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Coplanar Waveguide Fed Circularly Polarized Notch Band Antenna with Defected Ground Structure

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ABSTRACT

A compact printed wideband antenna with circular polarization is designed and the antenna parameters are analyzed in this work. Finite Element method based HFSS tool is used to design and simulate the antenna model. A basic structure of rectangular monopole is converted into a trapezoidal shape with tapered step ground. Different iterations of radiating element as well as defected ground structures are examined in this work to analyze the circular polarization characteristics of the antenna. A peak realized gain of 4.3dB and peak directivity of 3.8dB is attained from the current designed models. The design models are optimized and prototyped on FR4 substrate for measurement validation. By incorporating Split ring resonator (SRR) notch band characteristics are attained in the proposed wideband antenna.

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1. INTRODUCTION

Circular polarization has acknowledged as one of the extremely required characteristics of an ultra-wideband antenna [1-2]. Though, circular polarization which is the restricting instance of the most common elliptical polarization is fairly hard to accomplish because of the stringent demands on the phase and is understood just in the vicinity of two orthogonal components of the electric field vector in exact phase quadrature [3-8]. Generally, circularly polarized antennas were utilized for point to point satellite communications and accordingly, the antennas used to understand circular polarization had no space restrictions and could offer to be large [9-12]. Crossed dipoles, Archimedean Spirals and Yagi-Uda’s gave the required circular polarization characteristics. Additionally, the issue of spectrum by Federal Communications Commission (FEC) for Personal Area Network (PAN) operations has employed an increasing demand on the flexibility of the basic microstrip patch antenna need to be compact in size, robust in design and almost omnidirectional in radiation while in the meantime providing a large impedance bandwidth to fit for a numerous applications in the ultra-wideband region [13-18].

In this paper, basic structure of rectangular monopole is converted into trapezoidal shape with tapered step ground. Different iterations of radiating element as well as defected ground structures are examined in this work to analyze the circular polarization characteristics of the antenna. A defected structure etched in the metallic ground plane of a microstrip line is one of the smart solutions. It provides deep and extensive stop band, sharp cutoff with its compact size to encounter evolving applications. Current model consisting of a compact ultra-wideband uses an individual split ring resonator which is exited by a monopole antenna.

2. MATERIAL AND METHOD

In Figure 1, the antenna model 1 shows the trapezoidal shape slot antenna on defected ground structure. The antenna is designed on FR4 substrate of dimensions 60 x 50 x 1.53 mm. A ground is also printed in the same side of substrate along with radiating patch element. A rectangular slot of dimensions 40 X 23 mm is etched on ground plane and is excited by CPW feed line. The feed line is ended with a trapezoidal shaped tuning stub extended into the center of slot. The rectangular slot is cut into two circular arcs at lower left corner and upper right corner and having different radii to serve as perturbations required for recognizing circular polarization. The distance between the stub and the ground plane is represented as ‘S’ and the spacing between the feed line and the ground plane is represented by ‘G’. The trapezoidal shape stub has widths of Ws1 and Ws2 and has length as Ls. The parameter values are shown in Table 1.

