Take A Leap Of Certainty™

An Introduction to Multi-Frequency Adaptive Meshing in HFSS

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Conventions Used in this Guide

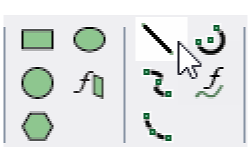
Please take a moment to review how instructions and other useful information are presented in this documentation.

- Procedures are presented as numbered lists. A single bullet indicates that the procedure has only one step.
- Bold type is used for the following:
  - Keyboard entries that should be typed in their entirety exactly as shown. For example, “**copy file1**” means you must type the word **copy**, then type a space, and then type **file1**.
  - On-screen prompts and messages, names of options and text boxes, and menu commands. Menu commands are often separated by greater than signs (>). For example, “click **HFSS** > **Excitations** > **Assign** > **Wave Port**.”
  - Labeled keys on the computer keyboard. For example, “Press **Enter**” means to press the key labeled **Enter**.
- Italic type is used for the following:
  - Emphasis.
  - The titles of publications.
  - Keyboard entries when a name or a variable must be typed in place of the words in italics. For example, “**copy** *filename*” means you must type the word **copy**, then type a space, and then type the name of the file.
- The plus sign (+) is used between keyboard keys to indicate that you should press the keys at the same time. For example, “Press Shift+F1” means to press the **Shift** key and, while holding it down, press the **F1** key also. You should always depress the modifier key or keys first (for example, Shift, Ctrl, Alt, or Ctrl+Shift), continue to hold it/them down, and then press the last key in the instruction.

Accessing Commands: *Ribbons, menu bars,* and *shortcut menus* are three methods that can be used to see what commands are available in the application.

- The *Ribbon* occupies the rectangular area at the top of the application window and contains multiple tabs. Each tab has relevant commands that are organized, grouped, and labeled. An example of a typical user interaction is as follows:

  "Click **Draw** > **Line**"

This instruction means that you should click the **Line** command on the **Draw** ribbon tab. An image of the command icon, or a partial view of the ribbon, is often included with the instruction.

- The *menu bar* (located above the ribbon) is a group of the main commands of an application arranged by category such File, Edit, View, Project, etc. An example of a typical user interaction is as follows:

  "On the **File** menu, click the **Open Examples** command" means you can click the **File** menu and then click **Open Examples** to launch the dialog box.

- Another alternative is to use the *shortcut menu* that appears when you click the right-mouse button. An example of a typical user interaction is as follows:

  "Right-click and select **Assign Excitation> Wave Port**" means when you click the right-mouse button with an object face selected, you can execute the excitation commands from the shortcut menu (and the corresponding sub-menus).

Getting Help: Ansys Technical Support

For information about Ansys Technical Support, go to the Ansys corporate Support website, http://www.ansys.com/Support. You can also contact your Ansys account manager in order to obtain this information.

All Ansys software files are ASCII text and can be sent conveniently by e-mail. When reporting difficulties, it is extremely helpful to include very specific information about what steps were taken or what stages the simulation reached, including software files as applicable. This allows more rapid and effective debugging.

Help Menu

To access help from the Help menu, click **Help** and select from the menu:

- **[product name] Help** - opens the contents of the help. This help includes the help for the product and its *Getting Started Guides*.
- **[product name] Scripting Help** - opens the contents of the *Scripting Guide*.
- **[product name] Getting Started Guides** - opens a topic that contains links to Getting Started Guides in the help system.

Context-Sensitive Help

To access help from the user interface, press **F1**. The help specific to the active product (design type) opens.

You can press **F1** while the cursor is pointing at a menu command or while a particular dialog box or dialog box tab is open. In this case, the help page associated with the command or open dialog box is displayed automatically.

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1 - Multi-Frequency Adaptive Meshing

This document looks at the different adaptive meshing schemes in HFSS for simulating electromagnetic devices. Multi-frequency adaption, which allows you to perform mesh adaption at more than one frequency is compared with single frequency adaptive meshing. Finally, examples are shown and results from the different mesh adaption schemes are compared.

Adaptive Mesh Refinement

Automatic adaptive meshing in HFSS is an essential and integral part of the simulation process. An appropriate mesh that supports electromagnetic calculations is essential to obtain accurate results. In HFSS, meshes representing the design and its electromagnetic characteristics are produced automatically ensuring efficient simulations in generating accurate results.

