Lecture 3: HFSS FEM Solution Setup

HFSS Getting Started

Release 2020 R2

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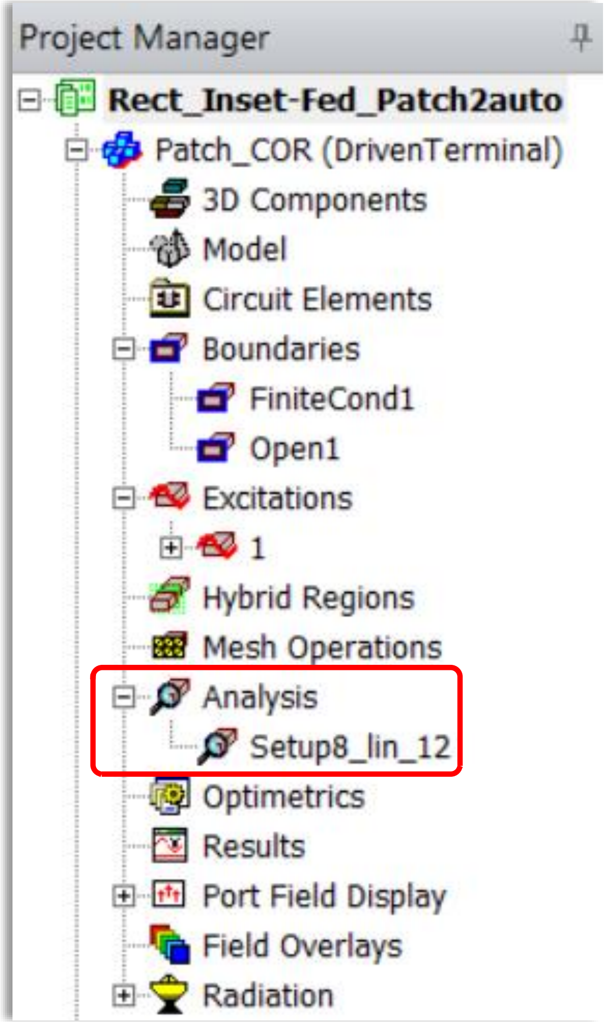
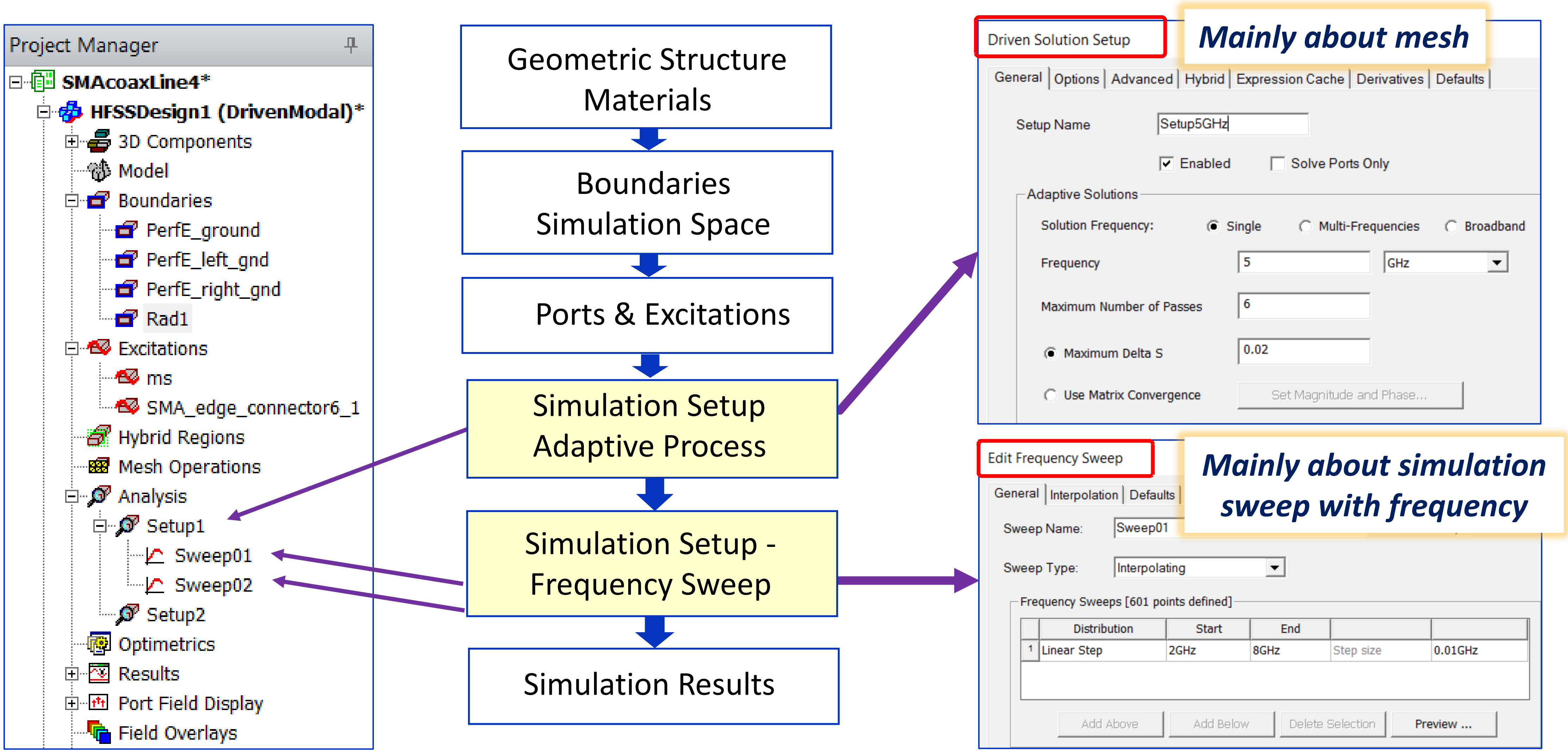
Outline HFSS Getting Started M03: Solution Setup

- Simulation Solution Setup Auto
  - Speed versus Accuracy
  - Frequency Sweep Settings
- Simulation Solution Setup Advanced
  - Driven Solution Setup
  - Frequency Sweep
- HFSS Adaptive Meshing
  - Adaptive Meshing algorithm flow
  - Frequency, Max # Passes, and Delta S
  - Specifying Delta S
- Accuracy and Resolution
  - Delta S & Maximum Number of Adaptive Passes
  - Sweep - density of data with frequency
  - Solution Frequency



This shows the ***HFSS Solution Setup Auto*** option.

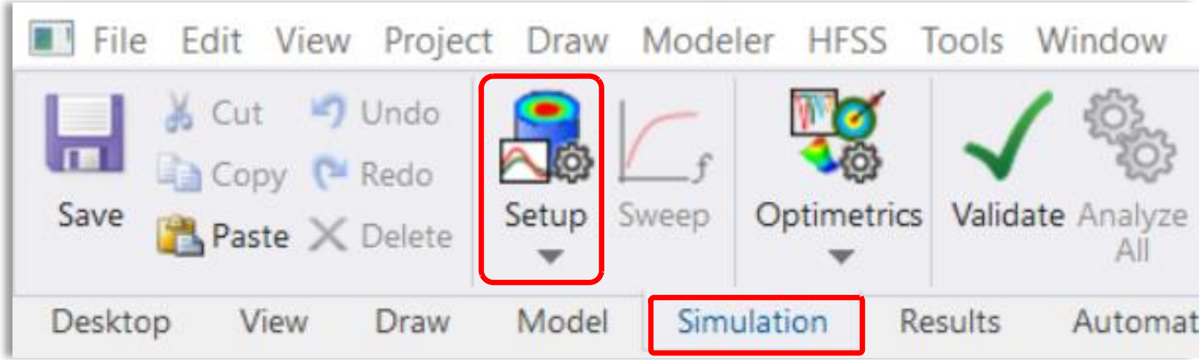
The HFSS Simulation Setup and Sweep in the Workflow



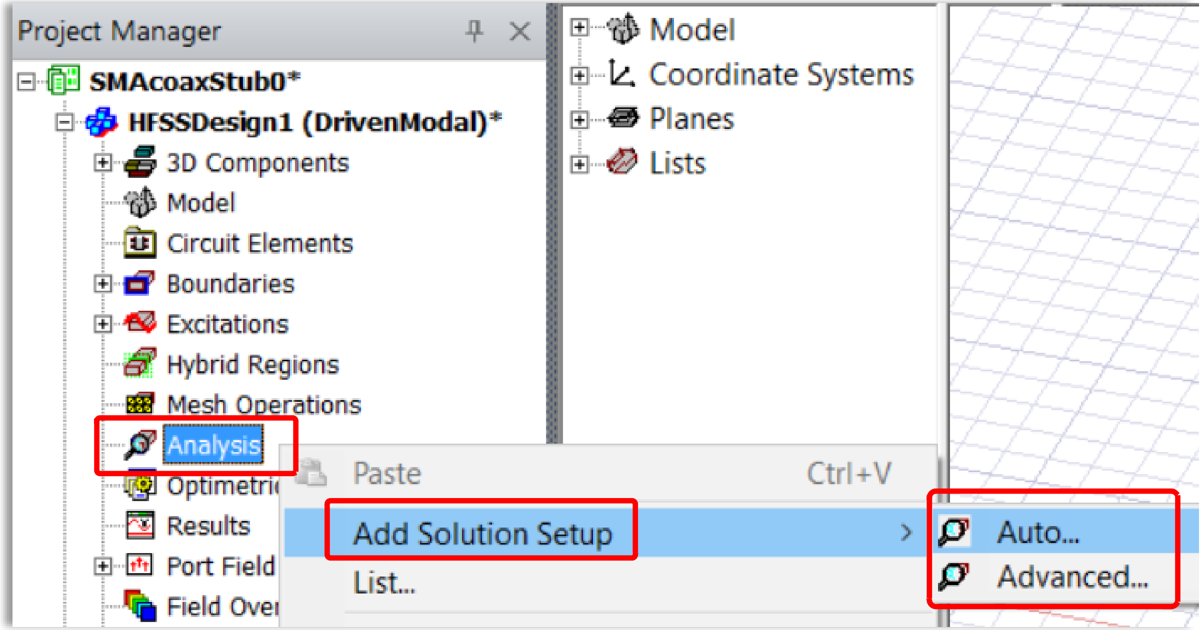
This shows the ***HFSS Solution Setup Advanced*** option.

