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Design Synergy: Combining LINC2 Circuit Synthesis with Sonnet EM Simulation

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LINC2 is a high performance, low cost, RF and microwave circuit design and simulation program from ACS (www.appliedmicrowave.com) while Sonnet (www.sonnetsoftware.com) provides a suite of EM simulation software with "a solid reputation as the world's most accurate commercial high frequency planar electromagnetic (EM) analysis tool suite for single and multi-layer planar circuits and antennas." [1]

This article describes the benefits of adding Sonnet EM simulation to the LINC2 design process. The synergy between these two tools provides a powerful, yet easy to use design flow for the RF designer, providing seamless synthesis, iterative design and verification.
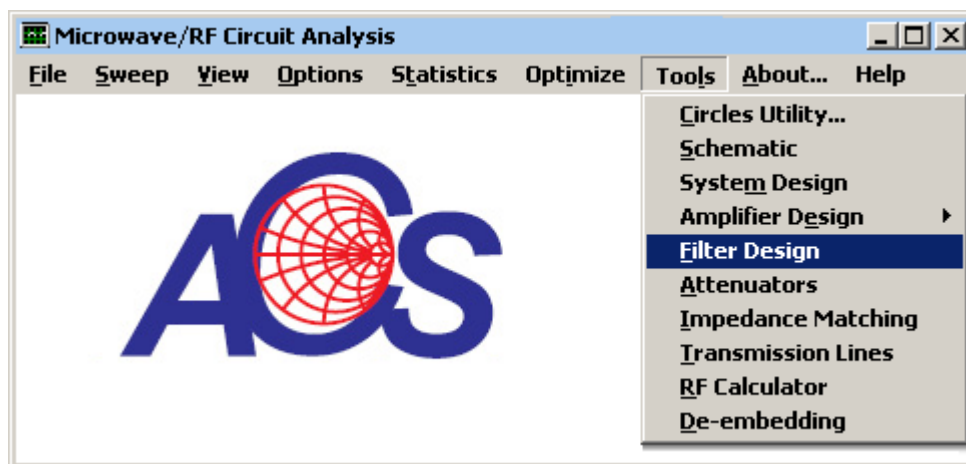

Figure 1, LINC2 Tools Menu

LINC2 Pro includes a suite of powerful circuit synthesis programs for the complete automated design of amplifiers, impedance matching networks, attenuators, couplers, filters and more (see Figure 1). The following band-stop filter design example highlights the benefits of applying EM simulation to an initial design created by the LINC2 Pro filter synthesis program.

Notch Filter Application and Goals

The notch filter was designed as a lab filter for RF PA (power amplifier) spectral purity testing. Its purpose is to take out most of the on-channel power of a 100 watt PA so that a spectrum analyzer can make out-of-band and out-of-channel spectral emissions measurements without becoming overloaded.

The PA is part of a digital wireless communications system employing a type of pulsed GMSK modulation at a rate that nearly fills one of a number of 13 MHz communications channels allocated to the system. The center frequency of the highest channel is approximately 1490 MHz. One of the concerns is how much unwanted emissions will fall in the L1 GPS band when the PA is operated in the highest channel, closest to the GPS signal. Thus the filter is designed to notch out the 1490 MHz channel for testing purposes because it is the closest to interfering with the GPS band at 1575 MHz.

The filter notch will need to be wide enough to reduce all the energy in the 13 MHz channel by at least 30 dB, but narrow enough so that the GPS signal 85 MHz away is above the upper 3 dB notch edge. The following filter goals should suffice.

Filter Goals:
- Fc (notch center frequency) = 1490 MHz +/- 3 MHz
- Upper 3 dB band-stop edge < 1575 MHz
- -30 dB bandwidth > 13 MHz

