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Designing Filters Efficiently using Simulation Tools

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Designing filters efficiently using simulation tools

Filters are an integral part of any RF/microwave system. Designing one efficiently and accurately can be a challenge, even when sophisticated simulation tools are available. Electromagnetic simulation, which is more or less an integral part of any commercial RF/microwave simulation software, can help designers meet this challenge. As an example, this article gives two bandpass filter (BPF) examples that were simulated using circuit and electromagnetic (EM) simulators and compares the simulated and measured results.

By Anurag Bhargava

To save time and effort, the initial filter design was performed using the Passive Circuit Design Guide available in Agilent's Advanced Design System (ADS) electronic design automation (EDA) software, at center frequencies of 4500 MHz and 5350 MHz, with bandwidth of 225 MHz, although they can be designed and simulated in many other ways. The circuit was optimized to fine-tune the filter performance and to achieve the desired results. The circuit design was then transferred to layout for electromagnetic simulation (using Momentum).

The layout, schematic and current distribution of the EM analysis for the 5350 MHz filter, are shown in Figures 1a to 1c. Figures 2a to 2c depict the layout, current distribution and fabricated filter for a 4500 MHz filter.

Substrate and EM setup details

Both the filters were designed on a 25 mil alumina substrate with a fabricated circuit size of one inch by one inch, with relative dielectric constant (ϵ_r) of 9.9 and loss tangent ($\tan\delta$) of 7×10^{-4} . The number of cells per wavelength for EM analysis was kept as 25 cells, and the Edge Mesh option was selected because the first and the last coupled sections spaced at 2.5 mil (as shown in Figure 1), and the edge mesh feature creates a relatively dense mesh pattern of small cells along the edges of metal. This is because most of the current flow occurs along the edges of slots or metals and a denser edge mesh gives better solution accuracy.

