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RESEARCH PAPER

Triple band circularly polarized compact microstrip antenna with defected ground structure for wireless applications

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Asymmetric slits loaded irregular shaped microstrip patch antenna with three different ground structures is proposed. All three antennas show triple band characteristics. First antenna with regular ground plane resonates at 1.95, 2.4, and 4.90 GHz with good radiation characteristics and shows right-hand circular polarization at 1.95 GHz. 18.75% of compactness is achieved with triple band characteristics. Further, same patch is used with different defected ground structures. Second antenna resonates at 1.85, 2.4, and 4.85 GHz with suppressed cross-polarization level and antenna shows right-hand circular polarization at 1.85 and 4.85 GHz. Compactness is further improved to the value of 22.91%. The third antenna resonates at 1.95, 2.4, and 4.85 GHz with better gain and radiation characteristics and antenna shows right-hand circular polarization at 1.95 and 2.4 GHz. The small frequency ratio f_2/f_1 is achieved and the value of f_2/f_1 is 1.29 and 1.23 for second and third configuration, respectively. Proposed structures show right-hand circularly polarized with suppressed left-hand circularly polarized radiations and suitable for fixed mobile wireless communication applications. All structures are analyzed using Ansoft HFSS v.14 based on finite element method and measured results satisfy the simulated results.

Keywords: Triple band, Circular polarization, Defected ground structure, Microstrip patch antenna

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I. INTRODUCTION

Microstrip antennas are earning major consideration for modern wireless communication due to their several advantages like low profile, light weight, easy fabrication, and MMIC (Monolithic Microwave Integrated Circuit) compatibility [1, 2]. With the rapid development of wireless communication, modern transceiver systems need compact multiband antenna with excellent radiation characteristics. These antenna acts as an alternative for two or more separate antennas thus miniaturizing operating equipments. Several designs have been proposed as multiband antennas [3–7]. A design of the band-rejected function has been proposed by inserting the strips on a wideband antenna [4]. A trapezoidal ground plane also has been used for the WLAN/WiMAX applications [5]. Multiband has been achieved using defected ground structure (DGS) [3–6]. Triple band has been achieved in monopole microstrip antenna using DGS [8]; however, it shows a quite high level of cross-polarization. DGS has been gained a lot of attraction of researchers for improving the deficiencies of conventional microstrip patch antenna (MPA), i.e. narrow bandwidth, single operating frequency, low gain, cross-polarized radiation, etc. [9–19]. The cross-polarized radiation has been theoretically studied in [9–10]. The suppression of cross-polarized radiations has been reported using DGS [9–11]. A suppression of 5 dB in cross-polarization level has been achieved using dot shaped defects in ground plane [9], and improved to the value of 10–12 dB using arc-shaped DGS [10]. Theoretical analysis has been reported for the microstrip-line fed DGS antenna and isolation of 35 dB is achieved between co-polar and cross-polarization level [11].

Latest communication devices should be versatile thus requires circularly polarized microstrip antennas. Circularly polarized antenna provides a powerful modulation scheme in active microwave systems [20, 21]. Circular polarization (CP) also combats multipath fading by introducing polarization diversity in radio propagation environment [22] Single feed cross slot loaded circularly polarized compact microstrip antenna has been proposed [23]; however, it operates at single frequency. Multiband microstrip antennas with CP also have been reported [24–29].

In this paper, triple band compact MPA is proposed. Asymmetric slits are integrated to achieve the CP at first operating frequency. Further, ground plane is made defected to achieve the CP at other two frequencies. Three antenna

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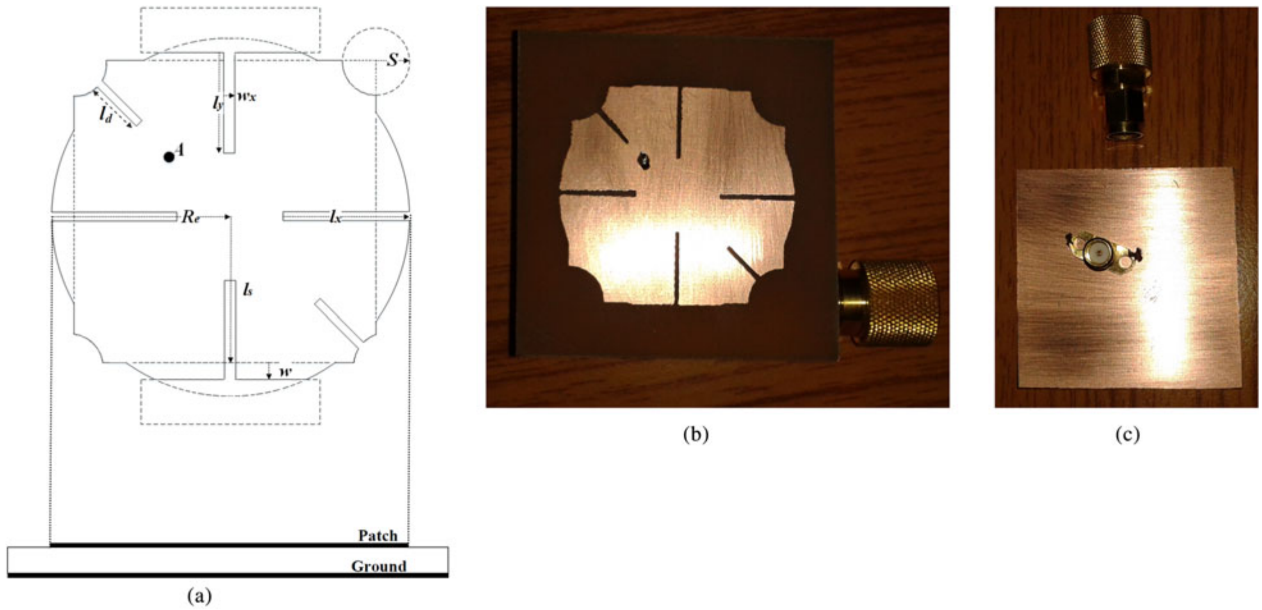

Fig. 1. Structure of the proposed antenna Ant1 (without DGS); (a) schematic, (b) top view, (c) bottom view.

structures with different ground shapes are proposed. Frequency dependent design equations for the defected ground plane are presented. Cross-polarization level is suppressed using DGS. The proposed structure is simulated and optimized using finite element method (FEM) based simulator Ansoft HFSS v.14 [30]. Antennas are fabricated on FR-4 epoxy substrate. The experimental results show good agreement with simulated results.

