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A novel compact CPW tunable stop band filter using a new Z-DGS-resonator for microwave applications

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Abstract

The paper presents a novel very compact CPW bandstop filter. The designed structure consists of one unit of new Z-DGS resonator, placed on top layer of ground plane between the input and output this structure, which is excited by 50-ohm coplanar line. The designed filter can be used in X-Band applications as the band stop can be shifted to any other desired frequency by tuning the length of the Z-DGS. The proposed filter topology has as benefits good performances in terms of wide stop-band rejection, low insertion loss, high return loss, simple design and more small size (17.908×10 mm^2) compared to other previous works those reported in literature. The stop-band width is from 3.96 GHz to 6.21 GHz, exhibits a 22.25-dB rejection bandwidth of 45% with high selectivity characteristic at the center frequency of 5.05 GHz.

***Keywords**: coplanar line, defected ground structure (DGS), stopband filter, tunable-stop stopband*

1. Introduction

With the technology developing, Bandstop filters became essential components of most microwave and mobile communication systems, while allowing desired signals to pass through and to suppress the interference signal and inhibit other higher harmonics [1, 2]. Ultra wide bandstop filters are less published, compare to microstrip. However, coplanar waveguide (CPW) present a lof of advantages such as easy connections in series, shunt without via hole and low dispersion effect in the microwave and millimeter devices and insentivity to substrate thickness [3, 4]. However, the design of an UWB-Bandstop filter with compact size, a low reflection coefficient in their stopband, low insertion loss and wide rejection-band, is a challenging task. Defected ground structures DGS one candidate of very successful approaches to achieve significant size reduction [5-7], and suppressing harmonics [8-10]. DGS elements can be used in various kinds of components such as bandpass filters, lowpass filters and stopband filters [11, 12], as well as in this paper, an etching certain patter in the ground plane change the equivalent capacitance and inductance of the transmission line and perturb the current distribution in the coplanar line, causing an increases in the effective inductance and capacitance of the line [13-15], and leads to a rejection of the signal at a certain frequency band determined by the parameters geometrics of defected ground shape.

There are various kinds of DGS configurations such as rectangular [16, 17], dumbbell [18, 19], spiral [19, 20], fractal [21], and H-shaped [22]. In this paper, a novel compact DGS with Z topology has been proposed for a novel Compact CPW Tunable Stop Band Filter. The structure has a very compact geometry, and presents good performance in terms of low insertion loss, high return loss, and fractional bandwidth. The tunable effect has been verified with an excellent result with adjusting on the length of Z-DGS resonator to getting other bands applications as can be used in X-Band applications. The compact filter are designed, fabricated and measured. The comparison between results shows a reasonable agreement between the measured and simulated responses.

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2. Characteristics of the New Z-DGS

Novel Z-shaped defected ground structure (DGS) on the coplanar line is presented to provide a band-rejection property with an improved factor. New geometrie Z DGS investigated, has simple shapes compared to the conventional DGSs, however, they provide more steep rejection characteristics. The idea was, the design of simple filter topology, which consists of one resonators placed vertically in the ground plane, and thus to further improve the sharpness of the transition knee and to reduce the circuit area with design flexibility. The U DGS can be easily reduced to an Z-shaped resonator by removing firstly the two vertical side arms to the two parallel horizontal form, as shown in Figure 1. This change causing the inductance of the DGS resonator to considerably decrease. Secondly, a new capacitance is created between the two horizontal arms by removing horizontal side arm of U DGS to sloping arm in the middle of DGS. Based on the U-slot DGS structure in [23], we propose an novel Z-shaped defected ground structure, as shown in Figure 1. The Z DGS in the ground plane excited by a 50 ohms line has a effect of resonator circuit, which can be modeled as parallel LC resonant circuit.

(a) (b)

Figure 1. Different DGS geometries: (a) u-shaped DGS, (b) the proposed Z-DGS

The equivalent circuit parameters can be extracted from an electromagnetic simulation by matching to a one pole Butterworth band stop filter response. The detailed analysis is explained in [24]. It can be modeled by a parallel LC circuit as shown in Figure 2. The values of the inductance L and capacitance C can be computed using the following equations [25, 26]:

$$C = \frac{w_C}{2Z_0(w_0^2 - w_C^2)} \quad (1)$$

$$L = \frac{1}{4(\pi f_0)^2 C} \quad (2)$$

The calculate values of parameters L and C are respectively L=0.153626 nH and C=6.4653pF. Simulation results are depicted in Figure 3, which shows the characteristics of a stop band filter. The DGS cell is simulated using Momentum Agilent. The values of the cut-off frequency fc and resonance frequency f0 can be found from the transmission characteristics of the Z DGS, with the values of f0=5.05 GHz and fc=3.967 GHz.

