MICROSTRIP COUPLED LINE FILTER DESIGN FOR ULTRA WIDEBAND APPLICATIONS

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ABSTRACT

A compact microstrip parallel coupled line filter for ultra wide band applications by means of combining a network of coupled line and defected ground is proposed. The design equations for three and five interconnected networks are derived and implemented. Simulations for three different configurations for filters are optimized. Then three prototype circuits are constructed, a bandpass filter with center frequency 2.25 GHz and two different bandpass filters (in terms of perturbations) with center frequencies 2.33GHz. For 2.25 GHz circuit wide fractional bandwidth of about 90% is obtained but undesired high return loss existed. For 2.33GHz circuit with grooves in sides fractional bandwidth of about 60% is obtained at about 3.4 GHz center frequency. However undesired return loss existed for this circuit whereas good out off band performance is achieved. For 2.33GHz circuit with grooves in whole sections the center frequency got shifted to about 3.4 GHz and about 50% fractional bandwidth is obtained with very good out off band performance observed.

KEYWORDS

Coupled Line Filters, Bandpass Filters, Ultra-Wide Band, Slotted Ground Structure, Perturbations in Structure

1. INTRODUCTION

In all microstrip directional filters, the main objective to achieve a broadband spectrum is to present a good passband performance with transmission power greater than -1 dB and reflected power less than -15 dB over the in-band frequencies. For a practical point of view a good frequency response can be achieved by selecting a very small value of strip gap and strip width for traditional coupler. Furthermore, filters out of band region behaviour also is of concern for design in terms of having suppressed harmonics.

Abbosh presented and proposed design of planar bandpass filters with ultra-wideband behaviour which utilize broadside coupling between elliptical-shaped patches and having an elliptical slot located at the mid layer [1]. Using defected structures in the ground plane is suggested and proved useful by Velazguez-Ahumada et al. [2]. They proved that the spurious transmission band is suppressed with the use of floating strip conductors. Another suggestion to supress spurious response in microstrip parallel-coupled bandpass filters came from Moradian and Tayrani [3]. They suggested the use of grooved substrates.

This research is divided into three main subsections, firstly a theoretical design implication is shown, secondly simulation of the results using an electromagnetic software is done, and lastly some measurements of fabricated circuits are demonstrated.

We introduce a modified three section parallel coupled line with the intention that improving the rejection in the out-of-band region by generating two transmission poles in terms of adjusting the ground aperture width and bringing out a broad out-of-band spectrum. Both in-band and stop-band performances are compared through implementing backside ground aperture and hence having floating line with slotted ground.

2. THEORETICAL DESIGN

In order to propose a feasible configuration mathematical theoretical design is implemented for parallel coupled lines. The scattering parameter equations for the multi-pole network can be derived using even and odd mode analysis. The general scattering parameters were derived by Mongia [4]. The interconnection of a two networks and derivation of the resultant S-parameters was done by Mohammed [5]. First, two interconnected transmission lines as shown in figure 1 below is done:

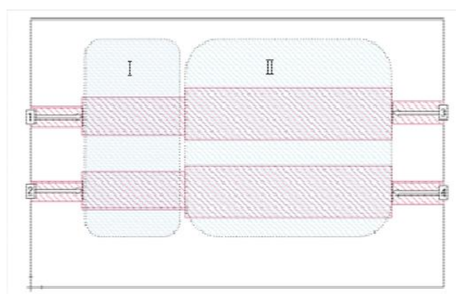

Figure 1. Interconnecting two section transmission line networks.

By connecting the two tranmission lines we obtain the following resultant S parameters for the four port matrix,

$$S_{RES1} = \begin{bmatrix} 0 & b+\dfrac{a^2 d}{1-bd} & \dfrac{ac}{1-bd} & 0 \\ b+\dfrac{a^2 d}{1-bd} & 0 & 0 & \dfrac{ac}{1-bd} \\ \dfrac{ac}{1-bd} & 0 & 0 & d+\dfrac{c^2 d}{1-bd} \\ 0 & \dfrac{ac}{1-bd} & d+\dfrac{c^2 d}{1-bd} & 0 \end{bmatrix} \quad (1)$$

where a denotes transmission scattering parameters for section I, b denotes coupled scattering parameters for section I, c denotes transmission scattering parameters for section II, d denotes coupled scattering parameters for section II. Similar approach is done by extending this idea to three subsections, considering the result of the above as one subsection and adding the other subsection as shown in Figure 2, we can obtain the resultant matrix in equation (2).