Accessing the HFSS *Driven Solution Setup* Dialog Box

From the ***Ribbon***, ***HFSS Solution Setup*** can be accessed from the Simulation tab.



From the ***Project Manager***, ***HFSS Solution Setup*** can be accessed from ***Analysis > Add Solution Setup***.



The two choices for ***HFSS Solution Setup*** are ***Auto*** and ***Advanced***.

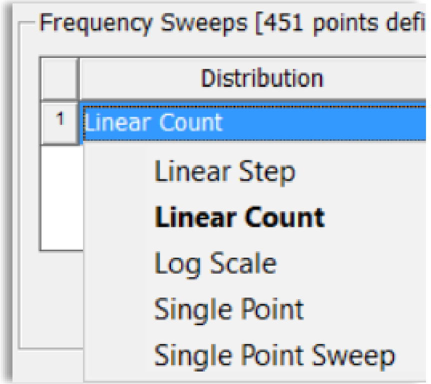
HFSS *Auto Solution Setup* - Meshing and Sweep

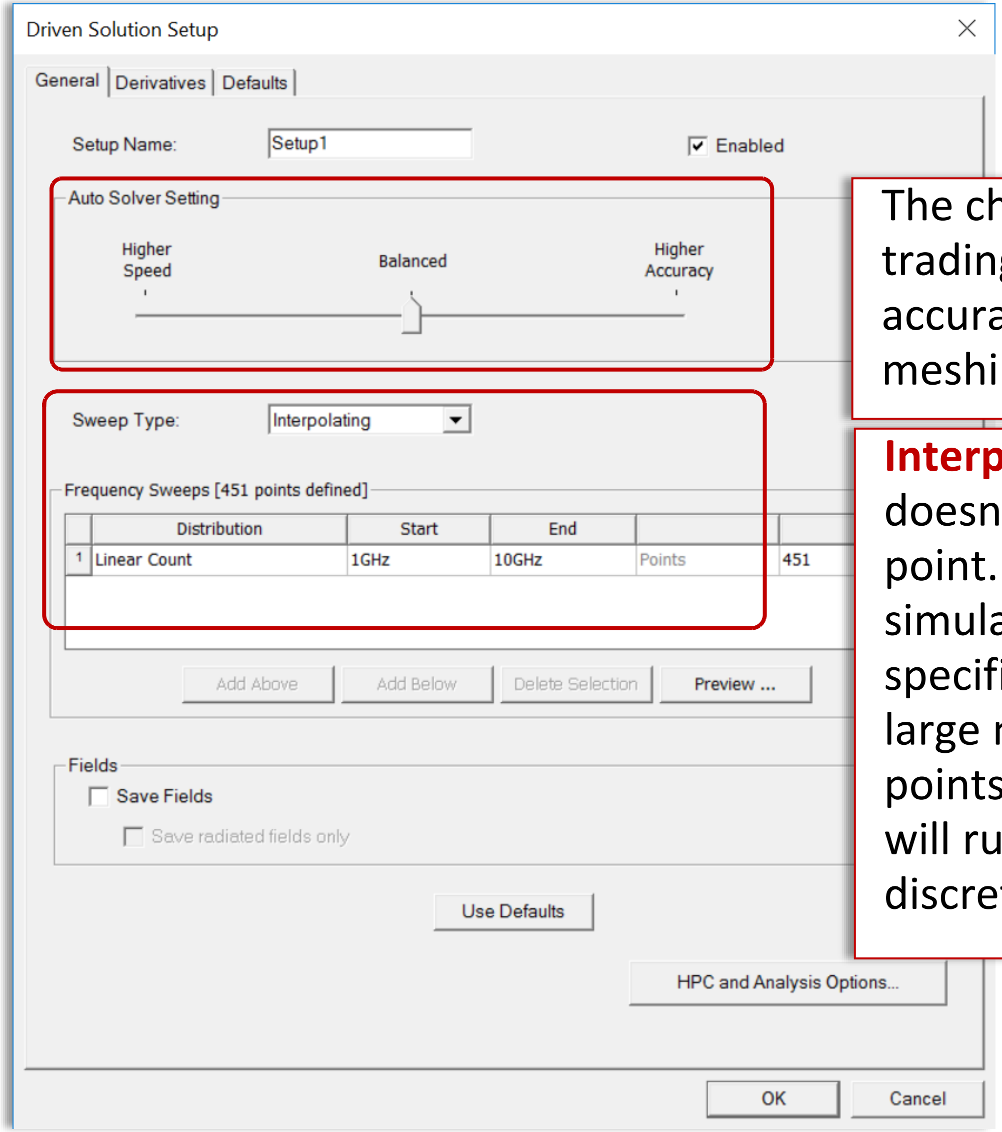
Two aspects of HFSS solution process are the

1. **meshing** … and the
2. **frequency sweep**.

In the ***HFSS Solution Setup Auto*** option, both the meshing and the frequency sweep are specified on the ***General*** tab of the ***Driven Solution Setup*** dialog box.

There are several ***Distributions.***



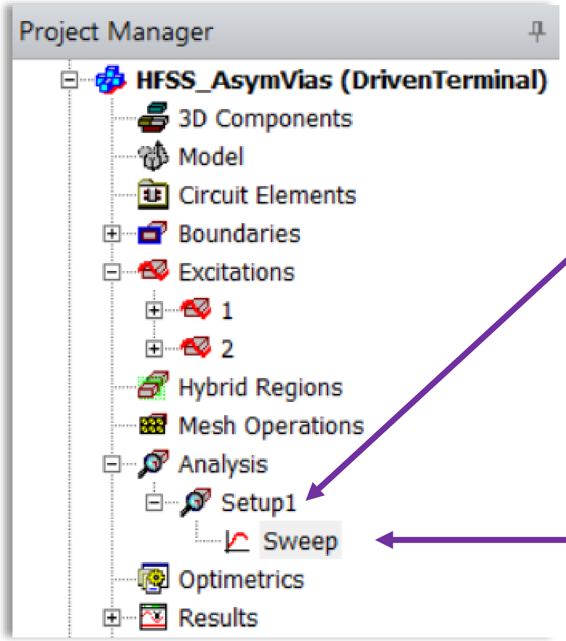


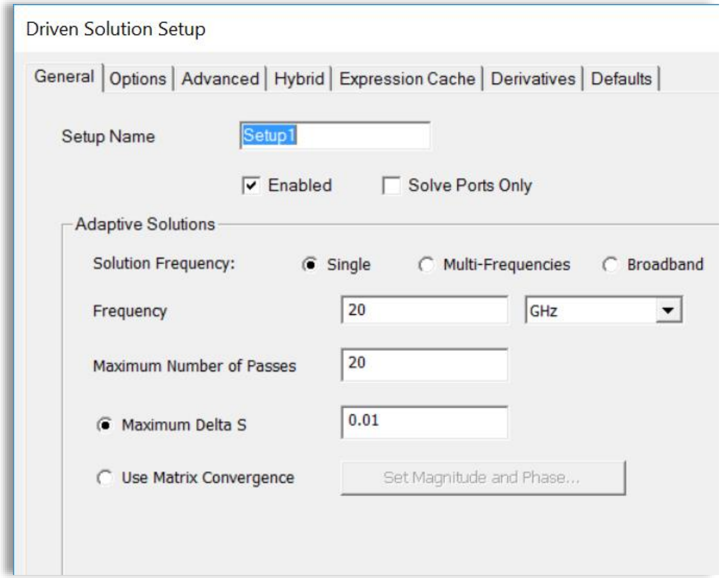
The choice of **slider** setting, trading off speed versus accuracy, specifies the HFSS meshing.

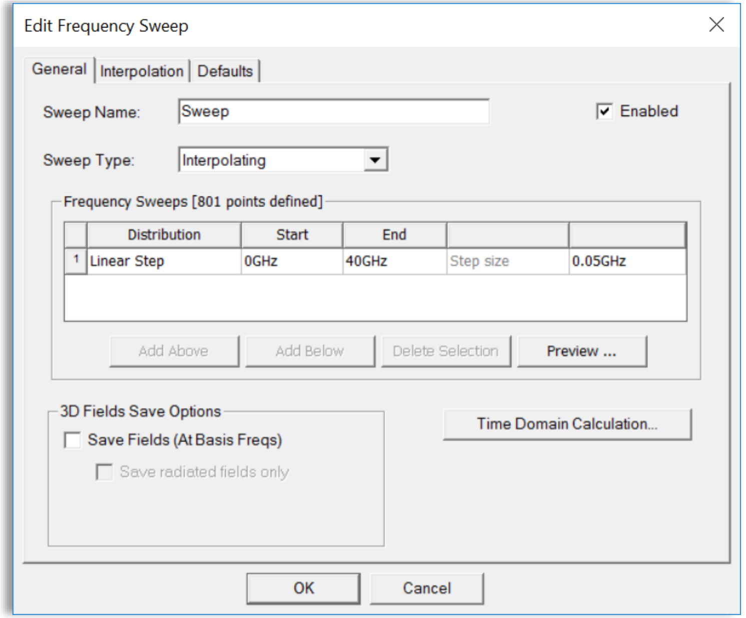
Interpolating sweep type doesn't simulate every single point. **Discrete** sweep does simulate every single point specified in the sweep. For large numbers of frequency points, interpolating sweep will run much faster than discrete sweep.