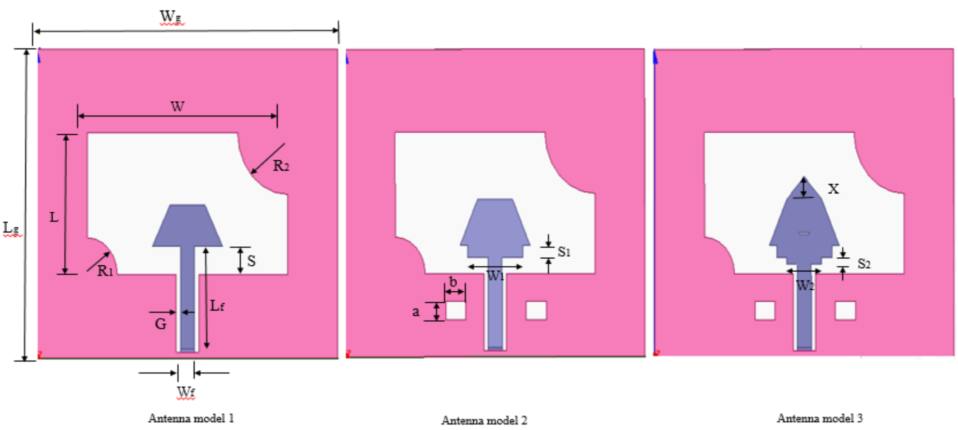

Figure.1 Tapered Ground Monopole, (a) Trapezoidal Monopole, (b) Trapezoidal Stub Monopole with DGS, (c) Trapezoidal Stepped Stub Monopole with DGS

Table 1. Antenna Model 1 Dimensions

Parameter	Dimensions(in mm)
Wg	60
Lg	50
W	40
L	23
R1	6
R2	10
Lf	16.62
Wf	2.8
S	3.68
G	0.85
Ws1	7
Ws2	14
Ls	7.5
H	1.53

From the antenna model 1 shown in Figure 1, the slot perimeter Sper and the stub height hs can be calculated as

$$S_{per} = 2L + 2W - 2R1 - 2R2 + \frac{\pi}{2}(R1 + R2) \quad \text{----} \quad (1)$$

$$h_s = S + \sqrt{L_s - \frac{(W_{s1} - W_{s2})^2}{2}} \quad \text{------} \quad (2)$$

The slot perimeter can be assessed to two guided wavelengths at the lower resonant frequencies. The lower resonant frequency is given as f1 and on the upper side, the monopole like operation of antenna takes place and the upper resonant frequency is given by

$$f_1 = \frac{2C}{S_{per}\sqrt{\epsilon_{reff}}} \text{-----} \qquad (3)$$

$$f_2 = \frac{C}{4_{hs}\sqrt{\epsilon_{reff}}} \text{------} \qquad (4)$$

In the above expression 'c' is the velocity of light in free space and εreff is the effective relative permittivity of the substrate and it is given by the

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + \frac{12h}{2}\right]^{\frac{-1}{2}} \text{----} \qquad (5)$$

Antenna model 1 is modified further to improve impedance bandwidth and circular polarization characteristics. Accordingly, the two modified version of antenna model 1 are designed they are named as antenna model 2 and antenna model 3. The antenna model 2 has step size 11 X 2 mm is added to trapezoidal shaped tuning stub, two rectangular slots of dimensions 3 X 4 mm are cut in the ground plane. In the antenna model 3, one more step is added to the tuning stub and a slit of dimensions 2 x 0.2 mm is cut at the center of trapezoidal tuning stub. The modified dimensions of antenna model 2 and antenna model 3 are shown in Table 2.

Table 2: Modified Dimensions (in mm) of antenna model 2 and antenna model 3

Parameter	W1	S1	W2	S2	X	a	b
Antenna model 2 dimensions	11	2	-	-	-	3	4
Antenna model 3 dimensions	11	2	7	1	3.6	3	4

3. RESULTS AND ANALYSIS

Figure 2 show the reflection coefficient of the antenna iterations shown in Figure 1. Antenna model 1 is giving a bandwidth of 4.8GHz and antenna model 2 is giving the bandwidth of 5.4 GHz. By changing the radiating element shape and by incorporating defected ground structure we attain additional resonant band for antenna model 2. To improve the bandwidth characteristics of the designed antenna model, we incorporated additional changes in the patch element by taking tapered step structure. Antenna model 3 is providing bandwidth enhancement of 7.2 GHz which is almost double to the basic antenna model 1.