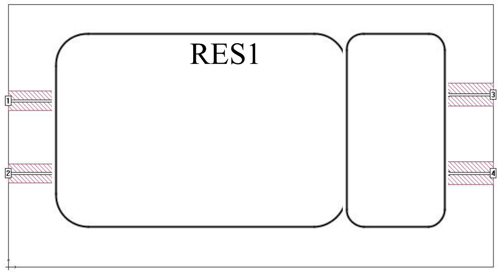

Figure 2. Interconnecting three section transmission line networks.

$$S_{RES2} = \begin{bmatrix} 0 & b+\frac{a^2[d(1-bd)-c^2b]}{(1-bd)^2-c^2b^2} & \frac{a^2c}{(1-bd)^2-c^2b^2} & 0 \\ b+\frac{a^2[d(1-bd)-c^2b]}{(1-bd)^2-c^2b^2} & 0 & 0 & \frac{a^2c}{(1-bd)^2-c^2b^2} \\ \frac{a^2c}{(1-bd)^2-c^2b^2} & 0 & 0 & b+\frac{a^2[d(1-bd)-c^2b]}{(1-bd)^2-c^2b^2} \\ 0 & \frac{a^2c}{(1-bd)^2-c^2b^2} & b+\frac{a^2[d(1-bd)-c^2b]}{(1-bd)^2-c^2b^2} & 0 \end{bmatrix} \quad (2)$$

Then we can extend the same idea to four subsections and then to five subsections. This can be found in our previous work and not shown in detail here [5].

2.1. Defected Ground Plane

Defected Ground Plane is used for relaxing the tolerance of the strip width and the gap space for coupled line filters. It is exploited to provide tight coupling coefficient to be applied on mid-section structure.

3. Circuit Design

Three prototype circuits were designed and simulated to verify the mathematical operations. The simulations were carried out for substrate Rogers [6] RO3210 (dielectric constant 10.8) with thickness 0.638mm and using copper as metallization layer using the Sonnet Lite [7] Software. The calculations based on equations were used and then simulator was used for optimization for better performance.

3.1 First Prototype Circuit

The first prototype of circuit is a three section coupler with defected ground plane at the bottom layer. The simulations were carried out and both transmission and reflection values were checked for optimization. The dimensions of the circuit and the response is indicated in Figures 3 and 4 given below:

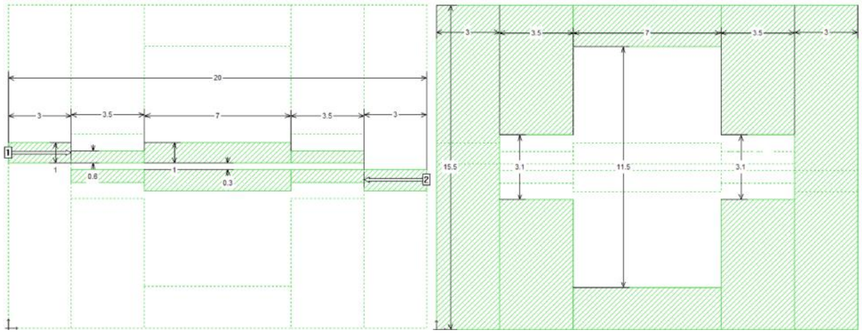

Figure 3. Circuit Layer and Defected Ground Layer.

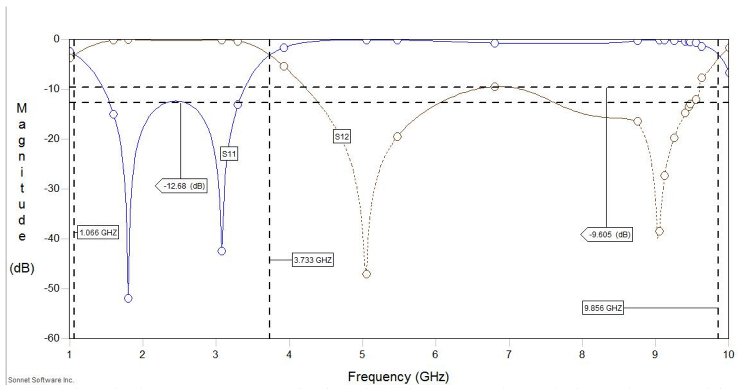

Figure 4. Simulation Response of Circuit (Three Section, defected ground layer).

