Improvement of Triple-Band Bandstop Filter Performances by using Parametric Analysis on Defected Ground Structure (DGS) and Mechanical Properties of Geopolymer Ceramic Reinforced Sn-0.7Cu

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Abstract. In this paper, the parametric analysis of the configuration defected ground structure (DGS) for triple-band bandstop filter is proposed. The defected ground structures are used to improve the selectivity and S-parameters losses of the bandstop filter response. The rectangular-shaped DGS are added to the ground of the bandstop filter. Initially, the DGS is applied to the first resonator (at 2.45 GHz) of the BSF. Several positions of the DGS are simulated to obtain the best S-parameters and selectivity performances. The same method is implemented on the second and third resonators of the BSF to obtain better performance in S-parameters and selectivity. Finally, all three resonators with the best DGS position are combined into one BSF to obtain triple-band BSF frequency response. This filter is designed by using Roger 4003C with relative dielectric constant, ε = 3.38 and substrate thickness, H = 0.508 mm. The bandstop filter is modelled and simulated by using high frequency Electromagnetic Simulator (EM). Simulated results show the insertion losses are, $S_{21} = -23.2$ dB (at 2.45 GHz), $-16.7$ dB (at 3.5 GHz) and $-24.4$ dB (at 5.2 GHz). The return losses are, $S_{11} = -0.49$ dB (at 2.45 GHz), $-0.64$ dB (at 3.5GHz), 0.49 dB (at 5.2 GHz). The results of different configurations of DGS are analysed and discussed.

1. Introduction

Nowadays, DGS is in demand extensively for various applications due to the successful implementation of DGS in the field of filters. It is very popular method that gives advantages in terms of small circuit size and filter characteristics. Defects in the ground of structures periodic or non-periodic cascaded will disturb the shield current distribution [1]. This disturbance alters the characteristics of a transmission line that will produce the additional inductance and capacitance. The band-rejection characteristics from the resonance property are produce when the DGS is applied in the ground planes of the microstrip filter.

The DGS is recently used in the bandstop filter since it has band-rejection properties that can enhance the stop band characteristics. Several types of DGS geometries from bandstop filter have been reported in the microstrip filter [2-4]. As reported in [5], the researcher used coupled Defected Ground Structure (DGS) resonators etched in the ground plane to implement compact band stop filters. Then, in order to obtain a band, stop filter response, it consists of symmetrical DGS resonators with a microstrip excitation. The bandwidth of band stop filter can be easily controlled by adjusting space S between the...
two DGS coupled resonators. The results show both measurement and simulation are in good agreement operate at 2 GHz and high rejection of stopband which is more than 25dB. The filter produces flat pass band frequency response ranging from 0 to 1GHz and 2.2 to 5GHz. However, the spacing gaps contribute to the S-parameters losses.

Stepped impedance line is used in [6] that combined with defected ground structure (DGS). The filter used double layout at the top and bottom layout. Stepped impedance line structure is design at the top layout to obtain the sharp and high selectivity of response. DGS structure at the bottom is used to get high-Q DGS resonator. Measurement result shows the insertion loss more than -40 dB at 14.2 GHz. The fractional bandwidth of 10 dB cutoff is 5%. This filter only obtains single stopband by using double layout structures.

In [7-8], the bandstop filters are structured by using C open-loop ring resonator and U resonator. These filters are utilizing multilayer procedure that comprises of three substrate layers, which are put vertically behind each other. The microstrip C open-loop and U resonator are designed at the top layer, while the middle layer and ground plane are etched by second and the third DGS resonators. Although by using multilayer method can enhance the first harmonic outcomes and minimized size, in the meantime, there are less acceptable outcomes showed up at the second and third harmonics are because of the transmitting loss of the used substrate and non-ideal positions of DGS.

DGS also introduced to realise the stop band and improve the poor upper pass band skirt of the SIRs [9]. In this paper, dual-band bandstop filter is designed by using a pair of defected ground structure (DGS) to obtain one stop band. On the other hand, the second stop band realise by using two stepped impedance resonators (SIRs). The result shows the return loss is more than 15 dB in the whole pass band, signify good impedance. However, SIRs introduced the spurious resonance of the first stop band.