HFSS *Solution Setup Advanced*

The ***HFSS Solution Setup Advanced*** option separates the meshing and the frequency sweep into two distinct parts.







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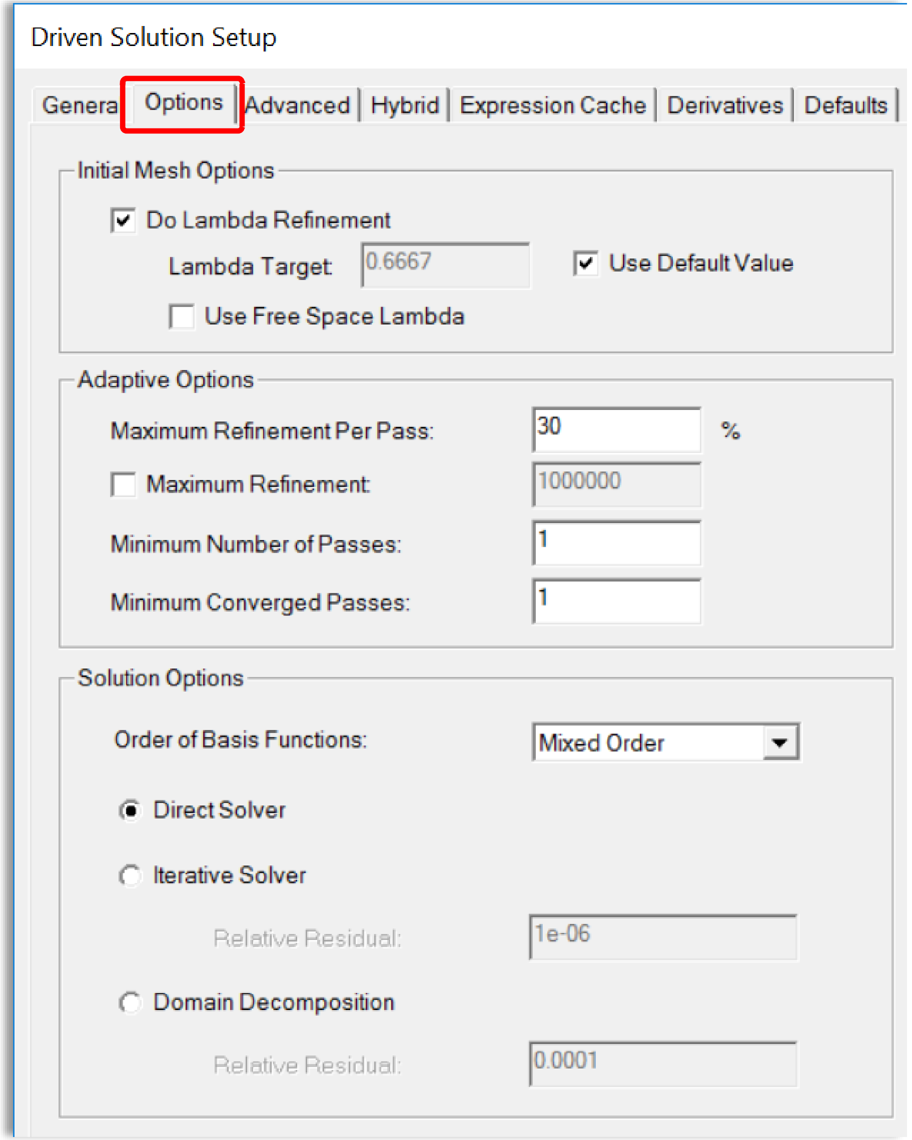
HFSS *Solution Setup Advanced* Options Tab

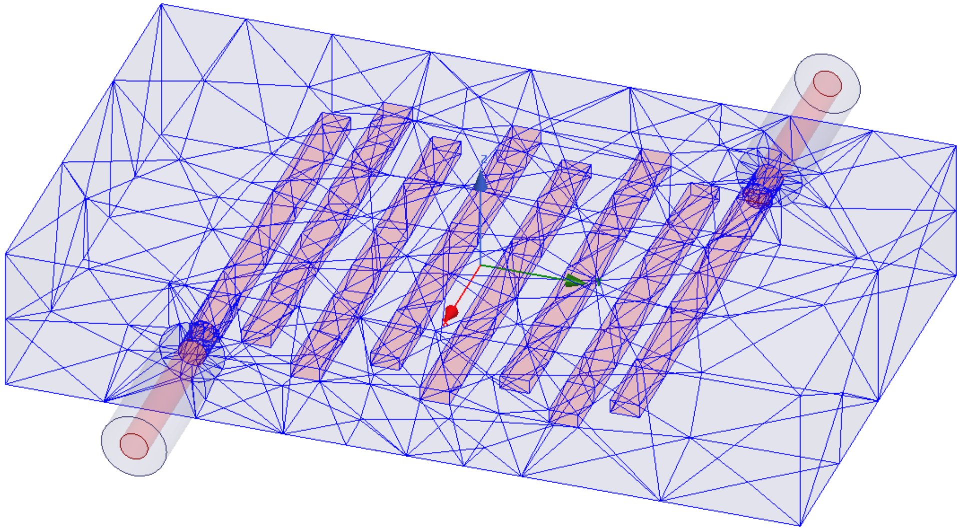
With the ***HFSS Solution Setup Advanced*** option, there are additional tabs in the ***Driven Solution Setup*** tab dialog box.

The ***HFSS Solution Setup Advanced*** option accesses details and options for setting up the HFSS mesh.

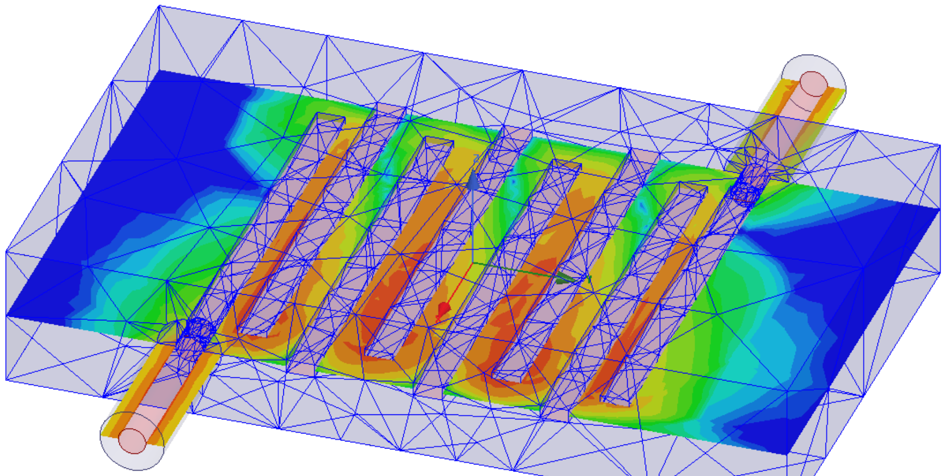


Meshing Discretizes the Computational Volume for Simulation

- Meshing discretizes the simulation space in an HFSS FEM (finite element method) simulation.
- The mesh is what actually gets simulated (not the CAD geometry).
- The mesh is profoundly important to simulation accuracy and speed.
- Creating a good mesh is very important.
- HFSS has an automated, iterative way of creating the FEM mesh, called ***adaptive meshing***.



band pass filter mesh



mesh with E-field overlay

Adaptive Meshing Is an Automated Process for Mesh Creation

Adaptive meshing is the automated process that HFSS uses to create and refine the FEM simulation mesh.

In the adaptive mesh refinement process, the mesh is refined iteratively and is localized to regions where the electric field solution error is high. This iterative refinement technique increases the solution's accuracy with each adaptive solution. The refinement process continues until HFSS converges to an accurate solution. Convergence is determined by monitoring a parameter from one adaptive pass to the next. The most common convergence criterion is to ensure that the difference in the S-parameter value between two consecutive solves is less than the specified magnitude.

From the document ***An Introduction to HFSS***, Chapter 1 ***Fundamentals of HFSS*** section titled ***Adaptive Solution Process and its Importance to HFSS***.

Adaptive Meshing Steps - Excerpts from HFSS Help

The adaptive process can be summarized as follows:

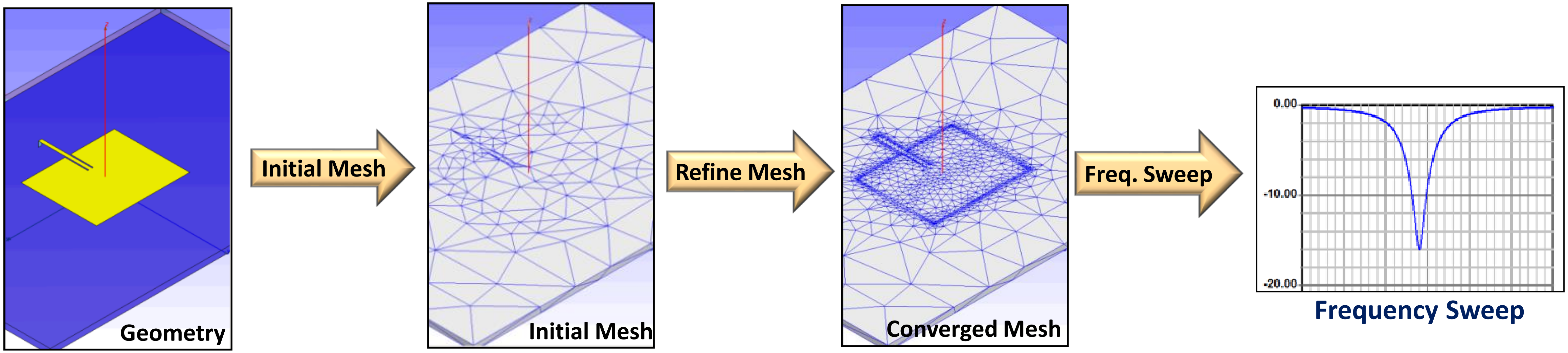
1. HFSS generates an initial geometrically conformal mesh.
2. Using the initial mesh, HFSS computes the electromagnetic fields that exist inside the structure when it is excited at the solution frequency.
3. Based on the current finite element solution, HFSS determines the regions of the problem domain where the exact solution has a high degree of error. A predefined percentage of tetrahedra in these regions is refined. The mesh is refined by creating a number of smaller tetrahedra that replace the original larger element.
4. HFSS generates another solution using the refined mesh.
5. HFSS recomputes the error, and the iterative process (solve -> error analysis -> refine) occurs until the convergence criteria are satisfied or the requested number of adaptive passes is completed.