As it can be observed the center frequency was around 2.4 GHz and fractional bandwidth is equal to 113%.

3.2 Second Prototype Circuit

The second prototype circuit is a five section coupler and the initial design values rely on five section coupler derived earlier [5]. The complete structure with dimensions is shown in Figure 5 below:

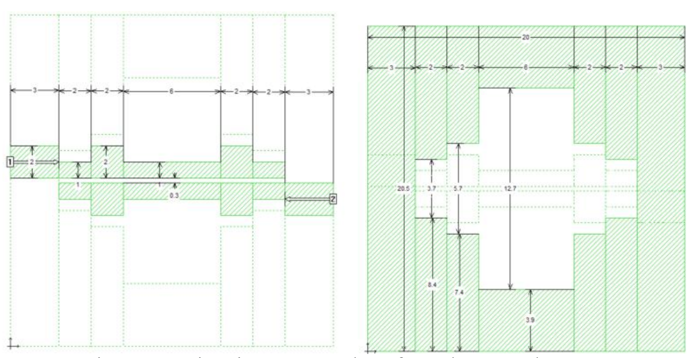

Figure 5. Circuit Layer and Defected Ground Layer.

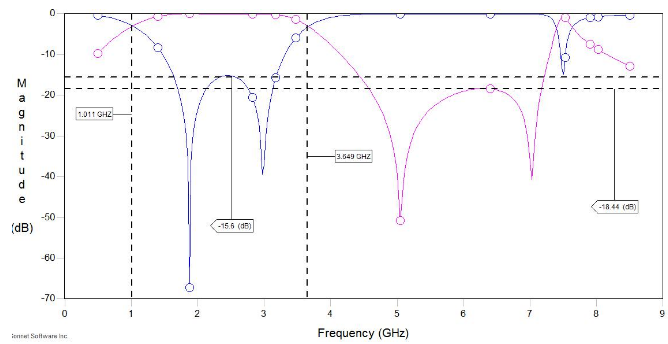

Figure 6. Simulation Response of Circuit (Five Section, defected ground layer).

Here, defected ground structure was also used in simulation. The response is shown in Figure 6. Again the center frequency was 2.4 GHz and the fractional bandwidth was 115%. Out of band noise was clearly suppressed to about -18 dB.

3.3 Third Prototype Circuit

For the improvement for the out-of-band performance, similar to work of Marimuthu & Esa [8], using a rectangular groove on the center and side sections was done. This method aids to suppress the return loss to a lower value without causing any effect on the in-band transmission or reflection's performance. The prototype was simulated upon the three section network. The design frequency was set to 2.4 GHz. The proposed and simulated circuit structure, and the simulation response are shown below in Figures 7 and 8.

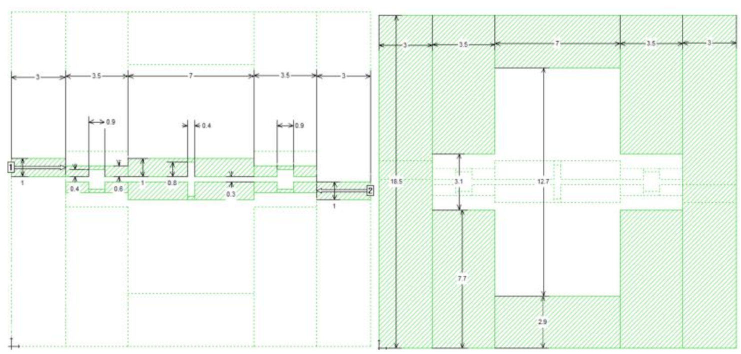

Figure 7. Circuit Layer and Defected Ground Layer for Prototype III.

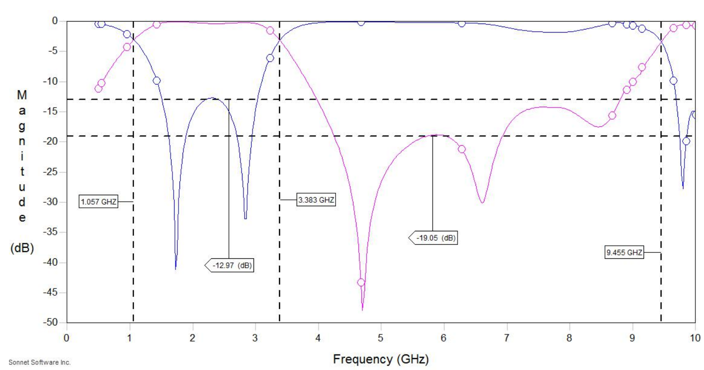

Figure 8. Simulation Response of Circuit (Three Section, grooves, defected ground layer).

