

Using LINC2 with Sonnet® EM Software Enhances Simulation Accuracy

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Designing high frequency circuits requires a varied approach to circuit simulation and verification if good results are to be obtained from the first physical prototype built. Different modeling and simulation techniques will be required to address all the concerns. In fact, there will be times when even different types of simulators will need to be employed (such as EM simulation) to correctly analyze the problem.

The major categories of circuit and component attributes that require special attention in high frequency circuits are:

1. "Parasitic" elements due to the physical construction of the component that depart from the ideal model.
2. Stray inductance and capacitance formed by a number of possibilities, including component lead length, wires or conductive paths involved in component interconnections, capacitance between component mounting pads and ground, mutual inductance and capacitance between adjacent components, and more.
3. Distributed or transmission line effects of components and traces due to their physical size relative to a wavelength.
4. Discontinuities in transmission lines such as a step change in microstrip width or abrupt bend etc.
5. EM (electromagnetic) coupling between lines or between components and conductive surfaces.

All of the above produce more and more pronounced effects on circuit behavior as the operating frequency increases. Eventually, operation of the physical circuit will no longer resemble the circuit simulation if these circuit and component attributes are not accounted for. Fortunately, the LINC2 circuit design and simulation software from ACS (Escondido, CA) can accurately deal with all these issues.

To address the concerns of item 1, above, LINC2 has an extensive device library and