Selecting Filter Design from the LINC2 Tools menu (Figure 1) opens the filter schematic window shown in Figure 2.
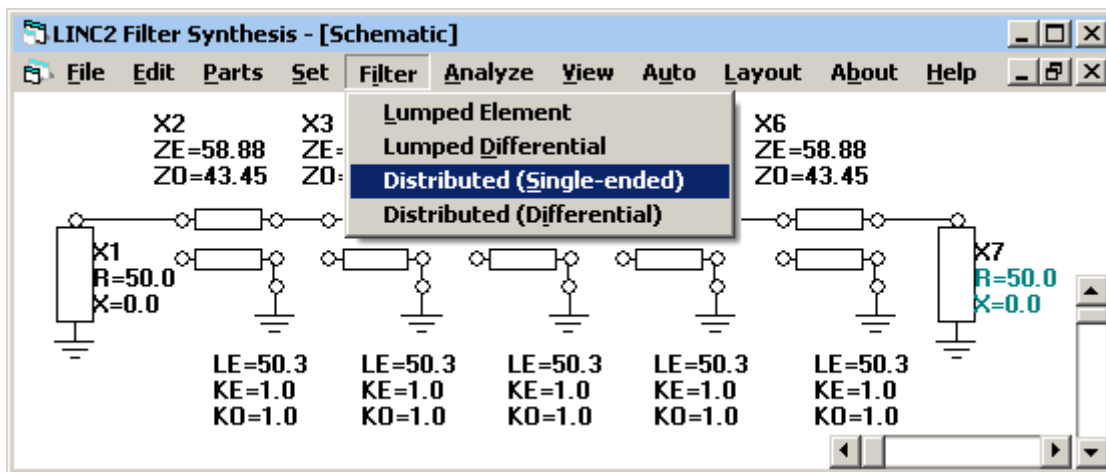

Figure 2, LINC2 Filter Synthesis Schematic

The LINC2 filter synthesis wizard can design distributed filters in either single-ended (unbalanced terminations) or differential (balanced terminations). For this example we select Distributed (single-ended) from the Filter menu (Figure 2). This action pops up the Design Specifications form shown in Figure 3.

Entering a few filter specifications and clicking the Synthesize Filter button is all that it takes to automatically create the 1490 MHz notch filter shown in Figure 2. A 20 MHz bandwidth was specified for the band-stop response (1480 to 1500 MHz) to give enough margin to achieve the desired -30 dB bandwidth of 13 MHz.

Selecting Analyze from the filter schematic menu bar runs a circuit simulation on the filter, returning the results shown in Figure 4. The simulation results yield a -30 dB bandwidth of 13.55 MHz centered at 1490 MHz, indicating that the desired bandwidth is achievable with the selected filter order (5th order filter).

In order to physically produce the filter, the ideal coupled transmission lines in the schematic of Figure 2 will need to be converted to physical microstrip. Fortunately, this is a one step process in LINC2. Simply selecting Auto > Convert T-Lines To…> Microstrip automatically transforms the ideal filter schematic of Figure 2 into the physically realizable schematic of Figure 5.

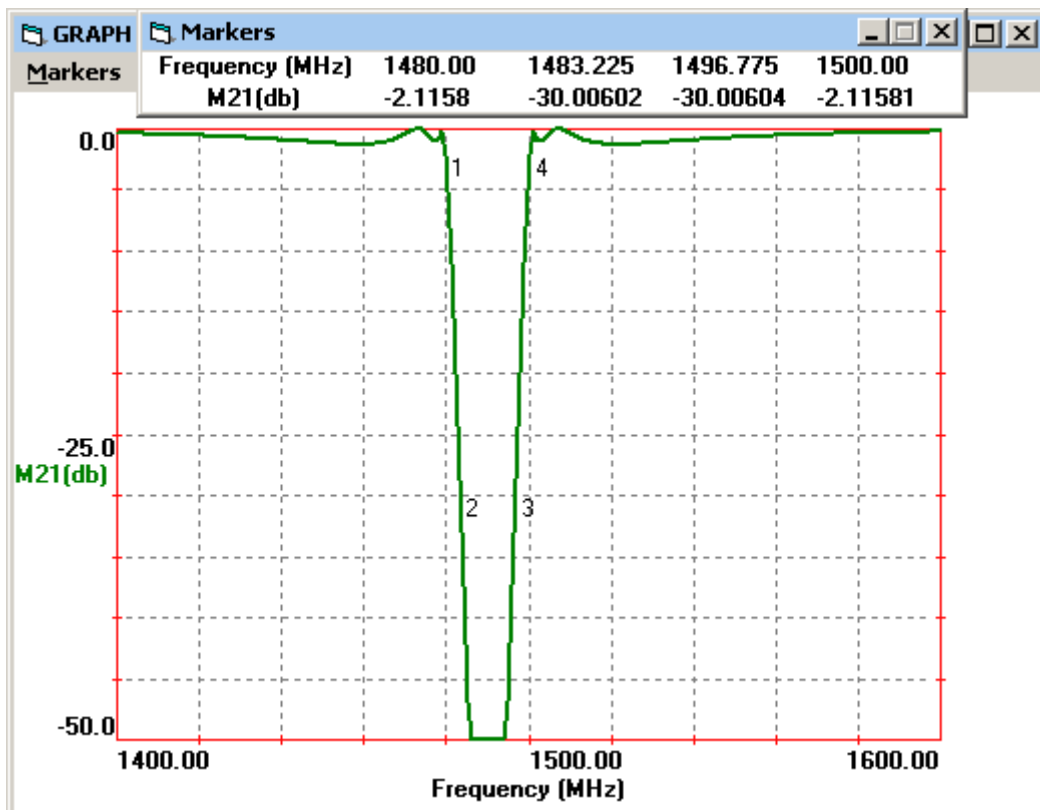**Figure 3, LINC2 Filter Specifications Form**

