

## ANSYS HFSS - Broadband Adaptive Meshing

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The cornerstone technology that ensures the accuracy and efficiency of ANSYS HFSS is the automatic adaptive meshing process. This process starts with ANSYS HFSS creating a conformal, non-homogeneous mesh to describe the modeled geometry. This mesh is solved for electric fields, and ANSYS HFSS determines where the solved fields have errors due to the mesh's failure to capture field gradients accurately. The mesh is automatically refined in those locations, and the new mesh is solved. This adaptive process continues until a specific output quantity, usually based on the S-parameters, changes less than a user-specified convergence criteria between two consecutive adaptive passes.

Up to now, this automatic adaptive meshing process has taken place at a single frequency, which works great for most simulations. In HFSS, the adaptive mesh refinement process is enhanced by adapting the mesh at multiple frequencies simultaneously. Here, the mesh is solved at multiple frequencies, and the errors found in the mesh, at all solved frequencies, is used to refine the mesh. The advantage of this improved meshing technology is ease of use and increased accuracy in the solutions over broadband frequency ranges.

This multi-frequency adaptive meshing feature is available in ANSYS HFSS and ANSYS HFSS 3D Layout.

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### **Automatic Adaptive Meshing at a Single Frequency**

The automatic adaptive meshing procedure at a single frequency is the cornerstone technology that enables ANSYS HFSS to accurately and efficiently calculate the electric fields in a model. The process starts with ANSYS HFSS translating the modeled geometry into a conformal, inhomogeneous tetrahedral mesh. This mesh is coarse in areas where the geometry consists of large objects, and dense in areas where the geometry has fine features. This initial mesh is refined to limit the maximum size of the mesh elements and comply with any user-specified mesh operations. The first adaptive pass is completed by solving this mesh at the single solution frequency to determine the electric fields and S-parameters of the model.

In certain regions of the model, the mesh is too coarse to accurately capture the electric field gradients, and ANSYS HFSS determines those locations automatically and locally refines the mesh or the mesh order in the locations of greatest error. The new mesh is now solved in the second adaptive pass for electric fields and S-parameters.

This automatic adaptive process continues until the mesh converges. The mesh is converged when an output quantity of interest, usually based on the S-parameters, changes between two consecutive adaptive passes by less than a user-specified convergence criteria. After completing the mesh adapting process, ANSYS HFSS will solve the mesh at numerous frequen-

cies to determine the user-requested frequency behavior of the model. Figure 1 outlines the procedure of the automatic mesh adapting at a single frequency.

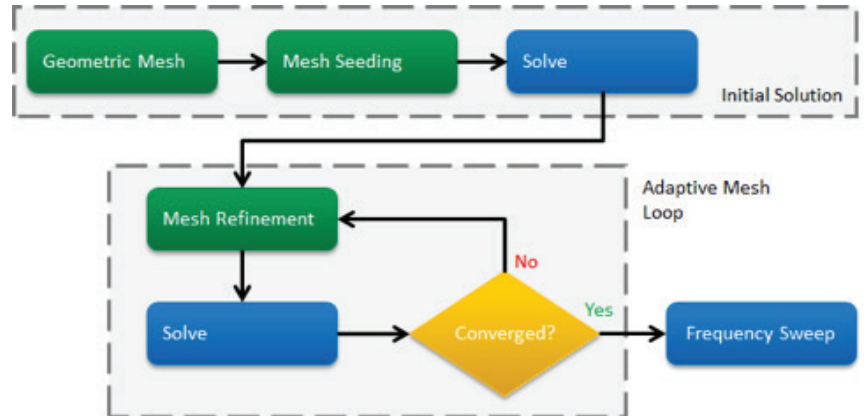


Figure 1: Automatic adaptive meshing at a single frequency

In most cases, the use of the single solution frequency is sufficient to generate accurate results. For a resonant structure the frequency sweep of interest is usually defined as a band centered at the resonant frequency; it is this frequency at which the model would most appropriately be meshed. For a broadband model in a digital application such as a high speed connector, it's appropriate to model at roughly  $\frac{1}{3}$  the maximum frequency, since the spectral energy for a digital signal is dominant in this part of the frequency spectrum.

