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Performance Enhancement of a Compact Circularly Polarized Slot Antenna Using Corner Truncation

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Abstract—This paper presents a design of a compact wide slot circularly polarized antenna which is fed by a microstrip feed line. The designed antenna covers an area of size 25 mm × 25 mm with a substrate thickness of 1.6 mm. The 3 dB axial ratio (AR) band can be produced by projecting a circular stub in the ground plane and feeding the slot through an asymmetry-fed microstrip feedline. The AR bandwidth of the antenna is further improved by adding truncation in the ground plane. Measured results show that the graph attains an impedance matching bandwidth of 124.3% centered at 7.4 GHz (2.8–12 GHz) and a 3 dB AR bandwidth of 52.42% centered at 5.15 GHz (3.8–6.5 GHz). The proposed antenna is suitable for the use in C-band applications.

1. INTRODUCTION

Recently, a lot of attention has been drawn from the research works which include the research on small antennas using different feeding structures, radiating elements and circular polarizations characteristics. Due to their several advantages in comparison with linearly polarized (LP) antennas, circularly polarized (CP) antennas are getting more popular in wireless communication systems. For certain advantages like wide bandwidth, low profile, and simple integration process, a lot of researchers are showing interest in the design of circularly polarized wide slot (WS) antennas [1].

The working principle of CP antennas is to stimulate two symmetrical modes with equivalent amplitude and in-phase quadrature. This can be accomplished by presenting some symmetrical and (or) unsymmetrical perturbations into wide slot or ring slot antennas [2–16]. These designs include embedding L-shaped structures in the ground plane from the opposite corners, and the further process by adding more L-shaped structures leads to generating a resonant mode for exciting two orthogonal E vectors which give a better result in terms of enhancement in the axial ratio part [2, 3, 18]. Also, by using L-shaped dielectric resonator strips (DRSs) circular polarization can be achieved in terms of dielectric resonator antenna (DRA) [4]. By utilizing the insertion of feeding techniques [5–6], parasitic strips [7–9, 14], G-shaped parasitic patch [10], annular ring slot structures [11–13], and finally MIMO antenna [15] and MIMO antenna array [16] designs have also been proposed earlier. To achieve these types of complex designs, a simple structure compact circularly polarized antenna is proposed in this paper which is referred from [17]. The proposed antenna consists of a microstrip feed line, a rectangular slot, and a circular stub projected out from the ground plane. By simply placing the microstrip feedline just under the projected stub, circular polarization mechanism can be achieved. Despite having a simple structure, it achieves a good AR bandwidth of 54.22% which ranges from 3.67 to 6.4 GHz whereas the impedance matching bandwidth also shows a good output of 118% between the range of 3.3 GHz to 12.45 GHz. Table 1 shows the compared values of impedance bandwidth and AR bandwidth along with the type and size of the antenna from [2–18].

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Table 1. Comparison of existing antenna geometries.

Reference	Antenna type	Antenna size (mm × mm × mm)	Impedance BW (%)	Axial Ratio BW (%)
[2]	Ring Slot	50 × 50 × 0.78	64.6	64.6
[4]	Wide Slot	76 × 76 × 0.8	44.7	38.7
[5]	Wide Slot	40 × 40 × 1.6	73.39	58.08
[6]	Wide Slot	101 × 64 × 1.52	86.9	74.3
[8]	Dipole antenna	138 × 138 × 0.8	61.8	51.6
[9]	Wide Slot	52 × 54 × 1.52	25.8	20.6
[10]	Wide Slot	30 × 30 × 1.6	70.1	37.1
[11]	Ring Slot	24 × 25 × 1.0	56.27	21.25
[12]	Ring Slot	30 × 15 × 0.25	46.43	29.82
[14]	Wide Slot	50 × 50 × 1.52	23	18.9
[15]	MIMO	25 × 20 × 1.6	46.3	41.34
[16]	MIMO antenna array	20 × 27.7 × 0.508	13.19	8.21
[17]	Wide Slot	25 × 25 × 1.6	90.2	40
Proposed antenna	**Wide Slot**	**25 × 25 × 1.6**	**124.3**	**52.42**

2. ANTENNA GEOMETRY AND DESIGN

The geometrical structure of the proposed CP antenna is depicted in Figure 1. As shown in the figure, the antenna is fed by a 50 Ω microstrip feed line which has been designed on an FR4 substrate having relative permittivity = 4.4 and height = 1.6 mm. The width of the feedline is 3 mm. The ground plane in placed on the bottom of the substrate and a large slot is introduced in the ground plane of an asymmetrical size with the designed value mentioned in Table 2. A circular stub is then projected from the right side of the ground plane towards the center of the slot which looks like an i-shaped structure when being viewed with both patch and ground. To realize the working operation of circular polarization, the stub is protruded from the right side towards the center, and the feedline is also placed on the right edge of the design.

