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Cell Size Definition in Microwave Office Design Suite's EMSight

Cell size definition is an important part of an electromagnetic (EM) analysis. EMSight™, the electromagnetic simulator in Microwave Office™ design suite from Applied Wave Research (AWR™), is a unique software tool that efficiently and easily solves this challenge. EMSight, which is used to simulate and analyze the behavior of high-frequency RF and microwave circuits and antennas, can analyze arbitrary planar circuits, including interconnecting vias, on an unlimited number of dielectric layers with an unlimited number of ports. The software accurately determines the multi-port scattering parameters and features robust 3D visualization and animation capabilities that show the magnitude and direction of currents within a structure.

Many times it is a matter of experience and intuition that determines cell sizes for experienced EM users. Many of these users have a good understanding of the physical properties of the structure they want to analyze. They know the effect of dimensional tolerances on the structure at the analysis frequencies because they have built and tested similar structures. For the novice EMSight user proper cell size definition can be very ambiguous. In this paper proper cell size is defined as a cell size that creates a sufficient mesh density for the accuracy of the simulation for a particular structure. Each structure is different, and, accordingly, the required accuracy for the solution varies. Guidelines in determining proper cell sizes will be discussed and examples will be given to illustrate each point. The discussion is divided into three main guidelines called FDS: frequency, dimension, and structure.

Guidelines to Determine Proper Cell Size: FDS

There are many guidelines that determine the proper cell size for a structure. The most important of these guidelines can be divided into three categories: frequency, dimension, and structure:

1. Frequency - the cell dimension is inversely proportional to the analysis frequency. As frequency increases wavelength decreases and therefore the cell size shrinks. Typically the cell size is chosen to fit the highest frequency. This is the most important guideline because it is taken into consideration in all other guidelines.
2. Dimension - this guideline describes an understanding of how dimensional tolerances affect a structure at the analysis frequency. The following questions

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should be addressed:

   1. How does the dimension of the width of the transmission line effect the impedance?
   2. What is the dimensional tolerance of the physical structure to be built and tested?
   3. What are the critical areas of the structure that must be held to a tight tolerance?

3. Structure - complexity of structure and type of structure determines cell size. A lange coupler will require much more precision than a step discontinuity in microstrip. Also, any coupling between discontinuities must be included in the simulation, therefore coupling drives the complexity of the structure.

Frequency

The first step in determining a proper cell size is to determine the wavelength of the transmission media. If the structure is of a standard transmission media such as coplanar waveguide, microstrip, or stripline, the Txline program in the Microwave Office software can be use to determine the propagation wavelength at a specific frequency. An approximate guideline for definition of cell size is .01 of the propagation wavelength for medium complexity circuits. For example, a microstrip tee as seen in Figure 1 has dimensions of width on ports two and three of 20 mils, while port one has a width of 72 mils. It is desirable to find a common denominator for both widths so that the cells will cover the entire width of each transmission line. At 10 GHz the propagation wavelength is about 720 mils. A common denominator for the two widths is four mils, which is equal to about .005 of the propagation wavelength. For ports two and three, a four mil cell size is chosen. On port one an 8 mil cell width is chosen (72/8=9). Since port one width is in the x direction and ports two and three widths are in the y direction, the final cell size is eight mils in x and four mils in y. This example ran in three minutes with a frequency range from one to 20 GHz in one GHz steps. This example was compared to various cell definitions which vary from very coarse to fine. The cell definitions are listed below.

- Very coarse — four mils in y, eight mils in x (memory required = .414Mbytes, simulation time = 42 secs)
- Coarse — four mils in both x and y (memory required = .868Mbytes, simulation time = one min 45 secs)
- Medium — two mils in x and y (memory required = 3.237Mbytes, simulation time = four min 20 secs)
- Fine — 1mil in x and y (memory required = 16.54 Mbytes, simulation time = 27 min)