Figure 4, Initial Notch Filter Response (Ideal TRL)
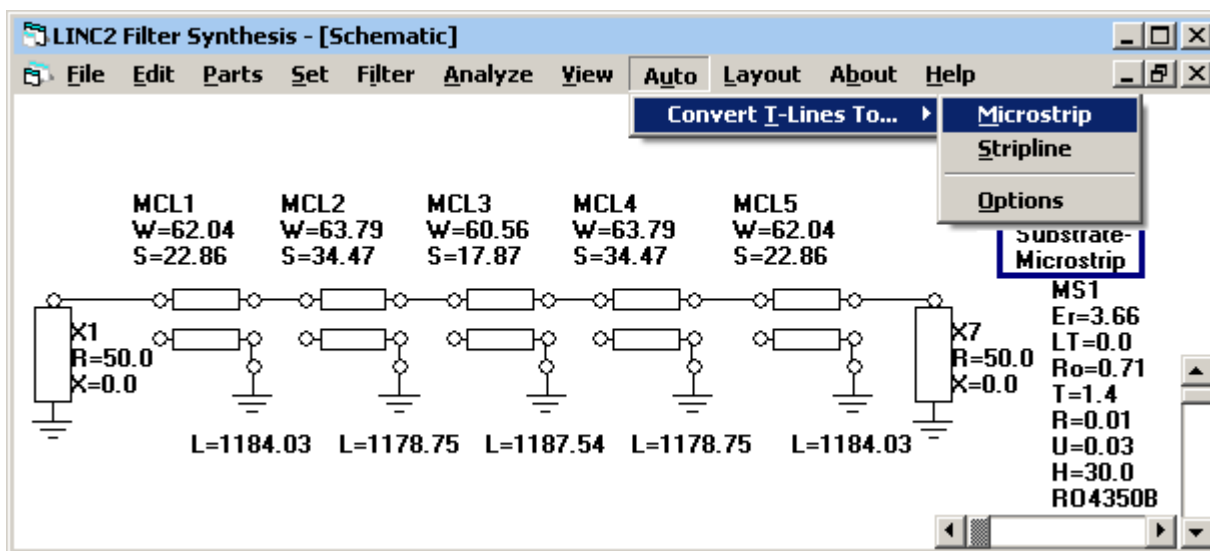
Figure 5, LINC2 Microstrip Filter Synthesis

Running a LINC2 circuit simulation on the filter converted to microstrip (Figure 5) indicates a slight downward shift in frequency response. Getting an accurate reading on the amount of frequency shift allows us to go back to the filter design wizard and compensate by entering a higher filter cutoff frequency (adjusted upward by the same amount as the observed downward shift). However, instead of using the LINC2 circuit theory simulator this time we will use Sonnet EM (electromagnetic) simulation for the most accurate results.

LINC2 Sonnet Interface

The next step is to select the Layout option where the design is prepared for export directly to Sonnet EM. By using Sonnet EM simulation we can get feedback on how to adjust the filter synthesis program to compensate for unwanted frequency and bandwidth shifts. This will produce an accurate filter design whereby a printed circuit board can be fabricated that will meet the design goals on first build.

The LINC2 Filter program has a built-in interface to Sonnet's EM simulation software. The latest version of Sonnet$^®$ Lite™ is included free with LINC2 Pro (or can be downloaded free from Sonnet Software's web site at www.sonnetsoftware.com/lite). The LINC2 Sonnet interface automatically starts the Sonnet EM program, sets up the EM simulation environment and exports the layout geometry into the Sonnet Project Editor ready for simulation.

ACS chose Sonnet Software as its first choice for integration into its LINC2 circuit simulation program because of Sonnet's outstanding overall performance, unrivaled accuracy and speed. Sonnet also has an excellent user interface that is easy to navigate. The Sonnet pop-up Quick Start Guide takes you through the process of setting up an EM simulation project from the start, including setting up the simulation environment, adding the geometry, analyzing and viewing the project results- all in wizard-like fashion! When using Sonnet with LINC2, this process is completed automatically. From LINC2, the entire design, geometry, and EM project setup is automatically transferred to Sonnet with a single menu click.

