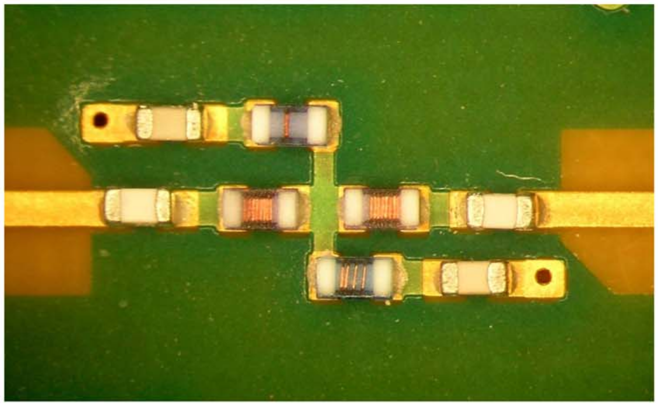
The Impact of Topology and Parasitics on SMT Bandpass Filters

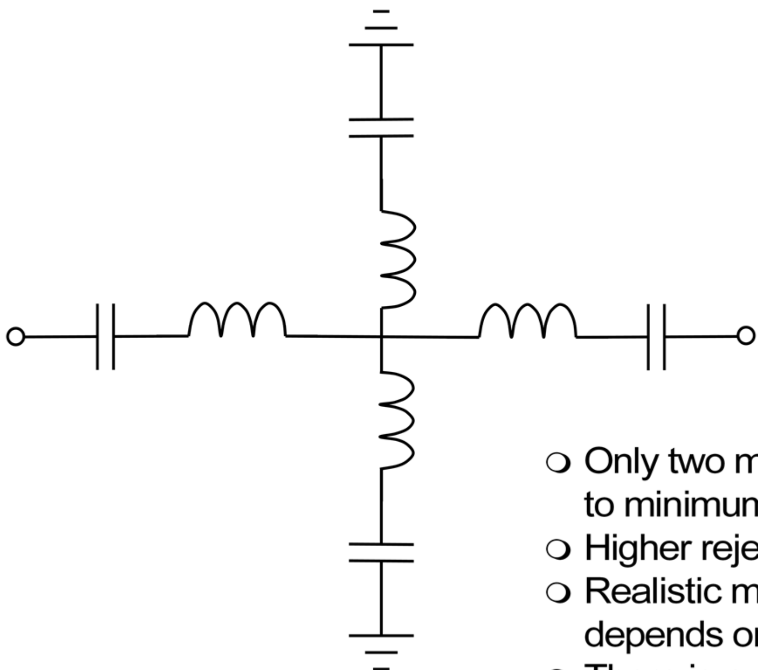


Dan Swanson
DGS Boulder, LLC
Boulder, CO

dan@dgsboulder.com

This presentation is a small subset of slides from a two day class on designing filters and multiplexers in a printed circuit board environment using standard surface mount technology (SMT) capacitors and inductors. While some standard SMT filters are available from various manufacturers there is often the need for a custom design. In this presentation we offer a few insights on the impact of filter topology and SMT component parasitics on our filter design.

Cauer-Chebyshev Elliptic Filter



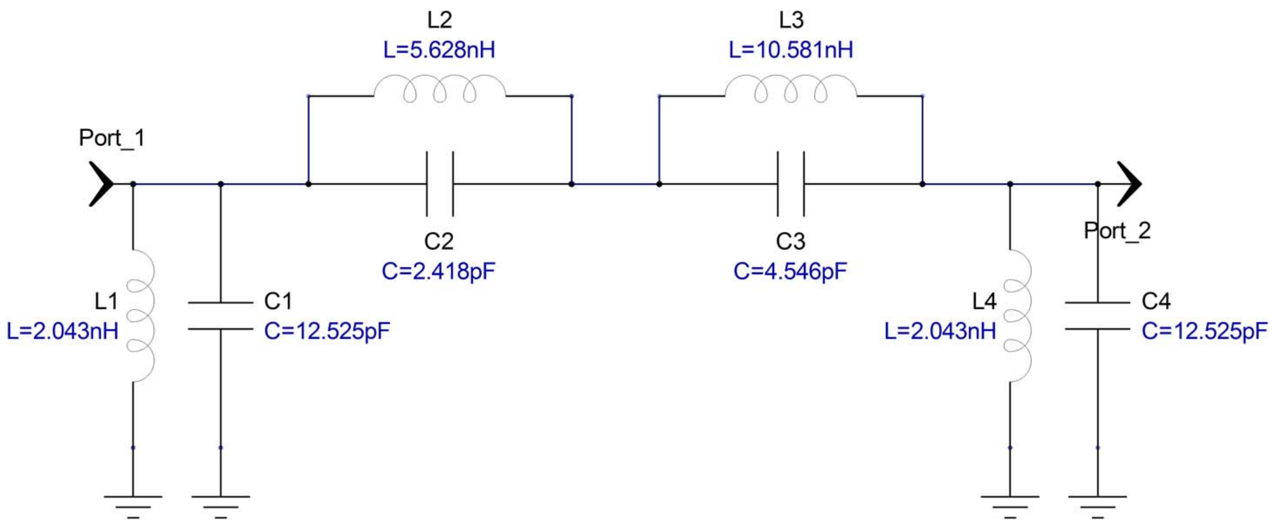
- Only two more components compared to minimum capacitor Chebyshev.
- Higher reject rate than Chebyshev.
- Realistic minimum stopband rejection depends on filter bandwidth.
- There is a parametric version with another series resonator.

PCB Filter Design PCB 6 - 2

There are many lumped element prototypes we could choose from to design our PCB filter. At the end of this presentation you will have some ideas on how to evaluate the usefulness of a given topology.

One very useful topology I have found is this N = 3 Cauer-Chebyshev elliptic function filter. This filter has two more components than the conventional minimum capacitor Chebyshev topology. And because it is elliptic it has a higher rejection rate than the Chebyshev filter. When you consider insertion loss and practical element values, a bandwidth of 15 to 20% and minimum rejection of -30dB in the stopbands seems to be a sweet spot for this topology. We have built these filters with center frequencies from 900 MHz to 5 GHz.

