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SLOTTED DEFECTIVE GROUND STRUCTURE FOR PERFORMANCE IMPROVEMENT OF TRI-BAND MICROSTRIP PATCH ANTENNA

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Abstract: In this research work a miniaturized microstrip patch antenna with defected ground structure (DGS) has been proposed. The proposed novel antenna structure has been obtained by removing circular notches and a circular slot from a rectangular patch and with three triangular slots in the ground plane for achieving bandwidth enhancement, improved return loss, good radiation pattern and better impedance matching. Proposed antenna exhibits tri-band behavior. It has dimensions of 25 × 38 × 1.6 mm^3 and resonates at 3.33 GHz, 6.97 GHz and 8.59 GHz frequencies. Prototype of the proposed structure has been fabricated on FR4 substrate and real time measurements were done on Vector Network Analyzer (VNA). Measured results were analyzed and compared which were in good agreement with the simulated ones.

Keywords: Microstrip. Slotted. Bandwidth. Return Loss. VNA. Substrate

1. INTRODUCTION

Due to development in wireless communication and standards, need of multiband antennas has emerged which are competent to handle different frequency bands and has ability to demonstrate better proclivity. Microstrip antenna stands the best candidate for it [1].

Besides having various advantages, conventional micro strip patch antenna suffers from some major drawbacks like low gain, narrow bandwidth, large size, single operating frequency, surface wave excitation and cross polarization which limits its performance [2][3]. To overcome these limitations and enhancing the performance parameters of micro strip antenna, various new technologies have been emerged and reported like introducing slots, notches, stacking, photonic band gap (PBG), electromagnetic band gap (EBG), Meta-material and many more [4][5]. A defected ground structure (DGS) is one of the new concepts applied in the field of microwave circuits over the past few years [6][7]. Microstrip patch antenna with DGS has attained much attention among all the proposed techniques for improving the performance of micro strip antennas as it provides simple structural antenna design and complexity is less [8][9]. DGS has gained much importance in the research field as it offers various advantages and has wide application areas in the microwave antenna designs [10]. It provides higher operating bandwidth and reduced antenna size along with improved return loss and high gain [11]. It also makes system compact and effective [12][13]. It has frequency selective properties which are utilized for rejection of undesired frequencies [14].

Suggested antenna has been designed and simulated using Empire XPU simulation software, it is one of the leading standards used for microwave component and antenna design. It is FDTD method based simulator software. It has powerful and fastest simulation engine with on the fly code generation capability.

2. ANTENNA LAYOUT

The configuration of the suggested antenna design is illustrated in Fig 1(a). It is an circular notched patch antenna with circular slot in centre incorporated with triangle defected ground structure. Ground and patch are designed using thin metallic layer and FR4 sheet is used as dielectric substrate. Radiating patch is made by removing semi-circular shaped notches and circular slot in suggested design. Circular notches are removed from the left, right and upper part of the patch and one slot is removed from the centre. Dimensions of the slot is r_1 and d. A quarter transformer feeding is used to feed the structure for better impedance matching with a width of w_f and a length of l_2 .