Selecting EM > EM Simulation (Sonnet) from the Geometry Layout menu (Figure 6) pops up the Sonnet geometry editor with the LINC2 filter geometry already loaded. Project > Analyze produces the Sonnet EM simulation results shown in Figure 7.
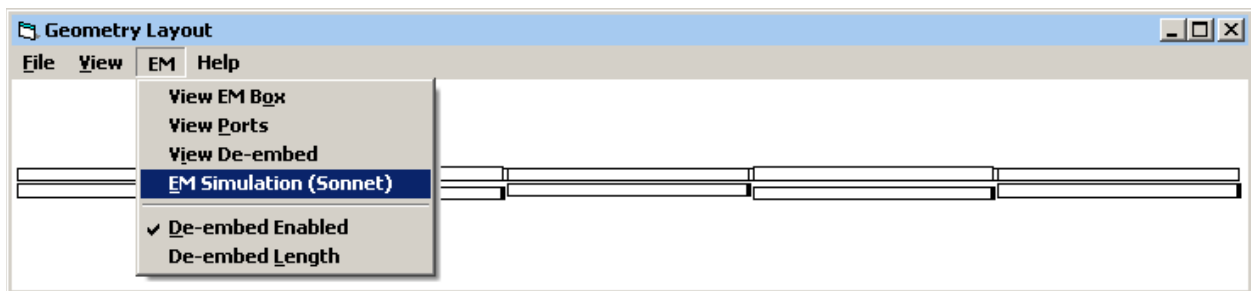

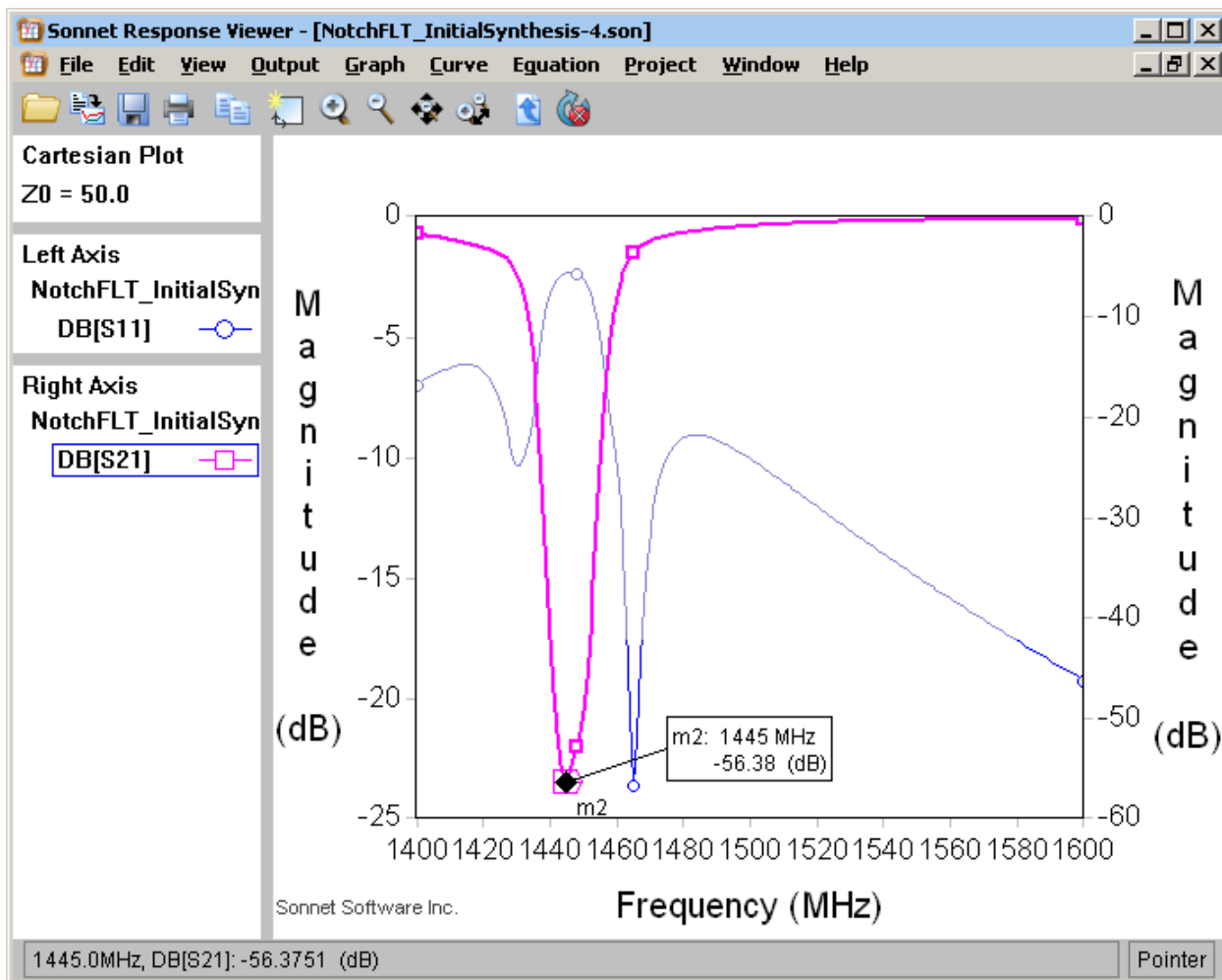**Figure 6, LINC2 Notch Filter Viewed in the Filter Layout Window**

