Wireless Personal Communications (2024) 136:1735–1747
https://doi.org/10.1007/s11277-024-11357-z

A Compact Dual-band Dual-sense Circular Polarized Wide Slot Antenna for WLAN Applications

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Accepted: 13 June 2024 / Published online: 25 June 2024

Abstract
This paper introduces a square slot antenna with circular polarization and dual-band capability. The structure of the antenna is similar to an L-shape patch but with modifications in the lower rectangular part of the L, the patch has been transformed into a circle. Additionally, two strips having rectangular shape are located on the ground plane at opposite corners. By adjusting the size of the rectangular strips, the antenna can achieve dual-band and dual-sense circular polarization. The measured results of this design indicate that the Impedance Bandwidths are 45.16% (2.4–3.8 GHz) and 43.75% (5–7.8 GHz), while the Axial Ratio Bandwidths are 45.16% (2.4–3.8 GHz) and 37.4% (5–7.3 GHz) for the lower and upper bands respectively.

Keywords Impedance bandwidth · Axial ratio · Circular polarization

1 Introduction

The microstrip patch radiator is a novel type of radiator that works with incorporated circuit innovation and has advantages like narrow profile, light weight, affordable pricing, and flexibility to conform to a curved surface. It is typically made to operate in single-mode, that is linearly polarized (LP) which is radiating only waves that are polarised either horizontally or vertically. This restriction is solved by a multi-band circularly polarized (CP) antenna. It serves as a means of transmission of independent information and gathering from the direction of both the transmitter and recipient, as well as correcting the multipath issues [1, 2].

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CP antennas are turning into a critical innovation for a variety of wireless frameworks, including satellite interchanges, mobile communications, global navigation satellite systems (GNSS), remote sensors, remote power transmission, wireless local area networks (WLAN), Worldwide Interoperability for Microwave Access (WiMAX) [3], and wireless personal area networks (WPAN). These advantages are due to the characteristics of circular polarization, which give CP radiators many significant advantages over radiators having linear polarizations [4].

In order to prevent fading or multi-path interferences, the CP antenna is particularly effective. Using a CP antenna, we get another benefit that there is no requirement of fixed orientation between the transmitting and receiving antennas [5].

Today, there is a greater need for compact dual-band or multi-band antennas due to the quick development of wireless communications systems. Research and development have advanced significantly in recent years which is drawing the attention of researchers towards this field. As a result, numerous dual-band CP radiators have undergone substantial research in recent years.

A double-band, dual-sense CP radiator is obtained by the integration of four uneven linear slots into the annular slot is shown in [6]. [7] Represents a CP cavity-backed annular slot antenna which is used for GPS. By loading two spiral-shaped slots in the ground plane and with the help of T shape strip dual band is achieved [8]. Similarly, using the printed spiral slots, another antenna has been designed for dual-band frequency with dual-sense circular polarization [9]. A coaxial probe with an integrated disk having eight curves along with a circular patch slot can generate a dual sense polarization [10]. In [11], a structure is proposed in which the antenna comprises with a slotted ground configuration of a bent feeding method which achieves dual polarization. The proposed design in [12] consists of a rectangular and L-shape stub in order to achieve dual-band polarization. In [13] a double band dual sense CP coplanar waveguide feed monopole antenna with two rectangular parasitic components and an I-shape grounded stub is proposed. In reference [14], the proposed antenna has a compact construction stacked with a D-shape integral split ring resonator, demonstrating double-band polarization.

A new design has been proposed in this paper which was obtained from [15] that addresses a simple design involving microstrip line feed and an L-shape radiation patch antenna which offers impressive results despite its simple structure. This design allows for the realization of dual-band dual-sense CP radiation by modifying the L-shape patch to create a circular look in the lower part of the L. The antenna is highly effective, by offering an impedance bandwidth of 32.25% (2.6–3.6 GHz) and 38% (5.1–7.5 GHz), and an axial ratio of 32.25% (2.6–3.6 GHz) and 31.5% (5.1–7 GHz) for both the bands (lower and upper) respectively. Table 1 provides a comparison of the results for some existing proposed structures in terms of impedance bandwidth, axial ratio, and antenna size.