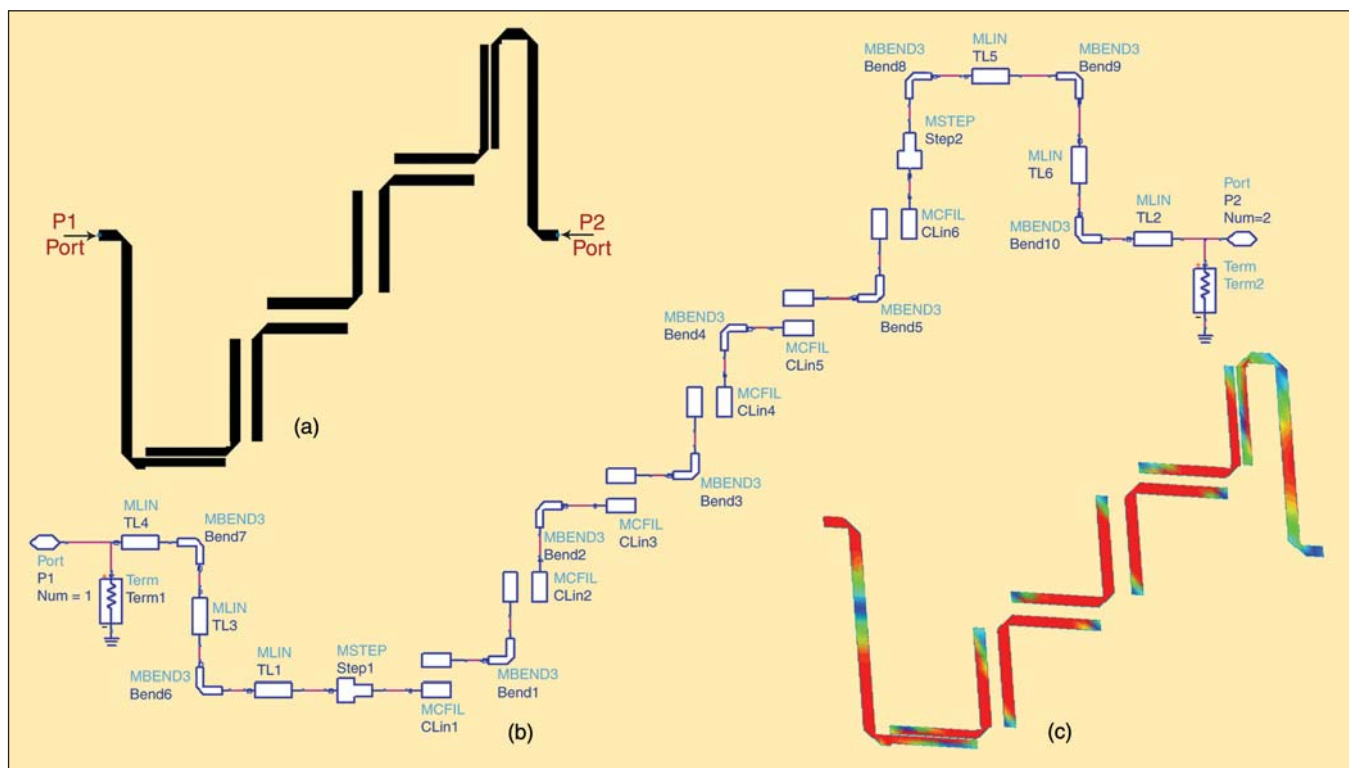


Figure 1(a). The layout of a 5350+/-112.5 MHz zigzag coupled line BPF with simulation mesh. (1b). A schematic of a 5350+/-112.5 MHz zigzag coupled line BPF. (1c). The current distribution in a 5350+/- 112.5 MHz zigzag coupled line BPF EM simulation.

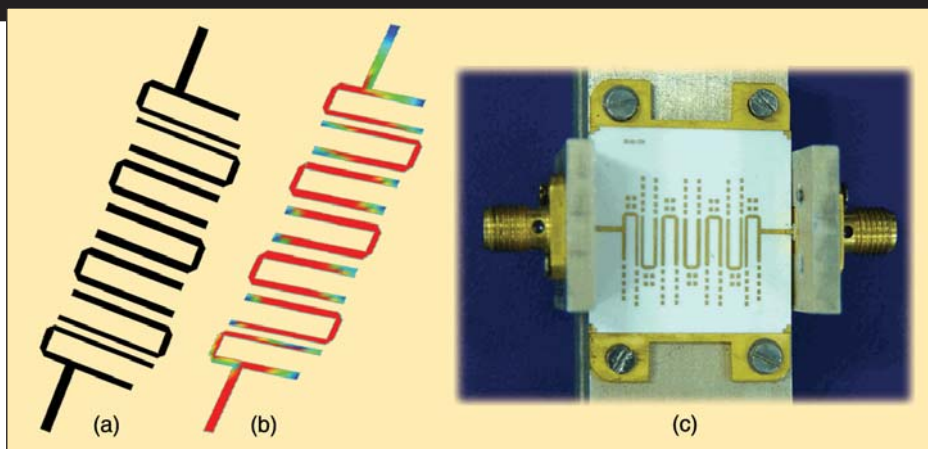


Figure 2(a). A layout of a 4500+/-112.5 MHz hairpin coupled line BPF with simulation mesh turned on. (b). The current distribution in a 4500+/- 112.5 MHz hairpin BPF EM simulation. (c). A fabricated 4500+/-112.5 MHz hairpin coupled line BPF.

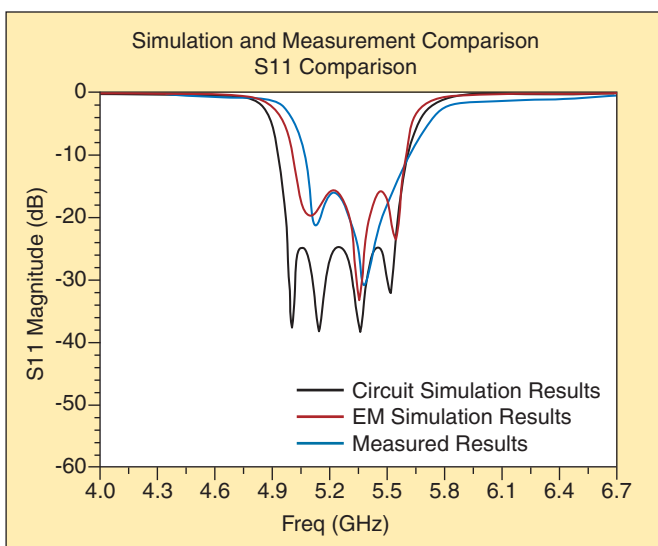


Figure 3a. S11 results for the 5350+/-112.5 MHz zigzag coupled line BPF.