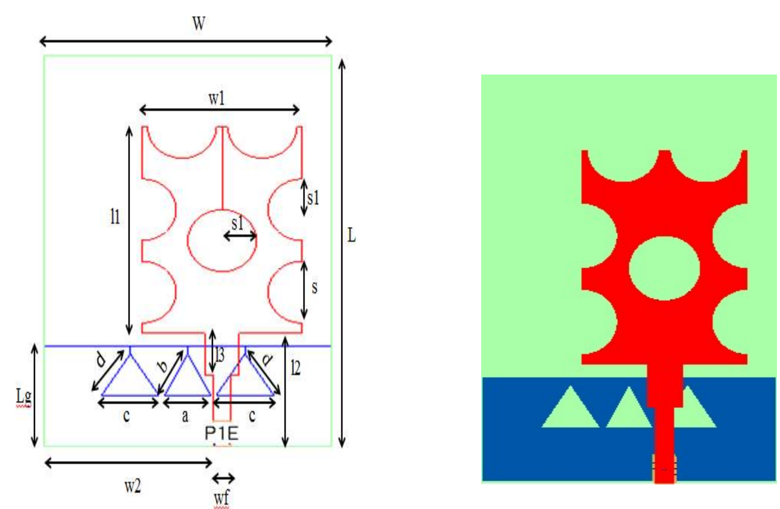

Fig 1 (a) Suggested antenna layout (b) Antenna design

Antenna layout is engraved at the top of the substrate and ground layer is engraved on the backside of the substrate as shown in Fig 1(b). In the DGS three triangular slots are removed to achieve higher gain [15], wide-bands and better impedance matching [16]. Final antenna layout is designed on 25 × 38 mm^2 FR4 substrate having dielectric constant of $\mathcal{E}_r$ =4.4, and thickness h = 1.6 mm. Values of effective dielectric constant and impedance has been calculated using equations (1) and (2) [1].

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$$\mathcal{E}_{\mathrm{reff}} = \frac{\mathcal{E}_{\mathrm{r}}+1}{2} + \frac{\mathcal{E}_{\mathrm{r}}-1}{2}\left[1\Big/\sqrt{1+12h/w}\right] \qquad (1)$$

$$Z_0 = \frac{120\pi}{\sqrt{\mathcal{E}\text{reff}}\left[\frac{w}{h} + 1.393 + 0.667 ln\left(\frac{w}{h} + 1.444\right)\right]} \qquad (2)$$

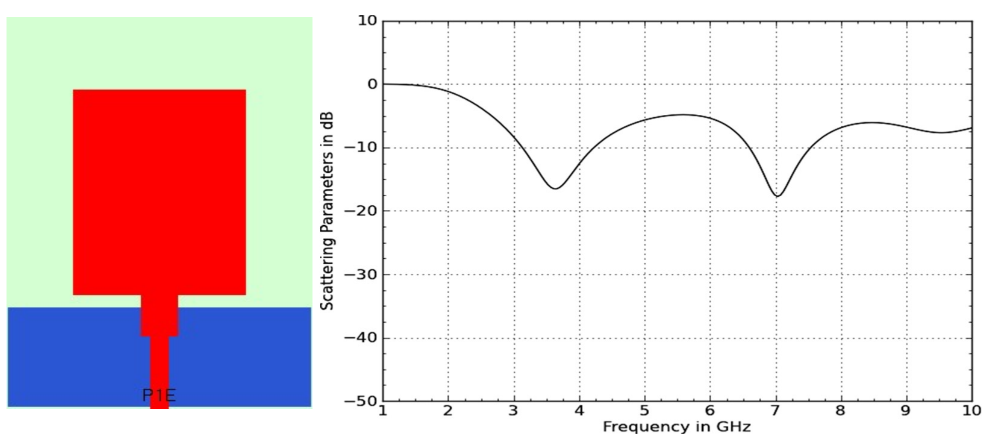
All parameters calculated used existing equations [1][17] for suggested design are given in Table 1.

Table 1: Proposed Antenna Design Parameters

Parameters	Size (mm)	Parameter	Size (mm)
W	25	L	38
w_1	14	l_1	20
L_g	9.75	w_f	1.6
l2	11	w_2	14.7
s_1	3	s	6
a	4	b	4.47
c	5	d	4.71
l_3	4	h	1.6

2.1 DEVELOPMENT OF SUGGEESTED ANTENNA AND SIMULATION RESULTS

The first step towards the designing of the suggested antenna consists of a rectangular patch and DGS as shown in Figure 2 (a). When simulated in electromagnetic simulator Empire XPU it resonates at two operating bands with resonant frequencies 3.6 GHz and 7.00 GHz respectively as shown in Fig 2(b). It is observed that suggested design has poor scattering parameter and weak impedance matching.



(a) (b)

Fig 2 (a) Antenna design A1 with defective ground (b) and it corresponding scattering parameters.

Next step involves cutting semi-circular notches [18] in the rectangular patch structure, as shown in figure 3 (a). Notches having radius 3mm are made from the 3 sides and a slot is created in the center of the radiating patch. As shown in figure 3 (b) by adding circular notches and slot, the antenna excites at third resonant frequency. It can be observed from the result that Antenna 2 resonates at frequencies at 3.3 GHz, 6.9 GHz and 8.9 GHz but the second and third band have poor impedance.

