



## Agilent EEsof EDA

### Filters with Complex-Impedance Terminations

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## **Subject: Filters with Complex-Impedance Terminations**

This Word document was attached to a post at the Founder's Forum of the Agilent/Eagleware-Elanix website on November 14, 2005. The document offers some techniques for designing filters with unequal or reactive terminations. This subject is closely related to matching, so this post may be of interest to those who use matching networks.

### **Unequal, Resistive Terminations: The Lowpass Filter**

A common request is "How do I design a lowpass filter with unequal terminations?" Consider the lowpass filter in Figure 1. Suppose the source is 50 ohms and the load is 300 ohms. The definition of lowpass is a response from DC to an upper frequency limit. Consider what happens with this network at DC or very low frequency. At low frequency, the shunt capacitors become high impedance and they vanish. The series inductors become low impedance and they vanish. So if all the components effectively vanish, how can this network match 50 ohms to 300 ohms and have a low-loss response at low frequency? It can't! The solution is theoretically unrealizable.

We have two options. One option is achieving maximum power transfer over a limited bandwidth as shown in Figure 2. The response is pseudo lowpass. The bandwidth of low insertion in this case is about 500 to 1000 MHz. The 3 dB insertion and return loss at low frequency are the same values that would exist without the network with 50 ohms driving a 300 ohm termination. The bandwidth of the response and the low-frequency insertion loss degrade with increasing termination resistance ratio. This pseudo lowpass was actually designed using the MATCH synthesis module rather than the FILTER module. MATCH offers many different network topologies. One of these is the LC Pseudo Lowpass. The distinction between filters and matching networks is often blurry. Greater bandwidth is achieved by specifying a higher order.

The second option is achieving a true Butterworth or Chebyshev response from DC to the upper cutoff, but accepting the resulting reflection, mismatch and insertion loss through the entire bandwidth. An example response is given in Figure 3. Filters of this latter type are easily designed using the impedance bisection theorem. This will be the subject of a future post.

### **Complex Terminations: The Lowpass Filter**

Imagine a filter requirement with a 50 ohm source and a complex load that is 50 ohms in parallel with 20 pF capacitance. If a lowpass filter is selected that has a shunt capacitor as the final element, the 1.5 pF load capacitance may simply be absorbed by the shunt capacitor in the filter, reducing the filter capacitor from 2.41 to 0.91 pF. This is shown in Figure 4. Likewise, if the load has series inductance, a lowpass filter with a series output inductor is used. This is illustrated in Figure 5. These techniques will work as long as the load reactor is smaller than the filter output reactor. Increased reactor values may be absorbed with lower cutoff frequency or higher passband ripple. Loads with series capacitance and shunt inductance may be handled using filters with a highpass response.

### **Equal-Resistance, Complex Terminations: The Bandpass Filter**

Much larger valued reactors, and either shunt or series capacitors or inductors are absorbed using the exact transform bandpass filter topologies (Minimum Inductor and Minimum Capacitor) in the FILTER synthesis module. This technique requires equal termination resistance, but the solution is exact. An example 800 to 1000 MHz filter is shown in Figure 6. Notice that this filter can absorb a much larger value of

shunt capacitor. This is a natural consequence of the bandpass bandwidth being less than the 1 GHz lowpass. Series reactors are absorbed by selecting a bandpass topology with a series output resonator. With narrow bandwidth, extremely large values of either series or shunt load reactors are absorbed.

### Unequal-Resistance, Complex Terminations: The Bandpass Filter

There are several coupled-resonator bandpass filter topologies in the FILTER module. An example is the top-C coupled parallel resonator bandpass. These topologies automatically let you specify unequal termination resistance. Topologies are available with shunt capacitors and series capacitors or inductors at the terminations to absorb termination reactance. The equations that compute element values for these topologies are approximate and this approach works best for bandwidths of 25% and less. For narrow bandwidth applications, these topologies absorb large values of reactors and these filters have the easiest element values to realize. They are the best choice for narrow bandwidth filters. Some success may be achieved with wider bandwidth by optimizing the initial synthesized solution.