II. ANTENNA CONFIGURATION AND DESIGN

In this section, the designs of proposed antennas are described. Figure 1(a) shows the schematic of the proposed antenna with regular shaped ground plane and antenna is referred as Ant1. A circular patch of radius R_e is combined with a square patch of dimension $2l_s \times 2l_s$. The centers of

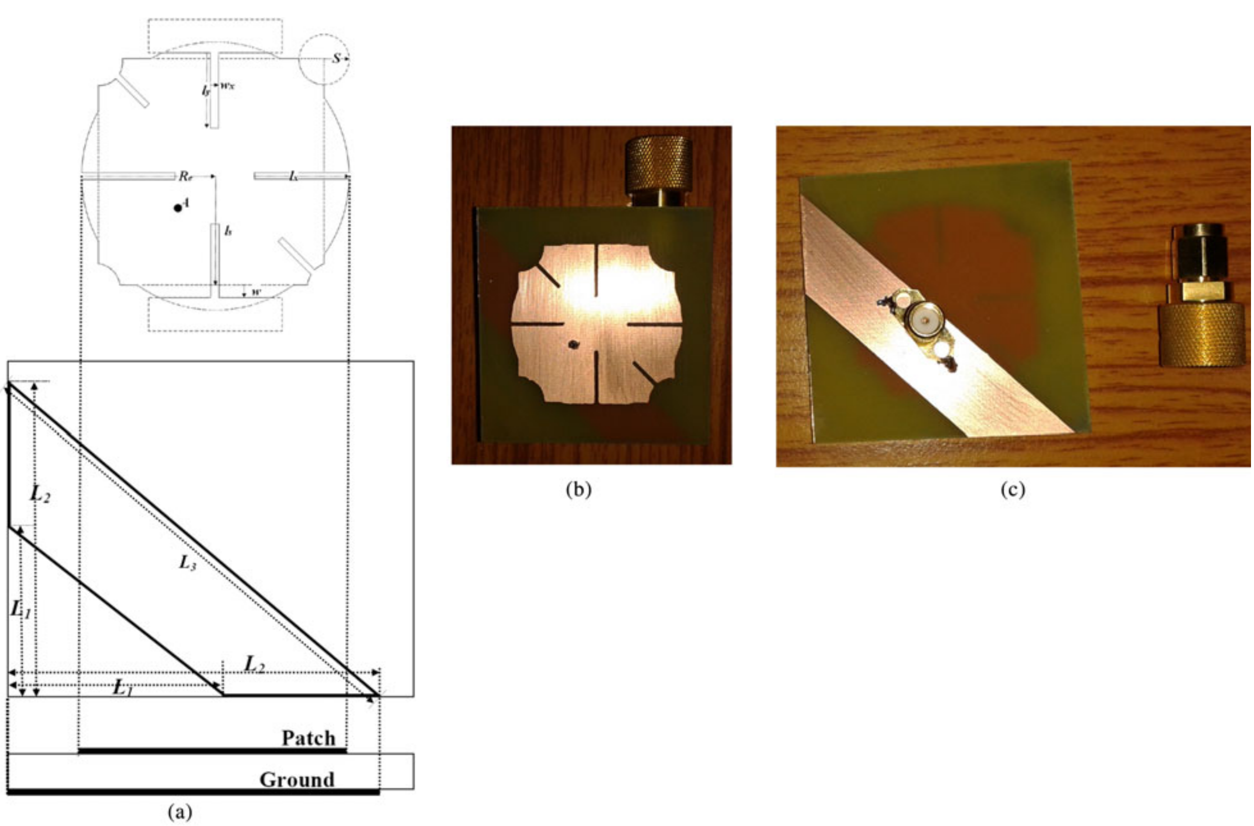

Fig. 2. Structure of the proposed antenna Ant2 (with trapezoidal shaped DGS); (a) schematic, (b) top view of fabricated Ant2, (c) bottom view of fabricated Ant2.

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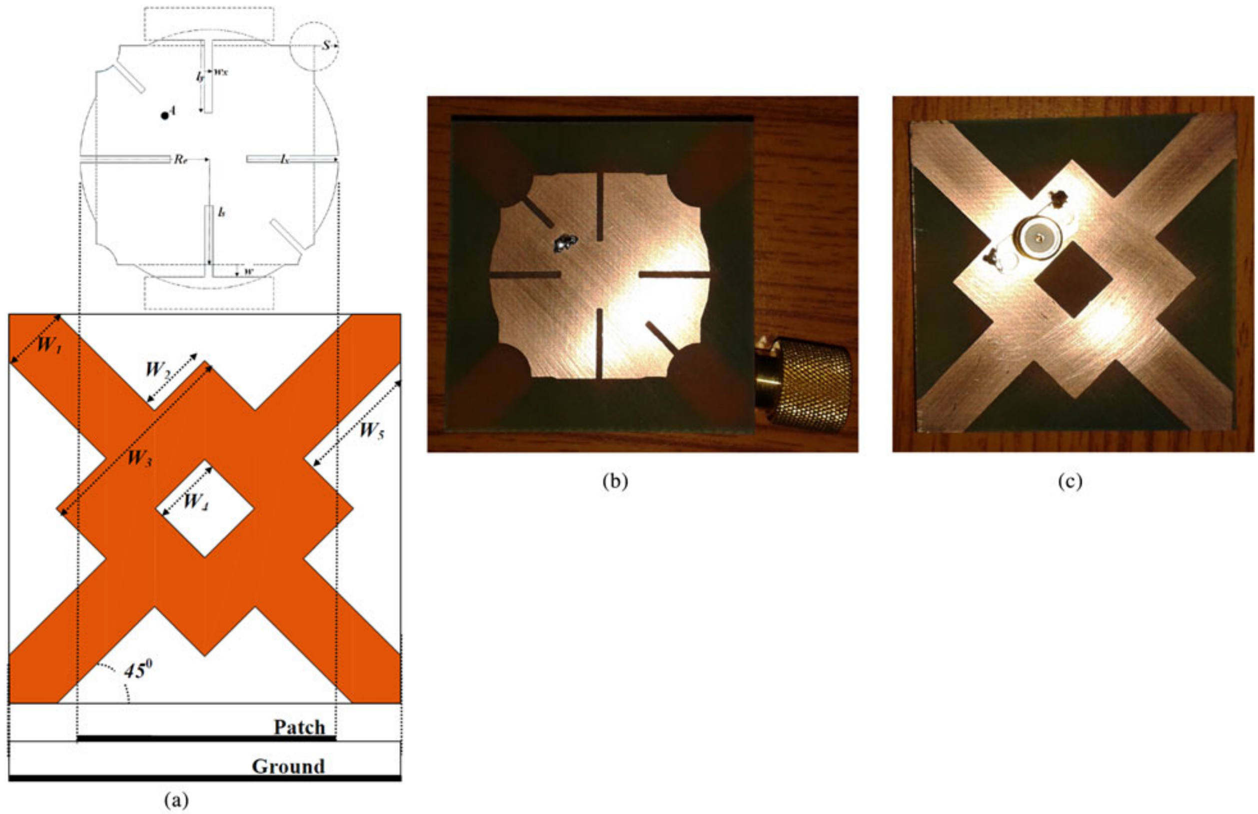

Fig. 3. Structure of the proposed antenna Ant3 (with DGS); (a) schematic, (b) top view of fabricated Ant3, (c) bottom view of fabricated Ant3.