The proposed CP antenna has a compact size of 25 × 25 × 1.6 mm^3 which is printed on an FR4

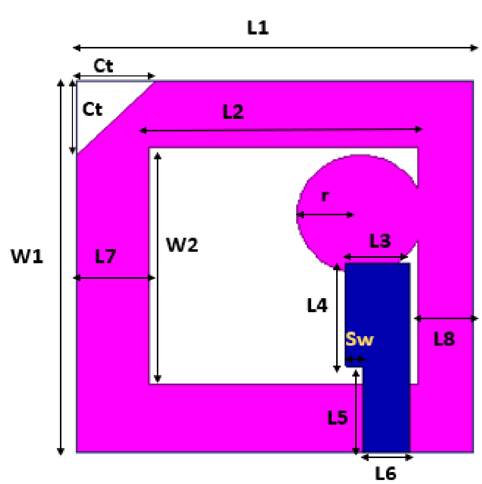


Figure 1. Geometry of the proposed antenna.

substrate. Numerical solutions of the proposed antenna and the software simulation part is performed by the commercially available software package Ansys HFSS version 21. The proposed dimension of the designed antenna is listed in Table 2.

Table 2. Parametric values of the proposed antenna.

Parameters	**Dimensions (mm)**	**Parameters**	**Dimensions (mm)**
$L1$	25	$L8$	3.5
$L2$	17	$W1$	25
$L3$	4	$W2$	16
$L4$	7	r	4
$L5$	5.75	Ct	4
$L6$	3	Sw	1
$L7$	4.5		

3. DESIGN PROCEDURE

The designed antenna works successfully with circularly polarized mechanism, when the axial ratio bandwidth (ARBW) completely falls under the impedance bandwidth (IBW) range of the antenna. The evolution process of the proposed antenna is shown in Figure 2 towards the realization process of circular polarization. Here four antennas have been discussed step by step, and finally the proposed antenna is shown and discussed. Ant 1 has a simple design with a slotted ground plane and a microstrip feed placed in the middle of the design. In Ant 2, a circular stub is introduced from the right side of the ground plane towards the center. In Ant 3, the feedline is shifted towards the right side ($+y$-axis) of the design. Ant 4 has a corner truncation from the top left corner, and then finally Ant 5 is the proposed antenna in which a small stub is placed on the left side (towards $-y$-axis) of the feedline. The effect of every antenna is explained step by step in the results section.

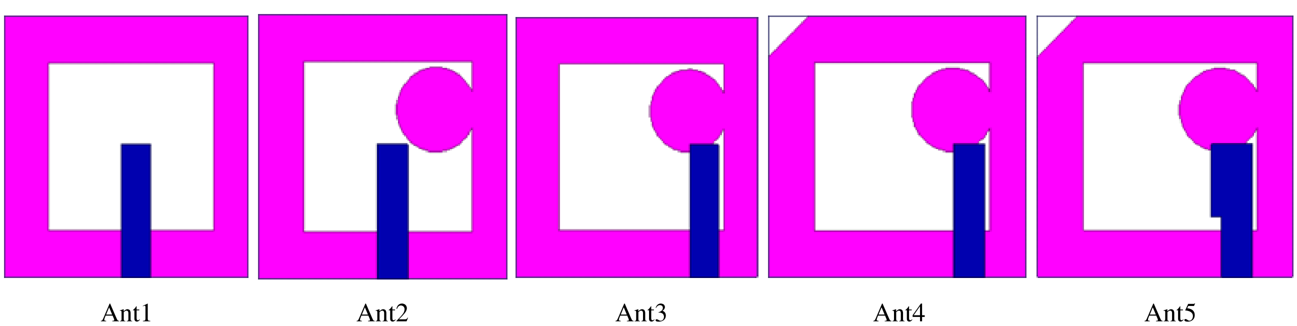


Figure 2. Evolution process of proposed antenna.