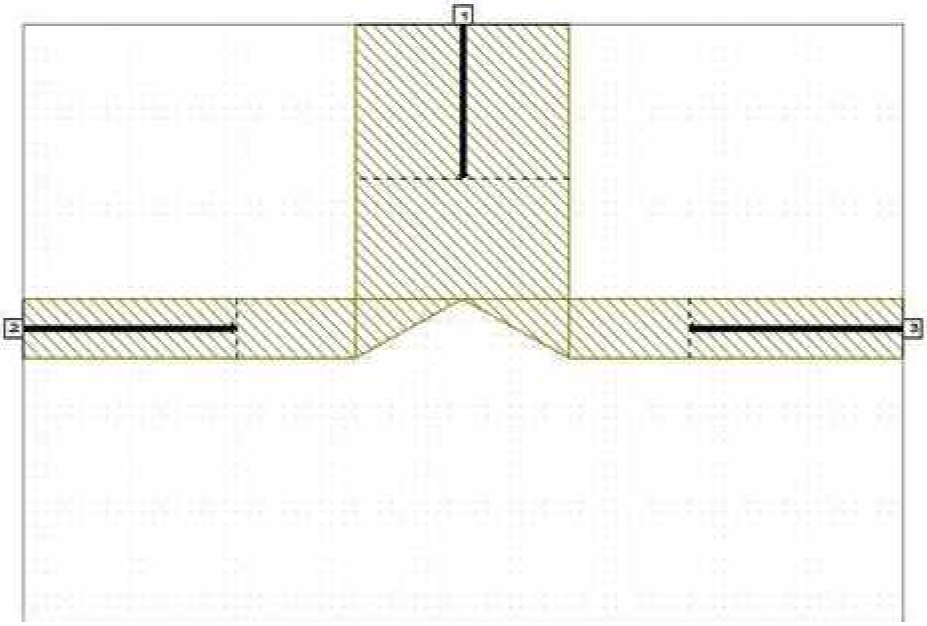


Figure 1. Port 1 width=72mil =2*4*9 Port 2&3 width = 4*5

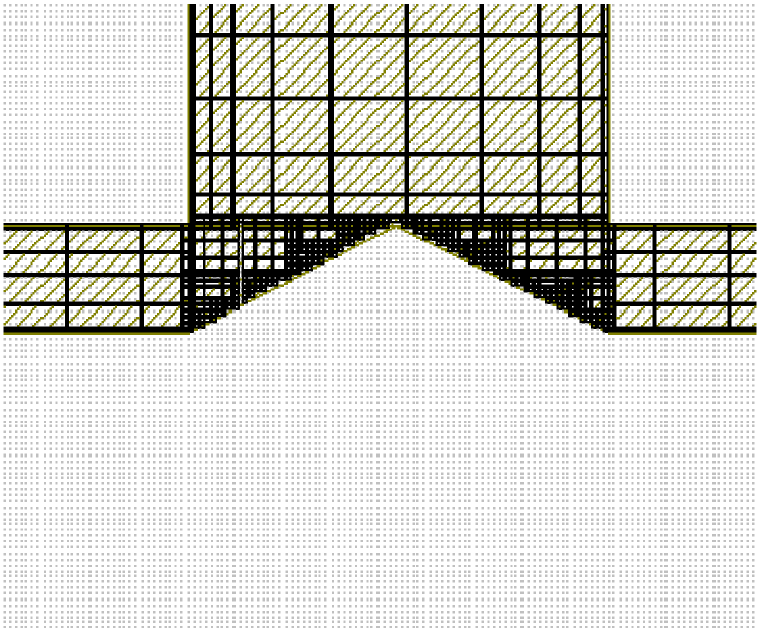


Figure 2. Closeup of fine mesh

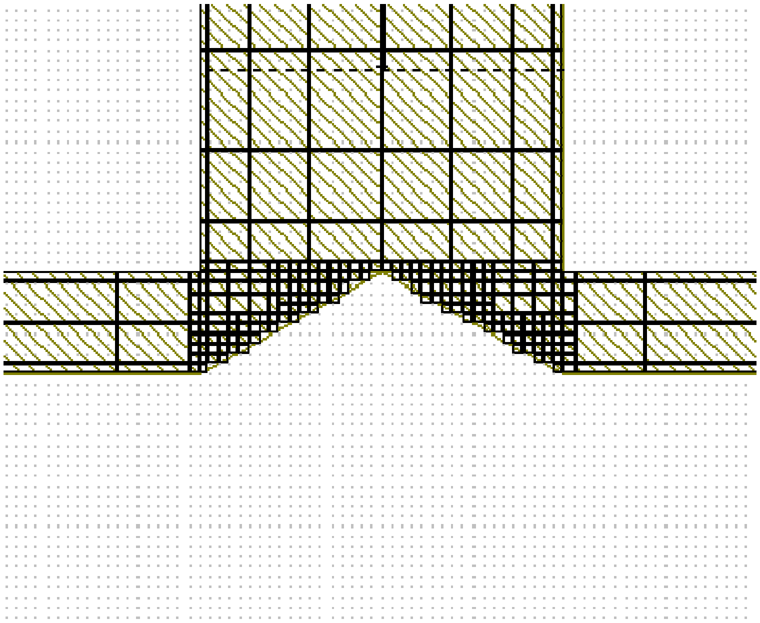


Figure 3. Closeup of medium mesh

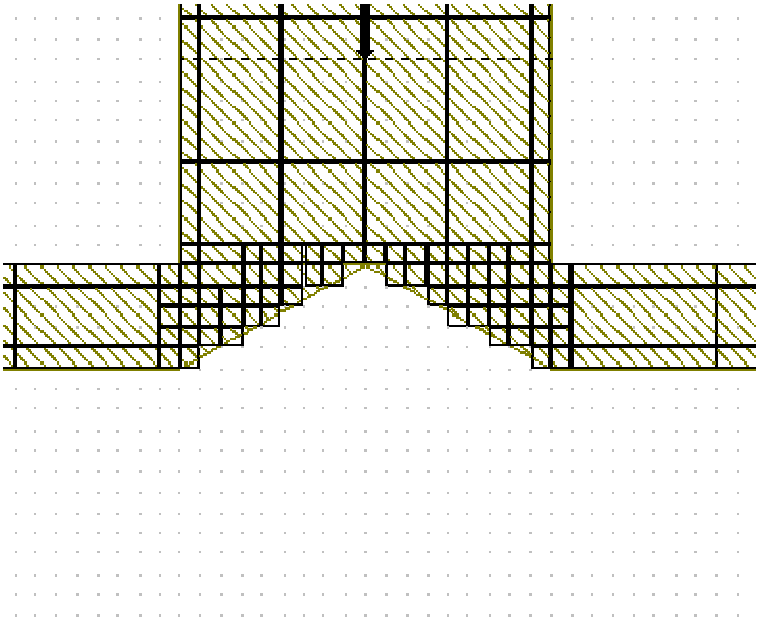


Figure 4. Closeup of coarse mesh

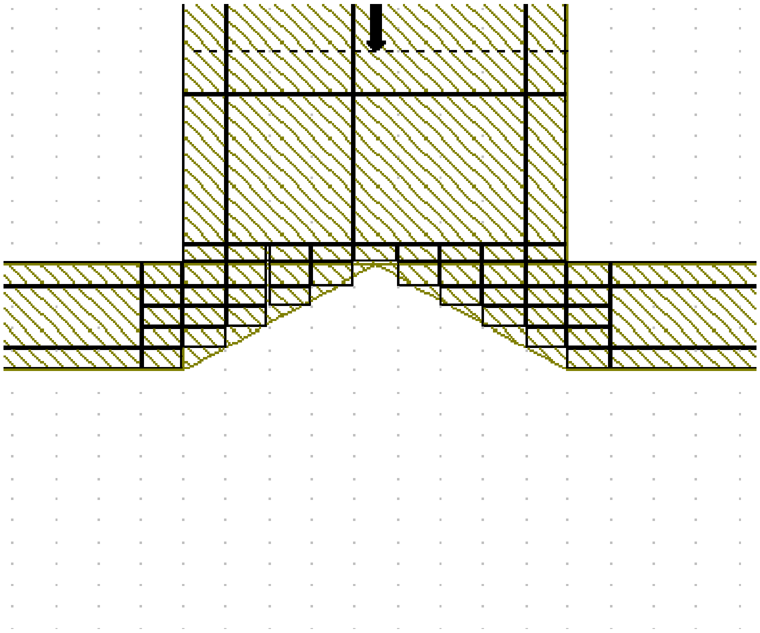


Figure 5. Very coarse mesh

The data shows that the divergence of the different cell definition solutions is small out to 20 GHz for the magnitude