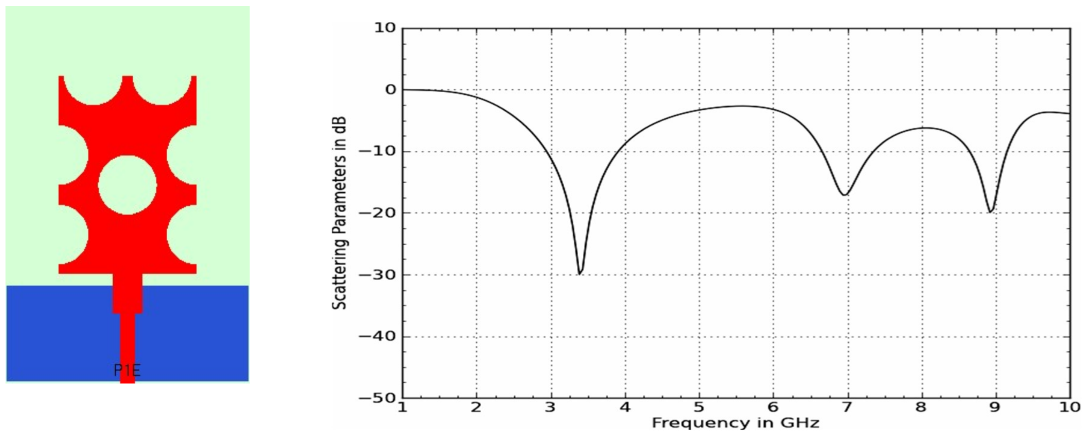
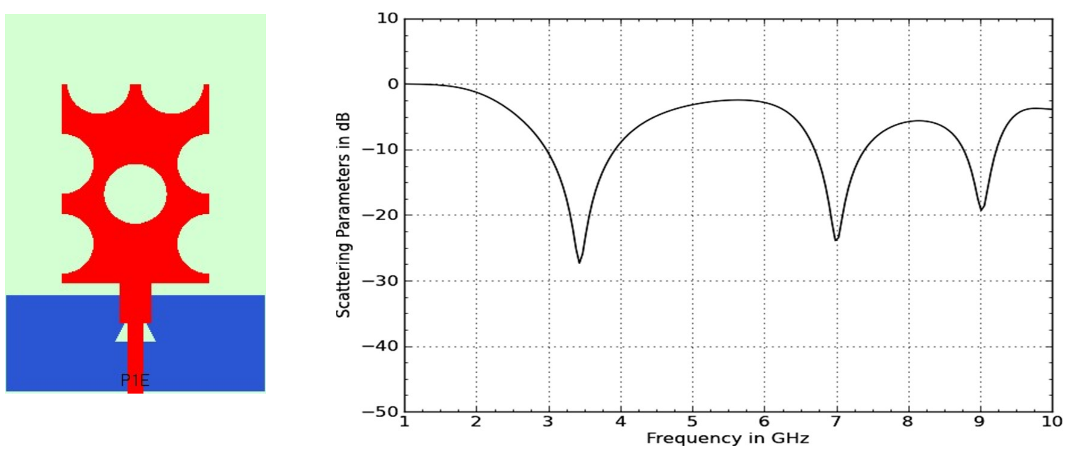


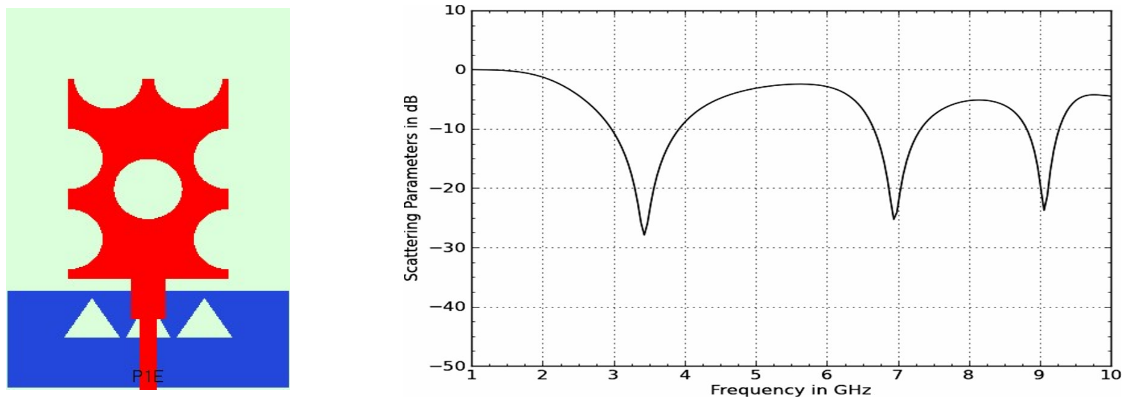
Fig. 3(a) Antenna design A2 with defective ground (b) and its corresponding scattering parameters.