As it can be seen in the simulation response very reliable in-band performance and out of band performance is obtained.

4. FABRICATED CIRCUITS AND MEASUREMENTS

Some prototype microstrip filters are designed and optimized using Sonnet Lite as explained in the previous section. In the final designs we fabricated and tested three different configurations. The central frequency was 2.25 GHz for Prototype I and it was 2.33 GHz for Prototypes II and III. The circuits were built on printed circuit boards KB-5152 which had dielectric constant value of 4.6. The simulations were redone and the circuit dimensions are scaled accordingly to compensate the dielectric change. Two boards were etched and fabricated one containing the circuit structure and one containing the defected ground plane. Anritsu MS4642A vector network analyzer [9] was used as a measuring device for the prototype circuits. Two port calibrations were performed by placing open, short and matched loads to the ports and then performing the thru and reflect calibrations.

4.1 Fabricated Prototype II Circuit with Defected Ground Structure

First, we fabricated a circuit with similar features to Simulation Prototype II, as described in section 3.2. We can see the fabricated five section center frequency 2.25 GHz circuit in Figure 9. The response showing the simulation (indicated by letter *s* in the graph) and measurement is also indicated in Figure 10.

Figure 9. Photograph of Fabricated Prototype II Circuit.

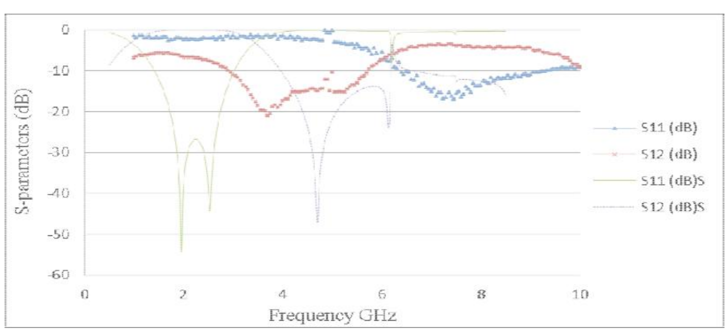

Figure 10. Measured and Simulated Response of Fabricated Prototype II Circuit.

For this circuit we observed about 133% bandwidth in terms of high insertion loss around -2dB was achieved in simulation. In the measurement, undesired return loss was observed over first half part on in-band spectrum, while the second half part seems to have better return loss around - 14.5dB. These results, to a certain extent, meet with the simulated behavior since obtaining a broader bandwidth and suppressing the second harmonic. Although the insertion loss value was low, we still observed the bandpass behaviour at about 2.25 GHz with about 90% fractional bandwidth. The second harmonic was supressed but the third harmonic with broad spectrum also existed with the insertion loss rising up to around -5dB.

4.2 Fabricated Prototype III circuit (using grooves in side-sections)

We fabricated a prototype III circuit which is a three section structure and placed small grooves on side sections only. The circuit is shown in Figure 11. The structure was measured directly by attaching the adapter's male pin over each port. The measurement showing the comparison and simulation can be observed in Figure 12.

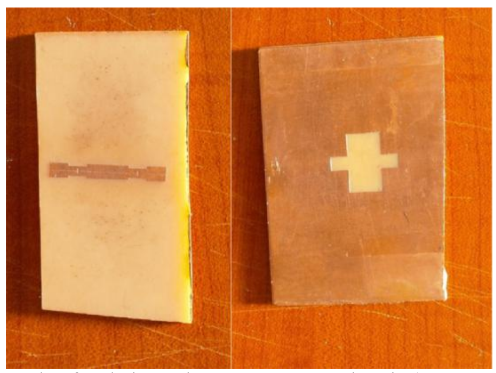

Figure 11. Photograph of Fabricated Prototype III Circuit (grooves in side sections).