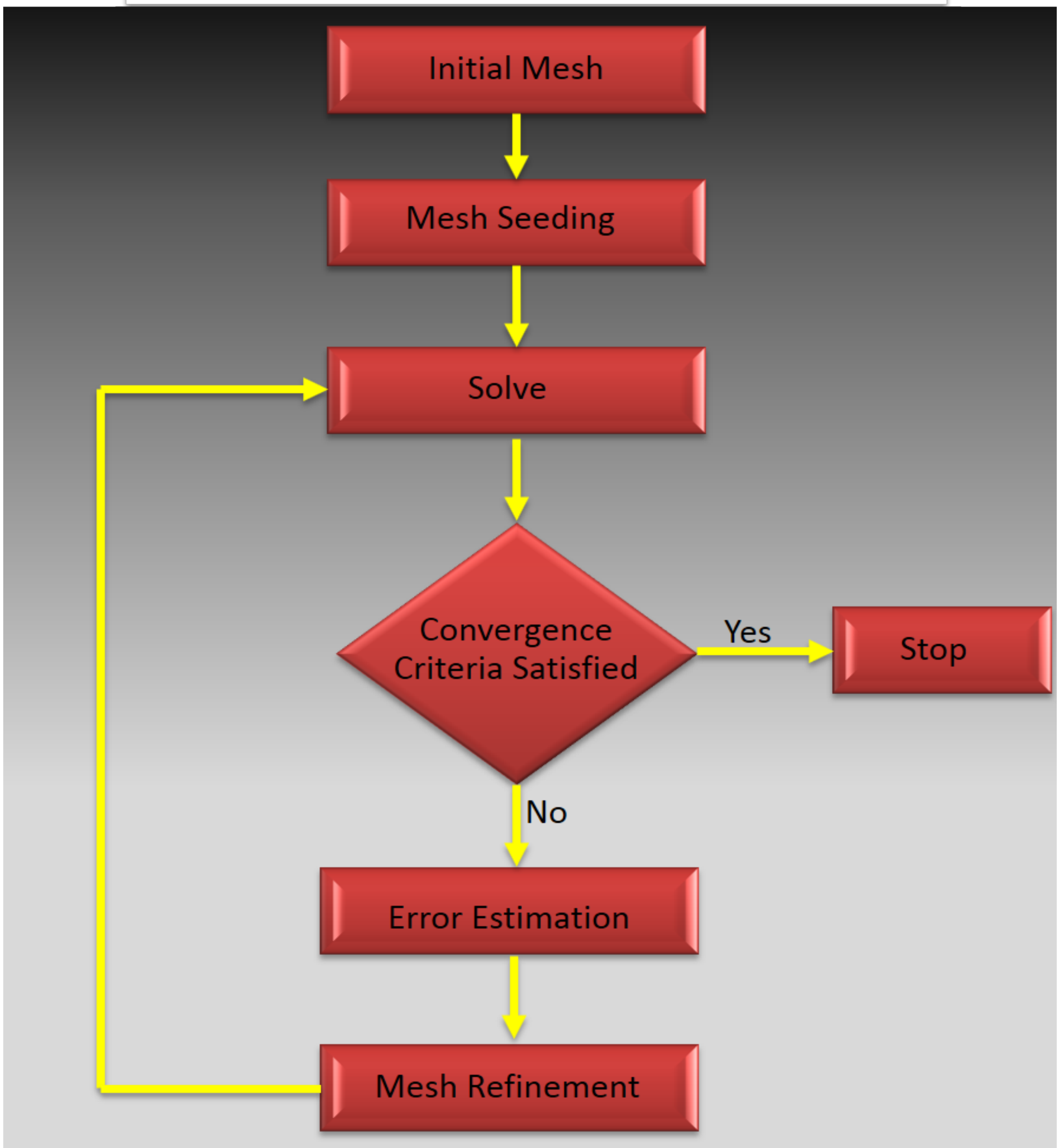
HFSS has always supported single frequency adaptive meshing. In this method, HFSS starts with an initial mesh, determines the mesh induced solution errors at a single frequency, and then refines the mesh at locations with the highest error. This process continues until the convergence criteria is satisfied and the solution converges.

The adaptive mesh refinement process is enhanced by the multi-frequency adaptive meshing feature, which generates solutions at several frequencies and combines the mesh induced solution errors across these frequencies to determine locations where further mesh refinement occurs. This iterative adaptive refinement continues until the solution converges. This ability to adapt the mesh at multiple frequencies yields more accurate solutions across a broad frequency range.

Concept of Single Frequency Adaptive Meshing

In HFSS, the single frequency adaptive meshing is a time-tested method for simulating electromagnetic structures and generating accurate solutions. In this method, HFSS starts with a coarse initial mesh. This mesh is solved to produce an error for each element in the mesh. The errors are used to determine how to refine the initial mesh and produce a mesh, better suited for physics simulation such as computational electromagnetics using FEM. Although we refer to mesh refinement, the process also includes modification to element size and the order of the basis functions used in the numerical method. Using the refined mesh, the solver is again invoked to produce a new set of errors for further mesh refinement. This iterative process continues until the mesh is deemed to be converged by monitoring the change of some critical parameter, such as S-parameters, between consecutive meshes. The following figure demonstrates the single frequency adaptive mesh refinement process flow. Optional seed refinement is included before the adaptive process starts for a more suitable starting mesh.

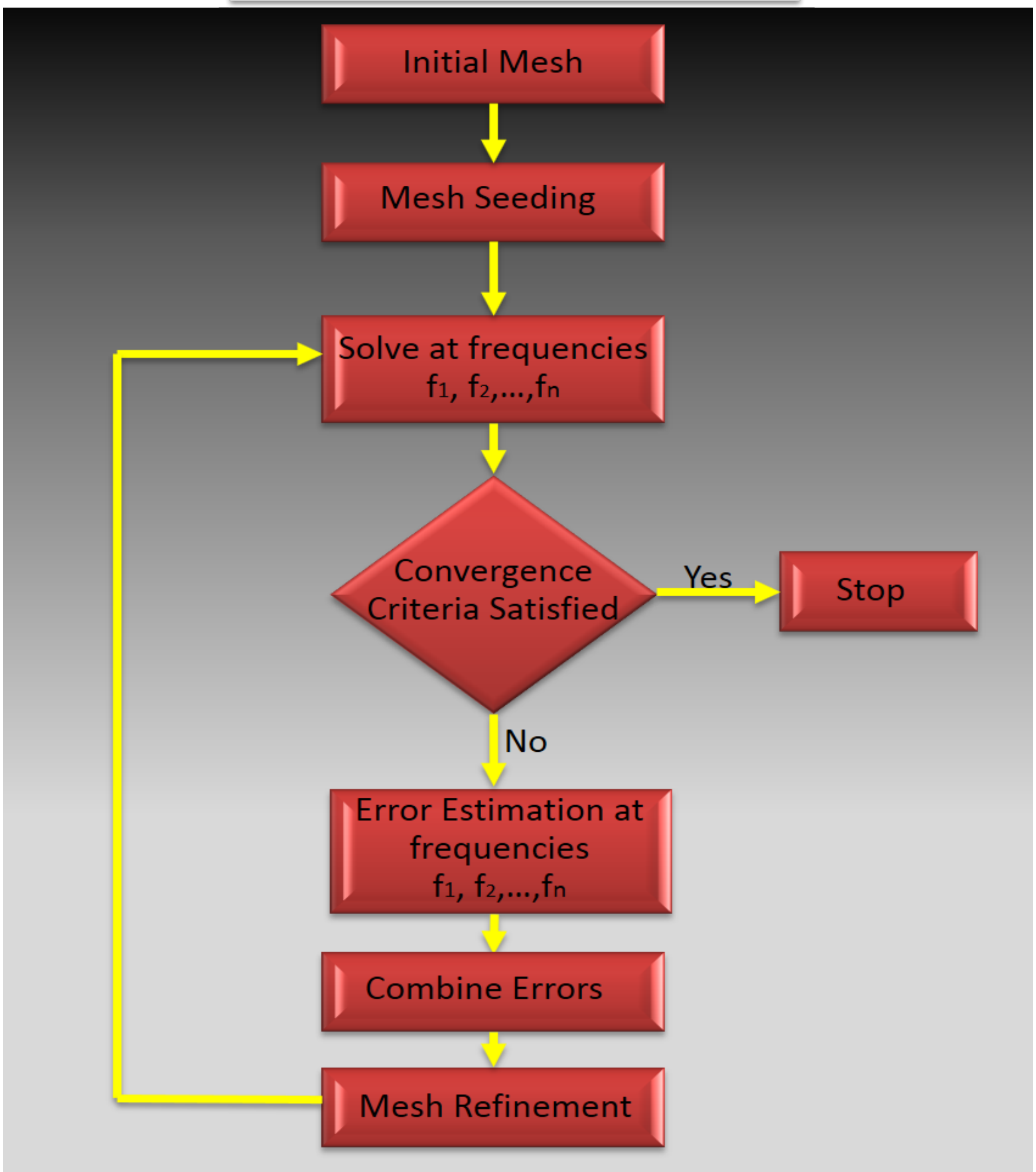
Single Frequency Adaptive Mesh Refinement Flow Chart