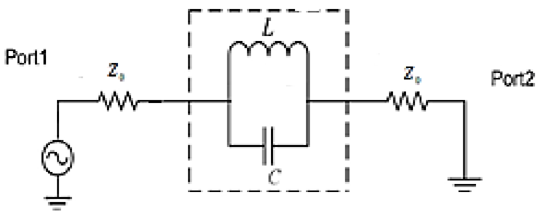


Figure 2. LC-equivalent circuit for Z-DGS resonator

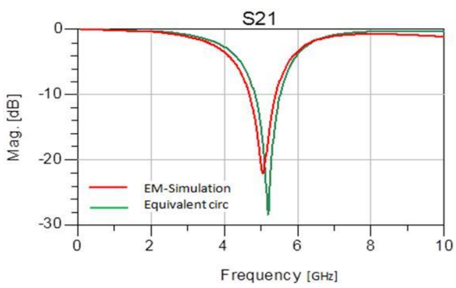


Figure 3. Circuit and EM-simulations of Z-DGS cell

3. Design of the Proposed CPW Stop Band Filter

The proposed compact stop band filter with the proposed configuration of Z-DGS on the ground plane of the coplanar line is shown in Figure 4. On the two sides of the ground plane, there are two Z-shapes which are connected to the gap of conductor line with two rectangular slots of the width w_s=0.204 mm, and length ls=0.4mm. The characteristic impedance of the coplanar line consists of a 50Ω, with a signal line width of W=1.5 mm and the gap width, G=0.204 mm. The proposed DGS stopband filter is designed on a FR4 substrate with a relative dielectric constant 4.4 and a thickness of 1.6 mm. Figure 4 shows, the DGS structure here is a Z shape etched in the ground plane. This Z shape DGS is connected to the line gap by a rectangle transverse slot with length of ls and width of ws. The proposed circuit is optimized by using Momentum based on moments method. The values of different parameters of structure are depicted in Table 1. The values of different parameters of structure are depicted in Table 1.

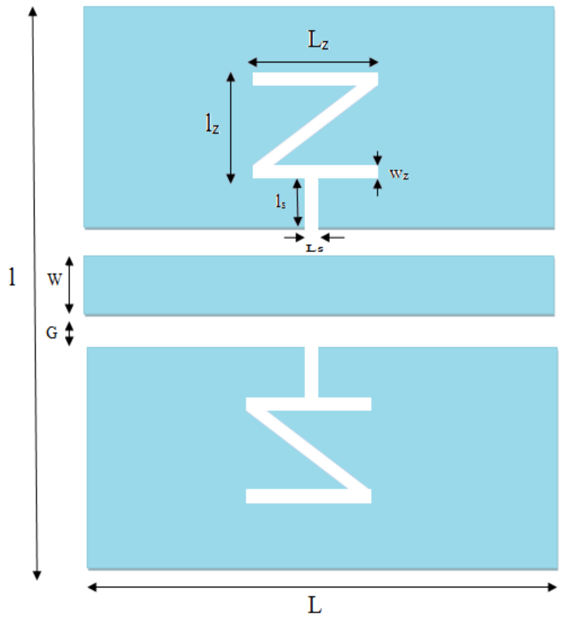


Figure 4. Structure of CPW stopband filter with Z-DGS

Table 1. Values of Different Parameters of Proposed CPW Stopband Filter

Parameter	Value (mm)
L	10
l	17.908
Lz	4
lz	4
wz	0.204
Ls	0.204
ls	0.4
w	1.5
G	0.204

