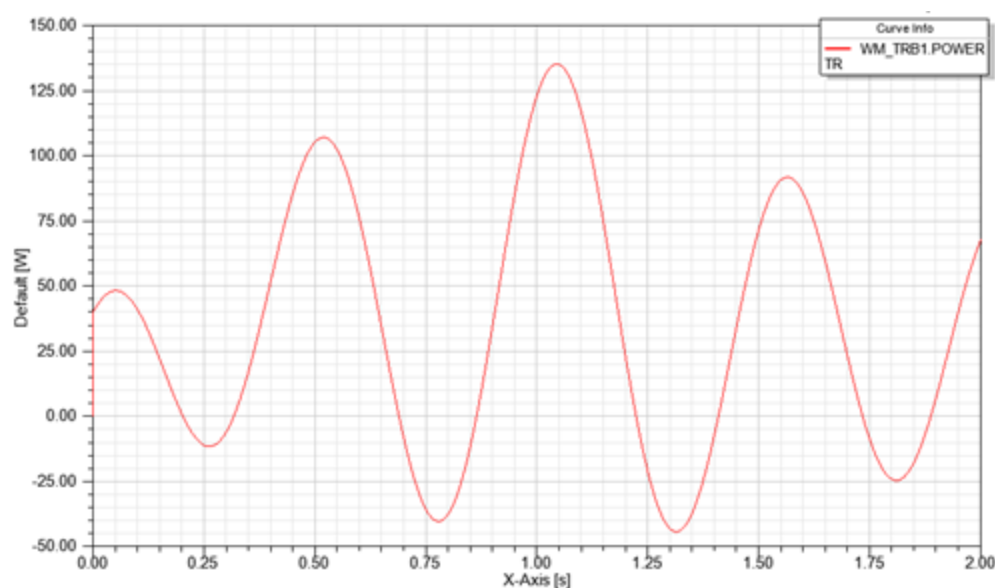


Figure 4. Simulation result-power of the system

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References

Velocity Source

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

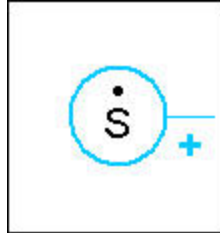


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Description

The component represents an ideal mechanical velocity source which supplies the defined velocity for an arbitrary force.

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Assumptions and Limitations

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Mathematical Description

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

Linear Velocity Source

The velocity is equivalent to the present value of the quantity specified in the text box, which can be a constant value, a time function, a variable, or a value determined in a state graph. All system quantities and variables can be combined with mathematical and logical operators and constants.

$$\frac{ds}{dt} = v(t) = \text{VALUE}$$

The force/torque through an ideal position source can be arbitrary. Real force sources have always an internal resistance. If the internal resistance is essential for the simulation target, a corresponding resistance must be connected in series.

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
TRB1	Pin Velocity Source	translational

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
VALUE	Velocity [m/s]	real	1 [m/s]
S0	Initial Position [m]	real	0 [m]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type

S	Displacement [m]	Output	real
F	Force [N]	Output	real
V	Velocity [m/s]	Output	real

Time-Controlled Velocity Source

The time-controlled velocity sources have the same properties as the linear velocity source above; the force flow can be arbitrary and the internal resistance is zero (ideal source). The value of the position instead is equivalent to the present value of the selected time function at each calculation step.

$$\frac{ds}{dt} = v(t) = f[\text{time function}]$$

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Conservative Pins

Table 4

Name	Description	Nature/Data Type
TRB1	Pin Velocity Source	translational

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Parameters

Table 5

Name	Description	Data Type	Default Value [Unit]
AMPL	Amplitude	real	1 [m/s]
S0	Initial Position	real	0 [m]
FREQU	Frequency (no trapezoidal function parameter)	real	50 [Hz]
TPERIO	Period	real	20m [s]
TDELAY	Delay	real	0 [s]

PHASE	Phase	real	0 [deg]
n/a	Angular Dimension		
OFF	Offset	real	0
PERIO	Periodic; PERIO=1, periodical function, PERIO=0; non-periodical function	real	1
DAMPING	Damping factor (only sine function) DAMPING>0, amplitude is exponentially decreasing (damped). DAMPING<0, amplitude is exponentially increasing, DAMPING=0, no damping	real	0 [1/s]
TRISE	Rise Time (only trapezoidal function)	real	5m [s]
TFALL	Fall Time (only trapezoidal function)	real	10m [s]
PWIDTH	Pulse Width (only trapezoidal function)	real	5m [s]

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Input/Output Quantities

Table 6

Name	Description [Unit]	Direction	Data Type
S	Displacement [m]	Output	real
F	Force [N]	Output	real
V	Velocity [m/s]	Output	real

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Example

Figure 2 shows application of the Velocity Source model. In this example, a constant velocity (10m/s) is applied to the system. Due to the damping element, the force applied to the mass sinusoidally decays with time. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3 and 4.

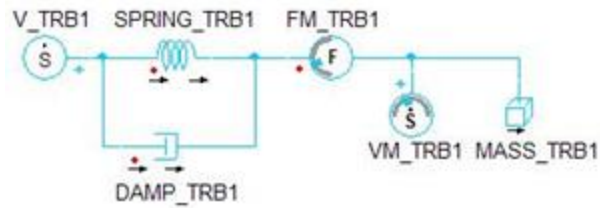


Figure 2. Application example of the Velocity Source model

Table 4

Component	Parameter	Value
Spring $SPRING\_TRB1$	C	10k [N/m]
Damper $DAMP\_TRB1$	DAMPING	5 [Ns/m]
Velocity Source V_TRB1	VALUE	10 [m/s]
	S0	0 [m]
Mass $MASS\_TRB1$	M	500 [Kg]
	S0	0 [m]
	V0	0 [m/s]

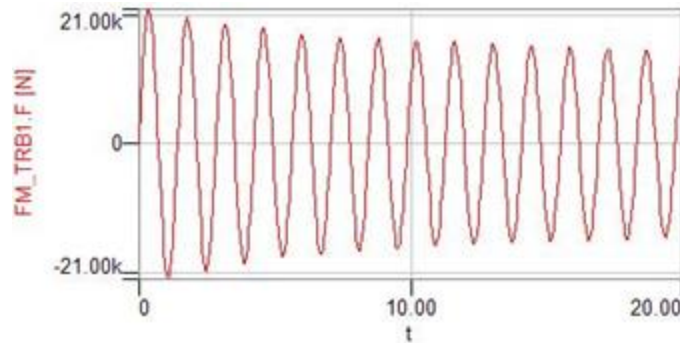


Figure 3. Simulation result-force applied to $MASS\_TRB1$

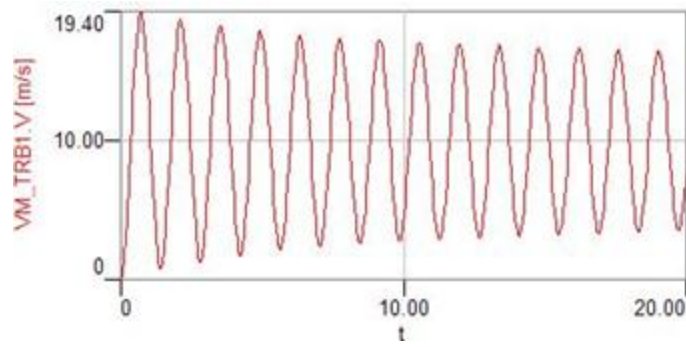


Figure 4. Simulation result-velocity of MASS_TRB1

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References

Velocity-Force Representation

The velocity-force representation consists of:

- [Rotational Components](#)
- [Translational Component](#)

Rotational_V Components

- [Damper \(DAMP_ROT\)](#)
- [Torque Source \(F_ROT\)](#)
- [Limit Stop \(LIMIT_ROT\)](#)
- [Mass \(MASS_ROT\)](#)
- [Spring \(SPRING_ROT\)](#)
- [Angle Velocity Source \(V_ROT\)](#)

Damper

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

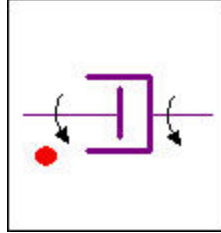


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Description

The component represents a simple damper specified by a linear damping coefficient.

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Assumptions and Limitations

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Mathematical Description

The Damper model can be described as:

$$M(t) = \text{DAMPING} \cdot \dot{\omega}(t)$$

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Netlist Syntax

UMODEL DAMP_ROT ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) ROT1:= %0,
ROT2:= %1 (DAMPING:= @DAMPING) SRC: DB(Lib:=@ModelLibraryName) ;

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
ROT1	Pin1	rotational_v
ROT2	Pin2	rotational_v

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
DAMPING	Damping Coefficient	real	1 [Nm*s/rad]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
PHI	Angle [rad]		real
M	Torque [Nm]	Output	real
OMEGA	Angular Velocity [rad/s]	Output	real

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Example

Figure 2 shows application of the Damper model. In this example, a constant angular velocity is applied to the system. Due to the damping element, the force applied to the mass sinusoidally

decays with time. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3 and 4.

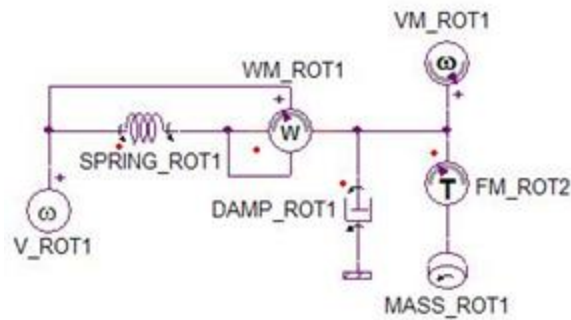


Figure 2. Application example of the Damper model

Table 4

Component	Parameter	Value
Spring SPRING_ROT1	C	10 [Nm/rad]
	PHI0	0 [m]
Damper DAMPER_ROT1	DUMPING	0.05 [Nms/rad]
Angular Velocity Source V_ROT1	VALUE	10 [rad/s]
Mass MASS_ROT1	M	1 [Kg m ²]
	PHI0	0 [rad]
	OMEGA0	0 [rad/s]

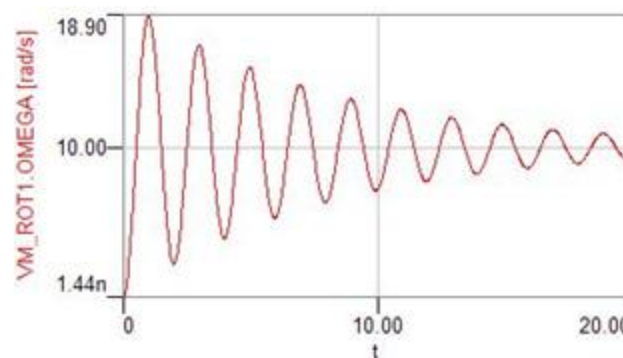


Figure 3. Simulation result-force applied to MASS_ROT1

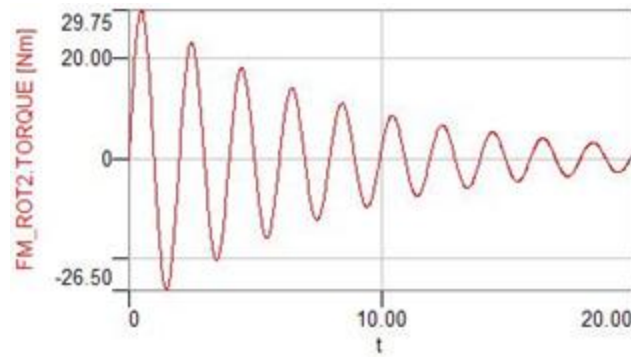


Figure 4. Simulation result- velocity of MASS_ROT1

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References

Torque Source

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

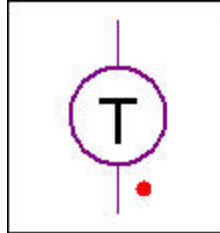


Figure 1. Component Symbol.

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Description

The component represents an ideal mechanical torque source which supplies the defined force/torque for an arbitrary position.

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Assumptions and Limitations

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Mathematical Description

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

Linear Torque Source

The torque is equivalent to the present value of the quantity specified in the input field, which can be a constant value, a time function, a variable, or a value determined in a state graph. All system quantities and variables can be combined with mathematical and logical operators and constants.

$$M(t) = \text{VALUE}$$

The position of an ideal torque source can be arbitrary. Real flow sources have always an internal resistance. If the internal resistance is essential for the simulation target, a corresponding resistance must be connected in parallel.

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
ROT1	Pin1	rotational_v
ROT2	Pin2	rotational_v

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
VALUE	Torque	real	1 [Nm]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
PHI	Angle [rad]		real
M	Torque [Nm]	Output	real
OMEGA	Angular Velocity [rad/s]	Output	real

Time-Controlled Torque Source

The time-controlled torque sources have the same properties as the linear torque source above; the position can be arbitrary and the internal resistance is zero (ideal source). The value of torque instead is equivalent to the present value of the selected time function at each calculation step.

$$M(t) = f[\text{time function}]$$

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Conservative Pins

Table 4

Name	Description	Nature/Data Type
ROT1	Pin1	rotational_v
ROT2	Pin2	rotational_v

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Parameters

Table 5

Name	Description	Data Type	Default Value [Unit]
AMPL	Amplitude	real	1Meg [Nm]
FREQU	Frequency (no trapezoidal function parameter)	real	50 [Hz]
TPERIO	Period	real	20m [s]
TDELAY	Delay	real	0 [s]
PHASE	Phase	real	0 [deg]
n/a	Angular Dimension		
OFF	Offset	real	0
PERIO	Periodic; PERIO=1, periodical function, PERIO=0; non-periodical function	real	1
DAMPING	Damping factor (only sine function) DAMPING>0, amplitude is exponentially decreasing (damped). DAMPING<0, amplitude is exponentially increasing, DAMPING=0, no damping	real	0 [1/s]
TRISE	Rise Time (only trapezoidal function)	real	5m [s]
TFALL	Fall Time (only trapezoidal function)	real	10m [s]
PWIDTH	Pulse Width (only trapezoidal function)	real	5m [s]

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Input/Output Quantities

Table 6

Name	Description [Unit]	Direction	Data Type
PHI	Angle [rad]		real
M	Torque [Nm]	Output	real
OMEGA	Angular Velocity [rad/s]	Output	real

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Example

Figure 2 shows application of the Torque Source model. In this example, the mass is accelerated by a constant Torque. The acceleration is limited due to the Limit Stop. The Limit stop represents a spring-damper combination which causes the mass to stop at the defined upper angle. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3 and 4.

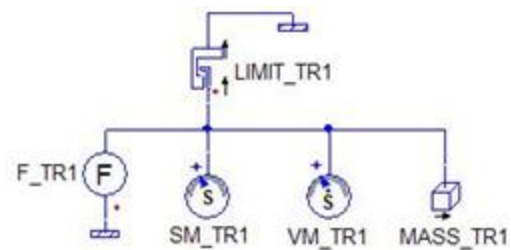


Figure 2. Application example of the Torque Source model

Table 4

Component	Parameter	Value
Limit Stop LIMIT_TR1	C	1.0e6 [Nm/rad]
	DUMPING	1.0e5 [Nms/rad]
	PHIUL	1 [rad]
	PHILL	0 [rad]
	PHI0	0 [rad]
Torque Source F_TR1	VALUE	10 [Nm]
Mass MASS_TR1	J	3 [Kgm ²]
	PHI0	0 [rad]
	OMEGA0	0 [rad/s]

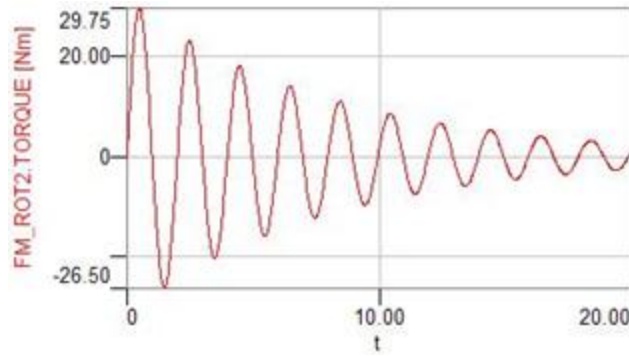


Figure 3. Simulation result-Torque applied to MASS_TR1

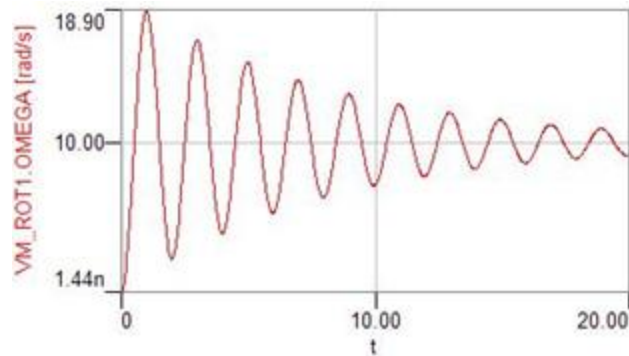


Figure 4. Simulation result-angular velocity of MASS_TR1

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References

Limit Stop

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

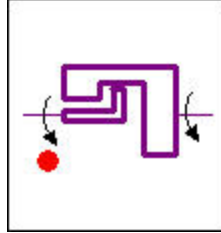


Figure 1. Component Symbol.

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Description

The component represents a parallel damper and spring combination within defined limits (upper and lower limit).

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Assumptions and Limitations

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Mathematical Description

The Limit Stop model can be described as:

```

if  $\varphi(t) > \text{PHIUL}$ 
 $M(t) = C \cdot (\varphi(t) - \text{PHIUL}) + \text{DAMPING} \cdot \omega(t)$ 
if  $\varphi(t) < \text{PHILL}$ 
 $M(t) = C \cdot (\varphi(t) - \text{PHILL}) + \text{DAMPING} \cdot v(t)$ 
else  $M(t) = 0$ 

```

[Top](#)**Netlist Syntax**

```

UMODEL LIMIT_ROT ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) ROT1:= %0,
ROT2:= %1 ( C:= @C, DAMPING:= @DAMPING, PHIUL:= @PHIUL, PHILL:= @PHILL, PHI0:=
@PHI0) SRC: DB(Lib:=@ModelLibraryName) ;

```

[Top](#)**Conservative Pins****Table 1**

Name	Description	Nature/Data Type
ROT1	Pin1	rotational_v
ROT2	Pin2	rotational_v

[Top](#)**Parameters****Table 2**

Name	Description	Data Type	Default Value [Unit]
C	Spring Rate	real	1.0e+006 [Nm/rad]
DAMPING	Damping Coefficient	real	1.0e+006 [Nm*s/rad]
PHIUL	Upper Angle Limit	real	1 [rad]
PHILL	Lower Angle Limit	real	0 [rad]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
PHI	Angle [rad]	Output	real
M	Torque [Nm]	Output	real
OMEGA	Angular Velocity [rad/s]	Output	real

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Example

Figure 2 shows application of the Limit Stop model. In this example, the mass is accelerated by a constant Torque. The acceleration is limited due to the Limit Stop. The Limit stop represents a spring-damper combination which causes the mass to stop at the defined upper angle. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3 and 4.

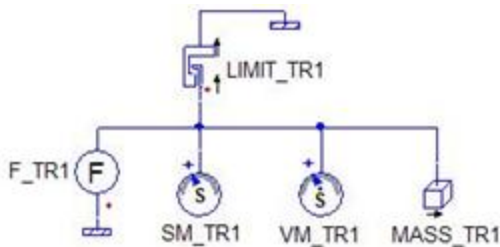


Figure 2. Application example of the Limit Stop model

Table 4

Component	Parameter	Value
Limit Stop LIMIT_TR1	C	1.0e6 [Nm/rad]
	DUMPING	1.0e5 [Nms/rad]
	PHIUL	1 [rad]
	PHILL	0 [rad]
	PHI0	0 [rad]
Torque Source F_TR1	VALUE	10 [Nm]
Mass MASS_TR1	J	3 [Kgm ²]
	PHI0	0 [rad]
	OMEGA0	0 [rad/s]

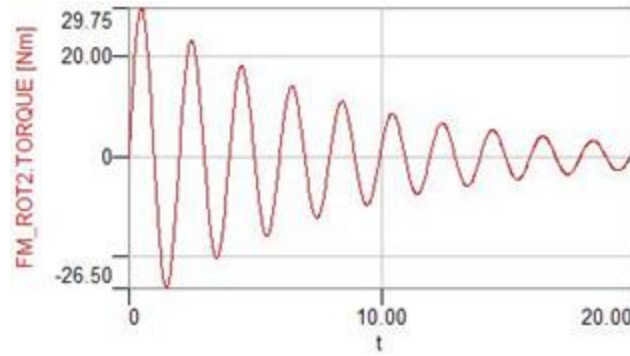


Figure 3. Simulation result-Torque applied to MASS_TR1

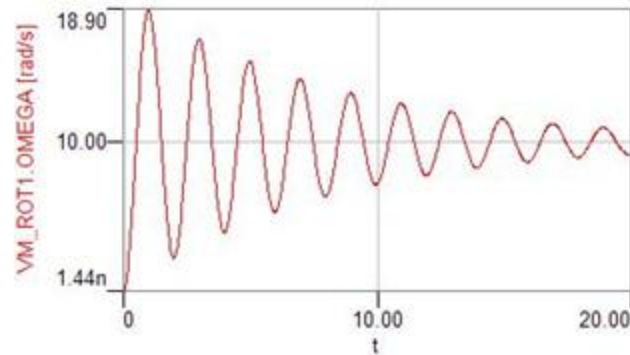


Figure 4. Simulation result-angular velocity of MASS_TR1

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References

Mass

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

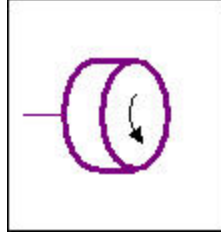


Figure 1. Component Symbol.

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Description

The component represents a mass specified by a mass/inertia and initial position/velocity.

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Assumptions and Limitations

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Mathematical Description

The Mass model can be described as:

$$M(t) = J \cdot a(t) \quad \varphi(t) = \int \omega dt + \varphi_0 \quad \omega(t) = \int a dt + \omega_0$$

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Netlist Syntax

UMODEL MASS_ROT ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) ROT1:= %0 (J:= @J, PHI0:= @PHI0, OMEGA0:= @OMEGA0) SRC: DB(Lib:=@ModelLibraryName) ;

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
ROT1	Pin1	rotational_v
ROT2	Pin2	rotational_v

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
J	Mass Moment of Inertia	real	1 [kg*m ²]
PHI0	Initial Angle	real	0 [rad]
OMEGA0	Initial Angular Velocity	real	0 [rad/s]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
PHI	Angle [rad]	Output	real
M	Torque [Nm]	Output	real
OMEGA	Angular Velocity [rad/s]	Output	real
ACC	Acceleration [rad/s ²]	Output	real

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Example

Figure 2 shows application of the Mass model. In this example, a constant angular velocity is applied to the system. Due to the damping element, the force applied to the mass sinusodially decays with time. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3 and 4.

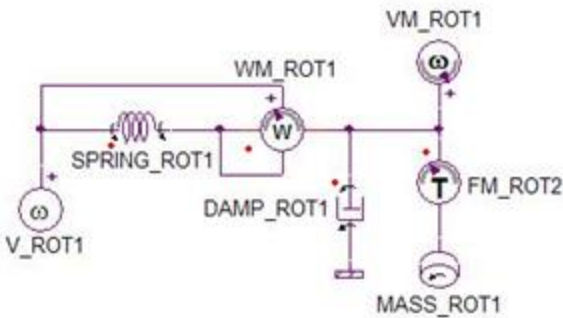


Figure 2. Application example of the Mass model

Table 4

Component	Parameter	Value
Spring SPRING_ROT1	C	10 [Nm/rad]
	PHI0	0 [m]
Damper DAMPER_ROT1	DUMPING	0.05 [Nms/rad]
Angular Velocity Source V_ROT1	VALUE	10 [rad/s]
Mass MASS_ROT1	M	1 [Kg m ²]
	PHI0	0 [rad]
	OMEGA0	0 [rad/s]

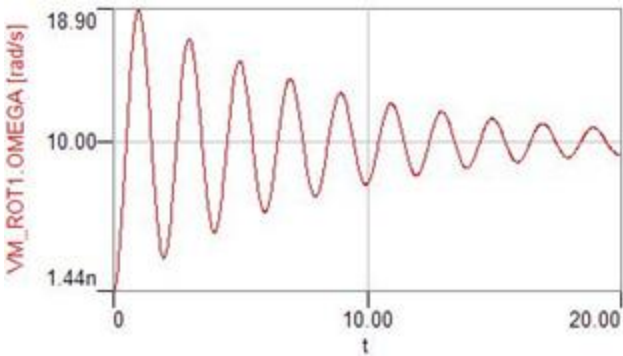


Figure 3. Simulation result-force applied to MASS_ROT1

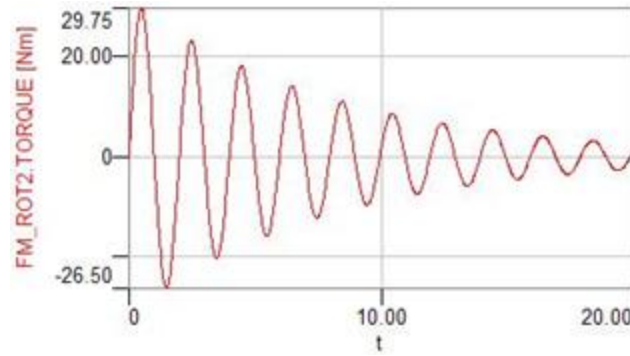


Figure 4. Simulation result- velocity of MASS_ROT1

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References

Spring

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

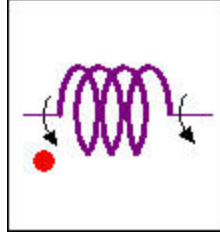


Figure 1. Component Symbol.

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Description

The component represents a simple spring specified by a spring rate.

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Assumptions and Limitations

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Mathematical Description

The Spring model can be described as:

$$M(t) = C \cdot \varphi(t)$$

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Netlist Syntax

UMODEL SPRING_ROT ?InstanceName(@InstanceName):(@ (Refbase)@(ID)) ROT1:= %0,
ROT2:= %1 (C:= @C, PHI0:= @PHI0) SRC: DB(Lib:=@ModelLibraryName) ;

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
ROT1	Pin1	rotational_v
ROT2	Pin2	rotational_v

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
PHI0	Initial Angle	Real	0 [rad]
C	Spring Rate	real	1 [Nm/rad]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
PHI	Angle [rad]	Output	real
M	Torque [Nm]	Output	real
OMEGA	Angular Velocity [rad/s]	Output	real

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Example

Figure 2 shows application of the Spring model. In this example, a constant angular velocity is applied to the system. Due to the damping element, the force applied to the mass sinusoidally

decays with time. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3 and 4.

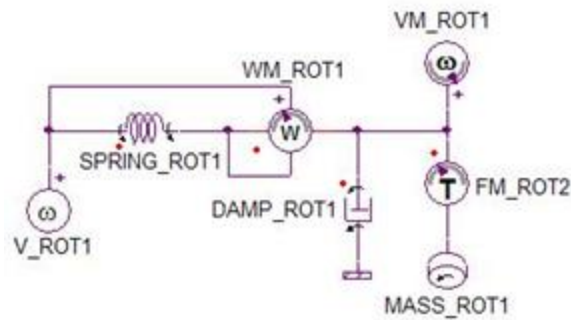


Figure 2. Application example of the Spring model

Table 4

Component	Parameter	Value
Spring SPRING_ROT1	C	10 [Nm/rad]
	PHI0	0 [m]
Damper DAMPER_ROT1	DUMPING	0.05 [Nms/rad]
Angular Velocity Source V_ROT1	VALUE	10 [rad/s]
Mass MASS_ROT1	M	1 [Kg m ²]
	PHI0	0 [rad]
	OMEGA0	0 [rad/s]

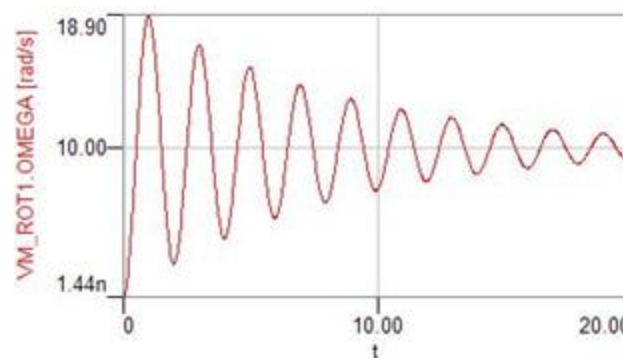


Figure 3. Simulation result-force applied to MASS_ROT1

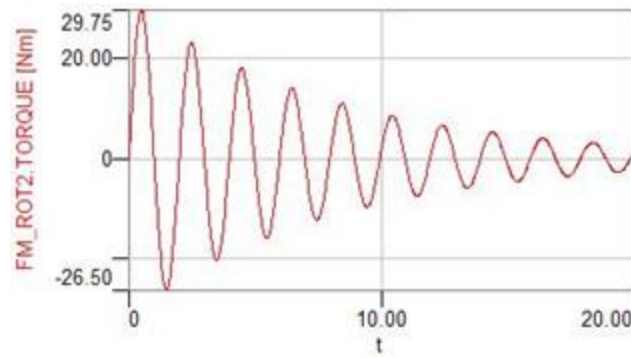


Figure 4. Simulation result- velocity of MASS_ROT1

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References

Angular Velocity Source

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

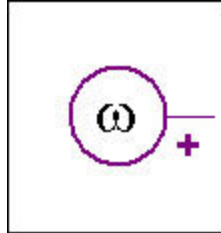


Figure 1. Component Symbol.

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Description

The component represents an ideal mechanical velocity source which supplies the defined velocity for an arbitrary torque.

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Assumptions and Limitations

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Mathematical Description

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

Linear Velocity Source

The velocity is equivalent to the present value of the quantity specified in the text box, which can be a constant value, a time function, a variable, or a value determined in a state graph. All system quantities and variables can be combined with mathematical and logical operators and constants.

The torque through an ideal angle source can be arbitrary. Real torque sources have always an internal resistance. If the internal resistance is essential for the simulation target, a corresponding resistance must be connected in series.

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
ROT1	Pin Angular Velocity Source	rotational_v

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
VALUE	Angular Velocity	real	1 [rad/s]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
PHI	Angle [rad]		real
M	Torque [Nm]	Output	real
OMEGA	Angular Velocity [rad/s]	Output	real

Time-Controlled Velocity Source

The time-controlled velocity sources have the same properties as the linear velocity source above; the torque flow can be arbitrary and the internal resistance is zero (ideal source). The value of the angle instead is equivalent to the present value of the selected time function at each calculation step.

$$\frac{d\varphi}{dt} = \omega(t) = f[\text{time function}]$$

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Conservative Pins

Table 4

Name	Description	Nature/Data Type
ROT1	Pin Angular Velocity Source	rotational_v

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Parameters

Table 5

Name	Description	Data Type	Default Value [Unit]
AMPL	Amplitude	real	1 [rad/s]
FREQU	Frequency (no trapezoidal function parameter)	real	50 [Hz]
TPERIO	Period	real	20m [s]
TDELAY	Delay	real	0 [s]
PHASE	Phase	real	0 [deg]
n/a	Angular Dimension		
OFF	Offset	real	0
PERIO	Periodic; PERIO=1, periodical function, PERIO=0; non-periodical function	real	1
DAMPING	Damping factor (only sine function) DAMPING>0, amplitude is exponentially decreasing (damped). DAMPING<0, amplitude is exponentially increasing, DAMPING=0, no damping	real	0 [1/s]
TRISE	Rise Time (only trapezoidal function)	real	5m [s]
TFALL	Fall Time (only trapezoidal function)	real	10m [s]
PWIDTH	Pulse Width (only trapezoidal function)	real	5m [s]

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Input/Output Quantities

Table 6

Name	Description [Unit]	Direction	Data Type
PHI	Angle [rad]		real
M	Torque [Nm]	Output	real

OMEGA	Angular Velocity [rad/s]	Output	real

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Example

Figure 2 shows application of the Angular Velocity Source model. In this example, a constant angular velocity is applied to the system. Due to the damping element, the force applied to the mass sinusodially decays with time. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3 and 4.

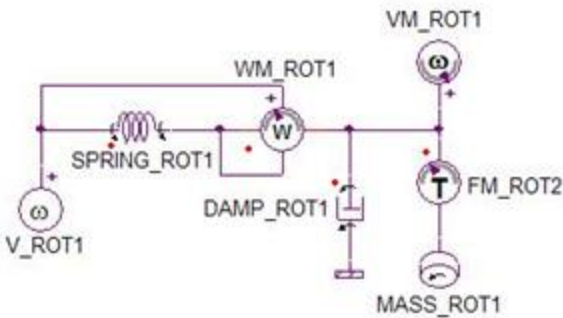


Figure 2. Application example of the Angular Velocity Source model

Table 4

Component	Parameter	Value
Spring SPRING_ROT1	C	10 [Nm/rad]
	PHI0	0 [m]
Damper DAMPER_ROT1	DUMPING	0.05 [Nms/rad]
Angular Velocity Source V_ROT1	VALUE	10 [rad/s]
Mass MASS_ROT1	M	1 [Kg m ²]
	PHI0	0 [rad]
	OMEGA0	0 [rad/s]

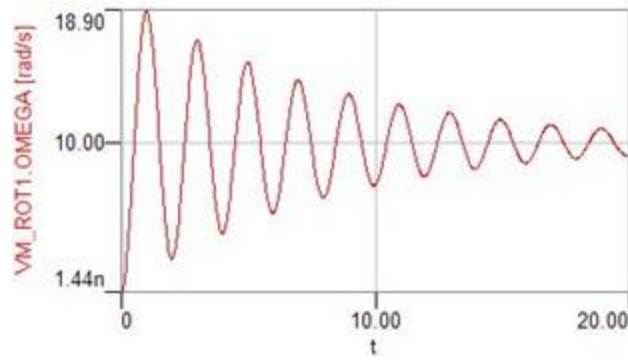


Figure 3. Simulation result-force applied to MASS_ROT1

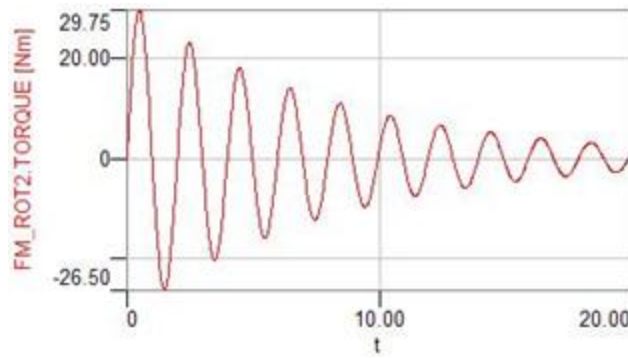


Figure 4. Simulation result- velocity of MASS_ROT1

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References

Translational_V Components

- [Damper \(DAMP_TR\)](#)
- [Force Source \(F_TR\)](#)
- [Limit Stop \(LIMIT_TR\)](#)
- [Mass \(MASS_TR\)](#)
- [Spring \(SPRING_TR\)](#)
- [Velocity Source \(V_TR\)](#)

Damper

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

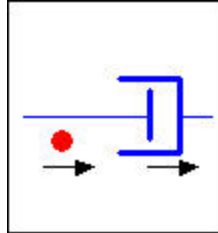


Figure 1. Component Symbol.

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Description

The component represents a simple damper specified by a linear damping coefficient.

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Assumptions and Limitations

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Mathematical Description

The Damper model can be described as:

$$F(t) = \text{DAMPING} \cdot v(t)$$

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Netlist Syntax

UMODEL DAMP_TR ?InstanceName(@InstanceName):(@ (Refbase)@(ID)) TR1:= %0, TR2:= %1 (DAMPING:= @DAMPING) SRC: DB(Lib:=@ModelLibraryName);

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
TR1	Pin1	translational_v
TR2	Pin2	translational_v

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
DAMPING	Damping Coefficient	real	1 [N*s/m]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
S	Displacement [m]		real
F	Force [N]	Output	real
V	Velocity [m/s]	Output	real

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Example

Figure 2 shows application of the Damper model. In this example, a constant angular velocity is applied to the system. Due to the damping of the system, the force applied to the mass sinus-

odially decays with time. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3 and 4.

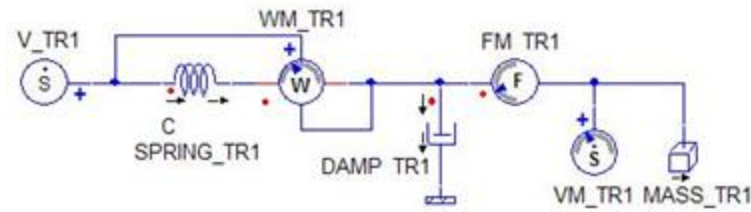


Figure 2. Application example of the Damper model

Table 4

Component	Parameter	Value
Spring SPRING_TR1	C	0.1 [N/m]
	S0	0 [m]
Damper DAMPER_TR1	DUMPING	0.05 [N s/m]
Velocity Source V_TR1	VALUE	10 [m/s]
Mass MASS_TR1	M	1 [Kg]
	S0	0 [m]
	V0	0 [m/s]

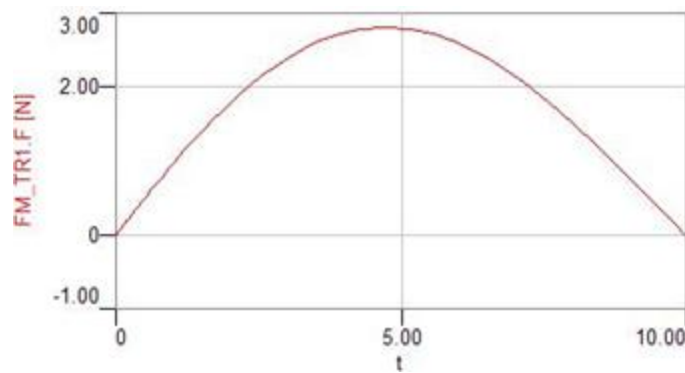


Figure 3. Simulation result-force applied to MASS_TR1

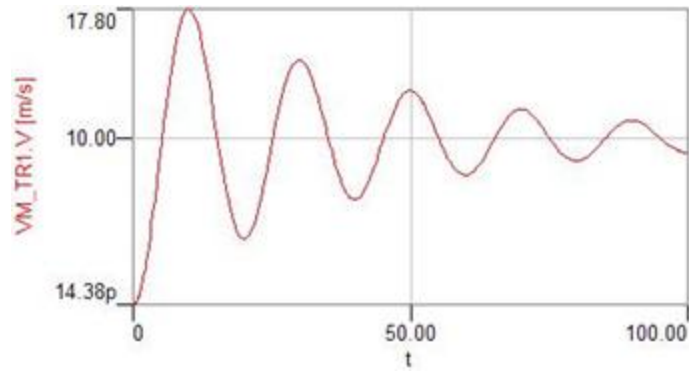


Figure 4. Simulation result- velocity of MASS_TR1

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References

Force Source

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

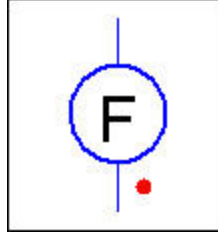


Figure 1. Component Symbol.

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Description

The component represents an ideal mechanical force source which supplies the defined force for an arbitrary position.

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Assumptions and Limitations

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Mathematical Description

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

Linear Force Source

The force is equivalent to the present value of the quantity specified in the input field, which can be a constant value, a time function, a variable, or a value determined in a state graph. All system quantities and variables can be combined with mathematical and logical operators and constants.

$$F(t) = \text{VALUE}$$

The position of an ideal force source can be arbitrary. Real flow sources have always an internal resistance. If the internal resistance is essential for the simulation target, a corresponding resistance must be connected in parallel.