Cauer-Chebyshev Elliptic

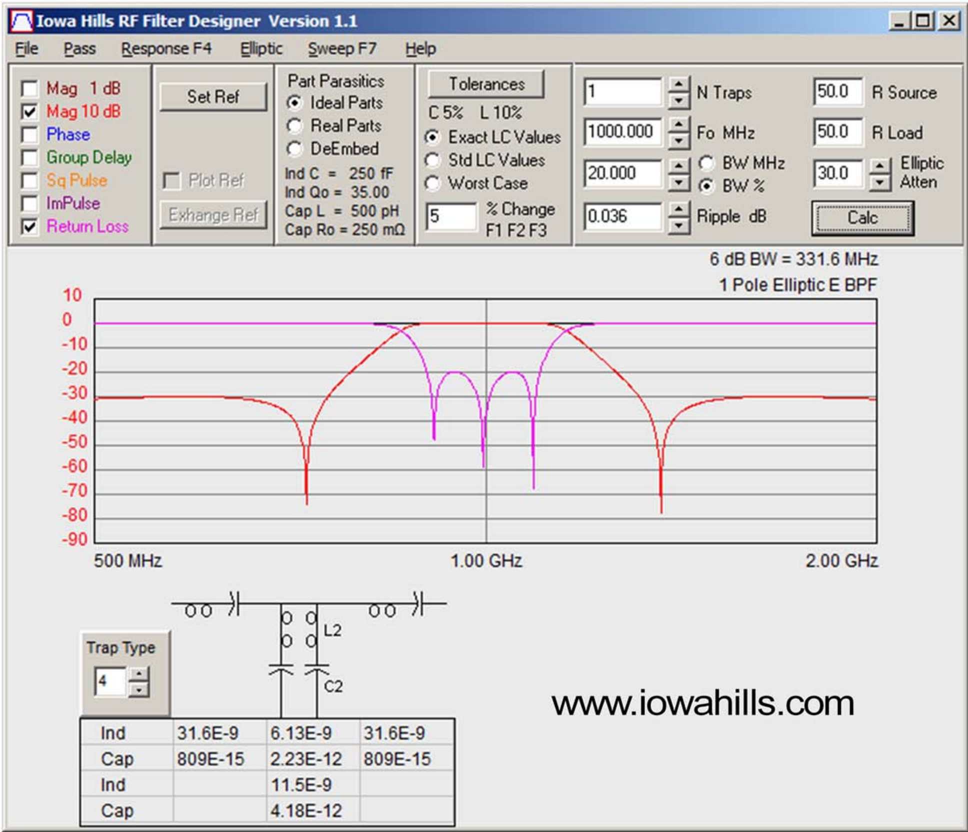


- Take dual of this network from Keysight Genesys Passive to get the network we want.
- I have not been able to figure out how to get the desired network directly in Genesys.

PCB Filter Design PCB 6 - 3

There are several ways to get a lumped element prototype for this filter. In Keysight Genesys Passive you can get the network shown here. You then have to take the dual of this network.

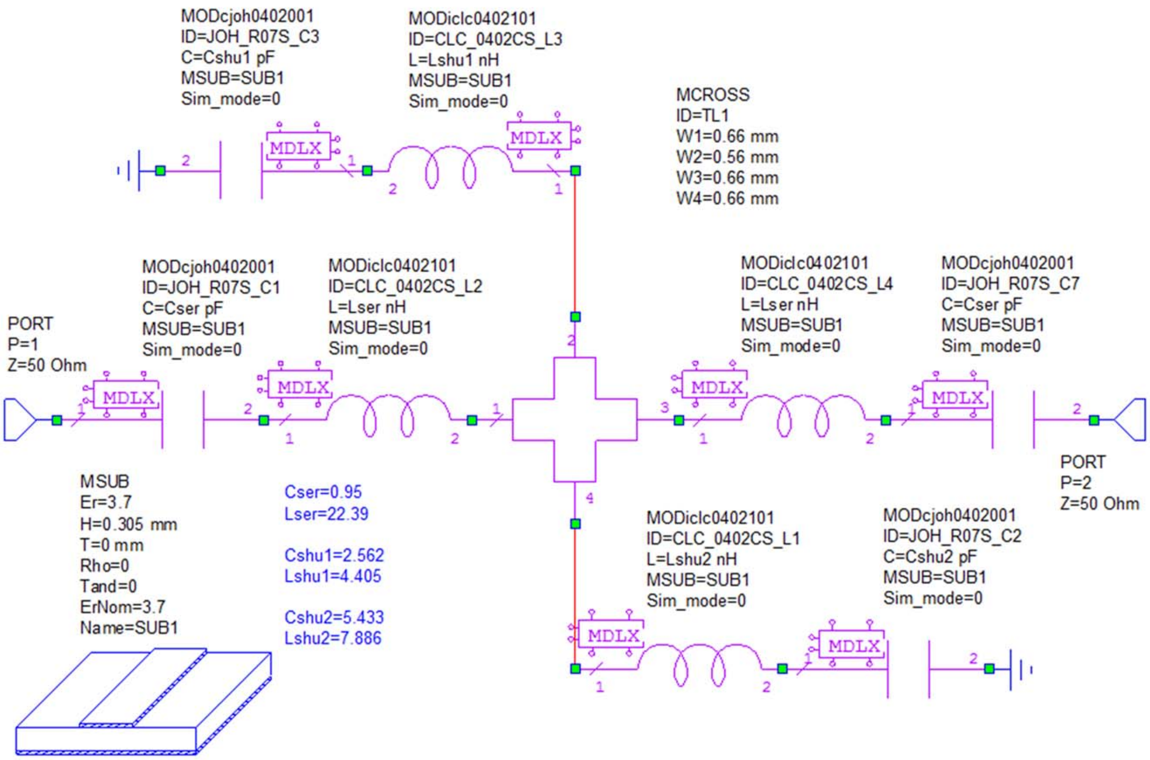
Iowa Hills RF Filter Designer



PCB Filter Design PCB 6 - 4

You can find this free filter design program at www.iowahills.com. It will design the filter and give you the desired topology directly.