Concept of Multi-Frequency Adaptive Meshing

The multi-frequency adaptive meshing method, implemented in Ansys HFSS, provides you with an efficient and convenient method to automatically obtain a mesh appropriate for broadband frequency simulation where the adaptive algorithm uses errors from *multiple time-harmonic frequency* simulations when refining the mesh instead of using only one frequency. Note that for each adaptive pass, the same mesh is used for all frequencies in order to generate errors for mesh refinement for the next adaptive pass. This process is described by the flow chart in the following figure. At a high level, the differences compared with single frequency adaption include generation of errors from multiple frequencies at each adaptive pass and combining of the errors before refining the mesh.

Multi-Frequency Adaptive
Mesh Refinement Flow Chart



There already exist adaptive techniques to tailor a mesh for broadband frequency analysis. Those techniques amount to adapting a mesh at N frequencies sequentially via mesh links in

HFSS. If the ordered frequencies are f_1, f_2,...,f_N the adaptive refinement process starts with $f_1$as the first frequency using a coarse initial mesh. The process then follows the steps shown in the Single Frequency Adaptive Mesh Refinement Flow Chart until convergence. Next frequency f_2 is solved using the converged mesh from f_1, as the initial mesh and once again the steps shown in the Single Frequency Adaptive Mesh Refinement Flow Chart are applied by the adaptive process. This process continues until the convergence of the final frequency f_N. The ability for all adapt frequencies to influence mesh adaption at each pass is a major benefit of using the new multi-frequency adaptive meshing algorithm in HFSS compared to the sequential multi-frequency adaptive meshing approach. It typically produces a smaller final mesh and improves the adaption performance by solving the frequencies in parallel.

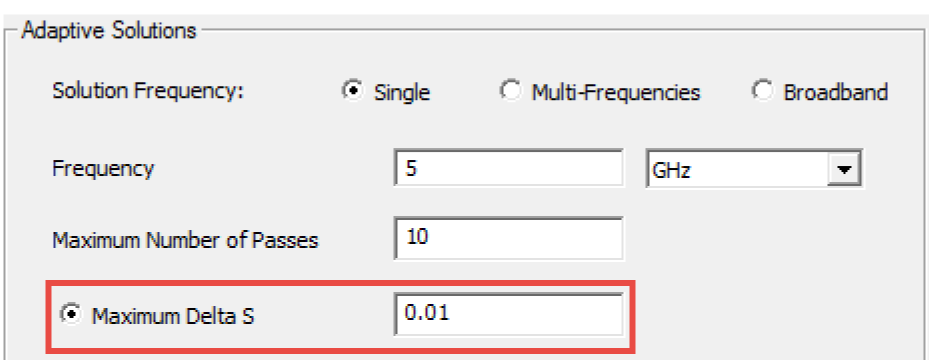
The multiple-frequency adapt algorithm has three potential performance benefits compared with the standard sequential algorithm. The benefits are as follows:

- Solves adapt frequencies in parallel.
- Reuses the solutions of all the adapt frequencies for subsequent frequency sweeps. In contrast the sequential method can reliably reuse only the solution of the last frequency since it solves other frequencies on different meshes.
- Obtains a smaller mesh that yields similar accuracy.

Solution Frequency Setups

There are three types of Solution Frequency setups in HFSS. These setups enable adaptive meshing to occur at either single or many different frequencies. The Multi-Frequencies and Broadband Solution Frequency setups provide you with two different options of adapting the mesh at various frequencies for your design. Based on the solution frequency setup and the specified convergence criteria, HFSS automatically creates a suitable mesh for your design and generates accurate solutions. Once the final mesh is generated, HFSS also creates a solution across a frequency range of interest provided you defined a frequency sweep.

The difference in the S-parameter value between two consecutive adaptive passes is known as Maximum Delta S. The most common convergence criterion is determined by the value of **Maximum Delta S**, which should be less than the specified magnitude. For example, in the following figure the specified value of **Maximum Delta S** is 0.01. Once **Maximum Delta S** goes below this value or if the **Maximum Number of Passes** is reached (whichever happens first) the simulation converges.