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
TR1	Pin1	translational_v
TR2	Pin2	translational_v

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
VALUE	Force	real	1 [N]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
S	Displacement [m]		real
F	Force [N]	Output	real
V	Velocity [m/s]	Output	real

Time-Controlled Force Source

The time-controlled force sources have the same properties as the linear force source above; the position can be arbitrary and the internal resistance is zero (ideal source). The value of force instead is equivalent to the present value of the selected time function at each calculation step.

$$F(t) = f[\text{time function}]$$

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Conservative Pins

Table 4

Name	Description	Nature/Data Type
TR1	Pin1	translational_v
TR2	Pin2	translational_v

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Parameters

Table 5

Name	Description	Data Type	Default Value [Unit]
AMPL	Amplitude	real	1 [N]
FREQU	Frequency (no trapezoidal function parameter)	real	50 [Hz]
TPERIO	Period	real	20m [s]
TDELAY	Delay	real	0 [s]
PHASE	Phase	real	0 [deg]
n/a	Angular Dimension		
OFF	Offset	real	0
PERIO	Periodic; PERIO=1, periodical function, PERIO=0; non-periodical function	real	1
DAMPING	Damping factor (only sine function)	real	0 [1/s]

	DAMPING>0, amplitude is exponentially decreasing (damped). DAMPING<0, amplitude is exponentially increasing, DAMPING=0, no damping		
TRISE	Rise Time (only trapezoidal function)	real	5m [s]
TFALL	Fall Time (only trapezoidal function)	real	10m [s]
PWIDTH	Pulse Width (only trapezoidal function)	real	5m [s]

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Input/Output Quantities

Table 6

Name	Description [Unit]	Direction	Data Type
S	Displacement [m]		real
F	Force [N]	Output	real
V	Velocity [m/s]	Output	real

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Example

Figure 2 shows application of the Force Source model. In this example, the mass is accelerated by a constant Force. The acceleration is limited due to the Limit Stop. The Limit stop represents a spring-damper combination which causes the mass to stop at the defined upper position limit. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3 and 4.

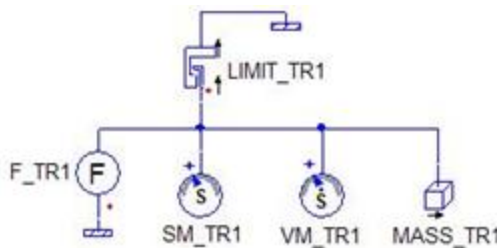
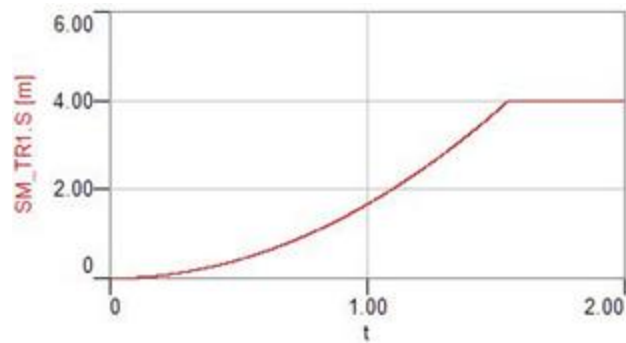
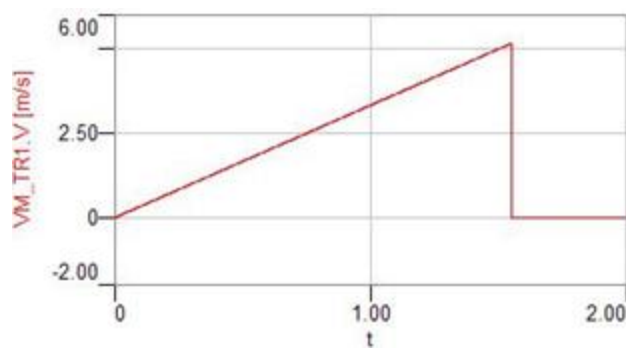


Figure 2. Application example of the Force Source model

Table 4

Component	Parameter	Value
Limit Stop LIMIT_TR1	C	1.0e6 [N/m]
	DUMPING	1.0e5 [Ns/m]
	SUL	1 [m]
	SLL	0 [m]
	S0	0 [m]
Force Source F_TR1	VALUE	10 [N]
Mass MASS_TR1	M	3 [Kg]
	S0	0 [m]
	V0	0 [m/s]

**Figure 3. Simulation result-Position of MASS_TR1****Figure 4. Simulation result-velocity of MASS_TR1**[Top](#)

References

Limit Stop

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

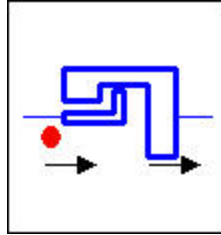


Figure 1. Component Symbol.

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Description

The component represents a parallel damper and spring combination within defined limits (upper and lower limit).

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Mathematical Description

The limit Stop model can be described as:

```

if  $s(t) > SUL$ 
 $F(t) = C \cdot (s(t) - SUL) + DAMPING \cdot v(t)$ 
if  $\overline{s(t)} < \overline{SLL}$ 
 $F(t) = C \cdot (s(t) - SLL) + DAMPING \cdot v(t)$ 
else  $F(t) = 0$ 

```

[Top](#)**Netlist Syntax**

```

UMODEL LIMIT_TR ?InstanceName(@InstanceName):(@Refbase)@(ID)) TR1:= %0, TR2:=
%1 ( C:= @C, DAMPING:= @DAMPING, SUL:= @SUL, SLL:= @SLL, S0:= @S0) SRC: DB(Lib:-
:=@ModelLibraryName);

```

[Top](#)**Conservative Pins****Table 1**

Name	Description	Nature/Data Type
TR1	Pin1	translational_v
TR2	Pin2	translational_v

[Top](#)**Parameters****Table 2**

Name	Description	Data Type	Default Value [Unit]
C	Spring Rate	real	1.0e+006 [N/m]
DAMPING	Damping Coefficient	real	1.0e+006 [N*s/m]
SUL	Upper Position Limit	real	1 [m]
SLL	Lower Position Limit	real	0 [m]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
S	Displacement [m]	Output	real
F	Force [N]	Output	real
V	Velocity [m/s]	Output	real

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Example

Figure 2 shows application of the Limit Stop model. In this example, the mass is accelerated by a constant Force. The acceleration is limited due to the Limit Stop. The Limit stop represents a spring-damper combination which causes the mass to stop at the defined upper position limit. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3 and 4.

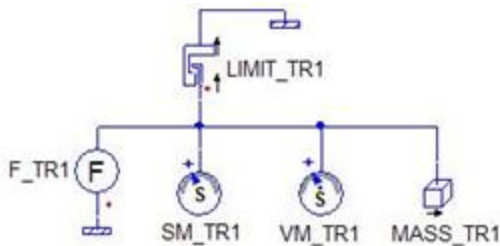


Figure 2. Application example of the Limit Stop model

Table 4

Component	Parameter	Value
Limit Stop LIMIT_TR1	C	1.0e6 [N/m]
	DUMPING	1.0e5 [Ns/m]
	SUL	1 [m]
	SLL	0 [m]
	S0	0 [m]
Force Source F_TR1	VALUE	10 [N]

Mass MASS_TR1	M	3 [Kg]
	S0	0 [m]
	V0	0 [m/s]

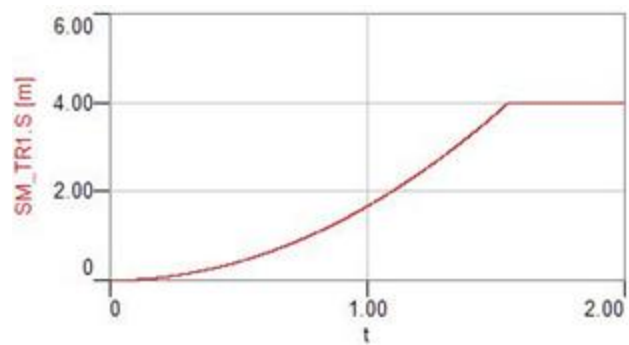


Figure 3. Simulation result-Position of MASS_TR1

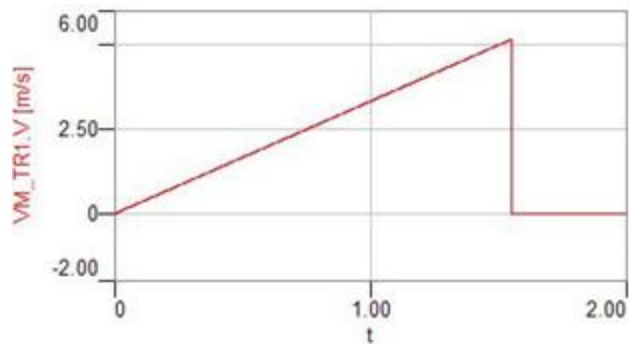


Figure 4. Simulation result-velocity of MASS_TR1

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References

Mass

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

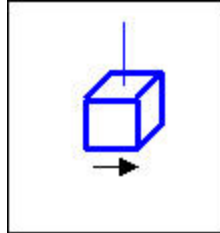


Figure 1. Component Symbol.

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Description

The component represents a mass specified by a mass/inertia and initial position/velocity.

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Assumptions and Limitations

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Mathematical Description

The Mass model can be described as:

$$F(t) = M \cdot a(t) \quad s(t) = \int v dt + s_0 \quad v(t) = \int a dt + v_0$$

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Netlist Syntax

UMODEL MASS_TR ?InstanceName(@InstanceName):(@Refbase)@(ID)) TR1:= %0 (M:= @M, S0:= @S0, V0:= @V0) SRC: DB(Lib:=@ModelLibraryName) ;

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
TR1	Pin1	translational_v
TR2	Pin2	translational_v

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
M	Mass	real	1 [kg]
S0	Initial Position	real	0 [m]
V0	Initial Velocity	real	0 [m/s]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
S	Displacement [m]	Output	real
F	Force [N]	Output	real
V	Velocity [m/s]	Output	real
ACC	Acceleration [m/s ²]	Output	real

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Example

Figure 2 shows application of the Mass model. In this example, a constant angular velocity is applied to the system. Due to the damping of the system, the force applied to the mass sinusoidally decays with time. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3 and 4.

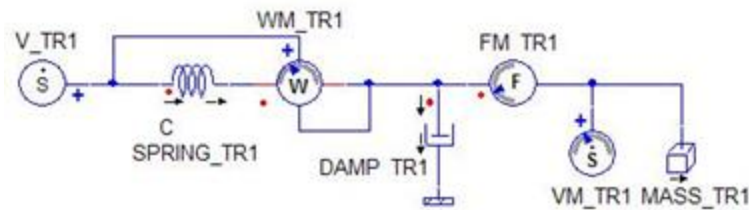


Figure 2. Application example of the Mass model

Table 4

Component	Parameter	Value
Spring SPRING_TR1	C	0.1 [N/m]
	S0	0 [m]
Damper DAMPER_TR1	DUMPING	0.05 [N s/m]
Velocity Source V_TR1	VALUE	10 [m/s]
Mass MASS_TR1	M	1 [Kg]
	S0	0 [m]
	V0	0 [m/s]

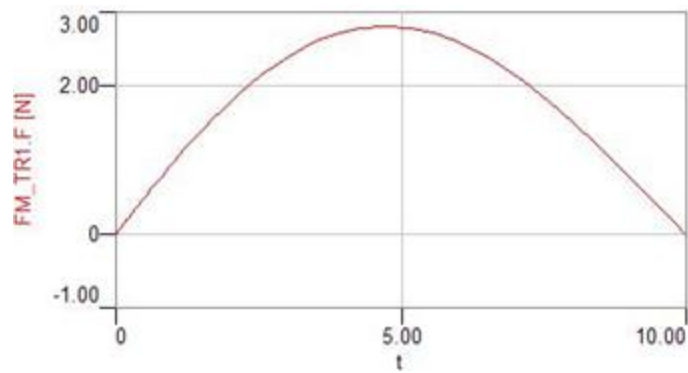


Figure 3. Simulation result-force applied to MASS_TR1

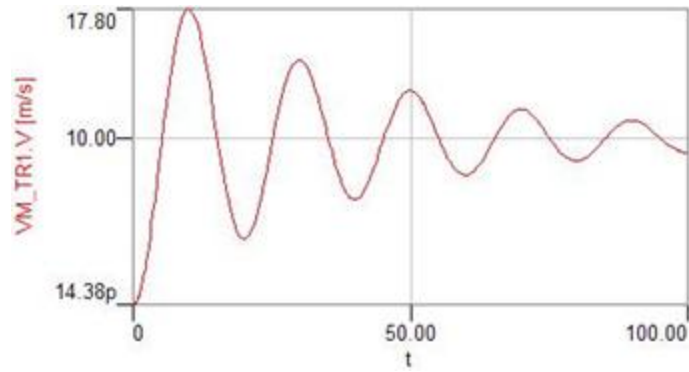


Figure 4. Simulation result- velocity of MASS_TR1

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References

Spring

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

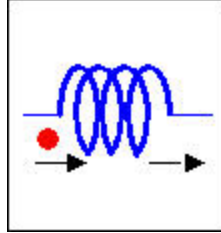


Figure 1. Component Symbol.

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Description

The component represents a simple spring specified by a spring rate.

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Assumptions and Limitations

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Mathematical Description

The Spring model can be described as:

$$F(t) = C \cdot s(t)$$

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Netlist Syntax

UMODEL SPRING_TR ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) TR1:= %0,
TR2:= %1 (S0:= @S0, C:= @C) SRC: DB(Lib:=@ModelLibraryName) ;

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
TR1	Pin1	translational_v
TR2	Pin2	translational_v

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
S0	Initial Position	real	0 [m]
C	Spring Rate	real	100 [N/m]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
S	Displacement [m]	Output	real
F	Force [N]	Output	real
V	Velocity [m/s]	Output	real

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Example

Figure 2 shows application of the Spring model. In this example, a constant angular velocity is applied to the system. Due to the damping of the system, the force applied to the mass

sinusoidally decays with time. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3 and 4.

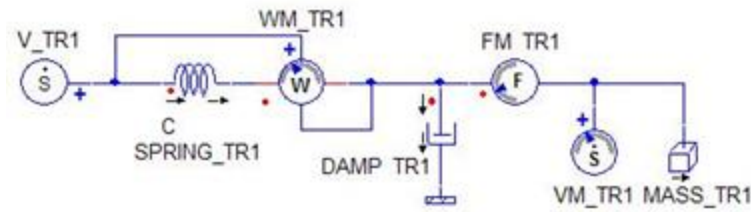


Figure 2. Application example of the Spring model

Table 4

Component	Parameter	Value
Spring SPRING_TR1	C	0.1 [N/m]
	S0	0 [m]
Damper DAMPER_TR1	DUMPING	0.05 [N s/m]
Velocity Source V_TR1	VALUE	10 [m/s]
Mass MASS_TR1	M	1 [Kg]
	S0	0 [m]
	V0	0 [m/s]

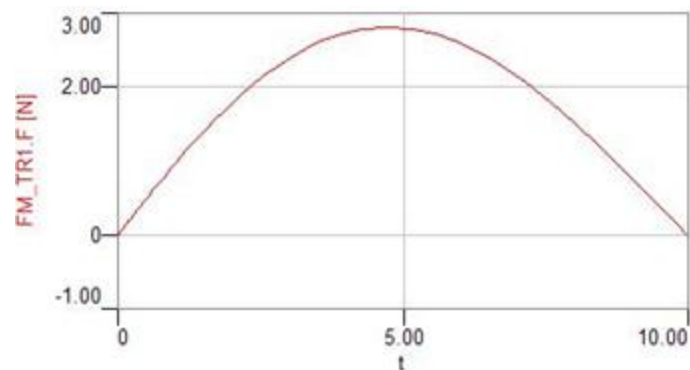


Figure 3. Simulation result-force applied to MASS_TR1

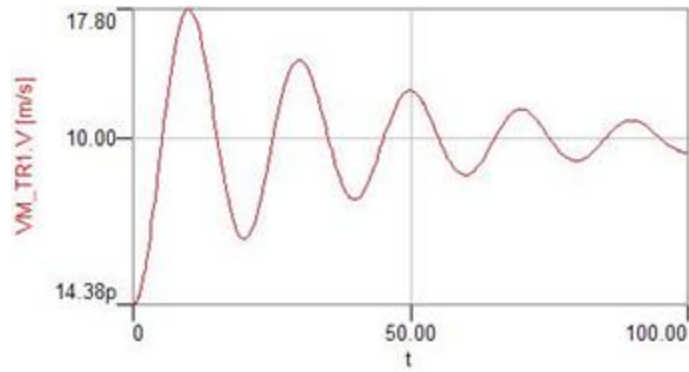


Figure 4. Simulation result- velocity of MASS_TR1

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References

Velocity Source

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

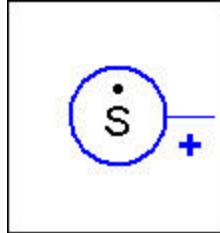


Figure 1. Component Symbol.

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Description

The component represents an ideal mechanical velocity source which supplies the defined velocity for an arbitrary force.

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Assumptions and Limitations

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Mathematical Description

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

Linear Velocity Source

The velocity is equivalent to the present value of the quantity specified in the text box, which can be a constant value, a time function, a variable, or a value determined in a state graph. All system quantities and variables can be combined with mathematical and logical operators and constants.

$$\frac{ds}{dt} = v(t) = \text{VALUE}$$

The force/torque through an ideal position/angle source can be arbitrary. Real force sources have always an internal resistance. If the internal resistance is essential for the simulation target, a corresponding resistance must be connected in series.

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
TR1	Pin Velocity Source	translational_v

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
VALUE	Velocity [m/s]	real	1 [m/s]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
S	Displacement [m]		real

F	Force [N]	Output	real
V	Velocity [m/s]	Output	real

Time-Controlled Velocity Source

The time-controlled velocity sources have the same properties as the linear velocity source above; the force flow can be arbitrary and the internal resistance is zero (ideal source). The value of the position instead is equivalent to the present value of the selected time function at each calculation step.

$$\frac{ds}{dt} = v(t) = f[\text{time function}]$$

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Conservative Pins

Table 4

Name	Description	Nature/Data Type
TR1	Pin Velocity Source	translational_v

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Parameters

Table 5

Name	Description	Data Type	Default Value [Unit]
AMPL	Amplitude	real	1 [m/s]
FREQU	Frequency (no trapezoidal function parameter)	real	50 [Hz]
TPERIO	Period	real	20m [s]
TDELAY	Delay	real	0 [s]
PHASE	Phase	real	0 [deg]
n/a	Angular Dimension		

OFF	Offset	real	0
PERIO	Periodic; PERIO=1, periodical function, PERIO=0; non-periodical function	real	1
DAMPING	Damping factor (only sine function) DAMPING>0, amplitude is exponentially decreasing (damped). DAMPING<0, amplitude is exponentially increasing, DAMPING=0, no damping	real	0 [1/s]
TRISE	Rise Time (only trapezoidal function)	real	5m [s]
TFALL	Fall Time (only trapezoidal function)	real	10m [s]
PWIDTH	Pulse Width (only trapezoidal function)	real	5m [s]

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Input/Output Quantities

Table 6

Name	Description [Unit]	Direction	Data Type
S	Displacement [m]		real
F	Force [N]	Output	real
V	Velocity [m/s]	Output	real

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Example

Figure 2 shows application of the Velocity Source model. In this example, a constant angular velocity is applied to the system. Due to the damping of the system, the force applied to the mass sinusoidally decays with time. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3 and 4.

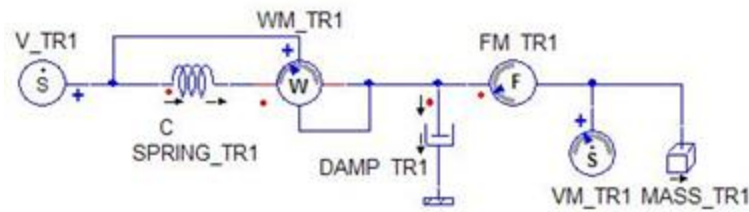


Figure 2. Application example of the Velocity Source model

Table 4

Component	Parameter	Value
Spring $SPRING\_TR1$	C	0.1 [N/m]
	S0	0 [m]
Damper $DAMPER\_TR1$	DUMPING	0.05 [N s/m]
Velocity Source V_TR1	VALUE	10 [m/s]
Mass $MASS\_TR1$	M	1 [Kg]
	S0	0 [m]
	V0	0 [m/s]

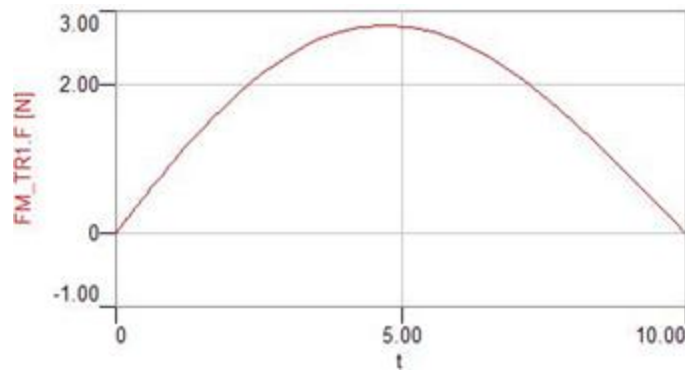


Figure 3. Simulation result-force applied to $MASS\_TR1$

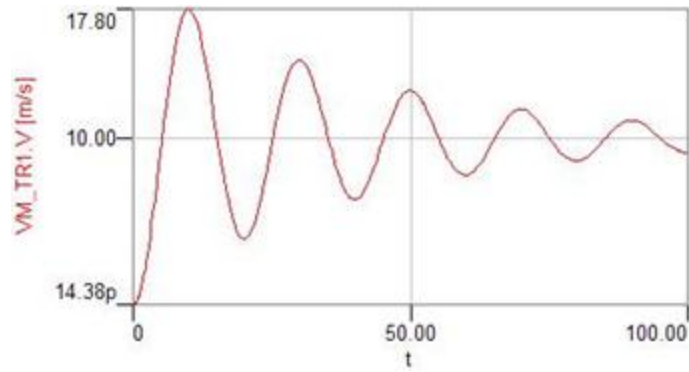


Figure 4. Simulation result- velocity of MASS_TR1

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References

Thermal Components

- [Thermal Capacitance \(CTH\)](#)
- [Heat Flow Source \(H\)](#)
- [Thermal Resistance \(RTH\)](#)
- [Temperature Source \(T\)](#)

The thermal domain components appear in the *Thermal* folder of *Physical Domains* in the **Basic Elements** library. The folder provides thermal basic components to model simple thermal equivalent circuits, for example cooling systems or heat sinks. The thermal domain uses the temperature as across and the heat flow as through quantity.

By default, components and wires of the thermal domain are represented in red in the graphical representation of the Schematic. To change the settings of nature colors, choose Tools\Options\Schematic Editor Options, click on the *color* tab, select *Wires* as the object type, and the color of wires for different domains can be edited.

Across and Through Quantity of the Thermal Domain

Table 1

Across	Through	Equation
Temperature [K]	Heat Flow [J/s]	$T(t) = K \cdot H(t)$

Thermal Capacitance

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

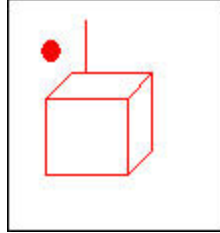


Figure 1. Component Symbol.

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Description

The component represents an ideal thermal capacitance.

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Assumptions and Limitations

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Mathematical Description

The Thermal Capacitance model can be described as:

$$\mathbf{H}(t) = C_{\text{TH}} \cdot \frac{dT(t)}{dt}$$

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Netlist Syntax

UMODEL CTH ?InstanceName(@InstanceName):(@ (Refbase)@(ID)) TH1:= %0 (C_TH:=
@C_TH, T0:= @T0) SRC: DB(Lib:=@ModelLibraryName) ;

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
TH1	Pin 1 (with red point)	thermal

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
C_TH	Thermal Capacitance	real	1 [J/K]
T0	Initial Temperature	real	0.293k [K]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
T	Temperature [K]	Output	real
H	Heat Flow [J/s]	Output	real

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Example

Figure 2 shows application of the Thermal Capacitance model. In this example, a thermal capacitance is charged and then discharged by a heat flow source in the lower circuit. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3 and 4.

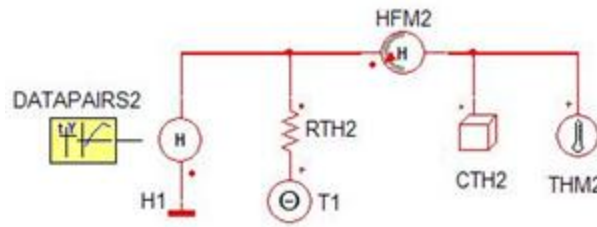


Figure 2. Application example of the Thermal Capacitance model

Table 4

Component	Parameter	Value
2D Lookup Table DATAPAIRS2	PHASE	0 [degree]
	TDELAY	0 [s]
	FILE	thermal_ssh__DATAPAIRS2.mdx
Heat Source H1	VALUE	10 [Nm]
Thermal Resistance RTH2	K	.25 [K/W]
Temperature Source T1	VALUE	273 [K]
Thermal Capacitance CTH2	C_TH	1 [Ks/W]
	T0	313 [K]

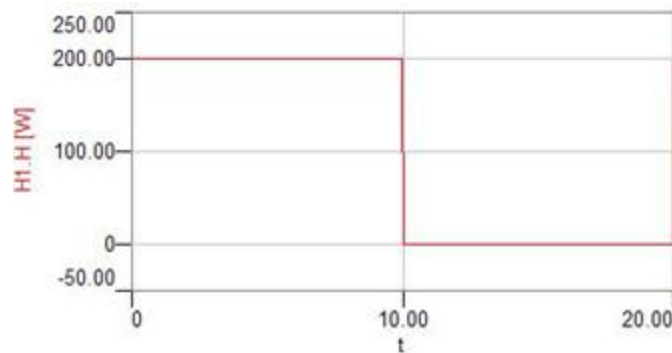


Figure 3. Simulation result-Heat output of H1

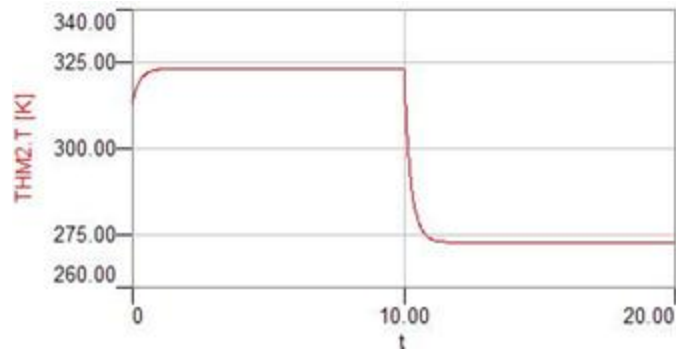


Figure 4. Simulation result-Temperature of CTH2

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References

Heat Flow Source

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

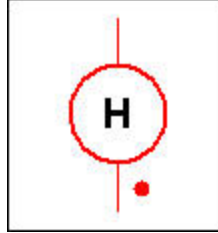


Figure 1. Component Symbol.

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Description

The component represents an ideal flow source which supplies the defined flow rate for an arbitrary pressure differential. Within the dialog you can choose a constant or the time-controlled type.

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Assumptions and Limitations

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Mathematical Description

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

Linear Heat Flow Source

The flow rate is equivalent to the present value of the quantity specified in the input field, which can be a constant value, a time function, a variable, or a value determined in a state graph. All system quantities and variables can be combined with mathematical and logical operators and constants.

$$H(t) = \text{VALUE}$$

The pressure of an ideal flow source can be arbitrary. Real flow sources have always an internal resistance. If the internal resistance is essential for the simulation target, a corresponding resistance must be connected in parallel.

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
TH1	Pin 1 (with red point)	thermal
TH2	Pin 2	thermal

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
VALUE	Heat Flow	real	1 [J/s]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
T	Temperature [K]	Output	real
H	Heat Flow [J/s]	Output	real

Time-Controlled Heat Flow Source

The time-controlled heat flow sources have the same properties as the linear heat flow source above; the temperature can be arbitrary and the internal resistance is zero (ideal source). The value of the flow rate instead is equivalent to the present value of the selected time function at each calculation step.

$$H(t) = f[\text{time function}]$$

The simulator internal names of time-controlled flow sources read as follows: Sine-HSINE; Pulse-HPULSE; Triangular-HTRIANG; Trapezoidal-HTRAPEZ; Saw-tooth Rising-HSZ_RISE; Saw-tooth Falling-HST_FALL. The names are only relevant to simulation scripts in SML. Access to source parameters is carried out only by the component name.

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Conservative Pins

Table 4

Name	Description	Nature/Data Type
TH1	Pin 1 (with red point)	thermal
TH2	Pin 2	thermal

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Parameters

Table 5

Name	Description	Data Type	Default Value [Unit]
AMPL	Amplitude	real	0.5 [J/s]
FREQU	Frequency (no trapezoidal function parameter)	real	1 [Hz]
TPERIO	Period	real	1 [s]
TDELAY	Delay	real	0 [s]
PHASE	Phase	real	0 [deg]
n/a	Angular Dimension		
OFF	Offset	real	0
PERIO	Periodic; PERIO=1, periodical function, PERIO=0; non-periodical function	real	1

DAMPING	Damping factor (only sine function) DAMPING>0, amplitude is exponentially decreasing (damped). DAMPING<0, amplitude is exponentially increasing, DAMPING=0, no damping	real	0 [1/s]
TRISE	Rise Time (only trapezoidal function)	real	250m [s]
TFALL	Fall Time (only trapezoidal function)	real	250m [s]
PWIDTH	Pulse Width (only trapezoidal function)	real	500m [s]

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Input/Output Quantities

Table 6

Name	Description [Unit]	Direction	Data Type
T	Temperature [K]	Output	real
H	Heat Flow [J/s]	Output	real

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Example

Figure 2 shows application of the Heat Source model. In this example, a thermal capacitance is charged and then discharged by a heat flow source in the lower circuit. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3 and 4.

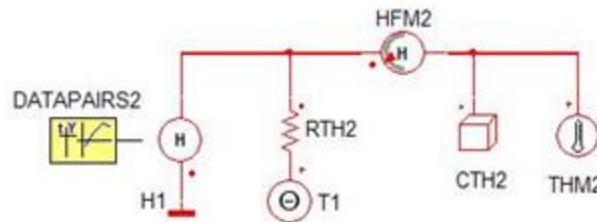


Figure 2. Application example of the Heat Source model

Table 4

Component	Parameter	Value
2D Lookup Table DATAPAIRS2	PHASE	0 [degree]
	TDELAY	0 [s]
	FILE	thermal_ssh__DATAPAIRS2.mdx
Heat Source H1	VALUE	10 [Nm]
Thermal Resistance RTH2	K	.25 [K/W]
Temperature Source T1	VALUE	273 [K]
Thermal Capacitance CTH2	C_TH	1 [Ks/W]
	T0	313 [K]

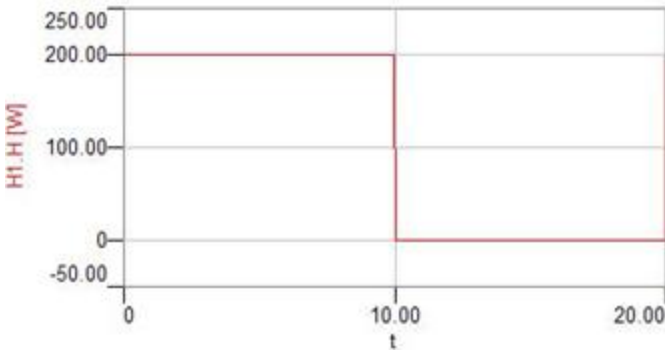


Figure 3. Simulation result-Heat output of H1

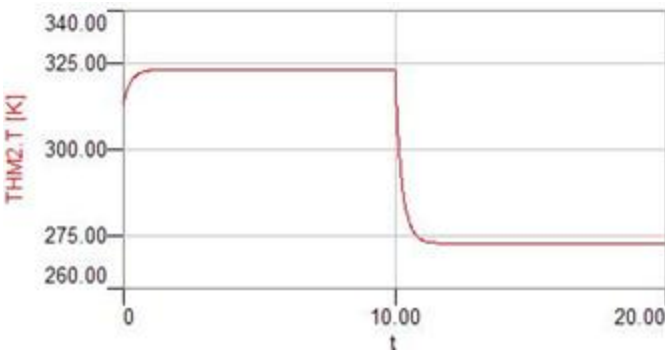


Figure 4. Simulation result-Temperature of CTH2

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References

Thermal Resistance

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

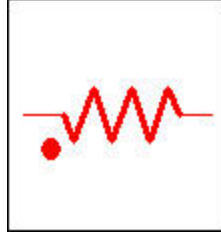


Figure 1. Component Symbol.

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Description

The component represents a ideal thermal resistance specified ba a linear coefficient.

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Assumptions and Limitations

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Mathematical Description

The Thermal Resistance model can be described as:

$$T(t) = K \cdot H(t)$$

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Netlist Syntax

UMODEL RTH ?InstanceName(@InstanceName):(@ (Refbase)@(ID)) TH1:= %0, TH2:= %1 (K:= @K) SRC: DB(Lib:=@ModelLibraryName) ;

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
TH1	Pin 1 (with red point)	thermal
TH2	Pin 2	thermal

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
K	Linear Coefficient	real	1 [K*s/J]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
T	Temperature [K]	Output	real
H	Heat Flow [J/s]	Output	real

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Example

Figure 2 shows application of the Thermal Resistance model. In this example, a thermal capacitance is charged and then discharged by a heat flow source in the lower circuit. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3 and 4.

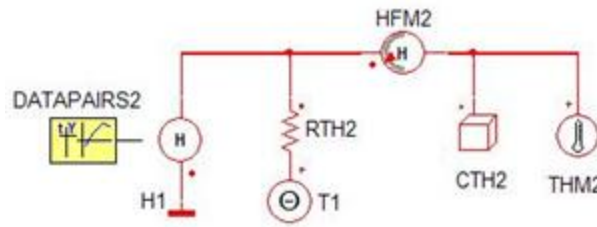


Figure 2. Application example of the Thermal Resistance model

Table 4

Component	Parameter	Value
2D Lookup Table DATAPAIRS2	PHASE	0 [degree]
	TDELAY	0 [s]
	FILE	thermal_ssh__DATAPAIRS2.mdx
Heat Source H1	VALUE	10 [Nm]
Thermal Resistance RTH2	K	.25 [K/W]
Temperature Source T1	VALUE	273 [K]
Thermal Capacitance CTH2	C_TH	1 [Ks/W]
	T0	313 [K]

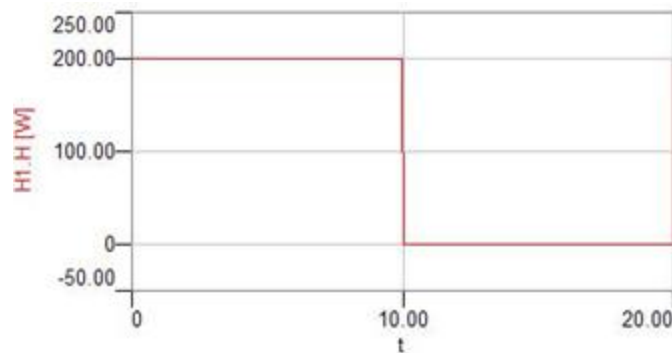


Figure 3. Simulation result-Heat output of H1

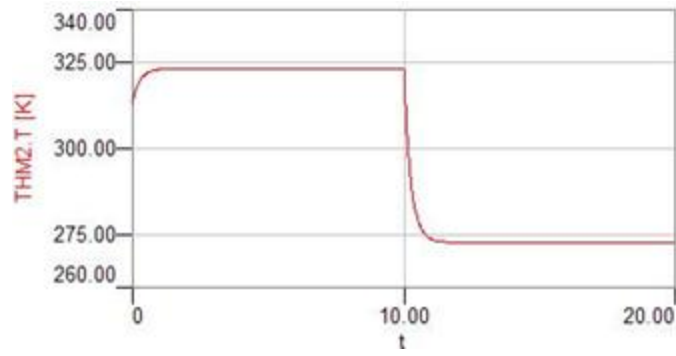


Figure 4. Simulation result-Temperature of CTH2

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References

Temperature Source

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

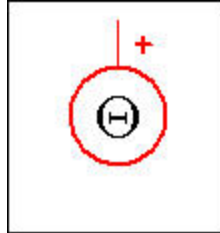


Figure 1. Component Symbol.

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Description

The component represents an ideal temperature source which supplies the defined temperature for an arbitrary heat flow. Within the dialog you can choose a constant or the time-controlled type.

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Mathematical Description

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

Linear Temperature Source

The temperature is equivalent to the present value of the quantity specified in the text box, which can be a constant value, a time function, a variable, or a value determined in a state graph. All system quantities and variables can be combined with mathematical and logical operators and constants.

$$T(t) = \text{VALUE}$$

The heat flow through an ideal temperature source can be arbitrary. Real temperature sources have always an internal resistance. If the internal resistance is essential for the simulation target, a corresponding resistance must be connected in series.

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Conservative Pins

Table 1

Name	Description	Nature/Data Type
TH1	Pin 1 (with red point)	thermal

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
VALUE	Temperature	real	0.293k [K]

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
T	Temperature [K]	Output	real
H	Heat Flow [J/s]	Output	real

Time-Controlled Temperature Source

The time-controlled temperature sources have the same properties as the linear temperature source above; the heat flow can be arbitrary and the internal resistance is zero (ideal source). The value of the temperature differential instead is equivalent to the present value of the selected time function at each calculation step.

$$T(t) = f[\text{time function}]$$

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Conservative Pins

Table 4

Name	Description	Nature/Data Type
TH1	Pin 1 (with red point)	thermal

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Parameters

Table 5

Name	Description	Data Type	Default Value [Unit]
AMPL	Amplitude	real	20 [T]
FREQU	Frequency (no trapezoidal function parameter)	real	1 [Hz]
TPERIO	Period	real	1 [s]
TDELAY	Delay	real	0 [s]
PHASE	Phase	real	0 [deg]
n/a	Angular Dimension		
OFF	Offset	real	0
PERIO	Periodic; PERIO=1, periodical function, PERIO=0; non-periodical function	real	1
DAMPING	Damping factor (only sine function) DAMPING>0, amplitude is exponentially decreasing (damped). DAMPING<0, amplitude is exponentially increasing,	real	0 [1/s]

	DAMPING=0, no damping		
TRISE	Rise Time (only trapezoidal function)	real	250m [s]
TFALL	Fall Time (only trapezoidal function)	real	250m [s]
PWIDTH	Pulse Width (only trapezoidal function)	real	500m [s]

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Input/Output Quantities

Table 6

Name	Description [Unit]	Direction	Data Type
T	Temperature [K]	Output	real
H	Heat Flow [J/s]	Output	real

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Example

Figure 2 shows application of the Temperature Source model. In this example, a thermal capacitance is charged and then discharged by a heat flow source in the lower circuit. The parameters of the system are listed in Table 4 and the simulation results shown in Figure 3 and 4.

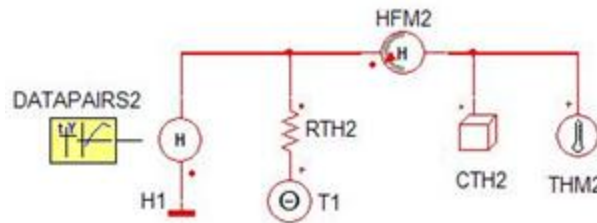


Figure 2. Application example of the Temperature Source model

Table 4

Component	Parameter	Value

2D Lookup Table DATAPAIRS2	PHASE	0 [degree]
	TDELAY	0 [s]
	FILE	thermal_ssh__DATAPAIRS2.mdx
Heat Source H1	VALUE	10 [Nm]
Thermal Resistance RTH2	K	.25 [K/W]
Temperature Source T1	VALUE	273 [K]
Thermal Capacitance CTH2	C_TH	1 [Ks/W]
	T0	313 [K]

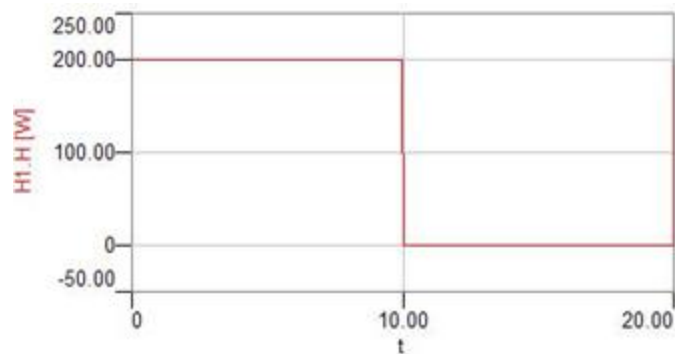


Figure 3. Simulation result-Heat output of H1

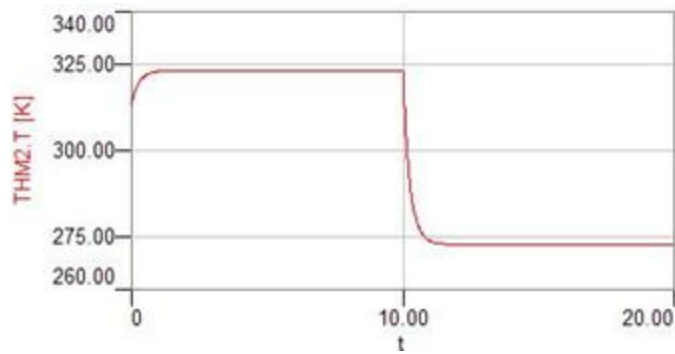


Figure 4. Simulation result-Temperature of CTH2

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References

Using Signal Characteristics

Special characteristic values are helpful in evaluating the behavior of a dynamic system and understanding the impact of system parameters on the dynamic system behavior. For an automated system design, it is necessary to have the characteristic parameters available during the simulation process so that an immediate adaptation can be made. The State Graph Machines provide an excellent tool to observe or to respond to certain events in the system under study.