2 Antenna Design and Geometry

The geometrical structure of the proposed antenna is shown in Fig. 1. The overall size of the proposed antenna design with 60×60 mm^2. The proposed antenna is fed by a 50 Ω microstrip feed line, which is fabricated on an FR4 substrate of thickness 1.0 mm and having a relative permittivity of 4.4 and a loss tangent value of 0.02. The designed antenna utilizes an L-shape structure with modifications made to create the patch section. Instead of a rectangular strip, a circle with a radius of 3.3 mm is used for the patch design. The patch

Table 1 Comparison table of proposed antenna measurements

Reference	Size (mm×mm×mm)	Lower IBW (%, GHz)	Upper IBW (%, GHz)	Lower ARBW (%, GHz)	Upper ARBW (%, GHz)
6	80×80×1.52	26.7%, 1.26–1.65	11.3%, 2.45–2.74	6.1%, 1.47–1.57	6.0%, 2.51–2.68
7	80×80×1.6	3.7%, 1.19–1.23	1.2%, 1.565–1.585	0.9%, 1.22–1.23	0.6%, 1.57–1.58
8	70×70×1.6	8.7%, 1.54–1.68	23%, 1.96–2.47	8.4%, 1.54–1.675	19.24%, 2.02–2.45
9	100×100×1.57	18.2%, 1.44–1.72	18.4%, 2.42–2.91	4.5%, 1.58–1.65	3.5%, 2.61–2.7
11	50×60×1.6	92.2%, 1.45–3.93		4.15% 65MHz	4.55% 107MHz
13	63×75×1.6	71.63%, 1.81–3.83		27.45%, 2.2–2.9	7.1%, 3.4–3.65
15	60×60×1	38.8%, 2.51–3.72	27.5%, 4.83–6.37	37.4%, 2.5–3.65	16.3%, 5.02–5.91
Proposed antenna	60×60×1	45.16%, 2.4–3.8	43.75%, 5–7.8	45.16%, 2.4–3.8	37.4%, 5–7.3

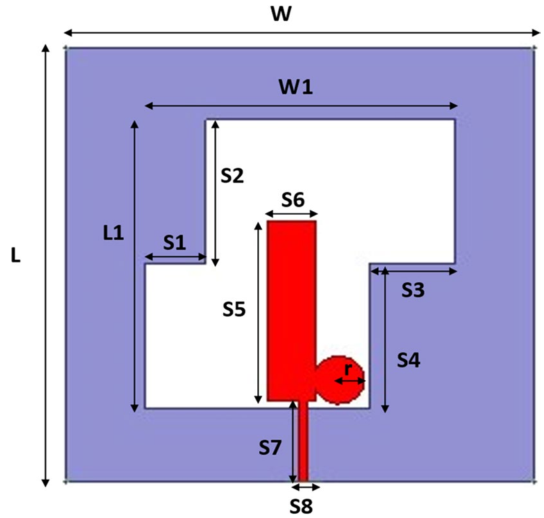


Fig. 1 Proposed antenna

radiator is printed on the substrate's upper surface to generate resonant frequency bands. The ground plane is located on the bottom of the substrate and features asymmetric shapes to produce circular polarized waves. On alternate corners of the ground plane, S1 × S2 and S3 × S4 rectangular strips are located with desired values found in Table 2 to generate CP waves. The antenna's design is simulated using Ansys HFSS ver. 21 software. The proposed antenna's design parameters are listed in Table 2.

3 Design and Evolution Procedure

By analysis and going through calculations for the below-listed mathematical expressions, we found the parametric values of length and width for the design antenna. After placing the ground and the substrate on it, we design the patch which resembles an L-shape structure, and then its lower arm is modified to give it a circular look which is further explained in the evolution steps.