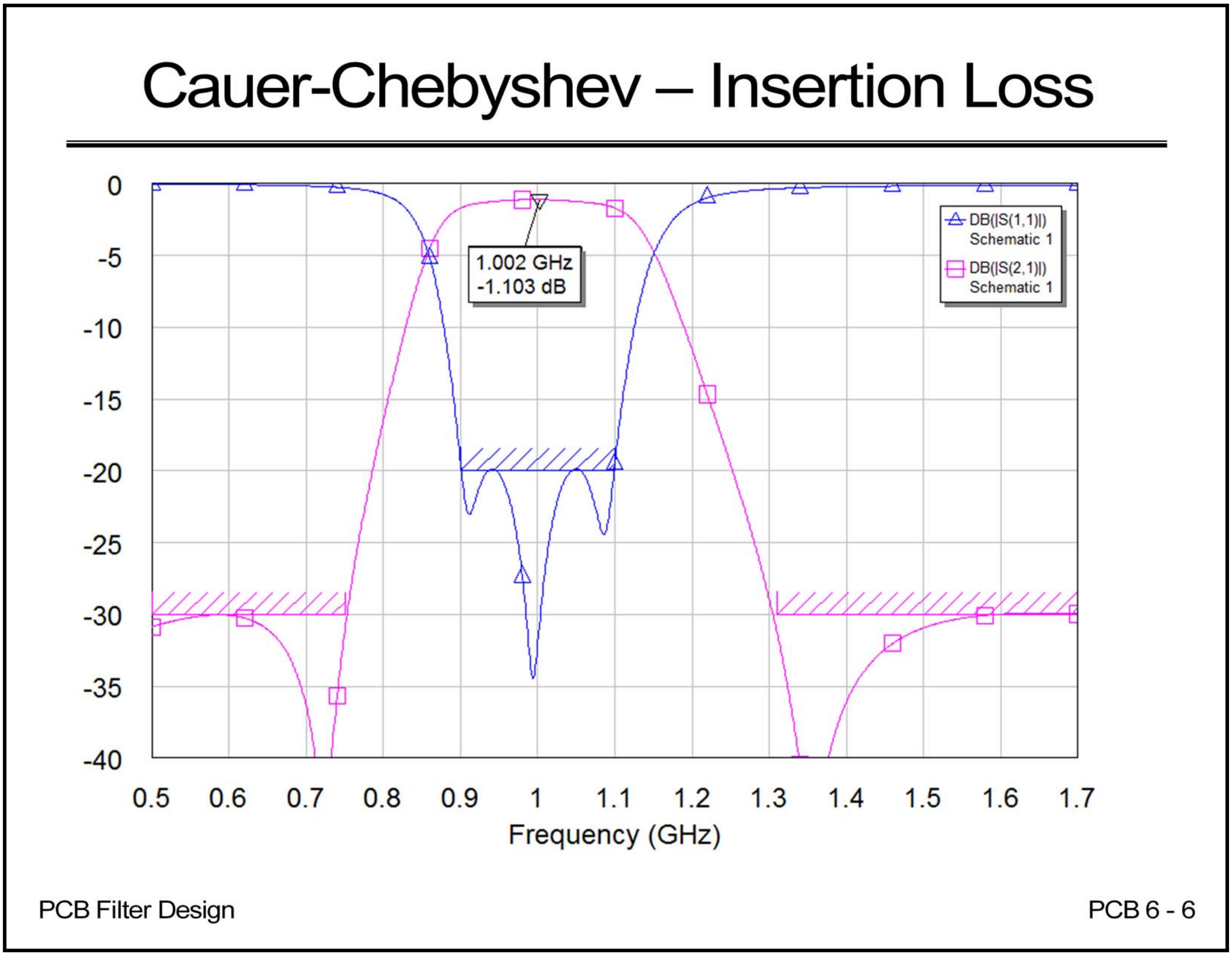
Convert To SMT Components



PCB Filter Design PCB 6 - 5

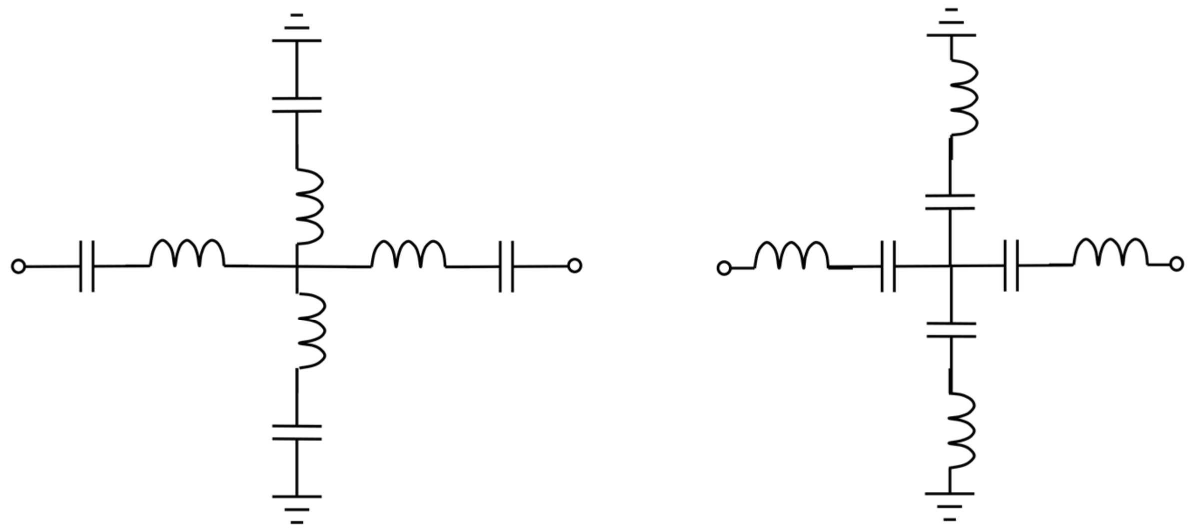
Using the Modelithics CLR library is critical to the success of these designs. To convert the ideal lumped prototype into an SMT design we substitute in the SMT components one at a time, or in pairs in case of symmetry, and optimize the filter back to the ideal response. We can also include the obvious layout details like the microstrip cross junction at this stage. We have not included grounding vias at ends of the shunt arms.

Due to the layout and component parasitics, the final element values for the SMT design will be significantly different than the ideal lumped prototype. This is important to understand when evaluating a new lumped element prototype.



Here is the predicted response from the circuit on the previous slide. The predicted midband insertion loss is -1.1dB which should be quite useful for many applications.

Which is Better?