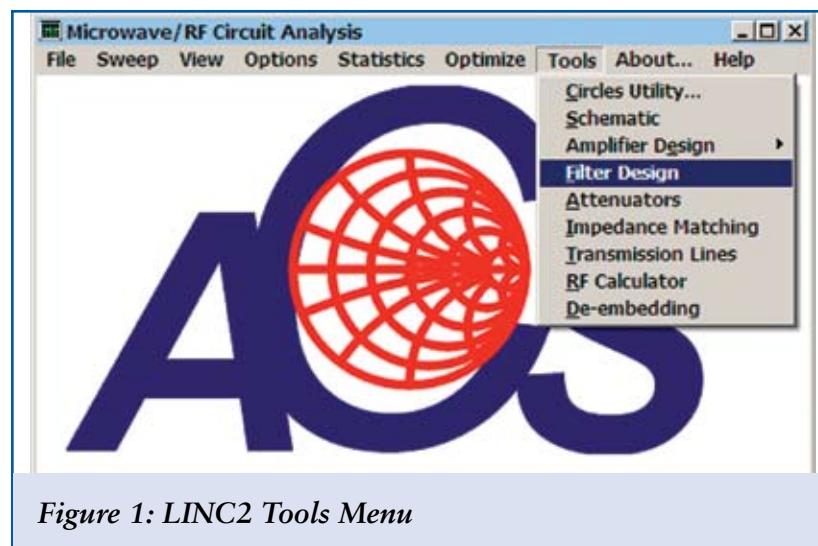


Figure 1: LINC2 Tools Menu

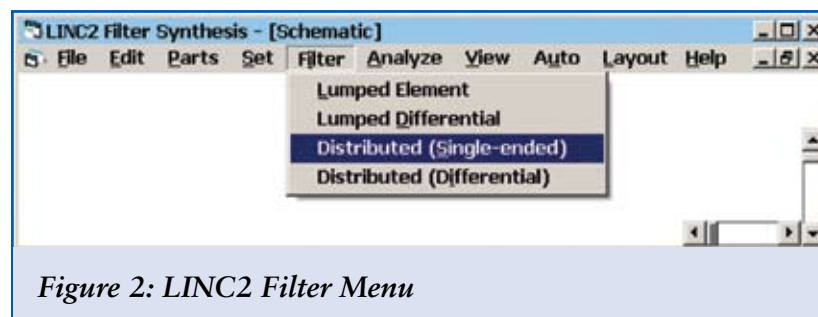


Figure 2: LINC2 Filter Menu

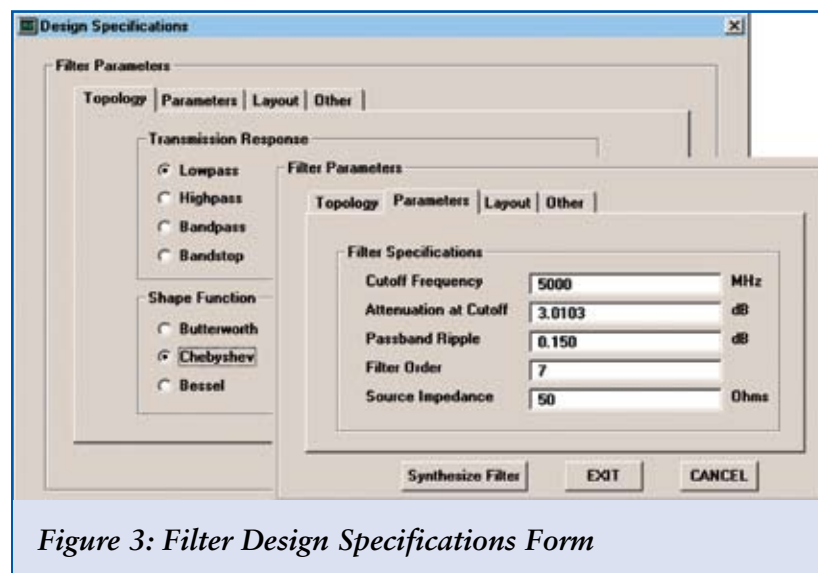


Figure 3: Filter Design Specifications Form

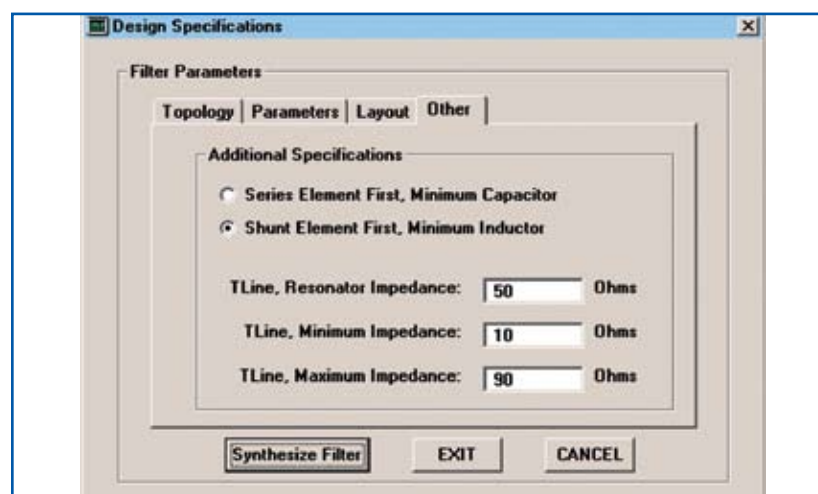


Figure 4: Other LINC2 Filter Synthesis Options

enhanced physical component models to accurately model parasitic elements. Circuit elements in the LINC2 Parts menu are available to model the effects of item 2, while EM simulation can be used to simulate the effects of 3, 4 and 5.

This article will use the LINC2 filter synthesis software to design a low pass distributed filter in microstrip to demonstrate the effects of transmission line discontinuities and other non-ideal elements on circuit performance. It will then be shown how EM simulation can be used to analyze the resulting performance shift and to determine how to correct for it.

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 geometry editor (xgeom) 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 beginning, 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.

Distributed Microstrip Low-Pass Filter Design Example

For this example, the design specifications will include the

following:

- Filter implementation: Low-pass stepped-impedance microstrip filter.
- Filter type: 7th order Chebyshev.
- Material: Rogers RO4003™.
- 3 dB cutoff frequency: 5000 MHz.
- Stop-band attenuation at 7500 MHz: 35 dB.
- Operating pass-band: 2500 - 4500 MHz.
- Minimum microstrip impedance: 10 ohms.
- Maximum microstrip impedance: 90 ohms.
- Pass-band return loss: > 10 dB.
- Pass-band ripple: 0.15 dB.

The LINC2 filter synthesis program is started by selecting Filter Design from the LINC2 Tools menu as shown in Figure 1. This action opens the LINC2 Filter Synthesis Schematic Window shown in Figure 2. LINC2 can design single-ended filters as well as differential filters for operation between balanced ports. For this example, Distributed (Single-ended) is selected from the Filter menu (Figure 2).

When the Design Specifications Form pops up, the design parameters for a 7th order low-pass Chebyshev filter are entered as shown in Figure 3.

The LINC2 Design Specifications Form is tailored to the type of filter selected, so the number and content of form tabs will vary somewhat from filter to filter. If there are layout related issues to deal with, they will be listed by selecting the Layout tab. For the distributed low-pass Chebyshev filter selected here, there are no layout issues at this time.