The subsequent sections describe each of these Solution Frequency setups.

Single Frequency

For the single frequency setup, HFSS adapts the mesh at that specified frequency for your design until the convergence criteria is satisfied. Once the solution converges, the final mesh is used to predict the electromagnetic characteristics of the design. The solution is also generated across a range of frequencies, if a frequency sweep is defined.

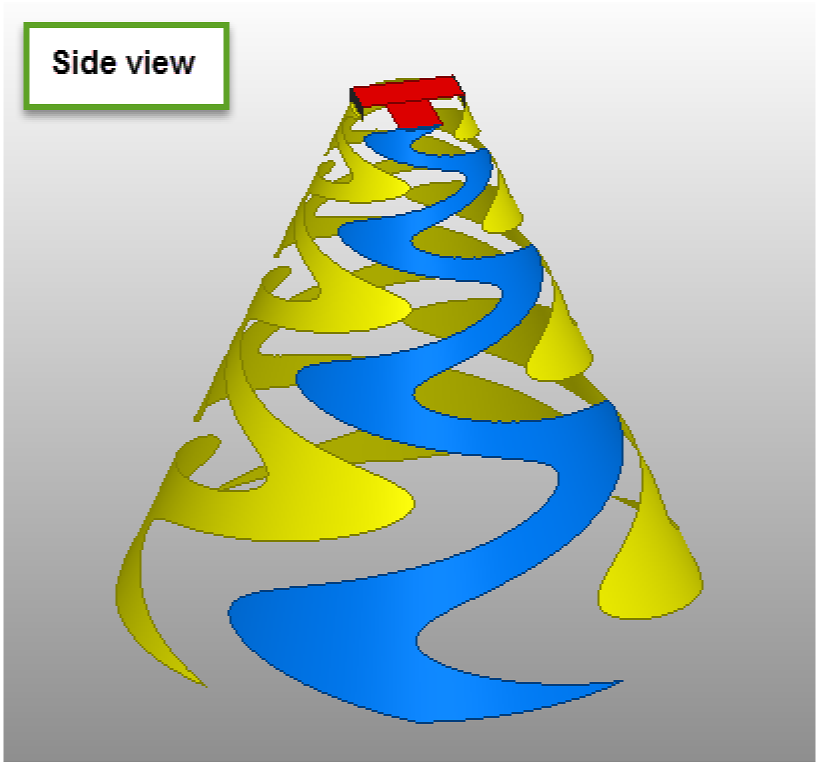
Broadband and Multi-Frequencies Solution Frequency Setups

In most cases, the Single solution frequency is sufficient to generate accurate results. For broadband devices if you want increased reliability and more accurate solutions, use the Broadband Solution Frequency setup. This feature is especially useful when you are uncertain about choosing the best frequencies for adapting the mesh. Broadband meshing eliminates this uncertainty by automatically determining the appropriate frequencies at which to adapt the mesh based on the user-entered range. Broadband will use at least three adapt frequencies and in order for additional frequencies to be used, you need to enable high performance computing (HPC) and have available hardware such that all adapt frequencies can be solved in parallel.

The interpolation sweep is predefined by a frequency range identical to the Broadband. In addition, the algorithm chooses the adapt frequencies in a way that they will likely be reused in the frequency sweep. If you know a priori the frequencies at which to adapt the mesh for your design, you can specify the Multi-Frequencies Solution setup. Adaptive meshing occurs at all the frequencies that you define in this setup.

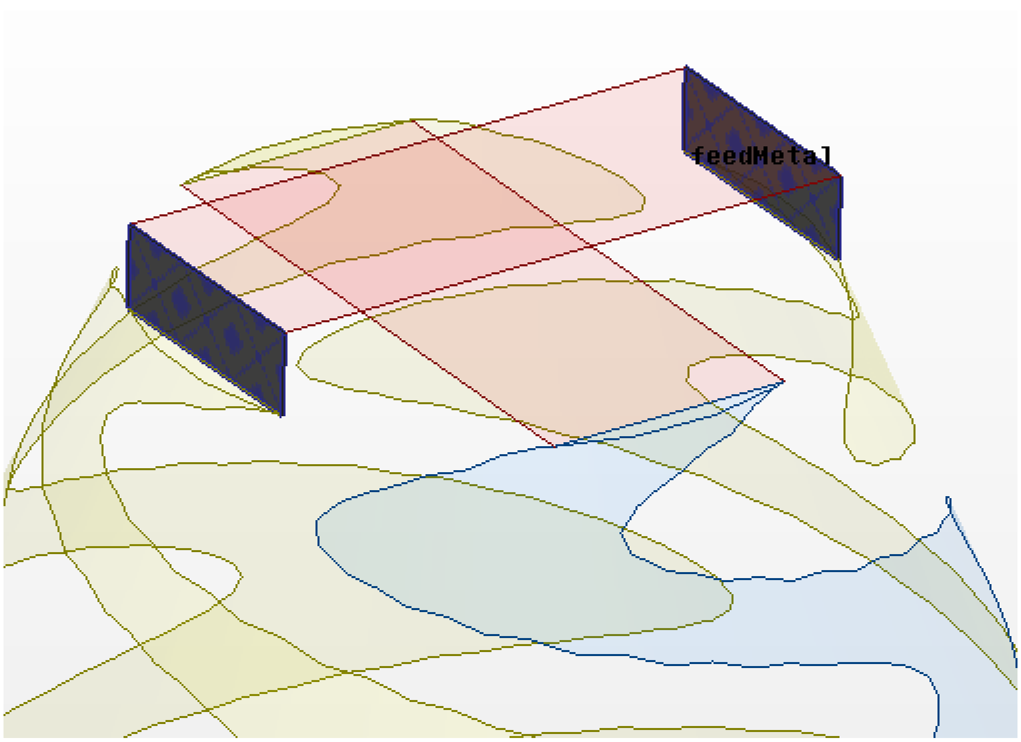
Broadband Adapt For Conical Sinuous Spiral Antenna

The figures below shows a conical sinuous spiral antenna design in HFSS.