Here, a couple of useful macros are presented, which determine various characteristic values. The macros are clearly arranged for different technical purposes: Common characteristic values, characteristic values for dynamic system behavior, characteristic values of dynamic performance of a controlled system, and special wave form parameters.

Signal Characteristic components appear in the *Signal Characteristics* folder of the Basic Elements library. Signal processing blocks display the following general features:

- The blocks produce multiple outputs in the same functional area.
- All but one is an ECM model for the analog simulator. The FFT is a block diagram model for the block diagram simulator.
- All run in DC, AC, and TR analyses. Outputs are zero if there is no appropriate behavior in a certain analysis mode.

[*Probe Types*](#)

[*Version 6 Block Mapping*](#)

[*FFT Parameter Mapping*](#)

[*References*](#)

Probe Types

• AC Probe	scans a magnitude response for the peak and RMS in AC analysis
• CTRL AC Probe	typical measures from a Bode plot in AC analysis
• CTRL ERR Probe	integral error measures in TR analysis
• CTRL TR Probe	overshoot, settling, and rise time measures in TR analysis
• F Probe	identifies a value at specified frequency in AC analysis
• FFT Probe	performs a Fast Fourier Transform in TR analysis
• PULSE Probe	time measurements based on the actual peak in a TR analysis
• PWR Probe	multi-phase power and energy measures for TR analysis
• T Probe	identifies a value at specified time in TR analysis
• TR Probe	peak and waveform quality measures for TR analysis

AC Probe

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

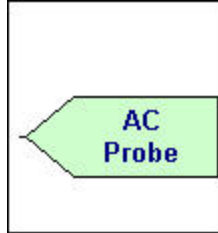


Figure 1. Component Symbol.

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Description

This is an ECM component for AC analysis, finding the minimum and maximum values and the frequencies at which they occur. It also finds the total RMS value. These outputs are updated continuously during simulation. Outputs are 0 for DC and TR. The main application for this component is to find resonant values and frequencies.

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Assumptions and Limitations

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Mathematical Description

The output of the AC Probe model can be expressed as following:

$$RMS = \sqrt{\sum_f (X_{rms-f})^2}$$

where X_{rms-f} is the RMS value of the input signal $x(t)$ at the frequency component f .

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Netlist Syntax

UMODEL AC_Probe ?InstanceName(@InstanceName):(@ (Refbase)@(ID)) (INPUT:=
@INPUT) SRC: DB(Lib:=@ModelLibraryName) ;

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Parameters

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Input/Output Quantities

Table 1

Name	Description	Direction	Data Type
MIN	Minimum magnitude value	Output	real
MAX	Maximum magnitude value	Output	real
FRQMIN	Frequency at which the minimum magnitude occurred [Hz]	Output	real
FRQMAX	Frequency at which the maximum magnitude occurred [Hz]	Output	real
RMS	Total RMS value	Output	real
INPUT	Input signal	Input	real

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Example

Figure 2 shows application of the AC Probe model. The parameters of the system are listed in Table 3. The waveform of the input signal for AC Probe PRB1 is shown in Figure 3, and the analysis result of PRB1 and the F Probe PRB2 are shown in Figure 4.

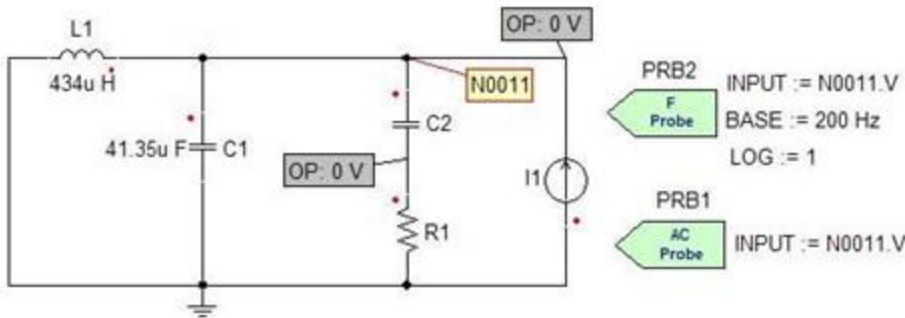


Figure 2. Application example of the AC Probe model**Table 3**

Component	Parameter	Value
Inductor L1	L	434u [H]
	I0	0 [A]
Capacitor C1	C	41.35u [F]
	V0	0 [V]
Capacitor C2	C	120u [F]
	V0	0 [V]
Resistor R1	R	1.6 [Ohm]
Current Source I1	IS	0.1 [A]
F Probe PRB2	BASE	200 [Hz]
	LOG	1

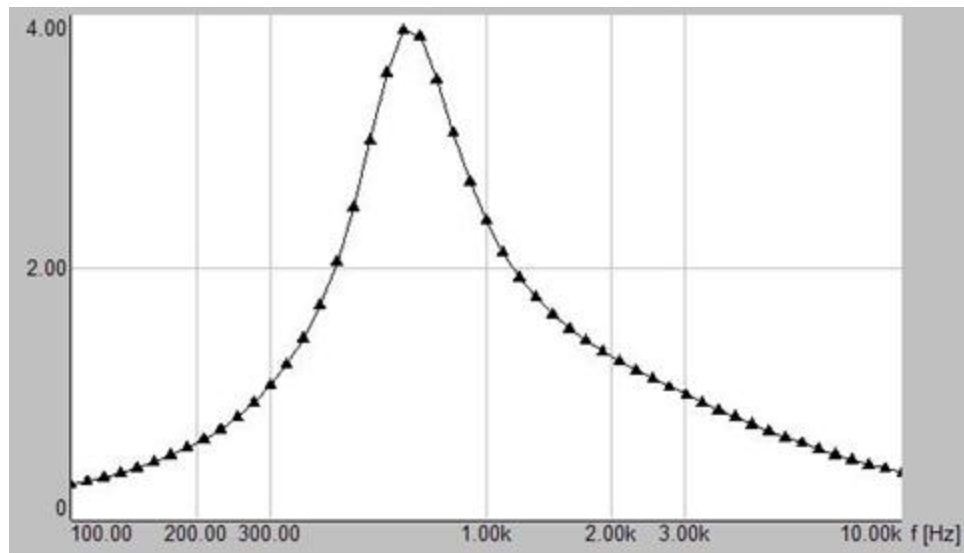


Figure 3. Simulation results-voltage of node N0011 in Frequency domain

DigViewSel1	
PRB2.VAL (r...	PRB2.VAL (i...
13.0553m	611.0728m
PRB1.MIN (r...	PRB1.MAX (r...
280.36m	3.89
PRB1.FRQM...	PRB1.FRQM...
100.00	630.96
PRB1.RMS (...)	
11.83	

Figure 4. Simulation results-analysis results of PRB1 and PRB2

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References

CTRL AC Probe

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

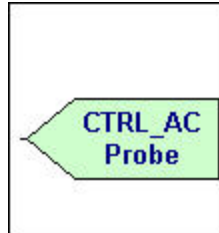


Figure 1. Component Symbol.

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Description

This ECM component calculates control system performance metrics in the frequency domain. In order to calculate the gain in dB, the source magnitude must be specified as GBASE, normally 1m for the AC_MAG source parameter. The phase angle uses PBASE as a reference, normally 0 degrees for the AC_PHASE source parameter. As an option, a reference signal may be specified, which then allows PBASE and GBASE to vary with frequency.

Outputs are calculated at the end of an AC sweep. The outputs are zero for DC and TR analysis. The main application is for automated control system design or evaluation.

With reference to a Bode plot, the outputs are defined in the following table.

Table 1

Output	Definition
GCROSS	The gain crossover frequency, where the gain is 0 dB.
PM	The phase margin, at a 180-degree phase angle, evaluated at GCROSS.
PCROSS	The phase crossover frequency, where the phase angle is 180 degrees.

GM	The gain margin, evaluated at PCROSS.
MP	The peak gain in dB.
FP	The frequency at which MP occurs.
FC1	Lower cutoff frequency, $\leq$ FP, where the gain is 3 dB less than MP.
FC2	Upper cutoff frequency, $\geq$ FP, where the gain is 3 dB less than MP.
BW	The bandwidth, FC2 - FC1.

For a first-order system, in which the gain rolls off monotonically, FC1 will be zero. For a second-order system with a true resonant peak, FC1 is probably greater than zero, but it may not define the system bandwidth of interest. In that case, FC2 would define the system bandwidth.

Note that when determining PCROSS, this component will extrapolate the phase angle below -180, rather than wrapping to +180 as in the Bode plot display. It is important to be aware of this when checking PCROSS graphically.

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Mathematical Description

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Netlist Syntax

```
UMODEL CTRL_AC_Probe ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) ( INPUT:=  
@INPUT, REF:= @REF, GBASE:= @GBASE, PBASE:= @PBASE) SRC: DB(Lib:-  
:=@ModelLibraryName) ;
```

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
GBASE	Base source magnitude for gain in dB [optional, may use REF instead]	real	1 [mV]
PBASE	Base source angle for phase shift [optional, may use REF instead]	real	0 [deg]
REF	Reference signal [optional, may use GBASE and PBASE instead]	real	0

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Input/Output Quantities

Table 3

Name	Description	Direction	Data Type
GM	The gain margin, evaluated at a 180-degree phase shift (PCROSS). [dB]	Output	real
PM	The phase margin, at unity gain. [deg]	Output	real
GCROSS	The gain crossover frequency, where the gain is 0 dB. [Hz]	Output	real
PCROSS	The phase crossover frequency, where the phase angle is 180 degrees. [Hz]	Output	real
FC1	Lower cutoff frequency. [Hz]	Output	real
FC2	Upper cutoff frequency. [Hz]	Output	real
BW	The bandwidth. [Hz]	Output	real
MP	Resonant peak. [dB]	Output	real
FP	Resonant frequency. [Hz]	Output	real
INPUT	Input signal	Input	real

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Example

Figure 2 shows application of the CTRL AC Probe model. The parameters of the system are listed in Table 3. The Bode diagram of the S-Transfer Function GS3 is shown in Figure 3, and the analysis results of PRB1 are shown in Figure 4.

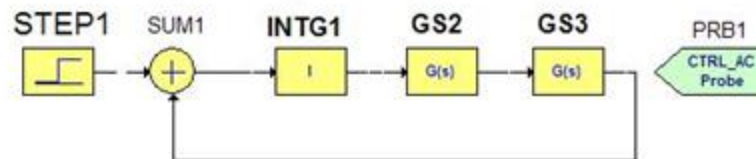


Figure 2. Application example of the CTRL AC Probe model

Table 3

Component	Parameter	Value

Step Function STEP1	T0	0 [s]
	TS	0* [s]
	AMPL	1
	Y0	0
Summation SUM1	INPUT[0]	STEP1.VAL
	INPUT[1]	-GS3.VAL
	TS	0* [s]
Integrator INTG1	KI	300m
	Y0	0
	TS	0* [s]
Derivative DIFF1	KI	0
	Y0	0
	TS	0* [s]
Summation SUM1	INPUT[0]	GAIN1.VAL
	INPUT[1]	INTG1.VAL
	INPUT[2]	DIFF1.VAL
	TS	0* [s]
S-Transfer Function GS2	N	0
	D	1
	B[0]	1
	A[0]	1.414
	A[1]	1
	TS	0* [s]
S-Transfer Function GS3	N	0
	D	1
	B[0]	1
	A[0]	1
	A[1]	5
	TS	0* [s]

CTRL_AC Probe PRB1	REF	STEP1.VAL
	GBASE	0
	PBASE	0 [degree]

* Simulation time step is used as the sample time.

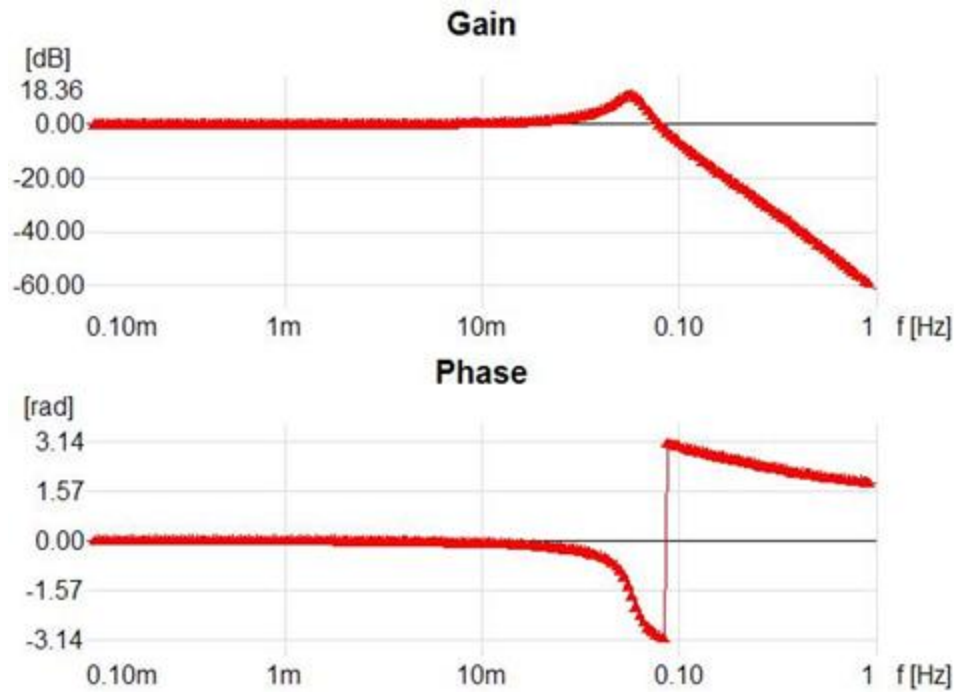


Figure 3. Simulation results-Bode diagram of GS3

DigViewSel1	
PRB1.GM (real) [dB]	PRB1.PM (real) [deg]
2.17	5.08
PRB1.GCROSS (real) ...	PRB1.PCROSS (real) ...
79.16m	84.70m
PRB1.FC1 (real) [Hz]	PRB1.FC2 (real) [Hz]
47.85m	64.18m
PRB1.BW (real) [Hz]	PRB1.MP (real) [dB]
16.33m	11.05
PRB1.FP (real) [Hz]	
57.54m	

Figure 4. Simulation results-analysis results of PRB1

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References

CTRL ERR Probe

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

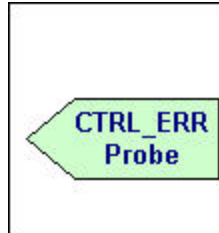


Figure 1. Component Symbol.

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Description

This is an ECM component for TR analysis, finding various integral error characteristics. These outputs are updated continuously during simulation. The final error is calculated as a steady-state error during DC simulation. All other outputs are 0 for AC and DC. The main application for this component is control system design, for all integral criteria related to a setpoint.

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Mathematical Description

The outputs of the CTRL ERR Probe model are calculated as following:

$$\text{err} = \text{input} - \text{setpoint}$$

$$\text{IAE} = \int |\text{err}| dt$$

$$\text{ISE} = \int \text{err}^2 dt$$

$$\text{ITAE} = \int (t \cdot |\text{err}|) dt$$

$$\text{ITSE} = \int t \cdot \text{err}^2 dt$$

where err is the difference between the input signal and the setpoint, and t is the simulation time.

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Netlist Syntax

```
UMODEL CTRL_ERR_Probe ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) (  
INPUT:= @INPUT, SETPOINT:= @SETPOINT, TSTART:= @TSTART, TSTOP:= @TSTOP)  
SRC: DB(Lib:=@ModelLibraryName);
```

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
SETPOINT	Setpoint or target (may be changed during simulation).	real	1
TSTART	Time to start monitoring.	real	0 [s]
TSTOP	Time to stop monitoring.	real	T _{end} [s]

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Input/Output Quantities

Table 2

Name	Description	Direction	Data Type
FINAL	Final error at the end of the measurement.	Output	real
IAE	Integral of the absolute error.	Output	real
ISE	Integral of the squared error.	Output	real

ITAE	Integral of the time-weighted absolute error.	Output	real
ITSE	Integral of the time-weighted squared error.	Output	real
INPUT	Input signal.	Input	real

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Example

Figure 2 shows application of the CTRL_ERR Probe model. The parameters of the system are listed in Table 3. The analysis results of PRB1 are shown in Figure 3.

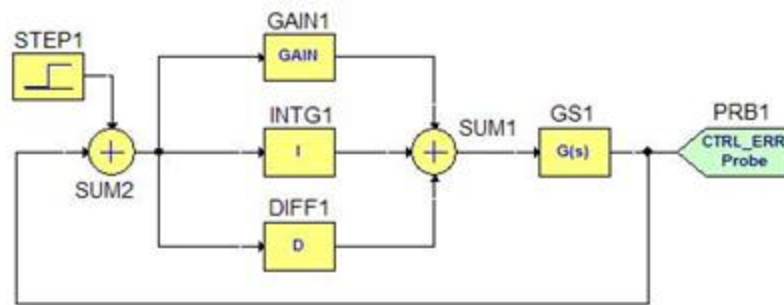


Figure 2. Application example of the CTRL_ERR Probe model

Table 3

Component	Parameter	Value
Step Function STEP1	T0	0 [s]
	TS	0* [s]
	AMPL	1
	Y0	0
Summation SUM2	INPUT[0]	-GS1.VAL
	INPUT[1]	STEP1.VAL
	TS	0* [s]
Gain GAIN1	KP	0.5
	TS	0* [s]
Integrator INTG1	KI	300m
	Y0	0
	TS	0* [s]

Derivative DIFF1	KI	0
	Y0	0
	TS	0* [s]
Summation SUM1	INPUT[0]	GAIN1.VAL
	INPUT[1]	INTG1.VAL
	INPUT[2]	DIFF1.VAL
	TS	0* [s]
S-Transfer Function GS1	N	0
	D	2
	B[0]	4.87
	A[0]	1
	A[1]	5
	A[2]	6.25
	TS	0* [s]
CTRL_ERR Probe PRB1	SETPOINT	0
	TSTART	0 [s]
	TSTOP	TEND** [s]

* Simulation time step is used as the sample time.

** TEND is the end of the simulation time.

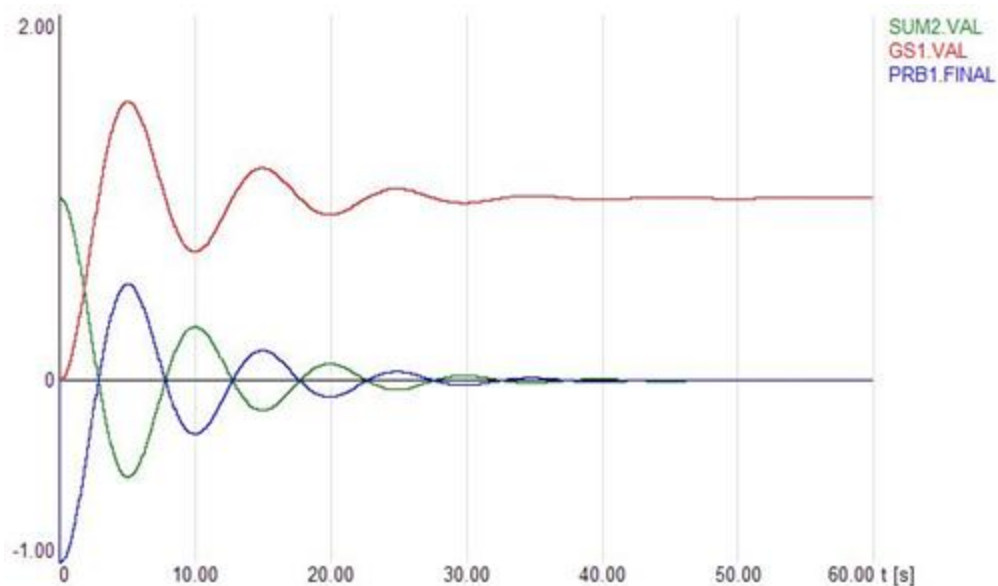


Figure 3. Simulation results

DigViewSel1	
PRB1.IAE	PRB1.ISE
5.44	2.32
PRB1.ITAE	PRB1.ITSE
43.63	8.33
PRB1.FINAL	
-773.45u	

Figure 4. Simulation results-analysis results of PRB1

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References

CTRL TR Probe

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

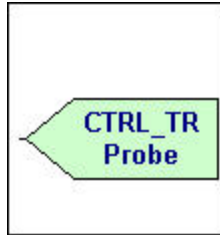


Figure 1. Component Symbol.

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Description

This is an ECM component for TR analysis, finding various overshoot and time response characteristics based on a specified target value. These outputs are updated continuously during simulation. The overshoot is calculated as a steady-state error during DC simulation. All other outputs are 0 for AC and DC. The main application for this component is control system design, for all time response criteria related to a setpoint.

Unlike the CTRL ERR Probe, the SETPOINT for this probe may not vary during simulation. ZERO is determined as the input signal value at the start of monitoring, and all times are output with respect to this monitoring start time.

The dead time is calculated as the earliest time at which the input lies outside the band $\text{ZERO} \pm \text{TOLZERO}$. The delay time is the earliest time at which the signal reaches 50% of the difference between ZERO and SETPOINT. The rise time is measured between 10% and 90%, of the difference between ZERO and SETPOINT. The settling time is calculated as the latest time at which the input lies outside the band $\text{SETPOINT} \pm \text{TOLERANCE}$.

For applications based on the actual peak, rather than a specified target value, use the PULSE Probe instead of the CTRL TR Probe. Also, note that the PULSE Probe's T1090 is defined differently than the CTRL TR Probe's TRISE.

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Mathematical Description

The outputs of the CTRL TR Probe model are calculated as following:

$$\text{err} = \text{input} - \text{setpoint}$$

$$\text{overshoot} = \frac{100 \cdot \text{err}}{\text{setpoint}}$$

where err is the difference between the input signal and the setpoint.

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Netlist Syntax

```
UMODEL CTRL_TR_Probe ?InstanceName(@InstanceName):(@Refbase@)(ID)) ( INPUT:=
@INPUT, SETPOINT:= @SETPOINT, TOLERANCE:= @TOLERANCE, TOLZERO:=
@TOLZERO, TSTART:= @TSTART, TSTOP:= @TSTOP) SRC: DB(Lib:-
:=@ModelLibraryName);
```

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
SETPOINT	Setpoint or target.	real	1
TOLERANCE	Bandwidth or tolerance on the setpoint.	real	0.1
TOLZERO	Bandwidth or tolerance on 'zero'.	real	20 [m]
TSTART	Time to start monitoring.	real	0 [s]
TSTOP	Time to stop monitoring.	real	TEND [s]

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Input/Output Quantities

Table 2

Name	Description	Direction	Data Type
OVERSHOOT	Maximum overshoot. [%]	Output	real
TPEAK	Time of the maximum overshoot. [s]	Output	real
TSETTLE	Settling time, measured from Tstart. [s]	Output	real
TRISE	Rise time, 10% to 90%, measured from Tstart. [s]	Output	real
TDELAY	Delay time, to 50%, measured from Tstart. [s]	Output	real
TDEAD	Dead time at 'zero', measured from Tstart. [s]	Output	real
INPUT	Input signal.	Input	real

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Example

Figure 2 shows application of the CTRL_TR Probe model. The parameters of the system are listed in Table 3. The simulation results are shown in Figure 3, and the analysis results of PRB1 are shown in Figure 4.



Figure 2. Application example of the CTRL_TR Probe model

Table 3

Component	Parameter	Value
Step Function STEP1	T0	0 [s]
	TS	0* [s]
	AMPL	1
	Y0	0

S-Transfer Function GS1	N	0
	D	2
	B[0]	900
	A[0]	900
	A[1]	12
	A[2]	1
	TS	0* [s]
CTRL_TR Probe PRB1	SETPOINT	1
	TOLERANCE	0.1
	TOLZERO	20m
	TSTART	0 [s]
	TSTOP	TEND** [s]

* Simulation time step is used as the sample time.

** TEND is the end of the simulation time.

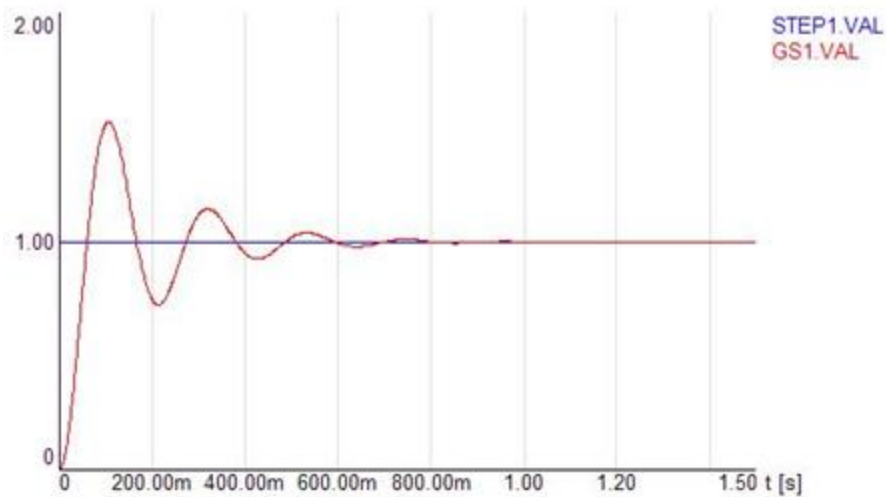


Figure 3. Simulation results

DigViewSel1	
PRB1.OVERSHOOT [%]	PRB1.TPEAK [s]
52.56	106.01m
PRB1.TSETTLE [s]	PRB1.TRISE [s]
347.01m	40.01m
PRB1.TDELAY [s]	PRB1.TDEAD [s]
37.16m	6.25m

Figure 4. Simulation results – analysis results of PRB1

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References

Event Triggered Probe

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2



Figure 1. Component Symbol.

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Description

The Event Triggered Probe component measures the value of a simulation quantity when user-defined conditions are met. This element can measure the simulation value quantity either once or every time the conditions are met. It can also force a time step when the conditions are met.

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Mathematical Description

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Netlist Syntax

```
UMODEL ETV ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) ( EVENT:= @EVENT,
INPUT:= @INPUT, OUT0:= @OUT0, EDGE:= @EDGE, SINGLE:= @SINGLE, BREAK:=
@BREAK) SRC: DB(Lib:=@ModelLibraryName);
```

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
EVENT	Conditional statement describing conditions for probe operation (e.g. $t > 2.5$)	boolean	0
OUT0	Initial output of probe	real	0

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Most recent value of the simulation quantity measured by the probe	Output	real
INPUT	Simulation quantity measured by probe	Input	real

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Example

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References

F Probe

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

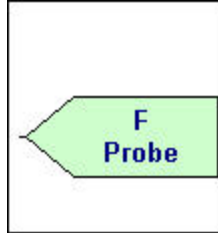


Figure 1. Component Symbol.

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Description

This is an ECM component that records the AC value occurring at a specified frequency. The output updates when that frequency is reached during the AC sweep. Output is 0 during DC and TR analysis. The main application is during automated design, to check whether a specified value has been achieved.

Because this block cannot set a solution frequency "break point" for AC, it will often have to interpolate the desired value. Usually this would be done on a logarithmic frequency scale, to match visual interpolation on a plot. Linear frequency interpolation gives a slightly different result.

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Assumptions and Limitations

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Mathematical Description

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Netlist Syntax

```
UMODEL F_Probe ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) ( INPUT:= @INPUT,
BASE:= @BASE, LOG:= @LOG) SRC: DB(Lib:=@ModelLibraryName) ;
```

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
Base	Frequency to capture the value.	real	0 [Hz]
LOG	Interpolate on logarithm of the frequency.	Bool	1

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Input/Output Quantities

Table 2

Name	Description	Direction	Data Type
VAL	Output value (complex) at the specified frequency.	Output	Complex
INPUT	Input signal.	Input	Complex

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Example

Figure 2 shows application of the F Probe model. The parameters of the system are listed in Table 3. The waveform of the input signal for AC Probe PRB1 is shown in Figure 3, and the analysis result of PRB1 and the F Probe PRB2 are shown in Figure 4.

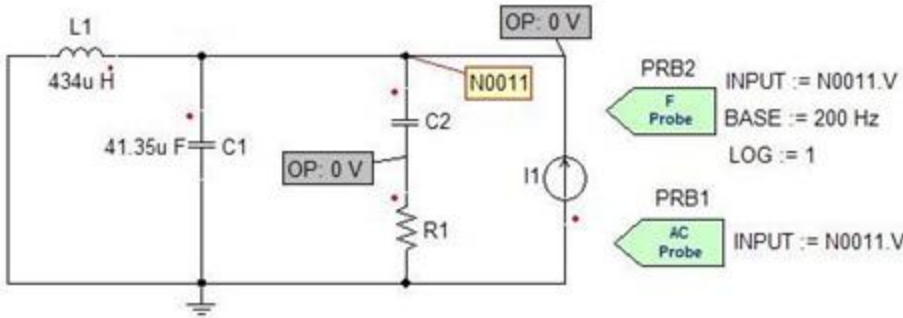


Figure 2. Application example of the F Probe model

Table 3

Component	Parameter	Value
Inductor L1	L	434u [H]
	I0	0 [A]
Capacitor C1	C	41.35u [F]
	V0	0 [V]
Capacitor C2	C	120u [F]
	V0	0 [V]
Resistor R1	R	1.6 [Ohm]
Current Source I1	IS	0.1 [A]
F Probe PRB2	BASE	200 [Hz]
	LOG	1

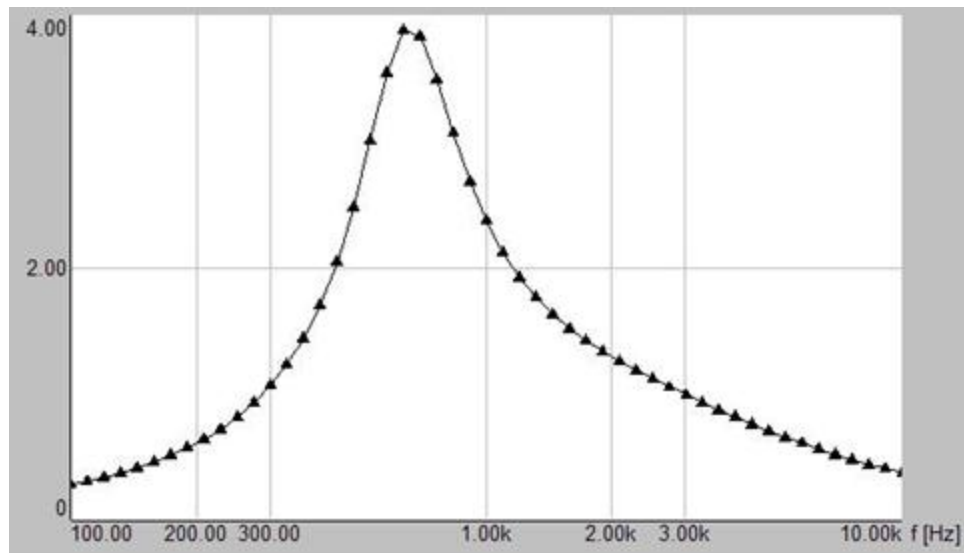


Figure 3. Simulation results-voltage of node N0011 in frequency domain

DigViewSel1	
PRB2.VAL (r...	PRB2.VAL (i...
13.0553m	611.0728m
PRB1.MIN (r...	PRB1.MAX (r...
280.36m	3.89
PRB1.FRQM...	PRB1.FRQM...
100.00	630.96
PRB1.RMS (...)	
11.83	

Figure 4. Simulation results-analysis results of PRB1 and PRB2

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References

FFT Probe

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

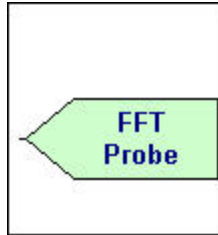


Figure 1. Component Symbol.

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Description

This is a Block Diagram component that performs a mixed-radix FFT on the sheet, where the number of sample points (N) need not be a factor of 2. Several harmonic distortion indices are provided. This block sets the scanning frequency and sample time automatically, from the user's input fundamental frequency and highest harmonic order to be computed. The FFT will be computed over one period of the fundamental.

Results from the FFT Probe may be checked against various IEEE and IEC harmonic standard limits, using the Mathematical Automation interface. The types of checks that may be performed are shown below.

Table 1

Standard	Normalize?	Notes
IEEE 519 Current	Yes	Requires system short-circuit ratio.
IEEE 519 Voltage	Yes	Requires bus kV at point of common coupling.
IEC 1000-3-2 A	No	Equipment ≤ 16 A, and not in class B, C, or D.
IEC 1000-3-2 B	No	Single-phase, portable power tools.
IEC 1000-3-2 C	No	Lighting except incandescent dimmers, requires power factor.
IEC 1000-3-2 D	No	Single-phase, < 600 W, PC/TV/-monitor, requires power level.
IEC 1000-3-4 Eq.	Yes	Three-phase, > 16 A, requires short-circuit ratio.
IEC 1000-3-4 Inst.	Yes	Three-phase for the whole installation.

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Assumptions and Limitations

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Mathematical Description

The FFT will be computed over one period of the fundamental.

$$N = 2(\text{ORDER} + 1)$$

$$\text{FSCAN} = \frac{\text{FUND}}{N}$$

$$\text{TS} = \frac{1}{\text{FSCAN}}$$

Where FUND is the fundamental frequency; FSCAN is the sampling frequency and TS is the block sample time; and ORDER is the highest harmonic order to compute. There will be an error if TS is less than HMIN. Note that according to Shannon Sampling Theory, FSCAN should always be at least twice the frequency of the highest harmonic content.

It is necessary to factor N by prime numbers. If the user input requires prime factors other than 2, 3, 5, and 7, the block will automatically increase ORDER to achieve an efficient value of N. An information message appears when the block does this.

Sampling begins when the DELAY time has passed, and the FFT is calculated when one period of N samples has been collected. Each sample will be at a time determined by TS, within the tolerance of HMIN. Outputs are provided after the first FFT has been calculated. If the TYPE is 1, the FFT will be re-calculated and the outputs updated after each period.

$$\begin{aligned} \text{RMS}_{DC} &= A0 \\ \text{RMS}_1 &= \frac{A1}{\sqrt{2}} \\ \text{RMS}_{AC} &= \sqrt{\sum_{h=1}^{\text{ORDER}} \text{RMS}_h^2} \\ \text{THD} &= 100 \cdot \frac{\sqrt{\text{RMS}_{AC}^2 - \text{RMS}_1^2}}{\text{RMS}_1} \\ \text{RIPPLE} &= 100 \cdot \frac{\text{RMS}_{AC}}{\text{RMS}_{DC}} \\ \text{KFACT} &= \frac{\sum_{h=1}^{\text{ORDER}} h^2 \cdot \text{RMS}_h^2}{\sum_{h=1}^{\text{ORDER}} \text{RMS}_h^2} \end{aligned}$$

For telephone interference metrics, a lookup table of standard weighting factors (wh) is employed for the summation of harmonics.

$$\begin{aligned} \text{TIF} &= \frac{\sqrt{\sum_{h=1}^{\text{ORDER}} \text{RMS}_h^2}}{\text{RMS}_{AC}} \\ \text{IT} &= \text{TIF} \cdot \text{RMS}_{AC} \\ C_h &= \frac{W_h}{5 \cdot f_h} = \frac{W_h}{5 \cdot h \cdot \text{FUND}} \\ \text{CMW1} &= \frac{\sqrt{\sum_{h=1}^{\text{ORDER}} C_h \cdot \text{RMS}_h^2}}{\text{RMS}_{AC}} \\ \text{CIT} &= \text{CMW1} \cdot \text{RMS}_{AC} \end{aligned}$$

The frequency cutoff parameter, FCUT, is a redundant way to specify ORDER. Internally, the block will set ORDER so that the highest calculated frequency is no more than FCUT. This input was retained mainly for backward compatibility. If the Amplitude cutoff AFLT is specified, harmonic outputs less than that percentage of the fundamental will be suppressed.

If NORMAL is 1, the individual output magnitudes will be in percentage of the fundamental. The normalizing magnitude will always be A1, even if one of the harmonics has a higher magnitude. The RMS outputs are never normalized by A1.

Outputs are 0 during DC and AC analysis.

Several window options are provided, but the Rectangular window (WINDOW=0) should always be used for electrical power systems, or any time the fundamental frequency is well established. The other window types find application when the fundamental frequency is not known, and significant leakage would otherwise occur in the frequency domain results.

Because this new block has more flexibility in choosing the number of samples, the results may be more precise and with fewer time steps than in previous versions. However, the results are still vulnerable to aliasing if the signal contains harmonic content above the input ORDER. Also, the accuracies partly depend on HMIN, because that limits the deviation from all target FFT sample times.

In situations with significant high-frequency content, the TR Probe and the PWR Probe offer measurements of the fundamental component that are more resistant to aliasing, and these may give better results than the FFT Probe.

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Netlist Syntax

```
UMODEL FFT_Probe ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) ( TS:= @TS,
INPUT:= @INPUT, TYPE:= @TYPE, WINDOW:= @WINDOW, NORMAL:= @NORMAL,
FUND:= @FUND, ORDER:= @ORDER, DELAY:= @DELAY, FCUT:= @FCUT, AFLT:=
@AFLT) SRC: DB(Lib:=@ModelLibraryName) ;
```

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
TS	Sample time.	real	0 [s]
INPUT	Input signal.	real	0
TYPE	Type (0=Fixed, 1=Repeating).	Integer	0
WINDOW	Window (0=Rect, 1=Tri, 2=Von Hann, 3=Hamming, 4=Blackmann, 5=Lanczos, 6=W-Weber).	Integer	0
FUND	Defined fundamental frequency. You may use a variable or expression for the fundamental frequency, but the variable/expression is used only when the simulation starts and cannot change during simulation.	real	60 [Hz]
ORDER	Highest harmonic order to compute (≤ 100).	Integer	7
DELAY	Time delay before the first FFT starts.	real	0 [s]
FCUT	Frequency cutoff (0 to ignore).	real	0 [Hz]
AFLT	Amplitude cutoff (0 to ignore).	real	0 [%]
NORMAL	Normalize amplitudes to the fundamental component, in % (1=Yes).	Integer	0

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Input/Output Quantities**Table 3**

Name	Description	Direction	Data Type
RMSDC	RMS value of the DC component.	Output	real
RMS1	RMS value of the fundamental component.	Output	real
RMSAC	RMS value of all the AC components.	Output	real
THD	Total Harmonic Distortion*	Output	real
RIPPLE	Ripple factor. [%]	Output	real
KFACT	K-factor for the transformer loss de-rating.	Output	real
TIF	Telephone influence factor (up to the 83rd harmonic).	Output	real
IT	IT (or VT) product (up to the 83rd harmonic).	Output	real
CMWI	C-message influence factor (up to the 83rd harmonic).	Output	real
CIT	C-message IT product.	Output	real
A0	DC amplitude.	Output	real
A1	Fundamental amplitude.	Output	real
A2	2nd harmonic amplitude.	Output	real
A3	3rd harmonic amplitude.	Output	real
A4	4th harmonic amplitude.	Output	real
A5	5th harmonic amplitude.	Output	real
A6	6th harmonic amplitude.	Output	real
A7	7th harmonic amplitude.	Output	real
A8	8th harmonic amplitude.	Output	real
A9	9th harmonic amplitude.	Output	real
A10	10th harmonic amplitude.	Output	real
A11	11th harmonic amplitude.	Output	real
A12	12th harmonic amplitude.	Output	real
A13	13th harmonic amplitude.	Output	real

P0	DC phase	Output	real
P1	Fundamental phase	Output	real
P2	2nd harmonic phase	Output	real
P3	3rd harmonic phase	Output	real
P4	4th harmonic phase	Output	real
P5	5th harmonic phase	Output	real
P6	6th harmonic phase	Output	real
P7	7th harmonic phase	Output	real
P8	8th harmonic phase	Output	real
P9	9th harmonic phase	Output	real
P10	10th harmonic phase	Output	real
P11	11th harmonic phase	Output	real
P12	12th harmonic phase	Output	real
P13	13th harmonic phase	Output	real
AVEC [0...100]	Amplitude vector	Output	real
PVEC [0...100]	Phase vector	Output	real
INPUT	Input signal	Input	real

*If TYPE is 0, the THD calculation from the FFT probe calculates the THD value only once through the entire simulation based on user-provided base frequency. If TYPE is 1, the FFT probe recalculates the THD value after each period. The calculation accuracy is dependent on the accuracy of the user-provided base frequency. So the THD calculation from FFT probe can be used in a simple periodical low harmonics signal with certain base frequency.

