A Novel Band-Stop Filter using Octagonal-Shaped Patterned Ground Structures along with Interdigital and Compensated Capacitors

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Abstract **─** This paper presents a novel compact microstrip band-stop filter (BSF) based on octagonal defected ground structure (DGS) along with interdigital and compensated capacitors. The proposed BSF has lower and higher cut-off frequencies of 3.4 GHz and 5.3 GHz, respectively. A comparison between simulation and measurement results confirms the validity of the BSF configuration and the design procedure. The compact filter occupies an area of ($0.45\lambda g \times 0.35\lambda g$) with $\lambda g = 0.044$ m on an $\varepsilon_r = 3.66$ substrate and shows a 44% bandwidth (≈ 2GHz) and a return loss of 0.1 dB. The experimental results show the excellent agreement with theoretical simulation results.

Index Terms **─** Band-stop filter (BSF), compensated capacitor defected, ground structure (DGS), interdigital capacitor (IDC).

I. INTRODUCTION

The main design goals of filters are focused on compact and high performance in which they are generally required to reduce the cost and improve system performance. In recent years, defected ground structures (DGS) have been presented in a variety of different versions for filter applications [1, 6] and they are applied widely to design the microwave and millimeter wave circuits. Therefore, various DGSs have been proposed and applied for suppression of spurious harmonics in filters response and also for amplifiers and antennas [6-9].

In this paper, a new microstrip band-stop DGS filter with two slotted octagonal including interdigital capacitors (IDC) ground structure using slow wave effect, electromagnetic coupling is presented. A good sharp cutoff frequency response and a good performance in both the pass and the stop bands have been obtained. The proposed filter is fabricated and measured. The use of the idea of multiple capacitors led to a simple way to control the resonant frequency of the filter, while the distance between the two neighboring DGS resonators is used to improve the filter response. All structures are designed and analyzed using IE3D, a commercial electromagnetic simulator based on an integral equation method and the method of moment.

The measurement results were in good agreement with the simulation results.

II. CHARACTERISTICS OF THE OCTAGONAL SLOT DGS WITH AND WITHOUT INTERDIGITAL CAPACITOR

The configuration of the 0° octagonal-slot DGS without IDC is shown in Fig. 1. It is composed of an open ring on the ground plane and a microstrip line on the top layer. The zero degree

(0°) indicates that the open ring is in parallel with the microstrip line. The substrate with 0.254 mm thickness and a dielectric constant of 3.66 is used for all simulations. The conductor strip of the microstrip line (50 Ω) on the top plane has a calculated width '*W*' of 0.55 mm.

Figure 2 shows the resonance and the cut-off frequencies versus the length '*l*' of an octagonal slot DGS without IDC. It can be observed that both frequencies decrease with the increase of the length '*l*'. The L and *C* of modelled Parallel *LC* circuit as shown in Fig. 2 are given by:

$$C = \frac{5 f_c}{\pi Z_0 \left(f_0^2 - f_c^2\right)} \quad \& \quad L = \frac{250}{C_p (\pi f_0)^2}. \qquad (1)$$

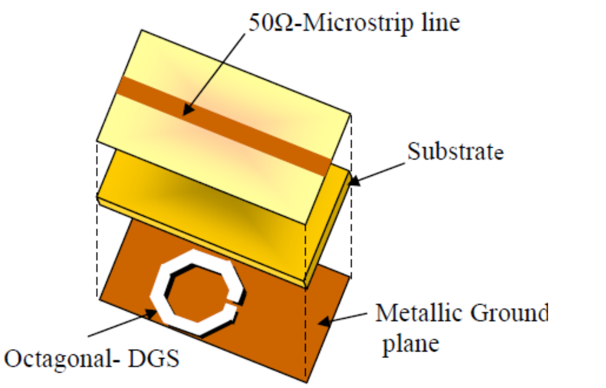

Fig. 1. The 3D view of the 0° octagonal-slot on the ground plane.

The values of the cut-off frequency *fc* and the resonance frequency *fc* can be found from the transmission characteristics of the octagonal slot [7, 8] as shown in Fig. 2.

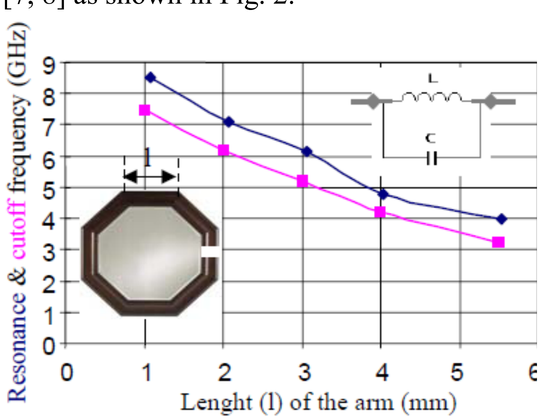

Fig. 2. Resonance and cut-off frequencies versus length '*l*' of an octagonal slot DGS without IDC.

