PLANAR SLOTTED GROUND STRUCTURES FOR THE MINIATURIZATION OF MICROWAVE CIRCUITS

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ABSTRACT

A band-pass filter implementation based on discontinuities on coplanar waveguide is presented here. The filter consists of a gap in the central conductor and a set of spiral shaped slots on the ground traces. The designs are simulated using a commercial full wave electromagnetic simulation software, IE3D and have been found to be frequency scalable within certain limits imposed by fabrication constraints. The designs shown here have sizes ranging from 0.03 to 0.05 times the free space wavelength and result in fractional 3dB bandwidth of 0.06 to 0.07% in the C-band.

I. INTRODUCTION

As technology advances, the demand for compact devices and systems is increasing tremendously. Recent developments in the area of monolithic microwave integrated circuits (MMIC) and radio frequency integrated circuits (RFIC) facilitate economical bulk fabrication of such systems and their components. Keeping up with the technology scaling, these methods of fabrication make systems not only compact, but also cheap and hence popular. The widespread use of mobile devices and the amazing new features proposed thereon, have in turn lead to a surge in the demand for the miniaturization of RF front ends. This requires that all the subsystems to have very small footprints. In addition, components of such sub-systems may also be compatible with the present RFIC technologies to facilitate appropriate on-chip integration.

Filters are essential components to any RF/microwave system [1]. To use in a compact system, the overall size of the filter has to be very small. Current methods to realize RF and microwave filters, such as using distributed elements, chip lumped elements, or surface acoustic wave (SAW) devices are not suited for the said purpose. Distributed element filters have inherent wavelength-dependence making these large, especially for currently used wireless bands. Off-chip lumped elements lead to bulky systems and can introduce large parasitics. SAW filters require piezoelectric substrates such as quartz. Hence on-chip lumped components are usually preferred for miniaturized microwave systems fabricated by IC technology on silicon or gallium-arsenide substrate. Thus alternate implementation approaches should be explored for compact RF filter designs. We propose here to use appropriately designed discontinuities in transmission lines for realizing compact RF/microwave sub-systems.

Among the planar microwave transmission lines, the coplanar waveguide (CPW) has very good characteristics at high frequencies, offer scalability, and have the flexibility for assembling shunt as well as series components on a single plane. Coplanar waveguide (CPW) is a relatively new type of microwave planar transmission line, proposed first by Wen [2] in 1969. It is a truly uniplanar transmission line, where ground planes and the conductor can be made on the same metal layer. Hence RFIC systems can be easily designed using CPW. Several discontinuities in CPW have therefore been explored for various circuit applications. The series-gap in the CPW central conductor adds a capacitance to the line at low frequencies [3]. It has recently been reported that slot cuts in the shape of spirals on to the ground trace of the CPW can introduce inductance in the series path at low frequencies [4] and can lead to interesting resonant characteristics at higher frequencies [5]. However, when both of these discontinuities are introduced together on a CPW line, they show band-pass filter characteristics. The operational frequency of the filter is advantageously designed to be near the self-resonant frequency of such spiral slots. Filters using such discontinuities require less footprint than those using conventional lumped components as the spiral here is not on the signal trace of the CPW. Design of such a filter is presented along with the electromagnetic (EM) simulation results using commercially available software.