Table 1. Design specifications.

Parameter	(mm)	Parameter	(mm)	Parameter	(mm)	Parameter	(mm)
l_x	10.69	w_x	1	w_5	15.63	R_e	16.50
l_y	10.30	w_1	8	w_4	7.82	L_1	28.27
l_d	6.23	w_2	8.35	S	5	L_2	43.73
l_s	15	w_3	25.40	w	0.3	L_3	61.85

square and circle are coinciding and all four corners of the square are circularly truncated with arc of radius *S*. Circular patch is further truncated with two rectangles by the distance of *w* from horizontal sides of the square. Further, six slits of width w_x are embedded in the structure. l_x, l_y, and l_d is the length of the horizontal, vertical, and diagonal slits. Antenna is fed with a coaxial probe at the location of *A*. Ant1 has regular ground plane of the 46 × 46 mm².

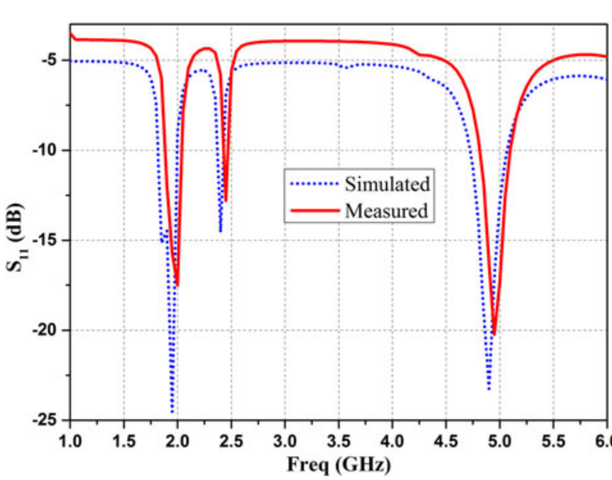

Fig. 4. Simulated and measured S11 variations with frequency of Ant1.

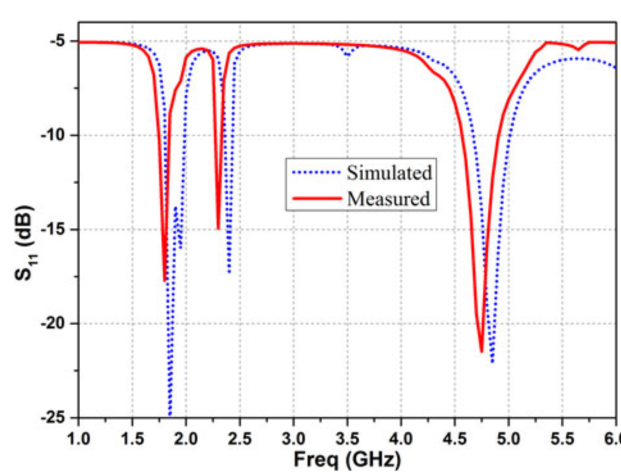

Fig. 5. Simulated and measured S11 variations with frequency of Ant2.

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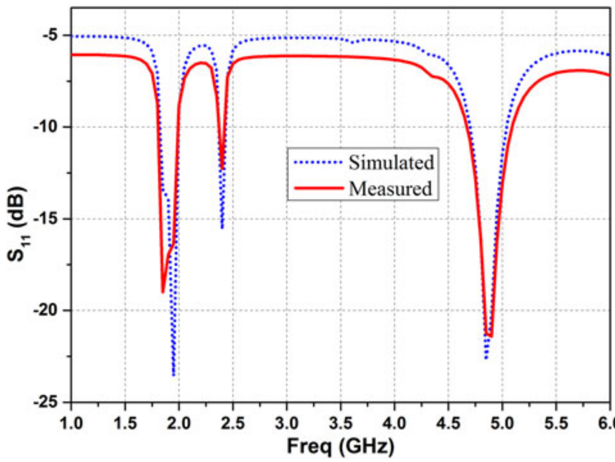

Fig. 6. Simulated and measured S11 variations with frequency of Ant3.

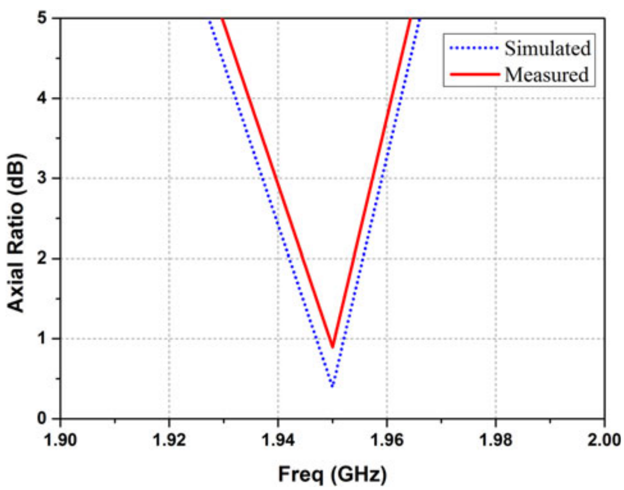

Fig. 7. Simulated and measured Axial Ratio variations with frequency of Ant1 (without DGS).

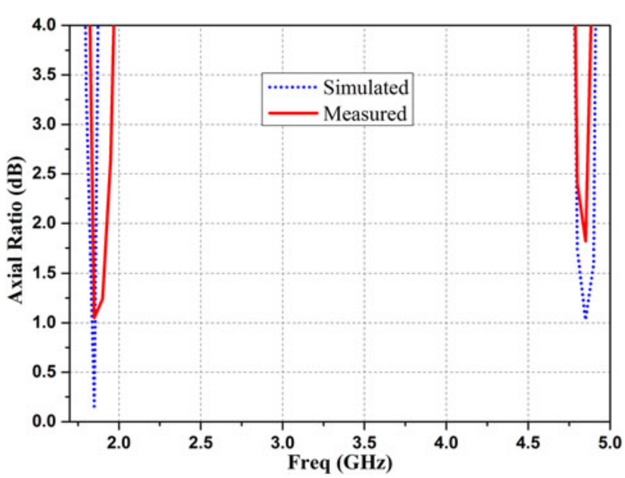

Fig. 8. Simulated and measured Axial Ratio variations with frequency of Ant2 (with trapezoidal shaped DGS).