Further a triangle cut is introduced in the DGS underneath the feed [19] line as shown in figure 4 (a) for better impedance matching while keeping the bands wider. As demonstrated in figure 4 (b), by removing the triangular slot in the DGS there has been a significant improvement in the return loss of first two resonant frequencies and better impedance matching has been achieved but 3rd band still requires improvement [20].



(a) (b)

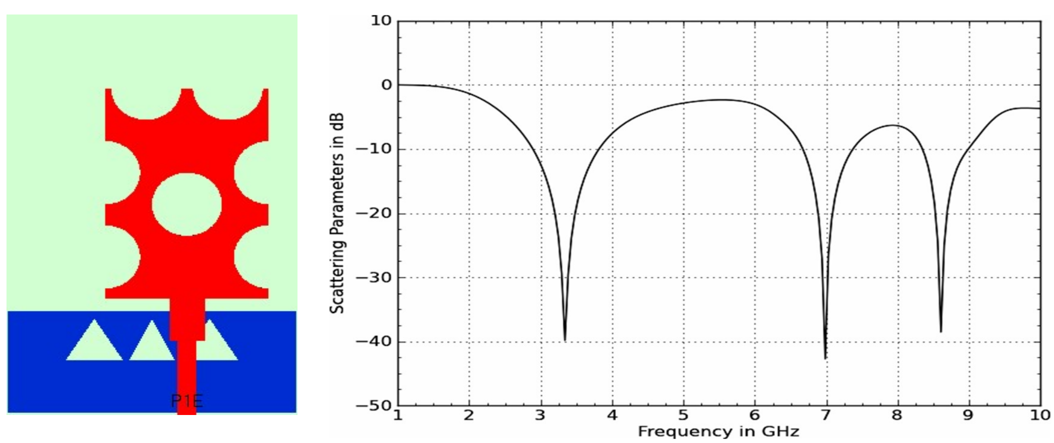
Fig. 4 (a) Antenna design A3 with defective ground (b) and its corresponding scattering parameters.



(a) (b)

Fig 5 (a) Antenna A4 with three triangular slots (b) its corresponding scattering parameters.

Finally, antenna A5 is designed as shown in Fig 6 (a) by combining the optimized results of variations in the ground length and by shifting the patch [21] and adjusting L*g* to 9.7 mm, L_2 to 11 mm and W_2 to 14.7 mm respectively. It can be observed from figure 6 (b) that all three bands of the suggested design to have improved return loss, excellent impedance matching and larger bandwidth.