The desired values of a proposed antenna can be calculated with the help of some inbuilt design equations that are given by

Table 2 Proposed antenna's parametric valuation

Parameters	Dimensions (mm)	Parameters	Dimensions (mm)
L	60	W	60
L1	40	W1	40
S1	8	S2	20
S3	11	S4	20
S5	25	S6	6
S7	11	S8	1
r	3.3		

The expression of ε_{reff} is given by:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{\frac{-1}{2}} \tag{1}$$

The change in length is given by:

$$\frac{\Delta L}{h} = 0.412\frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \tag{2}$$

The effective length (L_{eff}) becomes:

$$L_{eff} = L + 2\Delta L \tag{3}$$

For a resonance frequency (f_0), the effective length is given by :

$$L_{eff} = \frac{C}{2f_0\sqrt{\varepsilon_{reff}}} \tag{4}$$

Width (W) is given by:

$$W = \frac{C}{2f_0\sqrt{\frac{(\varepsilon_r + 1)}{2}}} \tag{5}$$

Figure 2 illustrates the development process of the CP antenna. There are four antennas displayed in a sequence, where Ant1, Ant2, and Ant3 are the initial designs aimed at achieving the CP antenna, while Ant4 is the ultimate and suggested one. Ant1 has a fundamental printed antenna structure, where the microstrip feed line is located in the center of the structure, and a large slot of size 40×40 is etched in the ground plane. Ant2 has a circular stub placed at the lower rectangular strip in the patch part, creating an L-like shape where the bottom portion of L is altered to a circle replacing the rectangle. Ant3 takes things a step further by establishing two rectangular strips of distinct sizes at the diagonally alternate corner in the ground plane to generate the CP waves. Finally, Ant4 is the final designed structure in which the feed line is shifted towards the right side of the structure to enhance the bandwidth.

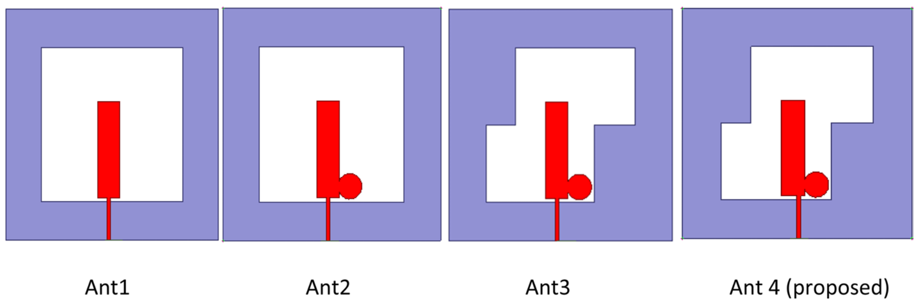


Fig. 2 Evolution step of antenna

4 Results and Discussion

The antenna's design procedure is explained step-by-step in Figure 2, and its performance is visualized in Fig. 3. Figure 3i shows the plot of S11 versus frequency, whereas Fig. 3ii shows the plot of AR versus frequency of Ant1-5. Ant1 is linearly polarized as the AR of Ant1 is not below the 3dB range, and the impedance bandwidth lies from 6.2 to 7.6 GHz frequency range. In Ant2, a circular stub is merged to the rectangular strip to create an L-shape structure with an impedance bandwidth of 1.7–3.1 GHz and 5.5–6.8 GHz, while maintaining linear polarization with an axial ratio above 3dB. In Ant3, introducing two rectangles from opposite corners in the ground plane, CP is generated. Figure 3 shows the axial ratio falls below 3dB from 2.5–3.3 GHz to 4.9–5.2 GHz, with an impedance range of 2.5–3.5 GHz and 4.7–6 GHz. In Ant4, the feedline is carried to the right side to widen the axial ratio bandwidth. This is visible in the widened axial ratio in comparison to the Ant3 bandwidth. From Fig. 3ii, the axial ratio bandwidth lies from 2.6 to 3.6 GHz and from 5.1 to 7 GHz, falling inside the impedance bandwidth range of 2.6–3.6 GHz and 5.1–7.5 GHz respectively which is shown in Fig. 3i. Therefore, the axial ratio bandwidth is within the impedance bandwidth range, making the proposed antenna circular polarized and with a widened bandwidth.