The last tab, shown in Figure 4, lists the other miscellaneous details of the filter design specifications. On the Other form, the first element is specified as a shunt element. The minimum and maximum T-Line impedance in specified as 10 and 90 ohms respectively.

At this point, clicking the Synthesize Filter button (Figure 4) generates the filter schematic shown in Figure 5.

Clicking Analyze now would yield simulation results for the schematic shown in Figure 5 with ideal electrical transmission line components. The

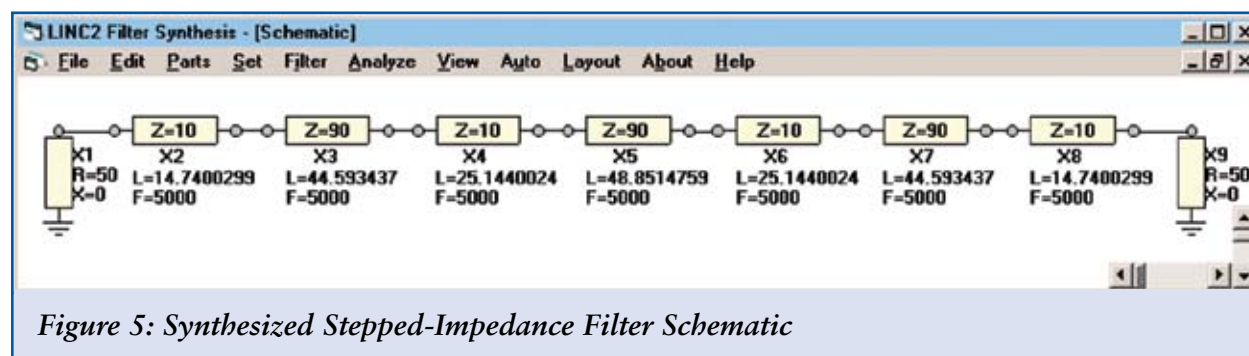


Figure 5: Synthesized Stepped-Impedance Filter Schematic

simulation results thus rendered on graphs and Smith chart displays of S21, S11 and S22 give a quick indication whether the final design is likely to meet specifications.

The next step is to use the Convert T-Lines to Microstrip feature from the Auto menu. This action automatically converts all the ideal transmission line elements on the schematic page to physical microstrip based on a pop-up substrate definition form as shown in Figure 6. The resulting converted schematic is shown in Figure 7. All of the physical dimensions required to build the filter are now contained on the schematic, including a description of the circuit board material. Anyone who has used a transmission line calculator to go through a schematic and manually convert all of the electrical (modeled) trans-

Figure 6: Microstrip Filter Substrate Parameters

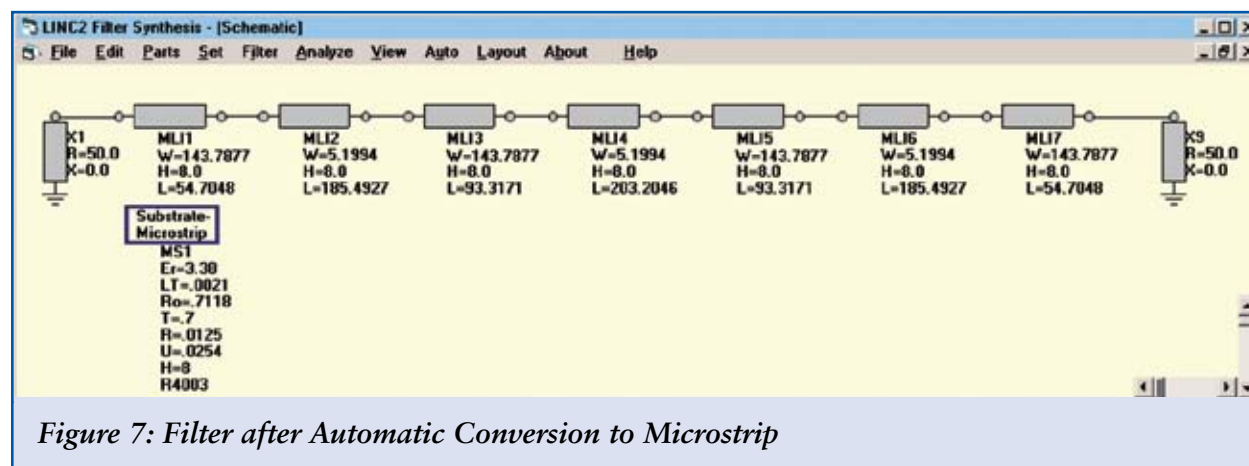


Figure 7: Filter after Automatic Conversion to Microstrip

mission lines to physical lines will appreciate the way LINC2 automates this process.