4. RESULTS AND DISCUSSION

The antenna was simulated with the help of Ansys commercial high frequency structure simulator (HFSS ver. 21) software. To clearly understand the antenna design, the evolution process is shown in Figure 2. To clarify the performances of proposed antenna, the axial ratios and impedance bandwidths of Ant 1–5 have been compared and shown in Figure 3. Figure 3(a) shows the impedance bandwidth of different steps of the proposed antenna in which we can observe that the bandwidth of Ant 1 is from 3.5 to 5.2 GHz, and the axial ratio is more than 25 dB which is linearly polarized. In Ant 2, a circular

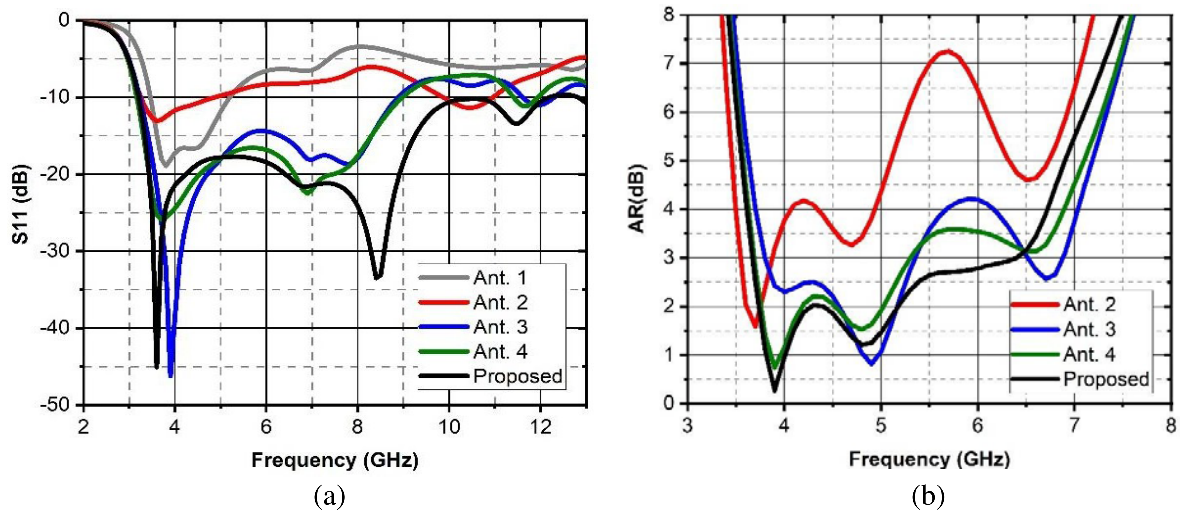


Figure 3. Simulated (a) S_{11}, (b) AR of the proposed antenna.

stub is introduced from the ground plane towards the center; the bandwidth of the structure is from 3.3 to 4.9 GHz; and again it arises between 9.9 and 11 GHz whereas the axial ratio bandwidth falls in the range of 3.6 to 3.9 GHz below 3 dB. In Ant 3, the feedline is sifted towards the right side in which the impedance BW ranges from 3.3 to 8.9 GHz, and at 3.9 GHz frequency it attains the deepest range which goes up to −46.24 dB whereas the axial ratio lies in the range of 3.8 to 5.3 GHz which states that the antenna is circularly polarized. In Ant 4, the top left corner is truncated in which the impedance BW is from 3.2 to 9 GHz, and the axial ratio lies between 3.7 and 5.3 GHz which satisfies the CP. Finally, Ant 5 is the proposed antenna in which a stub is added to the feedline whose impedance bandwidth is from 3.3 GHz to 12.2 GHz, and the axial ratio bandwidth also falls in the range of 3.7 to 6.4 GHz. Hence, the proposed antenna is circularly polarized, and it also gives a wide range of BW.

Figure 4 shows the comparison graph between the simulated and measured results of S_{11} and the axial ratio obtained from the fabrication part, respectively. Good satisfactory results are obtained with a similarity between the simulated and measured graphs.