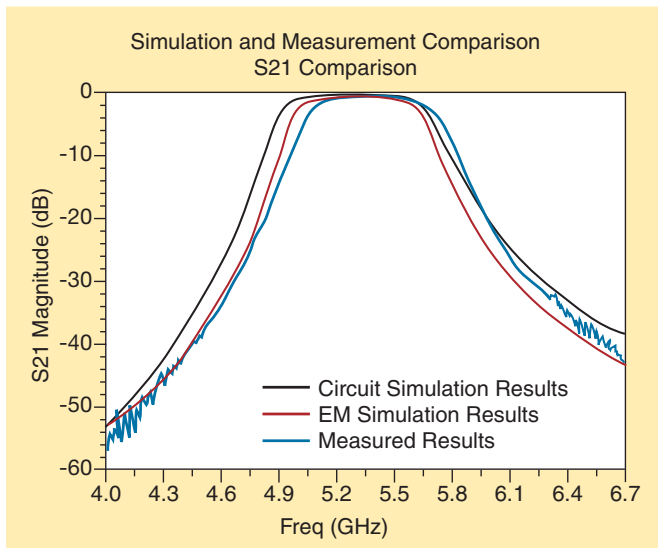


Figure 3b. S21 results for the 5350+/-112.5 MHz zigzag coupled line BPF.

Meshing guidelines for EM simulation

The most important part of setting up the EM simulation is the mesh setup. Use the following guidelines:

- Using the wavelength of the frequency, a linear function is approximated, also referred to as a rooftop basis function. The higher the frequency, the more wavelengths fit across the structure. Cells per wavelength are the minimum number of cells that fit under each wavelength. The more cells, the better the sinusoid is represented, and the more accurate the simulation^[1]. For example, if 30 cells per wavelength are used, the maximum deviation between the sinusoid and the linear approximation is about 1%. These parameters affect longitudinal current.

- Higher frequencies will result in a greater number of cells (increased density) for a mesh. Similarly, increasing the minimum number of cells per wavelength will also increase the density. In general, for optimal density, it is better to increase the number of cells per wavelength rather than increasing the mesh frequency. The optimal value for the mesh frequency is the highest frequency that will be simulated. This may avoid having to recalculate the substrate frequency band if it is not sufficient.

- In general, the cell size used when the geometry is infinitely large corresponds with the number of cells per wavelength. But when other details, edges, and user-defined mesh settings are included, cells might appear that are smaller than $\lambda/20$, resulting in more cells per wavelength than the value of 20 that was entered. Here are two specific cases where the actual number of cells per wavelength is greater:

- When the layout has details that are smaller than $\lambda/20$, the mesh follows the shape of the details. Since the mesh consists of triangles and rectangles only, the cells will be less than $\lambda/20$.

- When the default settings in the mesh setup controls dialog box are changed, such as the number of cells per transmission line width, then it directly influence the number of cells over the width of the transmission lines. This might lead to cells that are smaller than $\lambda/20$.

Edge mesh

A microstrip transmission line with a bend, using the default mesh, may have a cell size equal to the width of the line (one cell per line width). If it is long and the bend is not severe, then the default mesh may be adequate because the discontinuity is proportionally small compared to the line length. However, if the reference planes are moved inward or if the bend is more severe, the discontinuity and resulting parasitics are in greater proportion to the rest of the line. In this case, the default mesh may result in simulation inaccuracies.

To correct inaccuracies, the mesh should be increased and edge mesh should be used. When the area near the discontinuity is meshed so that the cell size is equal to a third of the line width (three cells per line width) the resulting error is reduced. The denser mesh allows for current crowding (parasitic series inductance) at the interior corner of the bend and charge build-up (parasitic shunt capacitance) at the outer edge of the bend.

The edge mesh feature automatically creates a relatively dense mesh pattern of small cells along the edges of metal or slots, and a less dense mesh pattern of a few large cells in all other areas of the geometry. Because most of the current flow occurs along the edges of slots or metals, the edge mesh provides an efficient solution with greater accuracy.