### Automatic Adaptive Meshing at Multiple Frequencies

For multi-band, multi-resonant devices it's useful to perform adaptive meshing at multiple frequencies. Previously, this multi-frequency adaptive meshing could be executed with a series of dependent mesh setups at multiple frequencies. With this in mind, the adaptive meshing process has been enhanced in HFSS to use information at multiple frequencies to efficiently adapt the mesh for a more accurate and reliable solution across a broad frequency range. This technique can also be leveraged for a broadband digital device when there is uncertainty about which frequency to execute the adaptive meshing process.

The multi-frequency adaptive meshing process is similar to the single frequency adaptive meshing process; the difference is that the single mesh describing the geometry of the model is solved at multiple frequencies in parallel. For each frequency, the solutions are analyzed and ANSYS HFSS determines automatically where to refine the mesh using information from the multiple frequencies to automatically reduce errors to the solution. The mesh is then refined locally, both in size and order of basis function, in the locations where the errors were relatively large. This refinement yields a mesh that is more accurate and reliable at the frequencies used in the adaptive process.

The automatic adaptive process is continued until the mesh is converged. This occurs when the output quantity of interest at the multiple frequencies changes between two consecutive adaptive passes by less than a user-specified convergence criteria.

Once the final mesh is generated, ANSYS HFSS also creates a solution across a frequency range of interest as defined in the frequency sweep. This automatic adaptive meshing process at multiple frequencies is outlined in Figure 2.

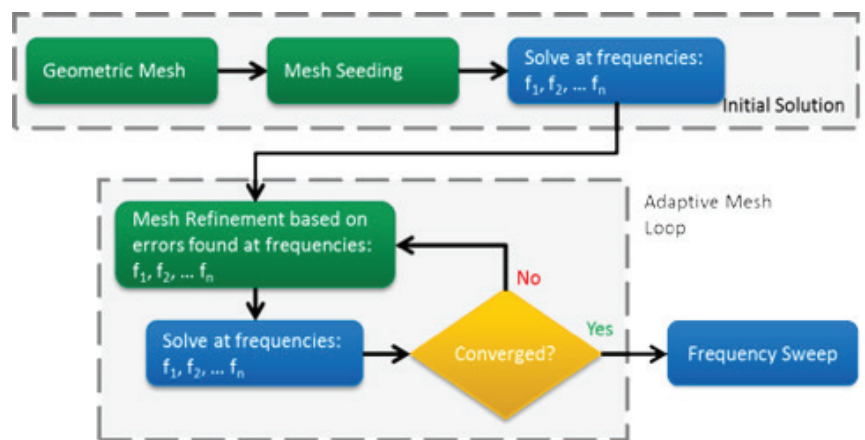


Figure 2: Automatic adaptive meshing at multiple frequencies

Two settings are available for the automatic adaptive meshing procedure. The multi-frequency solution setup allows the user to explicitly specify at what frequencies the mesh should be refined. This solution setup works great for multi-band resonant devices where the resonant frequencies are known before analyzing the simulation.

The broadband solution setup allows the user to define the frequency range of interest. ANSYS HFSS will intelligently decide which frequencies to utilize in the automatic adaptive meshing process. This solution setup is a convenient method to automatically obtain a mesh appropriate for broadband frequency simulations without requiring explicit user input.

#### Adaptive Solution Frequency Setup

The three types of solution frequency setups used in the automatic adaptive meshing process are selected in the Solution Setup: single frequency, multi-frequencies and broadband.

##### *Single Frequency:*

In the Solution Setup, the single solution frequency can be specified as shown in Figure 3. Based on this solution frequency and the specified convergence criteria, ANSYS HFSS automatically creates a suitable mesh for the design.

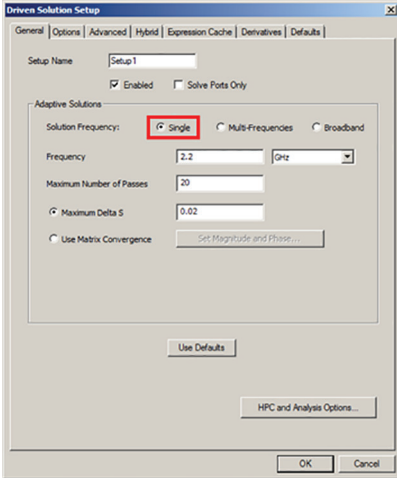


Figure 3: Single frequency solution setup

When utilizing high-performance computing (HPC) for simulations setup using the single frequency adaptive meshing process, all available computational resources will be dedicated to solving the mesh during each adaptive pass.

