Small Microstrip Low-Pass Filter by using Novel Defected Ground Structure for UWB Applications

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Abstract **─** In this paper, a novel low-pass filter using defected ground structure (DGS) slot with a protruded T-shaped strip inside the slot is presented. The resonant frequency of the slot can be easily controlled by changing the protruded T-shaped strips dimensions, without changing the area taken by the structure. Using this DGS slot, a quasi-elliptic low-pass filter was designed, fabricated, and tested. The experimental results show good agreement with simulation results and demonstrate that excellent stop-band performance could be obtained through the proposed low-pass filter. The filter has a cut-off frequency of about 3.4 GHz.

Index Terms **─**Defected ground structure, microstrip low-pass filter, protruded T-shaped strip, and T-shaped open stub.

I. INTRODUCTION

Conventionally, the microwave low-pass filter (LPF) is implemented either by all shunt stubs or by series connected high-low stepped-impedance microstrip line sections. However, generally these are not easily available in microwave band due to the high impedance microstrip line and the spurious pass-bands. To remove these disadvantages, defected ground structures for microstrip lines have been presented in recent years. They have been presented in a number of different shapes for filter applications [1-5]. Some of the DGS techniques that are used to design these kinds of filters with broad bandwidth include the following: embedding two complementary split ring resonators (CSRR) in the ground plane [2], embedding multilayer coupled resonator DGS [3], using a novel quarter-circle DGS shape [4], utilizing the octagonal defected ground structure (DGS) along with inter-digital and compensated capacitors [5]. This technique is suitable for periodic structures and for both low-pass and band-pass filters, e.g., [6-8]. The DGS applied to a microstrip line causes a resonant characteristic of the structure transmission with a resonant frequency controllable by changing the shape and size of the slot.

This paper introduces a DGS with folded T shaped arms. The resonant frequency of the structure with this slot can be controlled by adjusting the distance between the T-shaped arms without changing the area occupied by the slot or the aperture. A quasi-elliptic low-pass filter based on this slot was designed and fabricated on a Rogers RT/Duroid 5880 substrate with 0.635 mm thickness and with a relative dielectric constant of 2.2. The resonant behavior of the DGS used here introduces transmission zeroes to the filter response and consequently improves its stop-band performance.

II. FILTER DESIGN AND CONFIGURATION

The proposed microstrip filter configuration with apertures under the high-impedance transmission lines is shown in Fig. 1.

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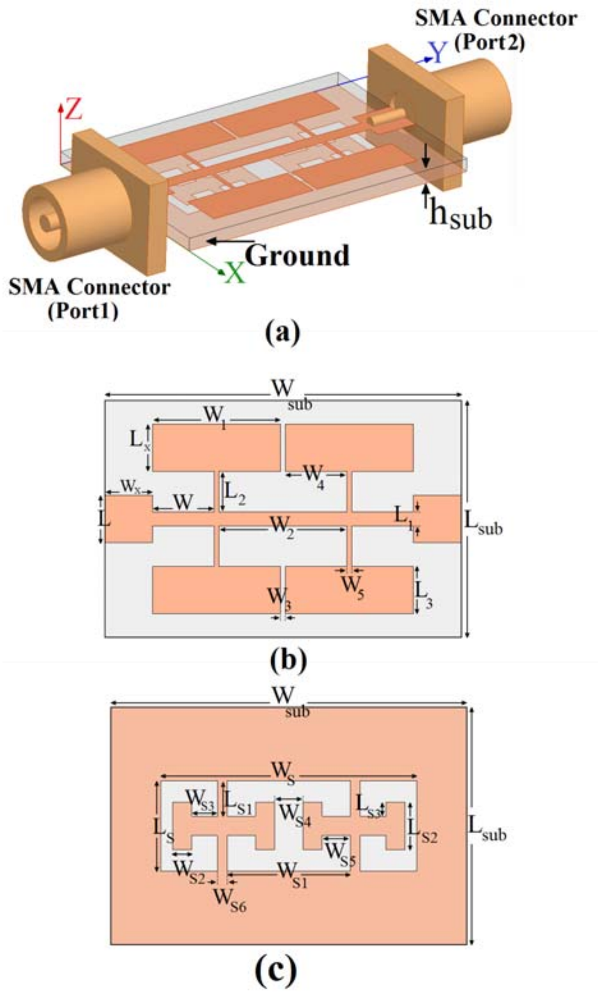


