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THE USE OF DEFECTED GROUND STRUCTURES IN DESIGNING MICROSTRIP FILTERS WITH ENHANCED PERFORMANCE CHARACTERISTICS

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Abstract: Until recently, microstrip filter designs were being done with full metallic ground-plane present on one side of the substrate. The state-of-the-art, however, changed when deliberately created defects in the ground (called Defected Ground Structures or, simply, DGS) were introduced, to further improve the filter performance. This paper presents four original design examples on low-pass and band-pass filters with and without DGS. Design methodology, optimization details, fabrication details, and experimentally-obtained data are presented, for each of the designs. The prototypes are tested using Rohde and Schwarz ZVA40 Vector Network Analyzer. It is found that the filter performance characteristics like passband ripple, 3-db bandwidth, return loss and stopband rejection show significant improvement when Defected Ground Structures are used in the design.

Keywords: Microstrip, filter, Defected Ground Structures, DGS

I. INTRODUCTION

In the past few years several new techniques have been applied to designing radio frequency (RF)/microwave components. One of them is the Defected Ground Structure (DGS). The DGS is a deliberately etched periodic or non- periodic cascaded configuration defect in the ground plane of a planar transmission line [1]. It disturbs the shield current distribution in the ground plane which eventually changes the characteristics of a transmission line such as line capacitance and line inductance. The use of various DGS geometries has been reported in the literature, such as rectangular, circular, square, dumbbell, spiral, L-shaped, concentric ring, U-shaped and V-shaped, hairpin DGS, hexagonal, cross shaped, arrow head slot, interdigital DGS etc [2]. Depending on the shape and dimensions of the defect the shielded current distribution in the ground plane is disturbed resulting in a controlled excitation and propagation of the electromagnetic waves through the substrate layer. The work reported in this paper mainly focuses on the dumbbell shaped DGS for high frequency filtering applications.

Figure 1 shows the structure of the Dumbbell shaped DGS etched on the metallic ground plane of a microstrip line [3]. It consists of two rectangular slots of dimension a x b connected by a narrow slot of dimension g x w thereby resembling a dumbbell [4].

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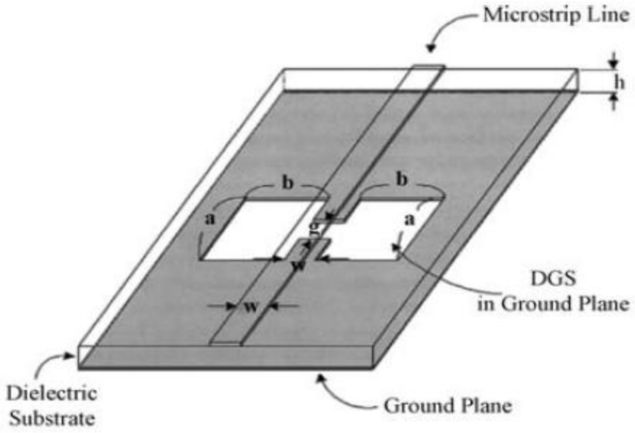


Figure 1. Dumbbell shaped Defected Ground Structure (DGS)

The work can be mainly divided into two sections. The first section describes the design and analysis of low pass filters with and without defected ground structures and the second section describes the design and analysis of bandpass filters with and without defected ground structures.

II. LOW-PASS FILTER DESIGN EXAMPLES

In this section a microstrip low pass filter has been designed. Subsequently the same design has been implemented using the defected ground structure technique and the performance of both the filters has been compared. Both filters have been designed to have a maximally flat response and a cutoff frequency of 1.2 GHz, with at least 20dB rejection at 2.2 GHz. The impedance of both input and output ports is assumed to be 50Ω.

A. Low-Pass Filter without DGS

In this design the conventional metallic ground plane is used without any defects. The lumped element low pass filter circuit to meet the above specifications is obtained by using the prototype filter available for a maximally flat response. The element values are obtained by proper impedance and frequency scaling. To implement this design using microstrip technology, alternating sections of very high and very low characteristic impedance lines are used. These kinds of filters are known as stepped impedance filters or hi-Z, low-Z filters. Such filters are easier to fabricate and take up less space. The characteristic impedance of the low- impedance lines is chosen as 11Ω and that for the high-impedance lines is chosen to be 150Ω. Widths and lengths of the alternating low and high impedance lines have been calculated and summarized in table 1.

