Combined Shaped Microstrip Line and DGS Techniques for Compact Low Pass Filter Design

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***Abstract*- A U-shaped defected ground structure (DGS) with shaped microstrip line is proposed for compact low pass filter (LPF) implementation. Inset feed and stub matching techniques are used to enhance the filter charactristics. The proposed filter is composed of double U-shaped DGS units at the ground plane and a shaped microstrip line on the top. This structure allows sharp cutoff frequency response and high harmonics suppression. Furthermore, it provides compact filter size without the need for cascading periodic DGS structures. The stop band attenuation is controlled by adjusting the depth of the inset feed and the length of the stub sections. It has a 3 dB cutoff frequency at 2.7 GHz and it is as small as 20 mm × 19 mm.**

***Index Term*— Defected ground structure (DGS), electromagnetic bandgap (EBG), U-shaped, flat pass band, low pass filter (LPF).**

I. INTRODUCTION

Since defected ground structure (DGS) was proposed in 1999 [1], it has been one of the most concerned topics in the electromagnetism and the microwave fields. The concept of the DGS has been derived from the photonic bandgap structure (PBGs). Although PBG structure was developed for using at optical frequencies, it is scalable to be used in microwave and millimeter wave frequencies under the name of electromagnetic bandgap (EBG). DGS has been used to refer to an etched unit cell or an etched array of unit cells (1-D) in the ground plane [1]. On the other hand, PBG refers to a complete 2-D lattice in the ground plane [2].

The DGS disturbs the shielded current distribution in the ground plane [1]-[11]. This disturbance exhibits slow-wave characteristic, therefore, it can change the characteristics of the transmission line such as the line capacitance and line inductance. Also, it increases the characteristic impedance of the microstrip line so; wider microstrip line may be used. This may lead to higher power capabilities from the transmitter.

It also, provides band rejection in certain frequency bands, which can be called as bandgap or stop band effect. The DGS has been applied to design microwave circuits such as microwave filters [1]- [16] , power divider, couplers, amplifiers, oscillators, and so on by using periodic patterns of DGS underneath the microstrip line. In other words, the DGS are used to achieve the reduction in size and improve the performance of the microstrip components [1]-[11].

The double equilateral U-shaped DGS unit presented in [10] is shown in Figure 1. It has a 50Ω microstrip line on the top and two equilateral U-shaped patterns that are symmetrically etched in the ground plane. Each U-shaped pattern consists of three etched lines with the same length but different widths (W_1, W_2, and W_3). The two U-shaped patterns have different lengths such that $L_1 > L_2$. The DGS unit has been simulated using IE3D on the Rogers RO4003 substrate of dielectric constant $\varepsilon_r = 3.38$ and thickness $h = 1.524\ mm$.

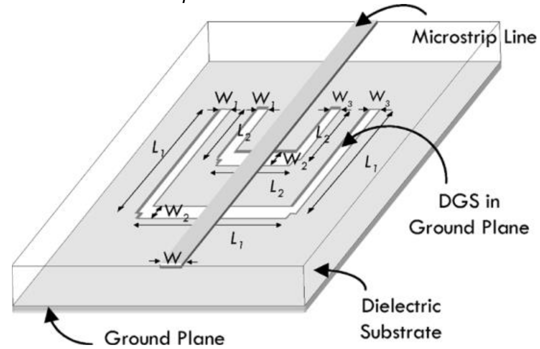


Fig. 1. Three-dimensional view of the DGS unit [10].

DGS elements with uniform dimensions are cascaded in a one-dimensional (1-D) periodic pattern [10]-[17] in order to realize wider stop band even the pass band ripple is concerned. To counteract this ripple problem, non-uniform configurations have been proposed to achieve much wider stop band and smaller pass band ripple simultaneously [10]–[21]. It is found that the more DGS elements are used, the wider stop band is achieved. More efforts are exerted to introduce compact microstrip filters using shaped transmission line coupled structures and resonator cells [22] and [23].