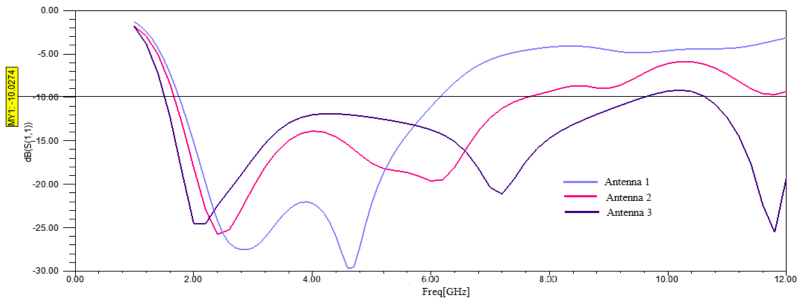

Figure 2. Reflection coefficient of antenna models 1, 2 and 3

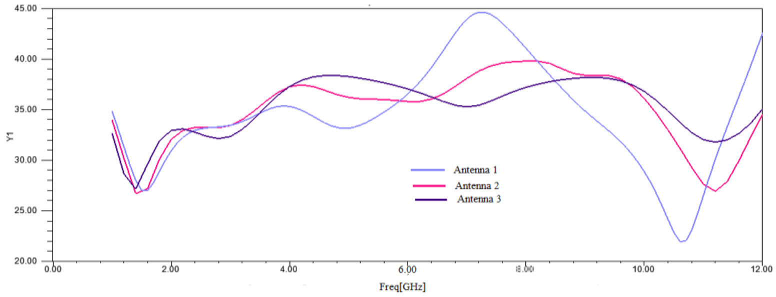

Figure 3. Impedance Vs Frequency of antenna models 1, 2 and 3

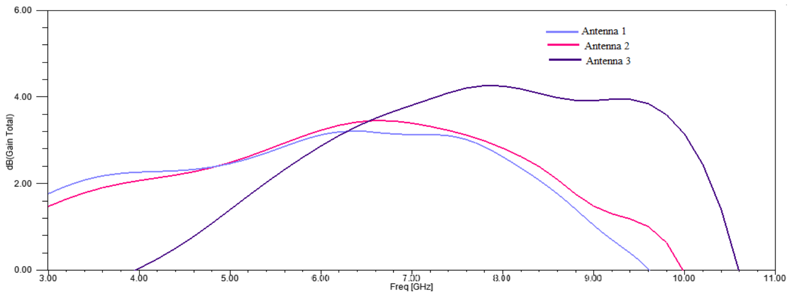

Figure 4. Gain of antenna models 1, 2 and 3 with respect to resonant frequency

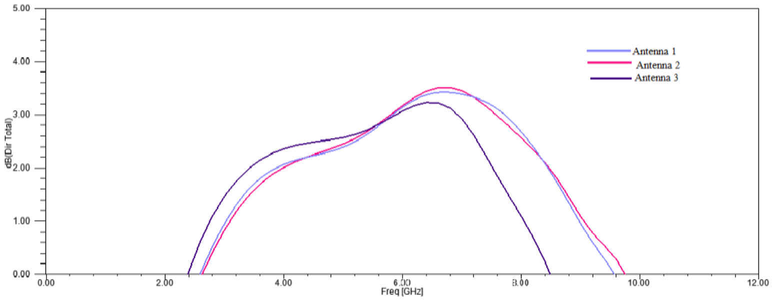

Figure 5. Directivity of antenna models 1, 2 and 3 with respect to resonant frequency

An impedance bandwidth of 120% is attained from the modified structure of antenna model 3. Figure 3 shows the impedance characteristics of the antenna models in Figure 1. All the models are showing an average impedance of 40 Ω. Figure 4 shows the gain characteristics of the designed antenna models with respect to operating frequency band. Model 1 is showing peak realized gain of 3dB whereas model 2 is showing 3.5dB and the modified model 3 is providing the peak gain of 4.2 dB. Figure 5 shows the directivity of the antenna models with a change in frequency. Antenna model 2 is giving superior directivity value when compared with the other models. A peak directivity of 3.5dB is attained from model 2.