Section	Z_{OL}orZ_{OC}(Ω)	W_i (mm)	l_i (mm)
1	11	22.5	1.28
2	150	0.18	6.53
3	11	22.5	5.47
4	150	0.18	11.53
5	11	22.5	6.45
6	150	0.18	9.77
7	11	22.5	3.65
8	150	0.18	2.29

Table 1: Summary of stepped impedance low pass filter without DGS

Figure 2 shows the physical layout of the top layer of the stepped impedance low pass filter.

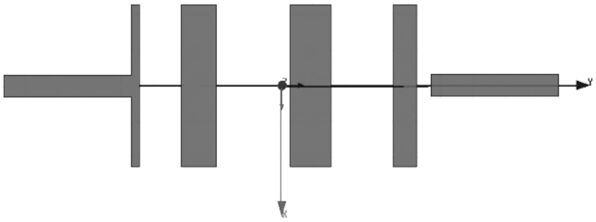


Figure 2. Physical layout of the stepped impedance low-pass filter without DGS

Figure 3 shows the photograph of the low pass filter prototype fabricated on the Flame Retardant 4 (FR4) substrate having thickness h=1.6mm and dielectric constant ε_r= 4.4 and a loss tangent of 0.02.This substrate has been used in all four designs and was chosen because it is readily available and is comparatively cheaper.

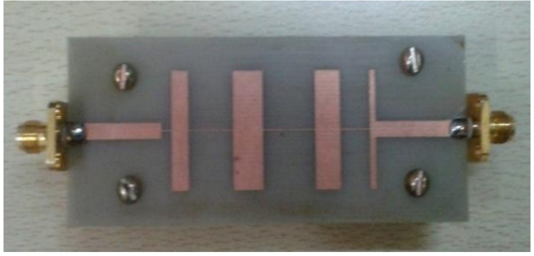


Figure 3. Photograph showing the Stepped Impedance low pass filter prototype without DGS

Figure 4 shows the experimental results obtained using the vector network analyzer. The graph clearly indicates a maximally flat response. The 3dB cutoff frequency is found to be 1.2 GHz and a return loss performance of mostly better than 20dB (59dB in the best case) is observed. Also the rejection obtained at 2.2GHz is better than the design requirement of 20dB.

B. *Low-Pass Filter with DGS*

In this design uniform periodic dumbbell shaped defects are incorporated in the ground plane. A DGS unit can be represented by an LC equivalent circuit. The etched lattice increases the series inductance to the microstrip line and the etched gap area which is placed under the inductance line provides the parallel capacitance with effective line inductance. The dimensions of the etched lattice were optimized to be a=4.4mm, b=4mm, l=0.18mm and f=0.4mm. The superimposed view of the top layer and the ground plane of the stepped impedance low pass filter with DGS as seen from the top is shown in Figure 5.

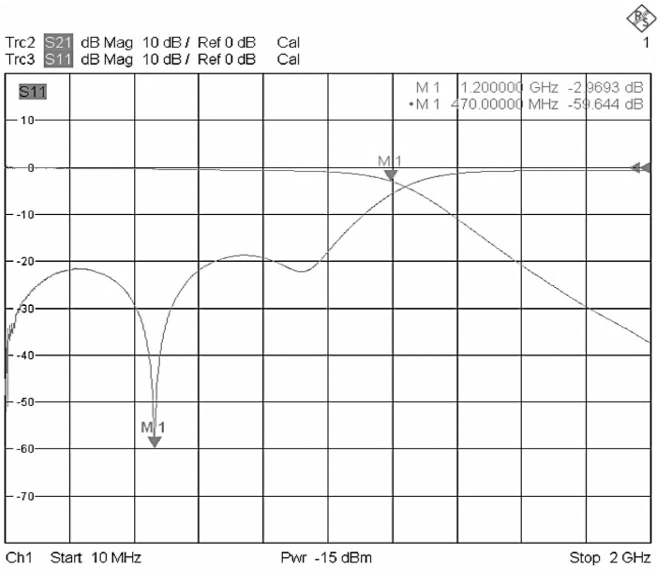


Figure 4. : Experimental data for the stepped impedance low pass filter without DGS

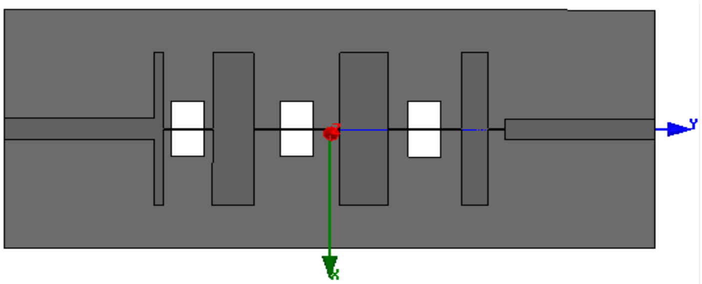


Figure 5. Superimposed view of top layer and ground plane of the low pass filter with DGS

Figure 6 shows the photograph of the prototype that was built and tested. Figure 7 shows the experimental results obtained using the Vector Network Analyzer.