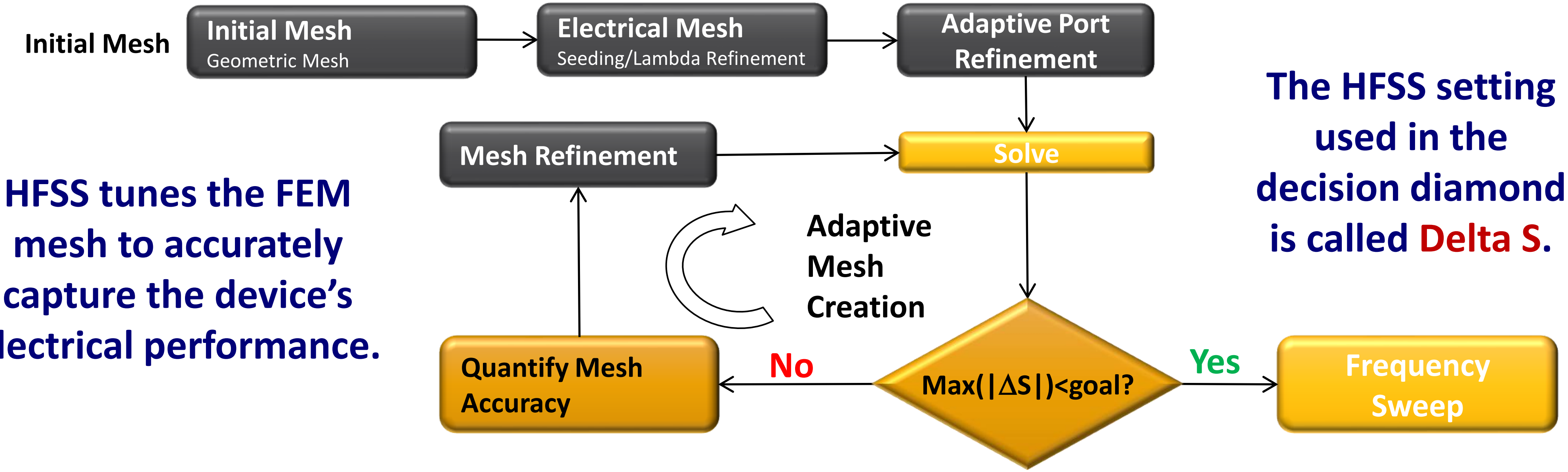
Adaptive meshing is the automated process that HFSS uses to create and refine the FEM simulation mesh.

These text graphics come from the HFSS Help document ***An Introduction to HFSS***, Chapter 1 ***Fundamentals of HFSS*** section titled ***Adaptive Solution Process and its Importance to HFSS***.

In the adaptive mesh refinement process, the mesh is refined iteratively and is localized to regions where the electric field solution error is high. This iterative refinement technique increases the solution's accuracy with each adaptive solution. The refinement process continues until HFSS converges to an accurate solution. Convergence is determined by monitoring a parameter from one adaptive pass to the next. The most common convergence criterion is to ensure that the difference in the S-parameter value between two consecutive solves is less than the specified magnitude.

HFSS FEM Automated Solution Adaptive Port Meshing Process



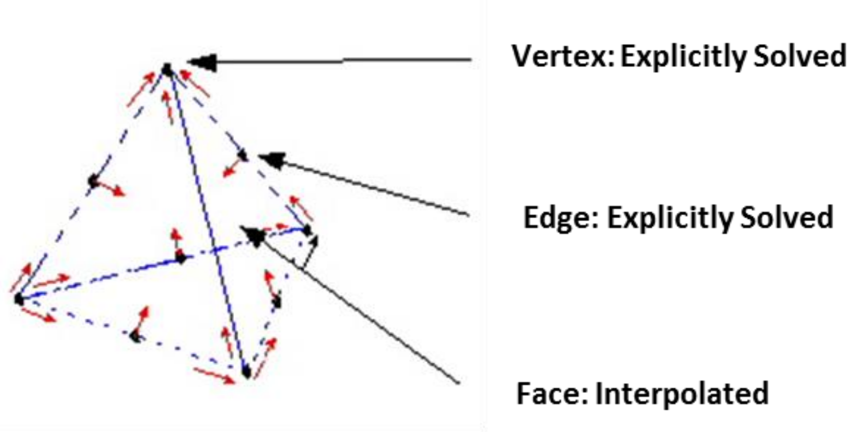


HFSS tunes the FEM mesh to accurately capture the device's electrical performance.

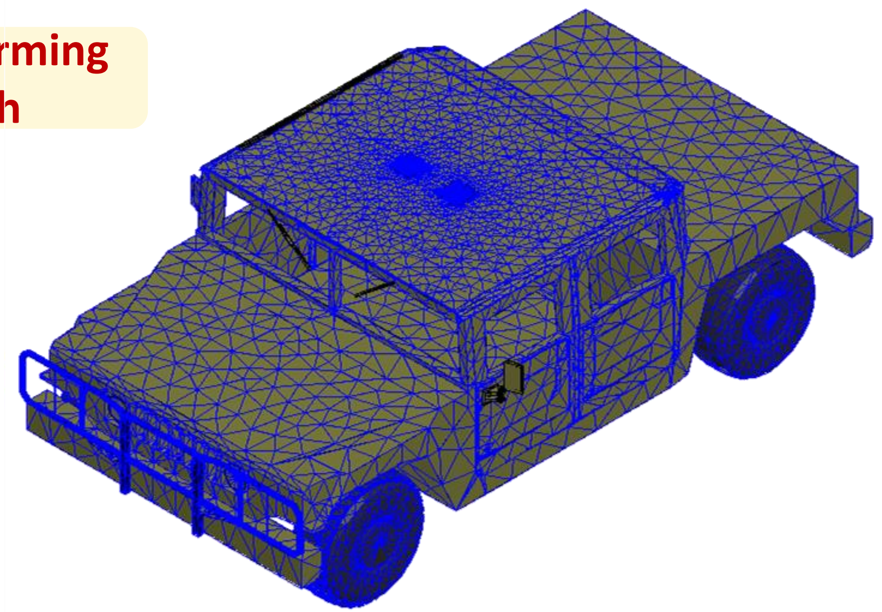
The HFSS setting used in the decision diamond is called Delta S.

Automatic Adaptive Meshing for HFSS FEM Simulation

- HFSS automatically generates a geometrically conforming, tetrahedral mesh.
- HFSS's iterative meshing algorithm solves the fields of the model and intelligently refines the mesh until S-parameters converge below a user defined threshold, ***Maximum Delta S***.
  - The user defines frequency or frequencies at which adaptive meshing is performed.
  - After each solution, tetrahedral elements are "graded" for their accuracy to Maxwell's equations.
  - User defines percentage of "bad" tetrahedral elements to be refined after each pass (30% Default).



Geometrically conforming tetrahedral mesh



Driven Solution Setup - ***General*** **Tab** - ***Solution Frequency***

The ***Solution Frequency*** sets:

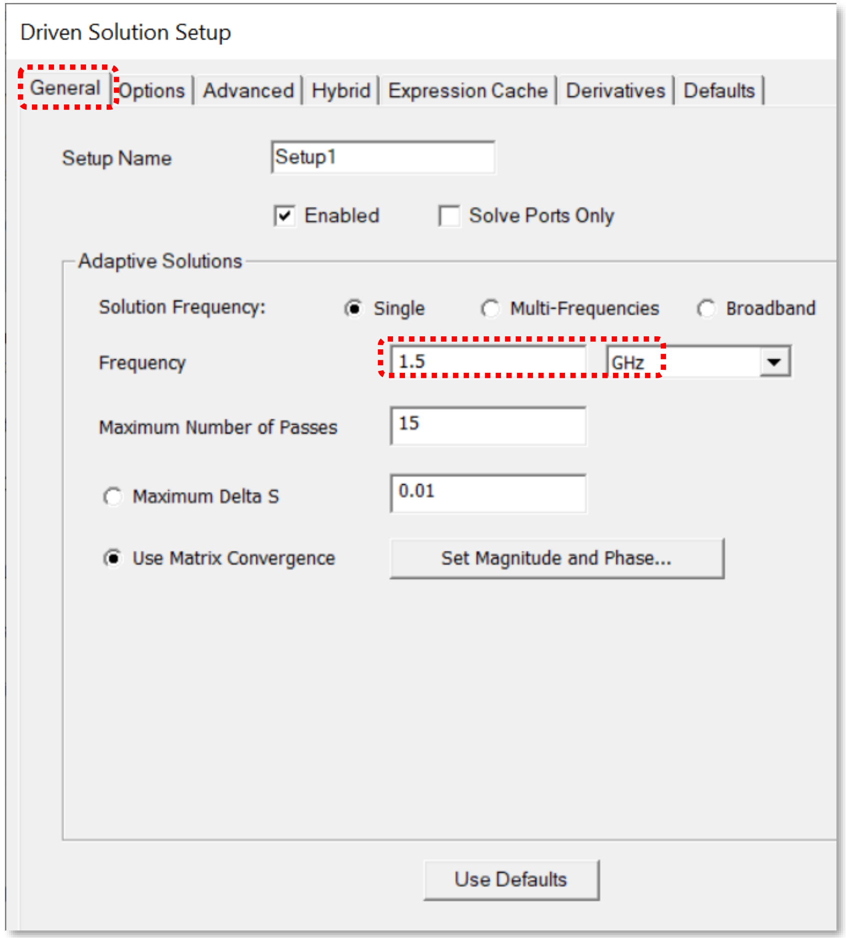
- The frequency used to create the adaptive mesh
  - Defines the spatial resolution of the mesh through the Lambda Refinement step
  - ***Lambda Refinement*** is wavelength dependent
- Determines the frequency used to evaluate the mesh's convergence
- Typically choose the highest frequency of interest or for resonant antennas, the resonant frequency