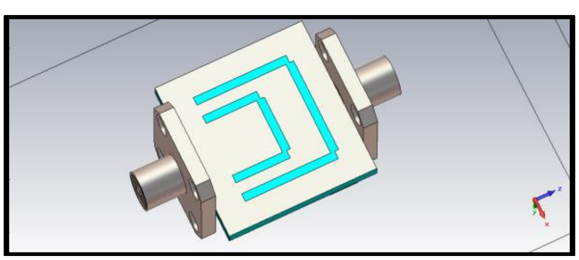
In this paper, a U-shaped defected ground structure with shaped microstrip line is proposed for compact low pass filter design. At the input terminal, an inset feed is created in order to adjust the impedance matching between the feeding port and the transmission line. In addition, two double stub sections with different widths and lengths are attached to the transmission line sections to enhance the filter characteristics.

The positions and lengths of the stub sections control the 3dB cutoff frequency of the filter. The use of this structure allows sharp cutoff frequency response and high stop band attenuation. Furthermore, it provides compact filter size without the need for periodic DGS structures. The proposed LPF is designed using the CST-MICROWAVE STUDIO simulator. The filter is simulated using Rogers's RO4003 substrate of dielectric constant $\varepsilon_r = 3.38$ and thickness $h = 1.524$ mm.

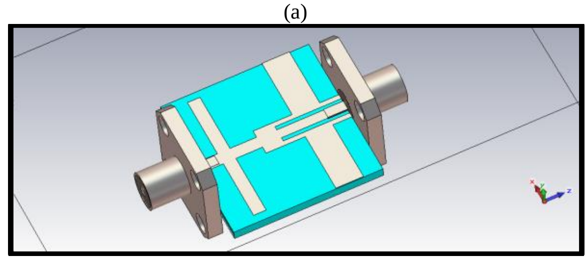
II. PROPOSED COMPACT LOW PASS FILTER STRUCTURE

In this section, a new design or pattern for compact low pass filter with relatively flat pass band characteristics is introduced. The introduced filter is an improved configuration from [10]. It has wide stop band with high attenuation. It is well known that a filter with its attenuation poles at finite frequencies, i.e. high selectivity, would be preferable owing to the ever increasing demand for currently expanding communication systems within finite spectrum resources. In order to demonstrate the effectiveness of the proposed pattern, it is used for LPF design which is illustrated in Figure 2. The designed LPF consists of a DGS cell with two interior U slots. The DGS cell is inserted to provide enough attenuation in a wide stop band range. Using the sharp cutoff frequency response of the etched DGS cell and considering the coupling effect between slots in the ground plane can provide the required elliptical function response of the filter. In addition, a shaped transmission line is placed on the top of the substrate. The transmission line consists of two sections of different widths where two open circuit double stub sections are attached. The addition of these stub sections controls the transmission line impedance which indeed provides a mean to control the attenuation level in the stop band. Furthermore, an inset feed is etched at the input port to control its impedance. The combination between the stub matching and the inset feed techniques exhibits more freedom to control the attenuation in the stop band. The detailed description of the DGS structure and the transmission line is shown in Figure 3.

As it can be seen that changing the structural parameters of the proposed pattern (such as the length and width of the stub sections, the depth of the inset feed, and the length of the U shaped arms) lead to control the cutoff frequency and sharpness factor of the designed filter, easily. This illustrates the flexible nature of the designed filter which achieved by inserting the mentioned pattern with interior U slots in the ground plane.