The circular polarization characteristics of the designed models can be observed through axial ratio curve of Figure 6. In the operating band of this antenna models only at certain frequency bands, the designed antennas are showing circular polarization characteristics. 3 dB cutoff circular polarization characteristics at certain frequency bands can be observed from Figure 6. Figure 7, 8 and 9 shows the radiation characteristics of the designed antenna models at center resonant frequency in the operating band. All these models are providing almost omnidirectional radiation pattern in H- plane and monopole like radiation in the E-plane. Figure 10 shows the surface current distribution of designed antenna models and by analyzing current distribution characteristics at different phases we examined the circular polarization from these models.

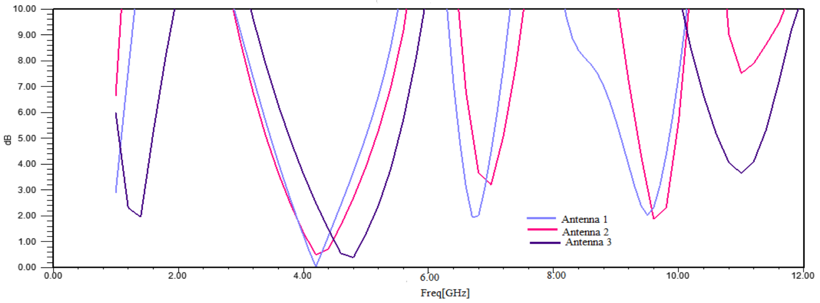

Figure 6. Axial ratio of antenna models 1, 2 and 3 with respect to resonant frequency