A higher frequency mesh is generally valid at lower frequencies

- A mesh created at a higher frequency will be denser than a mesh at lower a frequency because the wavelength is smaller
- The denser mesh is likely to pickup the field variations associated with lower frequencies behaviors

A low frequency mesh is generally NOT valid at higher frequencies

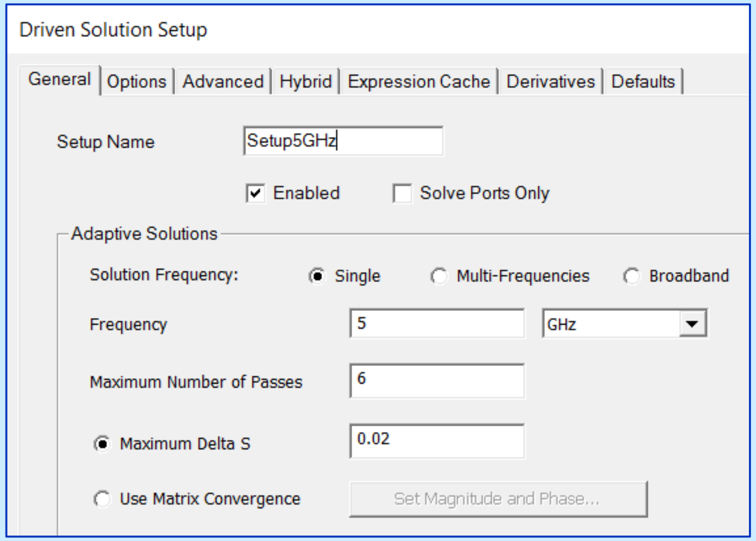
- A mesh created at a lower frequency will be coarser than a mesh created at a higher frequency because the wavelength is longer
- The coarser mesh is less likely to pickup field variations associated with the higher frequencies



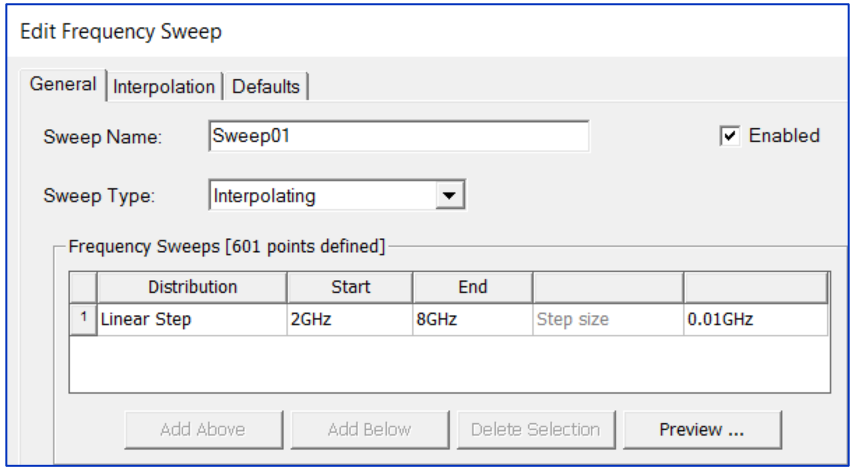
HFSS Solution Setup: Adaptive Meshing and Frequency Sweep

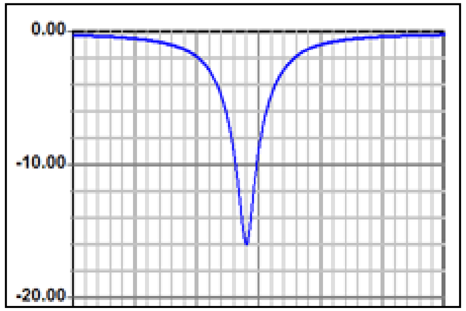
HFSS adaptive mesh settings are:

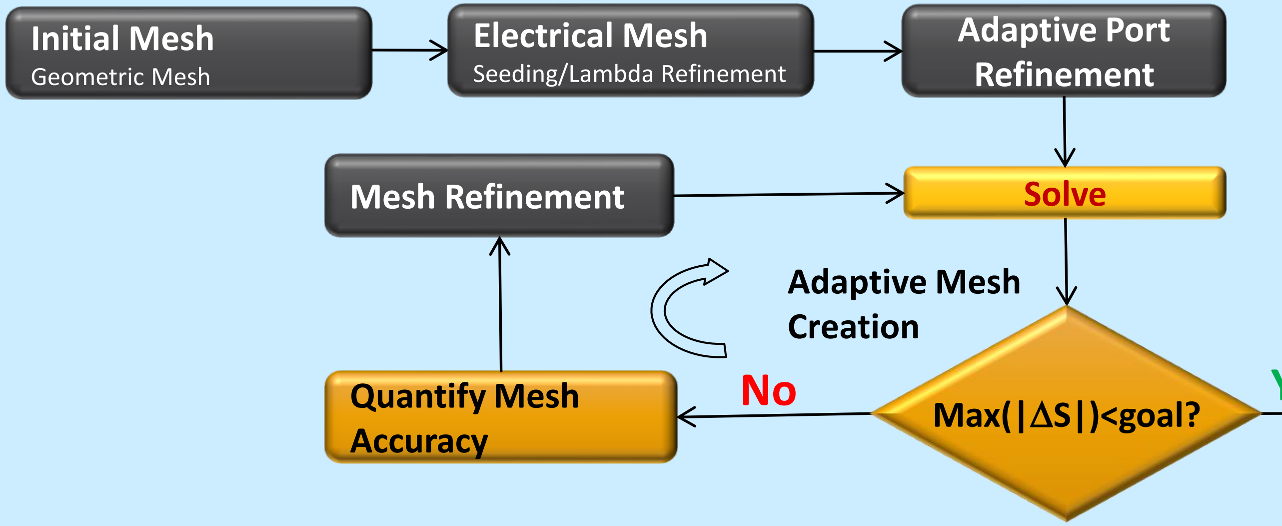
1. **Frequency**
2. **Maximum Number of Passes**
3. **Maximum Delta S**



S-parameter resolution comes from frequency sweep settings.







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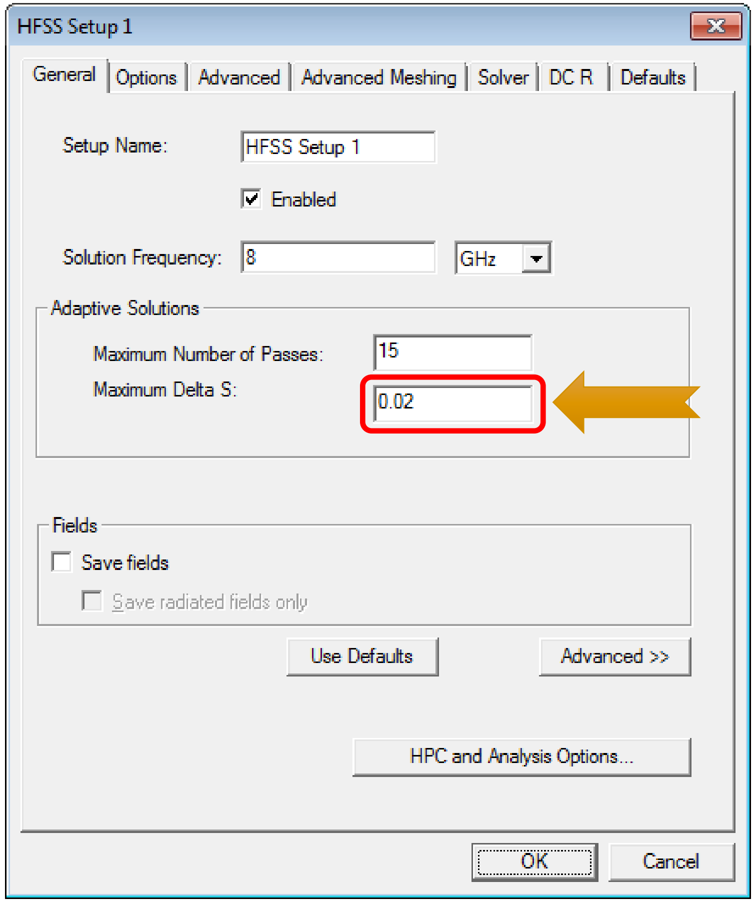
Converging on Maximum Delta S in HFSS Adaptive Meshing

- ***Delta S*** Summarizes the S-Parameter's sensitivity to change in mesh
  - A single number characterizing mesh sensitivity for the entire S-Matrix
  - Accounts for magnitude and phase variation between meshes of all S-parameters simultaneously.
  - Default value of **0.02** is reasonable for most cases
  - Reports the worst-case violation.

$$Max|\Delta S| = Max\left|[S]_N - [S]_{N-1}\right|$$



- DON'T over-specify
  - Setting the ***Maximum Delta S*** too small wastes computer resources and time.
- DON'T under-specify
  - Setting the ***Maximum Delta S*** too large jeopardizes accuracy.