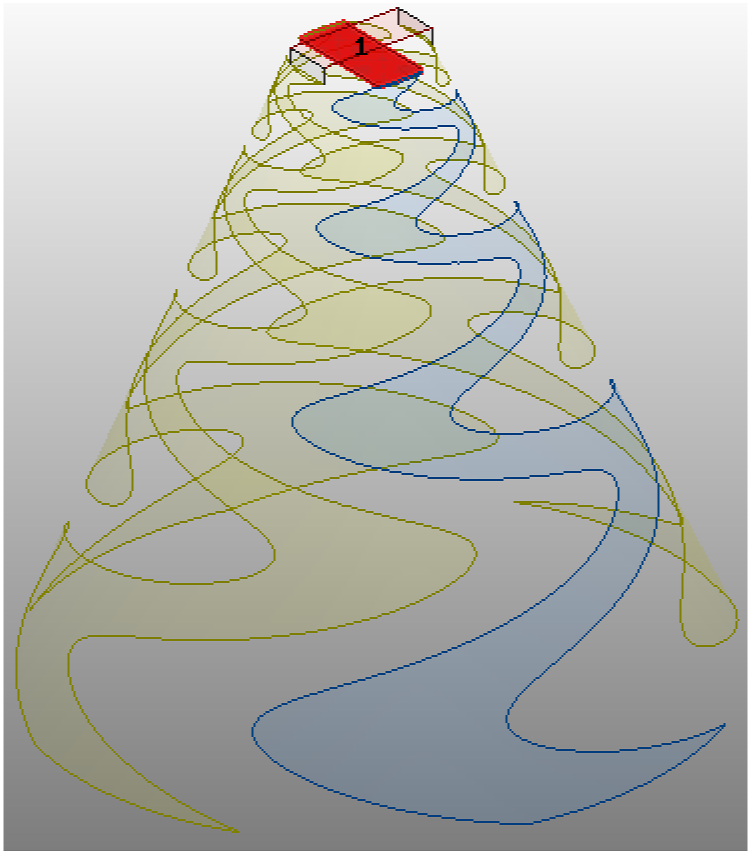

Side view


top view

Perfect E boundary conditions are assigned on the four arms of the antenna and the feed metal.

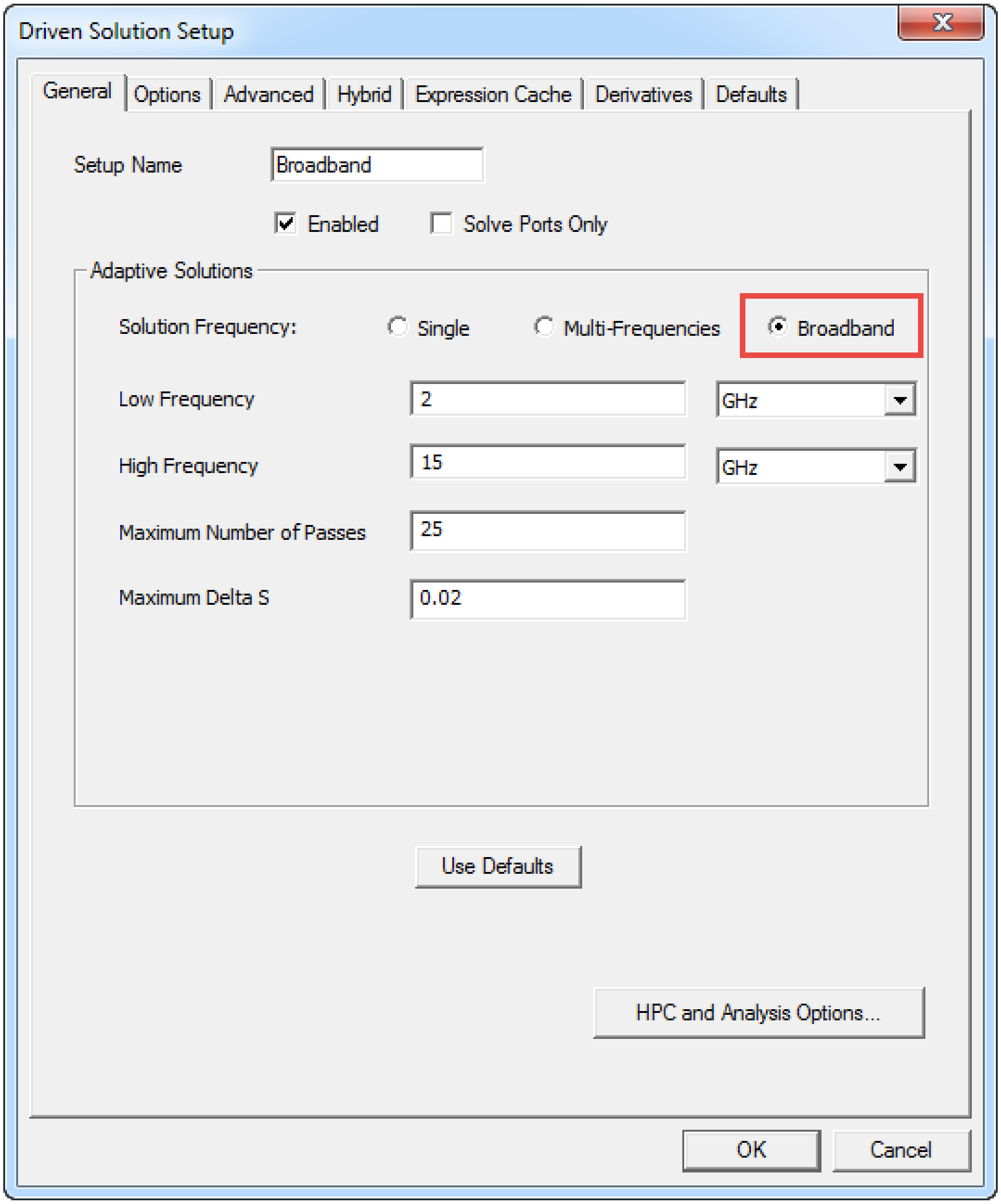


The antenna is excited with a lumped port.