The THD calculation from the TR probe takes care of the data dynamically, and the oscillation amplitude is smaller during the time, based on the data accumulated. The THD calculation from the TR probe can be better when the signal is more complicated and the base frequency needs to be estimated.

Note: Amplitudes A0 through A13 could be in % if the NORMAL is 1.

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Example

Figure 2 shows application of the FFT Probe model. The parameters of the system are listed in Table 3. The simulation results are shown in Figure 3. Note that the highest harmonic order is set to 3 in PRB1, the harmonic component Ealias in the composite signal is not detected by PRB1.

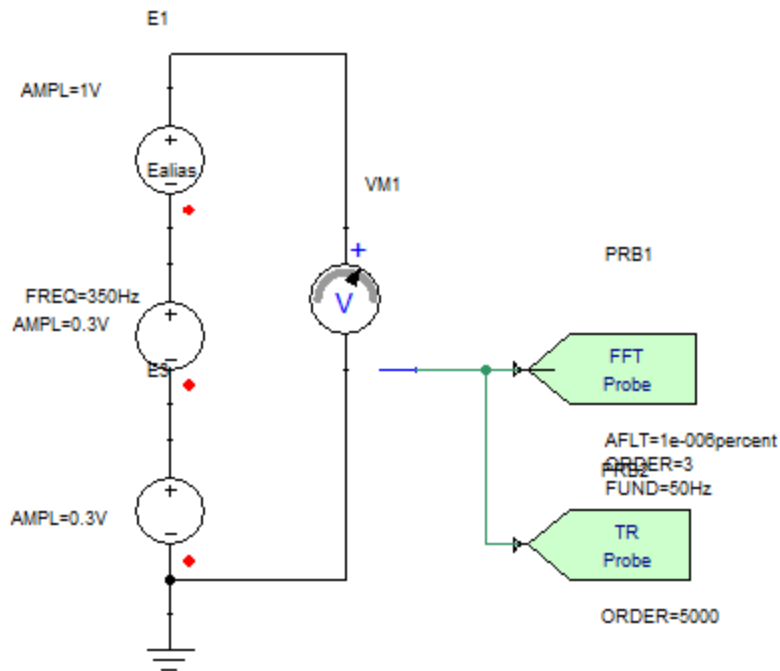


Figure 2. Application example of the FFT Probe model

Table 3

Component	Parameter	Value
Inductor L1	L	434u [H]
	I0	0 [A]
Capacitor C1	C	41.35u [F]
	V0	0 [V]
Capacitor C2	C	120u [F]
	V0	0 [V]
Resistor R1	R	1.6 [Ohm]
Current Source I1	IS	0.1 [A]
F Probe PRB2	BASE	200 [Hz]
	LOG	1

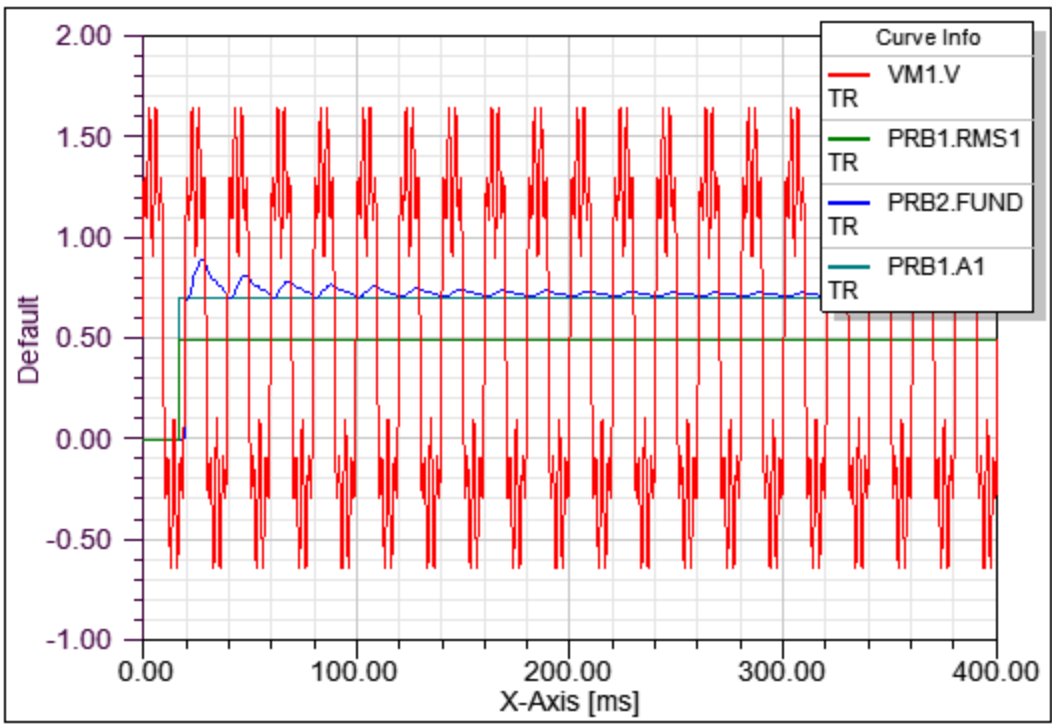


Figure 3. Simulation results-voltage of node N0011 in frequency domain

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References

Version 6 Block Mapping

Version 6 provided a set of blocks for signal characteristics, which correspond to the new Version 8 blocks as follows. The new blocks are located under Signal Characteristics, except where noted otherwise.

Version 6 Block	Version 7 Block- /Output	Version 7 Notes
Max within interval	PULSE or TR / MAX	
Min within interval	PULSE or TR / MIN	
Period determination	Event triggered probe	
Even triggered value	Event triggered probe	
Event triggered calculation	Event triggered probe	
Rise time	PULSE / T1090	
Fall time	PULSE / T9010	Does not need a final value or derivative, works for negative signals.
Pulse duration	PULSE / T5050	Does not need a final value or derivative, works for negative signals.
Sensitivity	Sensitivity	Not changed, under Blocks/Math
Dead time	CTRL TR / TDEAD	
Settling time	CTRL TR / TSETTLE	
Rise time (for controls)	CTRL TR / TRISE	
Overshoot	CTRL TR / OVERSHOOT	Does not support NFACT
Time of max overshoot	CTRL TR / TPEAK	
Integral absolute error	CTRL ERR / IAE	Does not need a derivative input

Integral squared error	CTRL ERR / ISE	Does not need a derivative input
Integral time abs. error	CTRL ERR / ITAE	Does not need a derivative input
Integral time sqr. error	CTRL ERR / ITSE	Does not need a derivative input
Mean	TR Probe / MEAN	
RMS	TR PProbe / RMS	
Sliding Mean	Moving Average / MEAN	Under Blocks/Math
Sliding RMS	Moving Average / RMS	Under Blocks/Math
Power	PWR Probe / POWERE	
Energy	PWR Probe / ENERGYE	
FFT	FFT Probe	See details under FFT Parameter Mapping.

FFT Parameter Mapping

The version 6 FFT block parameters map to the FFT Probe parameters as follows.

V6 Wizard Description	V6 SML Name	FFT Probe Translation
Min	TR Probe / MIN	
Type	TYPE	TYPE
Delay	TDELAY	DELAY
Cut-off Frequency	FCUT	FCUT
Amplitude Filter	AMPLFLT	AFLT
Window Type	WINDOW	WINDOW
Fundamental Frequency	TPERIO:=1/FUND	FUND
Input Signal	INPUT	INPUT
Scanning Frequency	TS:=1/FSCAN	calculated automatically
(no edit allowed)	NOUT:=24	ORDER:=NOUT (probably)
(not in v6)	(n/a)	NORMAL:=0 (by default)

The FFT block in version 6 provided more individual component magnitude and phase outputs. If these are need for version 7, use the Mathematical Automation script interface.

References

1. FFTW Home Page, www.fftw.org
2. IEEE Power Engineering Society, "Tutorial on Harmonics Modeling and Simulation", Chapter 2, 1998, also at http://enr.calvin.edu/PRibeiro_WEBPAGE/IEEE/ieee_cd/contents.htm.
3. Ward Jewell and Daniel J. Ward, "Single Phase Harmonic Limits", PSERC EMI, Power Quality, and Safety Workshop, April 2002, also at www.pserc.wisc.edu/ecow/get/publication/2002public/atlantaworkshoppaper.pdf.
4. Thomas S. Key and Jih-Sheng Lai, "IEEE and International Harmonic Standards Impact on Power Electronic Equipment Design", IEEE IECON, New Orleans, November 1998.
5. IEEE Working Group on Nonsinusoidal Situations, "Practical Definitions for Powers in Systems with Nonsinusoidal Waveforms and Unbalanced Loads: A Discussion", IEEE Transactions on Power Delivery, vol. 11, no. 1, pp. 79-101, January 1996.
6. N. R. Lomb, "Least-Squares Frequency Analysis of Unequally Spaced Data", Astrophysics and Space Science, vol. 39, pp. 447-462, 1976, also available at http://adsabs.harvard.edu/abstract_service.html.
7. G. L. Bretthorst, Bayesian Spectrum Analysis and Parameter Estimation, Springer-Verlag, 1988, also at <http://bayes.wustl.edu/glb/bib.html>.

PULSE Probe

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

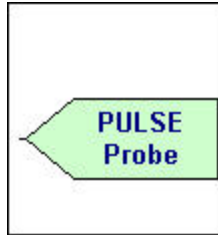


Figure 1. Component Symbol.

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Description

This is an ECM component for TR analysis, finding various rise time, fall time, and pulse width values. These outputs are updated continuously during simulation. Outputs are 0 for DC and AC analysis. The main application for this component is for measuring rise time of a pulse, by one of the standard methods.

For control applications, the defined response times are based on a specified target value, rather than the actual peak. For these applications, use the CTRL TR Probe instead of the PULSE Probe. Note that per IEEE and other standards, the time outputs of the PULSE Probe are defined differently than for the CTRL TR Probe. For example, in the CTRL Probe, TRISE is the time between 10% and 90% of the target value. The PULSE Probe multiplies that value by 1.25 to report T1090, which in effect, extrapolates the time to "virtual zero" and "virtual peak".

The prospective peak value and the signal derivative are not required inputs, as they were for version 6. The PULSE Probe scans its input to determine the minimal and maximal values, and then it compares these to the starting value. Whichever one is furthest from the initial value will be used as the peak. If the other one occurs later than this peak, the algorithm scans back from the peak to determine the first point on the front. The resulting values are output as MIN and MAX, occurring at TMIN and TMAX. These might differ from the actual minimum and maximum, but they clearly show the basis of the calculated pulse times.

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Mathematical Description

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Netlist Syntax

```
UMODEL PULSE_Probe ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) ( INPUT:=
@INPUT, TSTART:= @TSTART, TSTOP:= @TSTOP) SRC: DB(Lib:=@ModelLibraryName) ;
```

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
INPUT	Input signal.	real	0
TSTART	Time to start monitoring.	real	0 [s]
TSTOP	Time to stop monitoring.	real	TEND* [s]

* TEND is the end of the simulation time.

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Input/Output Quantities

Table 2

Name	Description	Direction	Data Type
MIN	Minimum value.	Output	real
MAX	Maximum value.	Output	real
TMIN	Time of the minimum value.	Output	real
TMAX	Time of the maximum value.	Output	real
T1090	Front time (10-90).	Output	real
T3090	Front time (30-90).	Output	real
TFALL	Fall time (90-10).	Output	real
WIDTH	Pulse width (50-50).	Output	real
TTAIL	Tail time (Pk-50).	Output	real

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Example

Figure 2 shows application of the Pulse Probe model. The parameters of the system are listed in Table 3. The simulation results are shown in Figure 3.

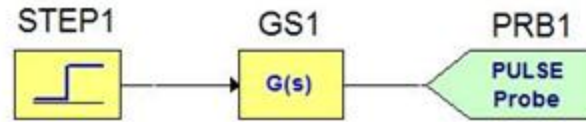


Figure 2. Application example of the Pulse Probe model

Table 3

Component	Parameter	Value
Step Function STEP1	AMPL	1
	T0	0
	TS	0*
	Y0	0
S-Transfer Function	N	0
	D	2
	B[0]	900
	A[0]	900
	A[1]	12
	A[2]	1
	SUM0	0
	TS	0*
Pulse Probe PRB1	TSTART	0
	TSTOP	TEND

* TS is set to the simulation time step.

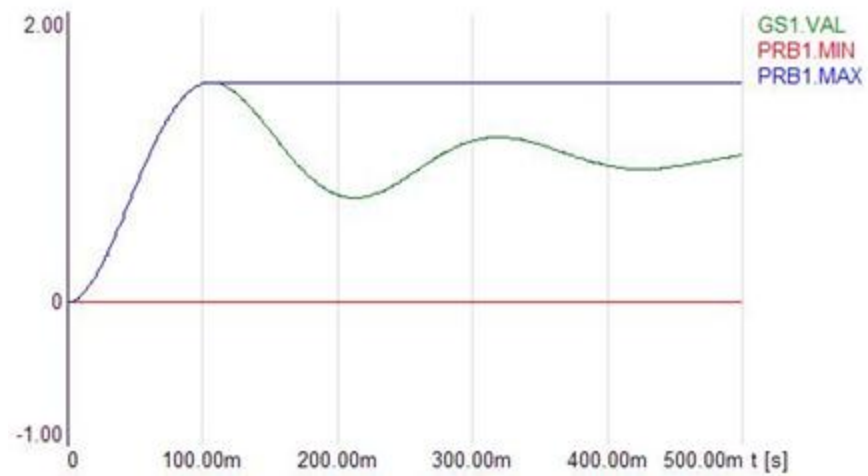


Figure 3. Simulation results

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References

PWR Probe

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

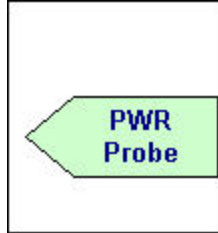


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Description

This is an ECM component for TR analysis, finding the power and energy for pairs of voltage and current inputs. These outputs are updated continuously during TR simulation. The instantaneous power outputs are $V * I$ for DC analysis. All other outputs for DC and AC analysis will be zero.

Using the model's **Component Dialog**, the parameter NPHASES must first be set to specify the desired number of VI input pairs. Thus, for a three-phase, three-wire system, set NPHASES = 3 and define the three input voltages (V[0], V[1], V[2]) and currents (I[0], I[1], I[2]) with respect to ground (or another common reference point). For a three-phase, four-wire system, set NPHASES = 4 and define each of the three phase voltages and currents, plus the neutral voltage and current, with respect to ground. You may specify these current and voltage inputs either by pin, or by name. When using pins, they should be wired to output pins of voltmeters and ammeters.

Similarly, NPHASES also specifies the number phase-related outputs. For example if NPHASE = 3, the output wave forms reside in POWER[0], POWER[1], and POWER[2]; ENERGY[0], ENERGY[1], ENERGY[2], etc.

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Mathematical Description

The probe always calculates the instantaneous power and energy for each voltage and current pair, and for the system total as the sum of the phases.

$$\begin{aligned}p_i &= v_i i_i \\e_i &= \int_0^t v_i i_i d\lambda \\p_e &= \sum_{i=1}^N p_i \\e_e &= \sum_{i=1}^N e_i\end{aligned}$$

If the fundamental frequency input is greater than zero, then many more outputs are calculated for average power, apparent power, reactive power, power factor, distortion power, etc. The RMS voltage and current is calculated for each phase, as moving averages over the fundamental period, T. For a specific phase i:

$$\begin{aligned}T &= 1 / FREQ \\P_i &= \frac{1}{T} \int_0^T v_i i_i dt \\S_i &= V_{i-rms} I_{i-rms} \\PF_i &= P_i / S_i\end{aligned}$$

The fundamental RMS magnitude and angle are also calculated by either Fourier Transform or Least Squares, discussed below. Even in the presence of distortion, the fundamental apparent power and power factor may be useful for designing or evaluating reactive compensation. RMS magnitudes of each phase i are denoted as V_i and I_i :

$$\begin{aligned}\theta_i &= \angle V_{i-1} - \angle I_{i-1} \\ P_{i-1} &= V_{i-1} I_{i-1} \cos \theta_i \\ Q_{i-1} &= V_{i-1} I_{i-1} \sin \theta_i \\ S_{i-1} &= V_{i-1} I_{i-1} \\ PF_{i-1} &= \cos \theta_{i-1}\end{aligned}$$

Given the total and fundamental RMS quantities, the harmonic RMS values, distortion power, and harmonic power are calculated for each phase. However, these distortion outputs will include sub-harmonics and inter-harmonics, not just the integer order harmonics.

$$\begin{aligned}V_{i-h} &= \sqrt{V_i^2 - V_{i-1}^2} \\ I_{i-h} &= \sqrt{I_i^2 - I_{i-1}^2} \\ DP_i &= \sqrt{(V_{i-h} I_{i-1})^2 + (V_{i-1} I_{i-h})^2} \\ HP_i &= V_{i-h} I_{i-h} \\ S_i^2 &\equiv S_{i-1}^2 + DP_i^2 + HP_i^2\end{aligned}$$

For multi-phase measurements, the total average power, as well as the fundamental real and reactive powers may be summed directly:

$$\begin{aligned}P_e &= \sum_{i=1}^N P_i \\ P_{e-1} &= \sum_{i=1}^N P_{i-1} \\ Q_{e-1} &= \sum_{i=1}^N Q_{i-1} \\ S_{e-1} &= \sqrt{P_{e-1}^2 + Q_{e-1}^2} \\ PF_{e-1} &= P_{e-1} / S_{e-1}\end{aligned}$$

But for the apparent power, distortion power, and harmonic power, the "system equivalent" voltage and current are defined as:

$$V_e = \sqrt{\frac{1}{n} \sum_{i=1}^n V_i^2}$$

$$I_e = \sqrt{\frac{1}{n} \sum_{i=1}^n I_i^2}$$

$$V_{e-1} = \sqrt{\frac{1}{n} \sum_{i=1}^n V_{i-1}^2}$$

$$I_{e-1} = \sqrt{\frac{1}{n} \sum_{i=1}^n I_{i-1}^2}$$

$$V_{e-k} = \sqrt{V_e^2 - V_{e-1}^2}$$

$$I_{e-k} = \sqrt{I_e^2 - I_{e-1}^2}$$

Finally, Se, DPe, HPe, and PFe are calculated from the system equivalent voltage and current, as if these were balanced single phases, and then multiplied by NPHASES.

DFT Calculation of the Fundamental

In this case the component will perform a Discrete Fourier Transform (not an FFT) at one frequency. The Probe will also force time steps to occur at $2 * (\text{ORDER} + 1)$ equally spaced points in each cycle.

$$\omega = 2\pi \text{FREQ}$$

$$T = T_{\text{STOP}} - T_{\text{START}}$$

$$a_1 = \frac{2}{T} \sum x_i \cos(\omega t_i) \Delta_i$$

$$b_1 = \frac{2}{T} \sum x_i \sin(\omega t_i) \Delta_i$$

$$RMS_1 = \sqrt{(a_1^2 + b_1^2) / 2}$$

$$\phi_1 = \tan^{-1}(b_1 / a_1)$$

The summations for a1 and b1 are performed by trapezoidal integration.

The DFT method works well if there are no significant harmonics, or, if the harmonics are of relatively low order. If there is a significant high-frequency content, the DFT results may become suspect, or may require too many time steps. The default method is a DFT of order 11, which would allow for harmonics up to the 22nd order without aliasing the fundamental component (only the fundamental component of the DFT is actually used.)

Least Squares Calculation of the Fundamental

In situations with PWM switching, irregular transients, or very large circuits, the Least Squares method may perform better than the DFT method. This method is very resistant to aliasing, because the sampling rate need not be constant. In effect, this bypasses the Nyquist criteria for the average sampling rate of a DFT.

The Least Squares estimate assumes that the underlying signal is a single-frequency sinusoid, plus Gaussian noise. The parameters a_1 and b_1 are chosen to minimize the RMS of the errors over all samples in a fundamental cycle.

$$v = a_1 \cos \omega t + b_1 \sin \omega t + err$$

The drawback of Least Squares is that it's based on Bayesian probability, and compared to "known" DFT results, a small but noticeable error would be observed until the number of samples becomes very large. In this application, the Probe generates more samples between time steps by linear interpolation, but it does not actually force time steps at those points. The justification for this is that Twin Builder should have generated these extra time steps, if the system response was actually deviating from linear interpolation.

When using Least Squares, a bare minimum ORDER=3 should be set, and ORDER=1000 or higher is preferable.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
NPHASES	Number of conductors.	real	1
V	Input voltage signal(s).	real	0 [V]
I	Input current signal(s).	real	0 [A]
TSTART	Time to start monitoring.	real	0 [s]
TSTOP	Time to stop monitoring.	real	TEND[s]
FREQ	Expected fundamental frequency (0 to skip).	real	0 [Hz]
METHOD	0=DFT, 1=Least Squares to calculate fundamental RMS	Integer	0

ORDER	Harmonic order of DFT, or N for LSQ.	Integer	11

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Input/Output Quantities

Table 2

Name	Description	Direction	Data Type
MIN	Minimum value.	Output	real
MAX	Maximum value.	Output	real
TMIN	Time of the minimum value.	Output	real
POWER	Instantaneous phase power.	Output	real
ENERGY	Total phase energy.	Output	real
POWERE	System instantaneous power.	Output	real
ENERGYE	System total energy.	Output	real
P	Average power -- phase.	Output	real
S	Apparent power -- phase.	Output	real
PF	Power factor -- phase.	Output	real
DP	Distortion power -- phase.	Output	real
HP	Harmonic power -- phase.	Output	real
S1	Fundamental apparent power -- phase.	Output	real
P1	Fundamental average power - phase.	Output	real
Q1	Fundamental reactive power - phase.	Output	real
PF1	Fundamental power factor -- phase.	Output	real
VE	System equivalent RMS voltage.	Output	real
VE1	System equivalent fundamental RMS voltage.	Output	real
IE	System equivalent RMS current.	Output	real
IE1	System equivalent fundamental RMS current.	Output	real
SE	Apparent power -- system equivalent.	Output	real
PE	Average power -- system equivalent.	Output	real
PFE	Power factor -- system equivalent.	Output	real
DPE	Distortion power -- system equivalent.	Output	real
HPE	Harmonic power -- system equivalent.	Output	real

SE1	Fundamental apparent power -- system equivalent.	Output	real
PE1	Fundamental average power - - system equivalent.	Output	real
QE1	Fundamental reactive power - system equivalent.	Output	real
PFE1	Fundamental power factor - system equivalent.	Output	real

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Example

Figure 2 shows application of the Power Probe model. The parameters of the system are listed in Table 3. The simulation results are shown in Figure 3.

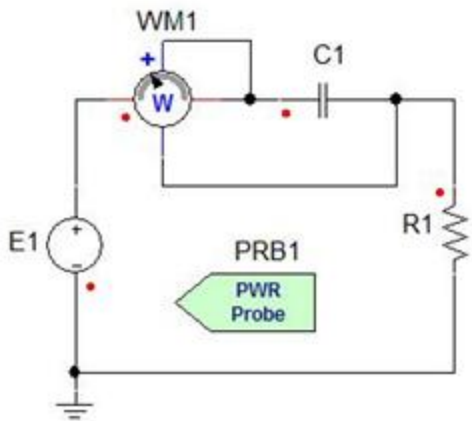


Figure 2. Application example of the Power Probe model

Table 3

Component	Parameter	Value
Voltage Source E1	EMF	100 [V]
Resistor R1	R	1k [Ohm]
Capacitor C1	C	10u [F]
	V0	0 [V]

Power Probe PRB1	NPHASES	1
	V[0]	C1.V
	I[0]	C1.I
	TSTART	0
	TSTOP	TEND
	FREQ	0
	METHOD	0
	ORDER	11

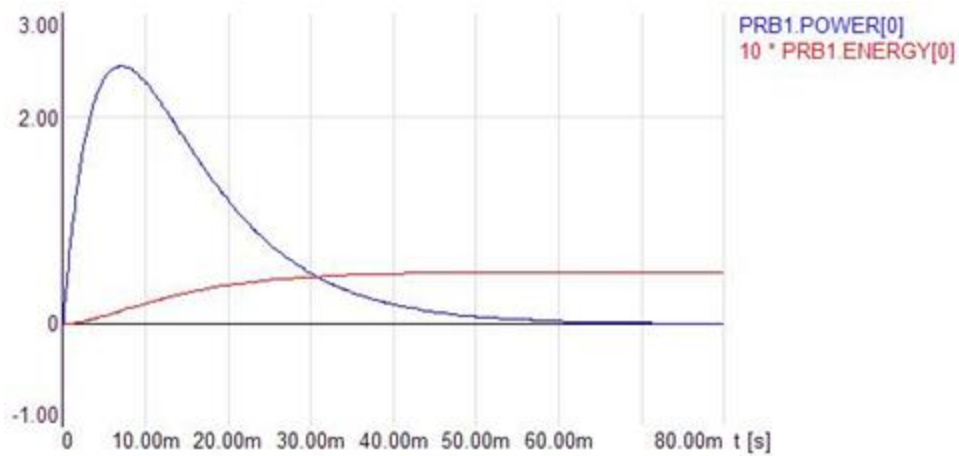


Figure 3. Simulation results

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References

T Probe

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

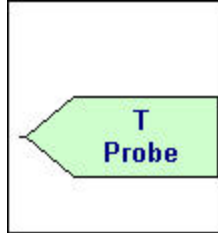


Figure 1. Component Symbol.

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- [Mathematical Description](#)
- [Netlist Syntax](#)
- [Parameters](#)
- [Input/Output Quantities](#)
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Description

This ECM component records the value occurring at a specified time. The output value is updated when the BASE time has been reached. Depending on user input, the block may force a time step at the BASE time, or use linear interpolation. The output is 0 for AC analysis, but it will be equal to the solved value for DC analysis. The main application for this component is for automated design to meet specified response at a certain time, or for a consistent voltage or current stress evaluation.

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Assumptions and Limitations

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Mathematical Description

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Netlist Syntax

```
UMODEL T_Probe ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) ( INPUT:= @INPUT,  
BASE:= @BASE, BREAK:= @BREAK) SRC: DB(Lib:=@ModelLibraryName) ;
```

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
Base	Time to capture the value.	real	0 [s]
BREAK	Force a time step at the capture time.	real	1

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Input/Output Quantities

Table 2

Name	Description	Direction	Data Type
VAL	Output magnitude at the specified time.	Output	real
INPUT	Input signal.	Input	real

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Example

Figure 2 shows application of the T Probe model. The parameters of the system are listed in Table 3. The simulation results are shown in Figure 3. Note that with its parameter BREAK set to 1, the T Probe PRB1 forces the a step at 22ms which may not happen otherwise.

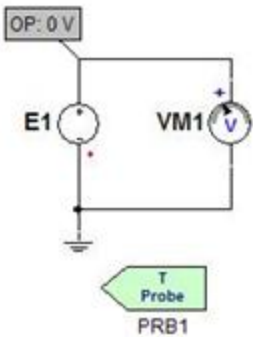


Figure 2. Application example of the T Probe model

Table 3

Component	Parameter	Value

Voltage Source (trapezoidal) E1	AMPL	1 [V]
	TDELAY	0 [s]
	OFF	0 [V]
	PHASE	0 [degree]
	TRISE	40m [s]
	TFALL	10m [s]
	PWIDTH	1 [s]
T Probe PRB1	BASE	22m [s]
	BREAK	1

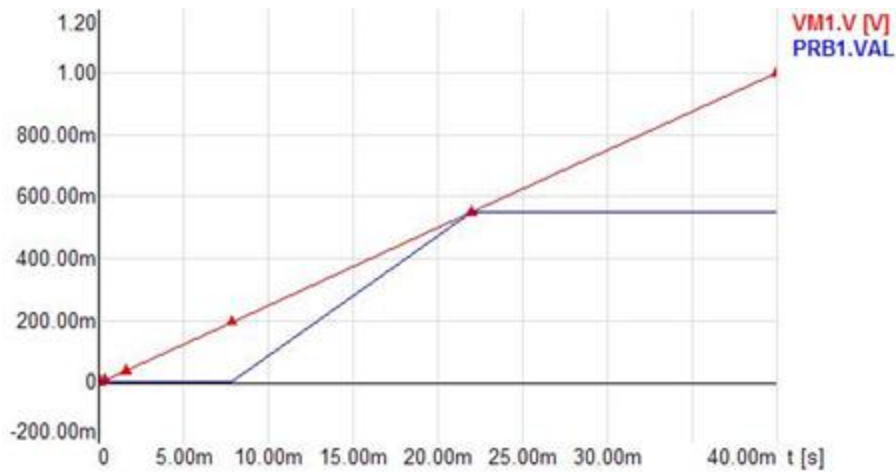


Figure 3. Simulation results

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References

TR Probe

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

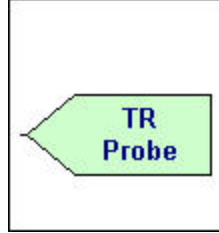


Figure 1. Component Symbol.

- Description
- Assumptions and Limitations
- Mathematical Description
- Netlist Syntax
- Parameters
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- Example
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Description

This ECM component records the minimum value, maximum value, their times of occurrence, and several integral characteristics within a specified time range between TSTART and TSTOP. During the specified time range, outputs are updated at each time step t , and all integral characteristics are calculated from TSTART to current time step t .

$$MEAN = \frac{1}{t - TSTART} \int_{TSTART}^t f(t) dt, \text{ when } TSTART \leq t \leq TSTOP$$

$$ABS = \frac{1}{t - TSTART} \int_{TSTART}^t |f(t)| dt, \text{ when } TSTART \leq t \leq TSTOP$$

$$PKPK = MAX - MIN$$

$$PKAVG = \left| \frac{MAX - MIN}{MEAN} \right|$$

$$INTEG = \int_{TSTART}^t f(t) dt, \text{ when } TSTART \leq t \leq TSTOP$$

$$RMS = \sqrt{\frac{1}{t-TSTART} \int_{TSTART}^t f^2(t)dt}, \text{ when } TSTART \leq t \leq TSTOP$$

$$FF = \frac{RMS}{ABS}$$

$$CF = \frac{\max(|MAX|, |MIN|)}{RMS}$$

$$RMS_{AC} = \sqrt{RMS^2 - MEAN^2}$$

$$RIPPLE = 100 \cdot \frac{RMS_{AC}}{MEAN}$$

The summations for INTEG are performed by trapezoidal integration.

The TR Probe can also calculate distortion, and the RMS magnitude at a specified fundamental frequency. In order to do this, FREQ must be specified as non-zero. The fundamental component RMS1 is calculated with a Discrete Fourier Transform. RMS1:

$$RMS_K = \sqrt{RMS_{AC}^2 - RMS_1^2}$$

$$THD = 100 \cdot \frac{RMS_K}{RMS_1}$$

The resulting distortion output includes all frequencies other than DC and the fundamental; it is not just the harmonic distortion. This feature can be useful when the system generates inter-harmonics or sub-harmonics.

All outputs are updated continuously during the simulation, except the FREQ-related updates do not begin until a full cycle of data has been collected at the fundamental frequency.

The outputs are all zero for AC analysis. For DC analysis, the minimum, maximum, mean, mean absolute, and RMS outputs are set to the solved value. The form factor and crest factor equal one. The other outputs are zero for DC analysis.

Note

The MEAN output in the TR Probe is different from the mean function listed in Range Function and Trace Characteristics due to different scenarios. MEAN output in the TR Probe calculates the average value of the variable over time, that is, the time integration of a variable divided by time. The mean function listed in Range Function and Trace Characteristics calculates the sum of plot points divided by the number of plot points.

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Assumptions and Limitations

When a TR probe is used to analyze values of quantities such as THD, RMS, and MEAN over a period of time, the output displays a dynamically updated plot instead of one absolute value for

each quantity. While the data from these outputs are correct, they are not meaningful as they are not per the standard definitions for these quantities. To obtain the expected standard plots for such quantities, use the corresponding math functions available in the *Report Dialog Box* in the main Twin Builder help.

See also *Defining Traces using Range Functions* and *Adding Trace Characteristics* in the main Twin Builder help.

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Mathematical Description

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Netlist Syntax

```
UMODEL TR_Probe ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) ( INPUT:=
@INPUT, TSTART:= @TSTART, TSTOP:= @TSTOP, FREQ:= @FREQ, METHOD:=
@METHOD, ORDER:= @ORDER) SRC: DB(Lib:=@ModelLibraryName) ;
```

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
TSTART	Time to start monitoring.	real	0 [s]
TSTOP	Time to stop monitoring.	real	T _{end} [s]
FREQ	Expected fundamental frequency (0 to skip).	real	0 [Hz]
ORDER	Harmonic order of DFT, or N for LSQ.	Integer	11

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Input/Output Quantities

Table 2

Name	Description	Direction	Data Type
INPUT	Input signal.	Input	real
FUND	RMS magnitude at the fundamental frequency.	Output	real
THD	Total Harmonic Distortion*	Output	real
MEAN	Average (DC) value.	Output	real

RMS	Total RMS value.	Output	real
RMSAC	RMS value of the AC components only.	Output	real
RIPPLE	Ripple factor.	Output	real
CF	Crest factor.	Output	real
FF	Form factor.	Output	real
ABS	Average of the absolute value.	Output	real
PKPK	Peak-to-peak value.	Output	real
PKAVG	Peak-to-average ratio.	Output	real
INTEG	Integral of the signal.	Output	real
MIN	Minimum value.	Output	real
TMIN	Time at which the minimum value occurred.	Output	real
MAX	Maximum value.	Output	real
TMAX	Time at which the maximum value occurred.	Output	real

*If TYPE is 0, the THD calculation from the FFT probe calculates the THD value only once through the entire simulation based on user-provided base frequency. If TYPE is 1, the FFT probe recalculates the THD value after each period. The calculation accuracy is dependent on the accuracy of the user-provided base frequency. So the THD calculation from FFT probe can be used in a simple periodical low harmonics signal with certain base frequency.

The THD calculation from the TR probe takes care of the data dynamically, and the oscillation amplitude is smaller during the time, based on the data accumulated. The THD calculation from the TR probe can be better when the signal is more complicated and the base frequency needs to be estimated.

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References

Modeling with States Components

Components that can be used to create state graphs appear in the *States* folder of the Basic Elements library. To use them, open the *States* folder, select a state or transition, drag the component onto the sheet and release the mouse button.

With Twin Builder's states library components, discontinuous processes can be modeled as event-oriented based on the Petri Net theory. The theoretical basis of the modeling is to divide a system into:

- significant states and
- events, or transfers from one state to the other

A process sequence can be considered as a sequence of states. The current state is called *active*. Switching the activity from states to their successor states is called an event. An event occurs only if all previous states are active, all following states are inactive and the transfer condition in the form of a logical expression is true. At the beginning of the simulation, one state must be defined as active.

The event occurs if

- all previous states are active (marked) and
- the transfer conditions are TRUE; if no transfer condition is specified, the default value FALSE is used.

The result of an event will be

- all previous states are deactivated and
- all successor states are activated

On entering a state, several arithmetic and logical instructions (actions) that influence the system behavior can be executed.

Note: You cannot use states in AC and DC simulations. To leave state components on the sheet, select the components and choose to deactivate the components. When you want to process a transient simulation, you can change this option.

[Creating State Graphs](#)

[Using Action in State Graphs](#)

[State Markers in State Graphs](#)

[Displaying the State of State Components](#)

[State Graph Components](#)

Using States Components

The states components are located in the *States* folder in the Basic Elements library. Select the folder, click the component name (transition or state), drag the component onto the sheet and release the mouse button. Within the dialogs you can define the transfer conditions (transition) and actions (states). A selected component can be rotated (R key) or flipped (F key).

Note: The Schematic editor does not test the pins during the routing and allows all connections. However, only reasonable state graphs lead to correct simulation results.

Using Actions in States Components

Actions can be defined for every state if the state is active. In the dialog for the State component, the available action types can be selected from a drop-down-list.

Actions in States

Table 1

Action	Description	Syntax in Value
CALC	The variable is calculated at each valid state calculation step and each transition.	<i>var1:=100*t</i>
STEP	The variable is calculated at each valid state calculation step.	<i>var2:=2*t</i>
CATI	The variable is calculated after the state graph at each valid simulation step and before the calculation of the electric circuit in the next valid simulation step.	<i>var3:=sqrt(t)</i>
SET	The variable is calculated only once at the moment of activation of the state.	<i>var4:=2.5</i>
DEL	Sets a delay. The variable is set to false at the moment of activation and set to true after the delay time.	Name##Value <i>var###time [s]</i> <i>delation##10m</i>
DELRES	Deletes a defined delay variable. DELRES only affects as-yet unexpired delays. Thus, if a delay has not yet expired, it would be removed - and any associated transitions would never occur.	<i>del4</i>
DIS	The variable value (and moment) is displayed in the simulator status window.	Name.Qualifier <i>dc.n</i>
TXT	The given text string is displayed in the simulator status window.	"Text String" <i>"State waiting"</i>
STOP	Interrupts the simulation (can be resumed).	No Parameters
BREAK	Finishes the simulation.	No Parameters
SAVE	Saves the active simulation status in a status file.	No Parameters
SCHED	Schedule a time trigger event at the specified time. Refer to <i>Using Time Trigger</i> in the Technical	PARAMETERS

	Notes in the main Twin Builder help.	
DESCHEDED	Deschedule a time trigger event.	Name

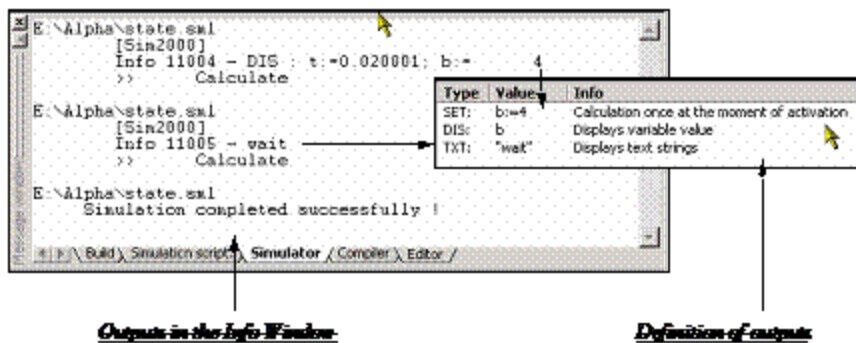
Differences in Assignment Actions in State Components

The action types CALC, STEP, and CATI differ in the sequence and computation frequency used by the simulator (that means, at each calculation step and transition, at each valid state calculation step, and outside the state graph at each simulation time step). A demonstrative example of the usage of CALC, STEP and CATI can be found at [installation directory] Examples\Simplorer\Components\Basic\States\StateGraph_action_diff.aedt.

See also *Simulator Backplane* in the main Twin Builder help.

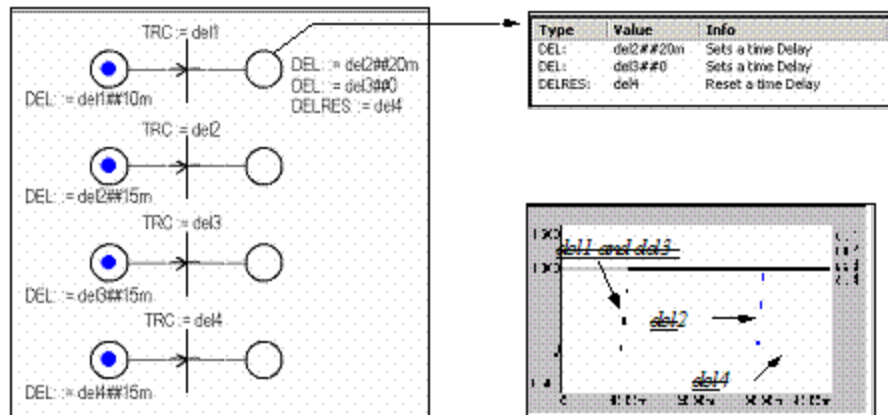
Displaying Variable Values and Text Strings by Action Types

The action types DIS and TXT show the value of a variable (and moment) and a user-defined text string. The simulator writes these messages into the **Message Window**. The text must be surrounded by quotation marks.