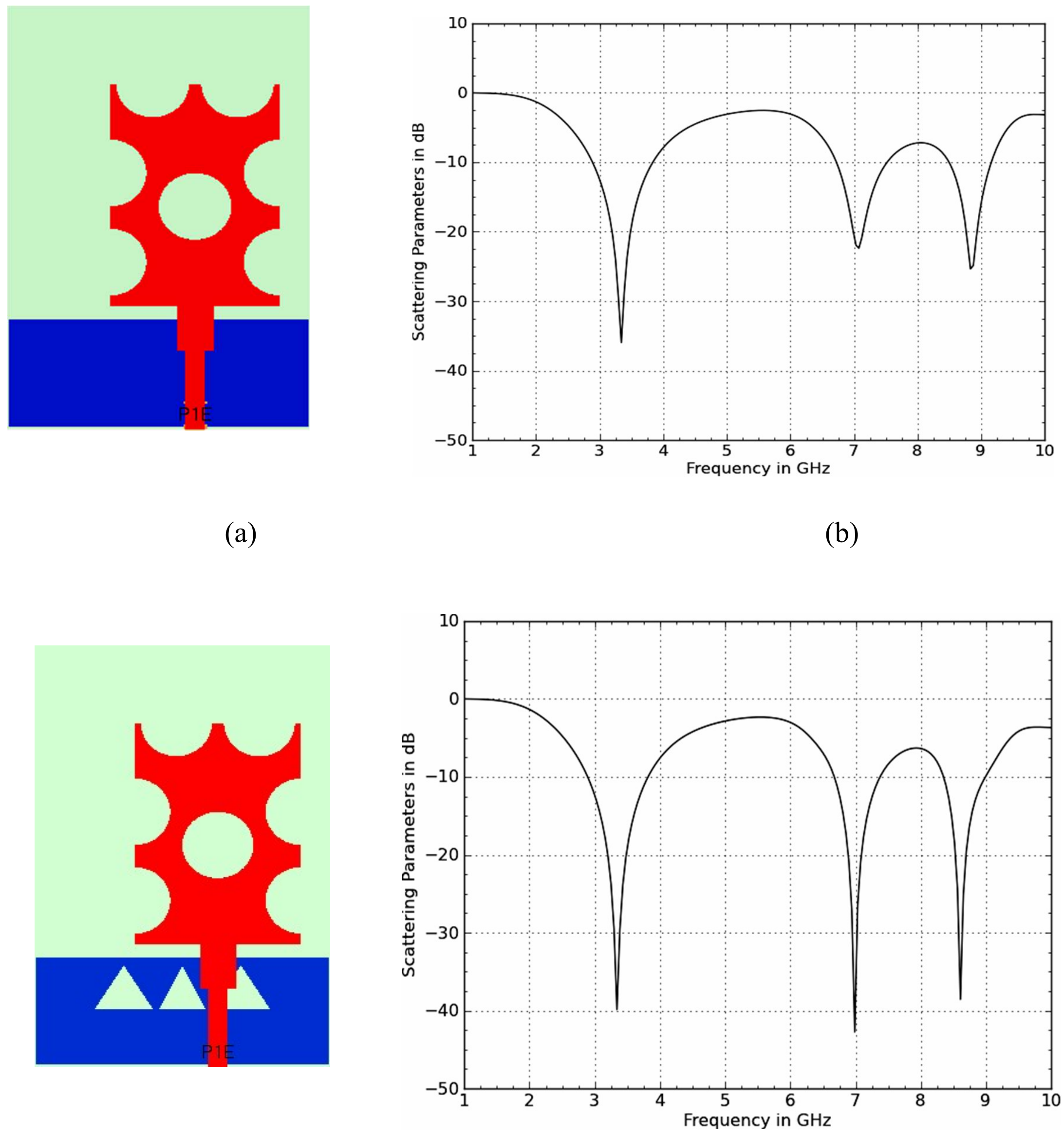
(a) (b)

Fig 6 (a) Antenna A5 by shifting patch and (b) its corresponding scattering parameters.

3. Comparison of Proposed Antenna With And Without Triangular Slots in the ground plane

Two structures of the proposed design with circular notches and circular slot in the DGS ground plane are shown in figure 7(a) and (b). It is clearly observed from figure 7 (c) that etching triangle slots in the ground plane results in improving [22] the scattering parameters to about -

40 dB for all 3 operating bands in comparison to return loss obtained without triangle slots as demonstrated in figure 7 (d).



(a) (b)

(c) (d)

Fig 7. (a) Proposed structure (b) its corresponding scattering parameters
(c) Proposed structure with triangular slots (d) and its corresponding scattering parameters