Fig. 1. Geometry of proposed microstrip filter, (a) side view, (b) top view, and (c) bottom view.

In general, the cut-off frequency of the microwave low-pass filter (LPF) can be adjusted by setting proper values of the lumped elements of the filter [9]. In addition, to realize the desired capacitive and inductive values of the filter elements by the stubs of the high/low impedance transmission lines, the characteristic impedance and effective dielectric constant of these transmission lines have to be determined. The low-pass filter shown in Fig. 1 was designed on a Rogers RT/Duroid 5880 substrate with 0.635 mm thickness and relative dielectric constant of 2.2.

Defected ground structure (DGS) evolved from photonic band gap (PBG); it is realized by etching defected pattern and slot in the ground plane. The etched defect in ground plane disturbs the shield current distribution in the ground plane. This disturbance can increase the effective capacitance and inductance of a transmission line, respectively. Thus, an LC equivalent circuit can represent the proposed unit DGS circuit [1-3]. The proposed DGS slot is shown in Fig. 1 (c). The slot is etched in the ground metallization under the microstrip line. This slot has a major advantage in providing tighter capacitive coupling to the line in comparison to known microstrip DGS. Moreover, the resonant frequency of the structure can be controlled by changing the distance between the folded T-shaped arms. The resonant frequency of the slot can be modified by changing the overall slot size, which shifts the cut-off frequency of the filter down. To shift the frequency up instead of frequency back, it is necessary to reduce the inductance of the narrow strip line that is located over the slot. This can easily be done by increasing the width of the strip [10, 11].

The final dimensions of the proposed low-pass filter are specified in Table 1.

Table 1: The final dimensions of the designed filter.

Param.	mm	Param.	mm	Param.	mm
W_{Sub}	15	L_{Sub}	10	W_S	10.8
L_S	3.8	W_{S1}	5.2	L_{S1}	1.5
W_{S2}	0.8	L_{S2}	2	W_{S3}	1.1
L_{S3}	0.6	W_{S4}	1.2	W_{S5}	1.2
W_{S6}	0.4	L	2	L_1	0.6
W_1	5.4	L_2	1.7	W_2	4.4
L_3	2	W_3	0.2	W_4	2.6
W_5	0.2	L_X	2	W_X	2

III. RESULTS AND DISCUSSIONS

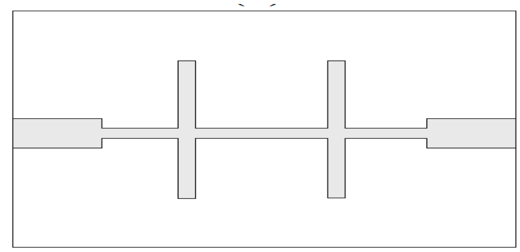
The microstrip low-pass filter shown in Fig. 1 was designed on both substrate sides by opening apertures in the ground metallization under the high-impedance transmission line. Replacing some of the apertures by the proposed folded T-shaped arms structure introduces transmission zeroes. The number of transmission zeroes is equal to the number of apertures with folded T-shaped arms. One transmission zero is introduced into the filter response by replacing the central aperture by the proposed folded T-shaped arms structure. This slot, however, shifts the cut-off frequency of the filter down. To shift the cut-off frequency back, it is necessary to reduce the inductance of the narrow strip line that is located over the slot [10]. For the input/output connections 50 Ω microstrip lines are used. The parameters of this proposed filter structure are studied by changing one parameter at a time while others are kept fixed. The simulated results are obtained using the Ansoft simulation software high-frequency structure simulator (HFSS) [12].