The document ***An Introduction to HFSS***, Chapter 1 ***Fundamentals of HFSS*** section ***Mathematical Method Used in HFSS*** gives a good technical description of the HFSS finite element solution process touching Green's functions and Maxwell's equations.

The Maximum Number of Passes and Maximum Refinement Per Pass

Refinement percentage and number of adaptive passes are both used in the adaptive solution process. The refinement percentage specifies the largest number of tetrahedra that can be subdivided per adaptive pass.

The maximum number of adaptive passes is the maximum number of times HFSS will refine the mesh in order to try and converge to an answer.

The adaptive solution process uses the delta-S, maximum refinement per pass, and maximum number of passes to converge to the correct answer. The delta-S and maximum number of passes determine when HFSS will stop the adaptive solution process. If convergence is reached before the maximum number of passes has been performed, the solution process stops. HFSS will stop if convergence is not reached, but the maximum number of passes has been reached. In such cases, it is recommended to increase the number of passes so that HFSS can reach convergence.

HFSS goes from adaptive meshing to frequency sweep in both/two cases:

1. **Convergence is reached** (before the Maximum Number of Passes is reached)

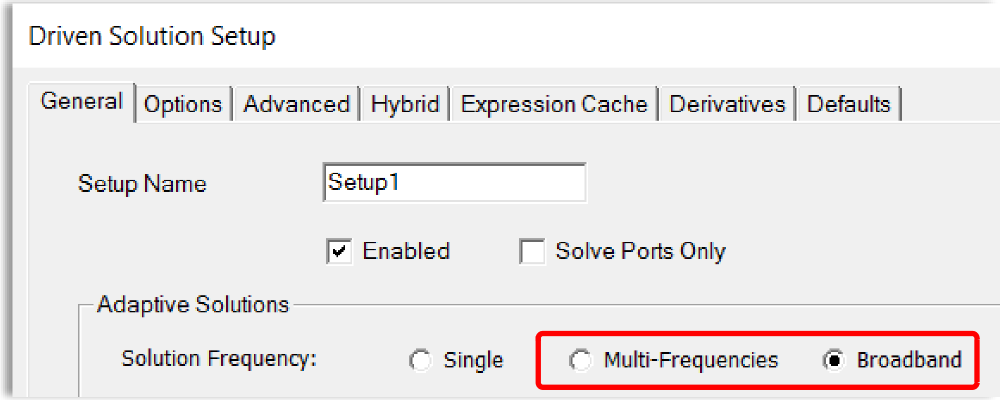
   OR

2. **Maximum Number of Passes is reached**, but convergence has not been reached.

Pay attention to the Message Manager at the bottom of the HFSS GUI as well as the Profile dialog box available by right-clicking on Setup in the Project Manager.

Broadband and Multi-Frequency Adaptive Meshing

In addition to ***Single*** frequency meshing, HFSS offers ***Broadband*** and ***Multi-Frequencies*** meshing.



Broadband Frequency

For most problems, specifying the Single solution frequency setup is adequate to obtain accurate results. If you desire increased reliability for broadband devices and more accurate solutions, you can specify the **Broadband** option for the Solution Frequency setup. The Broadband setup enables HFSS to intelligently determine the appropriate frequencies at which to adapt the mesh. The virtue of automatic broadband adaptive meshing lies in eliminating uncertainty in choosing the best frequency for adapting the mesh. You need only specify the highest and lowest frequencies of the range and HFSS determines the frequencies at which to adapt the mesh. The mesh is always adapted for a minimum of three frequencies within the specified frequency range. Adaptive meshing at additional frequencies require enabling the high performance computing (HPC) feature and availability of sufficient computational resources.

From the HFSS Online Help document ***HFSS.pdf,*** Chapter 19 ***Specifying Solution Settings*** section titled ***Broadband Frequency***.

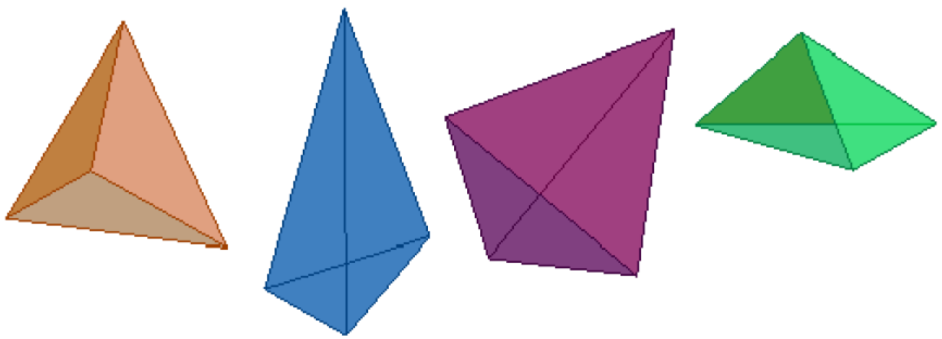
Additional HFSS FEM Learning and Reference Resources

For additional background on the finite element method (FEM) that HFSS uses for simulation, and closely related topics like boundaries, study the course **HFSS 3D Components, Boundary Conditions, Ports and Mesh.**

There are also several resources that come with HFSS.

In the HFSS install directories, such as AnsysEM…\Help\HFSS
there is an HFSS help document **HFSS.pdf** which includes sections:
20 - Assigning Boundaries in HFSS and HFSS-IE
30 - Meshing In HFSS
This chapter on meshing describes the tetrahedra used in HFSS FEM meshing
31 – Technical Notes
This chapter has a section "HFSS Technical Notes" that discusses FEM, including size of mesh versus accuracy.

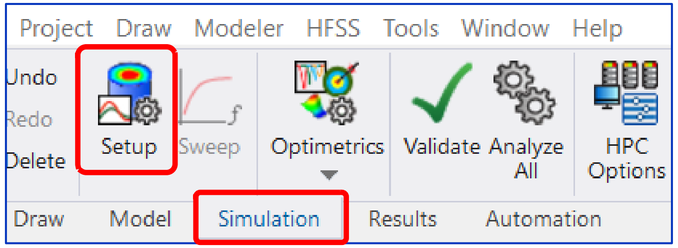
Different kinds of tetrahedra



And in the HFSS online ***Help*** there is a file:
An Introduction to HFSS.pdf. These are in the install directories.
This document discusses boundaries and adaptive meshing.
Chapter 5 ***HFSS Modeling GUI Basics*** includes a section called ***Modeling Practice in HFSS*** which shows an HFSS workflow.

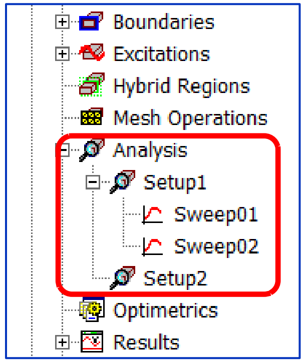
Driven Solution Setup Specifies the HFSS FEM Meshing

1.

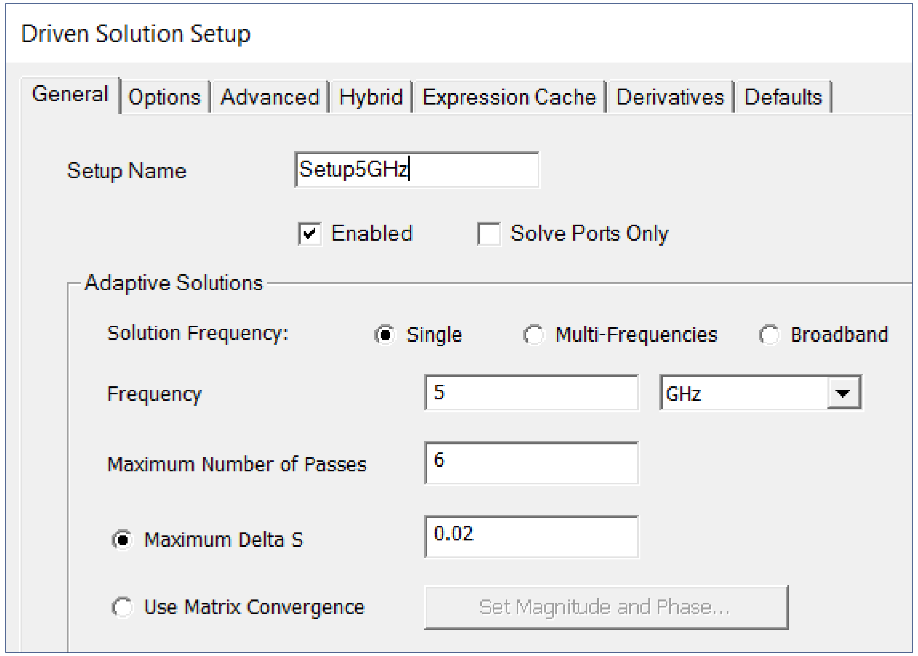


2. ***HFSS > Analysis Setup > Add Solution Setup***

3.



Right-click on Analysis



Three ways to bring up the ***Driven Solution Setup*** dialog box for setting HFSS mesh specifications using the ***Advanced*** Option.

