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A Compact Microstrip Low Pass Filter Based on DGS with Shaped Microstrip Line

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ABSTRACT

A triple U-shaped defected ground structure (DGS) with shaped microstrip line is investigated for compact low pass filter (LPF) applications. With this structure, the basic resonant element exhibits the elliptic-function low pass responses. The use of this structure allows sharp cutoff frequency response and high harmonic suppressions together with the small size to be obtained without the need for periodic DGS structures. The proposed DGS unit provides flat pass band characteristics and high stop band attenuation that can be controlled by the length of the opposite DGS.

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

1. 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 defected ground structure (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 defected ground structure (DGS) is based on etching a certain pattern unit/units in the metallic ground plane underneath the microstrip line like photonic bandgap structure (PBG) [12]-[16]. The defected ground structure 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, the defected ground structure 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.

The defected ground structure (DGS) provides band rejection in certain frequency bands, which can be called bandgap or stop band effect. Changing the physical dimensions of the etched pattern can easily control the effective inductance and effective capacitance. 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 with IE3D on the Rogers RO4003 substrate with a dielectric constant $\varepsilon_r = 3.38$ and a thickness $h = 1.524\ mm$.

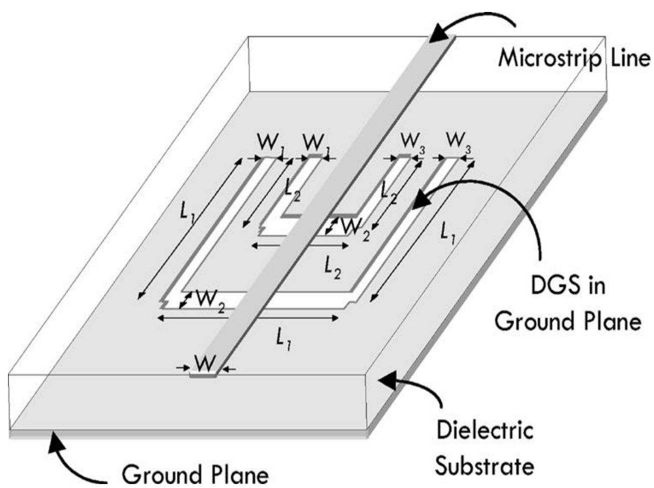


Figure (1) Three-dimensional view of the DGS unit [10]

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].

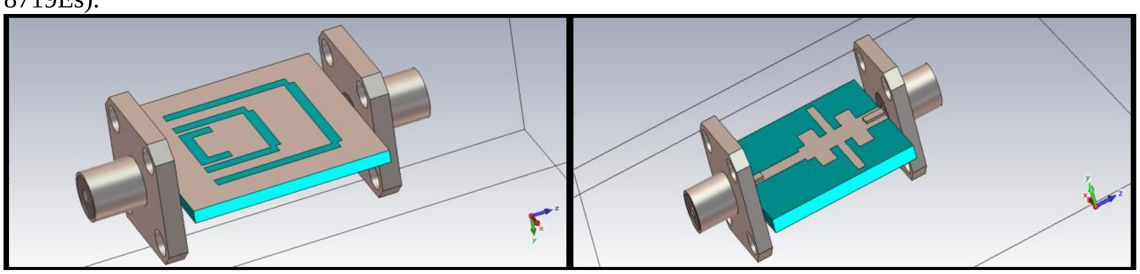
In this paper, a triple U-shaped defected ground structure (DGS) with shaped microstrip line is investigated for compact low pass filter (LPF) applications. With this structure, the basic resonant element exhibits the elliptic-function low pass responses. The use of this structure allows sharp cutoff frequency response and high harmonic suppressions together with small size to be obtained without the need for periodic DGS structures. The proposed LPF is designed using the CST-MICROWAVE STUDIO simulator. The filter is simulated using two different Rogers's substrates; RO4003 substrate with a dielectric constant $\varepsilon_r = 3.38$ and a thickness $h = 1.524\ mm$, and RO3003 substrate with dielectric constant $\varepsilon_r = 3$, and thickness $h = 1.5\ mm$. The proposed LPF is fabricated on the Rogers RO3003 substrate. The scattering parameters experimental measurements are made using the vector network analyzer (VNA HP8719Es).