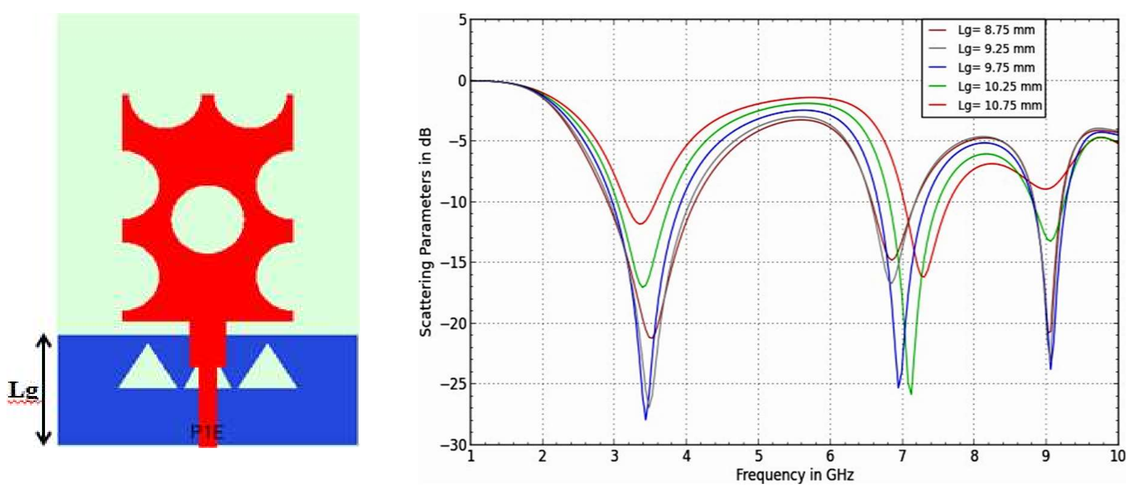
Table 3 Comparison between simulation results obtained for proposed antenna without and with triangle slots

Parameters	Simulated			Measured		
	1st Resonance	2nd Resonance	3rd Resonance	1st Resonance	2nd Resonance	3rd Resonanc

						e
Resonance frequency (GHz)	3.33	6.97	8.59	3.205	7.885	9.775
Scattering Parameter (dB)	-40	-43	-38.71	-35.9	-40	-17.72
Bandwidth (GHz)	0.950	0.779	0.653	0.854	1.432	0.672

4. OPTIMIZED RESULTS

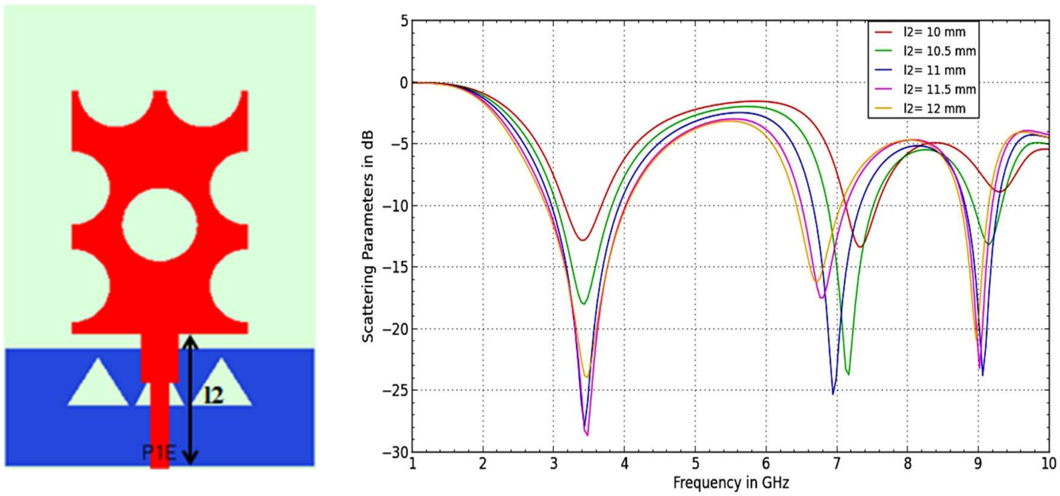
In order to further improve the performance parameters and to optimize the results, shifting of patch was performed by moving it *x* and *y* direction and by extending the DGS in *y* direction. Figure 8 shows the outcome of extending the ground length Lg to different dimensions of 8.75 mm, 9.25 mm, 9.75 mm, 10.25 mm and 10.75 mm. It is observed that with the ground length Lg=9.75 mm best simulation result has been obtained as all the three bands shows improved scattering parameters and impedance matching [23].