In order to design a compact band stop filter with an improvement characteristics in stop and pass band in terms of insertion loss, high return loss and a very sharp transition, and high quality factor, it is necessary to suppress the undesired harmonics, to achieve this goal there are a lot of methods as cascaded, periodic DGS structure and EBG, but these methods influence on the seize of the structure. To achieve this goal and kept the seize of filter unchanged, the present structure with Z-DGS topology is a good candidate with a good characteristics frequency without any additional elements. The complete analysis of the filter done with EM simulation tool. Figure 5 displays the insertion loss (S21) and return loss (S11) of Z-DGS structure. As noted from the S-parameter studies, the unit cell of Z-DGS for the proposed stopband filter exhibits minimal insertion loss, better than -1.0 dB along the pass band with return loss (S11) below −20 dB without any others harmonics response. A potentially wide stopband exists between 3.96 GHz and 6.21 GHz, with resonance frequency around 5.05 GHz, the insertion loss (S21) is better than −22 dB and a low return loss (S11) better than-1.0 dB in the stopband.

To investigate the effect of the change of dimensions of rectangular etched slot. Firstly, the length ls is changed and all other dimensions are kept constant. Secondly, the same process with the width Ls of the rectangular etched slot. As shown in Figure 6 (a) and Figure 6 (b), the modification of the length ls and the width Ls of the rectangular DGS slot have not a big influence on the frequency response. Therefore, these parameters are not significant to optimize the resonance frequency. So, for controlling the frequency response of the proposed stopband filter, it is necessary to investigate the parameters of the Z DGS, exactly the length lz and the width Lz.

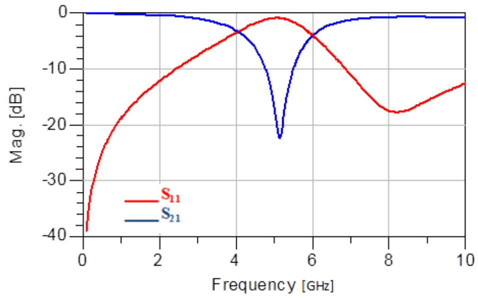


Figure 5. Simulated S-parameter of the proposed stopband filter with Z-DGS device

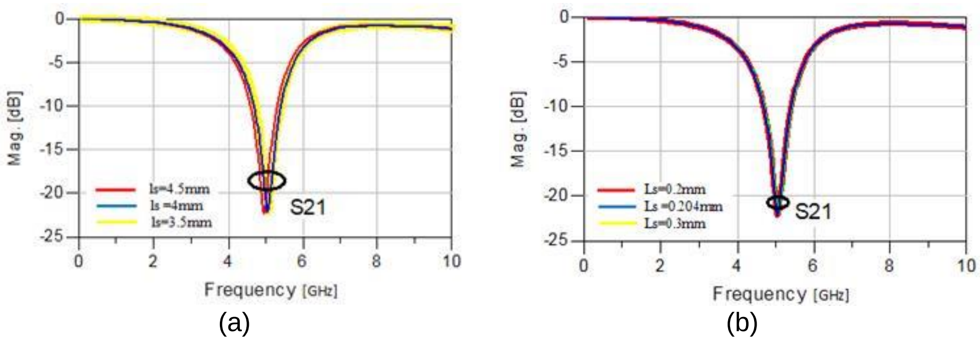


Figure 6. S-parameters of Z-DGS stopband filter: (a) Effect of variation of the length ls, (b) Effect of variation of the width Ls

4. Tuning of Z-DGS CPW Stopband Filter Characteristics

In order to control and to investigate the frequency response of the proposed stopband filter, to demonstrate the validity of structure to applied in other frequency response domains with required characteristics, the ADS Agilent momentum has been used to design and to optimize the proposed Z-DGS filter. As demonstrate above, Z-DGS unit is equivalent to a resonant circuit and can be modeled by a combination of inductive and capacitive elements. So, the arms of Z-DGS unit corresponds to a parallel inductance and capacitance. Therefore, any change in the parameters of Z-DGS unit will influence on the response frequency. It means that, the variation of the dimensions of Z-DGS unit, exactly the length and width, shifts the cut-off frequency and the attenuation pole of the proposed stop band filter in the frequency domain, as shown in Figure 7 and Figure 8. Firstly, the width (Lz) of Z arm was varied and all the other dimensions of Z DGS unit were kept unchanged. Figure 7 show the simulated results given with this process.