of S11. The overall error is plotted in Figure 2. At 20 GHz the error between the coarsest grid and the fine grid is only about 1.5 percent. As evident in this example, using cell sizes of .01 the propagation wavelength is very conservative for cell size definition.

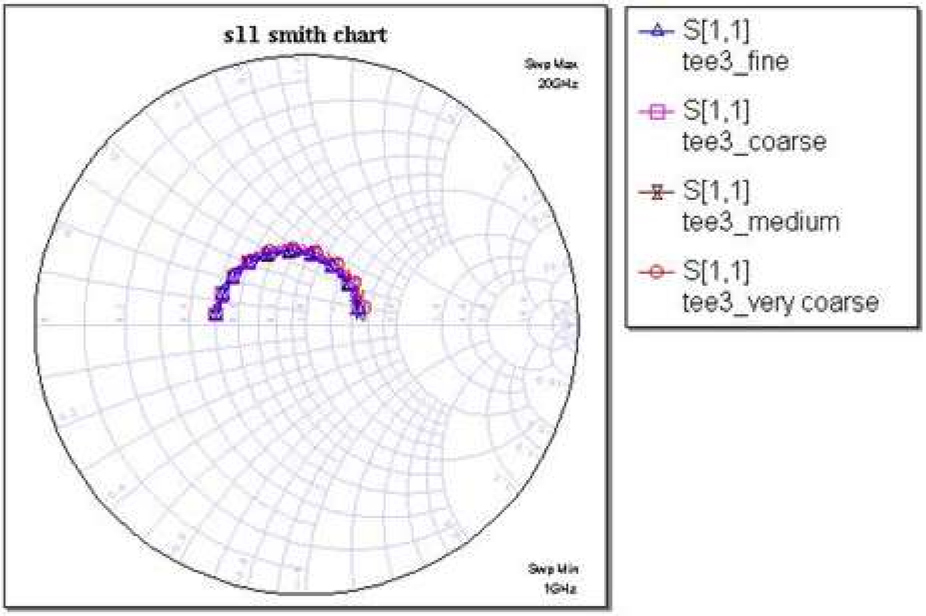


Figure 6. EMSight simulation data. Mesh density comparison.

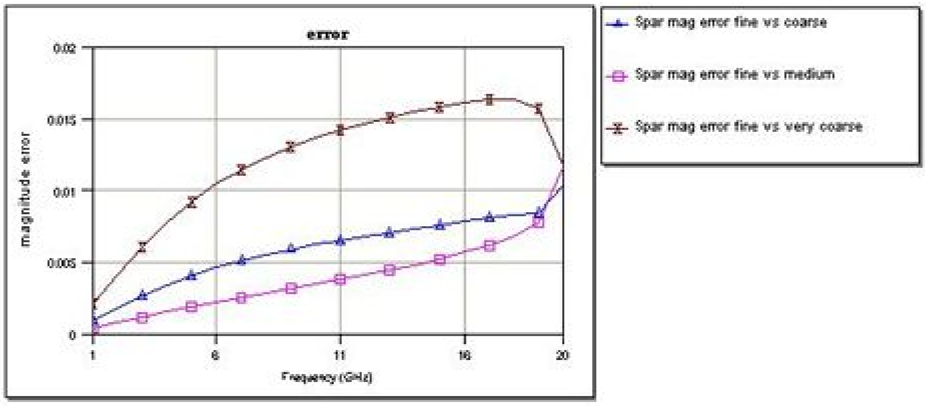


Figure 7. Error in simulation data comparing fine mesh vs. medium mesh and fine mesh vs. coarse mesh.