As reported in [10], the U-slots are integrated with conventional dumbbell DGS and spiral DGS. It is shows that U-slot can give stronger Q-factor however with dimensional constraints it cannot give high selectivity of the signal. In [11], dual-band bandstop filter is proposed by using method of T-DMS (Defected Microstrip Structure) on the top plane and U-DGS on the bottom plane to produce two stop bands. The T-DMS and U-DGS are cascaded by three elements. The dual stop bands are at 3.35 GHz and 5.47 GHz with the insertion losses are -46.036 dB and -35.465 dB. But this filter has loss in the return loss and the size is increased due to cascade the elements. In this paper, a triple-band bandstop filter is designed by added with rectangular- shaped DGS in the ground plane to achieve the deeper rejection, low insertion loss and sharper cut-off. Several positions of rectangular-shaped DGS are analysed and discussed in this paper. The DGS is simple structure and easy to fabricate.

2. Equations
DGS equivalent circuit can be represented as shown in Figure 1. The DGS contains inductor, L and capacitor, C. The representative circuit can be modelled as shown in Figure 1. The mathematical Equation for both inductor and capacitor is shown in Equations 1 and 2. [5]:

\[
\frac{1}{\text{pH}} \quad (1)
\]

\[
\frac{1}{\text{nH}} \quad (2)
\]

where is the 3 dB cut-off frequency and is the pole frequency of a DGS slot [12]. The cut-off frequency and pole frequency can be obtain from the simulated S-parameter of the designs.
3. Proposed Design Layout

3.1. Microstructural
In this filter, the substrate used is Roger 4003C, relative dielectric constant, $\varepsilon_r = 3.38$ and thickness, $H = 0.508\text{mm}$. The center frequencies of the three stop bands are at 2.45 GHz, 3.5 GHz, and 5.2 GHz. The triple-band bandstop filter is designed by using resonator that coupled to the transmission lines. The rectangular-shaped DGS are added at the ground plane of the printed circuit board to improve the S-parameters high performances such as insertion loss and return loss of the bandstop filter [13]. This method is easy to apply into the BSF structure and it is compact in size.

In the early stage of design, the rectangular-shaped DGS is added on the first resonator of the bandstop filter (for $f_c = 2.45$ GHz). The size of rectangular-shaped DGS for width and length already explained in [14]. There are several positions of the rectangular- shaped DGS are simulated to obtain the best S-parameter ($S_{21}$ and $S_{11}$) and selectivity responses. The positions are specified by measured the distance from the left to the right of resonator as shown in Figure 2. Each position ($d_1, d_2, d_3, d_4$ and $d_5$) are simulated one by one separately to find the best position for each frequency. The positions distance for each frequency is different according to the length of resonator. Then, the same method is implemented on the second and third resonators of the bandstop filter to realize better performance in S-parameters and selectivity. Based on the Figure 3, several positions of rectangular-shaped DGS are applied on the resonator.

![Figure 1. Equivalent Circuit for DGS [5]](image1)

![Figure 2. The rectangular-shaped DGS distance for each position](image2)
The comparisons of the simulated frequency response of insertion loss, S21 and return loss, S11 of the triple-band bandstop with different positions of rectangular-shaped DGS have been done. From the Figure 4(a) and Figure 4(b) for 2.45 GHz, we can observe the best S- parameter is at the 4.6 mm of the resonator. It shows the insertion loss, S21 at -23.2 dB and return loss at -0.49 dB. The second stop band at 3.5 GHz gives the insertion loss at -20.7 dB and return loss, -0.87 dB at 1.6 mm gives the best performance as shown in Figure 5(a) and Figure 5(b). However, the resonance frequency is shift to 3.52 GHz. Hence, the distance position is choosing at 3.3 mm according to the resonance frequency at 3.5 GHz and the S-parameters still in good performances at -16.78 dB and -0.64 dB. As Figure 6(a) and Figure 6(b), shows it can be seen from the results, the insertion loss at -24.4 dB and return loss -0.49 dB is a good s-parameter and selectivity for 5.2 GHz. The position of rectangular-shaped DGS is at 2.15mm in distance. Based on the results for three stop bands frequencies, it shows the best position for apply the rectangular-shaped DGS is at the d3 position or the center of the resonators. It is due to the magnetic and electric fields are focused close to the gap and the opposite side of the open loop resonator. When the rectangular-shaped DGS are applied far from the center of resonators, the S-parameter is decrease. The results are summarizing in Table 1
Table 1. SEM image for FA geopolymer, kaolin geopolymer, and slag geopolymer