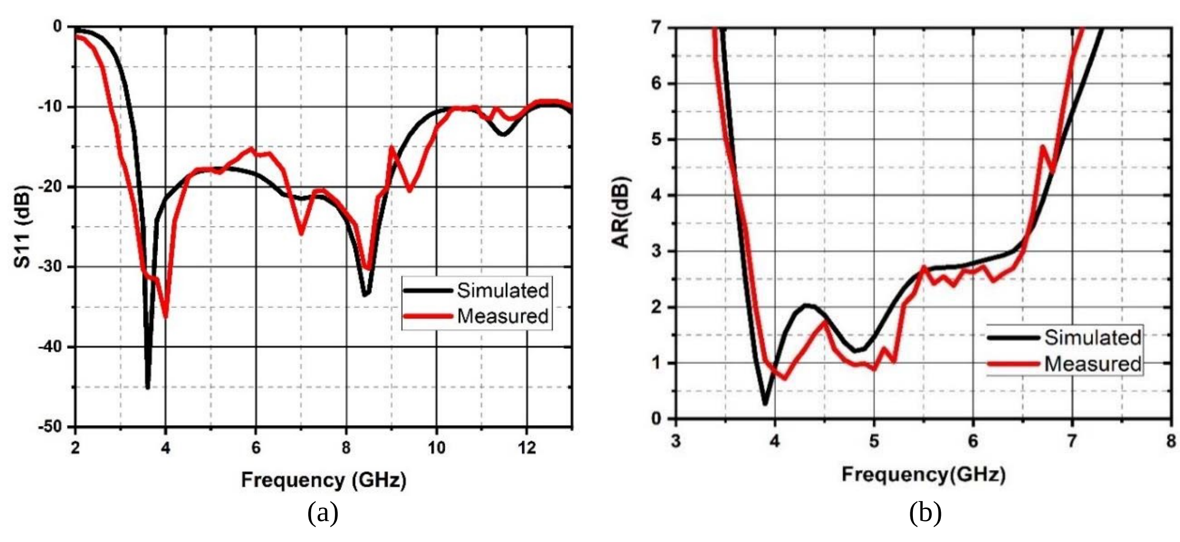


Figure 4. Measured vs simulated (a) S_{11}, (b) AR.

5. PARAMETRIC ANALYSIS

In the proposed antenna, the circular polarization is achieved by introducing a circular patch structure towards the center in the ground plane. By truncating the corner and also by varying the width of Sw, effects have been noticed in the results. Here three parameters, circle radius (r), Sw, and corner truncated (Ct), have been analyzed and studied using the help of Ansys HFSS by varying the parameters one after another while keeping the other parameters fixed.

5.1. Generation of CP Mode by Circular Stub Radius (r)

Figure 5 shows the impedance bandwidth and axial ratio bandwidth results of the variation of circle's radius in the proposed antenna. Here, 3 values of the radius $r = 3$ mm, 4 mm, and 5 mm are considered among which 4 mm is the proposed value whereas 3 mm and 5 mm values are considered for the analysis purpose. From the above graph we can observe that 4 mm radius value gives a satisfactory result in comparison to the other two values both in the cases of impedance bandwidth and axial ratio bandwidth.

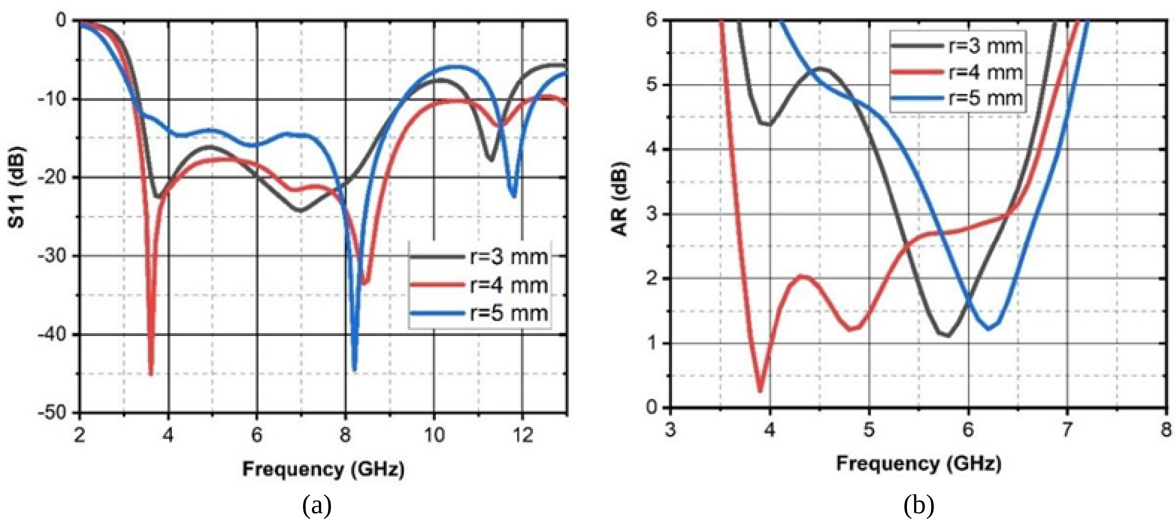


Figure 5. Effects of circle radius (r) on antenna performances, (a) S_{11}, (b) axial ratio.

5.2. Effects in Variation of Slot Width (Sw)

Figure 6 shows the graphs of impedance bandwidth and axial ratio bandwidth of the proposed antenna in the case of variation of Sw. Here, four values of $Sw = 0$, 1, 2, 3 mm are taken into account among which $Sw = 1$ mm gives a validatory result in comparison to the other three values. In Figure 6(a) which is a plot of frequency vs S_{11}, we can observe that the S_{11} value for the proposed Sw goes up to -45 dB, and a good bandwidth is also observed whereas the other values of Sw do not. Similarly in the case of AR, the value falls below 3 dB range for which the antenna can radiate circularly polarized wave.