Dimension

Dimensions of lines and spaces in a structure are very critical in the cell size definition. An understanding of the effect of dimensional tolerances on impedance and coupling effects of a structure is required to make wise decisions on cell size. Again the Txline program can aid in determining some of the important information needed to make those decisions. Many times transmission line dimensions are not of a cell size that is easily divisible by an integer number. For instance, the width of a 50 ohm line on 10 mil alumina at 10GHz is 9.8 mils. 9.8 mils is not divisible by an integer number. A 10 mil line, on the other hand, has an impedance of 49.5 ohms and it is easily divisible by two or five mils. The difference between a 49.5 ohm line and a 50 ohm line introduces insignificant errors in the analysis, but a 10 mil line that can be divided by an integral number significantly reduces the EM solution time. For coupling effects, it may be desirable to do quick studies on the effect of line widths and spacing on the linear simulator. By comparing the results of coupled lines of various space and widths using a simple faster technique, insight into a proper cell size can be deduced.

Dimensional tolerances of the actual structure to be built are also very important for cell size definition. A knowledge of the limitations and tolerances of processes used to fabricate a circuit can be very helpful in determining what dimensions can be changed in an EM analysis to define an integral cell size. For example, if a circuit is built using a process where the etching tolerances of the material for a microstrip line are plus or minus one mil, it is not necessary to define any cell size that includes tenths of a mil resolution. Knowledge of this type tolerance information also provides the ability to adjust the cell size to speed up the simulation.

Cell size definition is driven by the most critical part of a circuit. A knowledge of the critical areas of a circuit can be gained by following this rule of thumb: if lines or discontinuities are separated by more than two substrate widths (see the discussion in the PWB example) the coupling between them is insignificant and the lines or discontinuities can be separated and simulated individually.

Once the critical areas are determined the cell size should be defined by the dimensions of the lines or discontinuity in question. All the guidelines discussed previously should apply to this critical area.

Structure

Structure complexity along with frequency drives the cell size definition. Figures 8, 9 and 10 demonstrate this concept. Figure 8 shows a closeup of the fingers of a lange coupler. The lange fingers determine the performance of the circuit and therefore the dimension of the finger widths determine the cell size. In this case the finger widths are two mils, so the cell size is defined as 2 x 2 mils. The lange coupler can be considered a high complexity circuit because the finger widths and spaces are very critical to the performance of the coupler. The cell size used is the coarsest cell definition. For very complex circuits it is desirable to coarsely mesh the initial simulation to determine if the circuit is working properly. After the initial simulation, refining the mesh is recommended to see how the simulation changes.

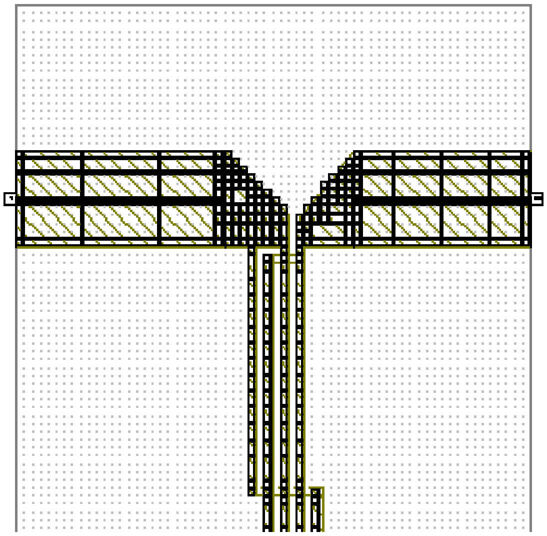


Figure 8. High complexity structure. Cell Size 2 mils in x 2 mils in y. Frequency = 20GHz

A medium complexity structure is shown in Figure 9. The combined filter response is dependent on the lengths and coupling of each resonant line. In this example, the cell definition was determined by the resonant line length and width. At two GHz the cell size can be much coarser than if this structure was being analyzed at 20 GHz. The cell definition is 5 x 15 mils. The 15 mil length is in the y direction and is defined that way because of the long length of the resonator. The 5 mil definition was made because of the sensitivity of the structure to the spaces and widths of lines in the x direction. This is considered a coarse mesh but it was found to be sufficient for the accuracy required for its application.