Figure 4i, ii depict the compared results of S11 and AR in terms of their simulated and measured values respectively. It can be observed that both graphs have a satisfactory value between them.

5 Analysis of Antenna Parameters

The proposed antenna accomplishes CP by presenting two rectangular pieces of various sizes in the ground plane. Effective results have also been noticed by varying the radius of the circle and also by changing the slot width. Here 4 parameters, (i) S1 × S2, (ii) S3 × S4, (iii) radius of the circle (r), and (iv) slot width (Sw) are taken into account and have been contemplated and examined by the assistance of Ansys HFSS with the change of a single parameter individually, keeping the other parameters constant.

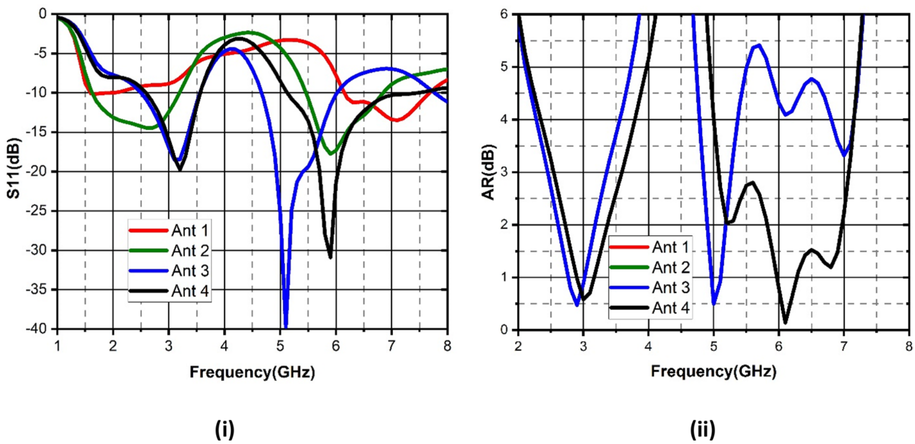
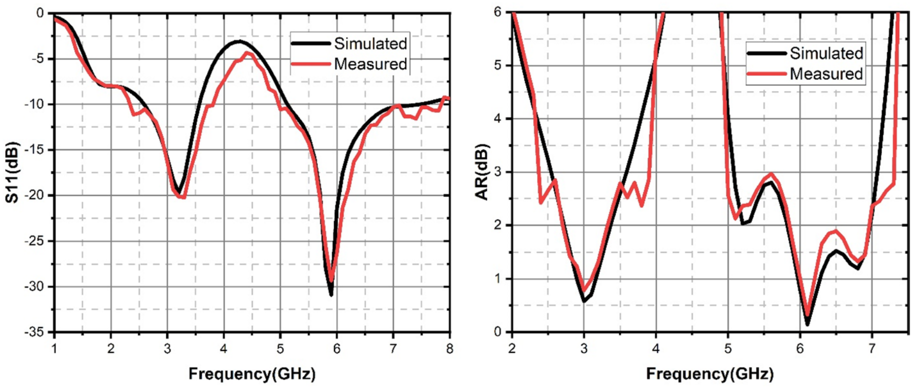


Fig. 3 Simulated **i** S11 **ii** AR of Ant 1-4



(i) (ii)

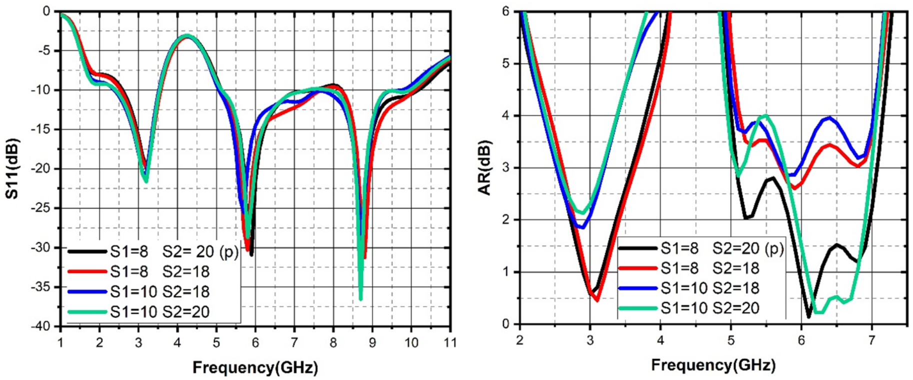
Fig. 4 Simulated Versus Measured **i** S11 **ii** AR