To minimize the physical size of the proposed low-pass filter and increase its bandwidth, four T-shaped open stubs are introduced into the microstrip transmission line to alter the input impedance characteristics. Figure 2 shows the structure of the various filter used for simulation studies. Return/insertion loss characteristics for ordinary microstrip transmission line (Fig. 2 (a)), with four rectangular open stubs (Fig. 2 (b)), and with four T-shaped open stubs (Fig. 2(c), which is the proposed structure) are all compared in Figs. 3 (a) and (b). From the results shown in Fig. 3 (a), it is observed that when four T-shaped open stubs are used, the return loss of the proposed filter is changed at lower frequencies. As shown in Fig. 3 (b), the four T-shaped open stubs also influence the bandwidth of the insertion loss [13]. The proposed transmission line structure can be used to extend the lower edge frequency and the upper edge frequency of the insertion loss bandwidth.

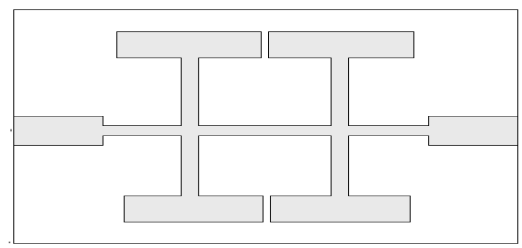
Another important parameter of this structure is the exterior length of the T-shaped open stubs L_X. Figure 4 shows the return loss for different values of L_X. It is seen that the lower-edge frequency of the return loss bandwidth is reduced with increasing L_X, but the matching became poor for larger values. Therefore, it can be realized that the optimized L_X is 2 mm.

In this paper, in order to increase the insertion loss bandwidth, two novel C-shaped slots and a rectangular slot with protruded T-shaped strips inside the slots are inserted in the ground plane of the proposed design as shown in Fig. 1. As illustrated in Fig. 5, the microstrip filter with slotted ground plane has wider insertion loss bandwidth in comparison to the same filter without slots in the ground plane [14, 15].

(a)

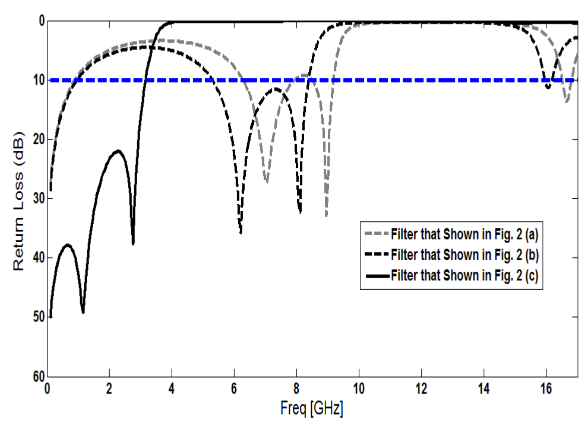


(b)

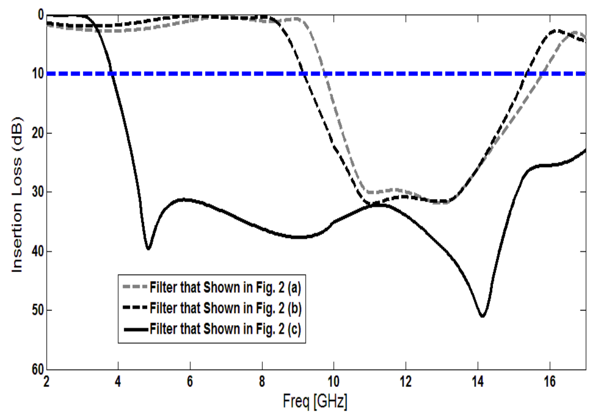


(c)

Fig. 2. (a) Ordinary microstrip transmission line (b) with four rectangular open stubs, and (c) with four T-shaped open stubs (the proposed structure).



