Thin-Film Lumped-Element Microwave Filters

Dan Swanson, Member, IEEE

Avantek, Inc.
481 Cottonwood Drive
Miliptas, CA 95035

Abstract

A method for the design and construction of thin-film lumped-element microwave filters is presented. The resulting filters exhibit broad spurious-free stopbands, small physical size, excellent amplitude and phase match, and high reliability due to their thin film construction. The necessary models for inductors and capacitors are discussed.

Introduction

Thin-film microstrip filters are an important component in modern hybrid integrated subassemblies. When filters are called for, the subsystem designer often uses edge-coupled, commensurate line, hairpin and other well-known distributed topologies.

Distributed topologies, however, have certain limitations. It is difficult to construct broadband distributed filters in conventional microstrip due to the large impedance ratios required. At the lower microwave frequencies distributed filters become physically quite large. Furthermore, due to the distributed nature of the filters, it is difficult to realize broad stopbands free of spurious responses.

Lumped-element microwave filters that address many of these limitations do exist, but present difficulties of their own when used in thin-film assemblies. Lumped-element filters are usually constructed using parallel-plate chip capacitors and air-wound inductors soldered into a small housing. Skilled manual labor is required to build and tune such a filter. While the volume occupied by these lumped filters is small compared to their distributed counterparts, it is often difficult to integrate them into an otherwise all-thin-film assembly.

In this paper, several lumped-element microwave filters fabricated entirely using thin-film techniques are described.

Figure 1 shows a low-pass thin-film filter using a one-and-three-quarter-turn spiral inductor and simple microstrip patch.

Figure 2 shows a band-pass filter with the familiar "tubular" or "dumbbell" topology, first realized in coaxial form. In this filter, the pi network of capacitors is realized using two parallel-coupled microstrip patches, a dielectric layer, and a second metal layer which provides additional series capacitance.

Figure 3 shows a pseudo-elliptic low-pass filter with a symmetrical topology based on a design procedure by Alseyab [1]. Multi-layer thin-film construction is again used to realize the pi networks and the crossovers for the printed inductors.

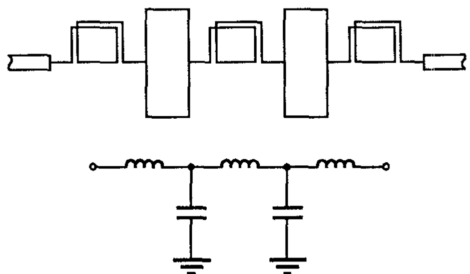

Figure 1 - Lowpass Filter

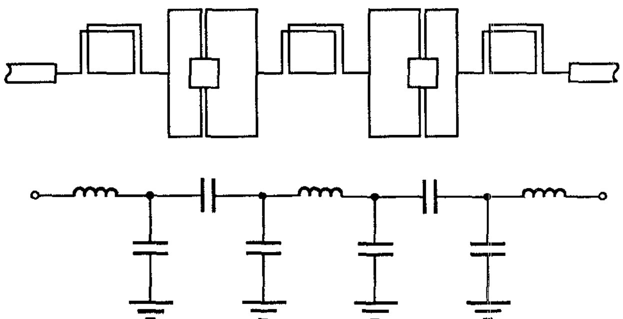

Figure 2 - Bandpass Filter

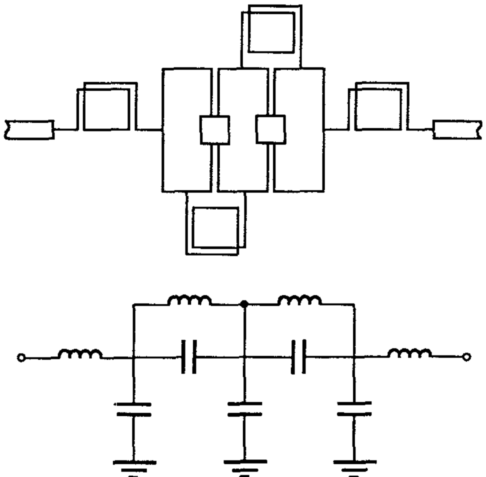

Figure 3 - Elliptic Lowpass Filter

Lumped-Elements In Microstrip

Three printed lumped elements represent the basic building blocks for all of these thin-film filter designs: the spiral inductor, the single shunt capacitor, and the pi network of capacitors. A computer model for each of these elements has been written.

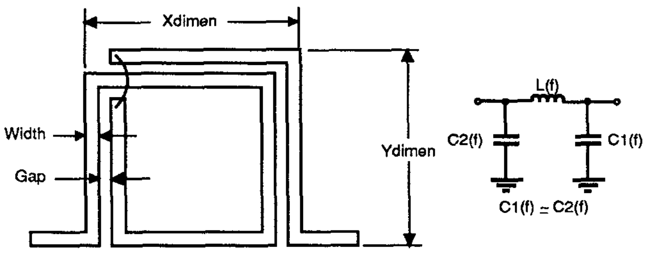

Figure 4 - Printed Spiral Inductor With Three Element Model

The spiral inductor and its lumped-element equivalent are shown in Figure 4. This particular spiral inductor topology has been studied by several authors [2,3]. Their models, however, ignored mutual coupling across the spiral, which has a significant impact on the accuracy of the derived lumped-element values. Later efforts have improved on this early work by accounting for mutual coupling effects [4,5]. Thin-film inductors with Q's greater than 100 have been fabricated using this topology.