In the second, the inverse process, when, the length (lz) of Z arm was varied and all the other dimensions of Z DGS unit were kept unchanged. Figure 8 (a) and Figure 8 (b), shows the simulation results of the return loss and the insertion loss, respectively. As results shown, the attenuation pole of the resonance frequency translates to higher frequency, while one of the dimensions (length and width) of Z arm decreases. While, the moves up of the resonance frequency remains very significant with the change of the length (ls), compared to variation of the width (Ls). It means that, the length (ls) of the Z-DGS unit remain the most important factor to adjust and tuning the central frequency to improve the compactness of the proposed filter for other high response frequency without any additional elements. Therefore, keep the compact seize of structure. At the length of 1 mm, the resonant frequency leads to higher frequency range around 9 GHz, with compact frequency characteristics. It means that, the designed filter can be used in X-Band applications, and other several microwave applications by adjusting the length of the Z-DGS unit.

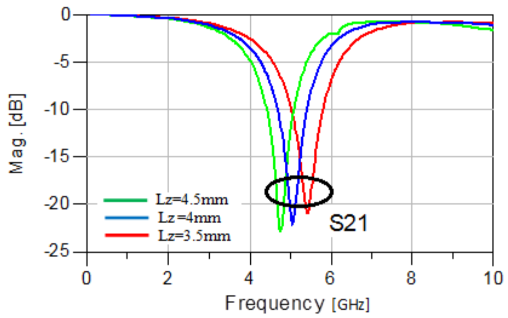


Figure 7. S21-parameters of Z-DGS stop band filter: Effect of variation of the width Lz

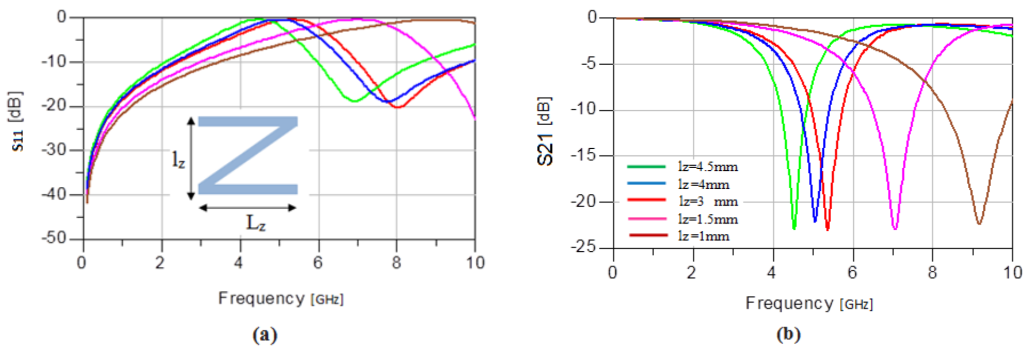


Figure 8. Effect of variation of the length lz: (a) S11-parameters of Z-DGS stop band filter, (b) S21-parameters of Z-DGS stop band filter

5. Distribution of Surface Current at Pass-Band and Stop-Band Frequency Ranges

Basing on behaviors of surface current density energies, the aim of this investigation is to demonstrate the relationship between the EM-simulation results and the surface current density distribution of the proposed Z-DGS stopband filter. Figure 9 shows the current distribution simulated at two different frequencies respectively in the passband Figure 9 (a), and in stopband Figure 9 (b). The first EM field distribution is at frequency 2 GHz and the second one at frequency 5 GHz. As a result, in Figure 9 (a) we can observe that the current energies was transmitted along the proposed filter structure from the input to the output and it is important around the Z-DGS, at the frequency of 2 GHz, which means that the filter is in the passband state. In the other side, as Figure 9 (b), shows, at the 5 GHz frequency, there is a high current distribution energies in the first part of structure, while blocked around the port 1 and the Z-DGS unit, and no current near to the output port 2, therefore no a transmission of RF power from the input port to the output port, which means that the filter is in the stopband state.