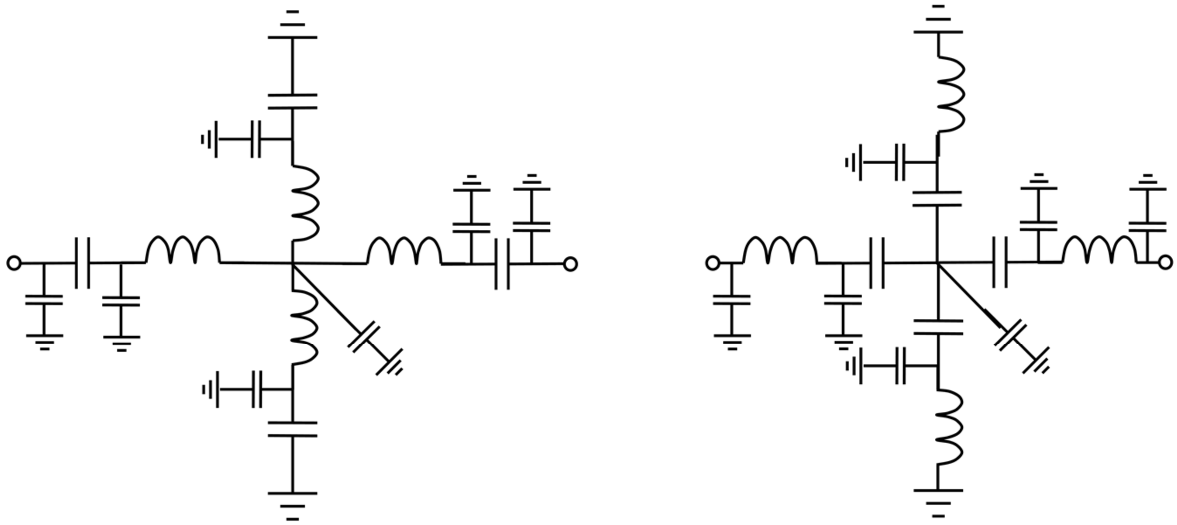


- Lumped prototype responses are exactly the same.
- Do SMT component parasitics have an impact?

PCB Filter Design PCB 6 - 7

In this topology we have four “arms” with a capacitor and inductor in series in each arm. An obvious question is: does the order of the elements make a difference? Of course the lumped prototype responses will be exactly the same. But do the SMT component parasitics and the layout parasitics have an impact.

Layout Parasitics

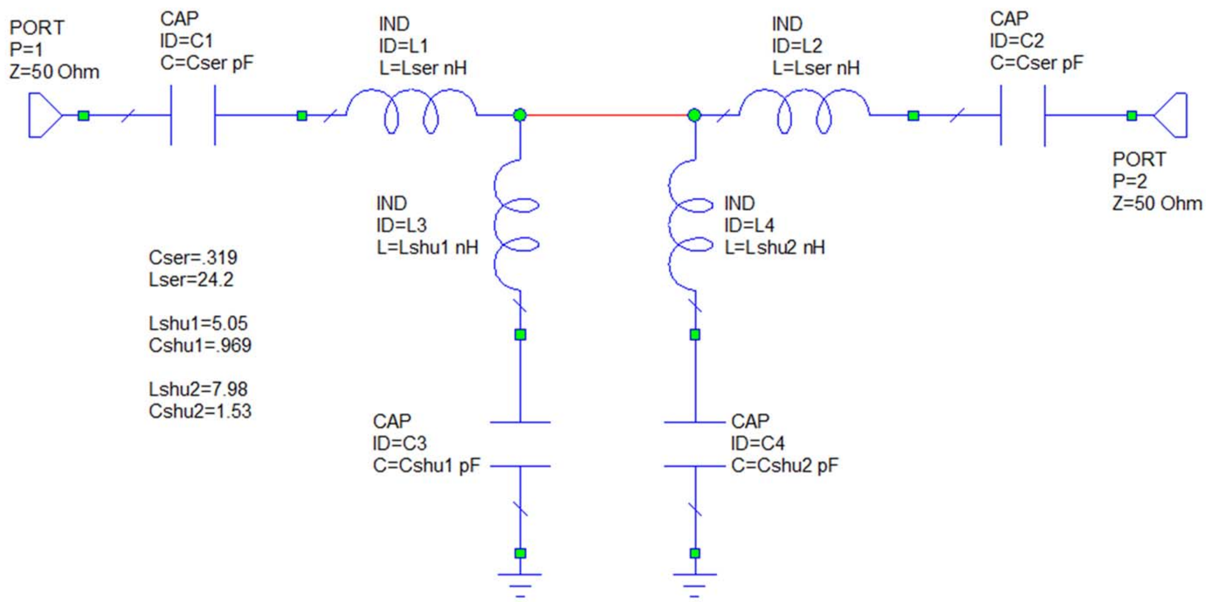


- The layout introduces parasitics.
- The SMT components also have internal parasitics.
- SMT inductors and SMT capacitors have resonances in the stopband.

PCB Filter Design PCB 6 - 8

The SMT padstacks have parasitics which are included in the Modelithics models. The SMT components also have internal parasitics and resonances that are also included in the Modelithics models. It is well known that inductors have a self-resonance that is a function of the inductance value. Smaller inductors have a higher self-resonance frequency. It is less well known that the SMT capacitors also have resonances that seem to be a function of the package geometry rather than capacitance value. These resonances are typically in the 2 to 3 GHz range.

Lumped Proto – Capacitors First



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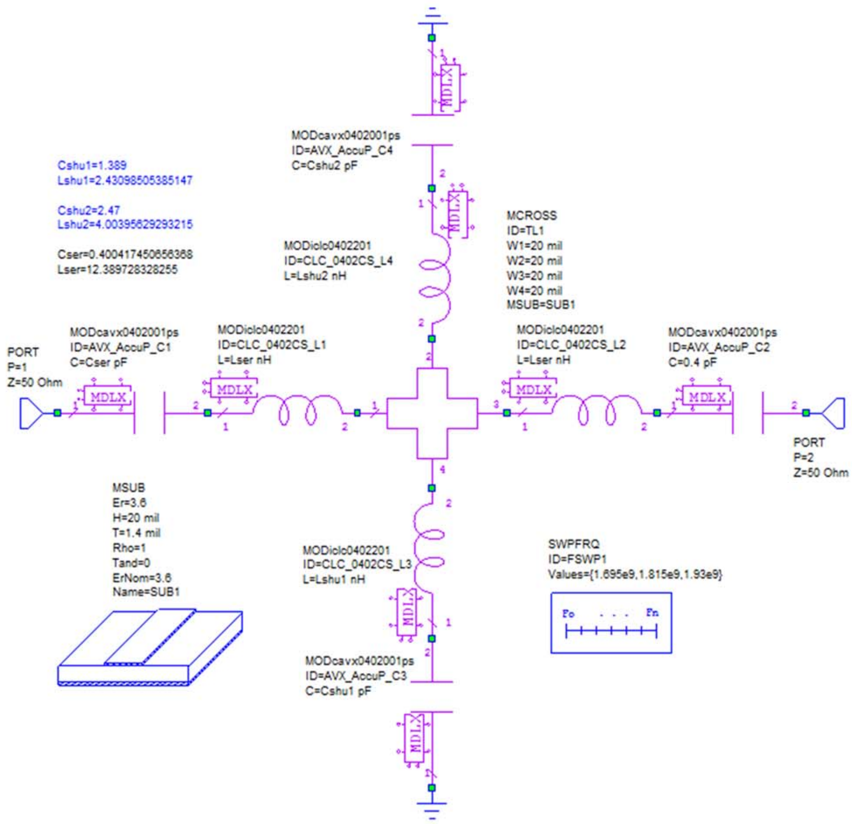
Here is our lumped prototype with the capacitors coming first at the input and output.