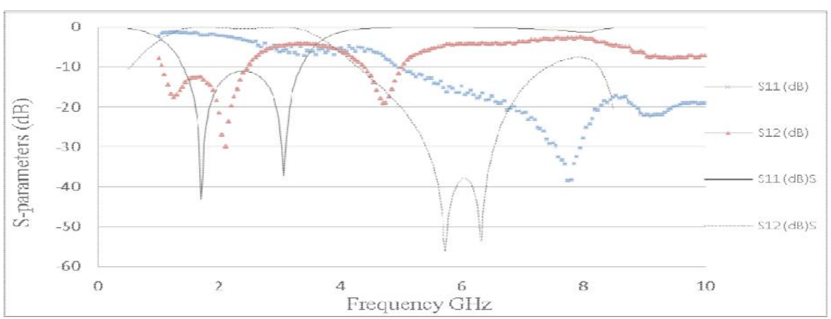

Figure 12. Measured and Simulated Response of Fabricated Prototype III Circuit.

The center frequency got shifted to about 3.4 GHz and fractional bandwidth of about 60% was obtained. Undesired high return loss existed in the passband region. The cut-off band performance over the broad frequencies was very good. The undesired harmonics may be because of either non-stable port attachment during the measurement time or the ground structure not being aligned properly.

4.3 Fabricated Prototype III (with grooves in side sections and middle section)

We fabricated a prototype III circuit which is a three section structure and placed small grooves on side sections and also another groove in the middle section. This fabricated circuit has the same characteristics and dimensions as the circuit described in section 3.3. The fabricated circuits the main structure and the ground structure is shown in Figure 13. The circuit was measured in similar conditions as the previous circuit and the simulated and measured responses are shown in Figure 14.

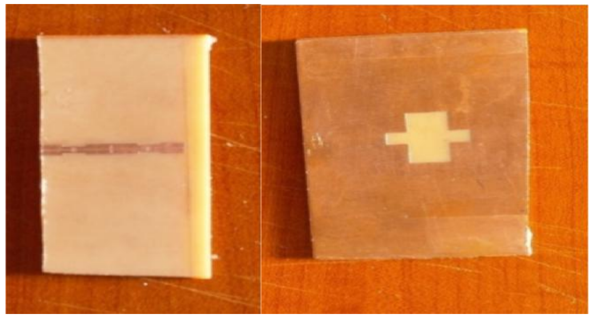

Figure 13. Photograph of Fabricated Prototype III Circuit (grooves in all sections).

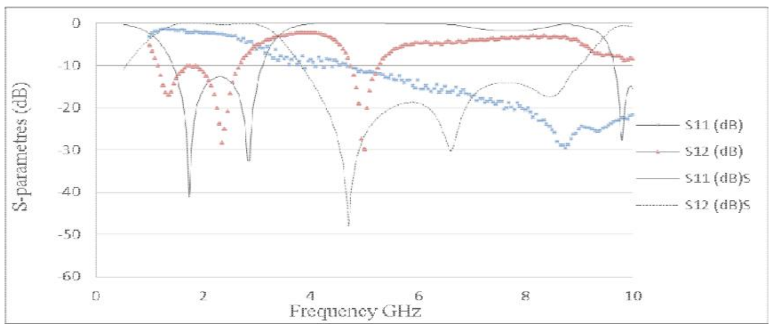

Figure 14. Measured and Simulated Response of Fabricated Prototype III Circuit.

In this case the frequency shift occurred again and the center frequency is at about 3.4 GHz with fractional bandwidth of about 50%. Also, again high return loss existed in the passband region. If we compare the result with the previous circuit in terms of simulations, the gaps between transmission poles were increased which attributed to raise the insertion loss deterioration for in-band performance. The frequency of the transmission zeros within out-of-band spectrum were shifted up with a better performance.

5. Conclusions

In conclusion, first a theoretical work in the design was done and then simulations were done to verify the use of defected ground structure as well as adding perturbations (grooves) to the filter structures. Design simulations for three subsections configuration it is proven that, high fractional bandwidth can be obtained by setting the physical dimensions for side sections such a half of mid sections. Also, by using defected ground structure we can relax the tolerance of physical dimensions of strip width and strip gap.

Adding a polygon groove to the side sections is suggested and it is noticed that in band behaviour is not influenced but better harmonic suppression is obtained. The second suggested change in prototype circuits was adding a polygon groove into the mid-section. A reasonable in-band performance is obtained based on applying the same design equations and defected ground plane pattern. 109.3% fractional bandwidth and –13.35 dB return loss was obtained in simulations while the higher frequencies are influenced by harmonics. The circuits which were built and measured suffered from high return loss in the passband regions, however about 90% fractional bandwidth was observed for the first built Prototype circuit at about 2.0 GHz center frequency and about 50% to 60% bandwidth at 3.4 GHz center frequency was observed for the other prototype circuits.

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