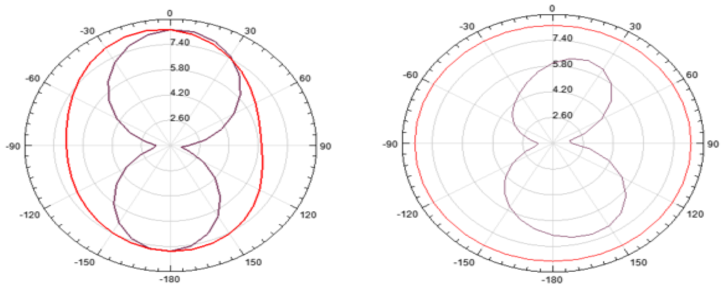

Figure 7. Radiation pattern of antenna model 1 at 4 GHz

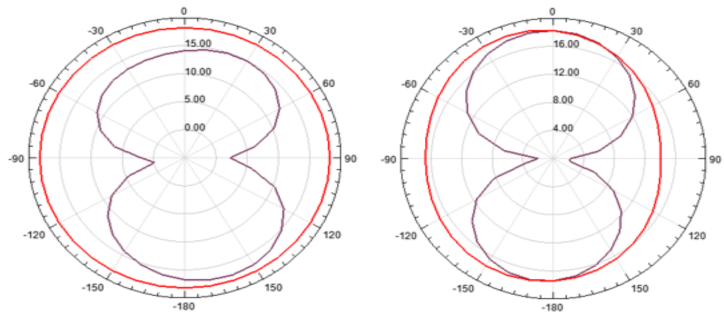

Figure 8. Radiation pattern of antenna model 2 at 4 GHz

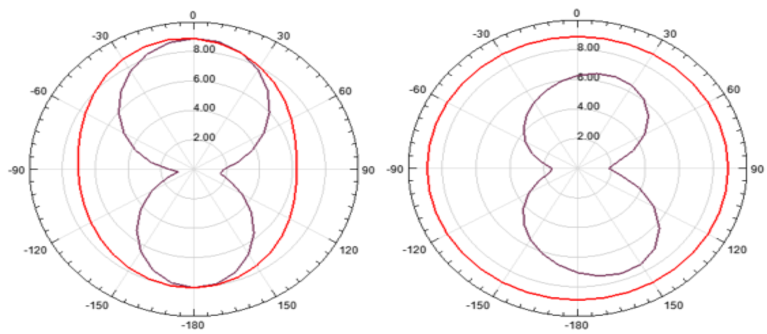

Figure 9. Radiation pattern of antenna model 3 at 4 GHz

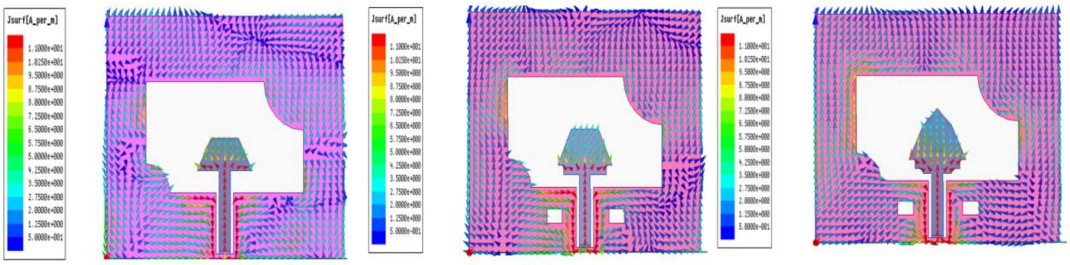

Figure 10. Current distribution of antenna models 1, 2 and 3 at 4 GHz

Figure 11 shows the modified antenna structures of basic models of 1, 2 and 3. In the modified structures, resonant frequencies are notched in the wide band by incorporating a split ring resonator shaped slots on the radiating element. The initial designs are modified by using a split ring resonator (SRR) which is placed almost on the radiating element to notch a particular band of frequencies and to observe the notch band characteristics in the designed wideband antenna. Figure 12 shows the corresponding reflection coefficient characteristics of the notch band antennas. The notching is occurred between 5 to 6 GHz which is popularly known for WLAN communication band. With the antenna model 6 we obtained a perfect notch band between 5.4 to 5.8 GHz (WLAN). The impedance characteristics of modified notch antennas can be observed from Figure 13.

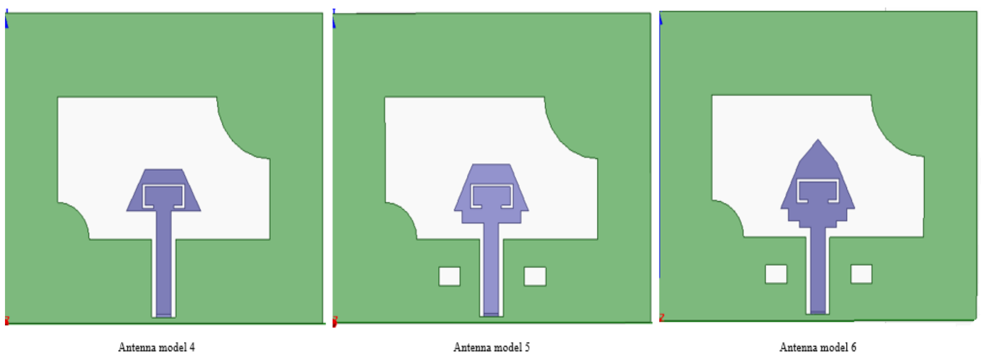

Figure 11. Modified antenna models 4, 5 and 6, (a) Trapezoidal Monopole with SRR, (b) Trapezoidal Stub Monopole with SRR and DGS, (c) Trapezoidal Stepped Stub Monopole with SRR and DGS