(a)



(b)

Fig. 3. Simulated return/insertion loss characteristics for the various filter structures shown in Fig. 2, (a) return loss and (b) insertion loss.

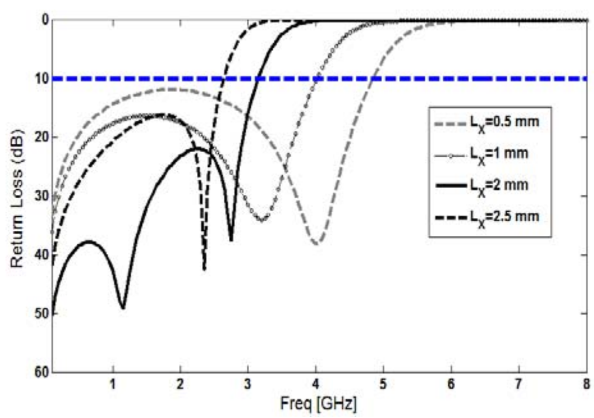


Fig. 4. Simulated return loss characteristics for various values of L_X.

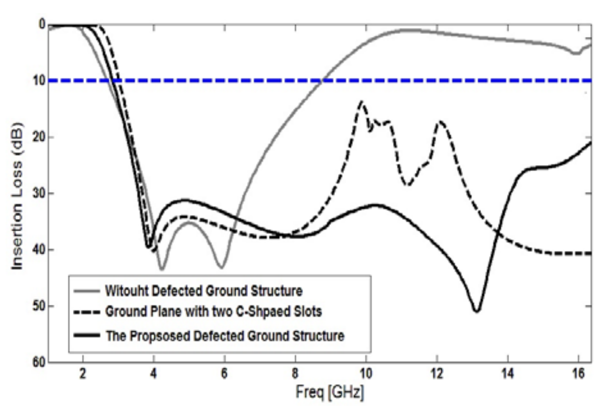


Fig. 5. Simulated insertion loss characteristics for the proposed filter with and without the proposed slots in the ground plane.

By inserting four modified T-shaped strips of suitable dimensions at the corners of ground plane slots, a new configuration can be constructed. The truncated ground plane is playing an important role in the broadband characteristics of this filter, as it helps matching of the transmission line in a wide range of frequencies. This is because the truncation creates a capacitive load that neutralizes the inductive nature of the patch to produce nearly-pure resistive input impedance [16, 17]. Three such slots with different sizes of T-shaped strips are specified in Table 2 as cases 1, 2, and 3.

Table 2: Three cases of the proposed filter with different values of T-shaped strips.

Case	W_{S2}	L_{S2}	W_{S3}	L_{S3}
1	0.5	2.3	0.7	0.9
2	0.8	2	1.1	0.6
3	1	1.8	1.4	0.45

Figure 6 shows the effect of T-shaped strips with different values on the insertion matching in comparison with the same filter without T-shaped strips. It is found that by inserting the four T-shaped strip of suitable dimensions at the ground plane additional transmission zero at 14 GHz is created and hence, much wider insertion loss bandwidth with multi transmission zeros can be produced, especially at the higher band.