2. PROPOSED COMPACT LOW PASS FILTER

An improved defected ground structure (DGS) with shaped microstrip line is investigated for compact low pass filter (LPF) applications. With this structure, the basic resonant element exhibits the elliptic-function low pass responses. The use of this structure allows sharp cutoff frequency response and high harmonic suppressions together with small size to be obtained without the need for periodic DGS structures.

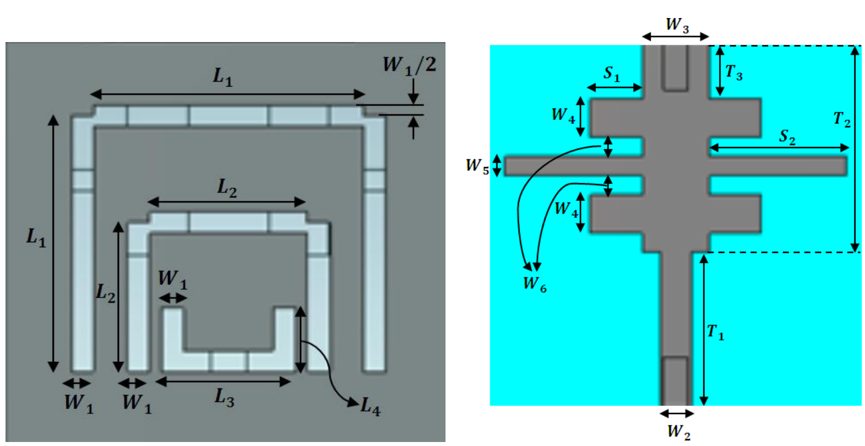
The introduced etched DGS pattern is an improved configuration from [10] and can effectively disturb the shield current distribution in the ground plane of microstrip line. This disturbance greatly changes the characteristics of the microstrip line such as line inductance L and capacitance C. With this structure, the basic resonant element exhibits the elliptic-function low pass responses.

In this section, a new design for a low pass filter with relatively flat pass band characteristics and wide stop band more than 8 GHz with high attenuation is proposed. The proposed filter is based defected ground structure (DGS) with shaped microstrip line as shown in Figure (3). A detailed description of the DGS structure and the transmission line is shown in Figure (4).



a) (b)

Figure (3) - (a) back view, and (b) front view of the simulated CST design of the proposed low pass filter



(a) **(b)**

Figure (4) Description of the (a) DGS unit and (b) the transmission line dimensions

The proposed filter has been simulated using the CST-MICROWAVE STUDIO software on the Rogers RO4003 substrate which has a dielectric constant $\varepsilon_r = 3.38$ and a 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 with dimensions ($L_1 = 12$ mm, $L_2 = 7$mm, $W_1 = 1$ mm).

2. Inverted U-shaped DGS unit placed inside the inner equilateral U-shaped DGS unit as shown in Figure (4-a). The dimensions of the inverted unit are ($L_3 = 6$ mm, $L_4 = 2.5$ mm, $W_1 = 1$ mm).

3. The addition of the inverted U-shaped DGS unit provides higher attenuation for the high frequency harmonics. The arm length L_4 of the inverted U-shaped DGS unit controls the attenuation in the stop band.

The Shaped Microstrip Line Consists of:

1. Two sections of microstrip line of different widths ($W_2 = 2.2$ mm, and $W_3 = 3.53$ mm) and different lengths ($T_1 = 8$ mm, and $T_2 = 11$ mm) as shown in Figure (4-b).

2. Three parallel double stub sections of different widths ($W_4 = 2$ mm, $W_5 = 1$ mm) and different lengths ($S_1 = 2.735$ mm, $S_2 = 7.235$ mm). $T_3 = 3$ mm) and the separation distance between the stubs is $W_6 = 1$ mm.