The parasitic capacitances to ground in the spiral model are small but significant for filter design. In the low-pass, band-pass and elliptic topologies shown here, the shunt capacitance of the printed inductor can be absorbed in adjacent shunt capacitors.

The single shunt capacitor required in the low-pass filter is realized as a simple microstrip patch. This patch is assumed to behave as a transmission line of width, W, and length, L, as shown in Figure 5. Fringing at the ends of the transmission line section is included in the capacitance computation.

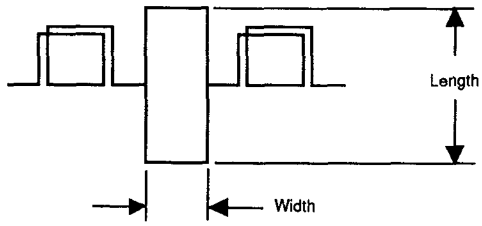

Figure 5 - Microstrip Shunt Capacitor

The pi network of capacitors required in the band-pass and elliptic filters is realized as a short section of asymmetric microstrip coupled line (Figure 6). The two printed strips provide the necessary capacitance to

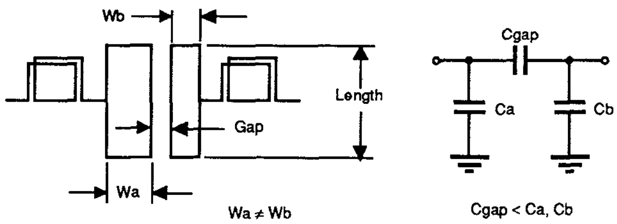

Figure 6 - Microstrip Pi Network and Model

ground, while the coupling between strips provides a small series capacitance. In many cases the required series capacitor is larger than either shunt capacitor. Additional series capacitance can be provided by depositing a dielectric layer and a second layer of metal which overlap both printed strips to produce the thin-film equivalent of a ceramic gap capacitor. The mechanical and thermal stability of these capacitors is excellent.

Experimental Results

The first example filter is a 13th-order low-pass with a cut-off frequency of 11.5 GHz, fabricated on a 500 mil by 150 mil substrate (Figure 7). The measured performance of the filter is shown in Figure 8. Excellent equi-ripple response was achieved in the passband without tuning. The insertion loss at the corner frequency is 2.2 dB and the ultimate rejection achieved is 55 dB. No spurious responses were found below 20 GHz.

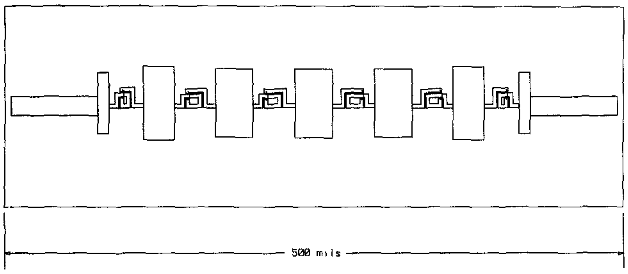

Figure 7 - Microstrip Lowpass Filter on 15 mil Alumina

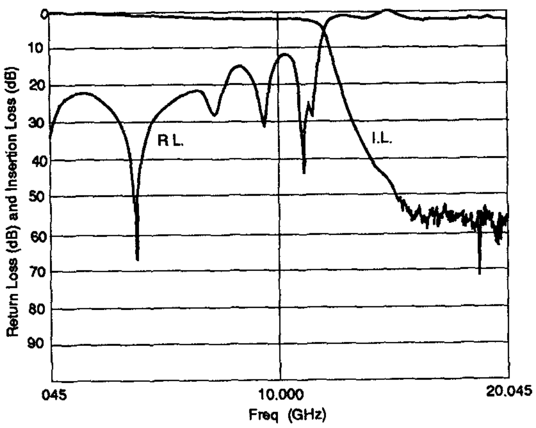

Figure 8 - Microstrip Lowpass filter Measured Response

The second example is a 25-percent-bandwidth bandpass filter centered at 1.6 GHz, fabricated on a 1200 mil by 300 mil substrate (Figure 9). The measured performance is shown in Figure 10. The insertion loss is 2 dB in the pass-band and the ultimate rejection achieved is 70 dB. The first spurious response does not appear until 9 GHz.

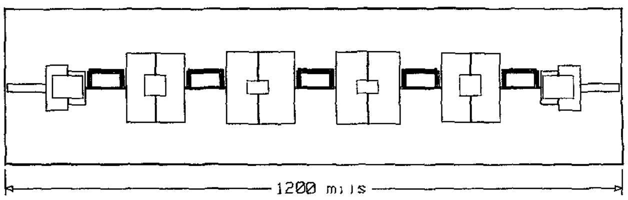

Figure 9 - Microstrip Bandpass Filter on 15 mil Alumina

The final example is a pseudo-elliptic low-pass filter with a cut-off at 3.3 GHz, fabricated on a 400 mil by 200 mil substrate (Figure 11). In this filter, all transmission zeros are at one frequency, and the filter is symmetrical, which helps control the spread of element values. The measured performance is shown in Figure 12. The insertion loss is 4 dB at the cut-off frequency and the ultimate rejection achieved is 50 dB. The first spurious response begins to appear at 15 GHz.