Further, same patch is proposed with a DGS and a trapezoidal shaped ground plane is used with coaxial probe feed. The proposed structure with trapezoidal shaped ground plane is referred as Ant2. The schematic of the Ant2 is shown in

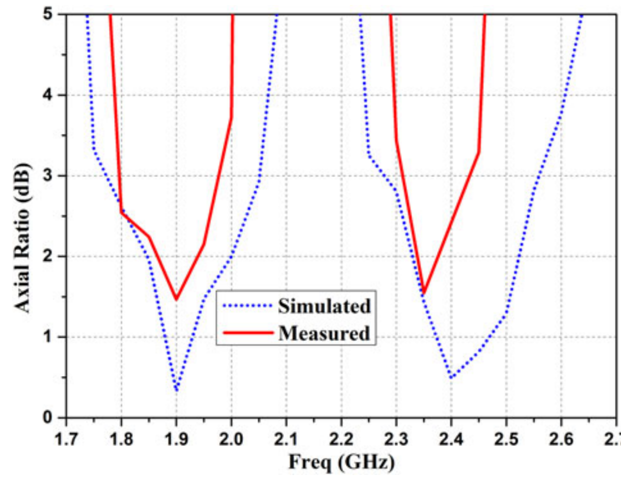

Fig. 9. Simulated and measured Axial Ratio variations with frequency of Ant3 (with DGS).

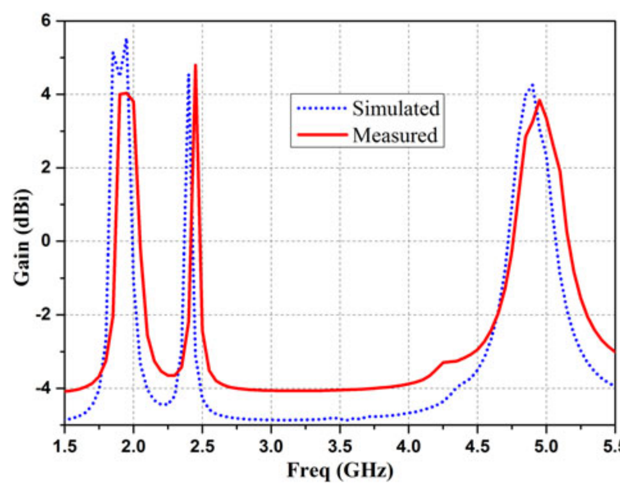

Fig. 10. Simulated and measured Antenna Gain variations with frequency of Ant1.

Fig. 2(a). The inclined length of trapezoidal is $(L_2 - L_1)$ and trapezoidal ground is located at the position of L_1 from the left-bottom corner of the substrate. The length $(L_2 - L_1)$ is taken as the quarter wavelength at third resonant frequency of Ant2.

$$(L_2 - L_1) = \frac{\lambda_{32}}{4} = \frac{c}{4.f_{32}}, \tag{1}$$

where, c, λ_{32}, and f_{32} are the speed of light in free space, wavelength, and third resonant frequency of Ant2, respectively.

The bigger parallel length of trapezoidal ground $(L_3 = L_2\sqrt{2})$ is taken same as the wavelength at third resonant frequency.

$$L_3 = \lambda_{32} = \frac{c}{f_{32}} = L_2\sqrt{2}. \tag{2}$$

Further, same patch is proposed with deferent shaped DGS and antenna is referred as Ant3. The schematic of Ant3 is shown in Fig. 3(a). A square ring with cross-rectangular

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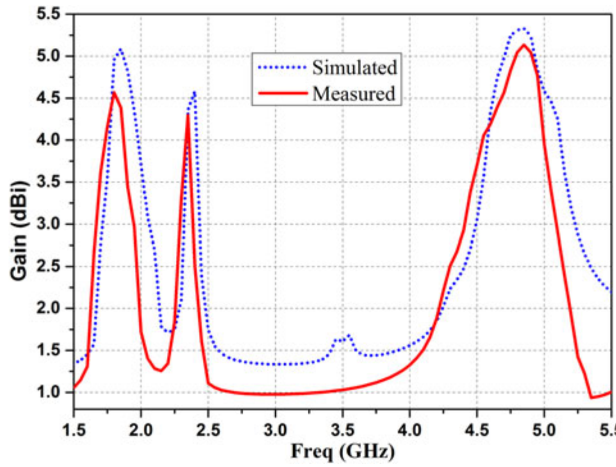

Fig. 11. Simulated and measured Antenna Gain variations with frequency of Ant2.

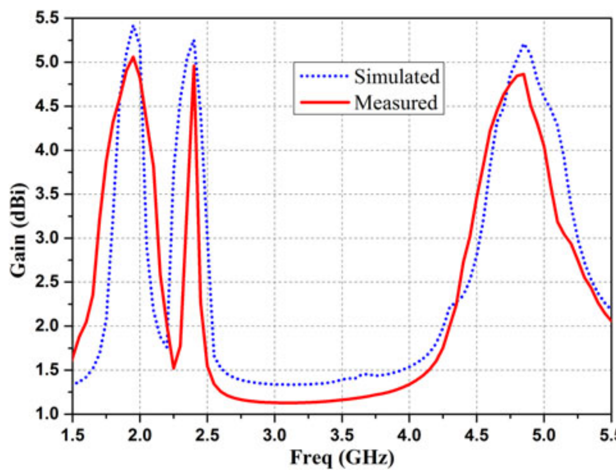

Fig. 12. Simulated and measured Antenna Gain variations with frequency of Ant3.

strips is used as ground plane and rotated at an angle of 45°. The dimension of outer square of square ring is $W_3 \times W_3$. A square slot of dimension $W_4 \times W_4$ is integrated at the center of the square. Four strips of width W_1 is attached with square ring at an angle of 45° and placed with a distance W_2 from the corner of square ring. The length W_5 and W_4 is taken as the multiple of quarter wavelength at second resonance of Ant3.

$$W_5 = \frac{\lambda_{23}}{8} = \frac{c}{8.f_{23}}. \tag{3}$$

$$W_4 = \frac{W_5}{2} = \frac{\lambda_{23}}{16} = \frac{c}{16.f_{23}}. \tag{4}$$

The radius of circular patch R_e is determined as [1]

$$R_e = \frac{F}{\left\{1 + \frac{50h}{\pi\varepsilon_r F}\left[\ln\left(\frac{\pi F}{50h}\right) + 1.7726\right]\right\}^{1/2}}, \tag{5}$$

where, h and ε_r is the thickness and dielectric constant of the substrate respectively. And F is

$$F = \frac{8.791 \times 10^9}{f_d\sqrt{\varepsilon_r}},$$

where, f_d is the designing frequency of the structure.

The dimension of the square patch is calculated as [1]

$$2.l_s = \frac{\lambda}{2} = \frac{c}{f_d\sqrt{\varepsilon_r}}, \tag{6}$$

where, c is the speed of light in free space. The designing frequency f_d is considered as 2.4 GHz for both the circular and square patch.