The response obtained is maximally flat with a rejection of approximately 40 dB at 2.2GHz which is much better than the design requirement. The return loss performance is seen to be slightly better than that obtained in the previous design (66 dB in the best case). The 3dB cut off frequency remains unaltered at 1.2GHz. Furthermore, it can be said that the power handling capability of the stepped impedance low pass filter with DGS will be better than that for the stepped impedance low pass filter without DGS since DGS helps in implementing high impedance inductance line with broader conductor width when compared to conventional microstrip

(a) Top view

(b) Bottom view

Figure 6. Photographs showing the Stepped impedance low pass filter with DGS prototype (a) Top view (b) Bottom view

III. BAND-PASS FILTER DESIGN EXAMPLES

This section describes the design and performance of stepped impedance resonator (SIR) bandpass filters. Two kinds of filters have been designed and fabricated followed by their performance analysis. The first design is a bandpass filter implemented using four stepped impedance resonators operating at a center frequency of 2GHz. The same design is implemented using defected ground structure technology in next design and the results obtained are compared with those of the previous design.

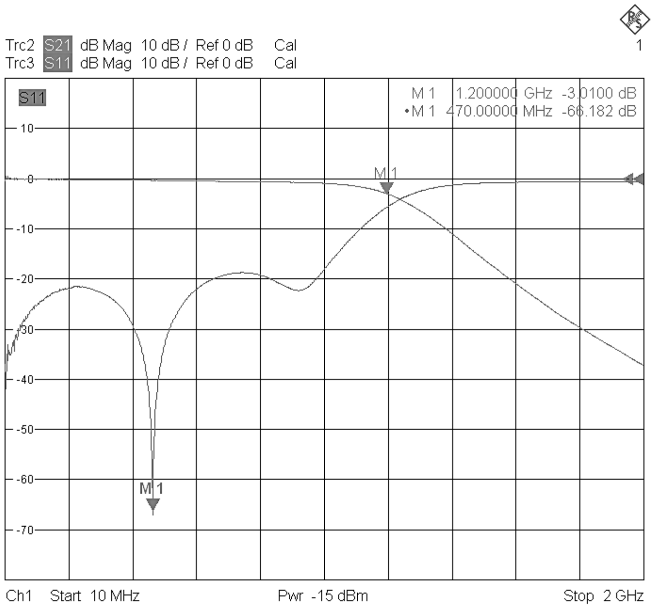


Figure 7. Experimental data for the stepped impedance low pass filter with DGS

A. SIR Band-pass Filter without DGS

A microstrip stepped impedance resonator (SIR) is formed by joining together two microstrip transmission lines with different characteristic impedance Z_1 and Z_2 with corresponding electric lengths θ_1 and θ_2, respectively [5]. Figure 8 shows a typical structure of a half-wavelength SIR.

The resonance condition of an SIR is given by,

$$K = \tan\theta_1 \tan\theta_2 = Z_2/Z_1 \tag{1}$$

where K= Impedance ratio.

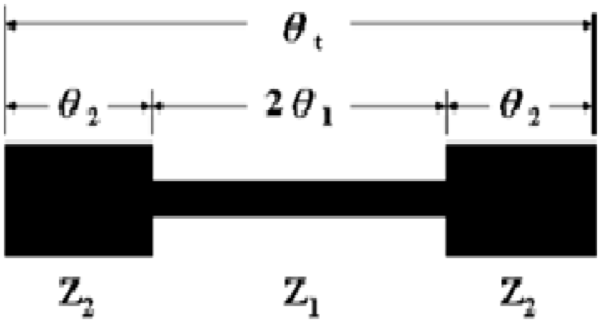
From equation 1 it is evident that the resonant condition of a stepped impedance resonator depends on the values of θ_1, θ_2 and K. Total electric length of the structural fundamental unit is given by [6]-[8],

$$\theta_t = \theta_1 + \theta_2 , K \neq 1 \tag{2}$$

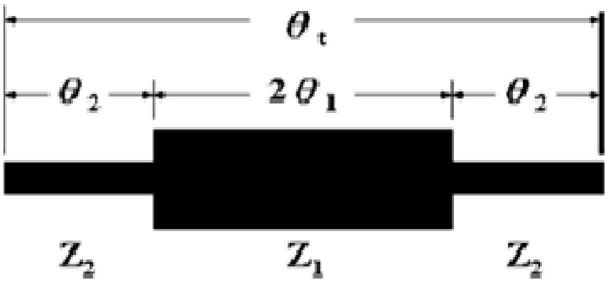
Also,

$$\theta_t = \pi/2 , \ K = 1 \tag{3}$$

It can be seen from equation 2 that the resonator's length reaches a minimum value for 0<K<1, and a maximum value for K>1.