### Multi-Frequencies:

For multi-band devices, such as a dual-band patch antenna [1] shown in Figure 4 (a), using the multi-frequencies solution setup shown in Figure 4 (b) will ensure that the resonances are captured accurately in the automatic adaptive meshing process. This multi-frequencies solution setup allows you to specify the adaptive meshing frequencies along with a convergence criterion for each frequency.

During each adaptive pass, the mesh is solved at each frequency in parallel if HPC is enabled and enough computational resources are available. Without HPC, or if the mesh is too large to be solved at multiple frequencies in parallel on the given computational resources, the mesh will be solved sequentially for each of the frequencies specified in the solution setup.

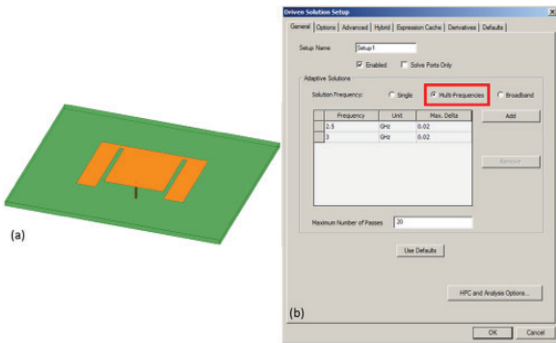


Figure 4: (a) Dual-band patch antenna and (b) multi-frequency solution setup

Figure 5 (a) shows a comparison of solving the dual band patch antenna shown in Figure 4 (a) using the multi-frequency setup from Figure 4 (b) and a single frequency solution setup set to the highest frequency in the band of interest, 3.5 GHz.

This comparison with measured data shows that capturing both resonant frequencies accurately is straightforward with the new multi-frequencies solution setup. Additionally, this comparison makes it clear that setting the single solution frequency to the highest frequency in the band of interest is not always the correct solution setup.

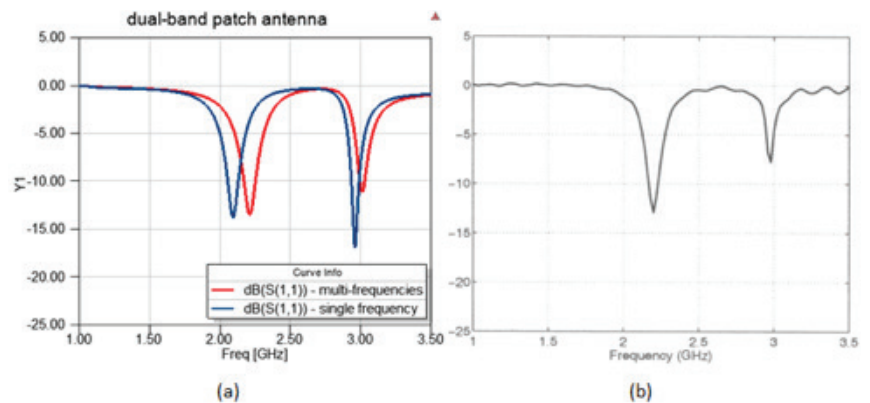


Figure 5: Return loss of dual band patch antenna, (a) simulated and (b) measured [1]