Figure 7, Sonnet EM Simulation of LINC2 Notch Filter

The EM simulation (Figure 7) indicates that the filter notch is shifted 45 MHz low in frequency, or about 3%. To correct for this, the lower cutoff frequency in the LINC2 Filter Design Specifications form is increased 45 MHz from 1480 MHz to 1525 MHz (Figure 8, F1). An additional 10 MHz is added to the upper cutoff frequency to increase the bandwidth of the filter (Figure 8, F2). The final version of the notch filter produced from these new design parameters is shown in Figure 9.

At this point a Sonnet EM simulation was run on the filter of Figure 9 to determine if the design goals are now being met. The results of the EM simulation, shown in Table 1, indicate that all the design goals are being met with margin to spare. The design is now ready for pcb (printed circuit board) layout and fabrication. The LINC2 filter program assists in this process by

automatically creating the layout and exporting it as a DXF file to be imported into pcb layout software. Figure 10 shows the finished printed circuit board.

The circuit is 100% microstrip and ground vias so there are no components to mount except for the SMA board edge connectors. Figure 11 shows the filter being tested using an HP-8720D vector network analyzer. The results of the test are shown in the Measured column of Table 1 (and the dark traces plotted in Figure 12). Measurements taken with the vector network analyzer verify that the filter is passing the design goals on all points from the first build.

Figure 8, New LINC2 Notch Filter Specifications
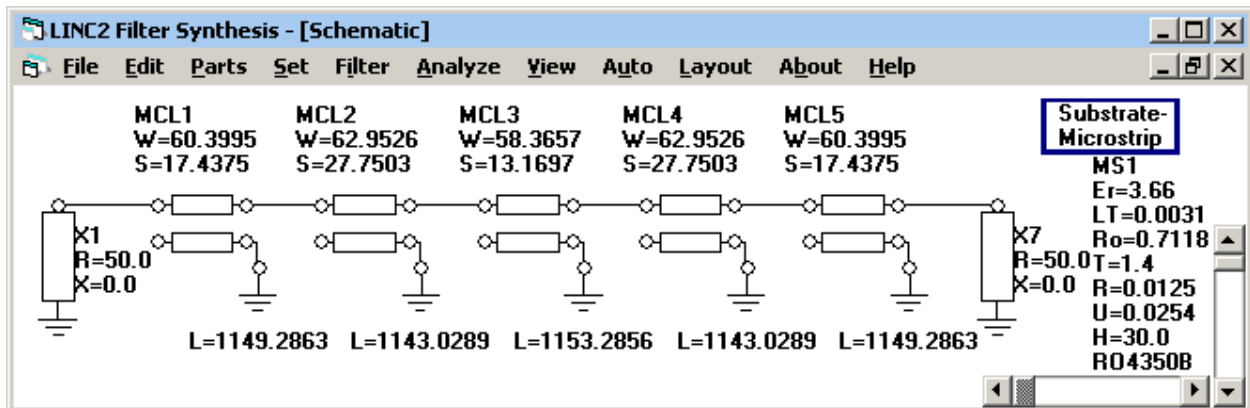
Figure 9, Final Version of the Notch Filter (EM Simulation Enhanced)
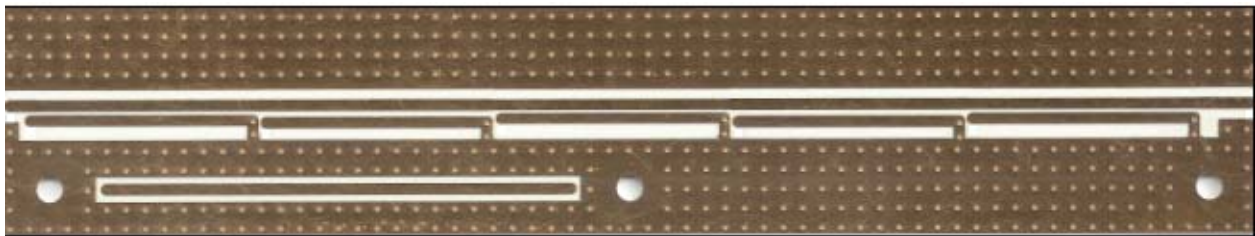
Figure 10, Notch Filter Printed Circuit