Defining and Resetting Delays

The action type DEL set a delay in seconds [s]. Throughout the stated delay time, the variable is set to FALSE, and when the delay time is over, set to TRUE. The variable in the DEL statement can be used in a transfer condition to set a delay within a state graph. The delay time can be reset, deleted or changed in other states of the simulation model.

Change, delete and reset a delay**Setting States with Key Actions**

The KEY statement in a state enables the user to mark a state or states by clicking on the corresponding symbol in the KEY command bar **during the simulation**.

Stopping Simulations

The action types STOP, BRK, and SAVE influence the simulation process, in addition to the simulator functions. If a state is marked with one of these action types, the simulation is stopped (STOP) or paused (BRK). The SAVE statement automatically writes the active simulation state into the model file (.krm).

Changing Action Types

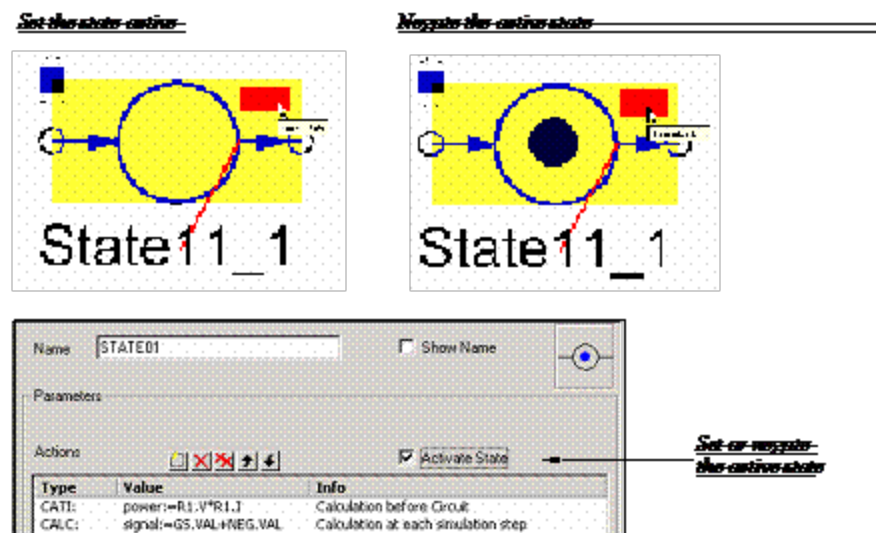
You can change the action types of previously defined actions. You can also modify the already existing value assignment. Double-click the symbol to open the component dialog or choose **Properties** in the shortcut menu to open the properties dialog and click the **CompDlg** button in the **Parameter Values** tab. Click the name of action type you want to change and select a new statement in the drop-down list. Confirm your entries with <OK>.

Using State Markers

Setting the Active State at the Beginning of the Simulation

Note: The active state defines the beginning of the simulation. There must be one active state set at the beginning of a simulation. A state can be set as active in the graphic display by clicking the red switch area or in the component dialog by selecting the **«Activate State»** option.

Selecting a switch changes the current state from active to inactive and vice versa. A blue circle indicates the state is active.



Note: The switch area is visible only if the state element is selected.

State Markers During a Simulation

During a simulation, the state markers are shown “running” through the various state components, depending on the active states in the simulation process.

Note: If you want to see the state markers changing, select the option **«Enable symbol animation»** in Twin Builder Circuit>Design Settings dialog Simulation Options tab.

Displaying the State of State Components

The state of every state component can be accessed from its parameter ST. A state component can be used in the following ways:

- As an input for the circuit or block diagram simulator.
- To be shown in display elements.

ST has the direction attribute INOUT.

Example: State1.ST

States Components

- [Transition \(TRANS\)](#)
- [States \(01, 10, 11, 33\)](#)
- [State Flexible \(STATE_Flexible\)](#)

State Components

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

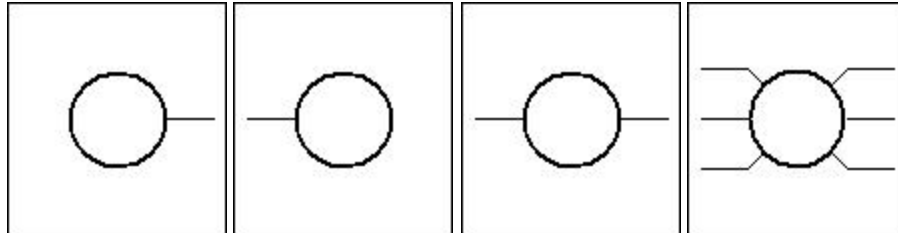


Figure 1. Component Symbol.

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Description

There are various symbols for states with different inputs and outputs. The choice of symbols depends on the structure of the state graph to be modeled.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
ST[n]	Pin n	real	
ST0	Define the Active State. Only at the beginning of a simulation.	real	0
Actions defined in the state. Please note: You cannot display these actions.		CATI: CALC: STEO: SET: DEL: DELRES: DIS: TXT: STOP: BREAK: SAVE: See Using Actions in State Graphs	

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
ST	Current Value of State	Input/Output	real
<i>Variable Name</i>	Dynamic Value Output of a variable defined within the dialog of the state.		real

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Example

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References

State Flexible

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

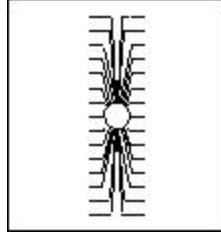


Figure 1. Component Symbol.

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Description

The State Flexible Component represents a state with 30 pins. This is the maximum number of pins available for a state component. All pins should be connected with a transfer component. If there are open pins on the sheet, you can hide the pin by deactivating the pin within the state output dialog box.

All other properties are identical with the state component described in

[See also State Components](#)

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Transition Component

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

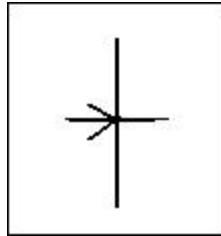


Figure 1. Component Symbol.

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Description

With the transition component, the transfer condition between the states of the system can be described. The transition component is switched if all previous states are marked and the transfer condition is true. In case of an event, all predecessor states are deactivated and all successor states are activated. If in the logical expression of the transfer condition $\geq$ or $\leq$ used, the simulator is synchronized exactly on this event. The event is calculated with a precision of $H_{min}/2$. If two events occur at the same time, that with the smaller priority number is computed first. In the dialog for the transition component, you define the transfer condition and the priority of the process, with '1' being the highest and '9' the lowest priority.

As part of the transfer condition any parameters from the simulation model and mathematical expressions can be used. If the equal operator is used, the synchronization is obtained with the minimum time step. This process can sometimes increase the simulation time. The default value for transfer conditions is FALSE.

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
TRC	Transfer Transition	real	false
PRI	Priority	real	5
ST_PRE	Previous States	real	
ST_SUC	Successor States	real	

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Example

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References

Modeling Tools

Complex simulation models usually need simple auxiliary functions to model typical curves, characteristics, and equations simply and quickly. So the real subject of simulation can be investigated faster and more precisely.

Nonlinear components need a characteristic to represent a behavior, sources a time function to generate typical wave forms, and signals can be controlled dependent on their properties.

Modeling tools appear in the *Tools* folder in the Basic Elements library. The folder is subdivided in time functions, characteristics, and equations. Select the folder *Tools*, open [Characteristics](#), [Equations](#), [Simulator Parameters](#), or [Time Functions](#) click a name, drag the component onto the sheet and release the mouse button.

All components can be used to provide input signals, characteristics, and mathematical functions for the simulation model.

Modeling Tools - Characteristics

- [Diffusion Capacitance \(CDI\)](#)
- [Junction Capacitance \(CSP\)](#)
- [Equivalent Line \(EQUL\)](#)
- [Exponential Function \(EXP\)](#)
- [Hyperbolic Function \(HYP\)](#)
- [Multidimensional Table \(NXMY\)](#)
- [Polynom 2nd Order \(PO2\)](#)
- [2D Lookup Table \(XY\)](#)

Using Modeling Tool Characteristics

Similar to time functions, characteristics can also be used to model nonlinear characteristics. In the electric circuit module, nonlinear characteristics are preferable for the behavioral description of passive components, static or dynamic behavior of semiconductor devices and controlled sources. In the block diagram module, the nonlinear transfer behavior of blocks can be described.

The characteristics are placed in the *Tools* folder in the Basic Elements library. Select the folder, click *Characteristics*, select a component, drag the element onto the sheet and release the mouse button.

Predefined Characteristics

Predefined characteristics have a quality determined behavior for which certain parameters can be defined. Predefined characteristics are: Equivalent Line, Exponential Function, Hyperbolic Function, and Polynom of 2nd Order as well Diffusion Capacitance and Junction Capacitance.

User-Defined Characteristics

In addition to the predefined characteristics, Twin Builder users can define their own characteristic. The 2D Lookup Table XY is used to create characteristic data pairs which are saved in an external file or in the simulation sheet.

Diffusion Capacitance

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

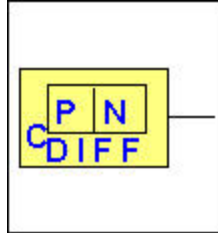


Figure 1. Component Symbol.

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- [Assumptions and Limitations](#)
- [Mathematical Description](#)
- [Netlist Syntax](#)
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- [Input/Output Quantities](#)
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Description

The diffusion capacitance represents the storage of the minority carrier within the junction after forward current flow. The diffusion and the junction capacitance were developed for modeling the dynamic switching behavior of the diode or another semiconductor component.

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Mathematical Description

The charge and the capacitance of the Diffusion Capacitance can be described as following:

$$q(t) = (TAU \cdot ISAT) \cdot \left(e^{\frac{v(t)}{VT}} - 1 \right)$$
$$C_{Diff} = \frac{dq(t)}{dv(t)} = TAU \cdot \frac{ISAT}{VT} \cdot e^{\frac{v(t)}{VT}}$$

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Netlist Syntax

```
INTERN CDI ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) ( VT := @VT , ISAT :=  
@ISAT , TAU := @TAU );
```

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
VT	Thermal Voltage	real	35m [V]
ISAT	Saturation Current	real	1p [A]
TAU	Minority Carrier Life-time	real	0.1u [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Value of the Diffusion Capacitance	Output	real

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Example

Figure 2 shows the application example of the Diffusion Capacitance model. The capacitance of the Capacitor CNL1 is described by the Diffusion Capacitance CDI1. The parameters of the system are listed in Table 3. The simulation results are shown in Figure 3~7.

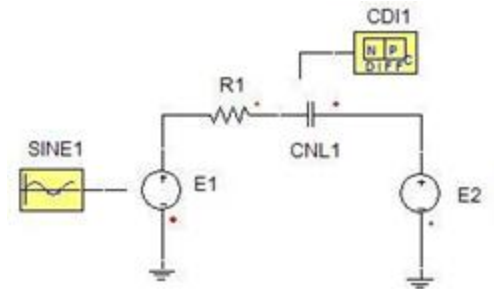


Figure 2. Application example of the Diffusion Capacitance model

Table 3

Component	Parameter	Value
Diffusion Capacitance CDI1	VT	35m [V]
	ISAT	1p [A]
	TAU	0.1u [s]
Voltage Source E1	EMF	SINE1.VAL [V]
Voltage Source E2	EMF	-1+2*t* [V]
Capacitor C1	C	CDI1.VAL [F]
Sine Wave SINE1	AMPL	5
	FREQ	1000
	PHASE	0
	TDELAY	0
	OFF	-1

* t is the simulation time

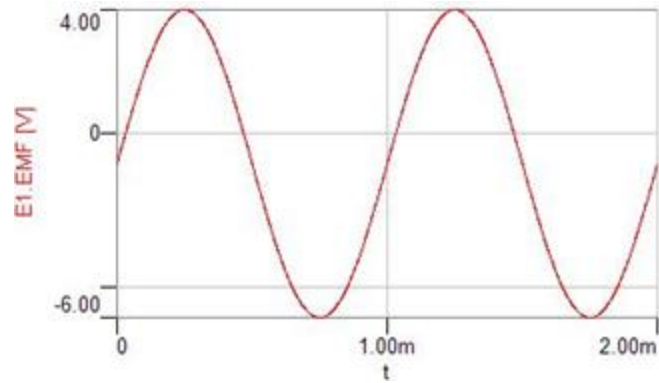


Figure 3. Simulation result-voltage output of E1

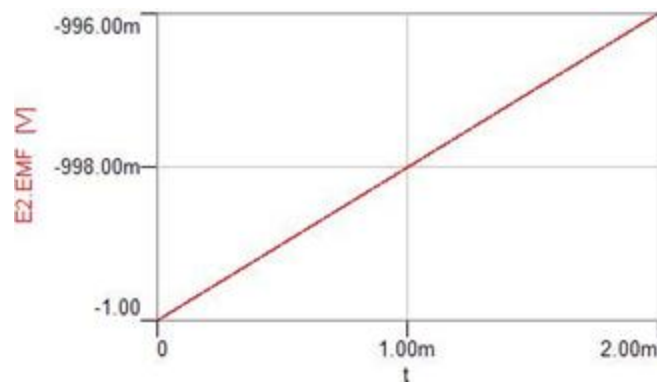


Figure 4. Simulation result-voltage output of E2

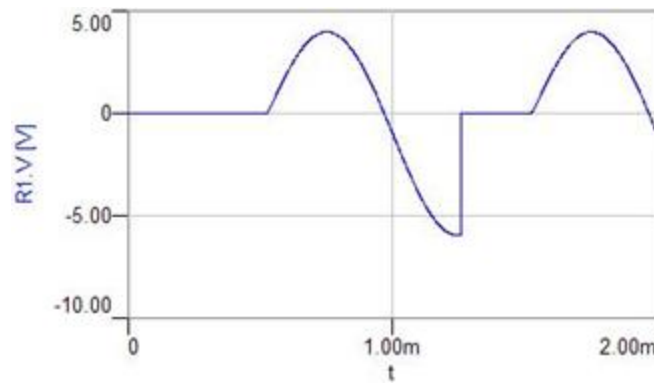
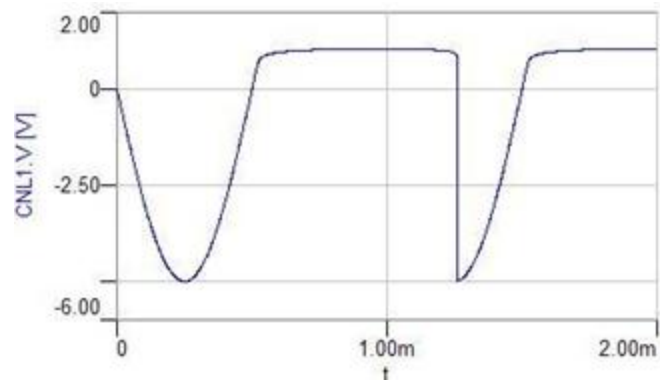
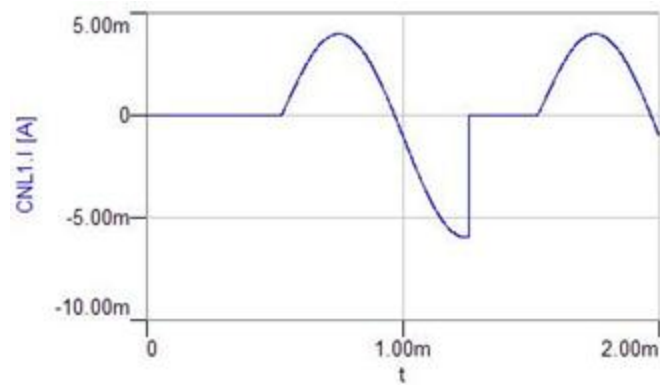


Figure 5. Simulation result-voltage across R1**Figure 6. Simulation result-voltage across CNL1****Figure 7. Simulation result-current through CNL1**[Top](#)

References

Junction Capacitance

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

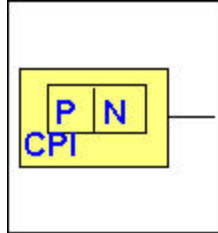


Figure 1. Component Symbol.

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Description

The junction capacitance represents the dependence of the resulting junction capacitance from the applied voltage due to the majority carrier distribution. The junction and the diffusion capacitance were developed for modeling the dynamic switching behavior of a diode or another semiconductor component.

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Mathematical Description

The capacitance of the Junction Capacitance can be described as following:

$$C = \frac{C_0}{\sqrt{1 - \frac{V}{V_d}}}$$

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Netlist Syntax

```
INTERN CSP ?InstanceName(@InstanceName):(@ (Refbase)@(ID)) ( C0 := @C0 , VD := @VD );
```

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
C0	Zero-bias Junction Capacitance	real	22n [F]
VD	Diffusion Voltage	real	35m [V]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Value of the Junction Capacitance	Output	real

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Example

Figure 2 shows the application example of the Junction Capacitance model. The capacitance of the Capacitor CNL1 is described by the Junction Capacitance CDI1. The parameters of the system are listed in Table 3. The simulation results are shown in Figure 3~7.

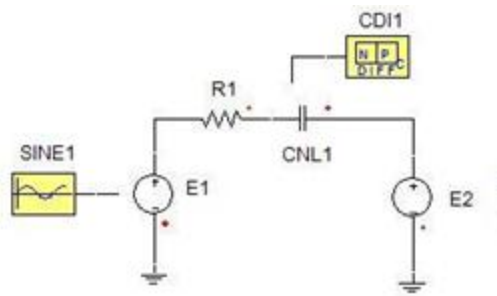


Figure 2. Application example of the Junction Capacitance model

Table 3

Component	Parameter	Value
Junction Capacitance CDI1	C0	22n [F]
	VD	35m [V]
Voltage Source E1	EMF	SINE1.VAL [V]
Voltage Source E2	EMF	-1+2*t* [V]
Capacitor C1	C	CDI1.VAL [F]
Resistor R1	R	1k [Ohm]
Sine Wave SINE1	AMPL	5
	FREQ	1000
	PHASE	0
	TDELAY	0
	OFF	-1

* t is the simulation time

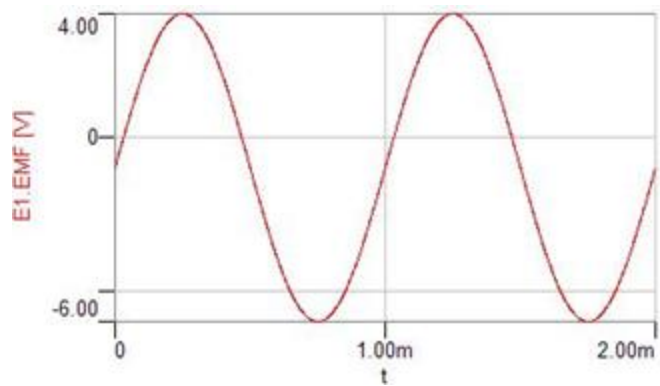


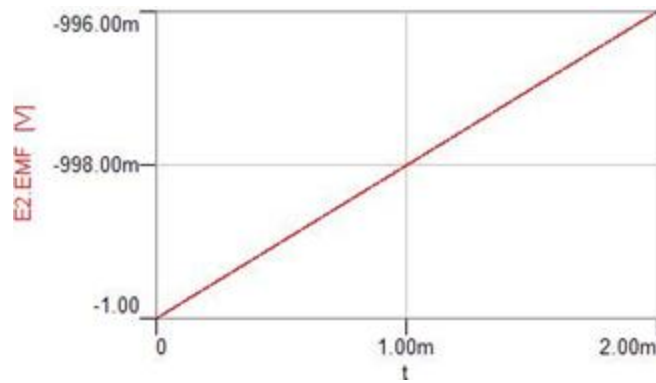
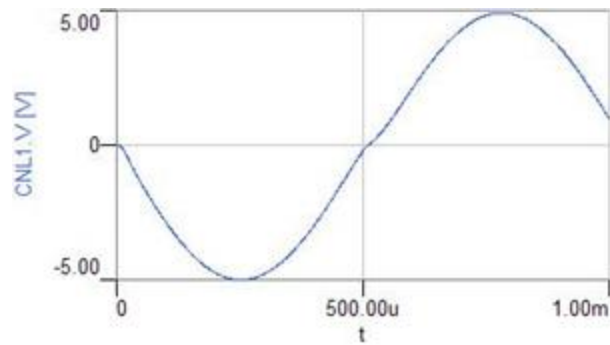
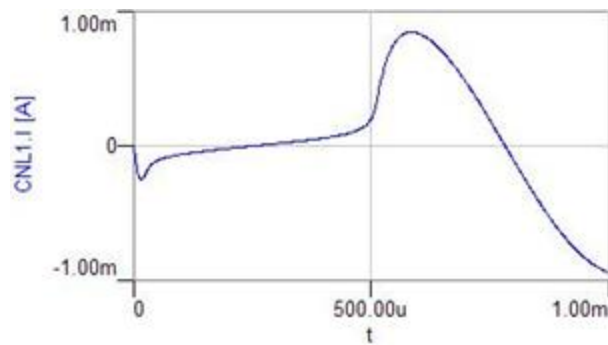
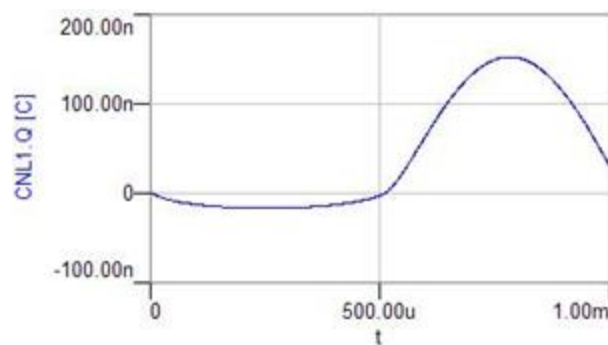
Figure 3. Simulation result-voltage output of E1**Figure 4. Simulation result-voltage output of E2****Figure 5. Simulation result-voltage across CNL1****Figure 6. Simulation result-current through CNL1**

Figure 7. Simulation result-charge of CNL1

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References

Equivalent Line

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

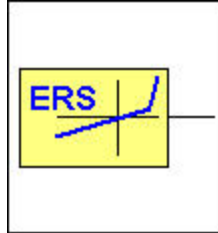


Figure 1. Component Symbol.

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Description

V_{limit} stands for the intersection of the forward and reverse characteristic and is calculated automatically. The equivalent line is a simply way to represent the nonlinear behavior of switching components. However, in some rare circumstances numeric instabilities can occur switching from one branch of the equivalent line to the other.

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Mathematical Description

The output of the Equivalent Line model can be described as following:

$$I = \frac{v(t) - V_F}{R_B} \quad \text{for } v(t) \geq V_{\text{limit}}$$

$$I = \frac{v(t)}{R_R} \quad \text{for } v(t) < V_{\text{limit}}$$

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Netlist Syntax

```
INTERN EQU L ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) ( VF := @VF , RB :=  
@RB , RR := @RR );
```

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
VF	Forward Voltage	real	0.8 [V]
RB	Bulk Resistance	real	1m [Ohm]
RR	Reverse Resistance	real	100k [Ohm]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Value of the Equivalent Line	Output	real

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Example

Figure 2 shows the application example of the Equivalent Line model. Here the characteristics of the Diode D1 is described by the Equivalent Line EQU1. The parameters of the system are listed in Table 3. The simulation results are shown in Figure 3~5.

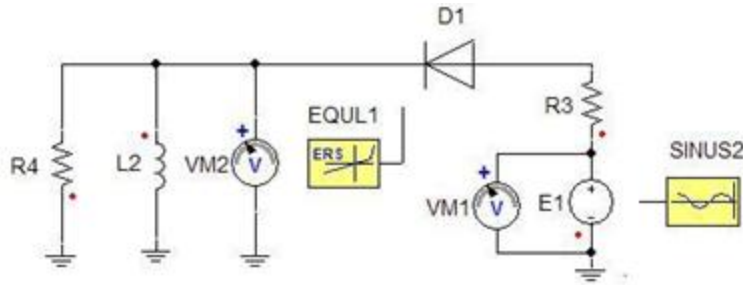


Figure 2. Application example of the Equivalent Line model

Table 3

Component	Parameter	Value
Equivalent Line EQUL1	VF	0.8
	RB	1m [Ohm]
	RR	100k [Ohm]
Voltage Source E1	EMF	SINUS2.VAL [V]
Sine Wave SINUS2	AMPL	300
	FREQ	50
	PHASE	0
	TDELAY	0
	OFF	0
Resistor R3	R	0.1m [Ohm]
Resistor R4	R	1e-6 [Ohm]
Inductor L2	L	1e-9 [H]
	I0	0 [A]
Diode (Equivalent Line) D1	CH	EQUL1.VAL

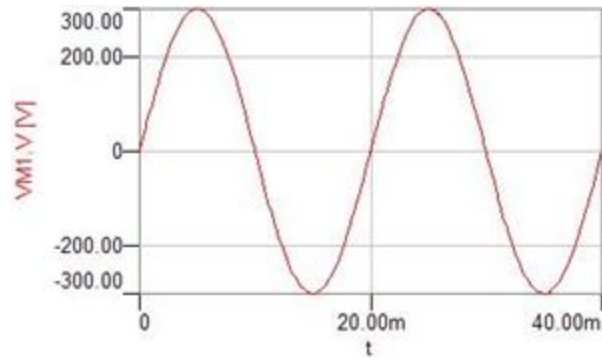


Figure 3. Output voltage of E1

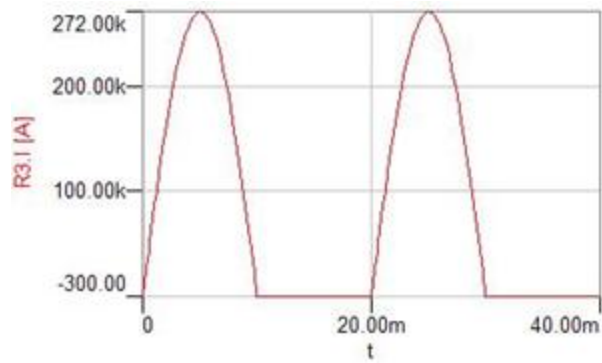


Figure 4. Current through R3

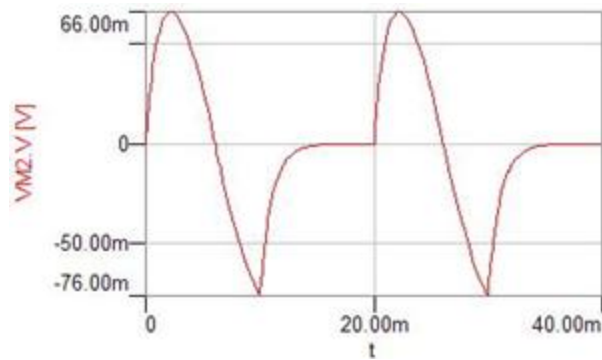


Figure 5. Voltage across L2

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References

Exponential Function

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

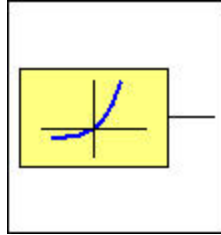


Figure 1. Component Symbol.

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Description

With the exponential function, the static behavior of switched components is represented accurately over a wide range. However, the use of exponential functions without specifying a bulk resistance R_B is not very practical for semiconductor components in power electronics. For these cases, the bulk resistance must be inserted by the user as a separate component in the circuit.

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Mathematical Description

The output of the Exponential Function model can be described as following:

$$i(t) = ISAT \cdot \left(e^{\frac{v(t)}{VT}} - 1 \right) \quad \text{for } v(t) \geq 0$$
$$i(t) = \frac{v(t)}{RR} \quad \text{for } v(t) < 0$$

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Netlist Syntax

INTERN EXP ?InstanceName(@InstanceName):(@ (Refbase)@ (ID)) (VT:=@(VT), ISAT:=@ (ISAT), RR:=@(RR)) ;

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
VT	Thermal Voltage	real	35m [V]
ISAT	Saturation Current	real	1p [A]
RR	Reverse Resistance	real	100k [Ohm]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Value of the Exponential Function	Output	real

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Example

Figure 2 and 3 show the application example of the Exponential Function model. The characteristics of the Bipolar Junction Transistors are described by the Exponential Function EXP1,

and switching of these transistors is decided by the state diagram. The parameters of the system are listed in Table 3. The simulation results are shown in Figure 4.

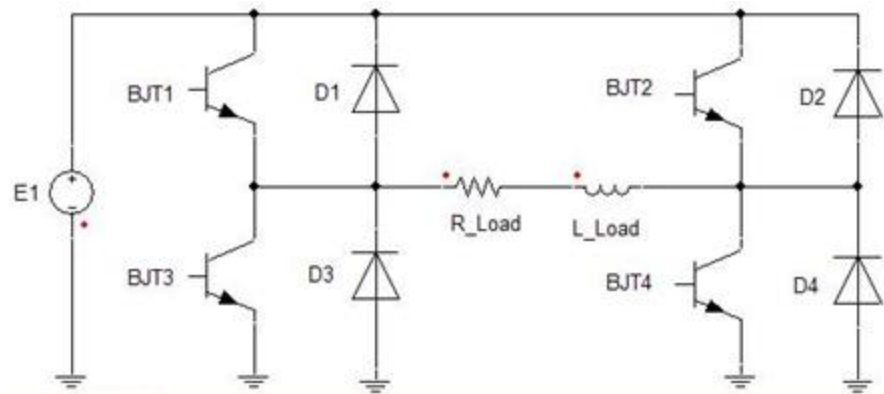


Figure 2. Application example of the Exponential Function model and H-bridge with an inductive load

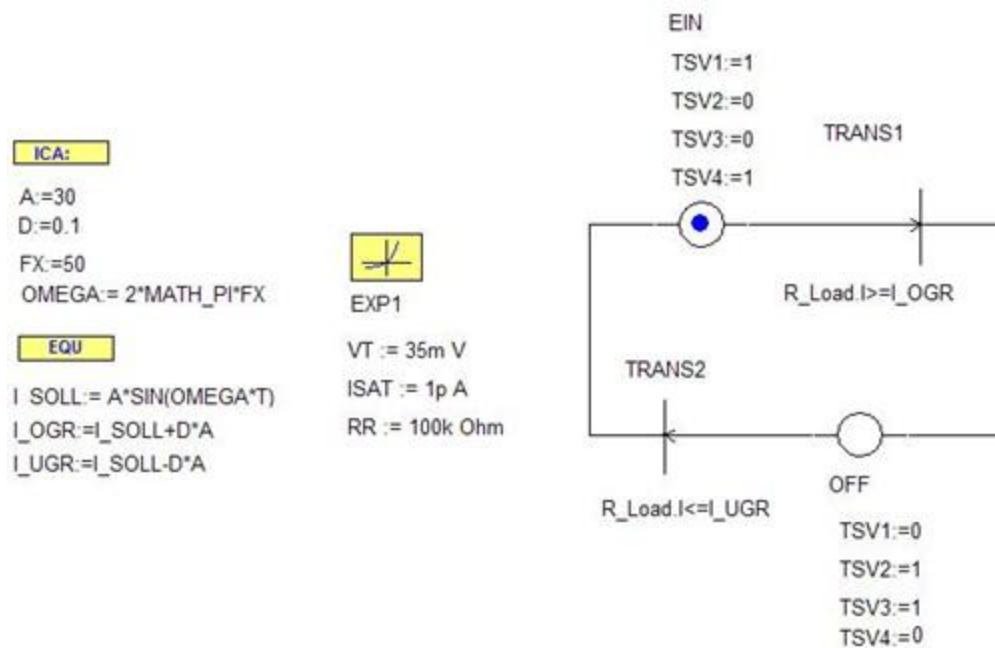


Figure 3. Application example of the Exponential Function model-controller for the H-bridge

Table 3

Component	Parameter	Value
Exponential Function EXP1	VT	35m [V]
	ISAT	1p [A]
	RR	100k [Ohm]
Voltage Source E1	EMF	?200 [V]

Bipolar Junction Transistor BJT1	CH	EXP1
	CTRL	TSV1
Bipolar Junction Transistor BJT2	CH	EXP1
	CTRL	TSV2
Bipolar Junction Transistor BJT3	CH	EXP1
	CTRL	TSV2
Bipolar Junction Transistor BJT4	CH	EXP1
	CTRL	TSV1
Diode D1/D2/D3/D4	CH	EXP1
Resistor R_Load	R	2 [Ohm]
Inductor L_Load	L	10m [H]
	I0	0 [A]

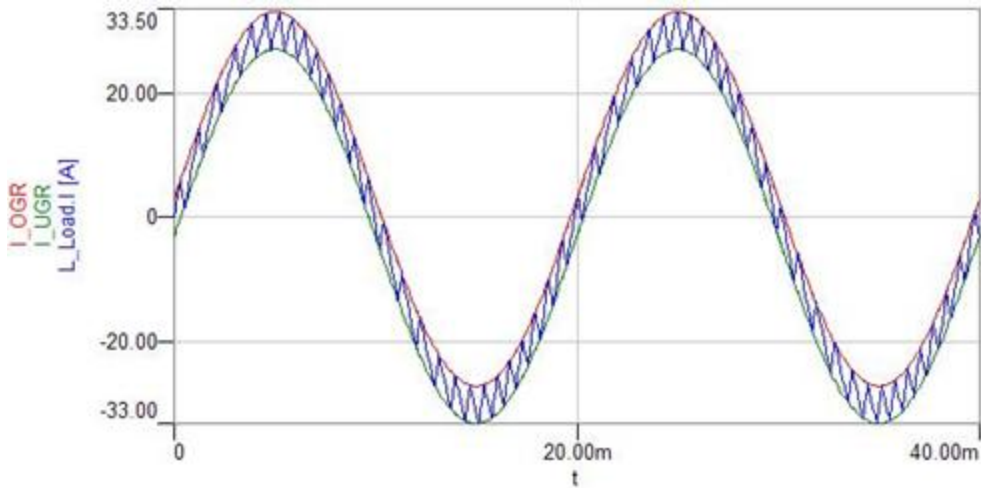


Figure 4. Simulation results

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References

Hyperbolic Function

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

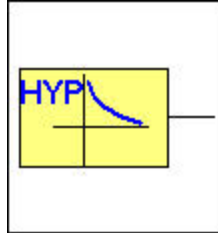


Figure 1. Component Symbol.

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Description

Because of the great sensitivity of the hyperbolic parameters caused by the large difference in bulk and reverse resistance, Twin Builder calculates these parameters itself. In contrast to the equivalent line function, the hyperbolic function has a steady first derivation in the entire range of input values. Thus, convergence problems possible with the equivalent line are avoided.

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Mathematical Description

The output of the Hyperbolic Function model can be described as following:

$$i(t) = V_1 \cdot v(t) + V_2 + \sqrt{V_3 \cdot (v(t))^2 + V_4 \cdot v(t) + V_5}$$

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Netlist Syntax

INTERN HYP ?InstanceName(@InstanceName):(@ (Refbase)@(ID)) (VF := @VF , RB := @RB , RR := @RR) ;

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
VF	Forward Voltage	real	0.8 [V]
RB	Bulk Resistance	real	1m [Ohm]
RR	Reverse Resistance	real	100k [Ohm]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Value	Output	real

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Example

Figure 2 shows the application example of the Hyperbolic Function model. The characteristics of the Diode D1 are described by the Hyperbolic Function HYP1. The parameters of the system are listed in Table 3. The simulation results are shown in Figure 3~5.

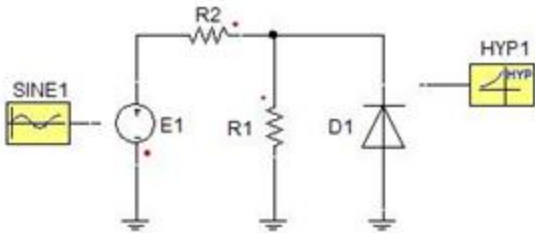


Figure 2. Application example of the Hyperbolic Function model**Table 3**

Component	Parameter	Value
Hyperbolic Function HYP1	VF	0.8 [V]
	RB	1m [Ohm]
	RR	100k [Ohm]
Voltage Source E1	EMF	SINE1.VAL [V]
Diode D1	CH	EXP1
Resistor R1/R2	R	1k [Ohm]
Sine Wave SINE1	AMPL	326
	FREQ	50
	PHASE	0
	TDELAY	0
	OFF	0

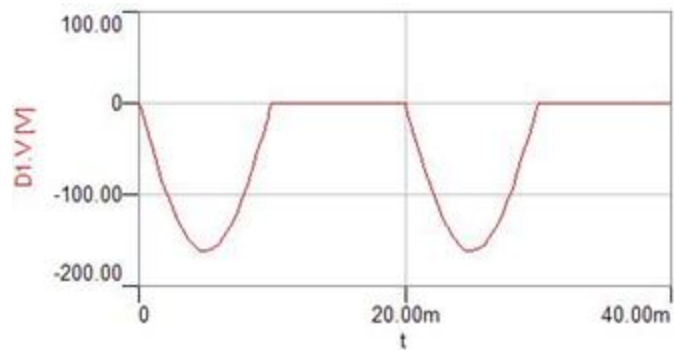
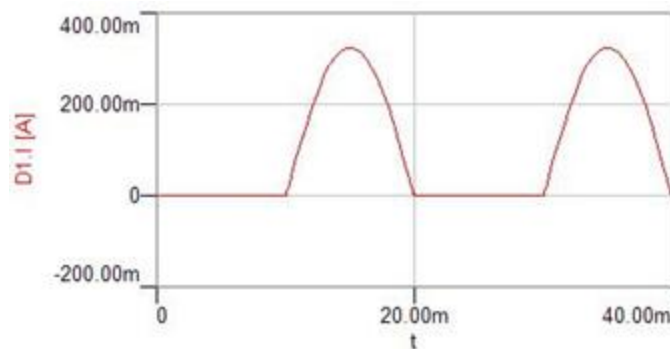
**Figure 3. Simulation result-voltage across D1**

Figure 4. Simulation result-current through D1

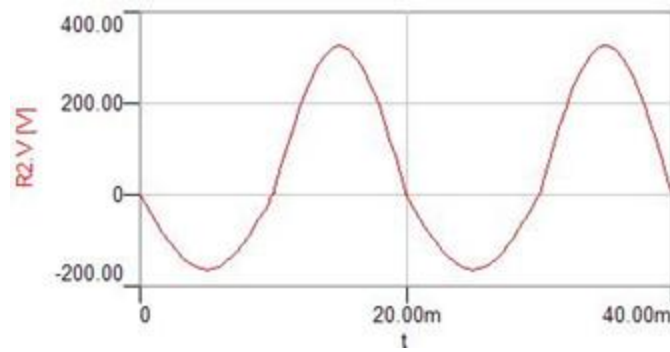


Figure 5. Simulation result-voltage across R2

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References

Multidimensional Table

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

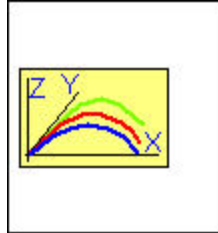


Figure 1. Component Symbol.

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Description

The Multidimensional Table NXMY is used to describe nonlinear behavior which is affected by multiple factors. This component is designed to be used in conjunction with predefined non-linear characteristics in Twin Builder. A list of components with such non-linear characteristics is given in Table 1.

The Multidimensional dataset must have at least 1 input (INPUT[0]) and 1 output (VAL[0]). When used to specify the predefined nonlinear characteristics, INPUT[0] and VAL[0] automatically become the independent and dependent quantities, respectively. For example, when used to define the nonlinear characteristics of a resistor, the voltage across the resistor will be used to look up the possible values in INPUT[0], and the corresponding VAL[0] determines the current through the resistor.

If more than one input is defined, then the extra inputs will be used in conjunction with INPUT[0] to determine the output value. For example, an NXMY component with 2 inputs and 1 output can be used to specify a nonlinear temperature-dependent resistor, and the extra input can be used to specify the temperature dependency of the resistance value.

If more than one output is defined, only one output can be selected as the output channel, which in turn will be the dependent quantity of the predefined nonlinear characteristic.

The characteristics dataset table can be entered either by users, or imported through a file. Note that the values of X must be monotonically increasing.

The accepted import data file formats are:

- Simpler Characteristic (*.mdx, *.mda)
- Microsoft Excel (*.xls, *.xlsx)
- Text (*.txt)
- Comma separated values (*.csv)
- Spice (*.out)
- Comtrade (*.cfg)
- TEK oscilloscope (*.dat)
- Tab delimited data files (*.tab)

Requirements for Characteristic Blocks

- a physically useful characteristic for each parameter value (for voltage '0' is also current '0', otherwise errors occur during simulation)
- the same sequence of monotonously increased or decreased values for the X axis
- a constant select parameter value (Y axis) for each block
- across all blocks the select parameter must be monotonously increased or decreased.