5.1 Effects Due to Rectangle S1 and S2

Figure 5 illustrates the variation of 1st rectangle S1 and S2 in the form of impedance bandwidth and axial ratio graphs. Here 4 types of variations of S1 and S2 are analyzed and then S1 = 8mm and S2 = 20mm are considered for the designed antenna. We can observe that results for all four values are almost the same in terms of S11 but when we consider the AR part, we can observe that 8 × 20 mm^2 rectangle gives the best result.

5.2 Effects Due to Rectangle S3 and S4

Figure 6 represents the variation of the 2nd rectangle S3 and S4 in terms of impedance bandwidth and axial ratio plots. Here also 4 variations of S3 and S4 are taken into account but S3 = 11 mm and S4 = 20 mm is then considered for the antenna design.



(i) (ii)

Fig. 5 Impact of S1 and S2 on antenna presentation **i** S11 **ii** axial ratio

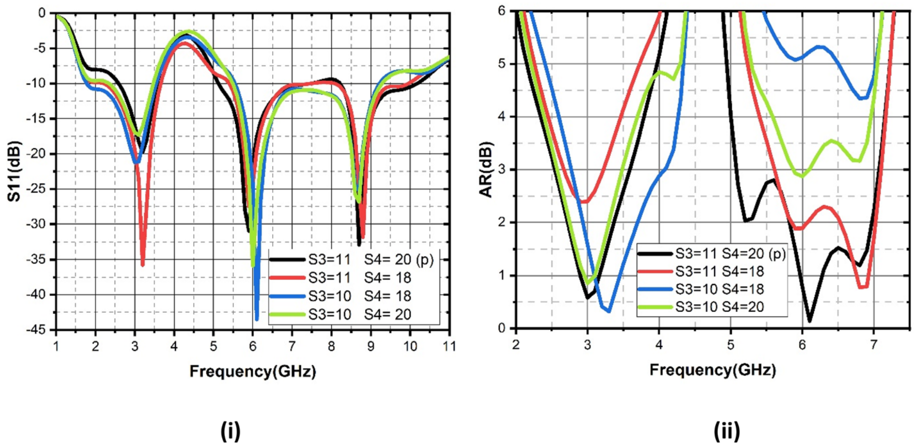


Fig. 6 Impact of S3 and S4 on antenna presentation **i** S11 **ii** axial ratio

Here also it can be visualized that other variations of S3 and S4 are almost giving good and same type results in terms of S11 versus frequency plot but if we analyze the AR plot, it can be stated that 11×20 mm^2 yields a better result.

5.3 Effects by the Radius of Circular Stub (r)

Figure 7 shows the variation of the circle's radius for different values in terms of impedance bandwidth and axial ratio. Here the radius having three values 3.2, 3.3, and 3.4 mm are considered from which 3.3 mm radius is selected for the designed antenna. The other two values are almost the same as the considered value but for better results in terms of widening of bandwidth 3.3 mm radius is considered.