III. FIELD DISTRIBUTION ALONG OF THE DGS-UNIT

The objective of this short investigation is to verify the dependence of the equivalent circuit elements (capacitance and inductance) on the surface as the distribution electromagnetic field. The simulation results are shown in Fig. 3(a) and Fig. 3(b). The microstrip structure is divided into two regions. In region I the electric field is highly concentrated in the gap, hence any change in dimensions of the gap affects the effective capacitance of the structure. In region II the electric field nearly vanishes [9-11]. On the other hand, the current is distributed throughout the whole structure. Therefore, any change in the length of the U-arm strongly affects the magnetic field distribution and hence the surface current, which in turn leads to a change in the effective inductance of the structure. Therefore, that region I corresponds to a capacitance and region II corresponds to an inductance. The full structure corresponds then to an *LC*-resonator.

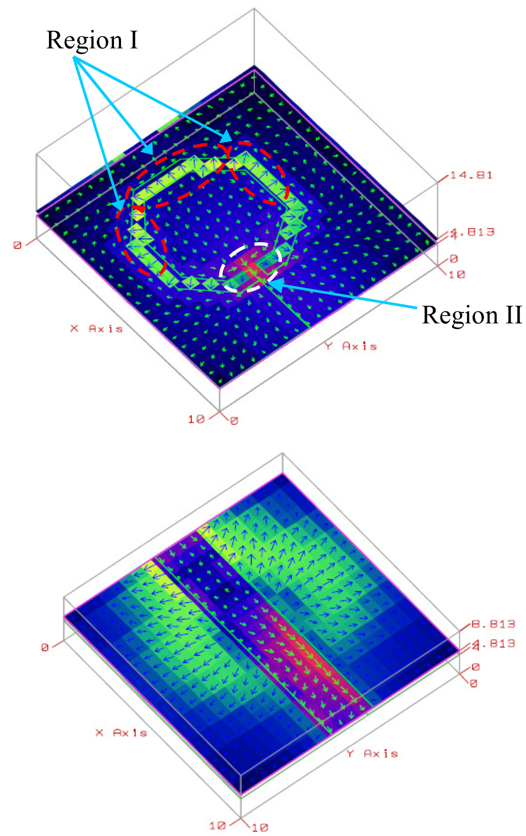

Fig. 3. EM field distribution at the resonance frequency, (a) EM field on bottom layer, (b) EM field on top layer.

IV. BAND STOP FILTER USING AN OCTAGONAL OPEN-RING INCLUDING IDCS

A schematic 3D view of the 90° octagonal DGS-band-stop filter (BSF) is shown in Fig. 4 with only one IDC [7, 8]. It is composed of an open-ring including IDCs in the metallic ground plane and a microstrip line on the top layer. The ninety degrees (90°) indicates that the open ring DGS is perpendicular to the microstrip line. In order to control the stopband, a simple idea is to add two IDCs in both sides as shown in Fig. 4.

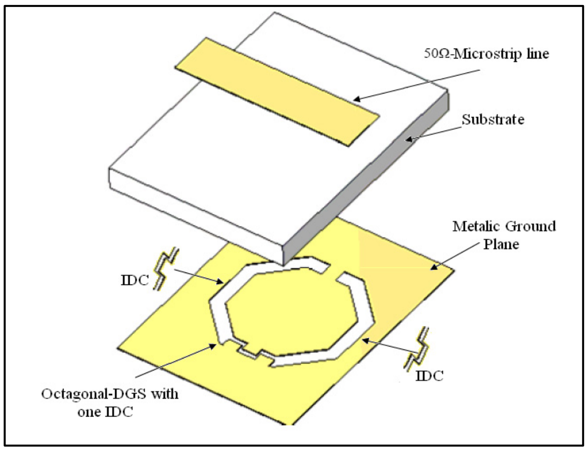

Fig. 4. The 3D view of the 90° octagonal-slot on the ground plane with IDC.

Figure 5 shows EM simulation results for the 90° octagonal slot with and without IDC on the ground plane of the microstrip line. As can be seen, when IDCs are included, the attenuation pole (f_0) of S_{21} response is shifted to low frequencies, i.e, from 5 GHz to 4.3 GHz. Moreover, the cutoff frequency (fc) depends also on the added IDCs, i.e, it decreased from 4.5 GHz to 3.9 GHz.