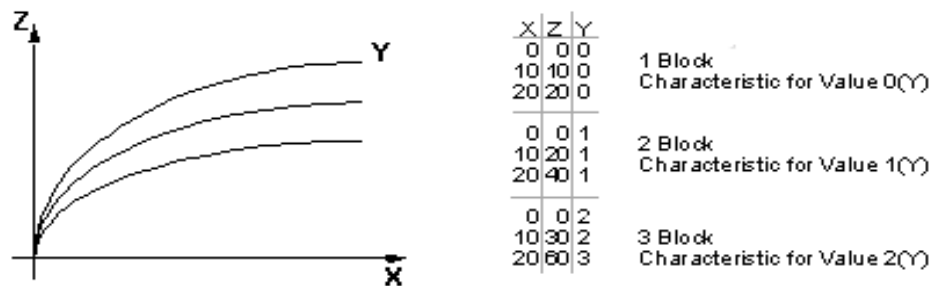


Figure 2. Monotonically increasing function in all parameters

Using 3D Lookup Tables with Components

Open the property dialog of a nonlinear component, for example of a resistor. Select **«Non-linear»** in the dialog and click <Characteristic>. Enter the name of the Multidimensional Lookup Table component in the text box (Name.VAL). You also use the characteristic pin to make direct connection to VAL[0] of the Multidimensional Lookup Table component..

During simulation, the current values of the nonlinear component are available for X, Y, and Z value in the 3D Lookup Table component. If you define outputs, you can display these quantities.

Components Using Characteristics

The table shows Simplorer's interpretation of the corresponding values of nonlinear components. The X, Y, and Z axis are interpreted as follows:

Table 1

Component	Description	x-Axis 1. Channel	z-Axis 2. Channel	y-Axis 3. Channel
RNL	nonlinear resistance	voltage v [V]	current i [A]	Parameter
GVNL	nonlinear conductance	current i [A]	voltage v [V]	Parameter
LNL	nonlinear inductance	flux Ψ [Vs]	current i [A]	Parameter
LINL	nonlinear dual inductance	current i [A]	inductance L [H]	Parameter
CNL	nonlinear capacitance	charge Q [As]	voltage v [V]	Parameter
CVNL	nonlinear dual capacitance	voltage v [V]	capacitance C [F]	Parameter

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Mathematical Description

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Parameters

Table 2

Name	Description	Data Type	Default Value [Unit]
Interpolation	Interpolation Method, 1-linear, 2-spline	real	1
FamilyParameter	Variable Name of Select Parameter	real	0

FamilyOfCurves	File Name, 3-dimensional .mdx File	real	0

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Input/Output Quantities

Table 3

Name	Description [Unit]	Direction	Data Type
VAL	Value	Output	real
X, Y, Z	Current X, Y, Z Values of the Non-linear Component	Output	real

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Example

Resistor RNL1 has nonlinear resistance value and it depends on temperature as well. The characteristic line of such a resistor can be given in a Multidimensional Table component NXMY1. The schematic of the example is shown in Figure 3, system parameters are listed in Table 4, and the simulation result is shown in Figure 4.

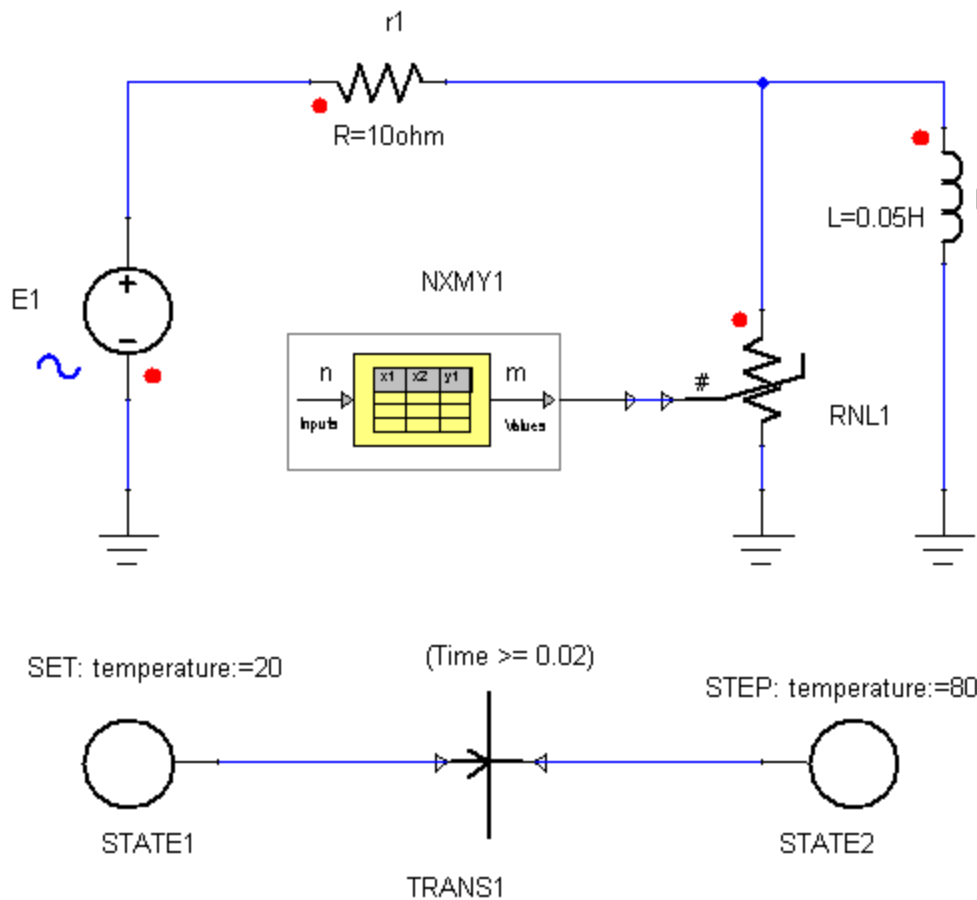


Figure 3. Application example of the Multi Dimensional Table Characteristic model

Table 4. System Parameters

Component	Parameter	Value [unit]
Voltage Source E1	Time Controlled	Sine
	AMPL	311 [V]
	FREQ	50 [Hz]
Resistor (Linear) R1	R	10 [Ohm]
Inductor (Linear) I	L	0.05 [H]

Resistor (NonLinear) RNL1	CH	NXMY1.VAL[0]
State_01 STATE1	EQU0	SET:temperature:=20
State_10 STATE2	EQU0	STEP:temperature:=80
Transition TRANS1	TRC	(Time >= 0.02)
	PRI	5
	ST_PRE	STATE1.ST[0]
	ST_SUC	STATE@.ST[0]
MultiDimensional Table NXMY1	INPUT[0]	voltage
	INPUT[1]	temperature
	Extrapolation	LINEAR
	Interpolation	NOSPLINE
	Output Chan- nel	current

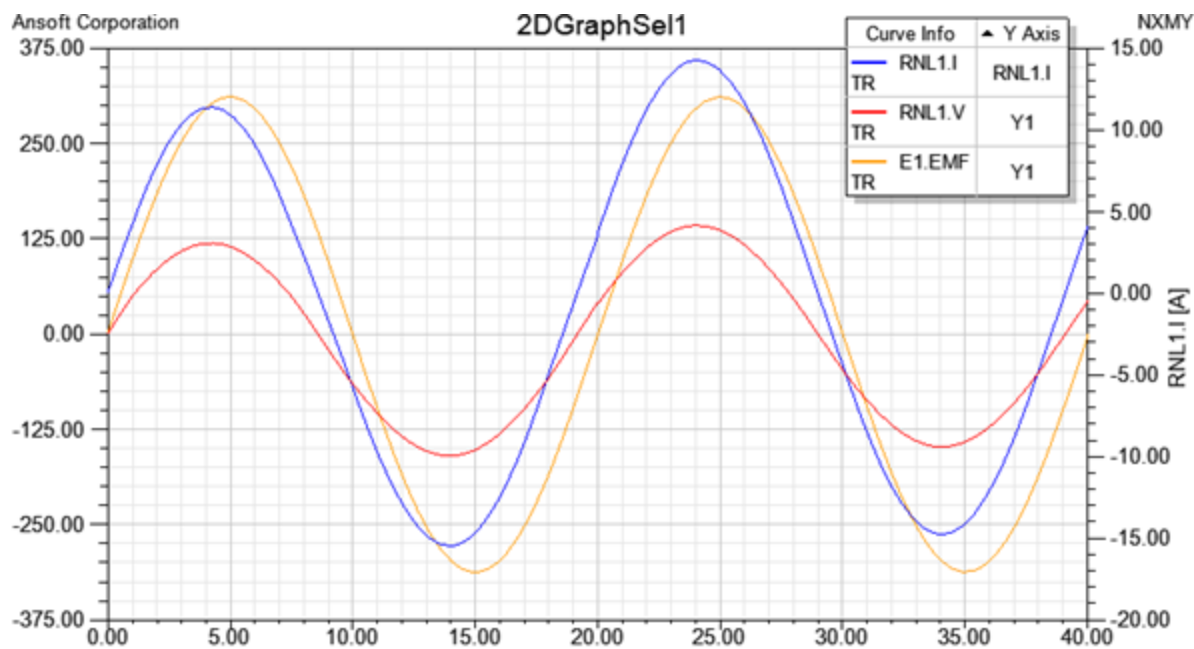


Figure 3. Simulation results-voltage across and current through R1

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References

Polynom of 2nd Order (parabolic)

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

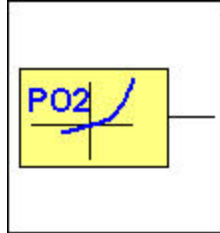


Figure 1. Component Symbol.

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Description

The parabolic function is characterized by a very favorable convergence behavior and thus is well suited for modeling frequently switched systems. V_{limit} stands for the intersection of forward and reverse characteristics and is calculated automatically. There are approximations which show a good coincidence between model and real components using all three parameters, A, B and C. In obtaining these parameters, however, special care must be taken so that only sensible combinations are specified. Parameters a, b and c are freely definable coefficients. Experience has proven that one should follow these guidelines in determining the parabolic parameters:

$$i(t) = A + B \cdot v(t) + C(v(t))^2 \quad \text{for } v(t) \geq V_{\text{limit}}$$

$$i(t) = \frac{v(t)}{RR} \quad \text{for } v(t) < V_{\text{limit}}$$

$$A = 0 \quad B = \frac{1}{RR} \quad C = \frac{I}{V(I)^2} \quad R = 100k\Omega$$

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Netlist Syntax

```
INTERN PO2 ?InstanceName(@InstanceName):(@ (Refbase)@(ID)) ( RR := @RR , A := @A ,  
B := @B , C := @C ) ;
```

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
RR	Reverse Resistance	real	100k [Ohm]
A	Coefficient A	real	0
B	Coefficient B	real	10u
C	Coefficient C	real	10

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Value of the Polynom	Output	real

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Example

Figure 2 shows the application example of the Polynom 2nd Order model. The characteristics of the Nonlinear Current Controlled Voltage Source EC1 is described by the Polynom 2nd Order PO21. The parameters of the system are listed in Table 3. The simulation results are shown in Figure 3 and 4.

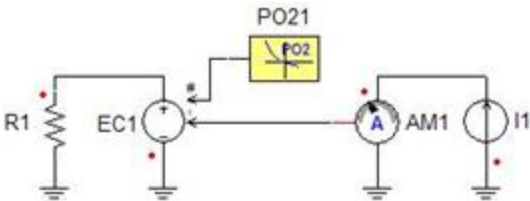


Figure 2. Application example of the Polynom 2nd Order model

Table 3

Component	Parameter	Value
Polynom 2 nd Order PO21	RR	0.1 [Ohm]
	A	-2
	B	0
	C	100
Current Source I1	IS	-1+t* [A]
Controlled Voltage Source (Nonlinear Current Controlled) E1	QUANT	AM1.I
	CH	PO21.VAL
Resistor R1	R	1k [Ohm]

* t is the simulation time

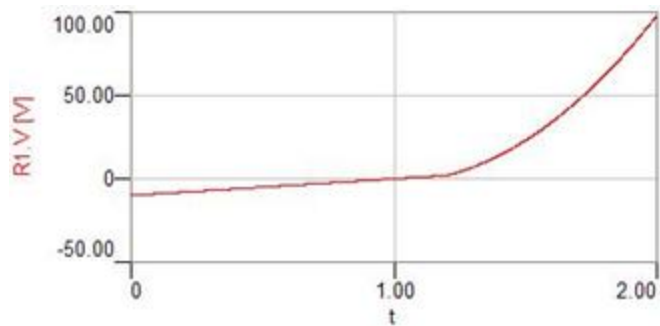


Figure 3. Simulation result-voltage across R1

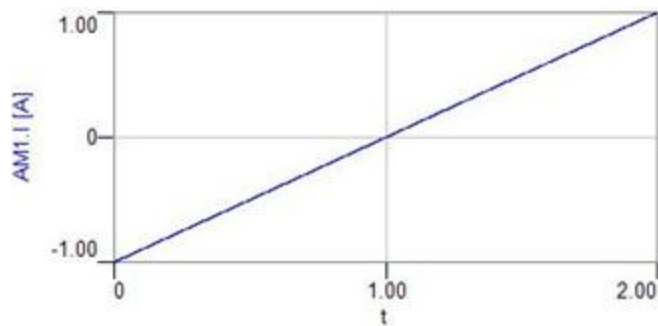


Figure 4. Simulation result-current output of I1

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References

2D Lookup Table XY

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

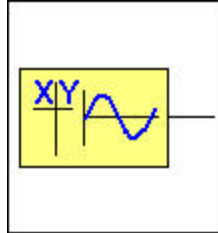


Figure 1. Component Symbol.

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Description

The 2D Lookup Table XY is used to describe nonlinear behavior different from the predefined characteristics.

The characteristics can be specified through the following 3 methods:

◆ Dataset

The 2D dataset can be either entered by users, or imported through a file. Note that the values of X must be monotonically increasing. The accepted import data file formats are:

- Twin Builder Characteristic (*.mdx, *.mda)
- Microsoft Excel (*.xls, *.xlsx)
- Text (*.txt)
- Comma separated values (*.csv)
- Spice (*.out)
- Comtrade (*.cfg)
- TEK oscilloscope (*.dat)

- Tab delimited data files (*.tab)

- ◆ File Reference

- ◆ File Name

The **.mdx** file is composed of characteristic blocks with 3 channels. For each parameter value (which represents, for example, a temperature) the values of the corresponding characteristic are defined.

The dataset specified by users can be exported in the form of tab delimited data files (*.tab).

The X values of the data-pairs must be monotonous rising. The last slope is effective for all values outside the X range. If you want to have a constant value outside the X range, you have to define two data-pairs with the same Y value at the end.

The X-Y assignment of current and voltage (as physical quantities) depends on the application of characteristics in the simulation model.

Note: This function is different from the 2D Lookup Table under **Twin Builder Components > Basic Elements Library > Modeling Tools > Time Functions**, which allows the definition of wave forms from a set of fixed data points with linear interpolation between them based on monotonous rising time points. For more information, see [2D Lookup Table](#).

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Mathematical Description

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
FILE	File Name	file	--

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Value	Output	real

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Example

Figure 2 shows the application example of the 2D Lookup Table XY model. The characteristics of the Nonlinear Resistor RNL1 is described by the 2D Lookup Table XY xyvar. The parameters of the system are listed in Table 3. The simulation results are shown in Figure 3~5.

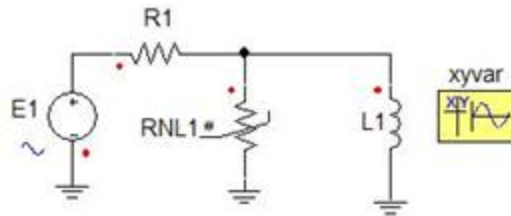


Figure 2. Application example of the 2D Lookup Table XY model

Table 3

Component	Parameter	Value
Voltage Source (sinusoidal) E1	AMPL	311 [V]
	FREQ	50 [Hz]
	PHASE	0 [Degree]
	TDELAY	0 [s]
	OFF	0 [V]
Resistor R1	R	1k [Ohm]
Nonlinear Resistor RNL1	CH	xyvar.VAL
2D Lookup Table XY xyvar	FILE	2d_lookup_table_ssh_xyvar.mdx
Inductor L1	L	[H]
	I0	[A]

* t is the simulation time

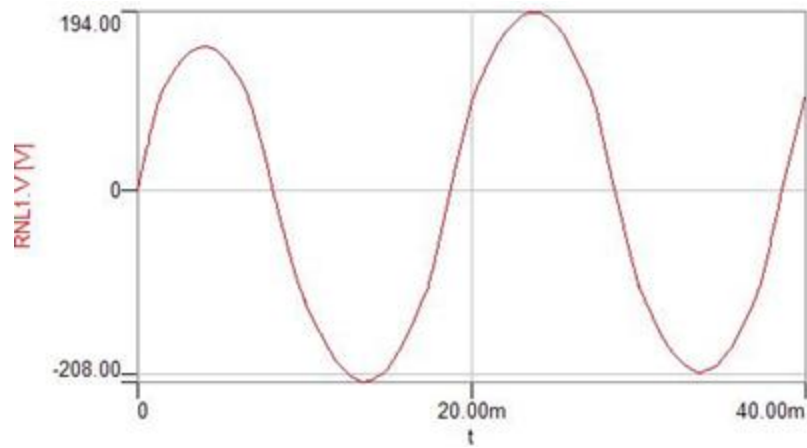


Figure 3. Simulation result-voltage across RNL1

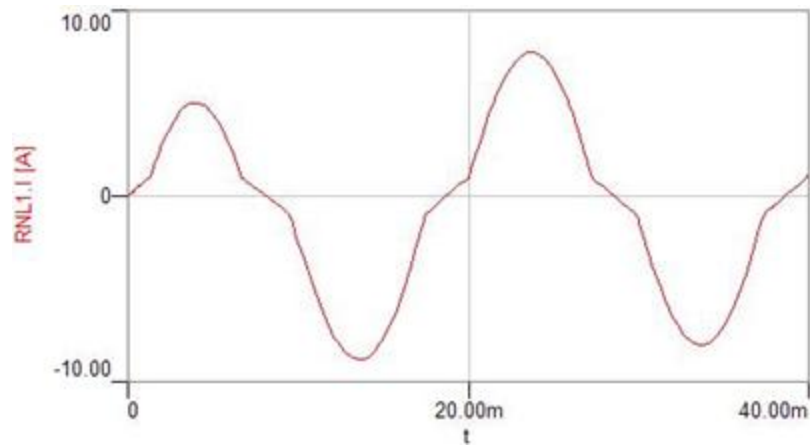


Figure 4. Simulation result-current through RNL1

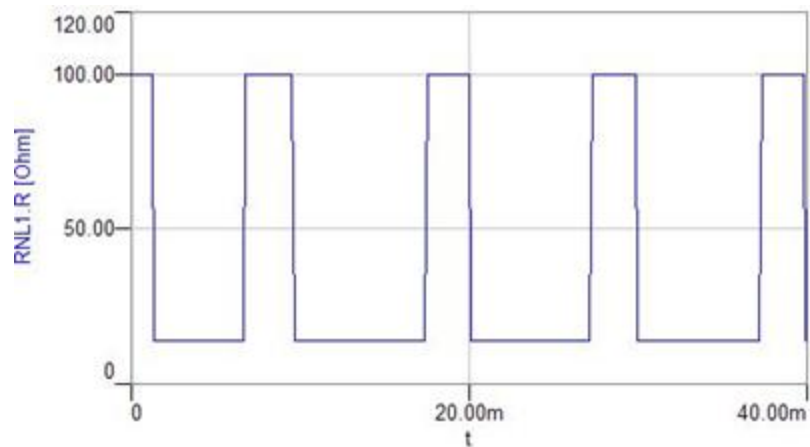


Figure 5. Simulation result-resistance RNL1

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References

Components Using Characteristics

The mapping of the X and Y values to physical quantities (voltage, current, and so on) depends on the used characteristics within the simulation model. The following table shows how Twin Builder interprets the data to calculate the present value of a component.

Component	Name	x	y
RNL	Nonlinear resistor	v	i
GVNL	Nonlinear voltage-controlled conductor	v	G
CNL	Nonlinear capacitor	q	v
CVNL	Nonlinear dual capacitor	v	C
LNL	Nonlinear inductor	Ψ	i
LINL	Nonlinear dual inductor	i	L
D	Diode	v	i
BJT	Transistor	v	i
TH	Thyristor	v	i
GTO	GTO-Thyristor	v	i
TRIAC	TRIAC	v	i
IGBT	IGBT	v	i
MOS	MOS	v	i
EVNL, IVNL	Nonlinear voltage-controlled sources	vc	E/I
EINL, IINL	Nonlinear current-controlled sources	ic	E/I
NL	Nonlinear transfer block	input	val
DCMENL	DC Machine Nonlinear electrical excitation	i	Ψ/L

Symbol	Description [Unit]
v	Component voltage [V]

i	Component current [A]
Ψ	Flux linkages of the inductor [Vs]
q	Charge of the capacitor [As]
L	Inductance [H]
C	Capacitance [F]
vc	Control voltage [V]
ic	Control current [A]
input	Block input (without dimension)
val	Block output (without dimension)
E/I	Source voltage/Source current

Separate Component Characteristic

The separate component characteristic dialog is used if you define a characteristic directly in the dialog of components using nonlinear characteristics.

Modeling Tools - Equations

- [Different Equation Solver \(DES\)](#)
- [Equation \(FML\)](#)
- [Initial Values \(FML_INIT\)](#)
- [Multi Dimensional Table \(NDTAB\)](#)

Differential Equation Solver

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

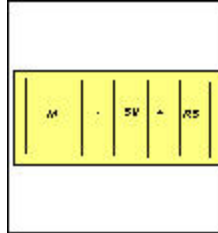


Figure 1. Component Symbol.

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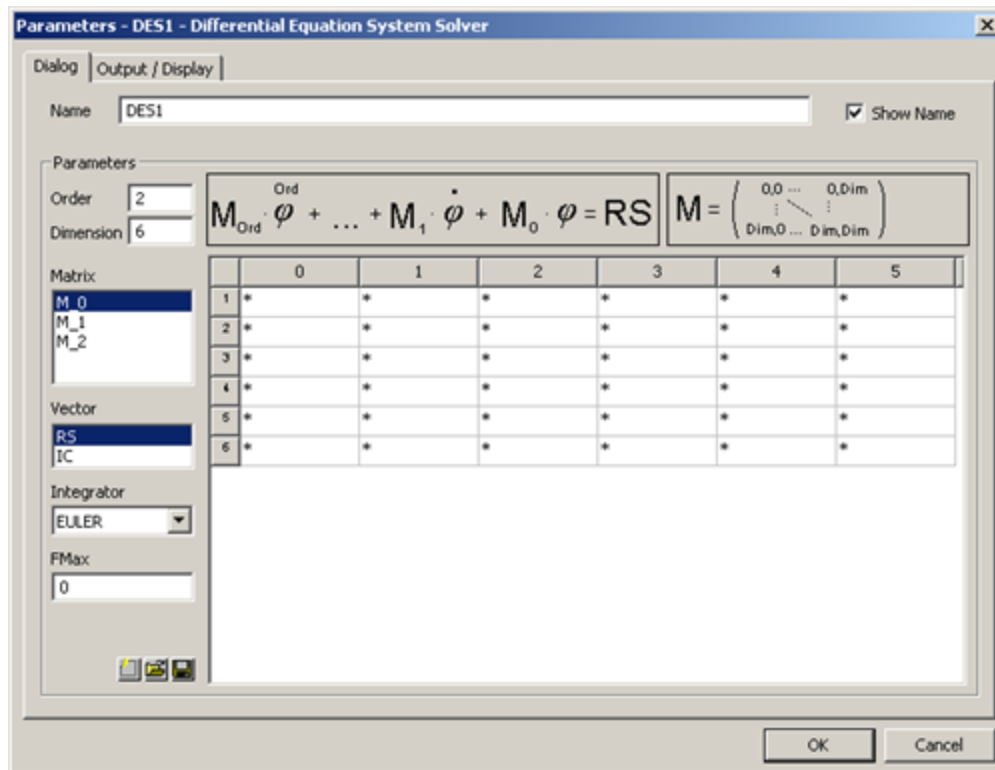
Description

The DES model integrates differential equation systems independent of electrical nodes and without equivalent circuits for circuits and block diagrams. Order and dimension of the equation system are unlimited. The component cannot be used with AC and DC simulation.

DES models are solved in a separate differential equation system. The simulation parameters HMIN and HMAX from the TR simulator are valid for the DES model too. The DES model is calculated after the circuit module.

See also *Simulator Backplane* in the main Twin Builder help.

Note: If you use the Runge-Kutta algorithm, the matrix M with the highest order must be non-singular.



Note: In empty fields the * must be placed; 0 is interpreted as a numerical value.

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Mathematical Description

The general form of the equation solved by the differential equation solver is:

$$M_n \cdot \varphi_{dim}^n + \dots + M_1 \cdot \varphi'_{dim} + M_0 \cdot \varphi_{dim} = RS_{dim}$$

where M_n represent the n -th order coefficient matrix which is a square matrix of dimension dim , φ_{dim} represents the variable vectors, and RS_{dim} is the right hand side vector of dimension dim . For simplicity, the case of a two dimensional equation system of order n is shown below:

$$\begin{bmatrix} M_n(1,1) & M_n(1,2) \\ M_n(2,1) & M_n(2,2) \end{bmatrix} \cdot \begin{bmatrix} \frac{d^n \varphi_1}{dt^n} \\ \frac{d^n \varphi_2}{dt^n} \end{bmatrix} + \dots + \begin{bmatrix} M_1(1,1) & M_1(1,2) \\ M_1(2,1) & M_1(2,2) \end{bmatrix} \cdot \begin{bmatrix} \frac{d\varphi_1}{dt} \\ \frac{d\varphi_2}{dt} \end{bmatrix} + \begin{bmatrix} M_0(1,1) & M_0(1,2) \\ M_0(2,1) & M_0(2,2) \end{bmatrix}$$

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
ORD	Order of Equation System	real	0
DIM	Dimension of Equation System	real	1

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
SV [dim,ord]	Coefficients of the Solution Vector	Output	real

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Example

Figure 2 shows the description of equation system of a 3-mass oscillation system using Differential Equation Solver model. The parameters of the system are listed in Table 3. The simulation results are shown in Figure 3.

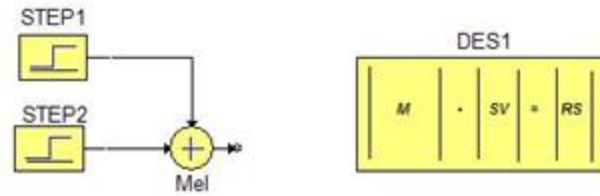


Figure 2. Application example of the 2D Lookup Table XY model

Table 3

Component	Parameter	Value
Step Function STEP1	T0	0 [s]
	TS	0* [s]
	AMPL	10
	Y0	0
Step Function STEP2	T0	0.01 [s]
	TS	0* [s]
	AMPL	-10
	Y0	0
Summation Mel	INPUT[0]	STEP1.VAL
	INPUT[1]	STEP2.VAL
	TS	0* [s]
Differential Equation Solver DES1	DIM	2
	ORD	3

* System simulation time is used as the sample time.

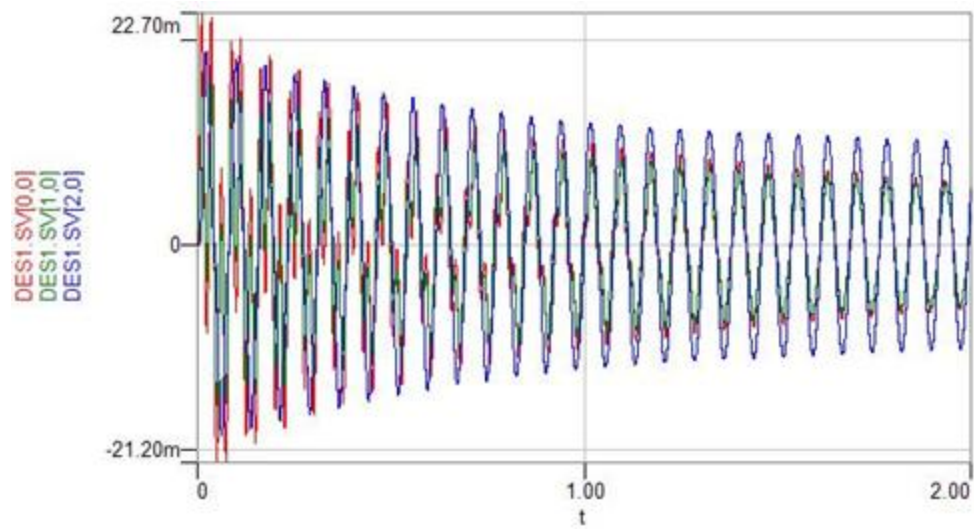


Figure 3. Simulation result

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References

Equations

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

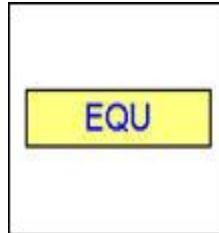


Figure 1. Component Symbol.

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Description

The equation function provides mathematical expressions to all Twin Builder modules. The formula interpreter manages general mathematical and logical expressions, which consist of a number of operands and operators. In addition, widely used mathematical standard functions are supported. Variables are allowed as operands (for example voltages or currents from the circuit components, quantities from the Block Diagram and variables and states from the State Graph). Of course, variables from other expressions can also be used in an expression.

The name of a variable is defined by the user. It can be up to 50 characters long and must start with a letter. The spelling of the variable names is case sensitive.

Note: The variable on the left side must not be a local design variable.

To add an equation, right-click the component, and select **Show Component Dialog**. For information about the settings, see [Component Dialog Settings](#).

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Mathematical Description

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Example

Figure 2 shows an example using equations and initial value components in a state graph to act as control signals in an analog simulation to switch voltage to a load. The parameters of the system are listed in Table 3. The simulation results are shown in Figure 3.

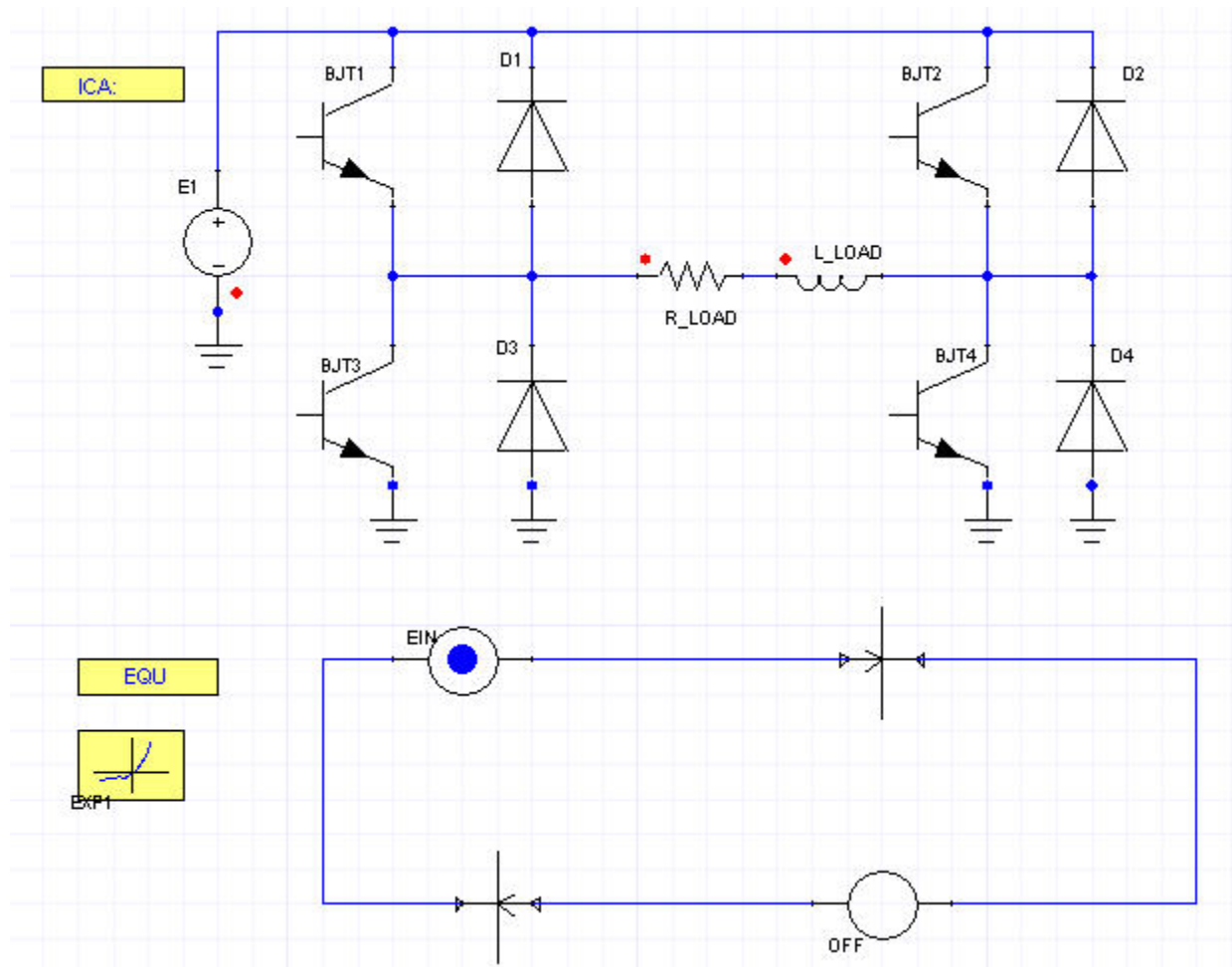


Figure 2. Application example of the FML and FML_INIT models

Table 3

Component	Parameter	Value
Voltage Source E1	EMF Value	200 [V]
	TPERIO	Tend+1 [s]
	PARTDERIV	1
Bipolar Junction Transistor BJT1/BJT4	Characteristic	EXP1.VAL
	CTRL	TSV1
Bipolar Junction Transistor BJT2/BJT3	Characteristic	EXP1.VAL
	CTRL	TSV2
Diode D1/D2/D3/D4	Characteristic	EXP1.VAL
Resistor R_load	R	2.0 [Ohm]
Inductor L_load	L	0.01 [H]
Initial Values FML_INIT1	EQU0	FX := 50
	EQU1	OMEGA := 2*pi*FX
	EQU2	A := 30
	EQU3	D := 0.1
State 11 EIN	TSV1	1
	TSV2	0
	TSV3	0
	TSV4	1
State 11 EIN	TSV1	0
	TSV2	1
	TSV3	1
	TSV4	0
Transition TRANS1	Priority	5
	Condition	(R_LOAD.I ≥ I_UPLIM)
Transition TRANS2	Priority	5
	Condition	(R_LOAD.I ≤ I_LOLIM)

Equation FML1	EQU0	$I\_SET := A \cdot \sin(\Omega \cdot \text{Time})$
	EQU1	$I\_UPLIM := I\_SET + D \cdot A$
	EQU2	$I\_LOLIM := I\_SET - (D \cdot A)$

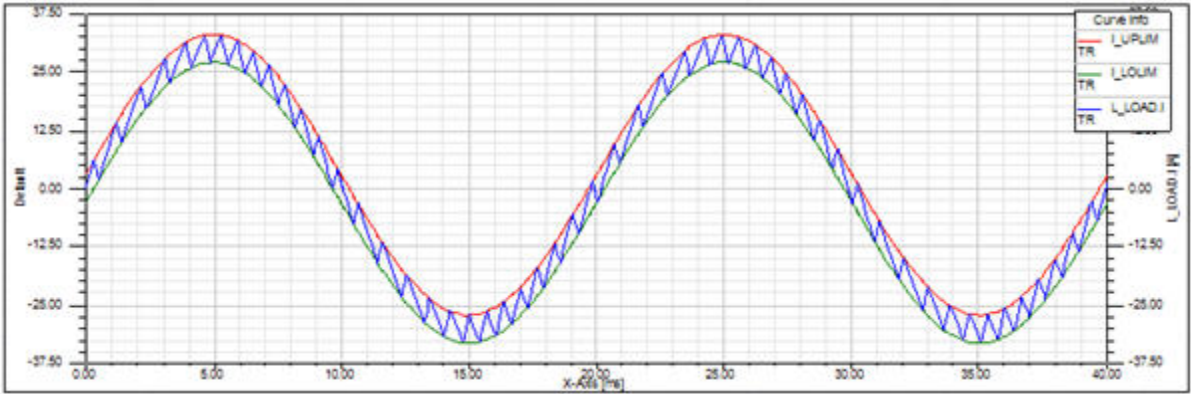


Figure 3. Simulation result

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References

Equation Calculator

Use the **Equation Calculator** dialog box to define a complex equation for loading into the **Equation** field of the parameter table. The dialog box lists all available quantities from the components in the schematic in the pane on the right, and the list of supported functions below the equation pane.

Type equations directly into the equation area of the dialog box, or selecting variables and functions to build the equation.

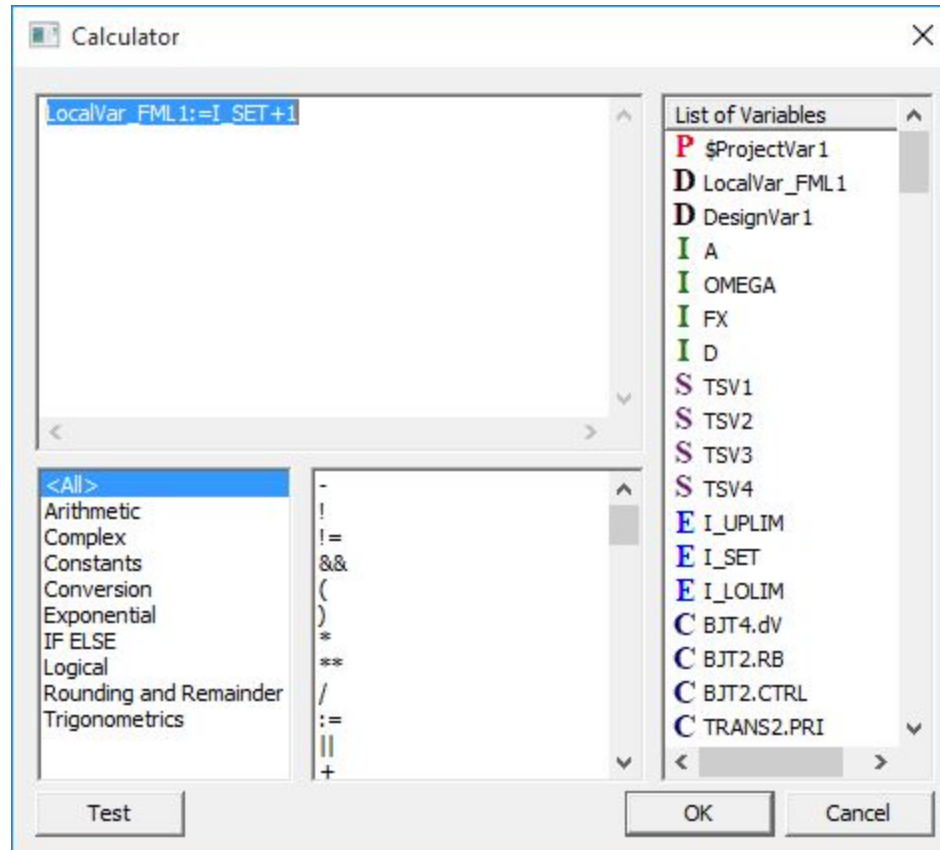
The following shows the variable types available in the list:

P	Project Variables
D	Design Variables (includes local variables defined in the current model/component)
I	Initialization Variables (coming from FML_INIT)
S	State Variables (coming from state graphs)
E	Equation Variables (as used in equations in FML components)
C	Component Variables (coming from all the other components in the schematic)

Note: The syntax used in FML FML_INIT is from the Simplorer modeling language (SML).

Click **Test** to verify the validity of the entered equation.

Click **OK** to close the equation calculator and return to the single line mode. If errors in the definition occur, an error message appears; you must correct the error before quitting the equation calculator.



See *Standard Mathematical Functions* in the main Twin Builder help.

See *Pre-Defined Constants* in the main Twin Builder help.

Initial Values

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2



Figure 1. Component Symbol.

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Description

The Initial Values component is used to specify the initial value of any parameters used in the simulation. Variables defined in an Initial Value Assignment are computed once at the simulation start. They can be used in each component on the sheet.

Note: Parameters, parametric variables, and parameter ports are allowed on the right-hand side as they are evaluated once during simulation. Quantities and signals are not allowed.