Table 1, LINC2 Designed Notch Filter - Measured Vs. Simulated Results

Filter Parameter	Design Goal	EM Simulated	Measured
Fc (Notch Center Frequency)	1487 - 1493 MHz	1489.8 MHz	1489.5 MHz
Upper 3 dB Cutoff	< 1575 MHz	1533.25 MHz	1559 MHz
-30 dB bandwidth	> 13 MHz	17.75 MHz	21.375 MHz
Notch Depth	Not Specified	41.78 dB	42.83 dB

Figure 11, Notch Filter Measurements on the HP-8720D VNA

Figure 12, LINC2 Designed Notch Filter Response - Measured (dark traces) Vs. Simulated (light traces)

Calibrating the Simulator

For a given filter order and specified bandwidth, the depth of the filter's notch is primarily related to the filter's losses. The notch will be deeper if the losses are 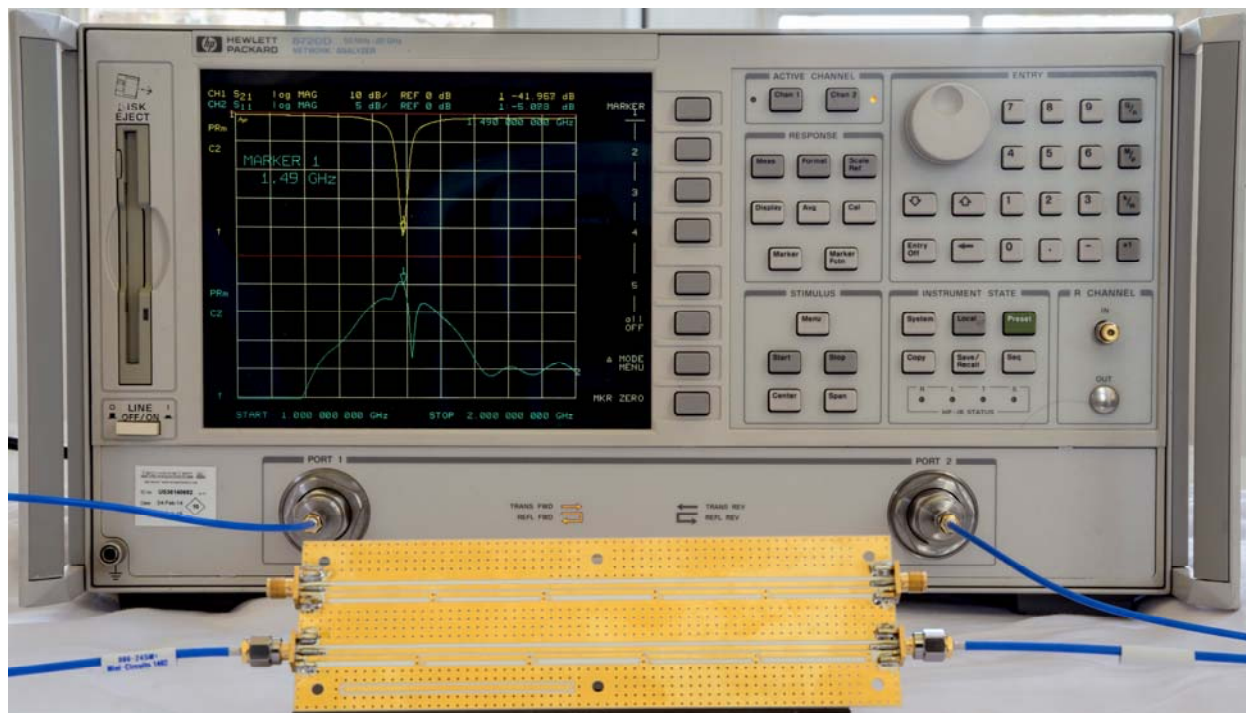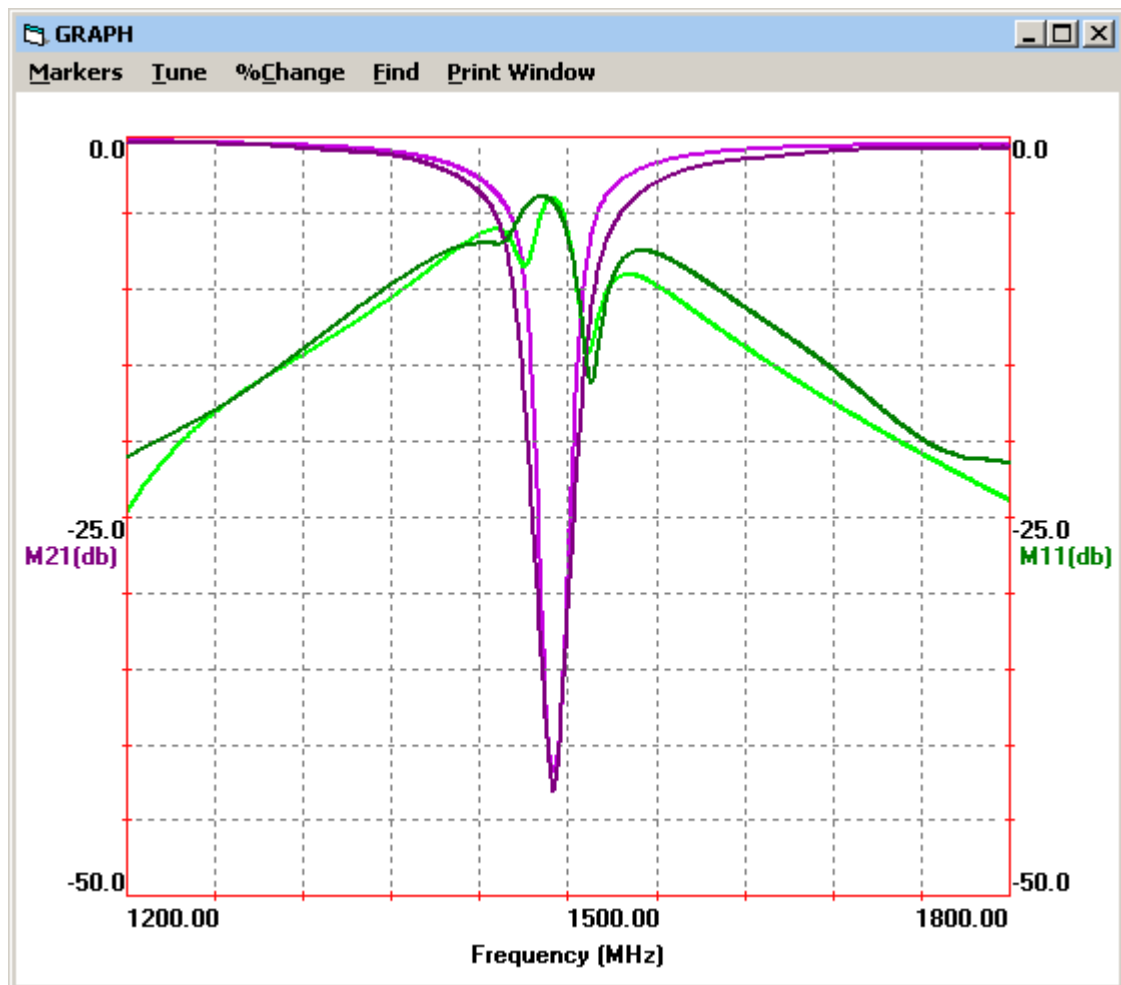low. Thus, getting a good simulation of the notch depth depends on making sure that the EM simulator is modeling not only the dielectric losses but also the metal losses (copper losses in this case). There are a number of metal models that can be selected in the Sonnet EM simulator including Normal, General, Rough Metal, Resistor, Thick Metal Model and others. The default, Normal, model was used in this example. The Normal model requires the specification of conductivity, resistivity or sheet resistance at DC and the metal thickness. Using the Normal metal model and specifying the conductivity for copper, the simulation predicted a notch depth within 1 dB of the measured 43 dB.

The EM simulator encloses the circuit in a conductive box. The top and/or bottom of the box can be open (free space) or closed (lossless or any of the specified metals). If the circuit being simulated is to be completely enclosed in a metal shield box then the EM box provides an excellent simulation of the actual product. However, if it is intended that the actual physical circuit is not to be shielded but instead is to reside on an open unshielded pcb then the EM box top should be specified as free space (the bottom of the closed EM box represents the ground plane of the pcb). The walls of the EM box are now an issue because they do not exist in the actual circuit but are necessary to perform the EM simulation. In this case some experimentation may be necessary to find the height of the EM box walls and the distance of the walls from the nearest circuit metal such that the EM simulation will most closely agree with measurement.