(a) (b)

Fig 8 (a) Extension in DGS and (b) Optimized scattering parameters

Figure 9 shows the outcome by varying the length L_2 to diverse dimensions of 10mm, 10.5mm, 11mm, 11.5 mm and 12mm. Its observed that with length L_2=11mm, best simulation result has been obtained.



(a) (b)

Fig 9 (a) Shifted patch in *y*-direction (b) Optimized scattering parameters

Fig 10 shows the outcome of relocating the structure by altering the width W_2 to dimensions 10.7 mm, 11.7 mm, 12.7 mm, 13.7 mm, 14.7 mm. It is observed that with width w_2=14.7 mm, best simulation result has been obtained. By combining the optimized results of variations in the ground length and shift in the patch and adjusting L_g, L_2 and w_2 to 9.7 mm, 11 mm, and 14.7 mm respectively a concluding design has been proposed as shown in Fig 10(a) and its optimized return loss results are shown in fig 10(b).

(a) (b)

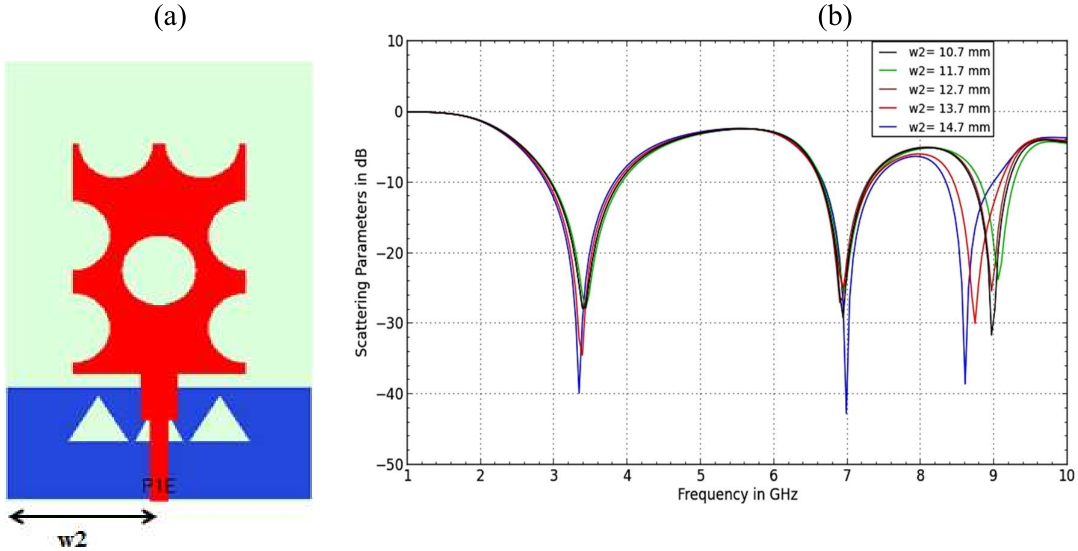
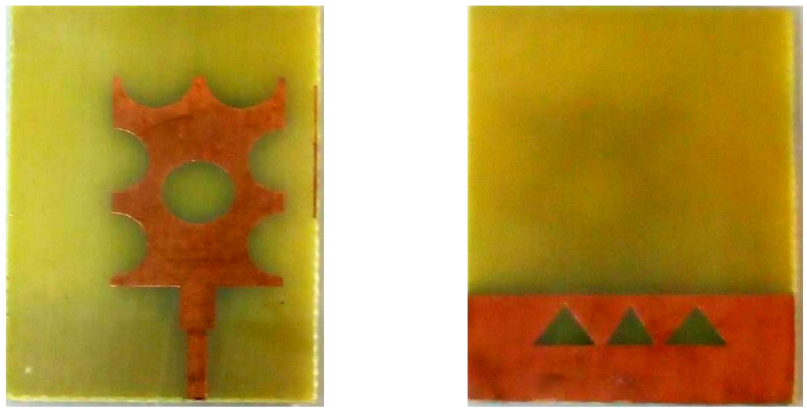


Fig 10 (a) Shifted patch in *x*-direction (b) Optimized scattering parameters

5. DEVELOPING PROTOTYPING AND EXPERIMENTAL WORK

To authenticate the simulation results, prototype of the suggested structure has been developed.