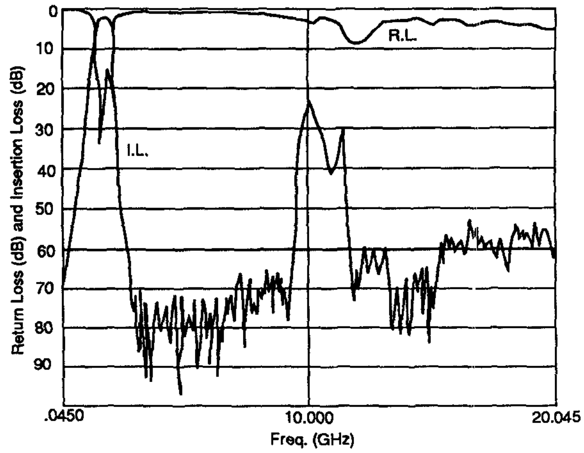

Figure 10 - Microstrip Bandpass Filter Measured Response

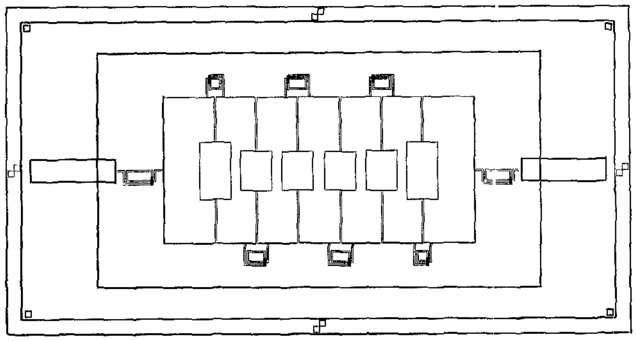

Figure 11 - Microstrip Elliptic Lowpass Filter on 15 mil Alumina

The uniformity and repeatability of these thin-film filters is demonstrated in Figure 13, which is a random sample of five pseudo-elliptic low-pass filters.

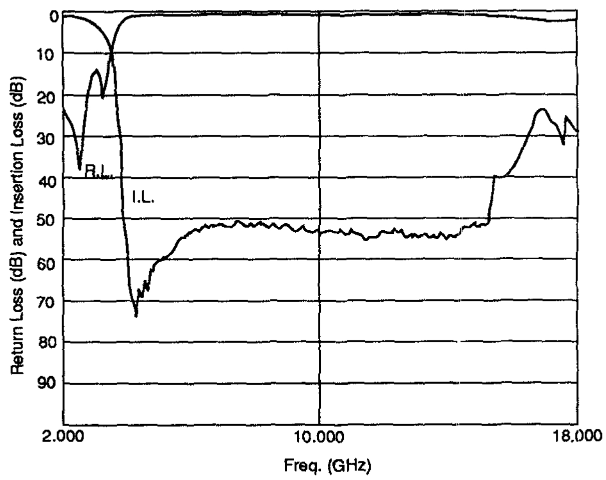

Figure 12 - Elliptic Lowpass Filter Measured Response

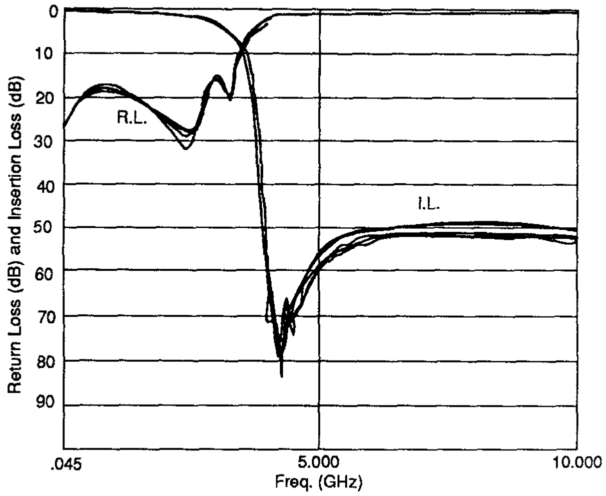

Figure 13 - A Random Sample Of Five Elliptic Lowpass Filters

Conclusions

A method for the design and construction of thin-film lumped-element microwave filters has been presented. The necessary models for inductors and capacitors were discussed. Multi-layer thin-film techniques make the construction of these filters efficient and cost-effective. These filters exhibit broad spurious-free stopbands, small physical size, excellent amplitude and phase match, and high reliability due to their thin-film construction. All of these qualities make them desirable components for use in microwave thin-film integrated subassemblies.

Acknowledgement

I would like to thank Bruce Kopp for two of the filter examples shown here.

References

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