For the filter in this example, the dimensions of the EM box primarily affected the notch frequency. The dimensions of the box can be adjusted to get good correlation with measurement (as was done here) and then used as a template for other like circuits. The Sonnet simulator offers several via models including circular, rectangular and edge vias. The type, size and location of the ground vias used to short the coupled lines also affect the notch frequency. For example, if the coupled lines terminate at the center of their shorting vias then the notch frequency will be slightly lower than for the case where the ground via is wholly contained within the end of the trace.

One way to "calibrate" the simulator is to lay out more than one circuit on the printed circuit board with each circuit varying by some simulation parameter (such as EM box size) then noting which simulation parameter value created the circuit that measures most closely to the design goals. Figure 11 shows two versions of the notch filter built on one pcb. The lower filter circuit, created from the schematic in Figure 9 (pcb layout section shown in Figure 10), produced measurement results most closely in accord with the simulation.

Summary and Conclusions

The notch filter performance as measured by the HP-8720D vector network analyzer is displayed in Figure 12 (dark traces). The EM simulated filter performance is plotted on the same graph in Figure 12 using light traces. As can be seen from the measured versus simulated plots, overlaid on the same graph, the first article prototype's performance follows that of the simulation very closely. The depth and frequency of the notch at maximum attenuation cannot even be distinguished as different for the measured and simulated cases since their plots almost exactly overlay one another.

The measured versus simulated values for depth of notch and frequency at maximum attenuation is -42.83 dB at 1489.5 MHz and -41.78 dB at 1489.8 MHz respectively. A couple of things (such as the height and width of the EM box) will affect the EM simulation slightly, but with a little experience (in addition to guidance from the Sonnet manual) the user will know how to appropriately size the box for good accuracy.

The cost of prototype pcb services and fabrication services (if there are components to be mounted on the circuit board) are significant. Even more costly is the time it takes to spin a new iteration of the design, including testing, laying out a new board with changes and going through another pcb/fab cycle. Thus, circuit designers are always on a quest for first-time-right design methods that really produce prototypes that meet the design goals the first time.

The example presented here demonstrated the possibility that first article prototypes can meet design goals when Sonnet EM simulation is employed to enhance the analysis capability of circuits design with LINC2 circuit synthesis software. LINC2 does not have built-in EM simulation capability and Sonnet software does not have the circuit synthesis capability of LINC2. However, together these two tools provide more power for the designer than either one alone.

Moreover, LINC2 leverages the power of Sonnet EM simulation through a seamless interface to Sonnet. LINC2 automatically creates the filter schematic from user input. One button click automatically coverts the distributed filter elements to microstrip or stripline and one button click automatically lays out the physical circuit in the LINC2 Geometry Layout window (Figure 6).

From the Geometry Layout window, one menu pick sends the physical design to Sonnet. The user does not have to start Sonnet or even have it running. The LINC2 interface will automatically start Sonnet if it is not already running, transfer the design to Sonnet and automatically set up all the EM project, physical and analysis parameters including analysis frequencies, physical units, dimensions, dielectric and metal layers, EM box and cell sizes, reference planes and ports etc.

Any of the Sonnet simulation parameters can be adjusted within Sonnet (including the ones imported from LINC2). The EM cell size or metallization loss models, for example, can be selected and adjusted. However, in many cases no further action need be performed because LINC2 will have already set up the appropriate entities within Sonnet without the need for user intervention. The only action that is needed to get EM simulation results for the filter is to select Analyze from the Sonnet Project Editor's Project menu; the software is really that easy to use!

Many people, in all disciplines, hang on to their old and familiar software for fear of having to learn how to use a new and often complex and difficult to use software package, even if the new software has powerful advantages. EDA (electronic design automation) software should have plenty of automation (tasks that are actually performed automatically for the user). Real design automation is what the LINC2 software suite provides in abundance.

The LINC2 Filter software used in this article is one of the many circuit synthesis products that are part of the LINC2 suite of circuit design and synthesis tools from ACS (Applied Computational Sciences). LINC2 offers exact circuit synthesis, schematic capture, circuit and system simulation, circuit optimization and yield analysis in a single affordable design environment. More information about LINC2 can be found on the ACS web site at www.appliedmicrowave.com.

References

[1] "About Sonnet," About Us, September 1, 2014, http://www.sonnetsoftware.com

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