Clicking Layout produces the layout view shown in Figure 8. The length of de-embedding from the sides of the EM box is set to 50 mils. The EM box is the space over which the EM simulation will be performed. Simply clicking EM Simulation (Sonnet) pops up the Sonnet geometry editor (xgeom) with the LINC2 filter geometry already loaded. View | View 3D now displays the filter geometry in three dimensions as shown in Figure 9.

The only action that is needed to get EM simulation results for the entire filter is to select Analyze from the Sonnet project editor, the software is really that easy to use!

When the EM simulation is completed, selecting Projects | View Response | New Graph displays the filter response plots on the graph shown in Figure 10. The heavy curves show the initial filter response before adjustment for the discontinuity effects of the large impedance steps between the shunt and series elements. The result is that the -3 dB cutoff

frequency has shifted down by nearly 10% to 4540 MHz. This should not be surprising since the lumped circuit theory model for the step discontinuity is itself a low pass structure with series inductance and shunt capacitance that act to lower the cutoff frequency.

Both LINC2 and LINC2 Filter Pro have built-in Parts menus that include microstrip and stripline stepped width/impedance models for modeling these discontinuities. When the stepped-impedance low-pass filter in this example is simulated in LINC2 with

these circuit theory discontinuity models added, the result is also a downward shift in the frequency response. With discontinuity modeling applied, the LINC2 simulation predicts a downward shift in the -3 dB cutoff frequency of about 8% to 4612.5 MHz.

The difference between Sonnet EM and LINC2 simulations is only 2% at 5GHz with this particular circuit and geometric structure. Circuit simulations of other structures may depend much more on EM simulation for accurate results. Also, as the operating frequency increases, EM simulation will almost always be needed to close the gap between simulated and measured performance.

Improved Synthesis Using EM Analysis

The EM simulation indicated that the effect of the stepped-impedance microstrip discontinuities was a downward shift of 460 MHz in the cutoff frequency. In less than a minute, another filter synthesis run can be completed, this time compensating for the frequency shift by specifying a cutoff frequency of exactly 460 MHz higher (or $F_c = 5460$ MHz). This was done and the results from the new EM simulation are shown as the light colored plots overlaid the original (heavy plots) in Figure 10. The new -3 dB cutoff frequency is now 5.02 GHz. This reduced the error in cutoff frequency from 10% to 0.4% in one iteration. All of the other original filter goals have been met, including return loss and stop-band attenuation.

Summary and conclusions

This stepped-impedance low-pass filter design was used to show how EM simulation can be used to uncover the effects of transmission line discontinuities in distributed filters, thus improving the accuracy of the simulation. As was shown in this example, lumped (circuit theory) discontinuity models can be included in the schematic based simulation to improve the accuracy. However, these transition models are usually based on lumped LC approximations. This means that there is a limit on the size of the discontinuity, the substrate dielectric, and in many cases there