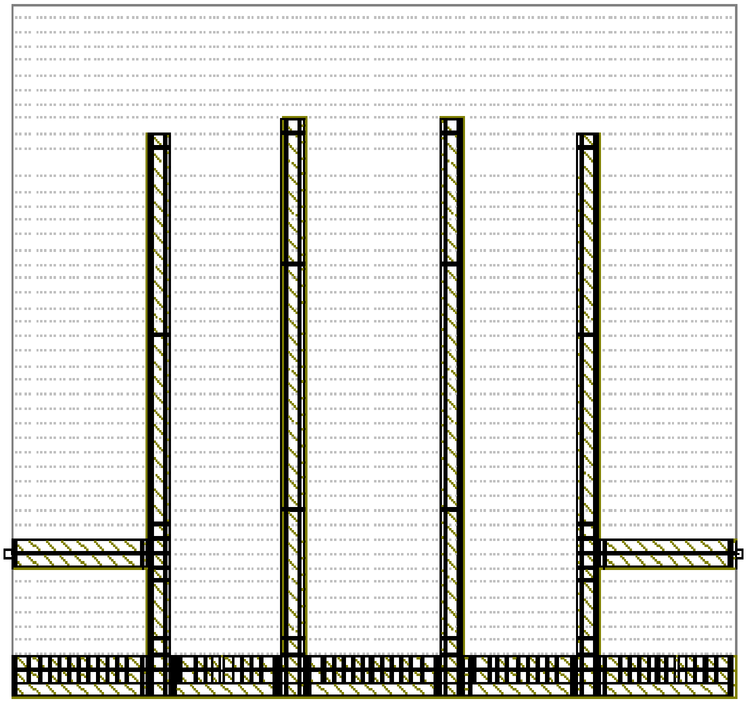


Figure 9. Medium complexity structure.
Cell Size 5 x 15 mils. Frequency = 2 GHz

The low complexity structure is shown in figure 10. The structure is a simple microstrip tee with chamfered lines. This structure is low complexity because it does not have coupling width or spaces that are critical to the performance. At 20 GHz a cell size of 4 x 4 mils was found to be sufficient for the accuracy of the solution. Typically low complexity circuits are discontinuities in transmission lines and require less meshing density for sufficient accuracy.

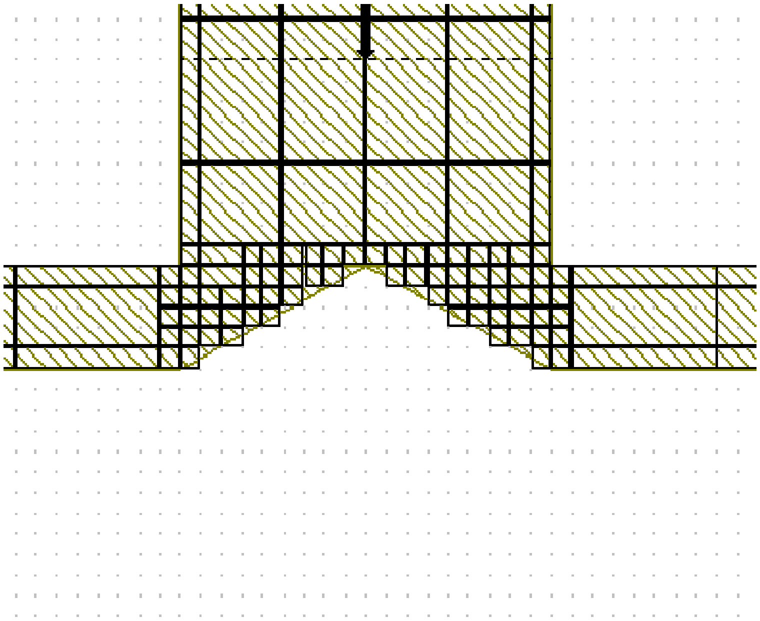


Figure 10. Low Complexity Structure.
Cell size 4 x 4 mils. Frequency = 20GHz

In summary, defining cell size for particular structures requires knowledge of three factors:

1. The accuracy required for the application of the circuit. For example, if a structure is complex and the application requires very tight specifications then it the meshing density may be high.
2. The effect of parts of the structure on the overall performance. For example, the lange couplers performance is determined by the widths and spaces of the coupling fingers.
3. Frequency of analysis (in general, higher frequency means smaller cell sizes)

PWB Example: How to determine what parts of a structure are critical to the solution

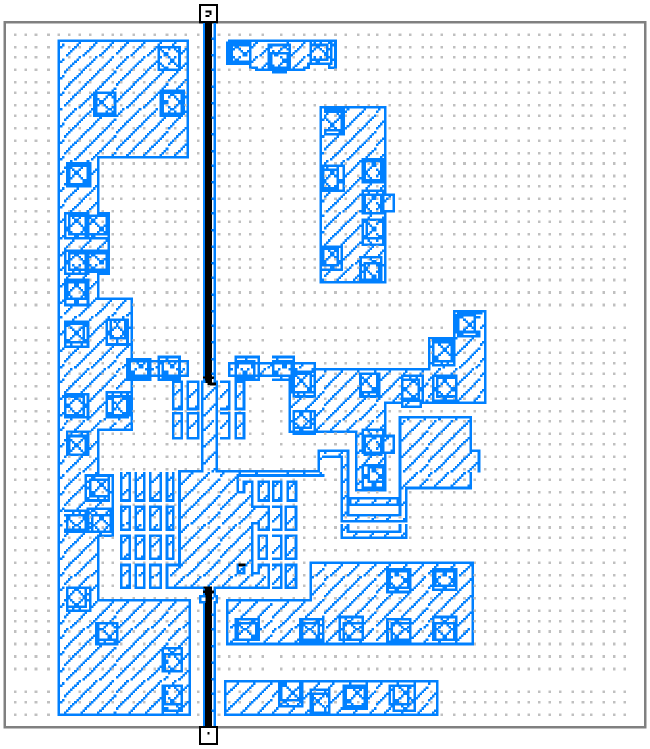
This example illustrates how a very complicated circuit can be simulated by judiciously choosing which parts of the structure are critical to the solution and reducing the structure into smaller parts. A microstrip circuit is analyzed for two separate cases.

Case one, called the *fullckt case,* is the lower part of the original structure with all insignificant vias deleted. All vias that are preceded by other vias on a ground pad have almost no effect on the main signal and were deleted. Also, any via further than two substrates thickness away from the main signal line were deleted.