### Unequal-Resistance, Complex Terminations: The Arbitrary Filter

The above techniques use popular cookbook and coupled-resonator filters. The topologies are set to fixed types. The large number of filter topologies designed by Eagleware/Elanix lets you select a filter to match your requirements. But by far the greatest flexibility to satisfy filter specifications is offered by the S/FILTER module. This module allows you to place filter transmission zeros and finite-frequency notches wherever you want them. After you have created the exact filter response shape you need, you are ready to deal with complex terminations.

S/FILTER has literally scores of built in network transforms to customize either lumped or distributed filters. Many of these deal with impedance transformations. Perhaps the most powerful are the Norton transforms. They work with many bandpass applications. The Norton transforms allow you to change the termination resistance. Then, the absorption techniques described earlier are used to deal with termination reactors. Shown in Figure 7 is a 684 to 1000 MHz bandpass filter terminated in 300 ohms resistance. This filter could be used to absorb either series capacitance or series inductance. As with the fixed topology filters, the largest values of reactors are absorbed with narrower filters. The Norton transforms require practice, but they are powerful tools for impedance control in filters. Using S/FILTER is a great way to learn about the Norton and other network transforms.

Clear skies and high Q  
Randy Rhea

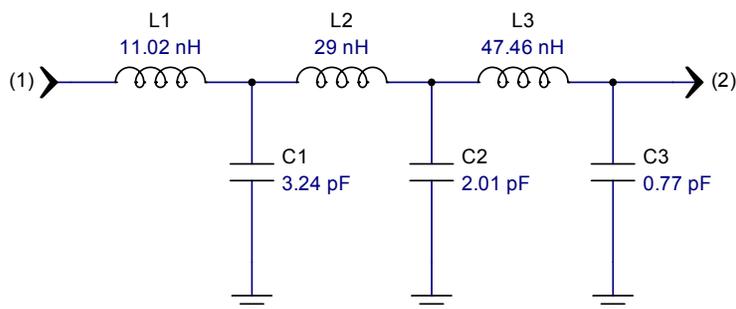


Figure 1

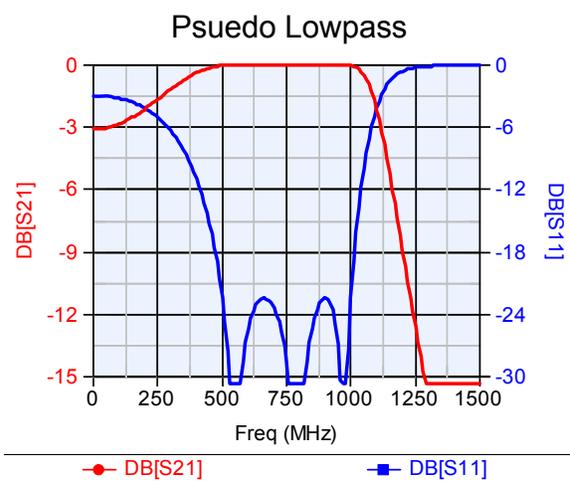


Figure 2

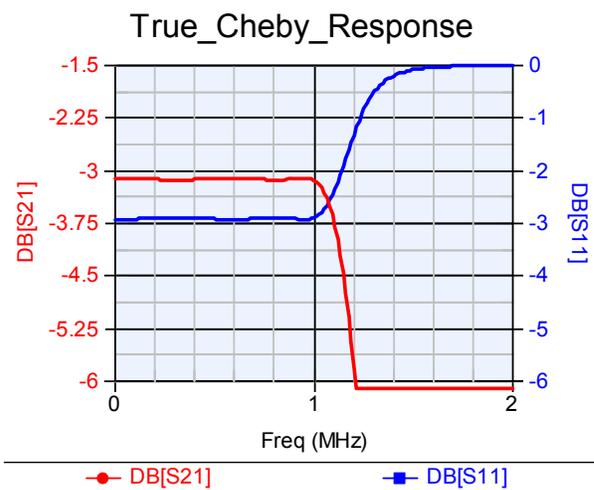


Figure 3

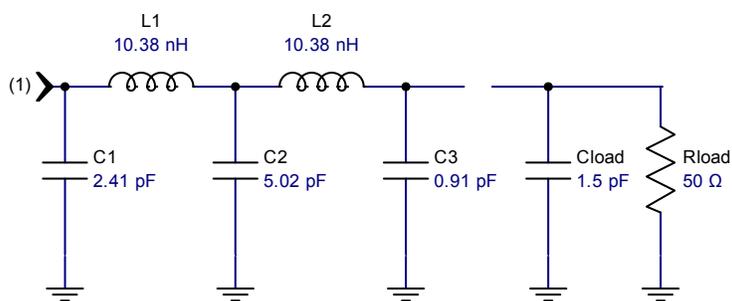


Figure 4

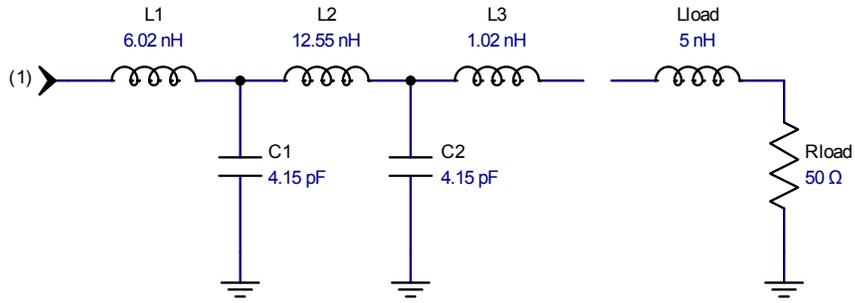


Figure 5

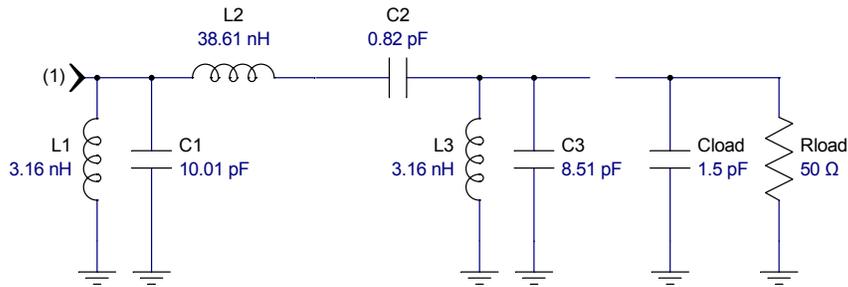


Figure 6

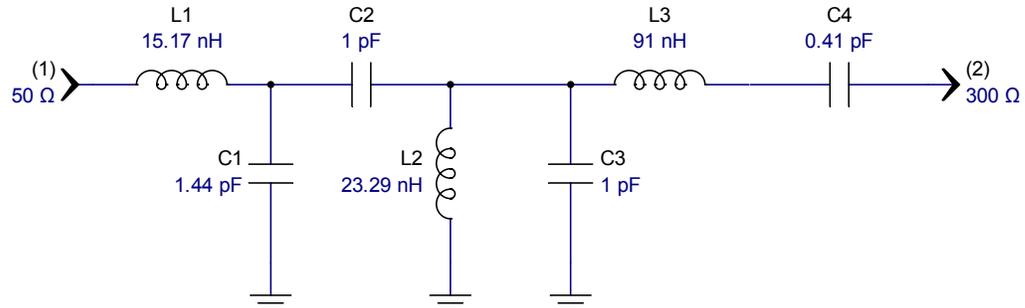


Figure 7

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