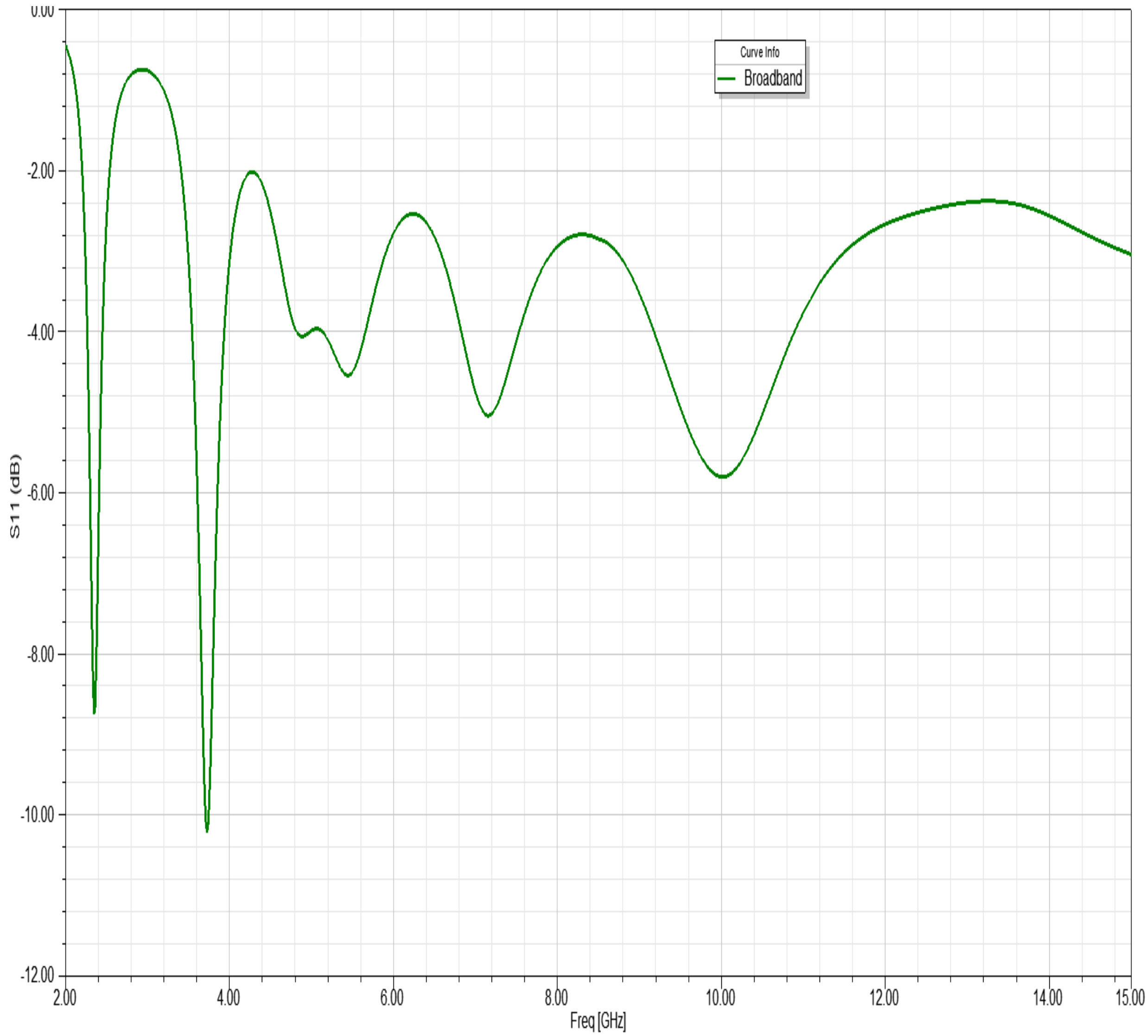


The Broadband Frequency Analysis Setup definitions are as follows:

- Broadband Frequency Range = 2 GHz to 15 GHz.
- An interpolating S-parameter frequency sweep ranges from 2 GHz to 15 GHz.
- Auto HPC is defined and 12 cores are used for the simulation.



The return loss after running the broadband solution frequency setup simulation is shown in the following figure.