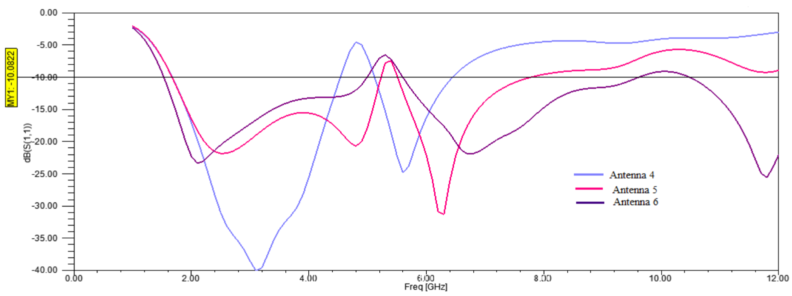

Figure 12. Reflection coefficient of antenna models 4, 5 and 6

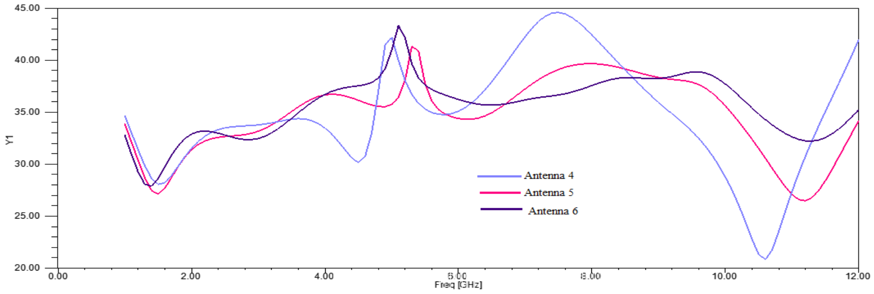

Figure 13. Impedance Vs Frequency of antenna models 4, 5 and 6

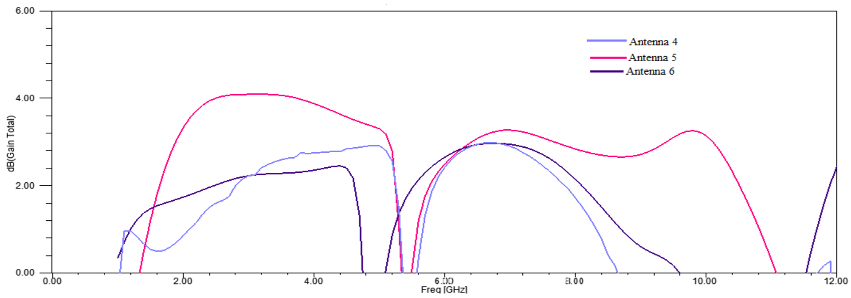

Figure 14. Gain of antenna models 4, 5 and 6 with respect to resonant frequency

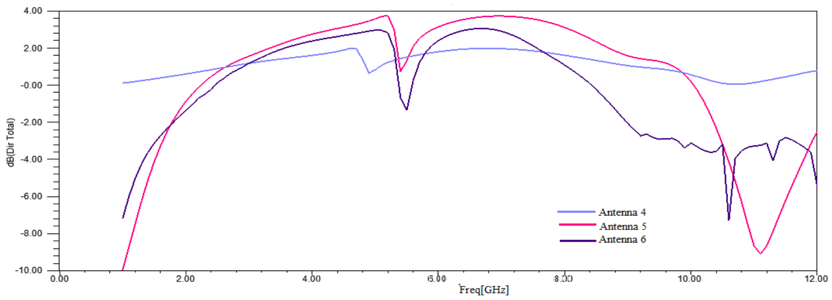

Figure 15. Directivity of antenna models 4, 5 and 6 with respect to resonant frequency

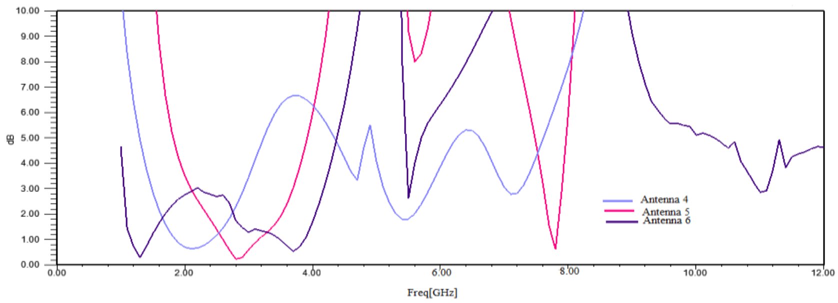

Figure 16. Axial ratio of antenna models 4, 5 and 6 with respect to resonant frequency

Figure 14 and 15 shows the gain and directivity plots of the modified notch antennas. At notch band frequencies we can observe the reduction in gain and directivity from these Figures. Figure 16 shows the axial ratio versus frequency plot of the notch band antennas. Except at notch band, at other operating bands antenna models are providing 3 dB axial ratio.