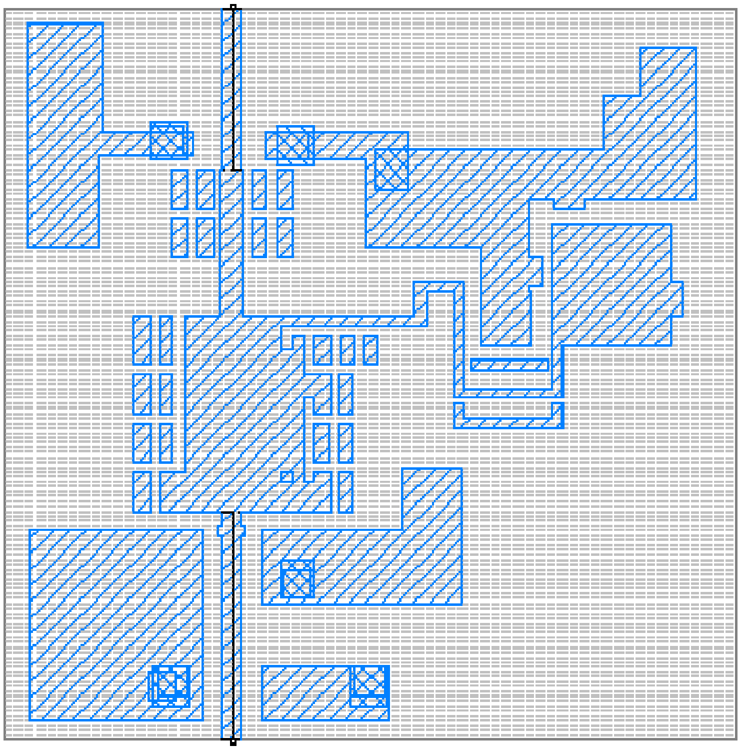
Case two is a stripped-down version of Case one. The following guidelines were used in simplifying the circuit:

1. Any metal patterns that were spaced more than one and a half times the substrate height were deleted. In this case, the substrate was 25 mils thick so lines more than 37.5 mils away from the main signal line were excluded. Typically, a rule of thumb is that any line that is spaced more than twice the substrate height away from another line has an insignificant coupling effect on the main line. This example illustrates that even at 1.5 the substrate thickness is insignificant for this solution.
2. All ground vias were deleted.

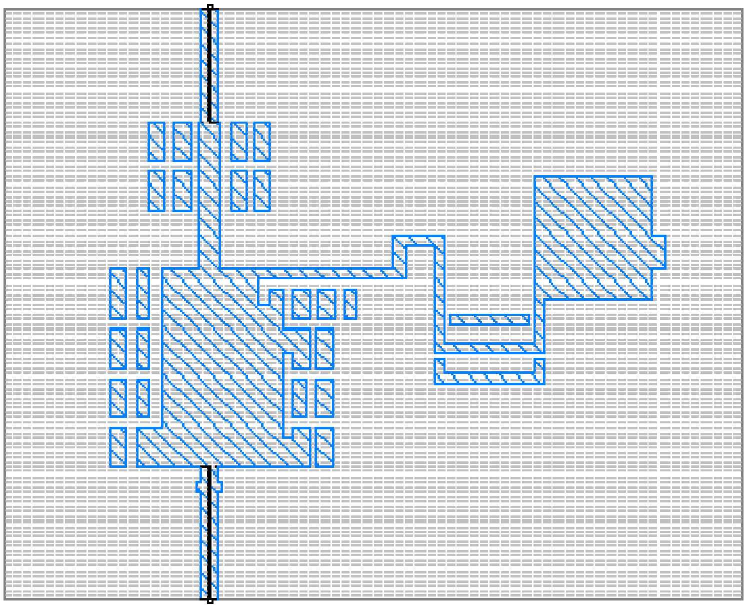
The original circuit is shown below.



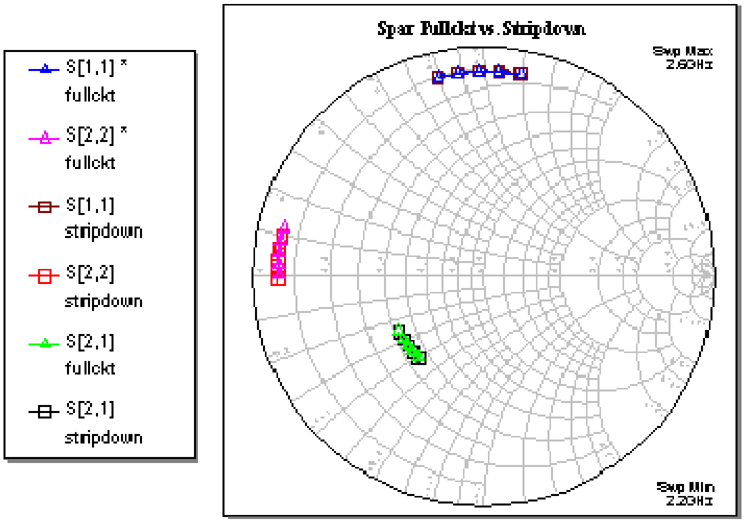
Case 1 is shown below.