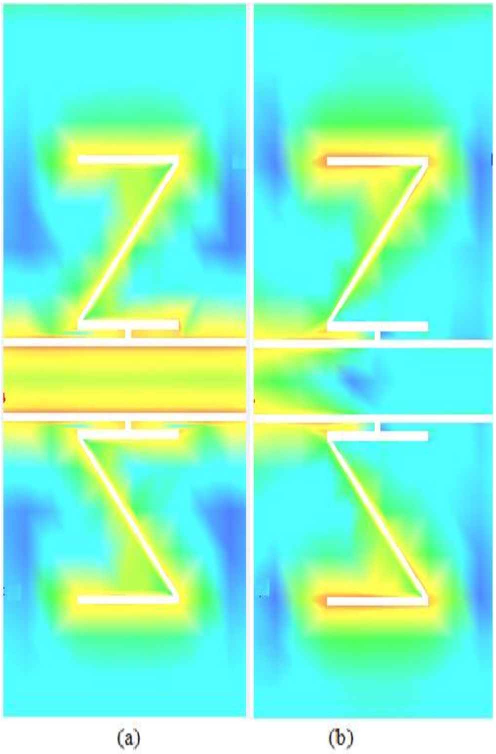


Figure 9. Simulated surface current density: (a) At f=2GHz, (b) At f=5GHz

6. Fabrication and Measured Results

The filter is designed and fabricated on the substrate with a thickness *h*=1.6 mm, dielectric loss tangent of 0.025 and a relative dielectric constant εr=4.4. The photograph of fabricated filter is shown in Figure 10. The simulated performance was obtained using Momentum Agilent based on MOM, and measurement is accomplished with Agilent 8757 D network analyzer. The simulated and measured results are shown in Figure 11. The fabricated stopband filter has minimal insertion loss, about -1.0 dB along the pass band, with return loss (S11) below −20 dB. The insertion loss (S21) is about −12dB and a low return loss (S11) about -2.0 dB in the stopband, without any others harmonics response. Compared with the simulated results, there is a slightly shift in the attenuation pole of the stopband and average return loss. Those introduced by the inaccuracy in fabrication, implementation and are expected mainly due to the reflections from the SMA connectors. Generally, a good agreement between the simulation and measurement is achieved.

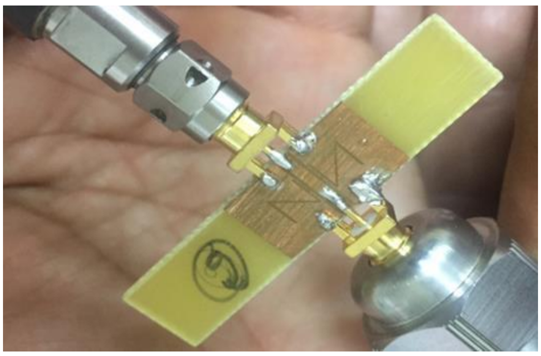
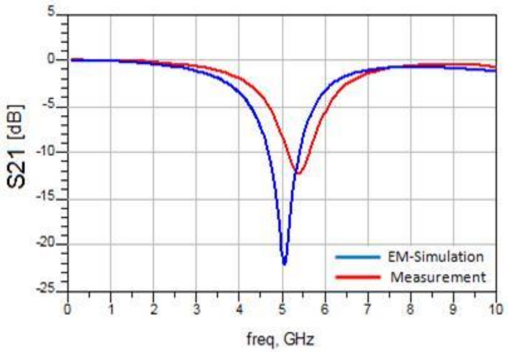
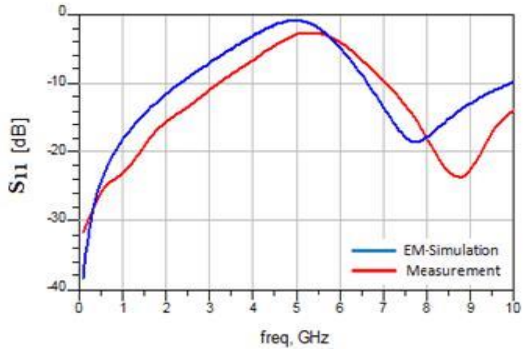


Figure 10. The photography of the proposed Z-DGS bandstop filter



(a)



(b)

Figure 11. Comparison between the measured and simulated results.
(a) S11-parameters, (b) S21-parameters

7. Conclusion

In this paper, A novel compact stopband filter using new Z-DGS topology was designed and simulated with its equivalent circuit. The new proposed filter is smaller in size, controllable in frequency and simple implementation, with simple unit and without any additional elements. To verify the performance, the filter was fabricated and measured. The measurements showed good agreement with the simulations. All these good features together, such compact size, tunable frequency and simple fabrication, our proposed structure with Z-DGS topology will be a good attractive candidate for applications in various integrated microwave circuits.

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