V. DESIGN OF THE PROPOSED BAND STOP FILTER

As in previous work [6], a DGS-resonator with an octagonal form has been used in order to improve the EM coupling between the neighboring DGS elements, and therefore, the enhancement for both the reject band and the compactness of the structure. The integration of an interdigital capacitor leads to control of the transmission zero of this filter. The using of multi-interdigital capacitors caused a creasing of the capacitance and this leads to a shifting of the transmission zero in the lower frequencies range, which means more compactness, as demonstrated in our work. Based on this idea, tunable compact band-pass/band-stop filters using varactor devices could be easy to im

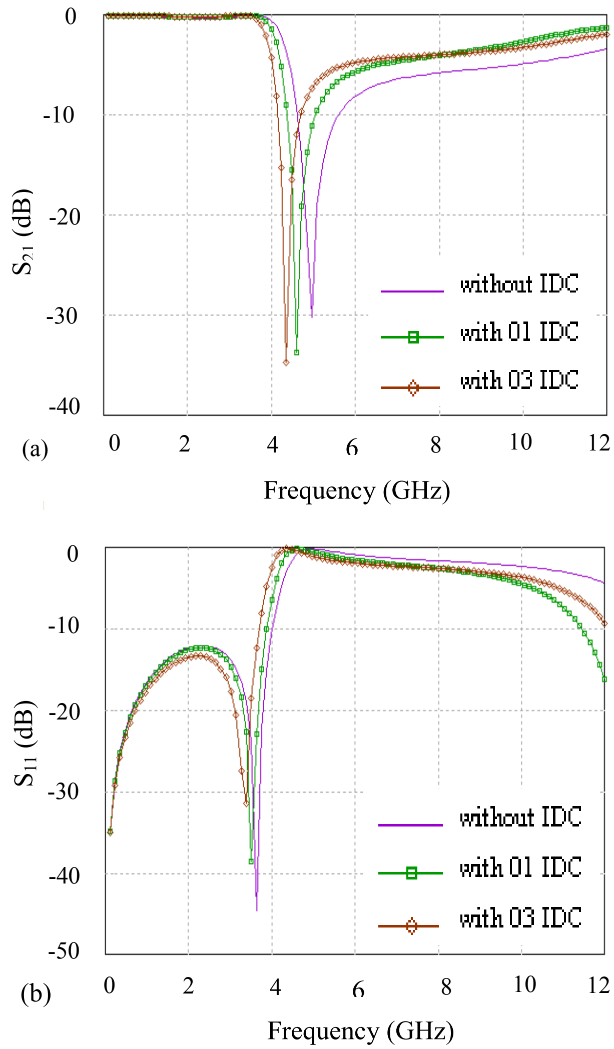

Fig. 5. EM simulation results for the 90° octagonal slot DGS with and without IDC (a) insertion loss (S_{21}) in dB and, (b) return loss (S_{11}) in dB.

A new band-stop filter is proposed and shown in Fig. 6. Different parameters of the proposed BSF are investigated and the best obtained ones are described in this section.

Figure 7 shows the simulation results of the BSF for various values of the parameter 'd' while the others are fixed to w = 0.8 mm, L = 3.5 mm and w_0 = 1.9 mm. It is observed that the BSF shows a good rejection which is greater than -18 dB in the stop band.

When d equals to 0.2 mm, the second harmonic has a level of around -18 dB which is well rejected [15-17].

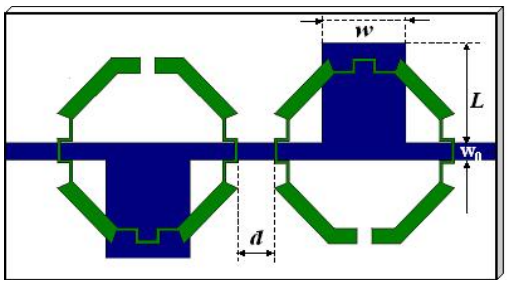

Fig. 6. The layout of the proposed band-stop filter.