5.3. Bandwidth Enhancement due to Corner Truncation (Ct)

Figure 7 shows the results of both impedance bandwidth and axial ratio bandwidth of the proposed antenna in the case of variation of corner truncation (Ct). The upper cut-off frequencies mainly vary due to the variation of Ct. Here, three values of $Ct = 3$, 4, and 5 mm are considered for the analysis purpose among which 4 mm is considered for the designed antenna. At $Ct = 4$ mm, the antenna can provide a wide AR bandwidth with maximum impedance bandwidth.

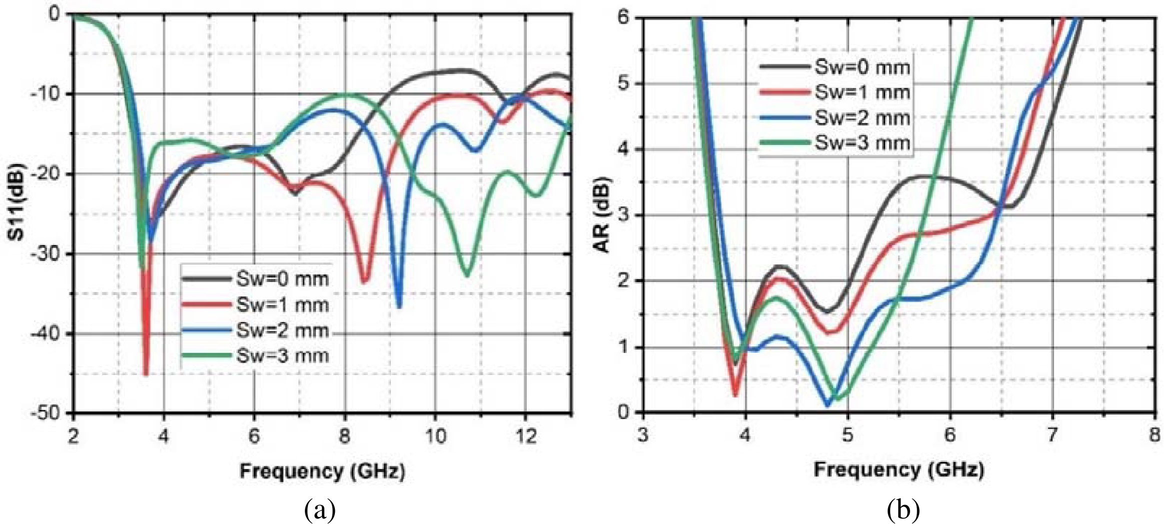


Figure 6. Effects of Sw on antenna performances, (a) S_{11}, (b) axial ratio.