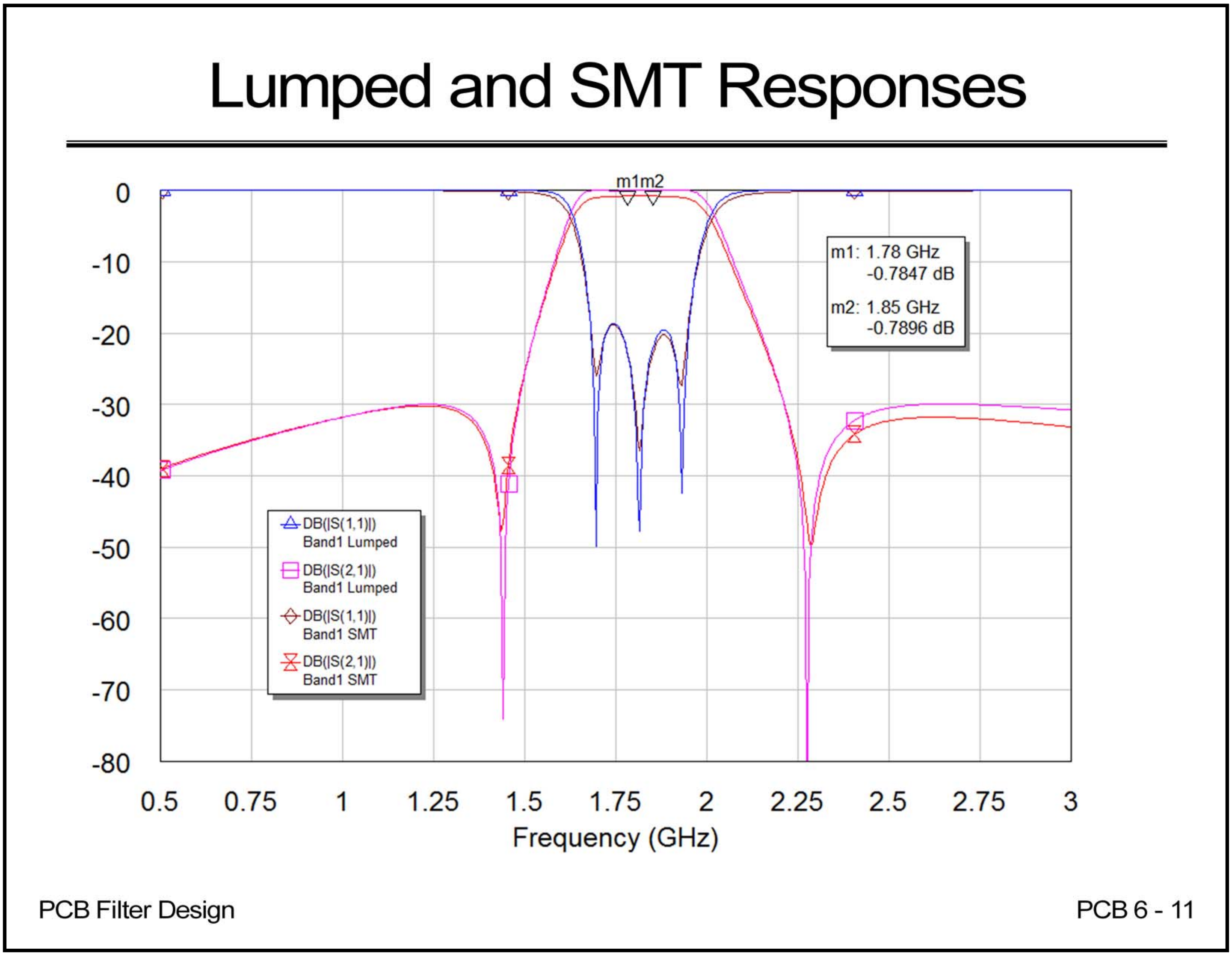
SMT Design – Capacitors First



	Lumped Proto	SMT Filter
Cser	0.319	0.4
Lser	24.2	12.39
Cshu1	0.969	1.389
Lshu1	5.05	2.43
Cshu2	1.53	2.47
Lshu2	7.98	4.00