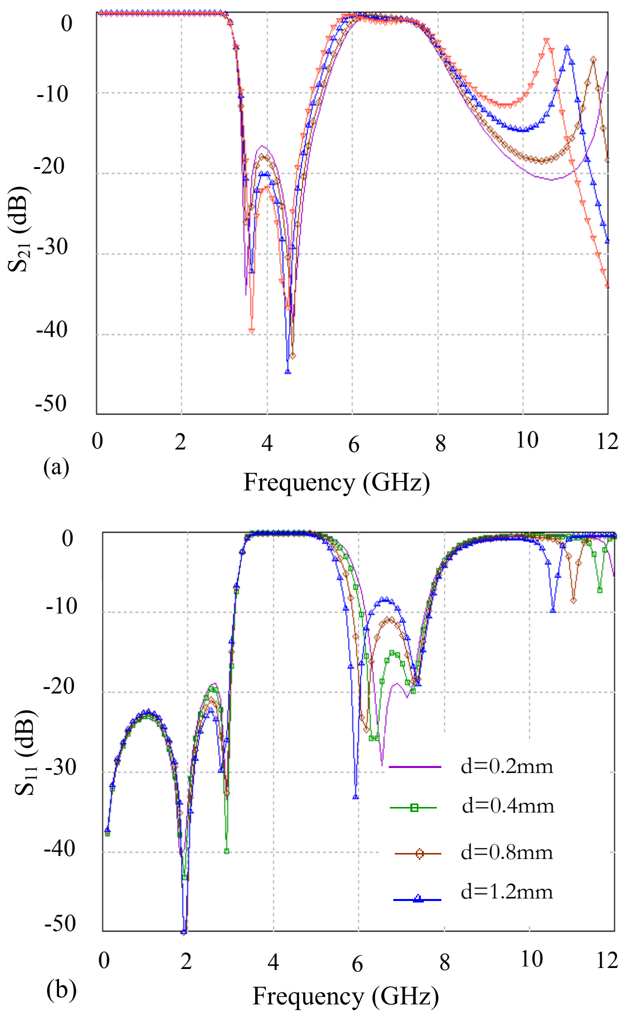

Fig. 7. Simulated S-parameters of the proposed band-stop filter for various d, (a) insertion loss (S_{21}) in dB and, (b) return loss (S_{11}) in dB.

VI. FABRICATION AND MEASUREMENT

Good performances have been obtained when the parameters d, w and *L* equal, respectively, to 0.2 mm, 0.8 mm, and 3.5 mm. Also, symmetry of the filter response has been achieved as shown in Fig. 7(b).

The proposed BSF with two octagonal DGSs including six IDCs in the metallic ground plane and microstrip capacitances on the top layer has been fabricated as shown in Fig. 8; whereas, the measured and the simulated results are shown in Fig. 9.

From Fig. 9, it can be seen that the fabricated BSF has an insertion loss less than 0.2 dB in the stop-band. The attenuation characteristic shows more than 20 dB in both pass-bands. The use of the IDCs lead to a compact size of this new filter and provides sharp rejection due to the reflection zeros near the stop-band edge. The small deviations between the simulated and measured results were caused by the SMA connectors and manufacturing errors. The performance of this novel BSF is experimentally characterized and compared with its simulation results which show a good agreement.

VII. CONCLUSION

This letter, a new octagonal DGS band-stop filter (BSF) has been introduced and investigated. It has been shown that the proposed filter has a good sharp cutoff frequency response and a good performance in both the pass-band and the stop-band. The use of the interdigital capacitor (IDC) idea improves the pass bands of the filter as compared to the filter without IDC and has also facilitated the control of the resonant frequency without using any extra devices and consequently, the structure has became very compact. A comparison between simulation and measurement results confirms the validity of the BSF configuration and the design procedure. In order to define the ideal coupling distance between the DGS-resonators, an empirical method has been used in this work.

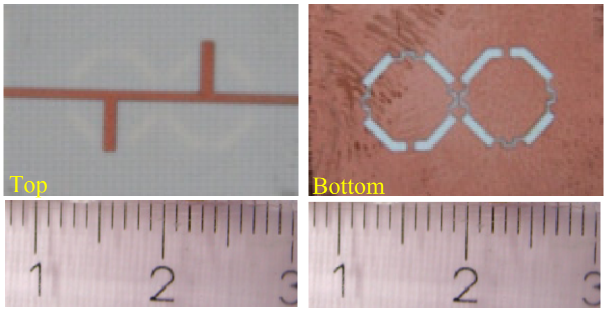

Fig. 8. The photography of the fabricated Band-Stop filter.

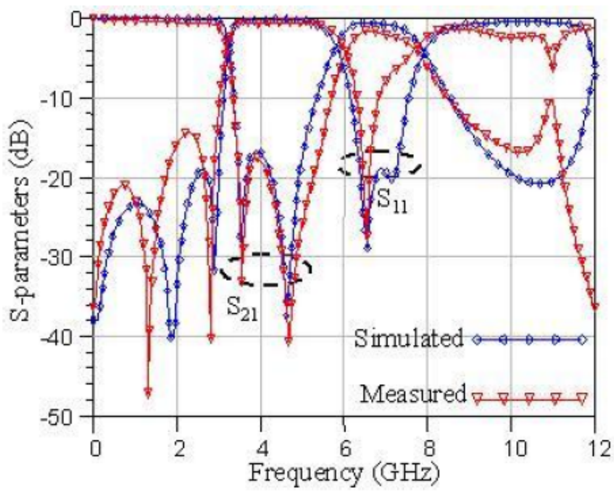

Fig. 9. Measured and simulated S-parameters of the proposed band-stop filter.

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