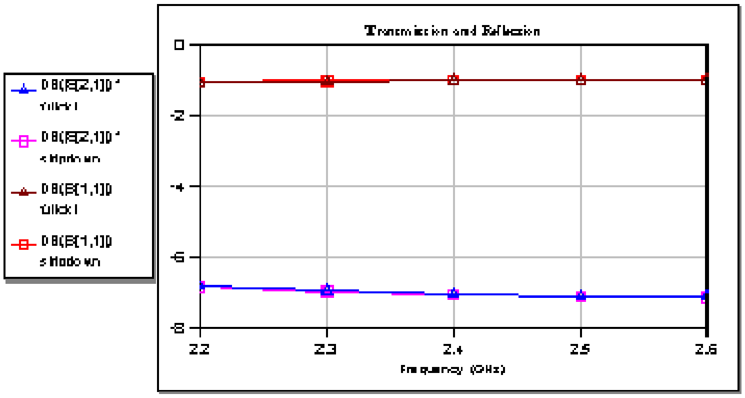


Case 2 is shown below.



The grid size for both cases was 5 mils in the x direction and 20 mils in the y direction. The enclosure dimensions for Case one: x=1500 mils, y=1500 mils, layer1=225 mils er=1, layer2=25 mils er=6.15. For Case two: x=1500 mils, y=1200 mils, layer1=225 mils er=1, layer2=25mils er=6.15. The simulation time for Case one was 4.6 hours using 98 Mbytes of ram. Case two simulation time was 27 minutes using 39 Mbytes of ram. The results for both cases are shown on a Smith chart for S-parameter data and on a rectangular grid for transmission and reflection in db. From the data it is obvious that simplifying the circuit has little or no effect on the solution for the structure.





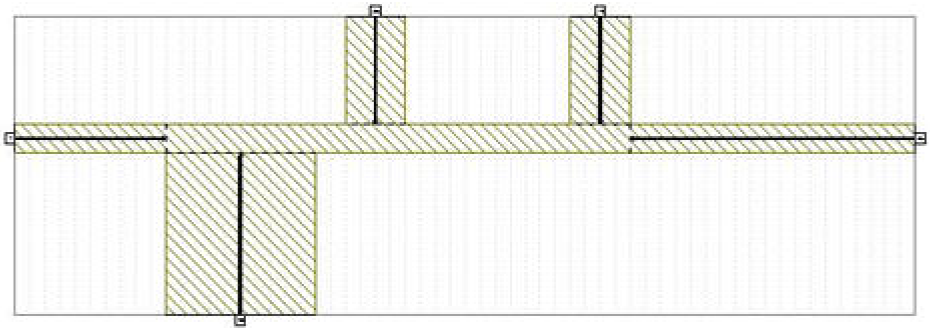
In summary, when doing EM simulations it is important to understand what parts of the structure are critical in the coupling of electromagnetic energy from the main transmission line to the other conductors or ground planes. "Double the substrate thickness" is a rule of thumb approximation for how to decide when coupling is occurring. To better understand the coupling, it is easy to simply isolate part of the structure in order to get an insight into what structures are critical in the final solution. It is also advantageous to break up the structure into pieces by excluding extended uniform transmission lines and breaking up the simulation into smaller parts where there is an absence of coupled discontinuities in the structure. The results of each part can be output into an S-parameter file that can be chained together in a schematic to create the solution for the entire structure. This simulation method can drastically reduce computational time.

Divide and Conquer

“Divide and conquer” is a term used to describe the partitioning of electrically large structures into smaller independent simulations that are recombined using the linear simulator. The best way to describe this method is to show an example.

Example: Coupled Mtees

The original structure to be simulated is seen in fig. 1. The structure consists of three microstrip tees (mtee) sections that are joined by microstrip lines (mlins). All of the mtees have input and output mlin widths of 10 mil. The first mtee from the left has a branch width of 50 mils and will be called mtee 50. The other two mtees both have branch widths of 20 mils and will be called mtee 20_1 and mtee 20_2. The mlin between mtee 50 and mtee 20_1 is 10 mils long while the mlin between mtee 20_1 and mtee 20_2 is 55 mils long. The microstrip lines are on a 25 mil thick alumina substrate er=9.8.



A common rule of thumb for determining the coupling between discontinuities is that any discontinuity spaced more than two substrate widths apart can be partitioned into a separate simulation. In this structure the first two mtees are spaced only 10 mils apart which is less than double the substrate thickness of 50 mils. Mtee 20_1 and mtee 20_2 are separated by 55 mils and therefore mte e20_2 can be simulated separately. Figures 2 and 3 show the new partition of the structure.

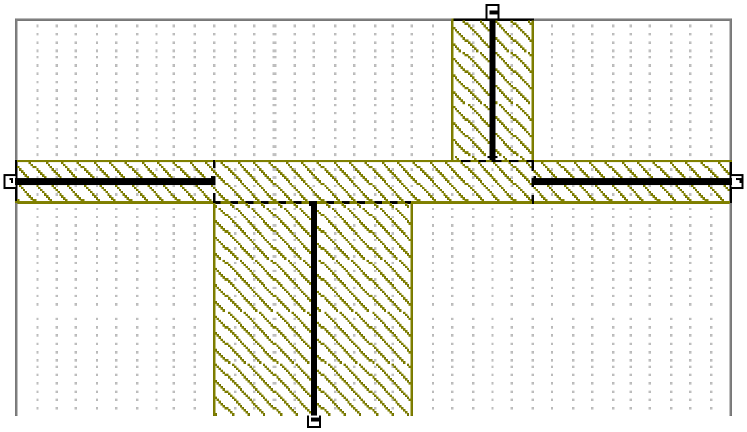


Figure 1. Partition 1: Coupled mtees - mtee50 and mtee20_1.