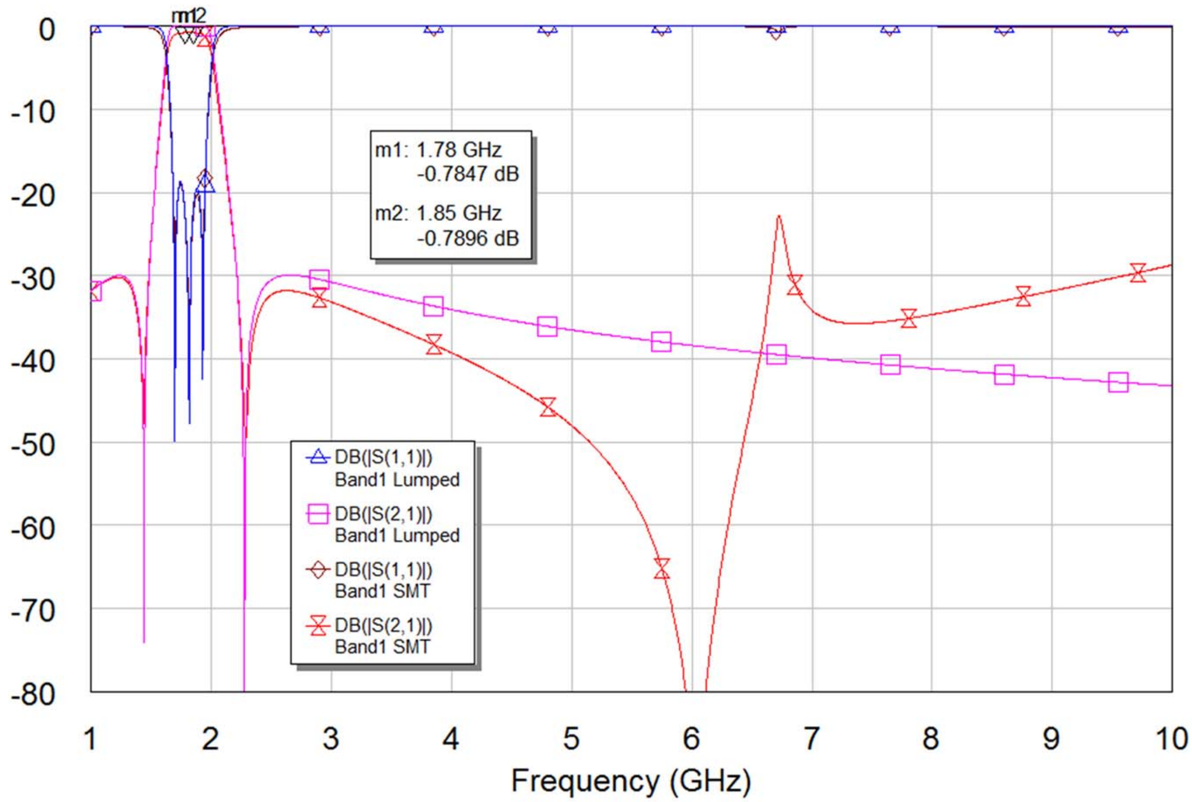
PCB Filter Design PCB 6 - 10

After conversion to SMT components we can look at the shift in element values. In all cases the capacitors, which are quite small in the prototype, get bigger. And in all cases the inductors, which can be quite large in the prototype, get smaller. So this is all good news, larger capacitors are easier to realize and smaller inductors are easier to realize. At higher frequencies, when the inductors get into the 1 to 2 nH range, we can print them on the PCB rather than using a SMT component.



After optimization the SMT design is a close match to our lumped element prototype. What about the stopbands?

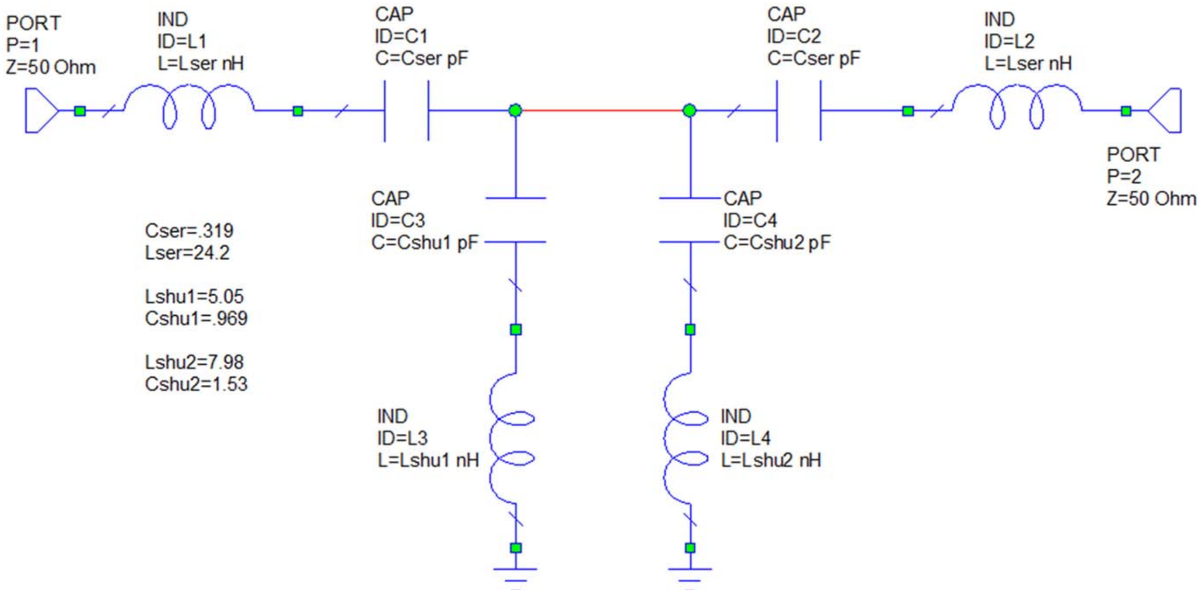
Broadband Responses



PCB Filter Design PCB 6 - 12

In the stopband we do see a resonance in the SMT design. But the resonance is at almost four times the center frequency, which is not bad performance. This is actually better stopband performance than many designs in the current literature.