|      | 2.4 GHz | 3.5 GHz | 5.2 GHz |
|------|---------|---------|---------|
|      | $d$ (mm) | $f_c$ (GHz) | $S_{21}$ (dB) | $S_{11}$ (dB) | $d$ (mm) | $f_c$ (GHz) | $S_{21}$ (dB) | $S_{11}$ (dB) | $d$ (mm) | $f_c$ (GHz) | $S_{21}$ (dB) | $S_{11}$ (dB) |
| $d_1$ | 2       | 2.66    | 12.2    | 0.70  | 1.6 | 3.79 | 20.7 | 0.87 | 2 | 5.9 | 20.7 | 1.02 |
| $d_2$ | 2.3     | 2.47    | 13.4    | 0.94  | 1.65 | 3.52 | 17.7 | 0.67 | 2.3 | 5.37 | 22.5 | 0.59 |
| $d_3$ | 4.6     | 2.45    | 23.2    | 0.49  | 3.3 | 3.5 | 16.7 | 0.64 | 4.6 | 5.2 | 24.4 | 0.49 |
| $d_4$ | 6.9     | 2.47    | 13.3    | 0.7   | 4.95 | 3.52 | 20.2 | 0.67 | 6.9 | 5.36 | 21.3 | 0.49 |
| $d_5$ | 9.2     | 2.66    | 13.84   | 0.8   | 6.6 | 3.79 | 19.3 | 1.02 | 9.2 | 5.9 | 21.1 | 0.70 |

Figure 4. Comparison of the simulated result for 2.45 GHz (a) $S_{21}$ (b) $S_{11}$

Figure 5. Comparison of the simulated result for 3.5 GHz (a) $S_{21}$ (b) $S_{11}$
After choosing the best distance position for each frequency, all three resonators will combine in the same transmission line to get triple-band bandstop filter as shown in Figure 7(a). The simulated result in Figure 7(b) shows the comparison between triple-band bandstop filter with and without rectangular-shaped DGS. The simulated result for filter without rectangular-shaped DGS shows the resonance frequencies of the stop band at 2.84 GHz, 3.97 GHz and 6.13 GHz. The insertion losses in the stop band are -2.73 dB, -8.47 dB and -11.77 dB. Whereas for return losses are at -6.56 dB, 2.94 dB and -2.41 dB. On the other hand, the filter with rectangular-shaped DGS shows the result has three resonance frequencies of 2.45 GHz, 3.5 GHz and 5.2 GHz. The insertion losses are -22.3 dB, -18.9 dB and -24.4 dB, while the return losses of this filter are -0.67 dB, -0.63 dB and -0.45 dB. According to the result, it is shows the S-parameter performances are improve to the better rejection level, improves sharpness rather than the filter without rectangular- shaped DGS. The resonance frequencies are slightly changed due to the etched area in the ground plane (DGS) has modified the characteristics of transmission line and produced the effective capacitance and inductance.

The L-C equivalent circuit for DGS has been done in Figure 8(a) for more verification of result. The values of inductor, L and capacitor, C are calculated by using Equations 1 and 2. The calculated values are used to construct the L-C model with a 50ohm source and load terminated prototype. This L-C
equivalent circuit is simulated by using Advanced Design System (ADS). The simulated result in Figure 8(b) shows the good agreement with simulated result in high frequency Electromagnetic Simulator (EM) Figure 7(b).

![L-C equivalent circuit of DGS](image1)

![Simulated result of the L-C equivalent circuit of DGS](image2)

**Figure 8.** (a) L-C equivalent circuit of DGS (b) Simulated result of the L-C equivalent circuit of DGS

4. Conclusions

In this paper, triple-band bandstop filter with rectangular-shaped DGS are designed. The positions of rectangular-shaped DGS for each frequency are analysed to find the best position that can gives better rejection level performances. The comparisons between triple-band bandstop filter with and without DGS are shown in this paper. The L-C equivalent circuit are simulated for more verification result also shows the good agreement between Advanced Design System (ADS) and high frequency Electromagnetic Simulator (EM).

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