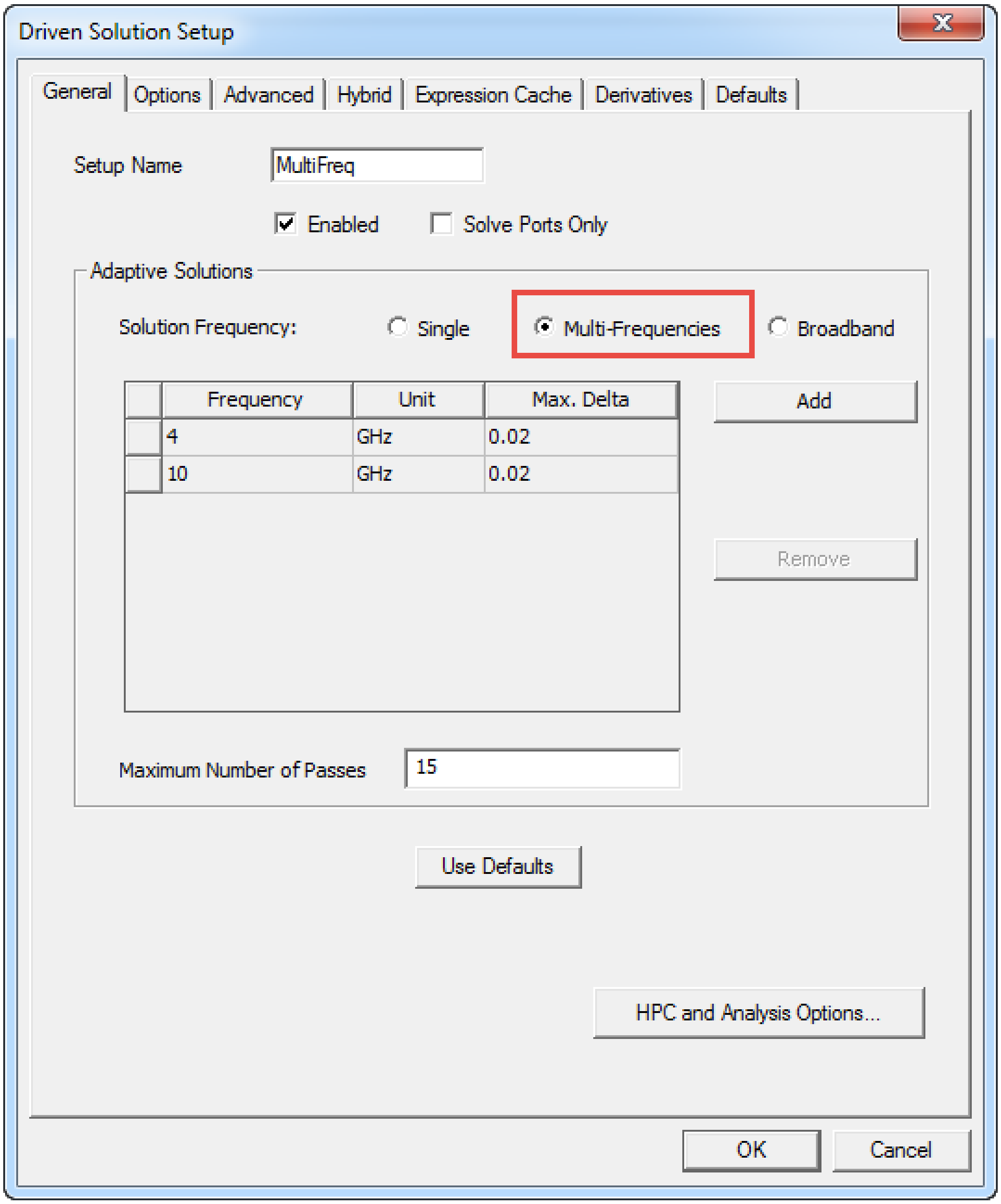
Multi-Frequency Setup For Conical Sinuous Spiral Antenna

For the same design of the conical sinuous spiral antenna you can define a multi-frequency setup provided you know a priori at what frequencies you want to adapt the mesh. In particular, this antenna was designed to work at 4 GHz and 10 GHz.

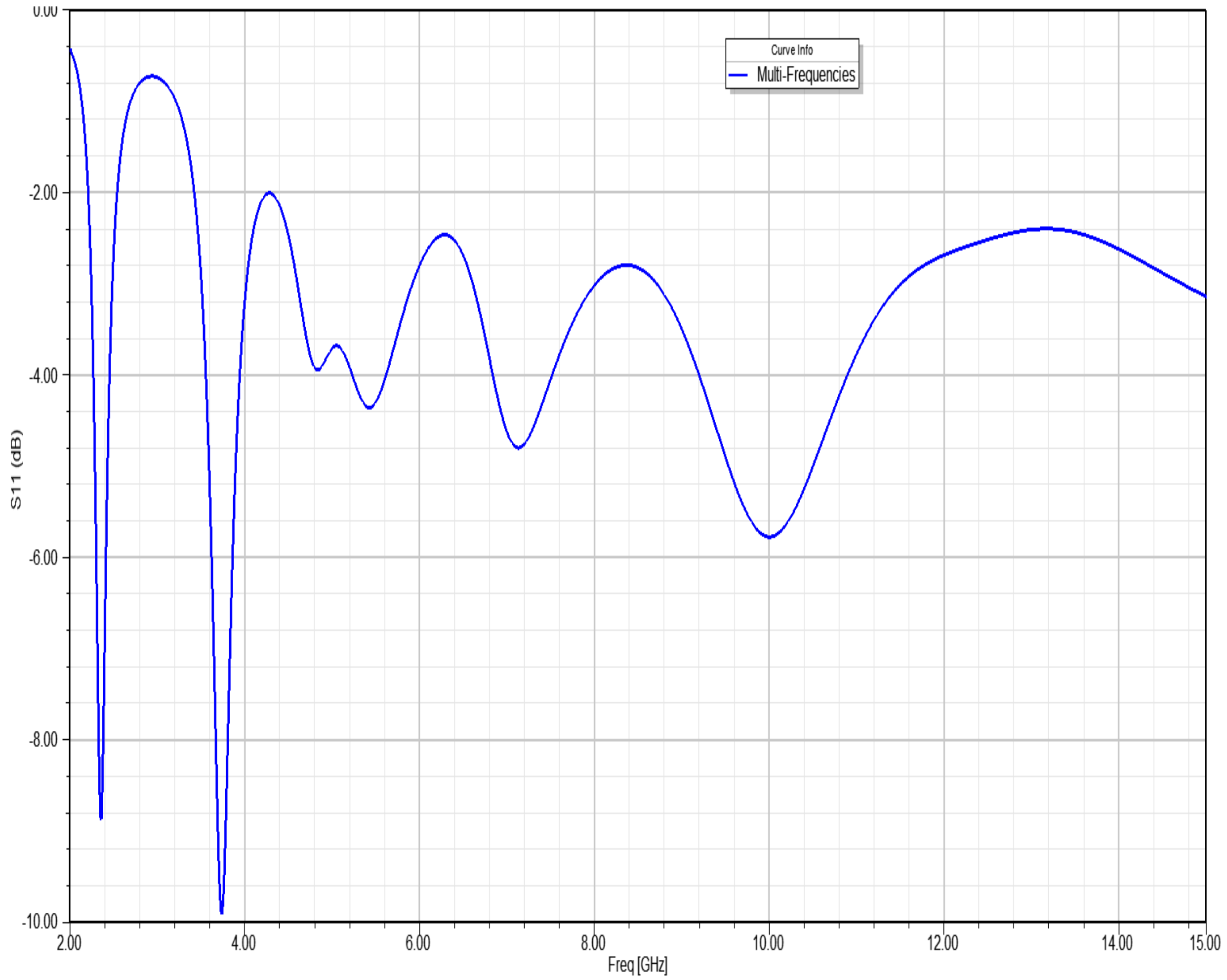
The Multi-Frequencies Analysis Setup definitions are as follows:

