Micromachined Filters on Synthesized Substrates

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***Abstract* — Effective frequency spectrum usage requires high performance filters with a sharp cut-off frequency and high stopband attenuation. Stepped impedance lowpass designs achieve this with large ratios of high and low impedance values. In high index materials, however, such as Si (11.7) and GaAs (12.9), these ratios are around 5 which significantly limit filter performance. This paper presents the use of Si micromachining to produce synthesized substrates with stepped-impedance low filter designs. Of the two designs, one offers a reduction of the low impedance value while the other offers an increase of the high impedance value to produce Z_H/Z_L ratios that are 1.5 to 2 times larger than conventional designs.**

1.0 INTRODUCTION

Efficient frequency spectrum usage by a diversity of communication-related applications (i.e. wireless, collision avoidance radars, etc.) demand development of high performance filters. In high frequency monolithic designs developed on high dielectric constant semiconductor materials, planar filters like stepped impedance ones suffer from less-steep cut-off frequencies and poor attenuation in the stopband. Optimum performance is achieved with large ratios of high and low impedance values which produce sharp cut-offs between the pass and stopband and high attenuation levels in the stopband. The dynamic range of realizable impedances in high index materials, however, is reduced considerably compared to designs on low index ones. Therefore, filters designs that rely on this mechanism for high performance are nearly impossible to realize in high index materials.

In many filter designs, performance is greatly affected by the ability to accurately realize prototype filter elements (i.e. capacitor and inductors) in equivalent transmission line components. These inductive and capacitive values, therefore, are highly dependent on the available high and low characteristic impedances of the chosen transmission type.

This paper presents a novel method for developing microstrip filters in high dielectric constant materials. Si micromachining is used to produce synthesized substrates in order to realize impedance values not commonly realizable in conventional substrates. These synthesized substrates have regions that are locally altered to reduce the thickness of the material. These alterations can result in two arrangements: (a) a reduced thickness microstrip region for a microstrip line, which decreases value of low-impedance line or (b) a reduced effective dielectric constant based on a combination of silicon/air, which increases the value of the high-impedance line.

2.0 DESIGN /FABRICATION APPROACH

2.1 Synthesized Low-Impedance Sections

This filter design is implemented using commercially available CAD tools, such as HP's Libra and MDS, on full thickness substrates. The design for the synthesized substrate is then transformed using Linecalc to determine appropriate dimensions for impedances on thinner substrates. The overall objective in this approach is to develop an equivalent design with a locally thinned substrate that produces impedance values that are lower than the conventional design.

In the work presented, a 7- section Butterworth filter is developed for a conventional and micromachined design using impedance values of 20 and 100 ohms. This was done to explore the impact that a synthesized substrate (i.e. reduced thickness region) would have on the filter response. While this design has not been optimized to include lower capacitive values (i.e. less than 20 ohms), an improved design will be developed and will be presented at the conference. The filter design and dimensions are given in Figure 1 and Table 1. Note that the inductive regions remain identical to the conventional design while the capacitive sections are developed on 50 micron thick regions to produce equivalent capacitance to the reference filter design.

The circuits are printed on high resistivity Si with a thickness of 100 microns. The low impedance sections are developed on 50 microns thick regions that have been etched using KOH anisotropic etchant [1]. The etched cavity regions produce a sloped sidewall angle of 54.7°

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that results in a gradient of 35.4 microns at each low impedance edge. Each design has a 50 ohm microstrip line and is fed by a coplanar waveguide probe pad that converts the on-wafer probe excitation to a microstrip mode. The circuits have 3.4 microns of electroplated Au and have a 2.5 micron ground plane metallization of Cr/Al/Cr/Au that has been evaporated to cover the entire wafer surface. These are attached to a secondary wafer for additional support with similar metal composition.

2.2 Synthesized High Impedance Sections

In this approach, dielectric material is removed using the etching process described earlier in the high impedance sections of the filter. This reduces the dielectric constant [2] and hence, produces a higher characteristic impedance. In this case, the inner walls of the cavities are not metallized as in the previous case and this results in very high impedance sections with much wider microstrip lines for the same impedance value (i.e. 70 microns vs. 3.2 microns on 250 um thick Si substrate). As shown in Figure 2 and Figure 3, the effective dielectric constant and characteristic impedance of microstrip lines on silicon micromachined substrates can be found using the full-wave FEM simulation for various geometrical factors [3].

Using the above approach, a 0.5 dB equi-ripple Tshebychev 7-section stepped impedance lowpass filter has been designed on 250 um thick silicon substrate, where 90% of the Si material has been removed from under the high impedance section of line (see Figure 4). The dimensions of each section have been tabulated in Table 2. Observe that the high impedance section width is increased by more than 20 times in the synthesized design compared to the regular one.