Solution Setup Specifies the HFSS Mesh

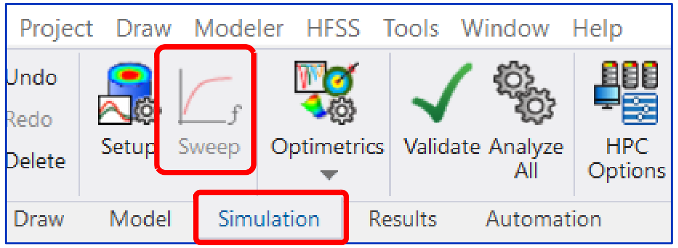
- Frequency
- Maximum Number of Passes
- Maximum Delta S.

A primary way to set accuracy in HFSS simulations

The document ***An Introduction to HFSS***, Chapter 4 ***HFSS Solution Setup*** includes a section ***Driven Solution Setup*** with more information.

Simulation Sweep Dialog - Edit Frequency Sweep

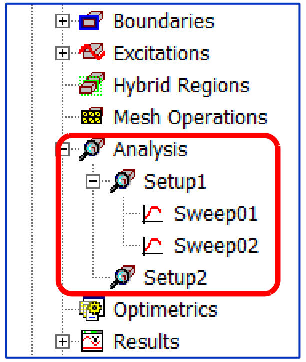
1.



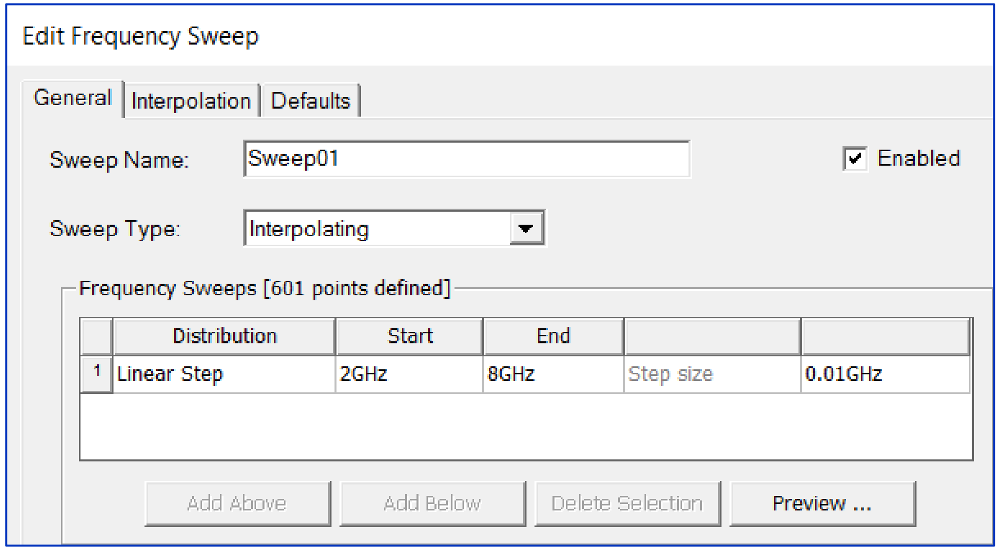
A ***Setup*** (from ***Analysis***) must be selected in order for **Sweep** to become available (not greyed out). (HFSS ***Solution Setup Advanced*** Option)

2. ***HFSS > Analysis Setup > Add Frequency Sweep***

3.

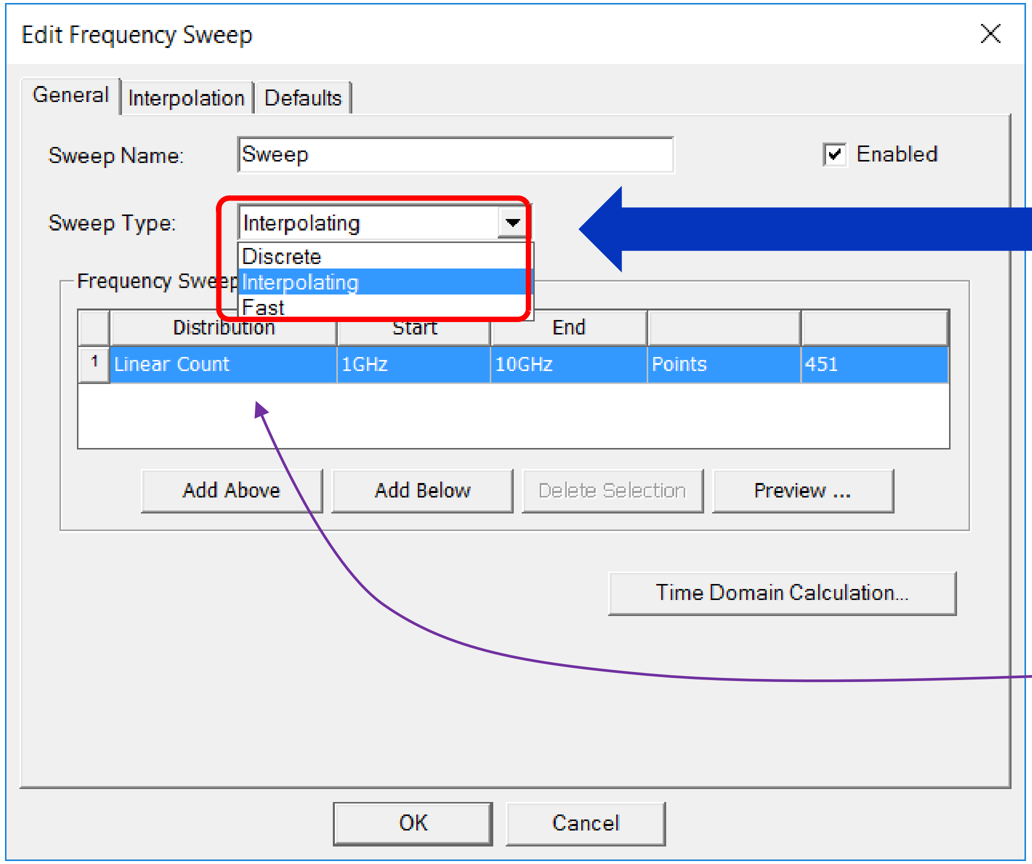


Right-click on Analysis



Three ways to bring up the ***Edit Frequency Sweep*** dialog box for specifying an HFSS frequency sweep.

Edit Frequency Sweep - Three Types of Frequency Steps



Three Sweep Types in HFSS

1. ***Interpolating***
   Good for wideband - no fields
2. ***Discrete***
   Generates fields at every frequency. Can also save fields.
3. ***Fast*** - (ALPS) - Use with caution
   Recommended only for the very narrow frequency sweeps when field information is necessary for many frequency points.

Linear Count

Total number of frequencies, spread over the whole frequency range

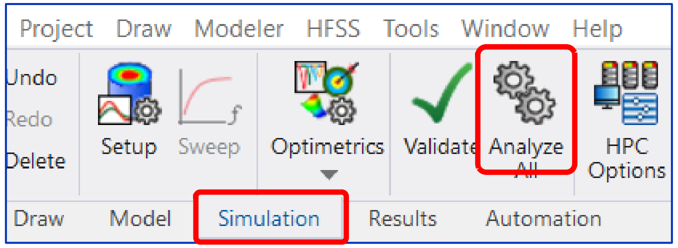
Linear Step

Frequency between steps

The document ***An Introduction to HFSS***, Chapter 4 ***HFSS Solution Setup*** includes a section ***Frequency Sweeps*** with more information.

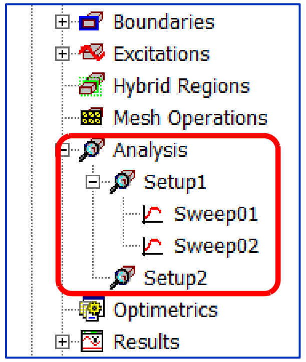
Three Ways to Start an HFSS FEM Simulation - *Analyze*

1.



2. ***HFSS > Analyze All***

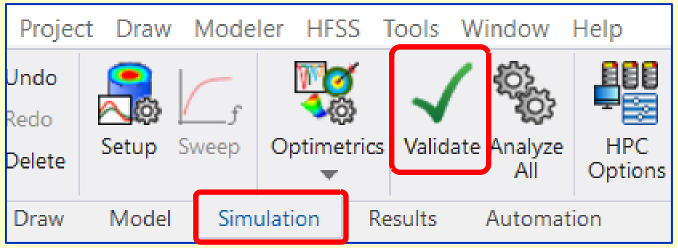
3.

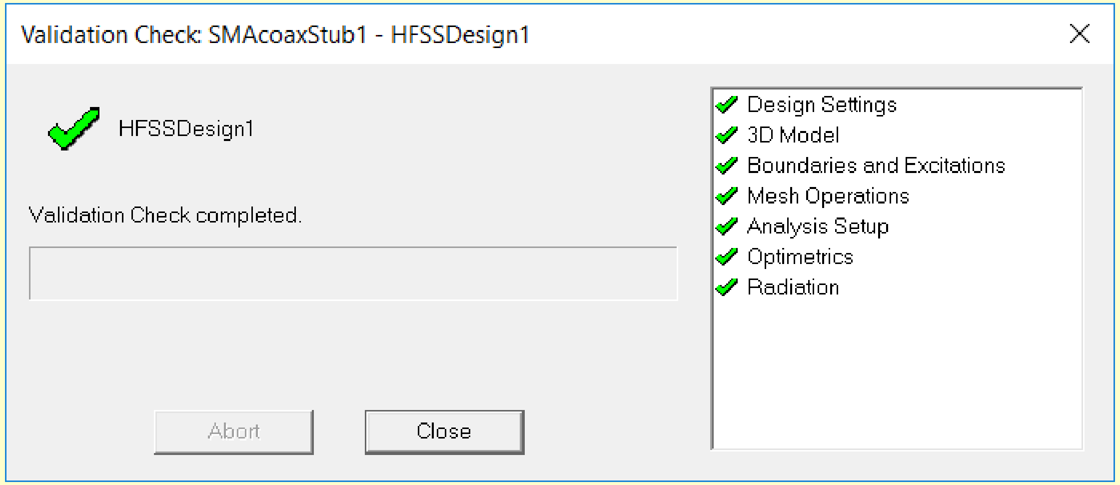


Right-click on Analysis

Three ways to start an HFSS simulation

Validate before simulation





Validation is an important and useful check before starting an HFSS simulation.