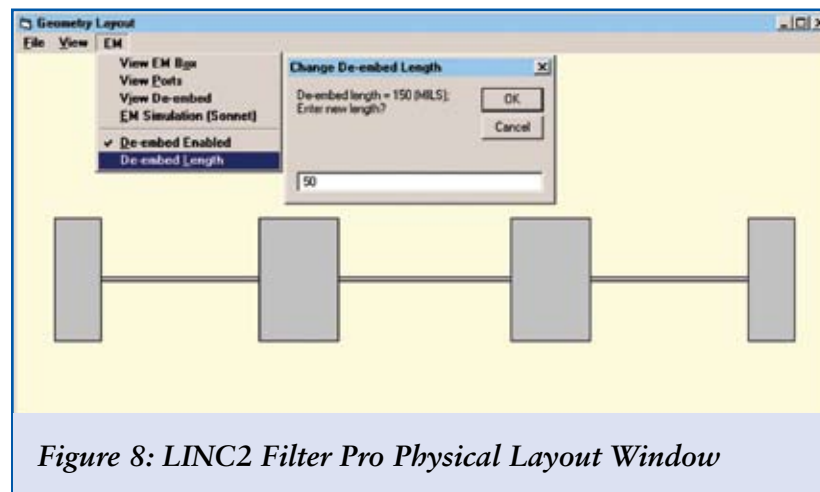


Figure 8: LINC2 Filter Pro Physical Layout Window

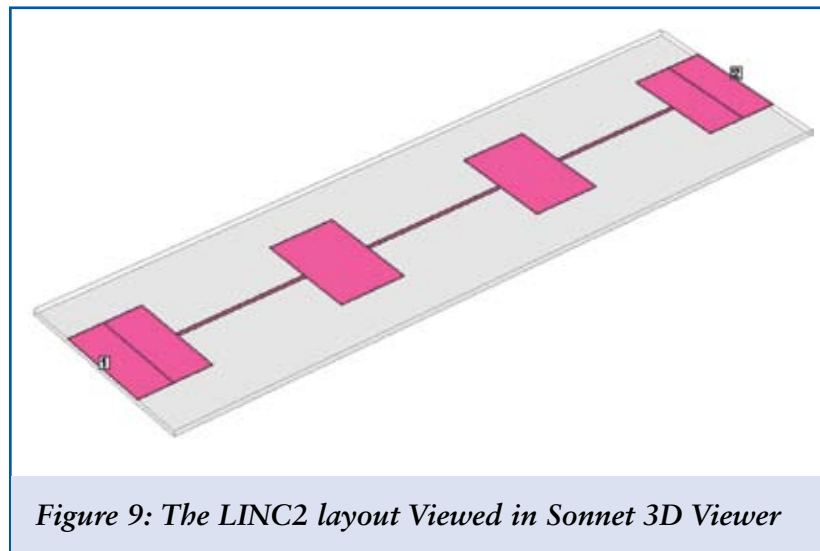


Figure 9: The LINC2 layout Viewed in Sonnet 3D Viewer

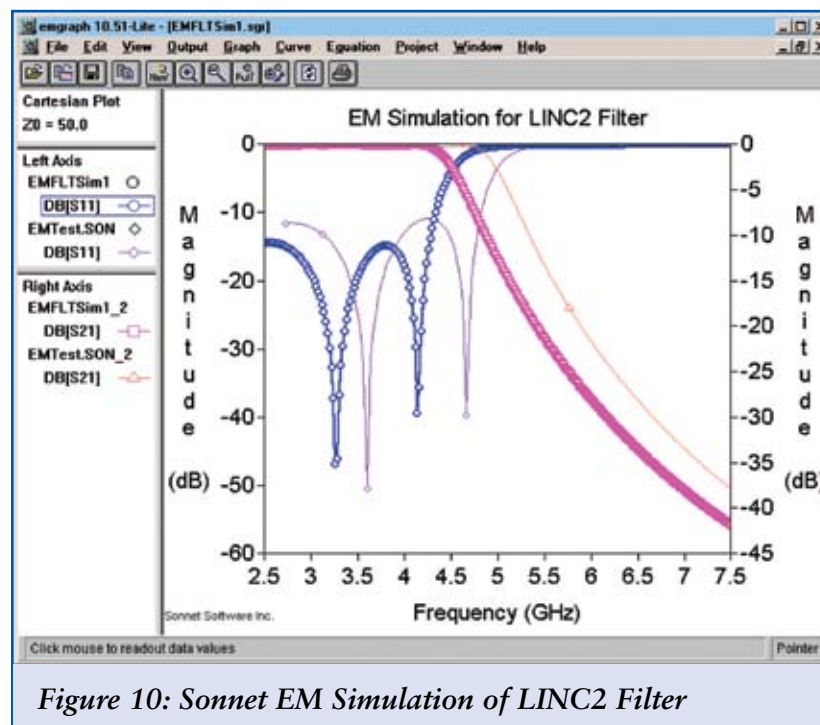


Figure 10: Sonnet EM Simulation of LINC2 Filter

are limitations on the frequency range as well.

In this example the ratio of the line widths at the impedance steps was nearly 28. The schematic based line width/impedance step models typically are only accurate to within a few percent for steps less than 10:1. Since these kinds of filters have such large impedance steps it is a good idea to use EM simulation for the best results.

LINC2 is a high performance RF and microwave design and simulation program from ACS. In addition to schematic based circuit simulation, optimization and statistical yield analysis, LINC2 Pro includes many value added features for automating design tasks, including circuit synthesis. LINC2 directly interfaces to leading RF and microwave design suites, allowing it to be used

stand-alone or by leveraging its capabilities with those of other major packages. The subject of this article, the LINC2 Sonnet interface, uses a single button click to automatically transfer the LINC2 layout geometry into Sonnet for world-class EM analysis. More information about LINC2 can be found on the ACS web site at www.appliedmicrowave.com.

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