The radiation characteristics of these notch band antennas can be observed from the Figure 17 to 22 and current distribution plot for proposed model given in Figure 23. The proposed antenna model is showing omni directional radiation pattern in the H-plane and monopole like radiation in the E-plane. The surface current distribution plots are showing the current intensity accumulation at strong positions on the feed line and patch surface at different frequencies.

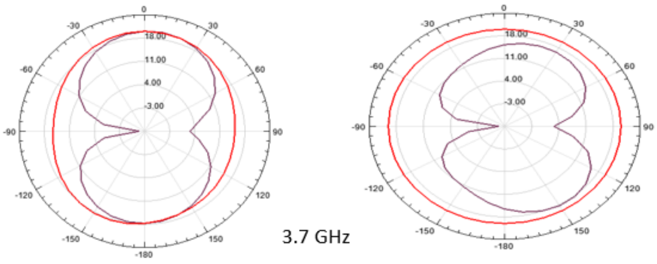

Figure 17. Radiation pattern of antenna model 4 at 3.7 GHz

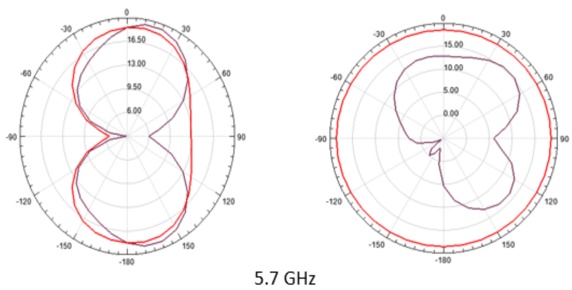

Figure 18. Radiation pattern of antenna model 4 at 5.7 GHz

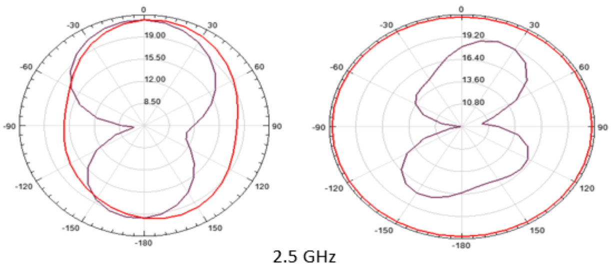

Figure 19. Radiation pattern of antenna model 5 at 2.5 GHz

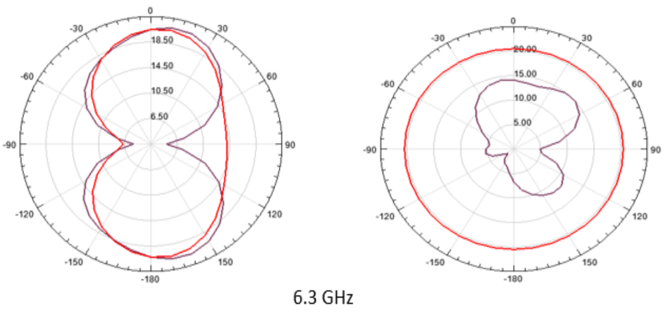

Figure 20. Radiation pattern of antenna model 5 at 6.3 GHz

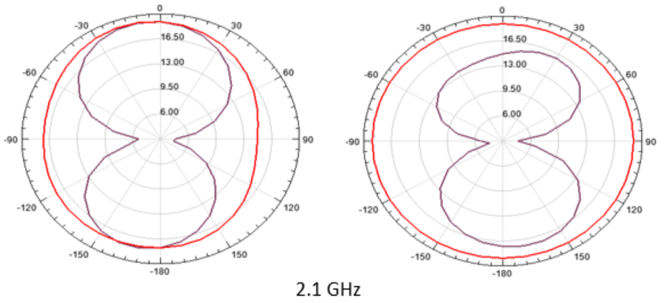

Figure 21. Radiation pattern of antenna model 6 at 2.1 GHz

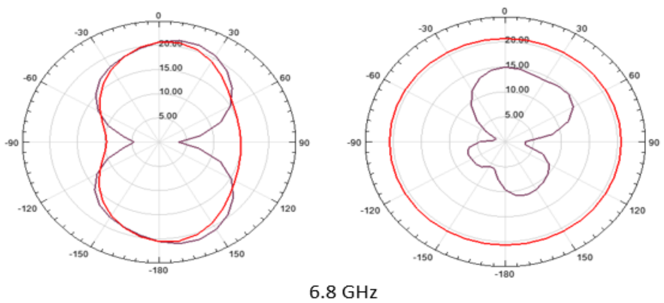

Figure 22. Radiation pattern of antenna model 6 at 6.8 GHz

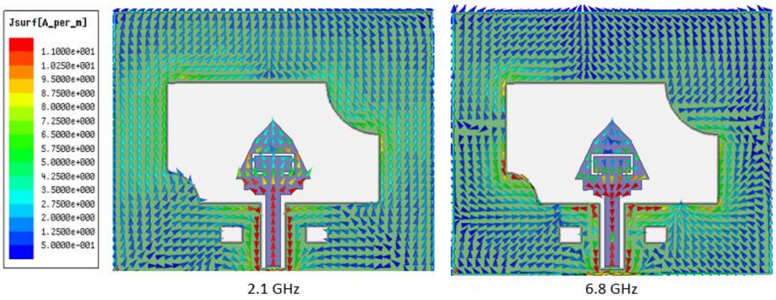

Figure 23. Current distribution of antenna model 6 at 2.1 and 6.8 GHz

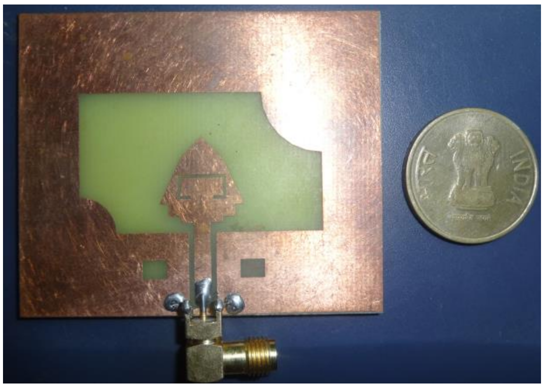

Figure 24. Fabricated Antenna

The proposed fabricated notch antenna is tested on ZNB 20 vector network analyzer and observed that the measured results are in good agreement with the simulated results. Prototyped antenna is shown in Figure 24 notching the frequency band between 4.5 to 5 GHz and the reflection coefficient is less than -10 dB in the operating band.

4. CONCLUSION

From the designed antenna models, the following conclusions were drawn:

A novel structure of trapezoidal monopole antenna with defected ground structure is designed in this work. A modified structure is drawn from the basic structure with split ring resonator to notch frequency band from 4.5 to 5 GHz and achieved circular polarization.

Peak realized gain of 4 dB and directivity of 3.8 dB is attained from the modified antenna structure. Antenna is showing omni directional radiation pattern in H-plane and dipole like radiation in the E-plane. At notch band antenna is showing low gain with disturbed radiation pattern. Circular polarization with axial ratio bandwidth of 45% and 68% is attained for the proposed antenna in both the pass bands.

The proposed optimized antenna model is fabricated on FR4 substrate and tested for reliability on ZNB 20 vector network analyzer. Measured reflection coefficient is showing bandwidth of 3.8 GHz at first resonant band and 4 GHz at second resonant band. The measured results are in very good agreement with simulated results taken from HFSS.

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