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Example

See example in [Equation \(FML\) Component](#)

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References

Multi Dimensional Table

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

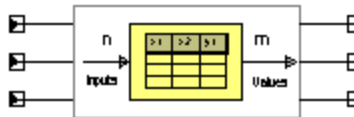


Figure 1. Component Symbol.

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Description

The multidimensional table provides a table of output values which depend on an input vector. Each input has a specific characteristic with extrapolation type. The characteristics of input signals can also be imported from a Twin Builder .mdx file.

NDTAB has 4 interpolation (IP) options: NOSPLINE, LASTSPLINE, DEEPSPLINE and LOOKUP. Note that the LOOKUP option is designed for parameter lookup at the initialization stage of the simulation. No interpolation is made for this option, and it's performed only once at the beginning of the simulation.

Note: If you are using the values of the NDTAB multi-lookup table to assign a component parameter, make sure you provide a valid initial value because during the initialization, the output of NDTAB is not yet executed. In such cases, a conditional assignment can be used as follows:

if (time > 0, NDTAB1.VAL[0], X), where X is a valid initial value (a numeric value or a predefined parameter)

Note: NDTAB and NDNL belong to different component types.

NDTAB is solved by the circuit simulator: for more detailed information, see *Circuit Simulator Processing* in the main Twin Builder help.

NDNL is solved by the block diagram simulator: for more detailed information, see *Block Diagram Simulator Processing* in the main Twin Builder help.

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Assumptions and Limitations

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Mathematical Description

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
INPUT[n]	Input Signal	real	
NOUTPUT	Length of Output Vector	real	
EP	Extrapolation Type	real	
IP	Interpolation Type	real	
CH_FILE	Table File Name	real	

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Output Vector	Output	real
VAL[n]	Output Values	Output	real

dVAL[n][m]	Derivative of Output Vector	Output	real

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Example

This example simulates the transfer characteristic of the IGBT component FS450R12KE3 from Infineon under 25 and 125°C (Vce=20V). The values of the parameter VP, K and N_FET under different working temperature in the component instance FS450R12KE3 are generated by the multidimensional lookup table NDTAB1. The schematic of the example is shown in Figure 2, system parameters are listed in Table 4, and the simulation result is shown in Figure 3.

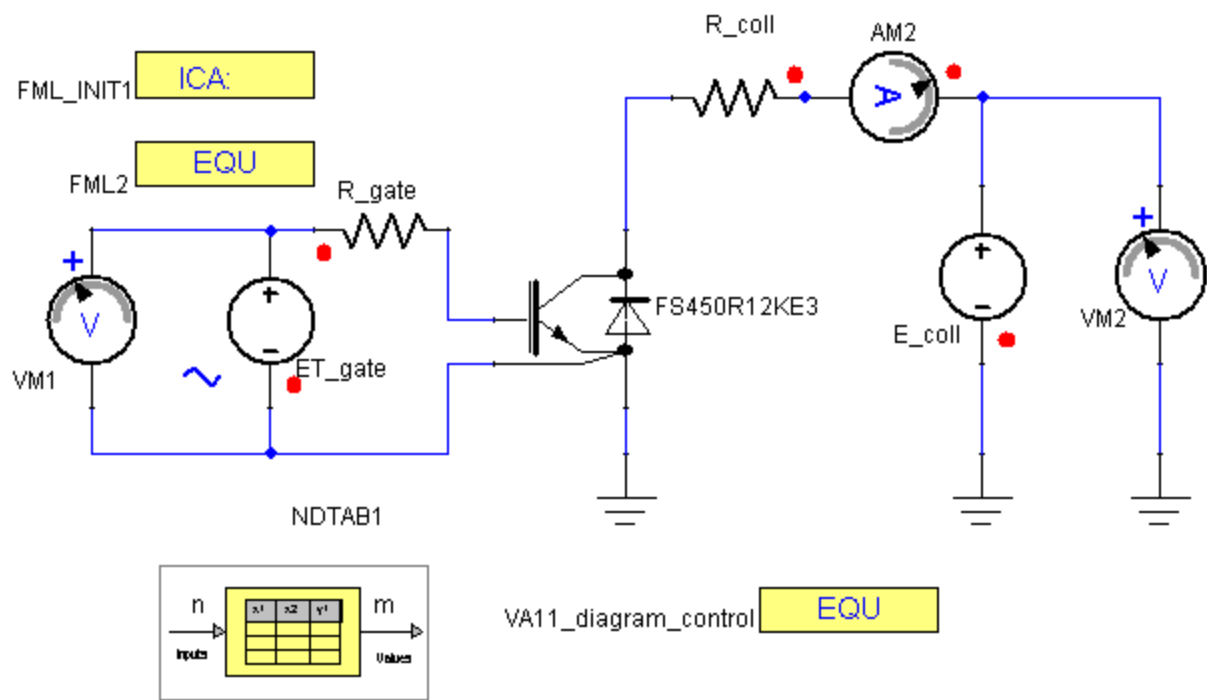


Figure 2. Application examples of the Multi Dimensional Table model

Table 4. System Parameters

Component	Parameter	Value [unit]
Voltage Source ET_gate	AMPL	ampl_gen
	OFF	offset_gen

	FREQ	frequ_gen
	TYPE	Triangular
Voltage Source ET_coll	EMF	U_2
Resistor (Linear) R_gate	R	1 [Ohm]
Resistor (Linear) R_coll	R	1e-6 [Ohm]
IGBT (Basic Dynamic) FS450R12KE3	CTHT1	2.39528
	RTHT1	0.00344543
	CTHT2	1.01297
	RTHT2	0.0216275
	CTHT3	4.15249
	RTHT3	0.0168381
	CTHT4	4.15153
	RTHT4	0.0168419
	CTHD1	1.66667
	RTHD1	0.006
	CTHD2	0.606061
	RTHD2	0.033
	CTHD3	1.5625
	RTHD3	0.032

	CTHD4	3.44828

RTHD4	0.029
TYPE_IGBT	2
TYPE_FWD	2
TYPE_THERM	10
TYPE_DYN	2011
VP	vp_igbt
K	k_igbt
A_FET	0.974674
M_FET	0.939185
N_FET	nfet_igbt
M_BJT	4.65908
ISAT_BJT	0.027036
RB_BJT	0.001
RP_BJT	1e012
M_FWD	1.10758
SYNC	VM1.V
ISAT_FWD	1e-006
RB_FWD	0.00279724
CIN0	3.36e-008
CIN1	6.0266e-008

	CR0	2.43897e-008

CR1	9.21918e-009
TAUFD	8.90327e-008
LC	1.6e-008
RC	0
RG	1.6
LE	1.6e-008
TEMPAMB	Tc
TEMPJNCT0	125 [cel]
VNOM	600
INOM	450
VGAP	1.1
TC_VP	0
TC_K	0
TC_NFET	0
TC_AFET	-0.0610691
TC_MFET	0.00106057
TC_ISAT_BJT	-22.0825
TC_M_BJT	-0.00134845
TC_M_FWD	-0.00757288
TC_ISAT_FWD	-29.5602

	TC_RB_FWD	0.00277806
	TAUTAIL	1.24919e-007
	TYPE_BREAKTHROUGH	0
Initial Values FML_INIT1	EQU0	Points:=100
	EQU1	Curves:=2
	EQU2	Tend:=1
	EQU3	Hmax:- :=Tend/Points/Curves/2
	EQU4	Hmin:=Hmax/1000
	EQU5	U_1_min:=0
	EQU6	U_1_max:=12
	EQU7	Tc_max:=25
	EQU8	Tc_min:=125
	EQU9	offset_gen:=0
	EQU10	ampl_gen:=0
	EQU11	periode_gen:- :=2*Tend/Curves
	EQU12	frequ_gen:=1/periode_gen
	EQU13	U_2:=20
	EQU14	Tc:=125
	Tc_max	0

	Tc_min	0
	Tc	0
Equation FML2	EQU0	$\text{delta\_Tc} := (\text{Tc\_max} - \text{Tc\_min}) / (\text{Curves} - 1)$
	EQU1	$\text{Tc} := \text{step} * \text{delta\_Tc} + \text{Tc\_min}$
	EQU2	$\text{nfet\_igbt} := \text{NDTAB1.VAL}[0]$
	EQU3	$\text{vp\_igbt} := \text{NDTAB1.VAL}[1]$
	EQU4	$\text{k\_igbt} := \text{NDTAB1.VAL}[2]$
Equation VA11_ diagram_control	EQU0	$\text{p} := \text{Time} / \text{Tend}$
	EQU1	$\text{step} := \text{int}(\text{Curves} * \text{p})$
	EQU2	$\text{offset\_gen} := (\text{U\_1\_max} + \text{U\_1\_min}) / 2$
	EQU3	$\text{ampl\_gen} := (\text{U\_1\_max} - \text{U\_1\_min}) / 2$
	EQU4	$\text{periode\_gen} := 2 * \text{Tend} / \text{Curves}$
	EQU5	$\text{frequ\_gen} := 1 / \text{periode\_gen}$
MultiDi- mensional Table NDTAB1	INPUT[0]	Tc
	Extrapolation	LINEAR
	Interpolation	NOSPLINE
	Channel X1=25	Y1=1.78512, Y2=5.99261, Y3=7.07072
	Channel X1=125	Y1=1.72348, Y2=5.4873, Y3=5.59914

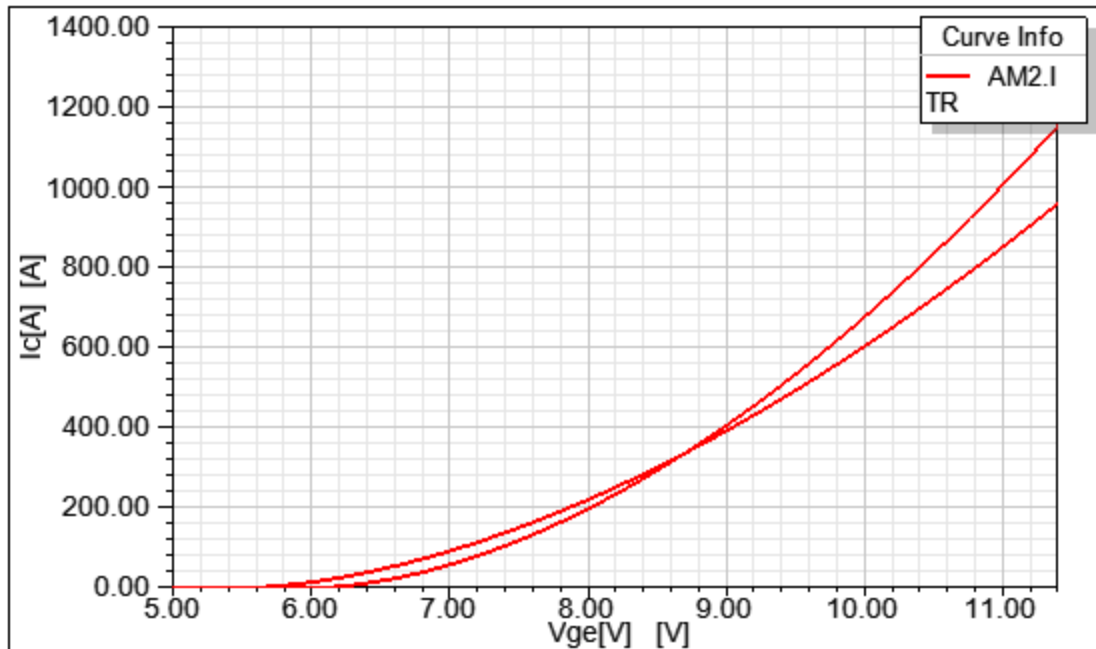


Figure 3. Simulation results-shows the transfer characteristic represented by the current through am2 (AM2.I)

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References

Simulator Parameters

When the simulator parameters block is placed on a Schematic sheet, seventeen Twin Builder simulator parameters can be used as simulation outputs.

Table 1

Description [Unit]	Name	Data Type
The number of iterations used in the last equation system of the current time step	Iterations	real
Size of the current time step [s]	Stepsize	real
Maximum step size used in the current simulation run [s]	Maxstep	real
Minimum step size used in the current simulation run [s]	Minstep	real
Logical output indicating whether transient analysis is occurring (1=yes, 0=no)	TR_Sim	real
Logical output indicating whether DC analysis is occurring (1=yes, 0=no)	DC_Sim	real
Logical output indicating whether AC analysis is occurring (1=yes 0=no)	AC_Sim	real
Real time elapsed during simulation [s]	RunTime	real
Total iterations made during the current simulation run.	TotalIterations	real
Total number of time steps taken during the current simulation run.	TotalSteps	real
Actual integration method used (1=Trapezoidal, 0=Euler)	Method	real
Actual number of iterations used in the current time step for all equation systems.	StepIterations	real
Number of equation systems used in the current time step.	EQSystems	real
Total number of rollbacks during simulation	TotalRollback	real
Total number of rollbacks in time step	StepRollback	real
Time step requested by the circuit solver [s]	ReqdStepSize	real
Reduction of minimum time step required	ReduceMinStep	real

Modeling Tools - Time Functions

- Arc Tangent (ARCTAN)
- 2D Lookup Table (DATAPAIRS)
- Needle Pulses (NEEDLE)
- Pulse Wave (PULSE)
- Pulse-Width Modulation (PWM)
- Saw-Tooth (ST_RISE/ST_FALL)
- Sine Wave (SINE)
- Trapezoidal Wave (TRAPEZ)
- Triangular Wave (TRIANG)
- Voltage Controlled Oscillator (VCO)

Using Time Functions

Time functions can be used for modeling in several ways.

- In electrical circuits, time functions can alter transient input signals of externally controlled sources.
- In block diagrams, time functions can define nominal values, disturbances and reference values.
- In the state graphs time functions define comparison functions and synchronization signals.

Predefined Time Functions

Predefined time functions have a quality determined behavior for which certain parameters can be defined. Predefined time functions are: Sine, Pulse, Triangular and Trapezoidal wave, Sawtooth rising and falling as well Needle pulses, Arc tangent and the Controlled oscillator.

In the property dialog box, the frequency, period, initial delay, amplitude, phase, periodicity, and offset can be modified.

Changing Period

You can change the period TPERIO independently of frequency. TPERIO reduces or lengthens the signal depending on the time span of the corresponding period ($1/\text{frequency}$). Figures 1, 2, and 3 show the output waveforms of the Triangular Wave TRIANG1 when $\text{TPERIO} = 1/\text{FREQ}$, $\text{TPERIO} < 1/\text{FREQ}$ and $\text{TPERIO} > 1/\text{FREQ}$.

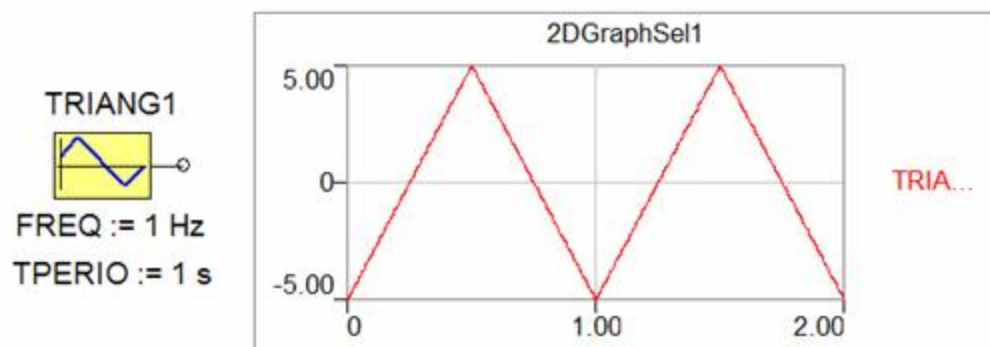


Figure 1. Waveform of the Triangle Wave when $\text{TPERIO} = 1/\text{FREQ}$

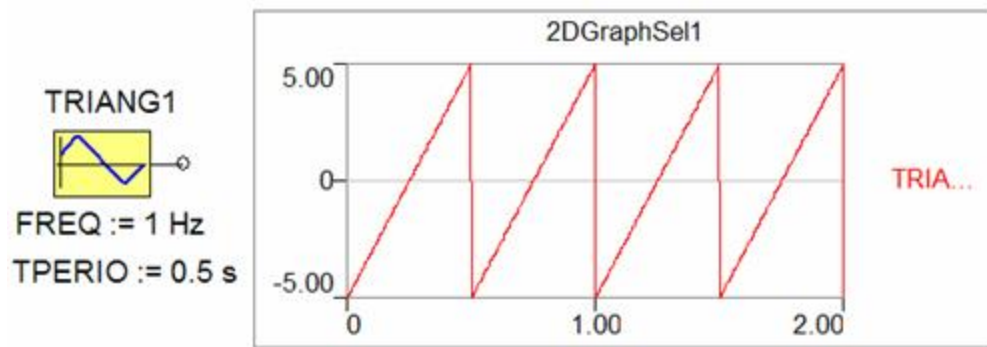


Figure 2. Waveform of a Triangle Wave when $TPERIO < 1/FREQ$

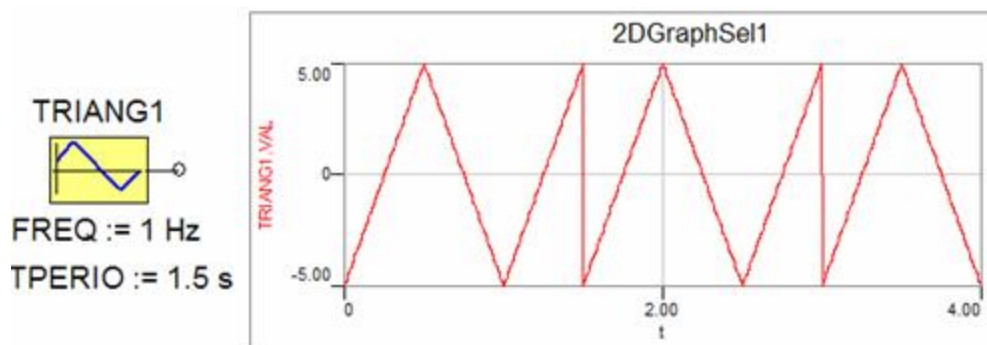


Figure 3. Waveform of a Triangle Wave when $TPERIO > 1/FREQ$

Changing Periodicity

For the [Sawtooth](#), [Sine](#), [Pulse](#), [Trapezoidal](#), and [Triangular](#) wave components, you can specify whether or not the wave is Periodical (PERIO=Yes or No) independently of its Period (TPERIO). Figures 4 and 5 show the output waveforms of the Sawtooth Wave SAWTOOTH1 when PERIO = Yes, and PERIO = No.

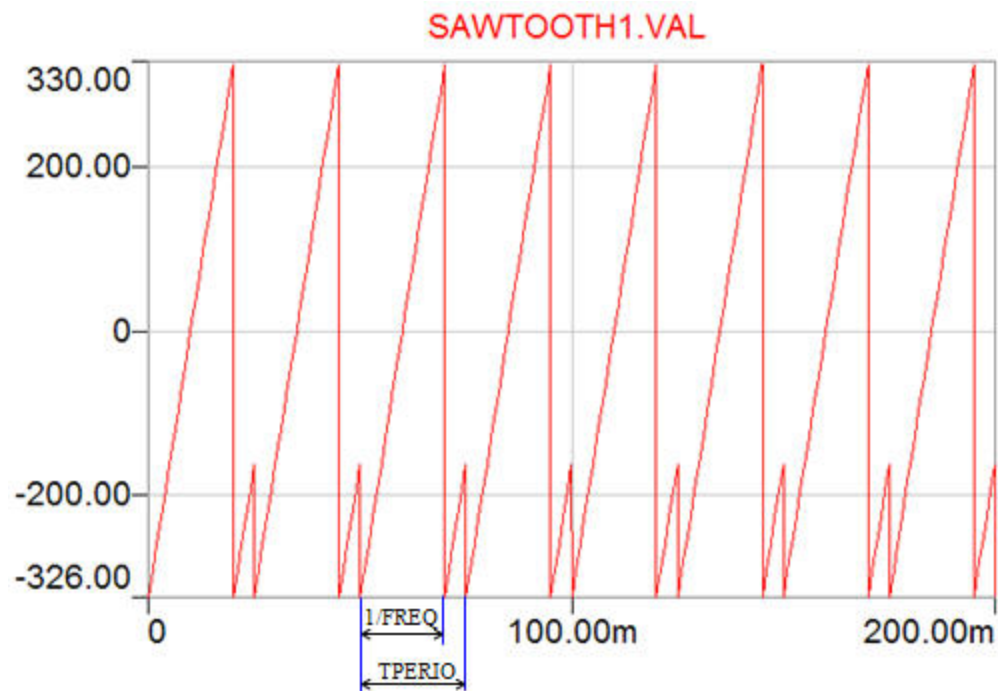


Figure 4. Waveform of a Sawtooth Wave when FREQ=50Hz, TPERIO=0.025s, and PERIO=Yes (1)

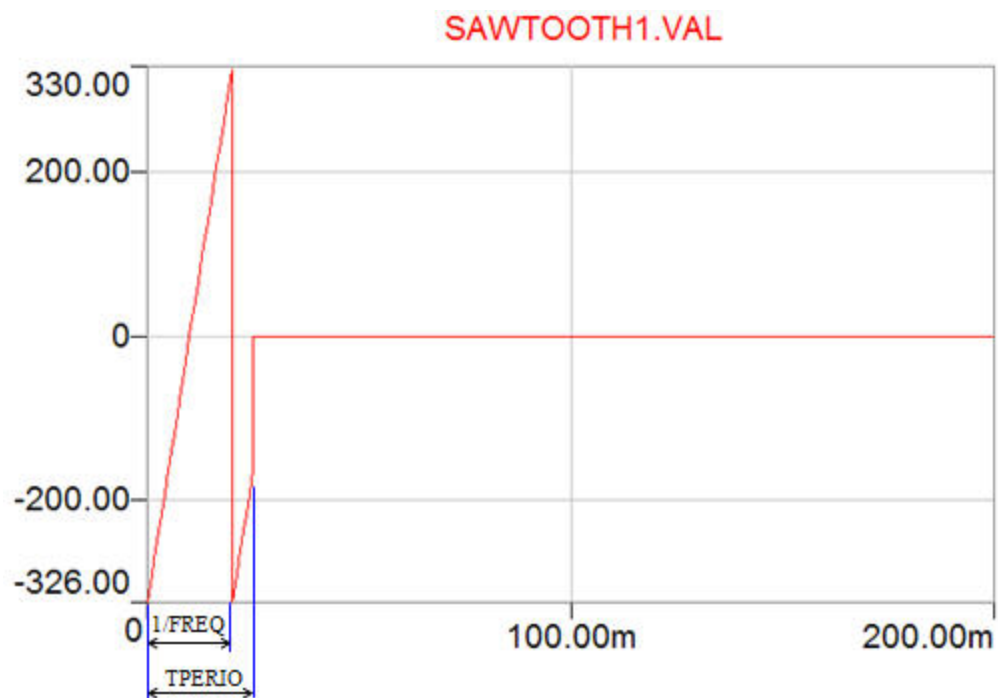


Figure 5. Waveform of a Sawtooth Wave when $FREQ=50\text{Hz}$, $TPERIO=0.025\text{s}$, and $PERIO=\text{No}$ (0)

User-Defined Time Functions

In addition to the predefined time functions, you can define your own time functions. The DATAPAIRS 2D Lookup Table creates time function data pairs which are saved in an external file or in the simulation sheet.

The parameters period, initial delay, phase and periodicity can also be changed in this dialog box.

Arc Tangent Function

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

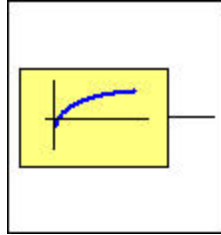


Figure 1. Component Symbol.

- [Description](#)
- [Assumptions and Limitations](#)
- [Mathematical Description](#)
- [Netlist Syntax](#)
- [Parameters](#)
- [Input/Output Quantities](#)
- [Example](#)
- [References](#)

Description

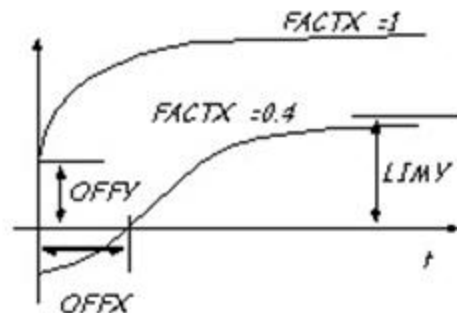


Figure 2. Effect of parameters on Arc Tangent output.

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Assumptions and Limitations

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Mathematical Description

The output of the Arc Tangent Function can be described as following:

$$y(t) = \frac{LIMY}{\pi/2} \cdot \arctan[FACTX \cdot (t-OFFX)] + OFFY$$

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
LIMY	Limit Y	real	1.578 [rad]
FACTX	Factor X	real	1
OFFX	Offset X	real	0 [s]
OFFY	Offset Y	real	0

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Arc Tangent Function	Output	real

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Example

Here the output waveform of the Arc Tangent Function is shown. The parameters of the system are listed in Table 3. The simulation results are shown in Figure 3.



Figure 2. Application example of the Arc Tangent Funciton model

Table 3

Component	Parameter	Value
Arc Tangent Function ARCTAN1	LIMY	1.578 [rad]
	FACTX	1
	OFFX	0 [s]
	OFFY	0

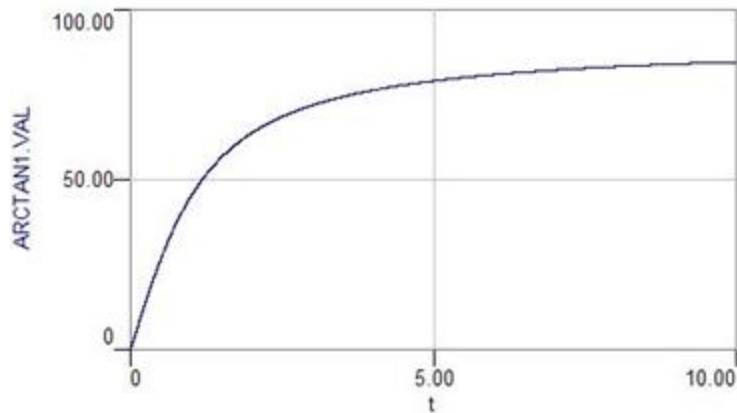


Figure 3. Simulation results

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References

2D Lookup Table

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

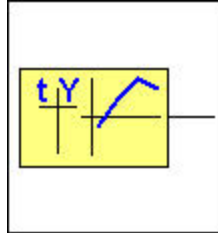


Figure 1. Component Symbol.

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- [Mathematical Description](#)
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- [Parameters](#)
- [Input/Output Quantities](#)
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Description

The function allows the definition of wave forms from a set of fixed data points with linear interpolation between them (straight lines from point to point) or rectangular lines between them (two orthogonal lines from point to point, which are parallel to the coordinate axes).

The t values of the data-pairs must be monotonous rising. If you have checked non-periodical and the simulation time is longer than the last defined t value, the time function provides '0' for all values outside the t range.

Note: The time T values in the data file are to be matched exactly, because of the simulator's internal step size algorithms. The next value of $T=T+dt$ are used for the computation.

The simulator tries to match all values of a data set exactly. Very large data sets (e.g., from a measuring instrument) cause a reduction in the simulator speed. If possible, reduce the data sets to a required minimum to decrease simulation time.

The function `DATAPAIRS(model_name, t-value)` provides the Y value of a given t value. For example, `DATAPAIRS(XY1.VAL,5) -> Y` value of the characteristic XY1 for the t value 5.

Note: This function is different from the 2D Lookup Table XY under **Twin Builder Components>Basic Elements Library>Modeling Tools>Characteristics**, which is used to

describe nonlinear behavior different from the predefined characteristics. For more information, see [2D Lookup Table XY](#).

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Assumptions and Limitations

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Mathematical Description

The output of the 2D Lookup Table with linear interpolation can be described as following:

$$y(t) = y(i) + \frac{y(i+1) - y(i)}{t(i+1) - t(i)} \quad t \text{ lies in the } i\text{-th interval}$$

The output of the 2D Lookup Table without interpolation is:

$$y(t) = y(i) \quad \text{for} \quad t(i) \leq t \leq (i+1)$$

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
TPERIO	Period	real	--[s]*
PHASE	Phase [deg]	real	0 [deg]
PERIO	Periodic	real	1
TDELAY	Initial Delay [s]	real	0 [s]
DPACCEL	Acceleration	real	0
FILE	File Name	real	--

* the default value of TPERIO is set automatically after the data pair is read in.

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Value	Output	real

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Example

Figure 2 shows the application example of the 2D Lookup Table. The parameters of the system are listed in Table 3. The simulation results are shown in Figure 3.

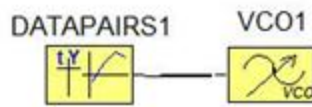


Figure 2. Application example of the 2D Lookup Table

Table 3

Component	Parameter	Value
2D Lookup Table DATAPAIRS1	TPERIO	3 [s]
	PHASE	0 [deg]
	PERIO	1
	TDELAY	0 [s]
Controlled Oscillator VCO1	UL	1
	LL	-1
	AMPL	1
	PHASE	0 [deg]

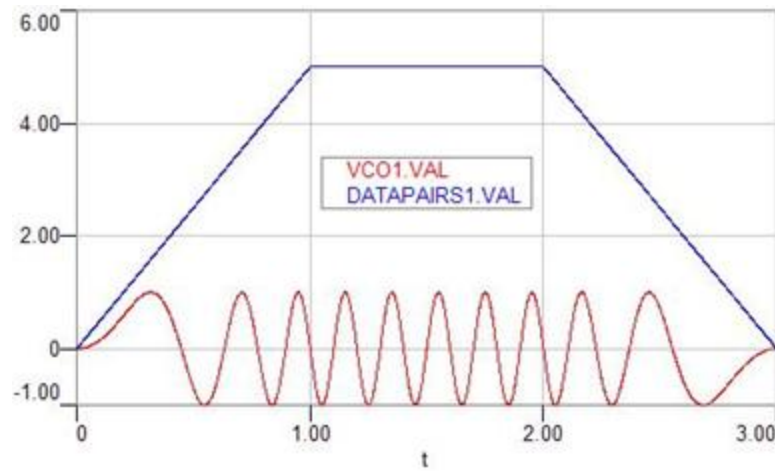


Figure 3. Simulation results

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References

Needle Pulses

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

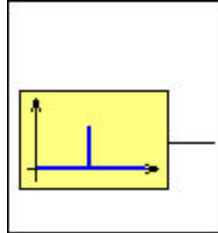


Figure 1. Component Symbol.

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Description

The function provides needle pulses with a defined amplitude and frequency after a delay to the simulation start and a delay within the period at the output.

If you have checked non-periodical and the simulation time is longer than the defined period plus delays, the time function provides the offset value for all values outside of this range.

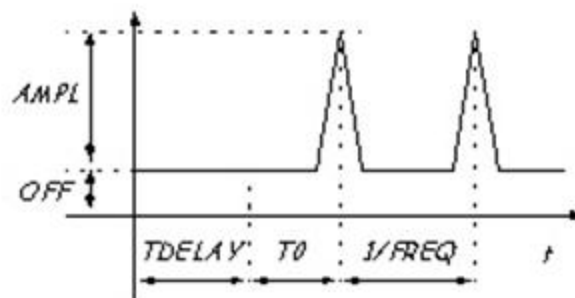


Figure 2. Effect of parameters on Needle Pulse output.

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Assumptions and Limitations

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Mathematical Description

The output of the Needle Pulses model can be described as following:

$$y(t) = \text{AMPL} \quad \text{if } t = \text{TDELAY} + T0 + \frac{K}{\text{FREQ}} \quad K \in \mathbb{N}$$

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
FREQ	Frequency [Hz]	real	50 [Hz]
AMPL	Amplitude of Pulses	real	1
T0	Delay within the Period [s]	real	0 [s]
PERIO	Periodic	real	1
OFF	Offset	real	0
TDELAY	Initial Delay [s]	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Needle Pulse Function	Output	real

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Example

Here the output waveform of the Needle Pulses is shown. The parameters of the system are listed in Table 3. The simulation results are shown in Figure 3.

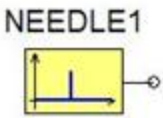


Figure 2. Application example of the Needle Pulses model

Table 3

Component	Parameter	Value
Needle Pulses NEEDLE1	FREQ	50 [Hz]
	AMPL	1
	T0	0 [s]
	PERIO	1
	OFF	0
	TDELAY	0 [s]

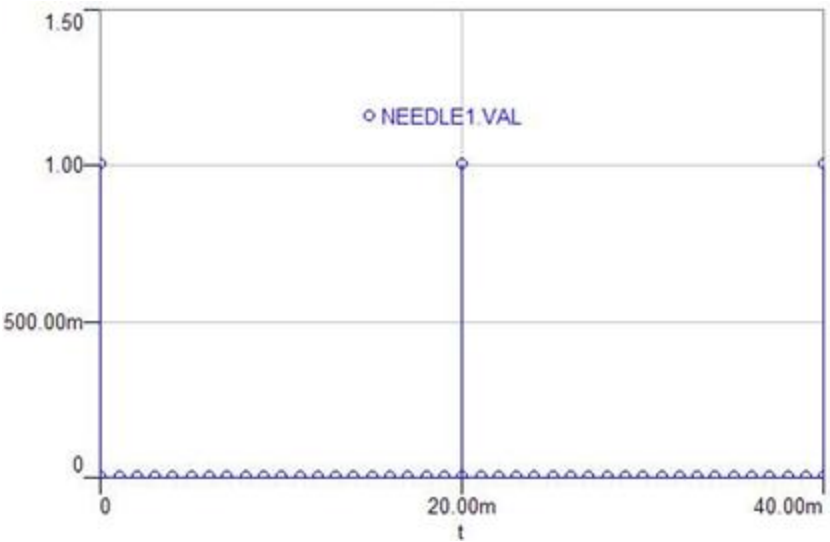


Figure 3. Simulation results

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References

Pulse

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

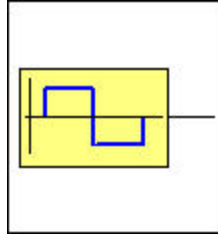


Figure 1. Component Symbol.

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Description

If you have set Periodical=No (PERIO=0), and the simulation time is longer than the defined Period (TPERIO) plus the initial delay (TDELAY), the time function provides '0' for all values outside of this range. (See also [Changing Periodicity](#).)

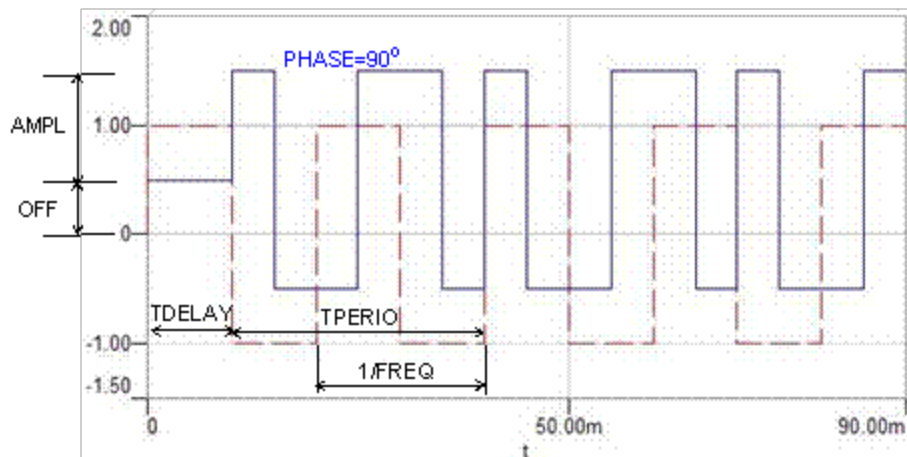


Figure 2. Effect of parameters on Pulse output.[Top](#)

Assumptions and Limitations

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Mathematical Description

The output of the Pulse Wave can be described as following:

$$y(t) = \text{AMPL} \cdot \text{pulse}(360^\circ \cdot \text{FREQ} \cdot t + \text{PHASE}) + \text{OFF}$$

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
FREQ	Frequency	real	50 [Hz]
TPERIO	Period	real	Tend + 1
AMPL	Amplitude	real	0.326k
PHASE	Phase	real	0 [deg]
PERIO	Periodic	real	1
OFF	Offset	real	0
TDELAY	Initial Delay	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type

VAL	Pulse	Output	real
dVAL	Derivative of Value	Output	real

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Example

Figure 2 shows application of the Pulse Wave model. The parameters of the system are listed in Table 3. The simulation results are shown in Figure 3.

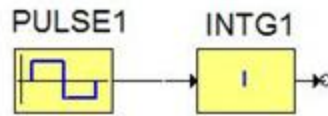


Figure 2. Application example of the Pulse Wave model

Table 3

Component	Parameter	Value
Pulse Wave PULSE1	AMPL	5 [V]
	TDELAY	0 [s]
	OFF	0 [V]
	FREQ	50 [Hz]
	PHASE	0 [degree]
Integrator INTG1	TS	0* [s]
	KI	1
	Y0	0

* system simulation time step is used as the sampling time.

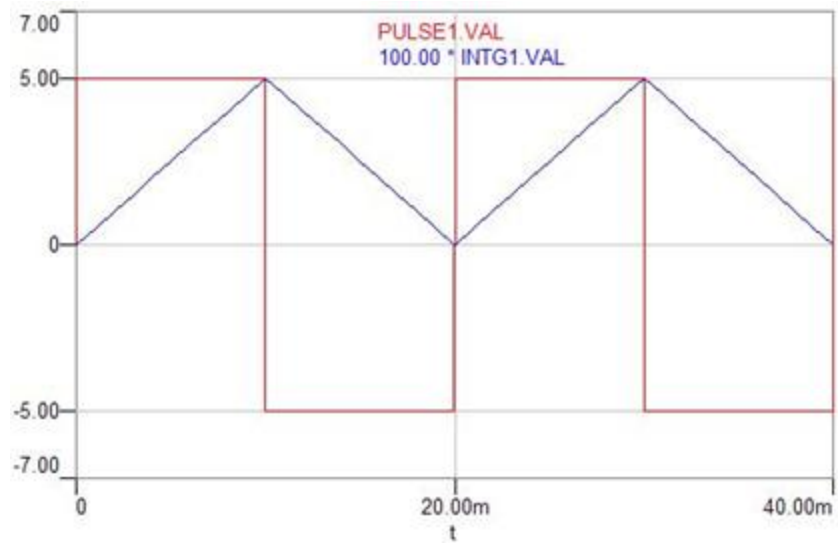


Figure 3. Simulation results

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References

PWM

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

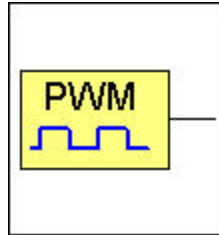


Figure 1. Component Symbol.

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Description

The PWM model provides a pulse-width modulated signal with amplitude '1'. The value remains at '1' for the duty time which is a fraction of the period time. The phase parameter shifts the positive edge of the PWM. If the phase shift is set to '0', the PWM value goes up to '1' with the start of every new period. The initial delay value delays the PWM at simulation start. As long as the simulation time is smaller than the initial delay, the output of the PWM remains '0'. Please note: The delay behavior of the PWM time functions differs from the other time functions.

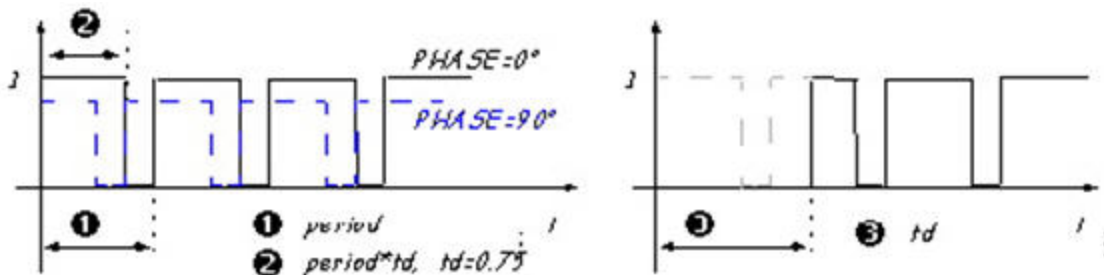


Figure 2. Effect of parameters on PWM output signal.

The minimum time step should consider the PWM times. Especially the synchronization on the edges of the PWM depends on the selected HMIN.