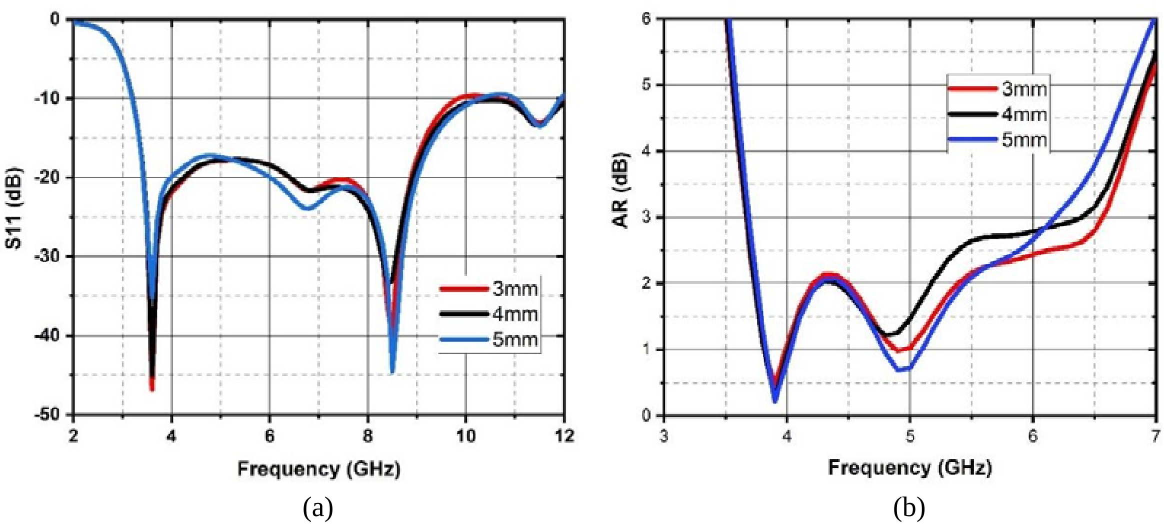


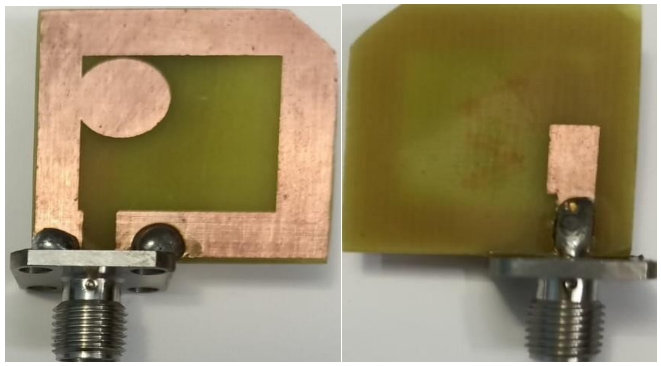
Figure 7. Effects of Ct on antenna performances, (a) S_{11}, (b) axial ratio.

6. EXPERIMENTAL VERIFICATION

The proposed CP antenna is simulated by using ANSYS HFSS and is also fabricated on a copper-based FR-4 epoxy substrate ($\varepsilon_r = 4.4$, $\tan\delta = 0.02$), as shown in Figure 8. To validate the design concept for application based, the antenna has been prototyped and measured in an anechoic chamber. Figure 8 presents the top and bottom views of the fabricated antenna.

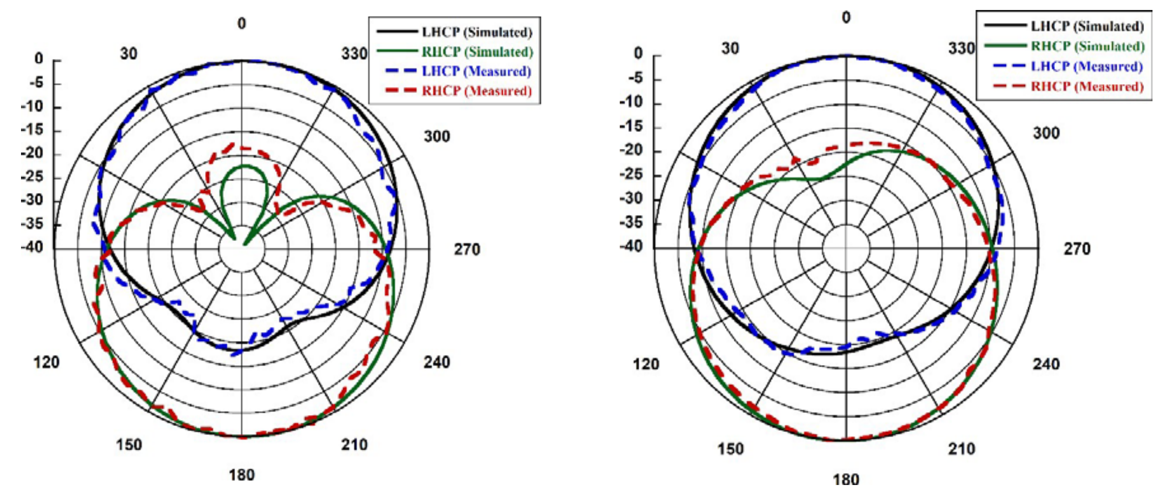
Figure 4(a) presents the simulated and measured IBWs which are 116.8% centered at 7.69 GHz (3.2–12.19 GHz) and 124.3% centered at 7.4 GHz (2.8–12 GHz), respectively. Similarly, the measured ARBW is 52.42% centered at 5.15 GHz (3.8–6.5 GHz), whereas the simulated ARBW is 54.22% centered at 5.03 GHz (3.67–6.4 GHz). For practical applications, where both the bandwidths, i.e., ARBW and IBW, must be ≤ 3 and ≥ 10 respectively for the realization of CP antenna by its overlapped bandwidth.

The far field action of proposed antenna is shown in Figure 9 which presents the radiation patterns of different frequencies at 3.9, 4.8, and 5.8 GHz. For all three frequencies, radiation patterns for both XZ and YZ planes are noted. It can be observed that the results show a good agreement between the