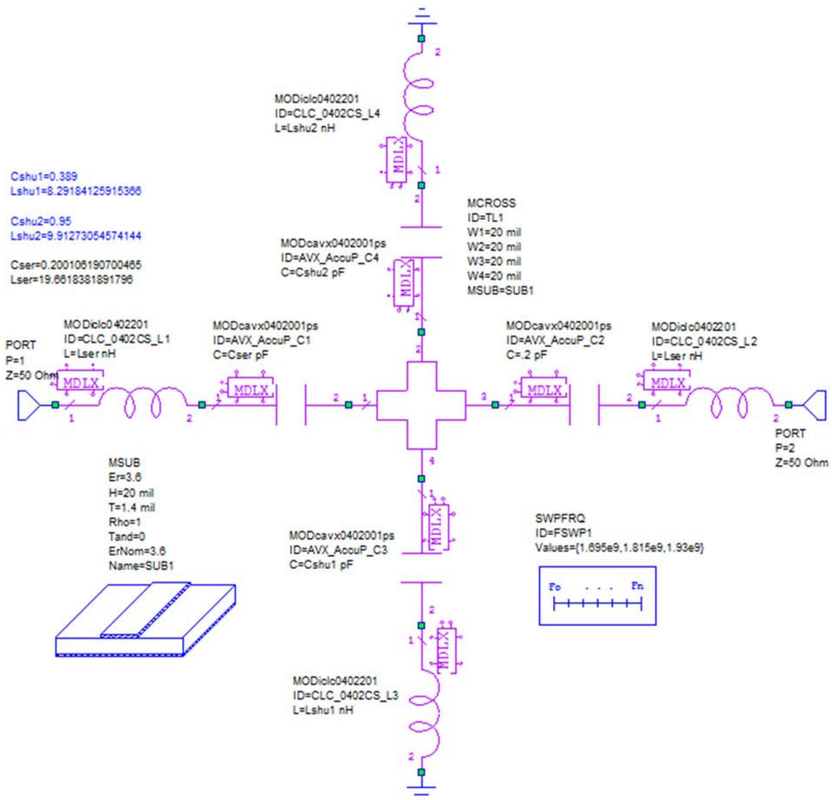
Lumped Proto – Inductors first



PCB Filter Design PCB 6 - 13

Now let’s change the order of the elements and put the inductors first at the input and output. Of course the element values don’t change in the lumped prototype.

SMT Design – Inductors First

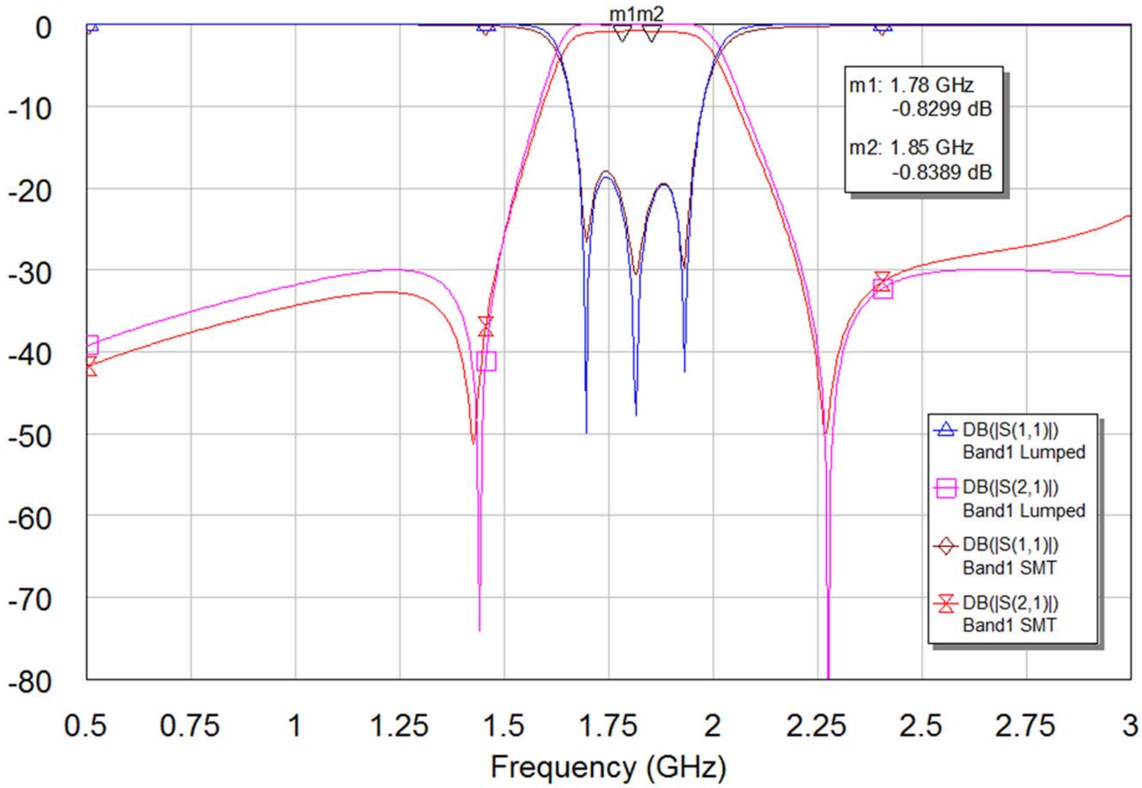


	Lumped Proto	SMT Filter
Cser	0.319	0.2
Lser	24.2	19.66
Cshu1	0.969	0.389
Lshu1	5.05	8.29
Cshu2	1.53	0.95
Lshu2	7.98	9.91

PCB Filter Design PCB 6 - 14

After conversion to SMT components we again look at the shift in element values. In all cases the capacitors have gotten smaller, which will make them harder to realize. The inductors at the input and output are smaller than the prototype, but larger than the other topology. The shunt inductors are larger than the prototype values.