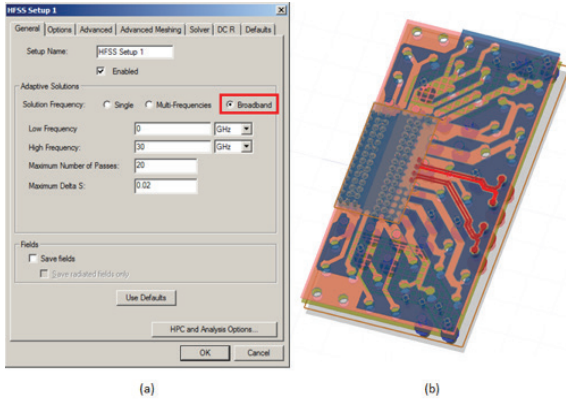


Figure 6: (a) Broadband solution setup and (b) BGA package in HFSS 3D Layout

### Broadband:

Utilizing the broadband solution frequency setup shown in Figure 6 (a) is a great way to increase the accuracy of solutions for broadband devices. This feature is especially useful when uncertainty exists about choosing the best frequencies for adapting the mesh. Figure 6 (b) shows a section of a BGA package in ANSYS HFSS 3D Layout. Two differential pairs, highlighted in red, are extracted over the 0 – 30 GHz frequency range.

Note that in case a frequency sweep is already defined before specifying the broadband solution setup, the low and high frequency in this solution setup will be automatically populated from the limits in the frequency sweep.

Using the broadband solution setup, ANSYS HFSS will automatically select which frequencies to include in the broadband adaptive meshing procedure. The broadband solution setup will solve three frequencies sequentially during each of the adaptive passes. Additional frequencies can be included in the automatic adaptive meshing process when using HPC. With sufficient computational resources, each adaptive mesh will solve the mesh at the auto-selected frequencies in parallel.

Figure 7 shows a comparison of the insertion loss of the two differential pairs on the BGA package using a single frequency solution setup at 15 GHz and the broadband solution setup indicated in Figure 6 (a). The broadband setup was solved on a 16-core computer. This configuration enabled the solving of 8 frequencies in parallel, each utilizing 2 cores.

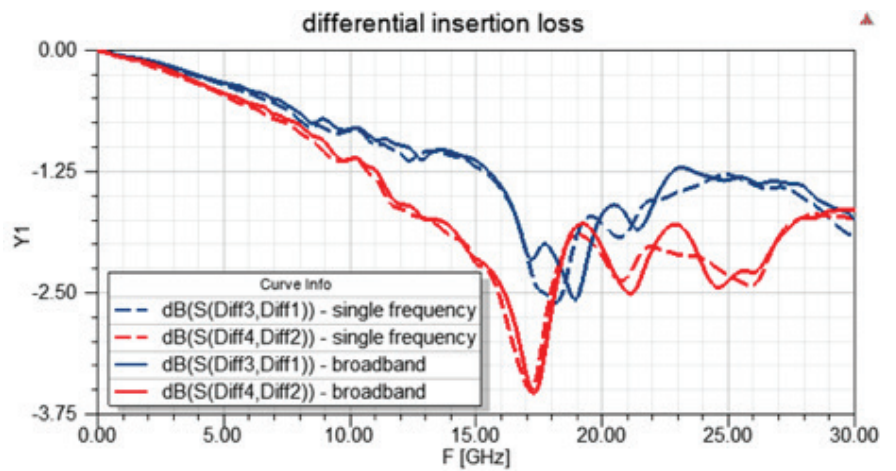


Figure 7: Differential insertion loss solved with single frequency and broadband methods

The comparison shows that the broadband adaptive meshing process captures more detail in the high-frequency behavior of these differential pairs.

### Summary

The multi-frequencies and broadband automatic adaptive meshing process introduced in HFSS extends the capability of the time-tested single frequency automatic adaptive meshing process. Instead of refining the mesh at a single frequency only, multiple frequencies can now be accounted for during the adapting process, facilitating higher accuracy in the results covering broad frequency ranges.

The multi-frequencies solution setup allows the explicit definition of frequencies to be used during the automatic adaptive meshing process. This approach is therefore suitable for multi-band devices, for which the resonant frequencies are known before running the simulation.

The broadband solution setup requires only the frequency range of interest; HFSS will automatically select which frequencies to include in the automatic adaptive meshing process. This approach is an efficient and convenient method to automatically obtain a mesh appropriate for broadband frequency simulations.

### References

[1] P. Salonen, J. Kim, and Y. Rahmat-Samii, "Dual-band E-shaped patch wearable textile antenna," in *IEEE Antennas Propag. Int. Symp. Dig.*, 2005, pp. 466–469.