3.0 RESULTS

The filter response presented shows measured results that are compared to numerical simulations generated either from HP's Libra, or full-wave FEM models developed at University of Michigan. The response is measured on a Cascade Microtech 9100 Probe station with 150 micron air coplanar waveguide probes and an 8510C Network Analyzer. All data was measured using the TRL calibration to eliminate the effects of the probe tips and feedlines in the measurement.

3.1 Synthesized Low-Impedance Sections

The study presented compares the performance of the filter on the synthesized substrate to the conventional substrate. In the low impedance sections, the line width decreases from 380 microns on the 100 micron thick substrate to 190 microns on the 50 micron thick region. As shown Figure 4, the response is very similar to the conventional design.

To accurately assess, the performance of the micromachined design, Figure 4 shows the response of the filter compared to FEM simulation. The FEM results, which model the performance of the filter on the etched substrate, show a response that is shifted down by 1 GHz. In this case, bowtie tapers were introduced to offer a transition along the etched angle profile in the low impedance section. The measured and modeled data in Figure 5 produced nearly identical results which indicates that the etch angle does effect the phase delay of the various sections. The response curves of this design are very similar to the regular one, with better attenuation in the stop band as well as a better cut-off frequency.

In Figure 4, the radiation loss is compared to all three designs. The higher loss in the bowtie design is believed to be due to the sharp corners along the discontinuity edge. Overall, this approach has shown merit and the synthesized and regular designs yield similar loss. Lower impedance values will be investigated to produce larger Z_H/Z_L ratios. Furthermore, the effect of the sloping walls will be evaluated to provide a better understanding of the impact of this type of design on filter performance. These new findings will be presented at the conference.

3.2 Synthesized High-Impedance Sections

The lowpass filter on synthesized high-impedance sections (see Figure 6) has been analyzed using the fullwave FEM. In this design, a cavity region is formed where 90% of the silicon substrate has been etched away underneath the high-impedance section. Each cavity region has a width of 190 μm and lengths corresponding to the given high-impedance line section.

As shown in Figure 7, the simulation results show very good stop and passband characteristics which are very close to those of ideal filter. The radiation loss of the filter is about -10 to -12 dB in the frequency region of interest. Note that the high attenuation level in the stopband is mainly attributed to the large ratio between the high and low impedance value of the filter.

4.0 CONCLUSION

This paper presents two approaches to improve the performance of high frequency planar designs that rely on large ratios of high and low impedance sections. We have shown filter responses that are equal to if not better than those on regular designs. Either the high or low impedance synthesized filter designs can improve the Z_H/Z_L ratio by a factor of 1.5 to 2 by reducing the low impedance section by half or increasing the high impedance sections by 1.5. Furthermore, with the use of Si micromachining synthesized substrates are easily realizable in high index semiconductor materials that are commonly used in high speed monolithic design.

5.0 ACKNOWLEDGEMENTS

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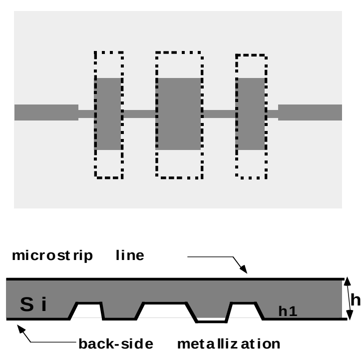

Figure 1 Circuit Layout for Micromachined Filter with Synthesized Low Impedance Section.

Section (ohms)	Length	Width (h=100)	Width (h=50)
1 (100)	135	10	10
2 (20)	270	380	190
3 (100)	684	10	10
4(20)	480	380	190
5(100)	684	10	10
6(20)	270	380	190
7(100)	135	10	10

Table 1 Synthesized Low-Impedance Design. Design A filter dimensions with synthesized low impedance sections: All dimensions are in microns.

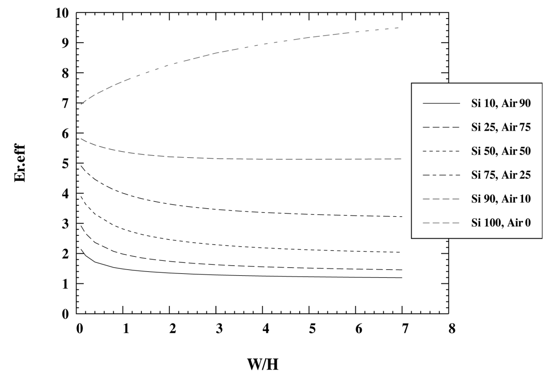

Figure 2 Effective Dielectric Constant Data.