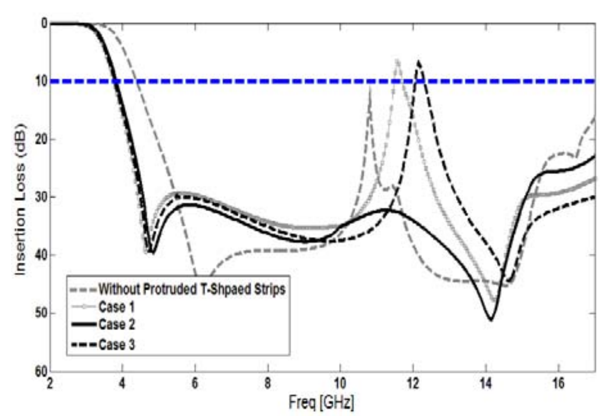
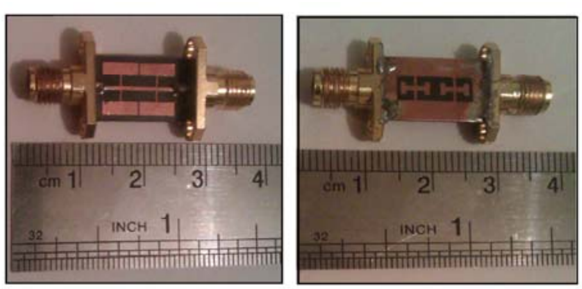


Fig. 6. Simulated insertion loss characteristics for the proposed filter without T-shaped strip and three cases 1, 2, and 3 with strips as shown in Table 2.

Table 3: Comparison of the proposed DGS-LPF with other related LPFs.

Reference	*Dimension (mm^2)*	*Return Loss (S_{11}<-20 dB)*	*Insertion Loss (S_{21}<-20 dB)*	*Cut-Off Frequency*	*Number of Transmission Zeros*
Ref [3]	30×30	1-1.85	3-4.93	2.2 GHz	2
Ref [4]	27×21	0-2.52	3.3-5.43	3.04 GHz	2
Ref [5]	25×14	0-2.5	5-20	2.95 GHz	3
Ref [6]	40×20	0-2.8	3.7-7.5	3.2 GHz	1
This Work	15×10	0-3.15	3.87-17.3	3.4 GHz	3

In Table 3 the performance of the proposed low-pass filter (designed based on the ideas, which are presented in previous sections) has been compared with prototypes in [3-6]. It can be seen from Table 3 that the proposed filter provides good performance in stop-band rejection and pass-band return loss and smaller in size than those reported in literature. The proposed filter with optimal design, as shown in Fig. 7, was fabricated and tested in the Antenna Measurement Laboratory at Iran Urmia University. Figure 8 shows the simulated and measured insertion and return loss of the filter. As shown in Fig. 8, two transmission zeros are introduced to the filter response at about 5.02 GHz and 14.12 GHz. Consequently, a wide stop-band was achieved. Additionally, the proposed DGS low-pass filter also has characteristics of wider and deeper stop-band than those of conventional low-pass filters.



(a) (b)

Fig. 7. Photograph of the realized printed low pass filter (a) top view and (b) bottom view.

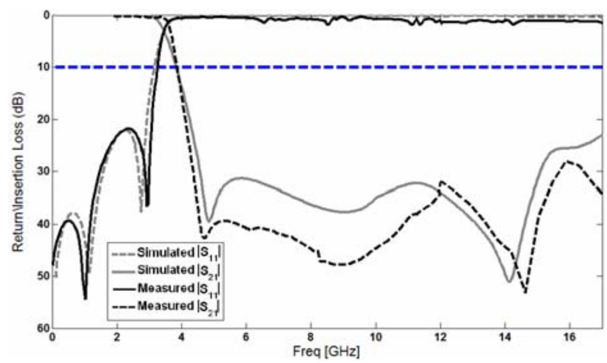


Fig. 8. Measured and simulated return/insertion losses for the proposed low pass filter.

IV. CONCLUSION

In this paper, two compact quasi-elliptic low-pass filters using novel DGS slot with folded T-shaped arms are designed and fabricated. The main advantages of the proposed DGS are its compact size and the fact that the parallel resonant frequency can be controlled without changing the overall slot area of the DGS. The transmission zeros introduced to the filter responses improves their stop-band behavior. Simulation results using 3-D HFSS shows good consistency with experimental results. It is also of potential to be used in microwave and millimeter wave ICs.

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