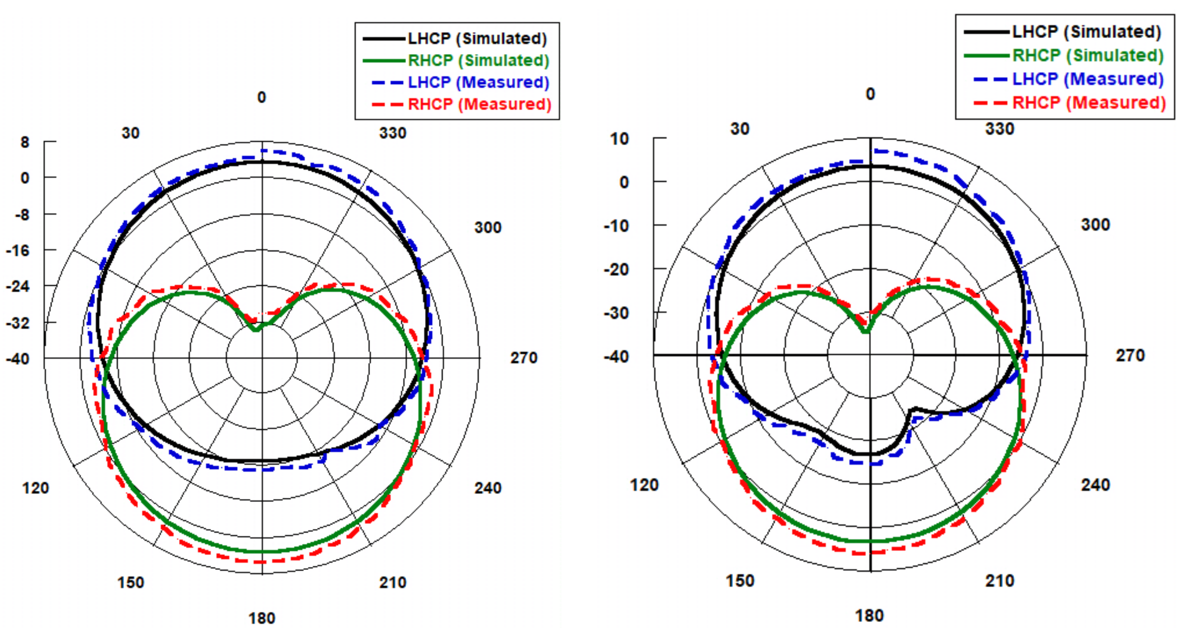


(a) (b)

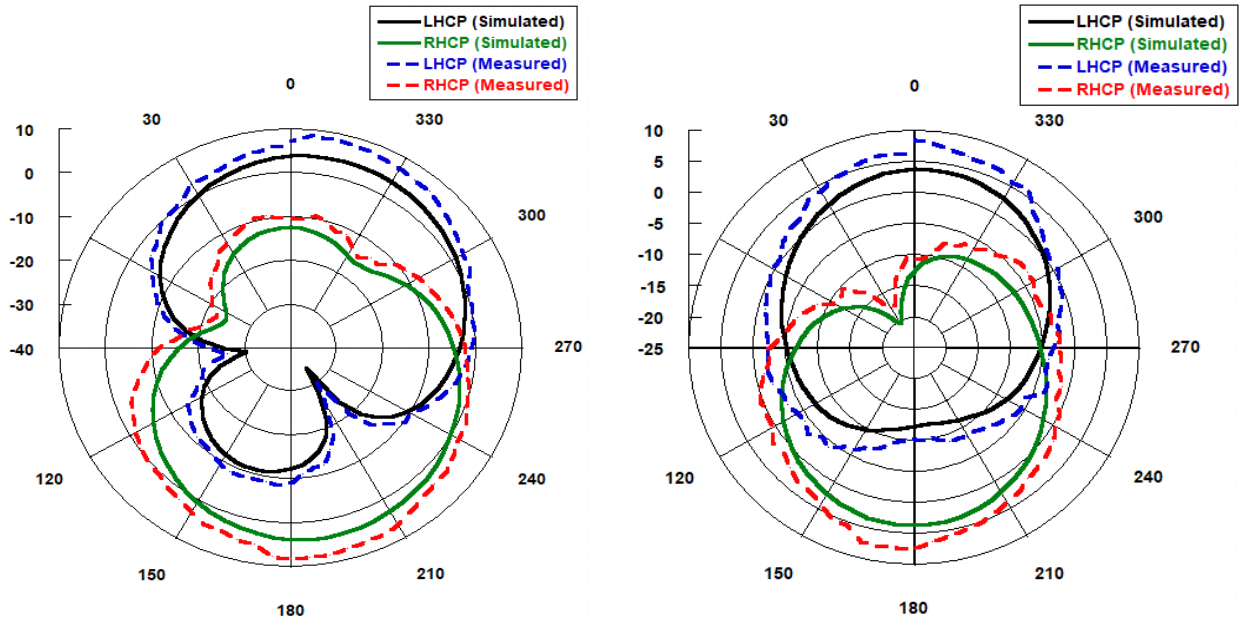
Figure 8. Antenna prototype. (a) Top view. (b) Bottom view.



(a)



(b)



(c)

Figure 9. Simulated and measured radiation patterns at (a) 4.8 GHz, (b) 3.9 GHz and (c) 5.8 GHz.