III. RESULTS AND DISCUSSION

A FR-4 epoxy substrate of dimension 46 × 46 × 1.6 mm^3 is used to fabricate all the three antennas. Fabrication is done by standard photolithography process. The dielectric constant ϵ_r, loss tangent $tan\delta$, and height h of the substrate are 4.4, 0.002, and 1.6 mm, respectively. The detailed dimensions

Table 2. Result analysis of Ant1.

Freq (GHz)	S_{11} (dB)		Gain (dBi)		Axial ratio (dB)	
	Simulated	Measured	Simulated	Measured	Simulated	Measured
1.95	−24.53	−19.00	5.53	4.03	0.39	0.89
2.4	−14.54	−14.30	4.54	4.79	–	–
4.9	−23.25	−21.74	4.25	3.84	–	–

Table 3. Result analysis of Ant2.

Freq (GHz)	S_{11} (dB)		Gain (dBi)		Axial ratio (dB)	
	Simulated	Measured	Simulated	Measured	Simulated	Measured
1.85	−25.36	−17.71	5.08	4.56	0.15	1.05
2.4	−17.38	−14.94	4.58	4.29	–	–
4.85	−22.12	−21.47	5.32	5.13	1.02	1.82

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Table 4. Result analysis of Ant3.

Freq (GHz)	S_{11} (dB)		Gain (dBi)		Axial ratio (dB)	
	Simulated	Measured	Simulated	Measured	Simulated	Measured
1.95	−23.56	−18.20	5.42	5.06	0.33	1.46
2.4	−15.55	−11.60	5.25	4.95	0.49	1.54
4.85	−22.71	−20.60	5.21	4.86	–	–

of proposed structures are listed in Table 1. The fabricated antennas are shown in Figs 1, 2, and 3. A 50-Ω SMA connector is used to feed the structure. The proposed antennas are analyzed using Ansoft HFSS v.14 [30] based on FEM.

The return loss of the fabricated antennas is measured on Agilent™ Network Analyzer PNA-L Series. The S_{11} variation with frequency of Ant1, Ant2, and Ant3 are shown in Figs 4, 5, and 6, respectively. By integrating the slits with combined shape of circular and square patch, the current path of the patch is increased and Ant1 resonates at frequencies 1.95, 2.4, and 4.9 GHz. The return loss level of Ant1 at these frequencies is 24.53, 14.54, and 23.25 dB, respectively. Small frequency ratio f_2/f_1 of the value of 1.23 is achieved. A compactness of 18.75% with triple band characteristics is achieved with respect to design frequency. Ant2 resonates at frequencies 1.85, 2.4, and 4.85 GHz. Compactness is further improved to the value of 22.91%. The return loss level of Ant2 at these frequencies is 25.36, 17.38, and 22.12 dB, respectively. The return loss level of Ant3 is 23.56, 15.55, and 22.71 dB at frequencies 1.95, 2.4, and 4.85 GHz, respectively.

Ant1 shows the right-hand circularly polarized (RHCP) characteristics at frequency 1.95 GHz. Figure 7 shows the axial ratio plot with resonant frequency of Ant1. The axial ratio of the Ant1 at 1.95 GHz is measured as 0.89 dB. Ant2 shows the RHCP characteristics at 1.85 and 4.85 GHz. The length L_3 and the distance $(L_2 - L_1)$ between parallel lines of the trapezoidal shaped ground plane are taken as the wavelength and quarter wavelength at frequency 4.85 GHz, respectively. These parameters of Ant2 are responsible for the CP at frequency 4.85 GHz. Figure 8 shows the axial ratio plot with resonant frequency of Ant2. The axial ratio of the Ant2 is measured as 1.05, and 1.82 dB at the frequencies 1.85 and 4.85 GHz, respectively. Figure 9 shows the axial ratio plot with resonant frequency of Ant3. Ant3 shows the RHCP characteristics at frequencies of 1.95 and 2.4 GHz. The length W_5 and W_4 of the ground plane of Ant3 is taken as $\lambda/8$ and $\lambda/16$ at frequency 2.4 GHz respectively. Thus, results in CP characteristics at frequency 2.4 GHz. The axial ratio of the Ant3 is measured as 1.46, and 1.54 dB at the frequencies 1.95 and 2.4 GHz, respectively.

Figures 10, 11, and 12 shows the gain characteristics of the proposed Ant1, Ant2, and Ant3 respectively. All three antennas show good radiation characteristics. Ant1 shows the gain of 5.53, 4.54, and 4.25 dBi at frequencies 1.95, 2.4, and 4.9 GHz, respectively. Ant2 shows the gain of 5.08, 4.58, and 5.32 dBi at frequencies 1.85, 2.4, and 4.85 GHz, respectively. Ant3 shows the gain of 5.42, 5.25, and 5.21 dBi at frequencies 1.95, 2.4, and 4.85 GHz, respectively. Tables 2, 3, and 4 give a comparative data of Ant1, Ant2, and Ant3.

Figures 13(a) and 13(b) show the co-polar and cross-polar radiation pattern of Ant1 (without DGS) at resonant frequency 1.95 GHz in *E*-plane and *H*-plane, respectively. The Ant1 shows RHCP behavior at frequency 1.95 GHz and