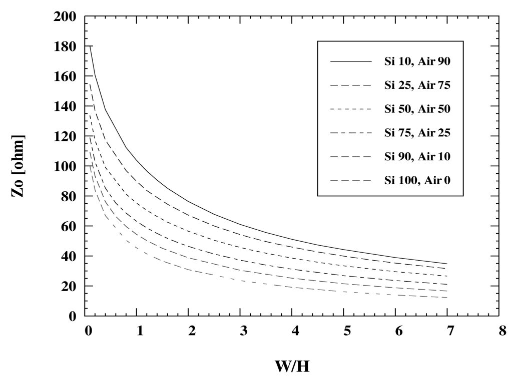

Figure 3 Characteristic Impedance of the synthesized high impedance sections of line.

Section (impedance in ohms)	Length	Width (h=250)	Width (10:90)
1 (30)	268	500	500
2 (150)	498	3.2	70
3 (30)	500	500	500
4(150)	600	3.2	70
5(30)	500	500	500
6(150)	498	3.2	70
7(30)	268	500	500

Table 2 Synthesized High-Impedance Design. Design parameters on regular thickness Si having height =250 microns and synthesized high impedance sections based on a 10:90 percent ratio of Si:Air regions. The total substrate height is 250 microns and all dimensions in the table are in microns.

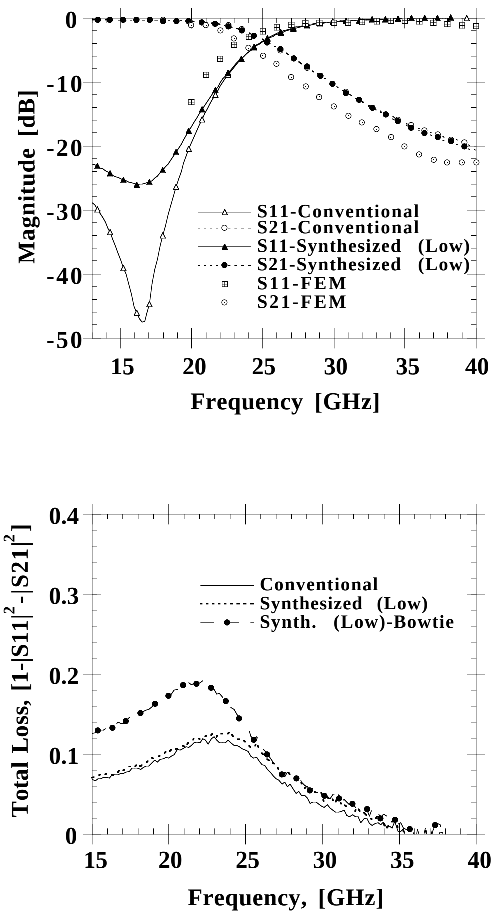

Figure 4 Synthesized Low-Impedance Filter Design. (a) Filter response with measurement and modeled results. (b) Total Loss calculations between two designs.

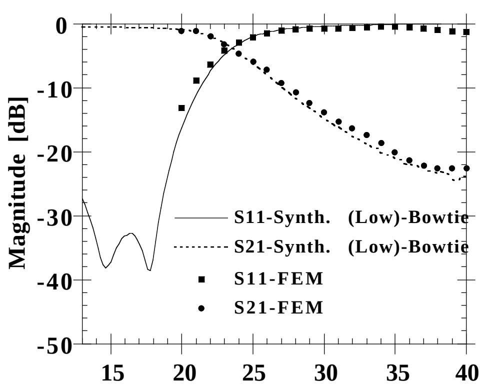

Figure 5 Comparison of FEM to Bowtie Response.

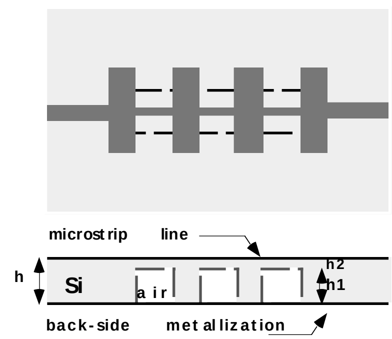

Figure 6 Circuit Layout for Micromachined Filter with Synthesized High Impedance Section.

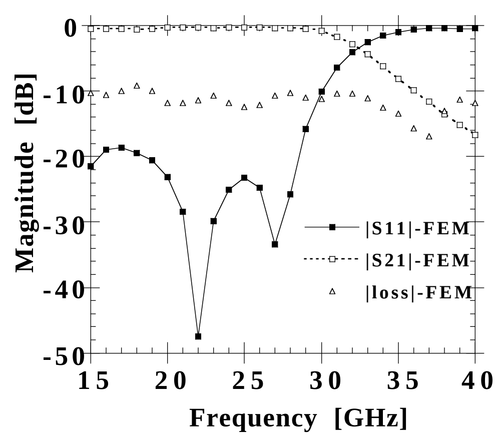

Figure 7 Synthesized High Impedance Filter Design. Simulation based on Finite Element Method. (a) Effective Dielectric Constant Design curves for mixed Si/Air region. (b) 7-Section Tshebychev Filter Response