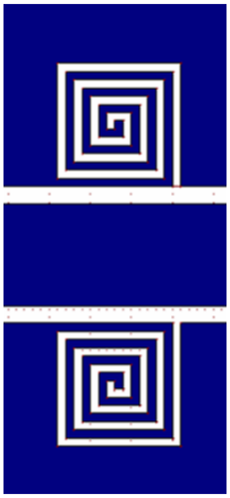

Figure 1: Spiral slot in the ground traces of CPW

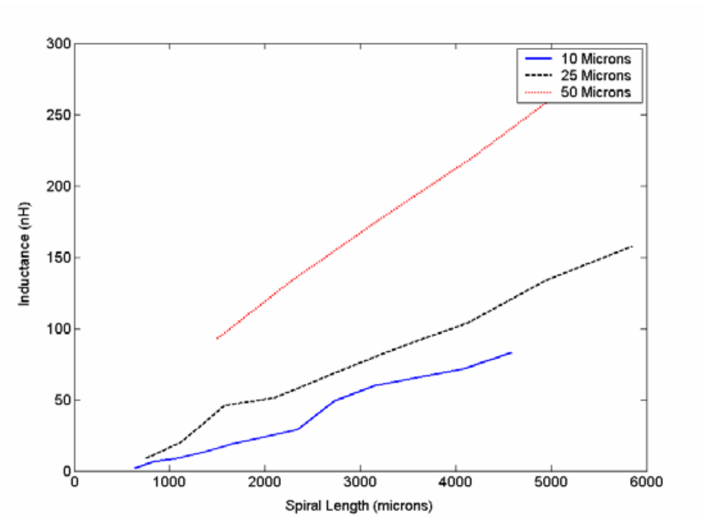

Figure 2: Variation of the inductance of the spiral slots shown in Fig. 1 for various number of turns.

II. DISCONTINUITIES IN COPLANAR WAVEGUIDE

Discontinuities in a transmission lead to disturbance to the normal fields on the line, and can be modeled with additional reactances introduced along the line. In certain cases, this disruption of the normal fields of the line result in current crowding leading to storage of magnetic energy, which could be modeled with an inductive reactance along the transmission line. Similarly, in a series gap in the transmission line electric field concentration may occur, which could be modeled with a capacitive reactance. Open-circuited and short-circuited lines, stepped impedance lines and bends are some of the discontinuities commonly encountered in RF/microwave analysis [6].

Recently it has been demonstrated that the spiral slot on the ground plane of a CPW (Fig. 1) adds inductance along the line, as demonstrated in the application of a phase shifter [4]. Based on extensive planar electromagnetic simulations it has been observed that the spiral slot adds to the inductance of the line. The variation of the inductance of such a spiral slot for various stretched-out lengths of the slot are as shown in Fig. 1. It was observed that as the length of spiral slot (thereby, the number of turns) increases, the inductance increases. This is in accordance with the behavior of spiral inductors, where the inductance is proportional to the number of turns. Furthermore, it was observed that as the slot width of spiral slot is increased the inductance increases, thus affirming the fact that larger inductors give higher inductance.

It may be recalled that both inductive and capacitive reactances are required to design a band-pass filter. Yet the discontinuities introduced should be very small compared to the free space wavelength so as to be considered as a lumped element. Thus, there is a need to introduce another discontinuity (capacitive) which when introduced along with the spiral slot, will resulting in band-pass characteristics. From the various discontinuities in literature, series gap in the central conductor is incorporated due to its simplicity.

III DESIGN OF BANDPASS FILTERS

The miniaturized band-pass filter has been designed on the silicon substrate in order to enable easy fabrication by lift-off technique. It is widely known that silicon is the preferred substrate for RFICs. 200μm thick silicon wafer has been taken as substrate. But since silicon being a semiconductor causes losses due to leakages, a 2μm silicon-dioxide layer is required on top of the substrate. The metal conductor in this study is taken as aluminum due to its good electrical properties and ease in processing. With this configuration a 50Ω transmission line is first designed with the following parameters:

Central conductor width, W = 390μm,
Slot width, S = 22μm,
*G*round width, G = 1500μm and
Transmission line length, L = 2000μm.

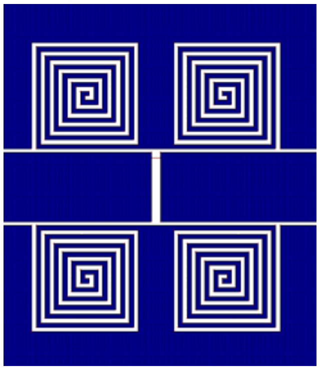

Figure 3: CPW filter configuration

Table 1: Geometrical parameters for the filter shown in Fig. 3.

PARAMETER	VALUE
Series gap width, *g*	50μm
Spiral slot width, *w*	25μm
Spiral slot gap, *g*	25μm
No of turns of spiral lost used	5 to 7
Spiral outer edge	500μm to 700μm
Device area	2000μm x 3434μm

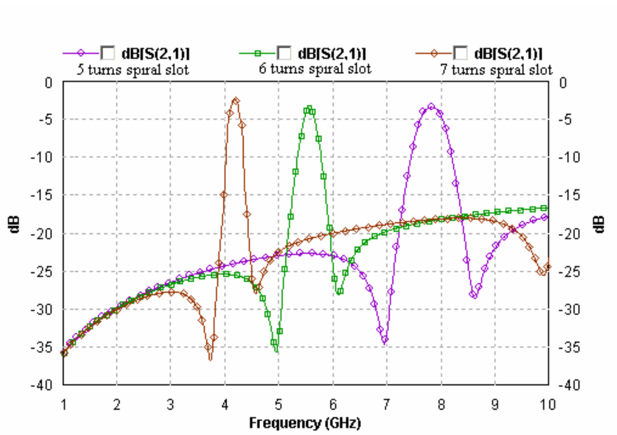

Figure 4 Results of IE3D simulations for various filter configurations described Table 1

Table 2: Summary of EM simulation results.