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Assumptions and Limitations

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Mathematical Description

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Netlist Syntax

```
MODEL PWM ?InstanceName(@InstanceName):(@ (Refbase)@(ID)) ( PERIOD:= @PERIOD,  
DC:= @DC, TD:= @TD, PHASE:= @PHASE) SRC: DB(Lib:=@ModelLibraryName) ;
```

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
PERIOD	Period Time	real	1 [s]
DC	Duty Cycle	real	0.5
PHASE	Phase Shift	real	0 [deg]
TD	Initial Delay	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
val	PWM Output [/]	Output	real

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Example

Figure 2 shows the application example of the PWM model. The Duty Cycle of the PWM block PWM1 is decided by the 2D Lookup Table DATAPAIRS1, and the output signal of PWM1 con-

trols the switching of the Ideal Switch S1. The parameters of the system are listed in Table 3. The simulation results are shown in Figure 3~5.

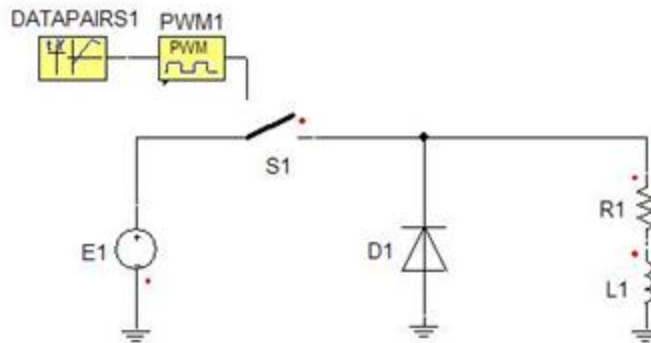


Figure 2. Application example of the 2D Lookup Table

Table 3

Component	Parameter	Value
2D Lookup Table DATAPAIRS1	TPERIO	0.1 [s]
	PHASE	0 [deg]
	PERIO	1
	TDELAY	0 [s]
PWM PWM1	PERIOD	1m [s]
	DC	DATAPAIRS1.VAL
	PHASE	0 [deg]
	TD	0 [s]
Voltage Source E1	EMF	1 [V]
Ideal Switch S1	CTRL	PWM1.VAL
Resistor R1	R	0.5 [Ohm]
Inductor L1	L	20m [H]
	I0	0 [A]
Diode (Equivalent Line) D1	VF	0.8 [V]
	RR	100k [Ohm]
	RB	1m [Ohm]

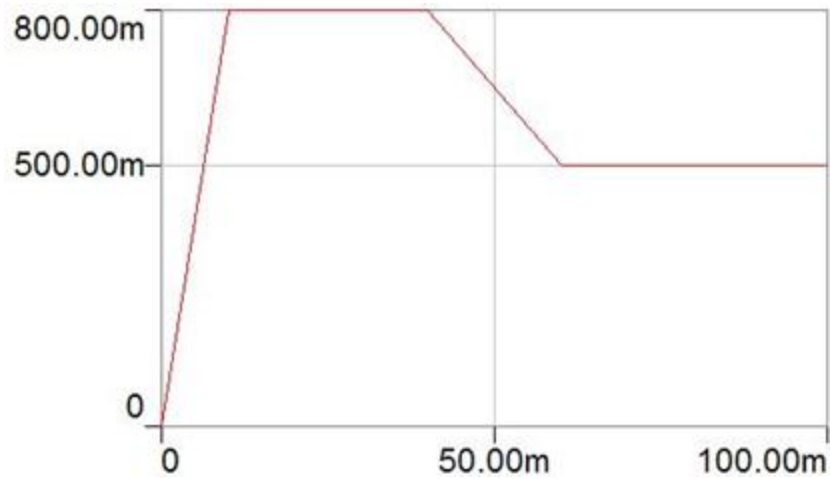


Figure 3. Data pair of DATAPAIRS1

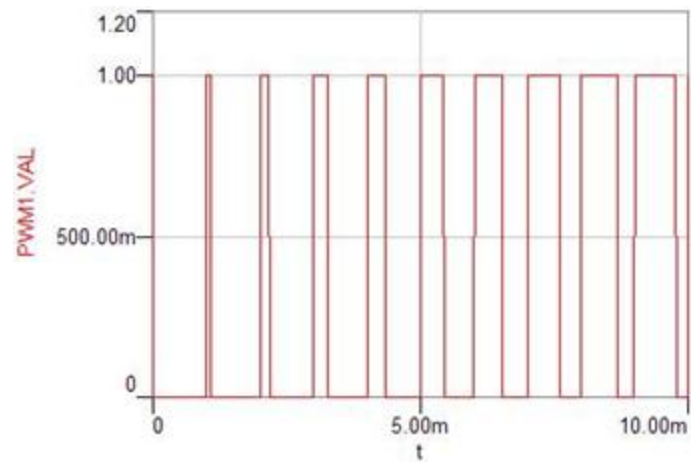


Figure 4. Output of PWM1

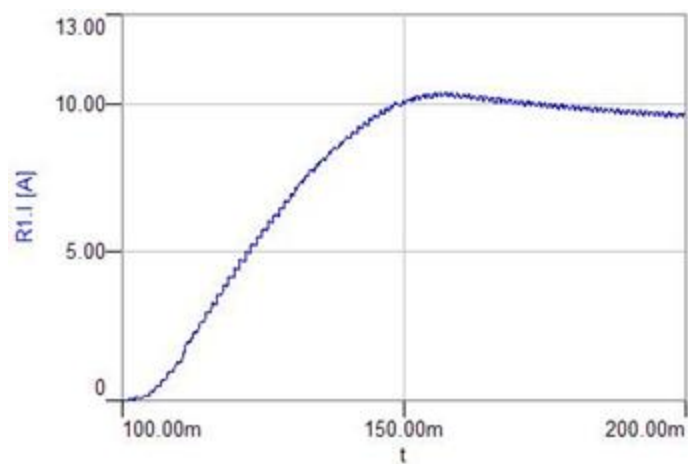


Figure 5. current through R1

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References

Saw-Tooth Function

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

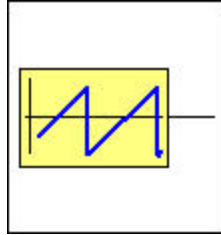


Figure 1. Component Symbol.

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Description

If you have set Periodical=No (PERIO=0), and the simulation time is longer than the defined Period (TPERIO) plus the initial delay (TDELAY), the time function provides '0' for all values outside of this range. (See also [Changing Periodicity](#).)

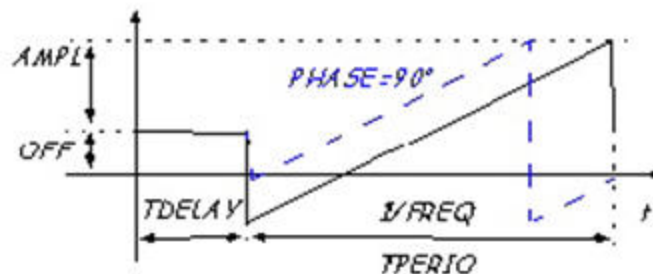


Figure 2. Effect of parameters on Saw-tooth Wave output.

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Assumptions and Limitations

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Mathematical Description

The output of the Saw-Tooth Function can be described as following:

$$y(t) = \text{AMPL} \cdot \text{sawtooth}(360^\circ \cdot \text{FREQ} \cdot t + \text{PHASE}) + \text{OFF}$$

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
FREQ	Frequency	real	50 [Hz]
TPERIO	Period	real	Tend + 1
AMPL	Amplitude	real	0.326k
PHASE	Phase	real	0 [deg]
PERIO	Periodic	real	1
OFF	Offset	real	0
TDELAY	Initial Delay	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Saw-tooth Function	Output	real
dVAL	Derivative of Saw-tooth Function	Output	real

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Example

Figure 2 shows the application of the Saw-Tooth Function model. The parameters of the system are listed in Table 3. The simulation results are shown in Figure 3.

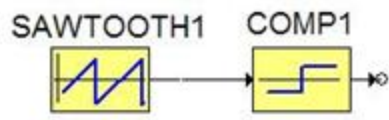


Figure 2. Application example of the Saw-Tooth Function model

Table 3

Component	Parameter	Value
Saw-Tooth Function SAWTOOTH1	FREQ	50 [Hz]
	TPERIO	20 [ms]
	AMPL	2
	PHASE	0 [deg]
	PERIO	1
	OFF	0
	TDELAY	0 [s]
Comparator COMP1	TS	0* [s]
	THRES	1
	VAL1	1
	VAL2	-1

* system simulation time step is used as the sampling time.

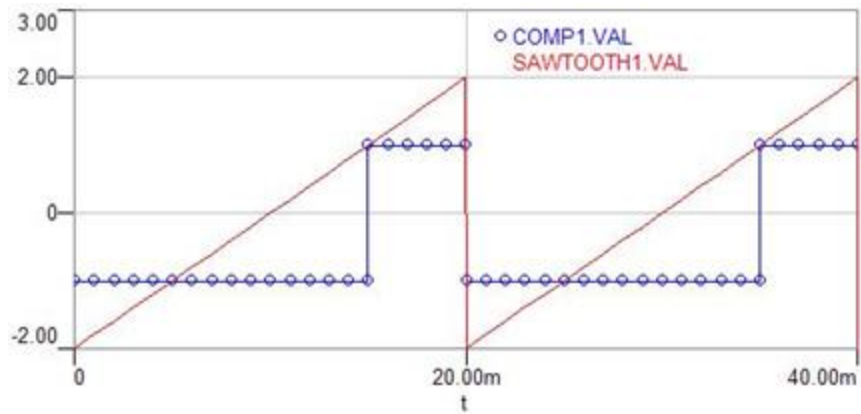


Figure 3. Simulation results

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References

Sine Wave

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

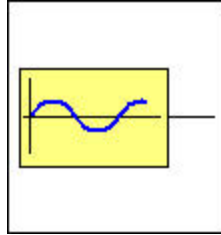


Figure 1. Component Symbol.

- Description
- Assumptions and Limitations
- Mathematical Description
- Netlist Syntax
- Parameters
- Input/Output Quantities
- Example
- References

Description

If you have set Periodical=No (PERIO=0), and the simulation time is longer than the defined Period (TPERIO) plus the initial delay (TDELAY), the time function provides '0' for all values outside of this range. (See also [Changing Periodicity](#).)

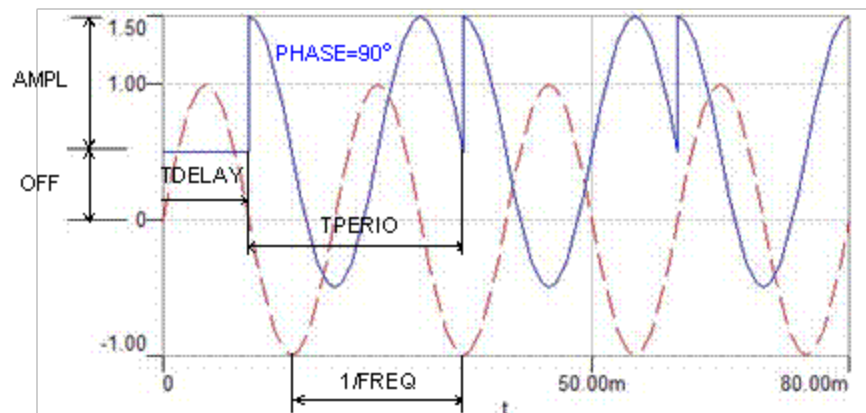


Figure 2. Effect of parameters on Sine Wave output[Top](#)**Assumptions and Limitations**[Top](#)**Mathematical Description**

The output of the Sine Wave can be described as following:

$$y(t) = \text{AMPL} \cdot \sin(360^\circ \cdot \text{FREQ} \cdot t + \text{PHASE}) + \text{OFF}$$

The RMS value of the output $y(t)$ can be calculated as:

$$\text{RMS} = \frac{\text{AMPL}}{\sqrt{2}}$$

[Top](#)**Netlist Syntax**

Netlist generated by [Special Component Dialog](#).

[Top](#)**Parameters****Table 1**

Name	Description	Data Type	Default Value [Unit]
FREQ	Frequency	real	50 [Hz]
TPERIO	Period	real	Tend + 1
AMPL	Amplitude	real	0.326k
PHASE	Phase	real	0 [deg]
PERIO	Periodic	real	1
OFF	Offset	real	0
TDELAY	Initial Delay	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Sine Wave	Output	real
dVAL	Derivative of Value	Output	real

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Example

Figure 2 shows application of the Sine Wave model. The parameters of the system are listed in Table 3. The simulation results are shown in Figure 3. Note that the integration of the output sinusoidal wave form of SINE1 gives out a inverted cosine waveform with an offset of 1, and an amplitude of $1/(2\pi)$, demonstrated as following:

$$\int_0^t \sin(2\pi \cdot f \cdot T) dT = \frac{1}{2\pi} [1 - \cos(2\pi f)]$$

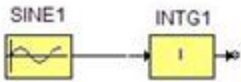


Figure 2. Application example of the Sine Wave model

Table 3

Component	Parameter	Value
Sine Wave SINE1	AMPL	1 [V]
	TDELAY	0 [s]
	OFF	0 [V]
	FREQ	1 [Hz]
	PHASE	0 [degree]
Integrator INTG1	TS	0* [s]
	KI	1
	Y0	0

* system simulation time step is used as the sampling time.

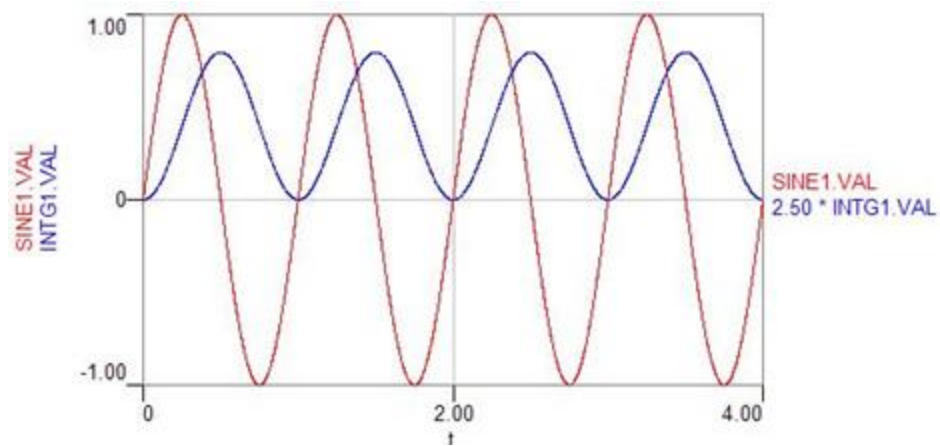


Figure 3. Simulation results

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References

Trapezoidal Wave

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

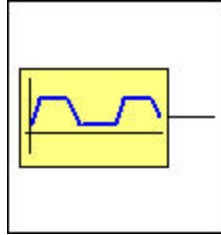


Figure 1. Component Symbol.

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Description

If you have set Periodical=No (PERIO=0), and the simulation time is longer than the defined period ($TRISE + PWIDTH + TFALL$) plus the initial delay (TDELAY), the time function provides '0' for all values outside of this range. (See also [Changing Periodicity](#).)

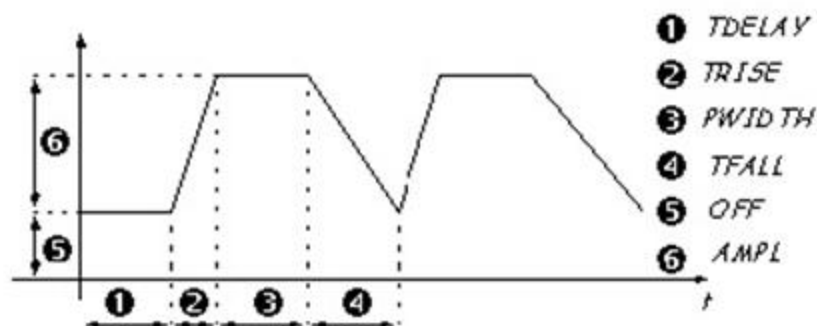


Figure 2. Effect of parameters on Trapezoidal Wave output.

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Assumptions and Limitations

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Mathematical Description

The output of the Trapezoidal Wave can be described as following:

$$y(t) = \text{AMPL} \cdot \text{trapez}(360^\circ \cdot \text{FREQ} \cdot t + \text{PHASE}) + \text{OFF}$$

$$\text{FREQ} = \frac{1}{\text{TRISE} + \text{TFALL} + \text{PWIDTH}}$$

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
TRISE	Rise Time	real	5 [ms]
TFALL	Fall Time	real	10 [ms]
PWIDTH	Pulse Width	real	5 [ms]
TPERIO	Period	real	20 [ms]
AMPL	Amplitude	real	0.326k
PHASE	Phase	real	0 [deg]
PERIO	Periodic	real	1
OFF	Offset	real	0
TDELAY	Initial Delay	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Trapezoidal Wave	Output	real
dVAL	Derivative of Value	Output	real

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Example

Figure 2 shows the application of the Trapezoidal Wave model. The parameters of the system are listed in Table 3. The simulation results are shown in Figure 3.

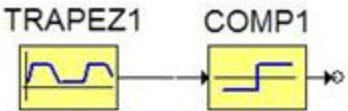


Figure 2. Application example of the Trapezoidal Wave model

Table 3

Component	Parameter	Value
Trapezoidal Wave TRAPEZ1	TRISE	5 [ms]
	TFALL	5 [ms]
	PWIDTH	10 [ms]
	TPERIO	20 [ms]
	AMPL	2
	PHASE	0 [degree]
	PERIO	1
	OFF	0
	TDELAY	0 [s]

Comparator COMP1	TS	0* [s]
	THRES	1
	VAL1	1
	VAL2	-1

* system simulation time step is used as the sampling time.

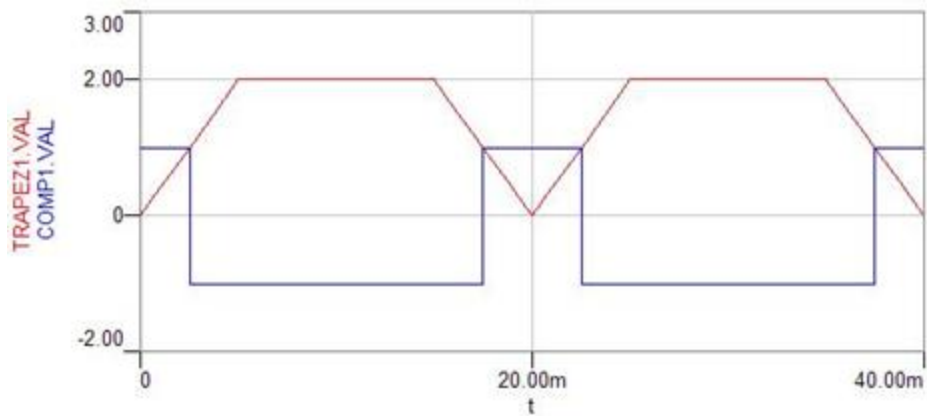


Figure 3. Simulation results

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References

Triangular Wave

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

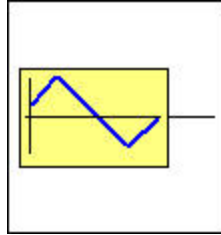


Figure 1. Component Symbol.

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Description

If you have set Periodical=No (PERIO=0), and the simulation time is longer than the defined Period (TPERIO) plus the initial delay (TDELAY), the time function provides '0' for all values outside of this range. (See also [Changing Periodicity](#).)

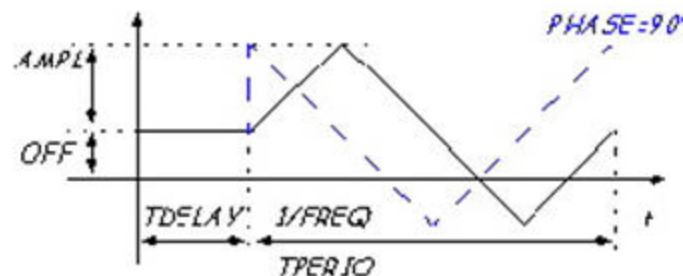


Figure 2. Effect of parameters on Triangular Wave output.

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Assumptions and Limitations

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Mathematical Description

The output of the Triangular Wave can be described as following:

$$y(t) = \text{AMPL} \cdot \text{triang}(360^\circ \cdot \text{FREQ} \cdot t + \text{PHASE}) + \text{OFF}$$

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
FREQ	Frequency	real	50 [Hz]
TPERIO	Period	real	Tend + 1
AMPL	Amplitude	real	0.326k
PHASE	Phase	real	0 [deg]
PERIO	Periodic	real	1
OFF	Offset	real	0
TDELAY	Initial Delay	real	0 [s]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Triangular Wave	Output	real
dVAL	Derivative of Value	Output	real

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Example

Figure 2 shows application of the Triangular Wave model. The parameters of the system are listed in Table 3. The simulation results are shown in Figure 3.

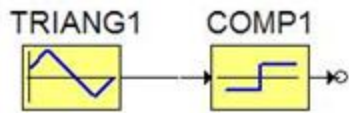


Figure 2. Application example of the Triangular Wave model

Table 3

Component	Parameter	Value
Triangular Wave TRIANG1	AMPL	5 [V]
	TDELAY	0 [s]
	OFF	0 [V]
	FREQ	50 [Hz]
	PHASE	0 [degree]
Comparator COMP1	TS	0* [s]
	THRES	2
	VAL1	-1
	VAL2	1

* system simulation time step is used as the sampling time.

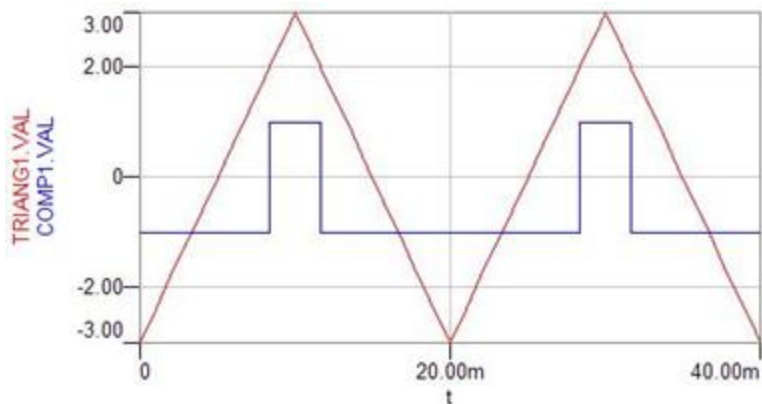


Figure 3. Simulation results

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References

Controlled Oscillator

Library: Basic Elements	Modeling Language: SML	Version Number: Twin Builder 2025.2

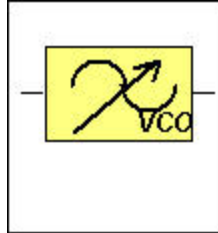


Figure 1. Component Symbol.

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Description

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Mathematical Description

The output of the Controlled Oscillator model can be described as following:

$$y(t) = \text{AMPL} \cdot \sin(360^\circ \cdot f + \text{PHASE})$$

$$\begin{array}{lll} f = \text{UL} & \text{when} & \text{UL} < \text{CTRL} \\ f = \text{LL} & \text{when} & \text{LL} > \text{CTRL} \end{array}$$

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Netlist Syntax

Netlist generated by [Special Component Dialog](#).

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Parameters

Table 1

Name	Description	Data Type	Default Value [Unit]
UL	Input Signal Upper Limit	real	1
LL	Input Signal Lower Limit	real	-1
AMPL	Amplitude	real	1
PHASE	Phase [deg]	real	0 [deg]

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Input/Output Quantities

Table 2

Name	Description [Unit]	Direction	Data Type
VAL	Sine Wave	Output	real
CTRL	Input Signal	Input	real
FREQ	Current Frequency [Hz]	Output	real

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Example

Figure 2 shows the application example of the Controlled Oscillator . The parameters of the system are listed in Table 3. The simulation results are shown in Figure 3.

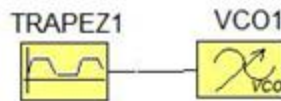


Figure 2. Application example of the Controlled Oscillator model

Table 3

Component	Parameter	Value

Trapezoidal Wave TRAPEZ1	TRISE	1 [s]
	TFALL	1 [s]
	PWIDTH	1 [s]
	TPERIO	3 [s]
	AMPL	5
	PHASE	0 [degree]
	OFF	0
	TDELAY	0 [s]
Controlled Oscillator VCO1	UL	1
	LL	-1
	AMPL	1
	PHASE	0 [deg]

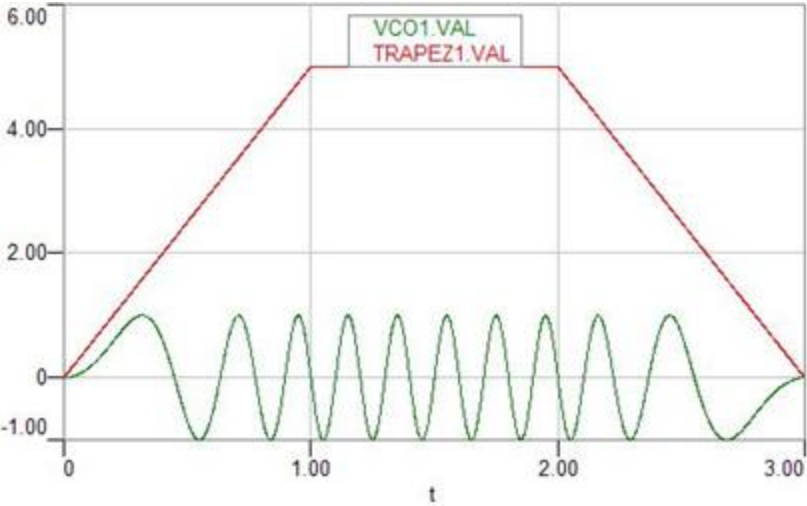


Figure 3. Simulation results

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References

Special Component Dialogs

Special Component Dialogs (EQU)

The following parameters are set in the Component Dialog for the **Equation** block:

Name:

Specify the Name of the component instance. Select the **Show Name** check box to display the name on the schematic.

Parameters:

- **Equation** – Choose the **Equation** field to enter the expression in the single line mode. In the single line mode, define the expression, for example $C:=A+B$ or $\text{var1}:=\sin(2*\text{PI}*50*t)$, by entering it directly into the field box. See also ***Equations, Expressions, and Variables*** in the main Twin Builder help.
- **{...} Button** – To open the equation [Calculator](#) window, click the ellipsis button. The editor window can display the complete text of an equation. In addition, you can insert standard mathematical functions and If-Else statements from a panel.
- **Show** – If the box is checked, the text from the **Equation** field is displayed on the schematic.
- **Calculation Sequence** – In the list, select **Before Analog Solver**, **Before State Graph**, or **After State Graph**. Before Analog Solver means the equation is calculated first of all simulation quantities (before circuit, block diagram, state graph, time functions, ...). Before State Graph is computed before the state graph is processed; After State Graph, after the state graph is processed. See also ***Simulator Backplane*** in the main Twin Builder help.
- **Information** – Field for user-specific information about an expression. Click in the field of the corresponding entry and enter the text. You can display this information on the sheet by checking the **Include Info** check box.
- **Include Info** – Enabled when **Show** is checked. If the box is checked, the text from the Information field is displayed on the schematic.

Outputs/Display

For information regarding displaying parameter pins, see ***Output/Display Tab*** in the Twin Builder main help.

Special Component Dialogs (ICA)

The following Parameters are set in the Component Dialog for the **Initial Value** block:

Name:

Specify the Name of the component instance. Select the **Show Name** checkbox to display the name on the schematic.

Parameters:

- **Parameter Table Buttons** – Create, delete, or move entries in the table with the buttons placed on the upper right side of the dialog box.
- **Equation** – Choose the **Equation** field to enter the expression in the single line mode. In the single line mode, define the expression, for example $C:=50$ or $OMEGA:=2*\pi*FX$, by entering it directly into the field box. See also **Equations, Expressions, and Variables** in the main Twin Builder help.
- **{...} Button** – To open the equation [Calculator](#) window, click the ellipsis button. The editor window can display the complete text of an equation. In addition, you can insert standard mathematical functions and If-Else statements from a panel.
- **Information** – Field for user-specific information about an expression. Click in the field of the corresponding entry and enter the text. You can display this information on the sheet by checking the **Include Info** checkbox.
- **Show** – If the box is checked, the text from the **Equation** field is displayed on the schematic.
- **Include Info** – Enabled when **Show** is checked. If the box is checked, the text from the Information field is displayed on the schematic.

Outputs/Display

For information regarding displaying parameter pins, see **Output/Display Tab** in the main Twin Builder help.

Special Component Dialogs (NDTAB)

The following Parameters are set in the Component Dialog for the **Equation Tools Multidimensional Table Model**:

Name:

Specify the Name of the component instance. Select the **Show Name** check box to display the name on the schematic.

Parameters:

- **Name** – Displays the component internal names of the input quantities which are defined in the **Table Values** dialog box. You cannot make changes in these fields.
- **Input** – The values of the defined signal control the values of output signals. Common parameter type. Enter a numerical value, a variable, or an expression in the text box or use the pin to connect the quantity.
- **Extrapolation** – Click the list field to select the **Linear**, **Periodic**, **Halfperiod**, **Constant**, **Even**, or **Odd** extrapolation type to define the quantity characteristics outside the range of parameter sweep. The default extrapolation is **Linear**.

Select **Linear** to extrapolate a linear waveform. This option takes the last two points of the wave and generates a straight line extending beyond the range of parametric sweep.

Select **Periodic** to repeat the wave outside the range of parametric sweep. Select

Halfperiod to mirror then repeat the waveform outside the range of parameter sweep.

Select **Constant** to extrapolate a constant value from the last point in the interpolation.

Select **Even** to repeat the wave outside the range of parametric sweep. Select **Odd** to repeat a reflection of the waveform outside the range of the parametric sweep. For example, extrapolating with this option reflects the wave into the positive range.

- **Use Pin** – If the box is checked, the input signal is defined by the quantity connected to the pin, otherwise the value in the text box is used.

Interpolation:

Click the list field to select the **NOSPLINE**, **LASTSPLINE**, or **DEEPSPLINE** interpolation type to define the quantity characteristic inside the range of parameter sweep. The default interpolation is **NOSPLINE**. The interpolation type is valid for all input quantities. An additional option, **LOOKUP**, can be used to look up and set values during initialization only.

Select **NOSPLINE** to fit a straight line between the points of interpolation. Select **LASTSPLINE** to apply a Bezier interpolation to the last quantity characteristic. Select **DEEPSPLINE** to apply a Bezier interpolation to all quantity characteristics.

Import Table:

Characteristics of input values may be defined in a file. Select **Import Table** to browse to a .mdx file containing the input value definitions. Otherwise, use the **Table Values** button to manually enter the input and output signals. See ***Characteristics in Simulation Models*** in the main Twin Builder help. Selecting a .txt, .dat, .out, or .csv file opens an **Import** dialog box in which you can specify settings for reading the data in the file for import. See ***Import Data from Generic Text Files*** in the main Twin Builder help for more information.

Table Values:

Click to open the dialog to create or edit input and output channel signals. See ***Dataset Parameters Dialog Box*** in the main Twin Builder help.

Outputs/Display:

For information regarding displaying parameter pins, see ***Output/Display Tab*** in the main Twin Builder help.

Special Component Dialogs (NXMY)

The following Parameters are set in the Component Dialog for the **Multidimensional Table Characteristics Model**:

Name:

Specify the Name of the component instance. Select the **Show Name** check box to display the name on the schematic.

Parameters:

- **Name** – Displays the component internal names of the input quantities which are defined in the **Table Values** dialog box. You cannot make changes in these fields.
- **Input** – The values of the defined signal control the values of output signals. Common parameter type. Enter a numerical value, a variable, or an expression in the text box or use the pin to connect the quantity.
- **Extrapolation** – Click the list field to select the **Linear**, **Periodic**, **Halfperiod**, **Constant**, **Even**, or **Odd** extrapolation type to define the quantity characteristics outside the range of parameter sweep. The default extrapolation is **Linear**.

Select **Linear** to extrapolate a linear waveform. This option takes the last two points of the wave and generates a straight line extending beyond the range of parametric sweep.

Select **Periodic** to repeat the wave outside the range of parametric sweep. Select

Halfperiod to mirror then repeat the waveform outside the range of parameter sweep.

Select **Constant** to extrapolate a constant value from the last point in the interpolation.

Select **Even** to repeat the wave outside the range of parametric sweep. Select **Odd** to repeat a reflection of the waveform outside the range of the parametric sweep. For example, extrapolating with this option reflects the wave into the positive range.

- **Use Pin** – If the box is checked, the input signal is defined by the quantity connected to the pin, otherwise the value in the text box is used.

Interpolation:

Click the list field to select the **NOSPLINE**, **LASTSPLINE**, or **DEEPSPLINE** interpolation type to define the quantity characteristic inside the range of parameter sweep. The default interpolation is **NOSPLINE**. The interpolation type is valid for all input quantities.

Select **NOSPLINE** to fit a straight line between the points of interpolation. Select **LASTSPLINE** to apply a Bezier interpolation to the last quantity characteristic. Select **DEEPSPLINE** to apply a Bezier interpolation to all quantity characteristics.

Import Table:

Characteristics of input values may be defined in a file. Select **Import Table** to browse to a .mdx file containing the input value definitions. Otherwise, use the **Table Values** button to manually enter the input and output signals. See ***Characteristics in Simulation Models*** in the main Twin Builder help. Selecting a .txt, .dat, .out, or .csv file opens an **Import** dialog box in which you can specify settings for reading the data in the file for import. See ***Import Data from Generic Text Files*** in the main Twin Builder help for more information.

Table Values:

Click to open the dialog to create or edit input and output channel signals. See ***Dataset Parameters Dialog Box*** in the main Twin Builder help.

Outputs/Display:

For information regarding displaying parameter pins, see ***Output/Display Tab*** in the main Twin Builder help.

Special Component Dialogs

The following Parameters are set in the Component Dialog for the **Multidimensional Table Source Model**:

Name:

Specify the Name of the component instance. Select the **Show Name** checkbox to display the name on the schematic.

Parameters:

- **Source Type** – In the list field, select Voltage (VSRC) or Current (CSRC) source for output.
- **Name** – Displays the component internal names of the input quantities which are defined in the **Table Values** dialog box. You cannot make changes in these fields.
- **Input** – The voltage/current of the defined quantities control the values of the sources. Quantity parameter type. The type accepts only a node potential or the current of an ammeters (e.g. N0003.V , AM2.I). The values cannot be assigned by a variable. Enter the quantity or use the pin to connect the quantity.
- **Extrapolation** – Click the list field to select the **Linear**, **Periodic**, **Halfperiod**, **Constant**, **Even**, or **Odd** extrapolation type to define the quantity characteristics outside the range of parameter sweep. The default extrapolation is **Linear**.

Select **Linear** to extrapolate a linear waveform. This option takes the last two points of the wave and generates a straight line extending beyond the range of parametric sweep.

Select **Periodic** to repeat the wave outside the range of parametric sweep. Select

Halfperiod to mirror then repeat the waveform outside the range of parameter sweep.

Select **Constant** to extrapolate a constant value from the last point in the interpolation.

Select **Even** to repeat the wave outside the range of parametric sweep. Select **Odd** to repeat a reflection of the waveform outside the range of the parametric sweep. For example, extrapolating with this option reflects the wave into the positive range.

- **Use Pin** – If the box is checked, the input signal is defined by the quantity connected to the pin, otherwise the value in the text box is used.

Interpolation:

Click the list field to select the **NOSPLINE**, **LASTSPLINE**, or **DEEPSPLINE** interpolation type to define the quantity characteristic inside the range of parameter sweep. The default interpolation is **NOSPLINE**. The interpolation type is valid for all input quantities.

Select **NOSPLINE** to fit a straight line between the points of interpolation. Select **LASTSPLINE** to apply a Bezier interpolation to the last quantity characteristic. Select **DEEPSPLINE** to apply a Bezier interpolation to all quantity characteristics.

Import Table:

Characteristics of input values may be defined in a file. Select **Import Table** to browse to a .mdx file containing the input value definitions. Otherwise, use the **Table Values** button to manually enter the input and output signals. See ***Characteristics in Simulation Models*** in the main Twin Builder help. Selecting a .txt, .dat, .out, or .csv file opens an **Import** dialog box in which you can specify settings for reading the data in the file for import. See ***Import Data from Generic Text Files*** in the main Twin Builder help for more information.

Table Values:

Click to open the dialog to create or edit input and output channel signals.
See ***Dataset Parameters Dialog Box*** in the main Twin Builder help.

Outputs/Display:

For information regarding displaying parameter pins, see ***Output/Display Tab*** in the main Twin Builder help.

Special Component Dialogs (NDNL)

The following Parameters are set in the Component Dialog for the **Multidimensional Table Block**:

Name:

Specify the Name of the component instance. Select the **Show Name** check box to display the name on the schematic.

Parameters:

- **Name** – Displays the component internal names of the input quantities which are defined in the dialog box. You cannot make changes in these fields.
- **Input** – The values of the defined signal control the values of output signals. Common parameter type. Enter a numerical value, a variable, or an expression in the text box or use the pin to connect the quantity.
- **Extrapolation** – Click the list field to select the **Linear**, **Periodic**, **Halfperiod**, **Constant**, **Even**, or **Odd** extrapolation type to define the quantity characteristics outside the range of parameter sweep. The default extrapolation is **Linear**.

Select **Linear** to extrapolate a linear waveform. This option takes the last two points of the wave and generates a straight line extending beyond the range of parametric sweep.

Select **Periodic** to repeat the wave outside the range of parametric sweep. Select

Halfperiod to mirror then repeat the waveform outside the range of parameter sweep.

Select **Constant** to extrapolate a constant value from the last point in the interpolation.

Select **Even** to repeat the wave outside the range of parametric sweep. Select **Odd** to repeat a reflection of the waveform outside the range of the parametric sweep. For example, extrapolating with this option reflects the wave into the positive range.

- **Use Pin** – If the box is checked, the input signal is defined by the quantity connected to the pin, otherwise the value in the text box is used.

Interpolation:

Click the list field to select the **NOSPLINE**, **LASTSPLINE**, or **DEEPSPLINE** interpolation type to define the quantity characteristic inside the range of parameter sweep. The default interpolation is **NOSPLINE**. The interpolation type is valid for all input quantities.

Select **NOSPLINE** to fit a straight line between the points of interpolation. Select **LASTSPLINE** to apply a Bezier interpolation to the last quantity characteristic. Select **DEEPSPLINE** to apply a Bezier interpolation to all quantity characteristics.

Import Table:

Characteristics of input values may be defined in a file. Select **Import Table** to browse to a .mdx file containing the input value definitions. Otherwise, use the **Table Values** button to manually enter the input and output signals. See **Characteristics in Simulation Models** in the main Twin Builder help. Selecting a .txt, .dat, .out, or .csv file opens an **Import** dialog box in which you can specify settings for reading the data in the file for import. See **Import Data from Generic Text Files** in the main Twin Builder help for more information.

Table Values:

Click to open the dialog to create or edit input and output channel signals. See **Dataset Parameters Dialog Box** in the main Twin Builder help.

Sample Time:

- **Use System Sample Time** – Enable the check box for simulator-defined variable sample time.

Leave the checkbox unchecked to define a numerical value, a variable, or an expression in the entry box or use the pin to connect a quantity.

Note that the sample time must be a positive value.

- **Use Pin** – If the box is checked, the sample time is defined by the quantity connected to the pin, otherwise the value in the text box is used.

Outputs/Display:

For information regarding displaying parameter pins, see **Output/Display Tab** in the main Twin Builder help.

Special Component Dialogs

The following Parameters are set in the Component Dialog for the **2D Lookup Table XY Characteristic Model**:

Name:

Specify the Name of the component instance. Select the **Show Name** check box to display the name on the schematic.

Parameters:

- **Dataset** – To specify the nonlinear characteristic of the pump with a dataset, select the Dataset radio button and choose the dataset from the pull-down list. If no datasets are defined, click the **Datasets...** button to define a dataset.
- **File Reference** – The name in the text box specifies a variable which refers to a subsheet port specifying a characteristic file.
- **File Name** – To define the data points, a two-dimensional data file is used which can be created by a text editor. The XY data file always has two channels (columns) where X value and Y value are stored. The length (number of lines) of the data files is arbitrary. To open or save files, click the symbols next to the text box. Please note: Select the correct file filter (.mdx) before browsing. See **Characteristics in Simulation Models** in the main Twin Builder help.

Outputs:

- **Value** – If the box is checked, the variable is saved in the result file during simulation. Please note: If you want to display a variable value, you have to select the box in the output dialog or in a display element. If the box is deactivated, you cannot display the variable value after the simulation.

Outputs/Display:

For information regarding displaying parameter pins, see **Output/Display Tab** in the main Twin Builder help.

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