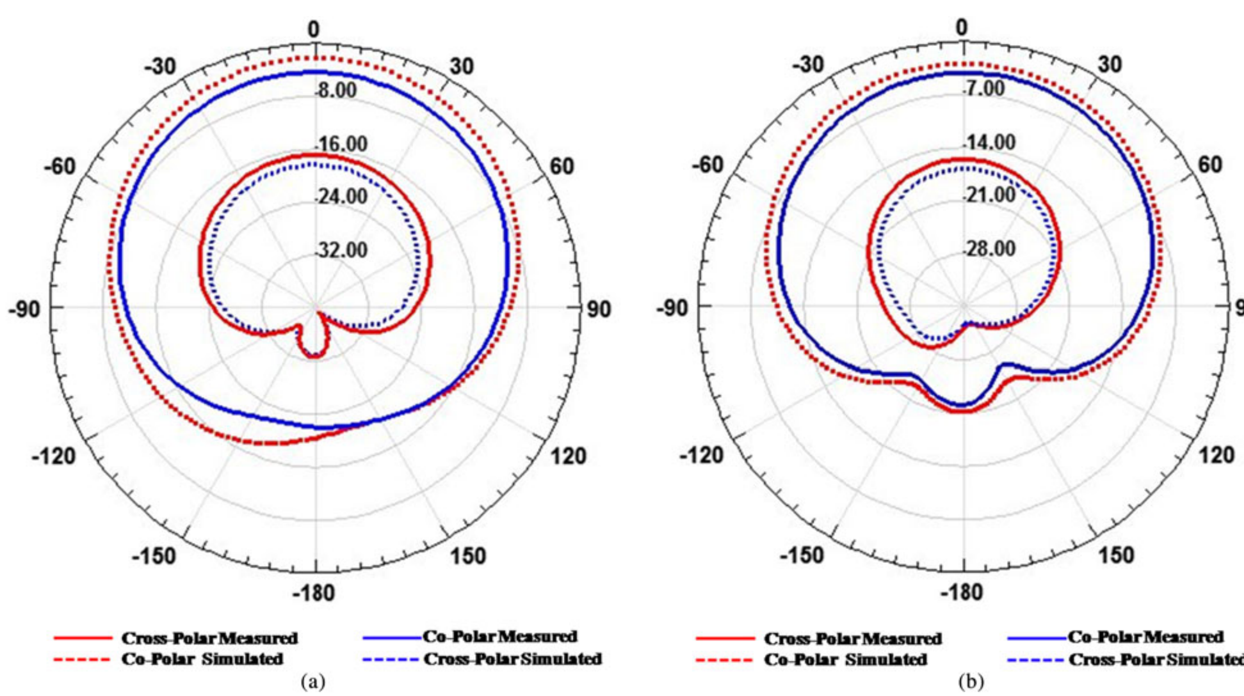

Fig. 13. Simulated and measured co-polar and cross-polar radiation pattern of Ant1 (without DGS) at frequency 1.95 GHz, (a) E-plane, (b) H-plane.

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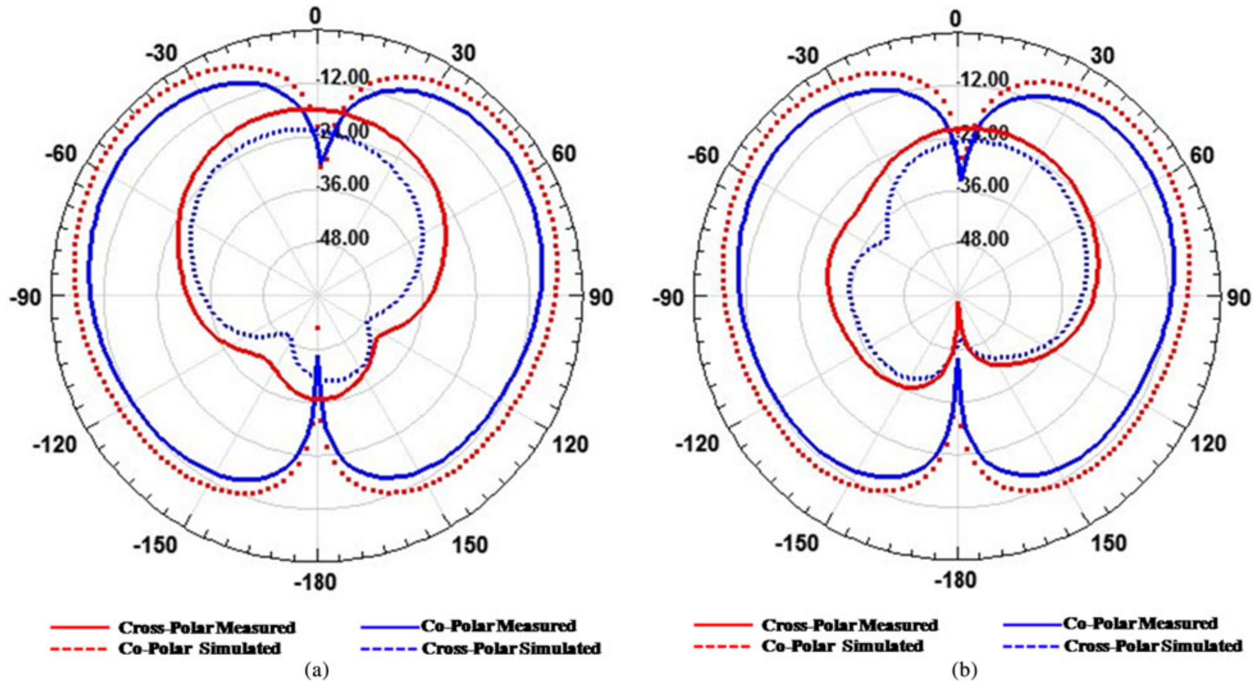

Fig. 14. Simulated and measured co-polar and cross-polar radiation pattern of Ant1 (without DGS) at frequency 4.9 GHz, (a) E-plane, (b) H-plane.

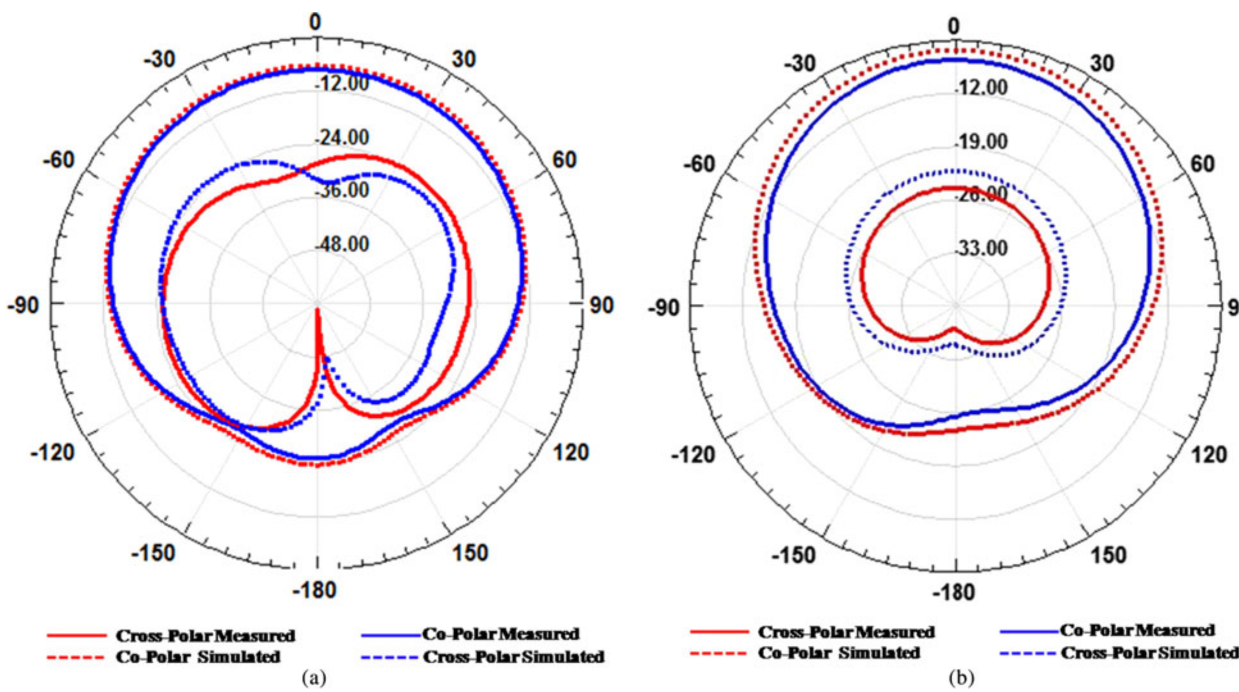

Fig. 15. Simulated and measured co-polar and cross-polar radiation pattern of Ant2 (with trapezoidal shaped DGS) at frequency 1.85 GHz, (a) E-plane, (b) H-plane.