3. The addition of the three parallel double stub sections provides impedance matching control for the input and output ports in order to obtain higher attenuation in the stop band.

3. SIMULATION RESULTS

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

3.1 Equilateral U-Shaped DGS LPF

The double equilateral U-shaped DGS low pass filter presented in [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, $W_1 = W_2 = W_3 = 1$ mm. Figure (5) shows the scattering parameters of the double equilateral U-shaped DGS low pass filter presented in [10] using the CST ready-made simulator.

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

1. The scattering parameter S_{11} in the pass band is not flat, which may yield signal distortion as each frequency component from the input signal will be subjected to different attenuation.

2. Low attenuation in the stop band 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 requires cascading several U-shaped DGS units. That leads to large filter size.

3.2 Proposed LPF

For the proposed structure, a wide stop band with attenuation more than 20-dB is obtained. Figure (5) shows the scattering parameters of the proposed filter compared to the double equilateral U-shaped DGS low pass filter presented in [10].

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 flat, which prevents 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 relatively low at wide range of the stop band frequencies.

3. The proposed low pass filter has relatively flat pass band characteristics and high stop band attenuation without the need for cascading several U-shaped DGS units that leads to compact filter size.

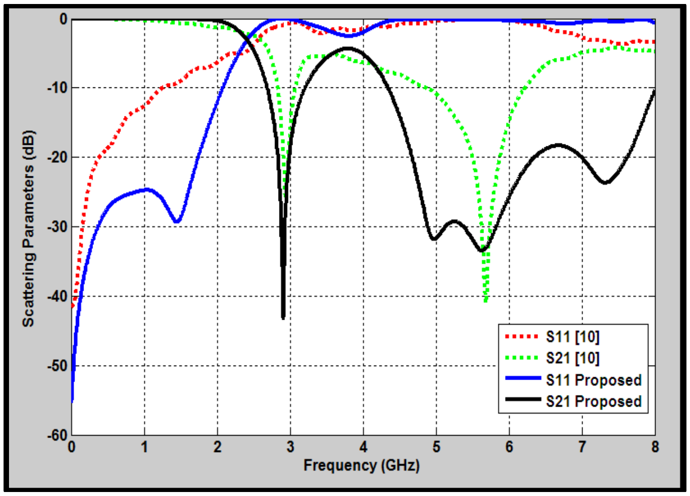


Figure (5) The scattering parameters of the proposed filter compared to the double equilateral U-shaped DGS low pass filter presented in [10]

4. FABRICATION OF THE PROPOSED FILTER

The proposed filter is fabricated on the Rogers RO3003 substrate with dielectric constant $\varepsilon_r = 3$, and thickness $h = 1.5\ mm$ instead of the Rogers RO4003 substrate with dielectric constant $\varepsilon_r = 3.38$, and thickness $h = 1.525\ mm$ which is not available in the fabrication laboratory. The fabricated filter has compact size of $(20mm \times 19mm)$. Figure (6) shows the picture of the fabricated filter.