PARAMETERS	5 turns of slots	6 turns of slots	7 turns of slots
Center frequency [GHz]	7.8	5.6	4.2
Insertion Loss [dB]	-3.51	-2.9	-2.47
3dB bandwidth [MHz]	540.5	357.5	238.1
Fractional bandwidth [%]	0.069	0.061	0.057
Roll-Off [dB/GHz]	48.87	68.72	83.15
Device length [λ_0]	0.052	0.0373	0.028

The design simulations are performed using a commercial full wave electromagnetic simulation software IE3D. This is a method of moments based software for accurately analyzing planar geometries. Proper meshing of the geometry is very important in the present context. IE3D uses non-uniform meshing. We used 100 cells per wavelength for accurate results. Further near the edges of the geometry electrical fields tend to concentrate and hence these edge cells should be made even smaller than other cells. Accordingly, edge cells of 3.8% of normal cells were used in these simulations.

IV. SIMULATION RESULTS

This structure shown in Fig. 3 was analyzed using IE3D. The simulation results are shown in Fig 4. It was observed that the configurations have operating frequency in C band, ranging from 7.85*GHz* to 4.2*GHz*, as the spiral slot dimension is varied from a 500μm x 500μm to 700μm x 700μm. Thus it can be concluded that by varying the spiral slot dimensions, the *frequency scaling* can be obtained. In other words, the resonant frequency of the filter decreases as the number of turns in the spiral slot is increased.

The bandwidth of these filters also decreases as the size of the spiral slot is increased. Thus, to have smaller bandwidths bigger spirals are needed. The response of these structures also gets sharper when the spiral slots turns are increased, as indicated by the roll-off. Further, the Quality factor, Q for these types of devices is found to be high. These filters have also demonstrated to have good out-of-band rejection characteristics. These characteristics are tabulated in Table 2. The insertion loss of the present filter design is about -2.4dB. For non-critical power levels this device may still be handy due to the fact that the overall size of the filter is much smaller than most on-chip components.

V. CONCLUSIONS

Band-pass filter using the discontinuities on the coplanar waveguide has been presented. The discontinuities used for this purpose are spiral slots in the ground traces of the CPW and a series gap in the central conductor of the CPW. Designs presented here are on silicon substrate to enable compatibility with RFIC fabrication technologies. The simulated results from a commercially available electromagnetic solver have been presented for the device.

The detailed design parameters are given, along with the filter characteristics obtained. It is shown that the size of the spiral slots on the ground traces can be used as the control parameter for changing the frequency response of the filter. The designs shown here have sizes ranging from 0.03 to 0.05 times the free space wavelength and result in fractional 3dB bandwidth of 0.06 to 0.07% in the C-band.

REFERENCES

[1] R.Levy, R.V.Snyder, and G.Matthaei, "Design of microwave Filters," *IEEE Trans. Microwave Theory Tech.*, **30**, 783-792, 2002.

[2] C. P. Wen, "Coplanar waveguides : A surface strip transmission line suitable for non reciprocal gyromagnetic device applications," *IEEE Trans. Microwave Theory Tech.*, **MTT-17**, 1087-1090, 1969.

[3] K.C.Gupta, R.Garg, and R.Chadha. *Computer-Aided Design of Microwave Circuits*. Artech House, Dedham, MA, 1981.

[4] I. Paul, "Design and Optimization of Micromachined Phase Shifter," Masters Thesis, Dept. of Instrumentation, Indian Institute of Science, Bangalore, June 2004.

[5] J.S.Lim, C.S.Kim, Y.Taek., D.Ahn, and S.Nam, "A spiral-shaped defected ground structure for coplanar waveguide," *IEEE Microw. & Wireless Comp. Lett.*, **12**, 330-333, 2002.

[6] R.N.Simons. *Coplanar Waveguide Circuits, Components, and Systems*. Wiley Interscience, New York, 2001.