Use the edge mesh to improve simulation accuracy when solving circuits where the modeling of current flow in any edge area is a critical part of the solution. This includes circuits where the characteristic impedance or the propagation constant are critical for

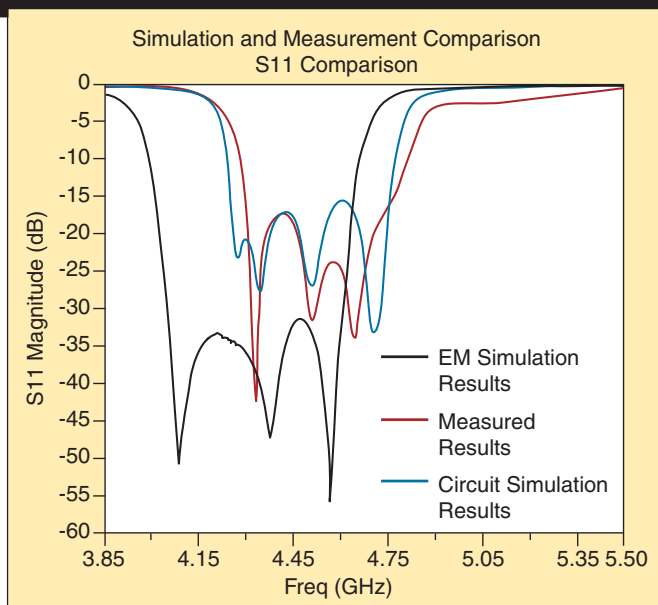


Figure 4a. S11 results for the 4500+/-112.5 MHz hairpin coupled line BPF.

determining the electrical model, circuits in which close proximity coupling occurs, or circuits where edge currents dominate the circuit behavior. Applications for using the edge mesh include:

- tightly coupled lines;
- patch antennas;
- resonant circuits;
- delay lines; and

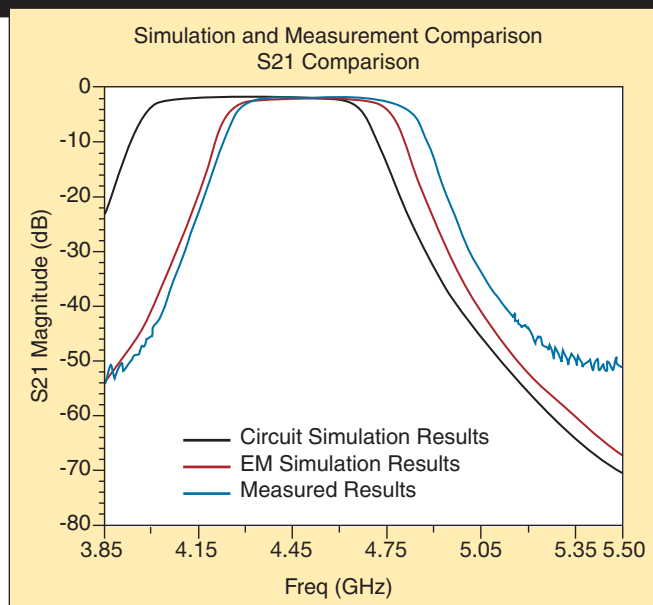


Figure 4b. S21 results for the 4500+/-112.5 MHz hairpin coupled line BPF.

- hairpin filters.

Transmission line mesh

Use the transmission line mesh when the number of cells between parallel lines in a layout needs to be specified. This feature can save computation time and memory because it will create a mesh that is appropriate for straight-line geometry. For example, the simulation results for a single transmission line with one or two cells across the width will be equal. If the circuit has coupled lines, the results will differ.

Simulated and measured results

Simulated and measured results for BPF's at center frequencies of 5350 MHz and 4500 MHz are summarized in Figures 3a and 3b and 4a and 4b, respectively.

The results comparisons shown clearly indicate that the accuracy offered by EM simulation is quite good as compared with the circuit simulation. EM simulation results also match quite well with the measured results.

Conclusion

The results comparisons shown in this article indicate that the EM simulation provides results that are quite close to the measured results. Circuit performance can be predicted quite accurately using EM simulation with the appropriate sizing of simulation parameters such as mesh sizing, helping to reduce the post production tuning problems often faced by designers reducing design cycle time and overall time to market. **RFD**

References

1. Advanced Design System User's Guide: Chapter 7, Mesh, Agilent EEs of EDA, 2004.

ABOUT THE AUTHOR

Anurag Bhargava earned his Bachelor of Science degree in Engineering from North Maharashtra University in India in 1996. He worked as a scientist in the Indian Space Research Organization in Ahmedabad, India, for six years prior to joining Agilent EEs of EDA as an application engineer in 2004. He can be reached at anurag_bhargava@agilent.com.

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