(a)



(b)

Figure 8. Structure of the SIR. (a) $K=Z_2/Z_1< 1$. (b) $K=Z_2/Z_1> 1$.

For this particular design impedance ratio '*K*' is chosen to be 0.55. Subsequently, Z_2 is chosen to be 50Ω and Z_1 is chosen to be 90Ω. The resultant widths, electrical lengths and physical lengths are tabulated in Table 2.

Z(Ω)	**W(mm)**	**h(mm)**	**Electrical length(Θ) (degrees)**	**Physical length(*l*) (mm)**
50	3.06	1.6	25°	5.7
90	0.93	1.6	50°	11.84

Table 2: : Summary of widths, electrical lengths and physical lengths of SIR bandpass filter

Figure 9 shows the physical layout of the SIR bandpass filter and Figure 10 shows the photograph of the prototype that was built and tested.

Each resonator has a hairpin structure in order to minimize size and to make the filter as compact as possible.

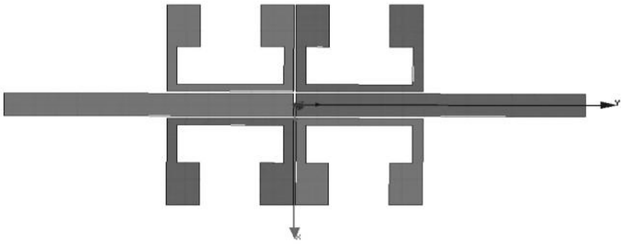


Figure 9. Physical layout of hairpin SIRbandpass filter

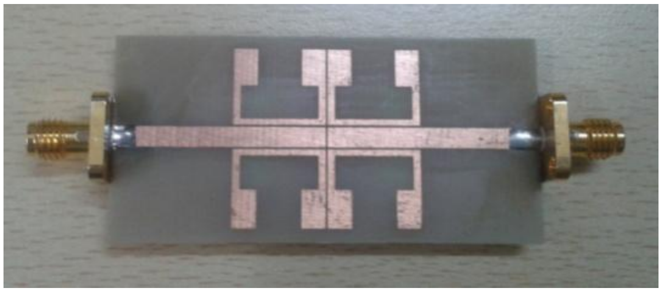


Figure 10. Photograph showing the Stepped impedance resonator bandpass filter prototype without DGS

Figure 11 shows the experimental results obtained. The center frequency is found to be 2GHz. The maximum passband insertion loss is found to be 3.59dB and the maximum return loss obtained is 11.44dB. At 2GHz the return loss is approximately equal to 6dB which is not desirable. The 3-dB bandwidth is found to be 0.2GHz.

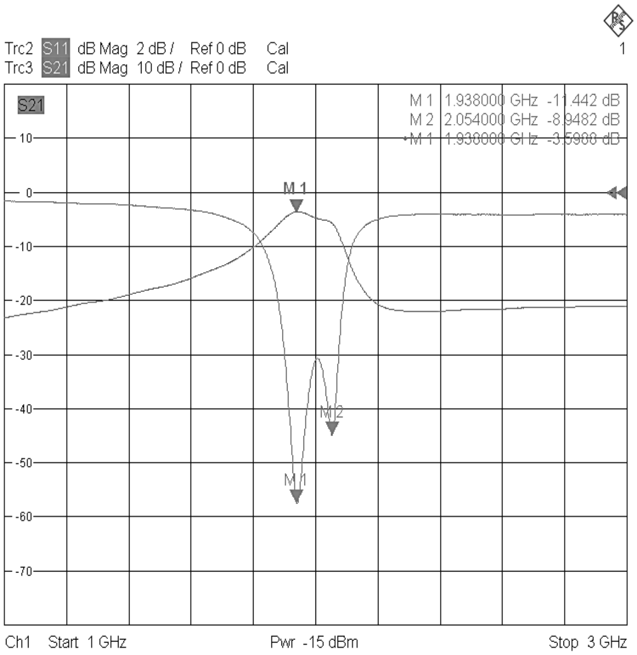


Figure 11. : Experimental data for the SIR bandpass filter without DGS

B. SIR Band-pass Filter with DGS

Since the design specifications are same as those of design in section 3.1, the procedures to obtain the widths, electrical lengths and physical lengths of the resonators remain the same. In this case a unit cell dumbbell shaped defect is etched in the ground plane. Initially, taking a=15mm, b=3mm, l=15mm and f=2mm as nominal values a parametric analysis was performed wherein the slot width was varied from 1mm to 3mm. The best results were obtained for a=15mm, b=3mm, l=15mm, and f=1mm. Figure 12 shows the superimposed view of the top layer and the ground plane of the hairpin SIR bandpass filter with DGS as seen from the top.