cross-polarization is considered as left-hand circularly polarized (LHCP). The LHCP level of Ant1 (without DGS) is about −16 and −15 dB at frequency 1.95 GHz in *E*-plane and *H*-plane, respectively. The co-polar and cross-polar radiation pattern of Ant1 (without DGS) at frequency 4.9 GHz in *E*-plane and *H*-plane is shown in Figs 14(a) and 14(b), respectively.

The cross-polarization level of Ant1 at frequency 4.9 GHz is about −24 dB in both *E*-plane and *H*-plane shown in Figs 14(a) and 14(b), respectively. The radiation patterns of all three antennas at frequency 2.4 GHz are almost identical to the radiation patterns at third resonant frequency correspondingly. Thus, radiation patterns at frequency 2.4 GHz are not shown in this paper.

The co-polar and cross-polar radiation pattern of Ant2 (with trapezoidal shaped ground plane) at resonant frequencies 1.85 and 4.85 GHz is shown in Figs 15 and 16, respectively. By using trapezoidal shaped defected ground plane, the

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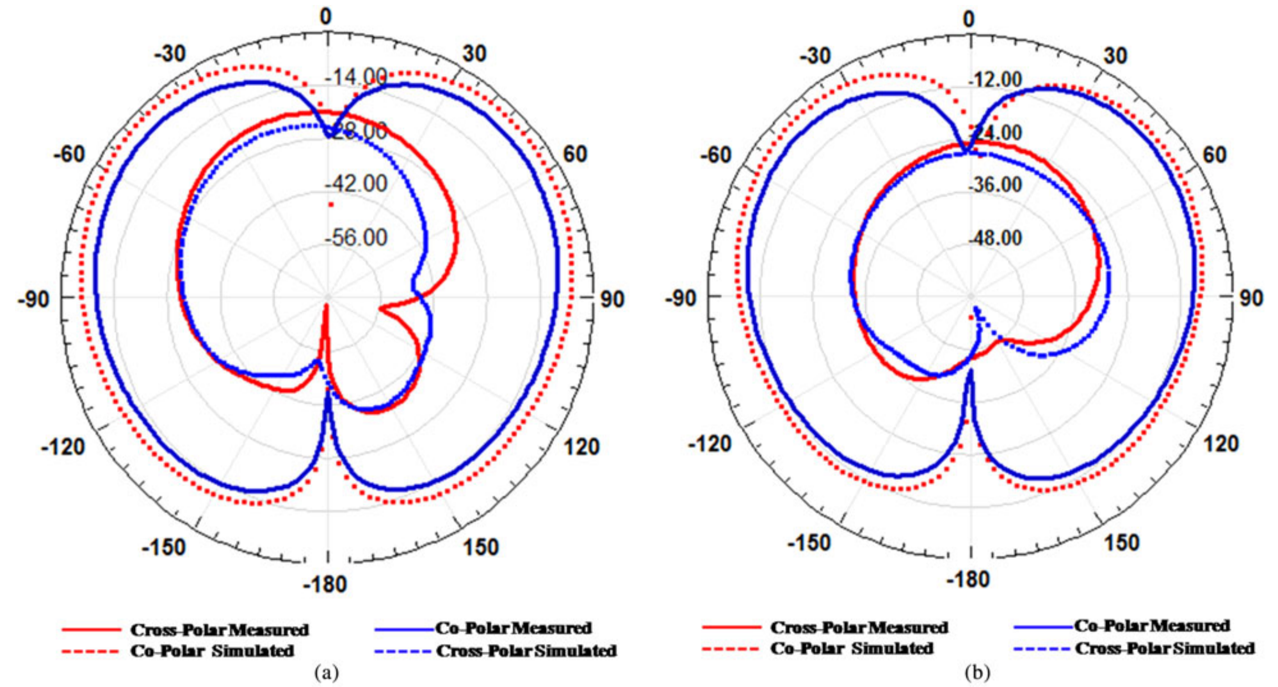

Fig. 16. Simulated and measured co-polar and cross-polar radiation pattern of Ant2 (with trapezoidal shaped DGS) at frequency 4.85 GHz, (a) E-plane, (b) H-plane.