- Multi-Frequencies = 4 GHz and 10 GHz.
- An interpolating S-parameter frequency sweep ranges from 2 GHz to 15 GHz.

- Auto HPC is defined and 12 cores are used for the simulation.



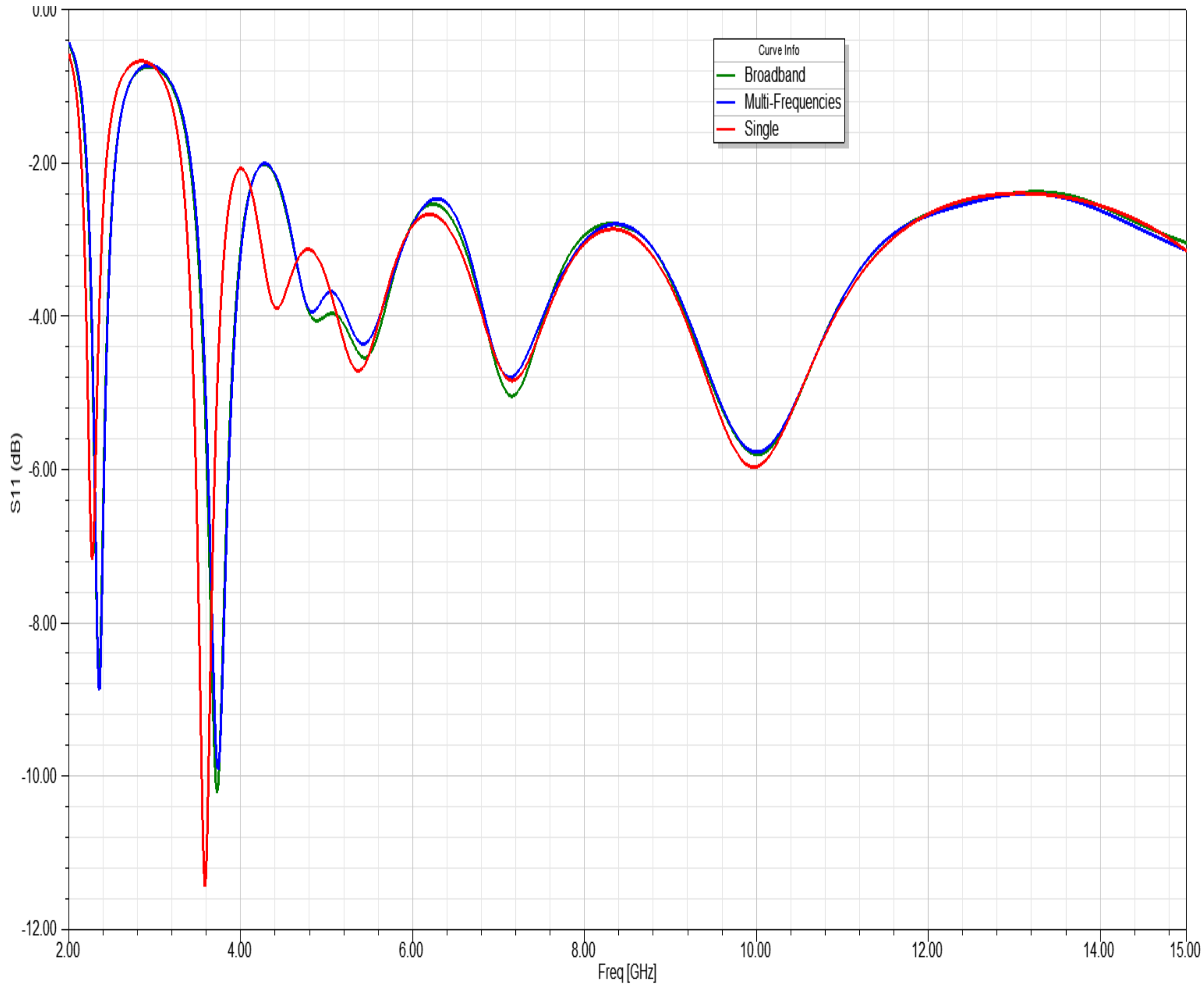
The return loss after solving the Multi-Frequency analysis setup is shown below.



Comparison of Sinuous Antenna Results

The antenna is solved at a center frequency of 8.5 GHz with 12 cores and auto HPC.

Comparison of the return loss results for the three solution frequency setups are shown below.



This example demonstrates the power of using broadband adaptive meshing as it produces very accurate results without the need for you to specify specific adaptive frequencies. Additionally, the performance of Broadband adapt was similar with Multi-Frequencies partly because the six adapted frequencies were solved in parallel and reused, rather than re-solving those frequencies, for the interpolating sweep.