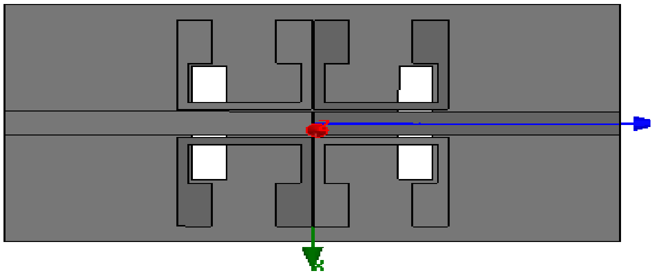
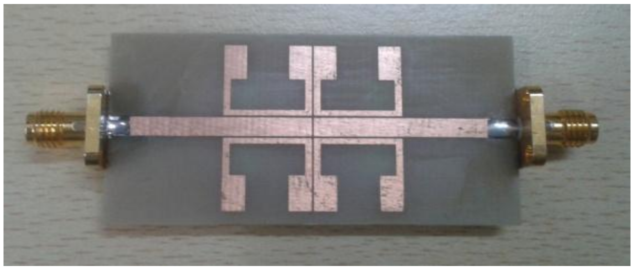


Figure 12. Superimposed view of top layer and ground plane of the hairpin SIR filter with DGS

Figure 13 shows the prototype of the hairpin SIR bandpass filter with DGS that was built and tested.



(a) Top view

(b) Bottom view

Figure 13. : Photographs showing the Hairpin SIR bandpass filter with DGS prototype (a) Top view (b) Bottom view

Figure 14 shows the experimental results obtained. The center frequency is found to be 1.67 GHz. The return loss and insertion loss obtained at the center frequency are 18.2dB and 2dB respectively. The bandwidth obtained is 400 MHz which is twice the value obtained for the design in section 3.1. It is observed that the introduction of defect in the ground plane causes a shift in the center frequency but by varying the dimensions of the defect such as slot width, the desired frequency can be achieved. It is clearly evident that the performance of the hairpin SIR resonator with DGS (especially in terms of the passband ripple and the 3-dB bandwidth) is much superior to that of the hairpin SIR resonator without DGS.

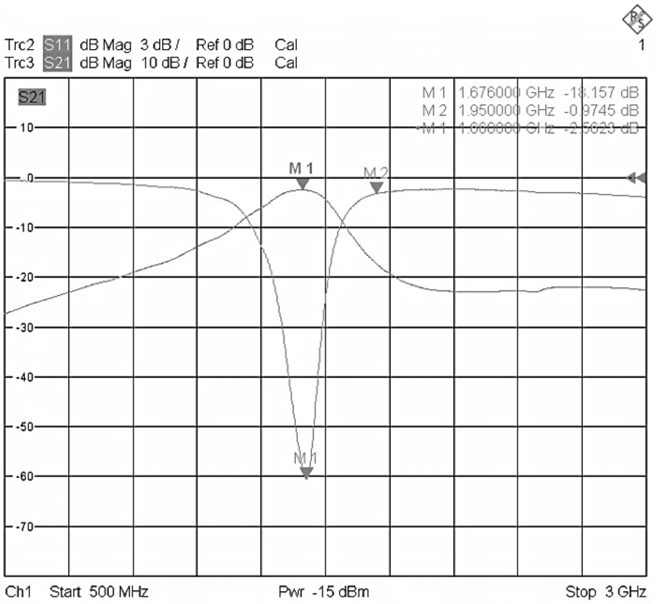


Figure 14. Experimental data for the SIR bandpass filter with DGS

IV. CONCLUSIONS

a) In case of low pass filter designs, when the DGS was introduced, the cutoff frequency remained unaffected, and there was slight improvement in the return loss performance.

b) In case of bandpass filter designs, when the DGS was introduced, considerable improvement was observed in the passband ripple, in the 3-dB bandwidth, in the return loss and in the stopband rejection.

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