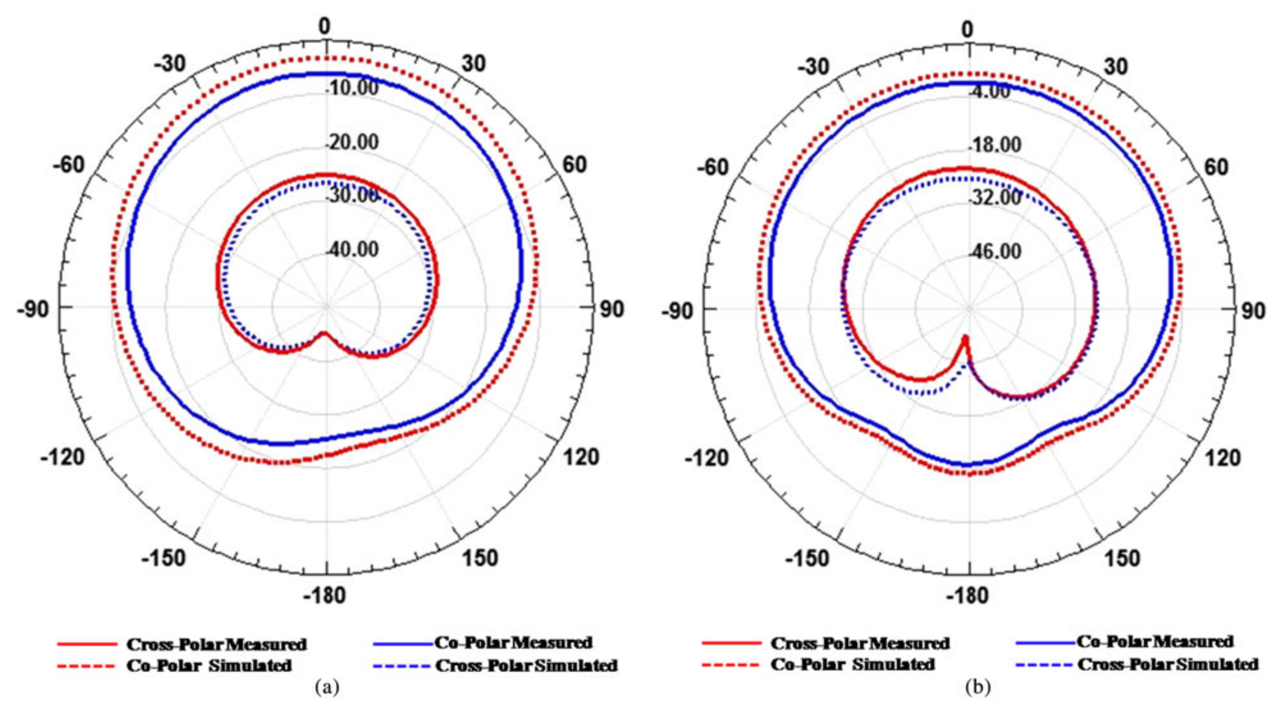

Fig. 17. Simulated and measured co-polar and cross-polar radiation pattern of Ant3 (with DGS) at frequency 1.95 GHz, (a) E-plane, (b) H-plane.

cross-polarization level is suppressed to the value of −24 dB in both *E*-plane and *H*-plane at resonant frequency 1.85 GHz shown in Figs 15(a) and 15(b), respectively. The cross-polarization level of Ant2 at frequency 4.85 GHz is about −28 dB in both *E*-plane and *H*-plane shown in Figs 16(a) and 16(b), respectively.

The co-polar and cross-polar radiation pattern of Ant3 at resonant frequencies 1.95 and 4.85 GHz is shown in Figs 17 and 18, respectively. The cross-polarization level is further suppressed to the value of −28 dB in both *E*-plane and *H*-plane at resonant frequency 1.95 GHz. At frequency 4.85 GHz the cross-polarization level of Ant3 is suppressed

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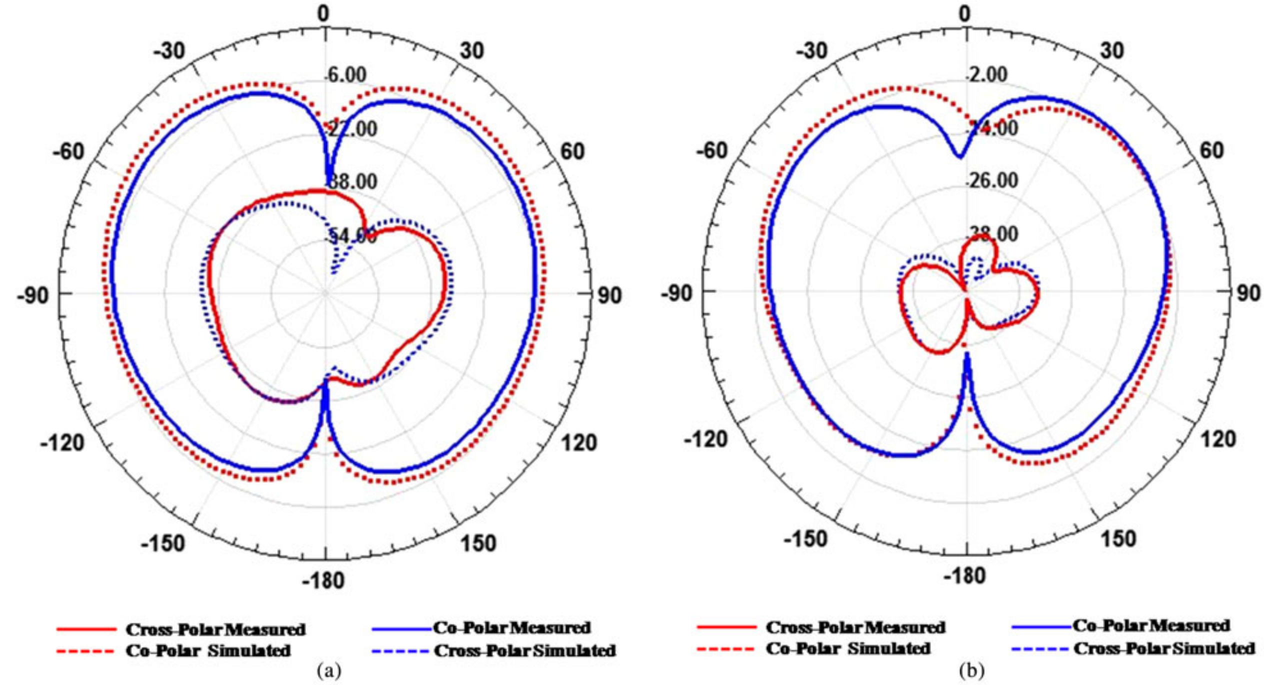

Fig. 18. Simulated and measured co-polar and cross-polar radiation pattern of Ant3 (with DGS) at frequency 4.85 GHz, (a) E-plane, (b) H-plane.

to the value of −38 dB in both *E*-plane and *H*-plane, shown in Figs 18(a) and 18(b), respectively.

IV. CONCLUSION

Asymmetric slits loaded and corner truncated irregular shaped MPA with and without DGS is designed and fabricated. By integrating the slits compactness of 18.75% with triple band characteristics and small frequency ratio f_2/f_1 of the value of 1.23 is achieved. Ant1 without DGS resonates at three frequencies 1.95, 2.4, and 4.9 GHz with antenna gain of 5.53, 4.54, and 4.25 dBi respectively. Ant1 shows RHCP at frequency 1.95 GHz. Further, same patch is used with trapezoidal shaped DGS and Ant2 resonates at 1.85, 2.4, and 4.85 GHz with antenna gain of 5.08, 4.58, and 5.32 dBi, respectively. Compactness is further improved to the value of 22.91% and antenna shows the RHCP at frequencies 1.85 and 4.85 GHz. By using trapezoidal shaped DGS cross-polarization level is suppressed to the value of −24 and −28 dB in both planes at resonant frequencies 1.85 and 4.85 GHz, respectively. Further, same patch is used with different shaped DGS and Ant3 shows resonance at frequencies 1.95, 2.4, and 4.85 GHz with antenna gain of 5.42, 5.25, and 5.21 dBi, respectively. Ant3 shows RHCP characteristics at frequencies 1.95 and 2.4 GHz with the axial ratio of the value of 1.46 and 1.54 dB respectively. Cross-polarization level is further suppressed to the value of −28 and −38 dB in both planes at resonant frequencies 1.95 and 4.85 GHz, respectively. Thus, all three proposed antennas are suitable for modern wireless applications due to their compact size, minimum return loss level, good antenna gain, and circular polarization characteristics with suppressed cross-polarization level.

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