Real time measurements were carried out by testing it on VNA. A comparative study of the simulated and measured results were obtained has been presented and discussed. Front and back of the fabricated antenna has been shown in Fig 11(a) and (b). The microstrip feed line is used for feeding the patch antenna.



(a) (b)

Fig 11 Fabricated antenna (a) front view (b) back view

Measured results of the suggested antenna are shown in Fig 12. Comparative study of these results is shown in Table 5. Any variation in the is due to the presence of solder bumps, skin effect losses of the cable and other environmental factors which were not counted during the simulation [24].

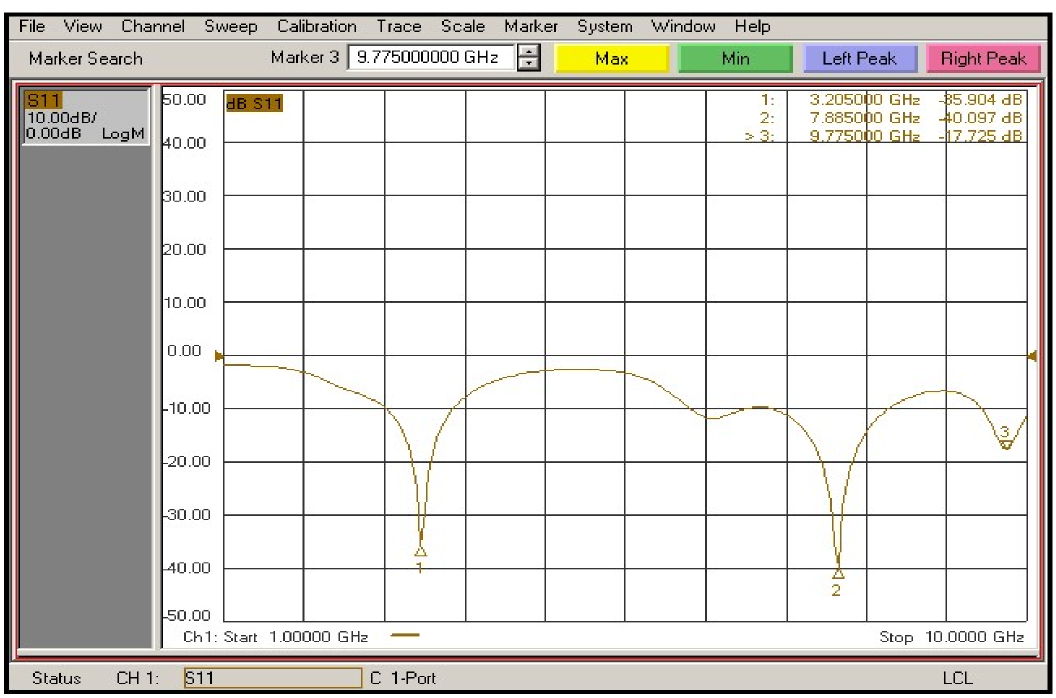


Fig 12 Measured results of antenna prototype as obtained from the VNA instrument

Table 5 Comparison between simulated and measured result with DGS

Parameters	Simulated			Measured		
	1st Resonance	2nd Resonance	3rd Resonance	1st Resonance	2nd Resonance	3rd Resonance
Resonant frequency (GHz)	3.33	6.97	8.59	3.205	7.885	9.775
Scattering parameter (dB)	-40	-43	-38.71	-35.9	-40	-17.72
Bandwidth (GHz)	0.950	0.779	0.653	0.854	1.432	0.672

CONCLUSION

In this research work, instead of using conventional patch design, a rectangular patch with circular notches and center slot in the radiating structure and with three triangle slots in the DGS has been presented. The proposed antenna structures have been designed by using Empire XPU simulation software and simulation results have been obtained. Then optimized results are obtained by varying ground length and dimensions of the microstrip patch. Thus, a miniaturized triple band antenna has been obtained which has bandwidths of 0.934 GHz, 0.732 GHz and 0.653 GHz with centre frequencies at 3.33 GHz, 6.97 GHz and 8.59 GHz and return loss for the three operating bands are -40 dB, -43 dB and -38.71 dB respectively which can be used for ultra-wideband and possible future 5G applications.

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