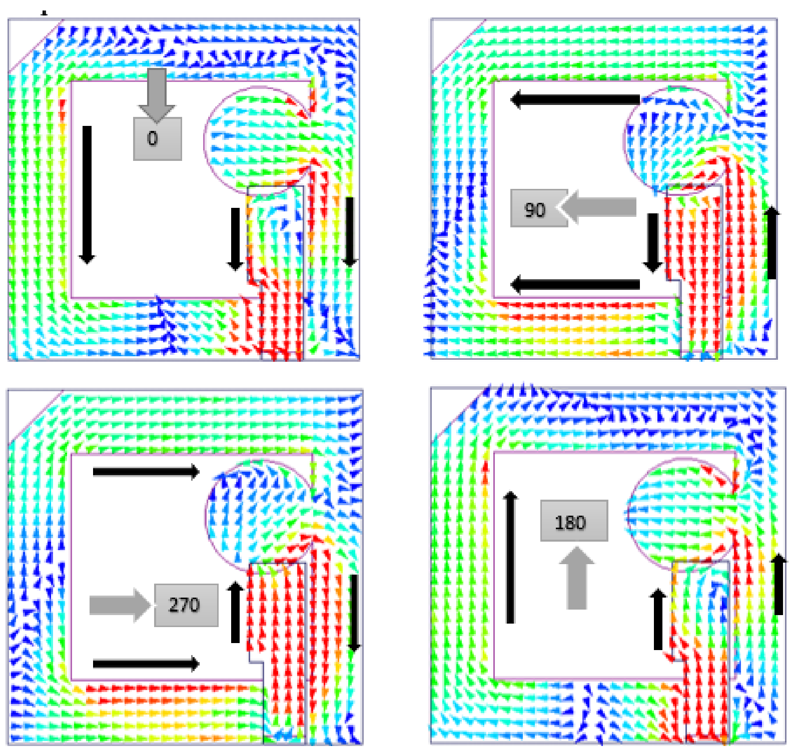


Figure 10. Surface current distribution on feed and ground plane at 4.8 GHz in 0°, 90°, 180° and 270°.

simulated and measured data. Further it can also be noted that the proposed antenna is Left Hand Circularly Polarized (LHCP) throughout the frequency range that is at lower band, mid band, and upper band too.

The simulated time varying nature of surface current distribution of proposed antenna at 4.8 GHz is shown in Figure 10. The figure presents the current distribution at 4.8 GHz for 0°, 90°, 180°, and 270° phases. It can be noted that in 90° and 270° phases the current flows in opposite directions for the patch and ground plane for which we can say that they cancel out the effect of each other. In 0° and 180° phases, the current flows in the downward and upward directions, respectively, for both feed and ground plane. Hence, we can say that the current flows in clockwise direction which means that the antenna is LHCP, and it can also be observed from the radiation patterns in Figure 9.

The simulated and measured peak gains of proposed antenna are shown in Figure 11. A good agreement can be observed between the simulated and measured results.

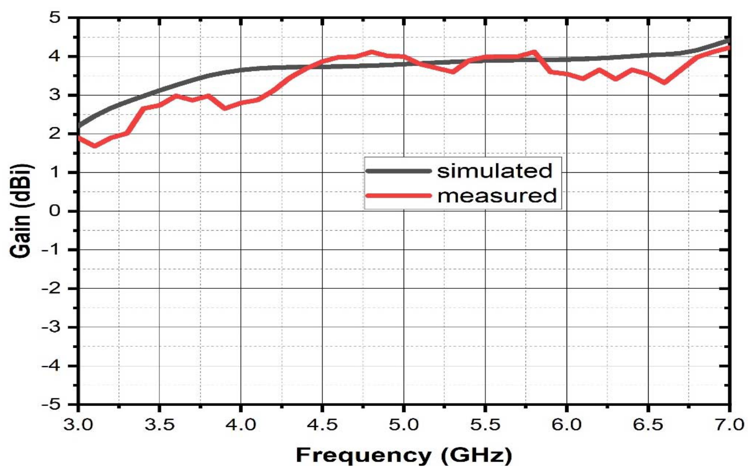


Figure 11. Simulated and measured gain of designed antenna within the AR band.

7. CONCLUSION

In this communication, a circularly polarized wide slot antenna fed by a microstrip line is implemented and successfully measured for the hardware simulation. The antenna covers a very small area and also shows good result both in the case of impedance as well as axial ratio bandwidth. Measurement results show that the proposed antenna attains a 10 dB return loss of 124.3% which ranges from 2.8 to 12 GHz, and likewise it attains a 3 dB AR of 52.42% in the range of 3.8 to 6.5 GHz. Measured and simulated results show a good agreement between them. Finally, it can be concluded that the antenna is circularly polarized and can be used for the applications in the UWB range.

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