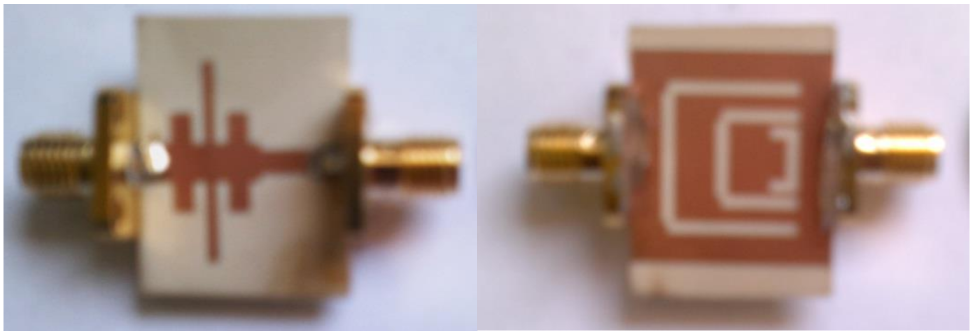


Figure (6) The picture of the fabricated filter on Rogers RO3003 substrate

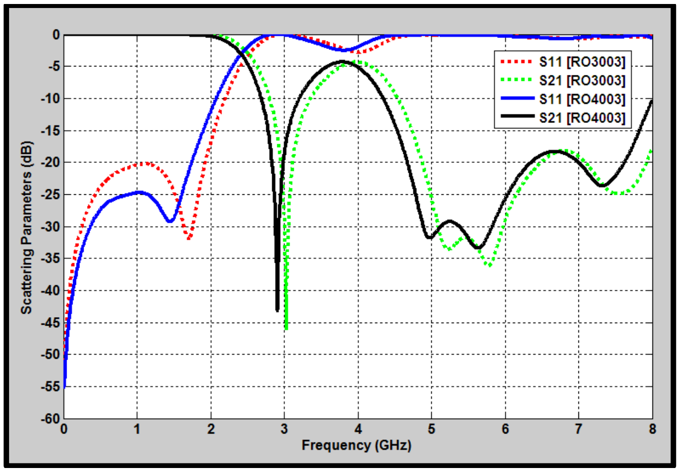


Figure (7) Frequency shift occurred in the simulated scattering parameters using Rogers RO4003 versus Rogers RO3003 substrates

As a result of this material "*substrate*" change, a slight frequency shift of about $0.2GHz$ occurs in the simulation results of the scattering parameters as shown in Figure (7).

Figure (8) shows the scattering parameters of the proposed low pass filter obtained using the CST ready-made simulator compared to the experimental measurement results. The experimental measurements are done using the vector network analyzer (VNA HP8719Es). Good agreement is found between the measurements and the simulation results.

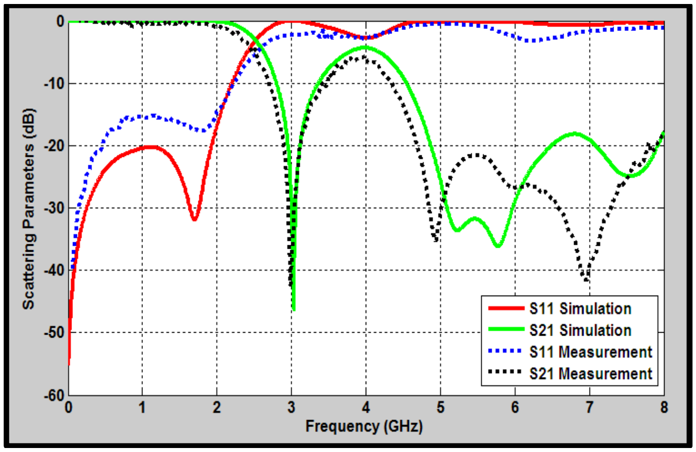


Figure (8) The scattering parameters of the proposed low pass filter obtained using the CST ready-made simulator compared to the experimental measurement results

5. CONCLUSION

In this paper, an improved defected ground structure (DGS) with shaped microstrip line is investigated for compact low pass filter (LPF) applications. With this structure, the basic resonant element exhibits the elliptic-function low pass responses. The use of this structure allows sharp cutoff frequency response and high harmonic suppressions together with small size to be obtained without the need for periodic DGS structures. The simulation results indicate that the proposed low pass filter has many features such as: the scattering parameters S_{11} and S_{21} in the pass band are relatively flat, which prevents signal distortion as each frequency component from the input signal will be subjected to the same attenuation; The stop band has high attenuation as the scattering parameter S_{21} is relatively low at wide range of the stop band frequencies; The proposed low pass filter has flat pass band characteristics and high stop band attenuation more than 20dB without the need for cascading several U-shaped DGS units. That leads to compact filter size.

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