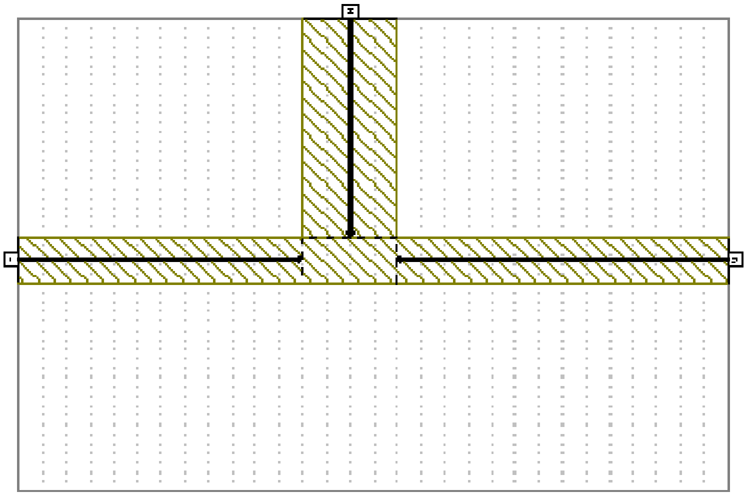


Figure 2. Partition 2: Isolated mtee — mtee20_1.

The combined simulation of the new partition is done using the linear simulator. Each partition becomes a subcircuit, which can be placed in a schematic and connected together to simulate the combined effect of both structures (see Figure 3).

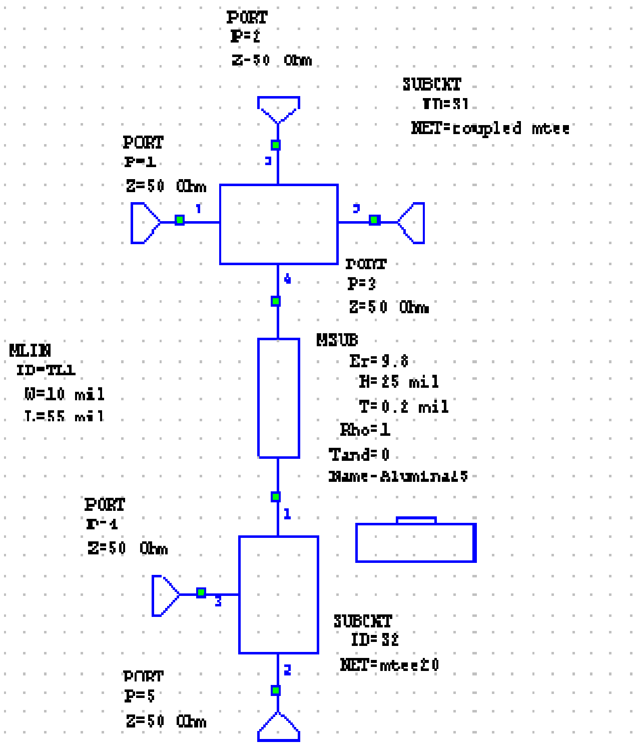
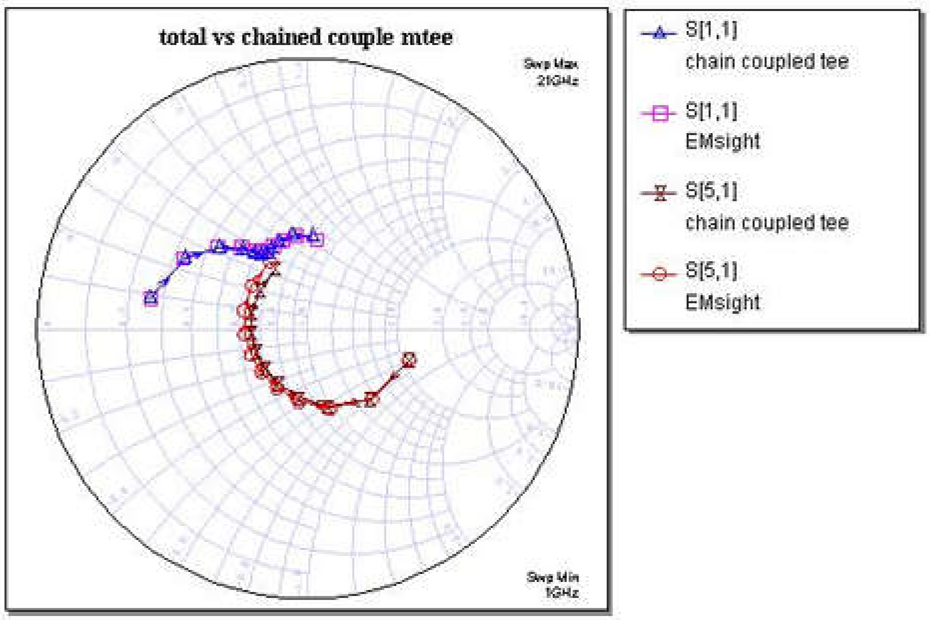


Figure 3. Schematic for combined simulation of partitions 1 and 2.

The entire structure and the partitioned structure were simulated for comparison. The data shows negligible differences that verify the accuracy of this method.



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