HFSS Solution Type - *Driven Modal* versus *Driven Terminal*

Solution Types

Before creating the design, you must specify the type of solution that you want HFSS to calculate. The following solution types are available:

1. Driven Modal
2. Driven Terminal
3. Transient
4. Eigenmode

From the document "***An Introduction to HFSS***", Chapter 1 ***"Fundamentals of HFSS"*** section titled ***"Solution Types"***.

For most HFSS simulations, the Driven Modal solution type is used. For simulations that deal with signal integrity, Driven Terminal solution type is preferred; such problems generally include transmission lines with single as well as multiple conductors.

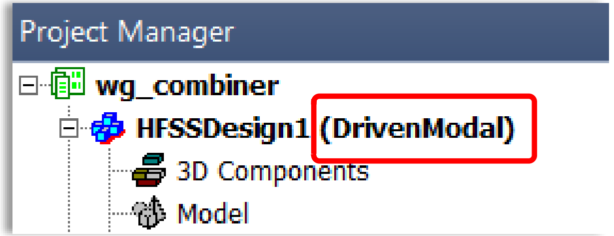
Simulations that use the driven modal solution type yield S-matrix solutions that are expressed in terms of the incident and reflected powers of transmission line modes. The S-matrix that is produced by the driven terminal solution type, however, is expressed in terms of terminal voltages and currents.

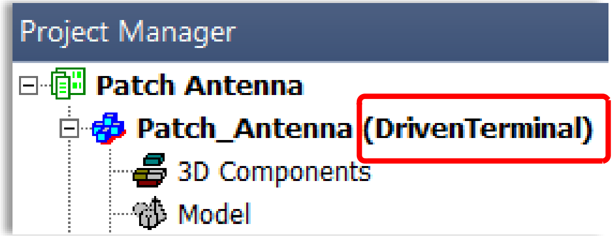
Fundamentals of HFSS 1-12

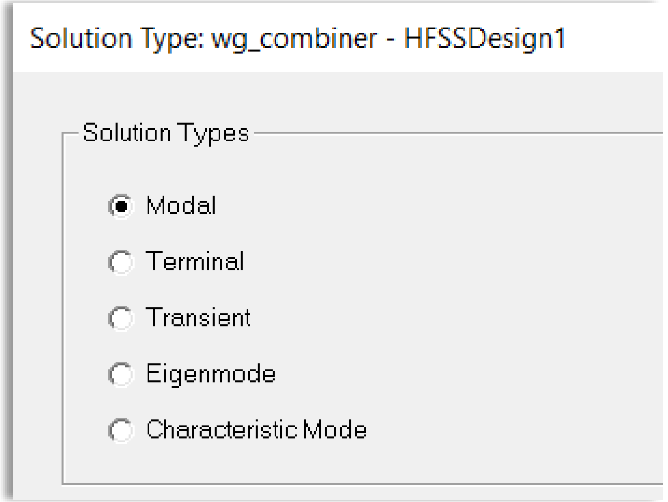
Solution types are a fundamental part of every HFSS simulation.

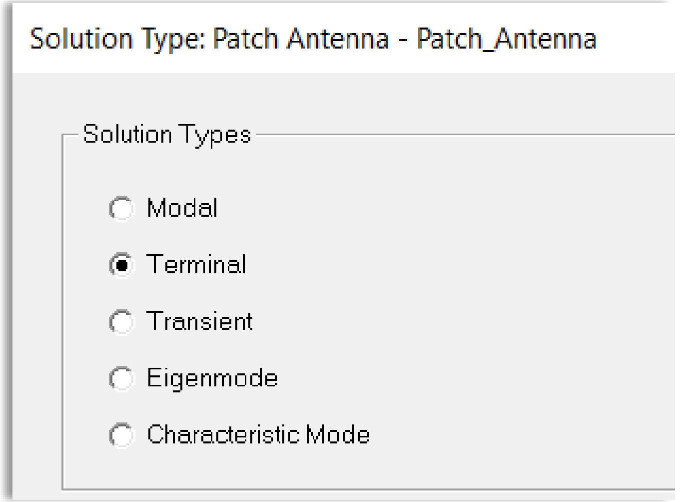
Among all the possible HFSS ***Solution Types***, this course, focusing on frequency domain, looks at ***Modal*** and ***Terminal***.

HFSS *Solution Type* - *Driven Modal* versus *Driven Terminal*









Access the HFSS ***Solution Type*** dialog box with ***HFSS > Solution Type.***

Driven Modal versus *Driven Terminal Solution Type* S-Parameters

Solution Types in HFSS

Driven Modal Solution

Choose the **Driven Modal** solution type when you want HFSS to calculate the modal-based S-parameters of passive, high-frequency structures such as microstrips, waveguides, and transmission lines. The S-matrix solutions will be expressed in terms of the incident and reflected powers of waveguide modes. **Network Analysis** is the default and functions as before.

Composite Excitation provides a method for solving fields in a large frequency domain problem.

Driven Terminal Solution

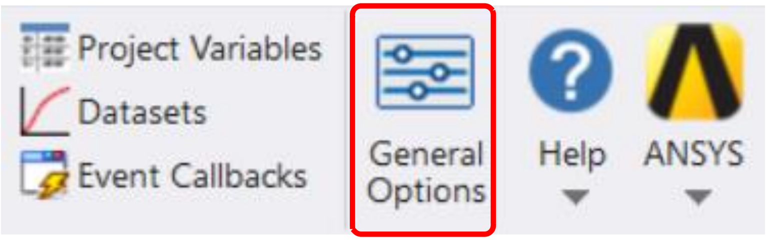
Choose the **Driven Terminal** solution type when you want HFSS to calculate the terminal-based S-parameters of single and multi-conductor transmission line ports. The S-matrix solutions will be expressed in terms of voltages and currents on the terminals. **Network Analysis** is the default and functions as before.

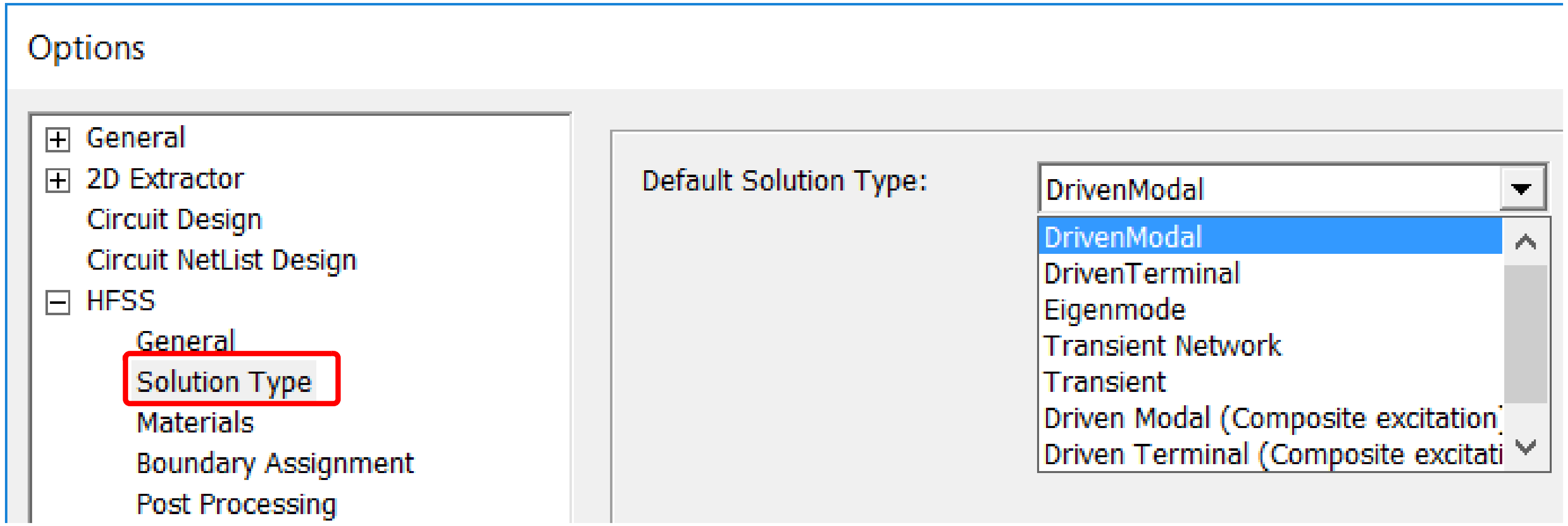
Composite Excitation provides a method for solving fields in a large frequency domain problem.

Modal versus terminal solution types will be revisited in the study of HFSS lumped and wave port setups.

HFSS Default *Solution Types* Under *Tools > Options*

The HFSS ***Solution Type*** gets set by default for new projects. Access this ***Options*** dialog box from the ***Ribbon***, in the Desktop tab, with ***General Options.***





Another way to access this dialog box with ***Tools > Options > General Options.***

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End of Presentation