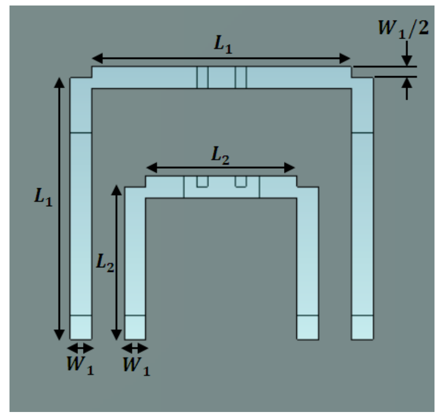


(a)

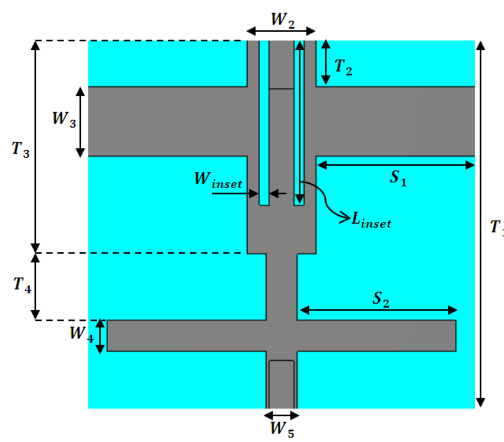


(b)

Fig. 2. (a) Back view and (b) Front view of the simulated CST design of the proposed low pass filter.



(a)



(b)

Fig. 3. Description of the (a) DGS unit and (b) the transmission line dimensions.

The proposed filter has been simulated using the CST-MICROWAVE STUDIO software using Rogers RO4003 substrate of dielectric constant $\varepsilon_r = 3.38$ and thickness $h = 1.524\,mm$ as the same as the double equilateral U-shaped DGS filter presented in [10].

The DGS structure consists of:

1. Two equilateral U-shaped DGS units of the same dimensions as the design presented in [10] ($L_1 = 12$ mm, $L_2 = 7$mm, $W_1 = 1$ mm).

The shaped microstrip line consists of:

1. Two sections of microstrip lines of different widths ($W_2 = 3.53$ mm, and $W_5 = 1.6$ mm) and different lengths where ($T_1 = 19$ mm, $T_2 = 2.47$ mm, $T_3 = 11$ mm, and $T_4 = 3.4$ mm) as shown in Figure 3-b.
2. Two open circuit double stub sections of different widths ($W_3 = 3.53$ mm, $W_4 = 1.6$ mm) and different lengths ($S_1 = 8.235$ mm, $S_2 = 8.2$ mm).
3. An inset feed of width $W_{inset} = 0.5$ mm and depth $L_{inset} = 8.5$ mm.

The addition of the double stub sections and the inset feed provides a mean for impedance matching at both the input and output ports. The attenuation in the pass band and stop band is controlled by adjusting the lengths of the stub sections and the inset depth.

III. SIMULATION RESULTS

In this section, the simulation results of the double equilateral U-shaped DGS low pass filter [10] and the proposed filter are introduced.

(a) Equilateral U-Shaped DGS LPF

The double equilateral U-shaped DGS low pass filter [10] is simulated using the ready-made software package CST MICROWAVE STUDIO. The low pass filter is realized on Rogers RO4003 substrate with dielectric constant $\varepsilon_r = 3.38$, and thickness $h = 1.524\ mm$. The double equilateral U-shaped DGS dimensions used in simulation are $L_1 = 12$ mm, $L_2 = 7$mm, and $W_1 = W_2 = W_3 = 1$ mm. Figure 4 shows the scattering parameters of the filter using the CST ready-made simulator.

The simulation results indicate that the low pass filter has some disadvantages:

1. The scattering parameter S_{11} in the pass band is not flat, which may yield output signal distortion as each frequency component from the input signal will be subjected to different attenuation.
2. The stop band attenuation is low as the scattering parameter S_{21} is relatively high at wide range of the stop band frequencies.
3. To obtain low pass filter with flat pass band characteristic and high stop band attenuation, it requires cascading several U-shaped DGS units as shown in figure 5. But, this technique leads to much larger filter size.

(b) Proposed LPF

The proposed structure provides wide stop band with high attenuation more than $30dB$ at wide range of the stop band frequencies. For comparison and showing the effectiveness of the designed filter it is compared with LPFs which are explained in literature. Here the designed filter is compared with [10]. Figure 4 shows the scattering parameters of the proposed filter compared to the double equilateral U-shaped DGS low pass filter presented in [10]. It is clear that the designed filter has better stop band characteristic and presents sharper cutoff response in comparison to previous work. Besides these, it has flexible nature and has a simple design procedure.