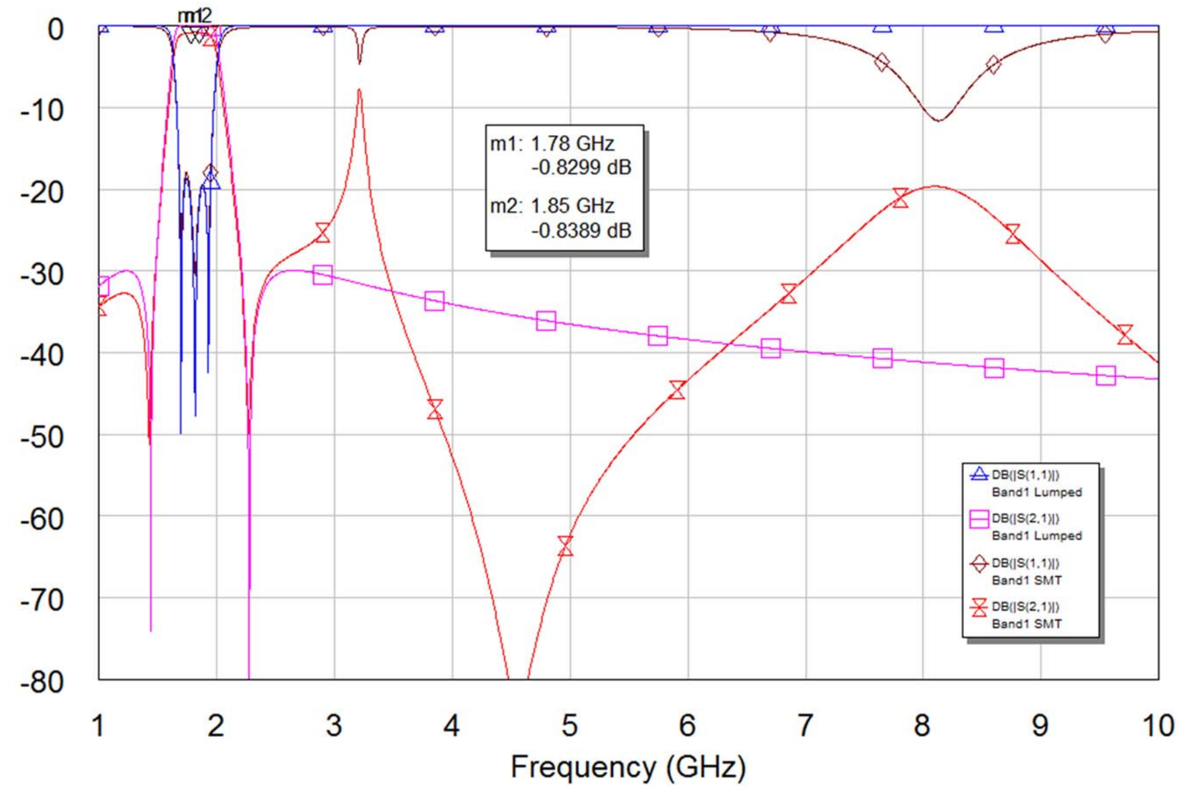
Lumped and SMT Responses



PCB Filter Design PCB 6 - 15

After optimization the SMT design is a close match to our lumped element prototype. But we can see the hint of a problem in the upper stopband.

Broadband Responses



PCB Filter Design PCB 6 - 16

With this topology we have a strong resonance close to the passband. Past experience and analysis has shown that the source is the SMT capacitors.

Compare Final Element Values

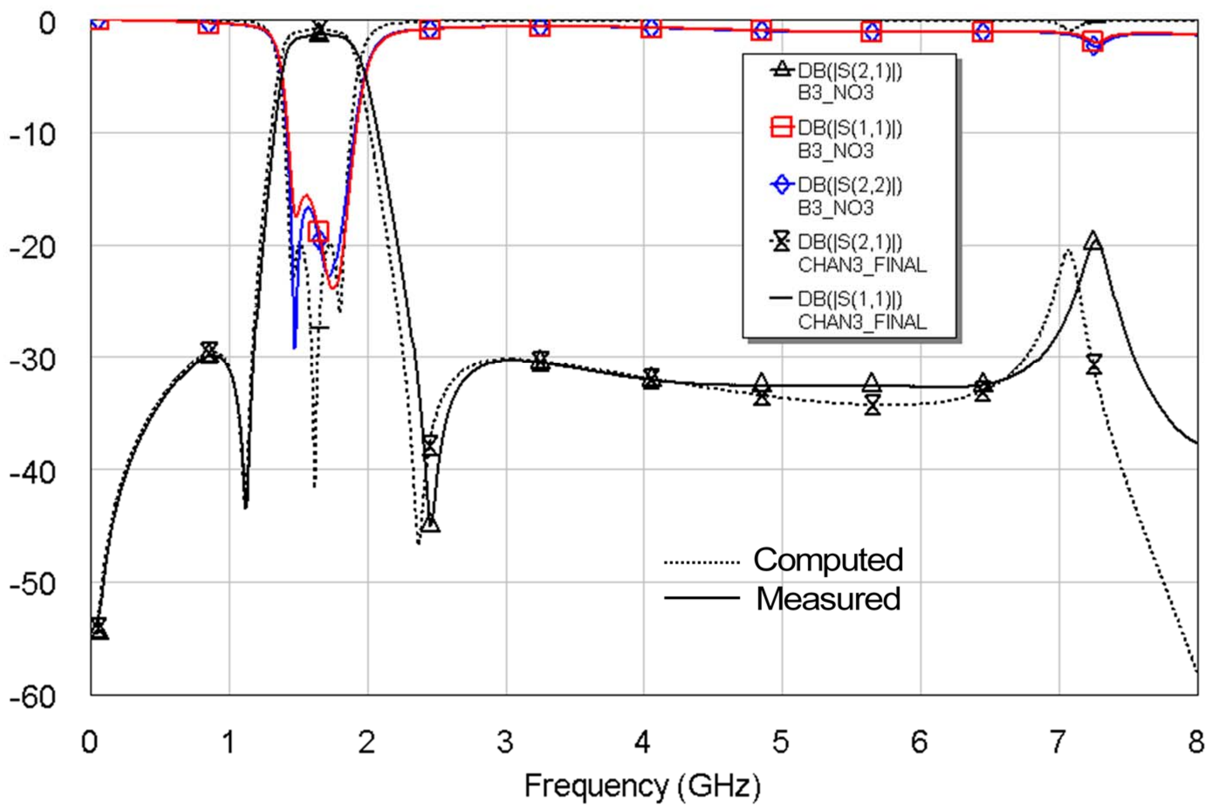
	Lumped Proto	Capacitors First	Inductors First
Cser	0.319	0.4	0.2
Lser	24.2	12.39	19.66
Cshu1	0.969	1.389	0.389
Lshu1	5.05	2.43	8.29
Cshu2	1.53	2.47	0.95
Lshu2	7.98	4.00	9.91

- Putting the capacitors first gives us better stopband performance.
- Capacitors first also gives us larger capacitors and smaller inductors.

PCB Filter Design PCB 6 - 17

In this slide we have summarized the final element values for the two topologies. In general, the capacitor first topology gives us component values that are easier to realize. But the more important conclusion is that the capacitor first topology gives us much better stopband performance.

Measured vs Modeled Results



PCB Filter Design PCB 6 - 18

This slide shows measured versus modeled performance for a filter very similar to the one we have analyzed in this presentation. Note that the center frequency and bandwidth predictions are quite good. And we can predict the first resonance in the stopband quite closely as well. Without the Modelithics CLR library this would not be possible.

Acknowledgements

I would like to thank:

NI AWR for access to Microwave Office

and

Modelithics, Inc for access to their CLR Library

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I would like to thank NI AWR and Modelithics for supporting this work.

Follow Up Classes

PCB Filters and Multiplexers
Using Standard SMT Components

An intensive two day class (12 hours of class time).

An open course or an in house course
can be arranged on request.

Contact: www.dgsboulder.com

PCB Filter Design PCB 6 - 20

This material is a subset of a two day class on PCB filter and multiplexers. An open course or an in house course can be arranged on request.