The simulation results indicate that the proposed low pass filter has the following features:

1. The scattering parameters S_{11} and S_{21}in the pass band are relatively flat, which prevents the output signal distortion as each frequency component from the input signal will be subjected to the same attenuation.
2. The stop band has high attenuation as the scattering parameter S_{21} is less than $-30dB$ at wide range of the stop band frequencies.
3. The proposed low pass filter has flat pass band characteristics and high stop band attenuation without the need for cascading several U-shaped DGS units.
4. Figure 5 shows the measured scattering parameters of the type-I low pass filter of Fig.6 presented in [10] where to have stop band attenuation more than $30dB$, it requires cascading five DGS structures. This cascading results in much larger filter dimensions of about $(20\text{mm} \times 108mm)$, while the proposed filter dimensions do not exceed $(20\text{mm} \times 19mm)$.
5. Also, figure 5 shows that the type-I low pass filter of [10] has large ripples in the pass band while the proposed filter has flat pass band characteristic.

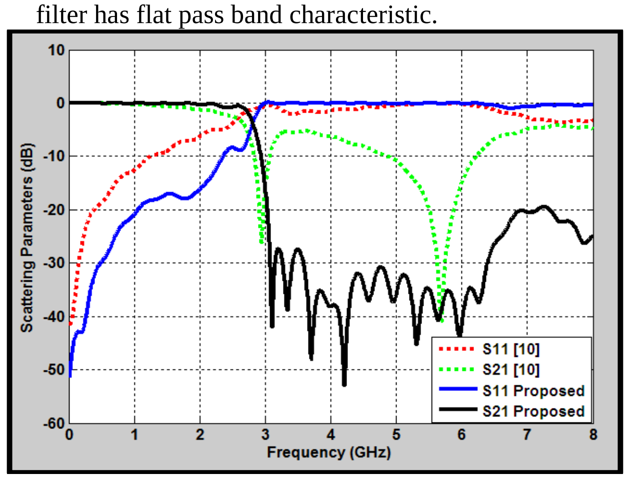


Fig. 4. The scattering parameters of the proposed filter compared to the double equilateral U-shaped DGS low pass filter presented in [10].

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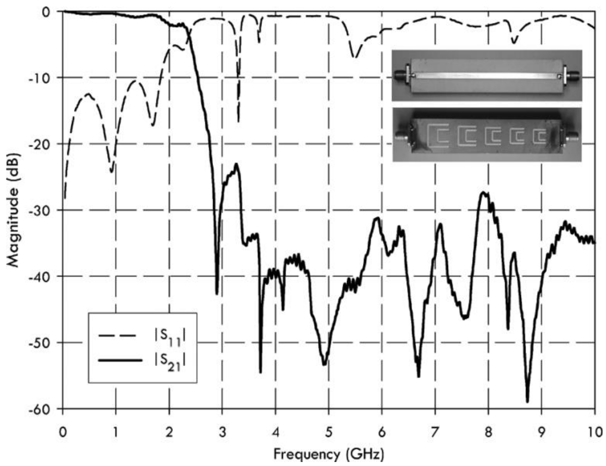

Fig. 5. The S-parameters of the type-I low pass filter of Fig.6 presented in [10].

IV. CONCLUSION

In this paper, an improved filter structure is investigated for compact low pass filter implementation. The proposed design allows sharp cutoff frequency response and high harmonics suppression. Furthermore, it allows size reduction without the need for cascading periodic DGS structures. The proposed low pass filter dimensions do not exceed $(20\text{mm} \times 19mm)$. The simulation results indicate that the proposed filter has relatively flat pass band and high stop band attenuation more than 30dB at wide range of the stop band frequencies. The designed LPF exhibits a sharp cutoff frequency response, low insertion loss and excellent stop band performance. Furthermore, it is easy to fabricate, also this design is simple and it has a flexible nature.

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