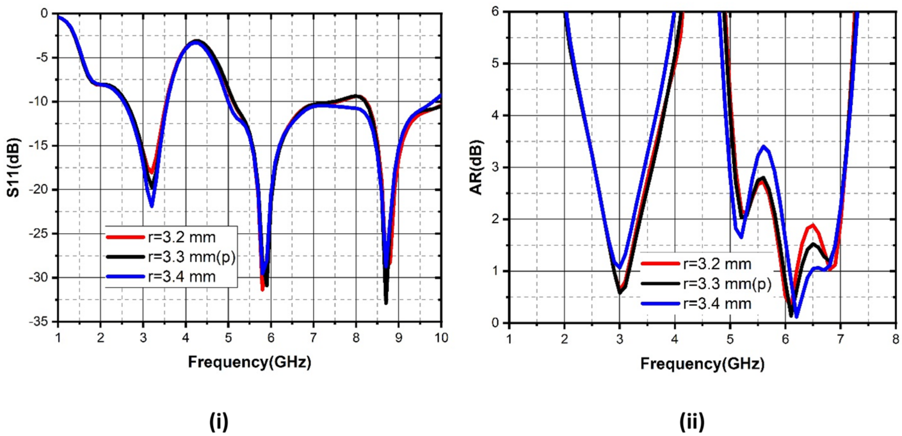


Fig. 7 Impact of circle radius (r) on antenna presentation **i** S11 **ii** axial ratio

5.4 Effects in the Variation of Slot Width (Sw)

Figure 8 shows the graph of (i) impedance bandwidth and (ii) axial ratio in terms of variation in slot width. Here 4 values of Sw = 0.5, 1, 1.5, and 2 mm are considered among which 1 mm value is taken for the antenna design. From Fig. 8i, we can notice that the S11 values for Sw = 1 mm gives a good result and its notch goes up to a deep of −32dB when compared to other values. In terms of axial ratio, we can also observe that it falls below the 3dB level and also has a widened bandwidth so it is considered to be the best among all other values.

The far-field representation of the designed radiator is displayed in Fig. 9 which represents the radiation patterns for two frequencies 3 GHz and 6 GHz for both the bands. For both XZ and YZ planes, radiation patterns are noted in the case of both frequencies. It can be detected that the results show a decent understanding between the simulated and measured data. Further, it is observed that the proposed antenna is Right Hand Circularly Polarized (RHCP) for the lower frequency band and is Left Hand Circularly Polarized (LHCP) in the case of upper-frequency band.

The simulated and measured peak gain of the proposed antenna is shown in Fig. 10. We can note that they have a good agreement between them and the graph is plotted inside the axial ratio band range in which the proposed antenna follows the circular polarization mechanism.

6 Experimental Verification

The proposed CP antenna is designed using Ansys HFSS software and fabricated on an FR4 substrate ($\varepsilon_r = 4.4$, $\tan\delta = 0.02$) as displayed in Fig. 11. The simulated structure was prototyped and measured in the anechoic chamber to validate the design and practical applications. Figure 11 represents the top and bottom perspectives of the manufactured antenna.

Figure 4i, ii represents the simulated and measured values for both impedance bandwidth and axial ratio bandwidth respectively. From graph Fig. 4i we can conclude that

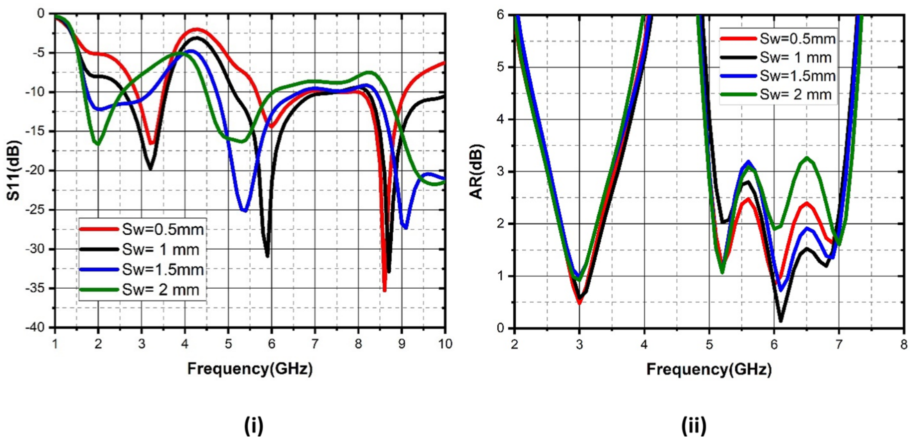


Fig. 8 Impact of Sw on antenna presentation **i** S11 **ii** axial ratio

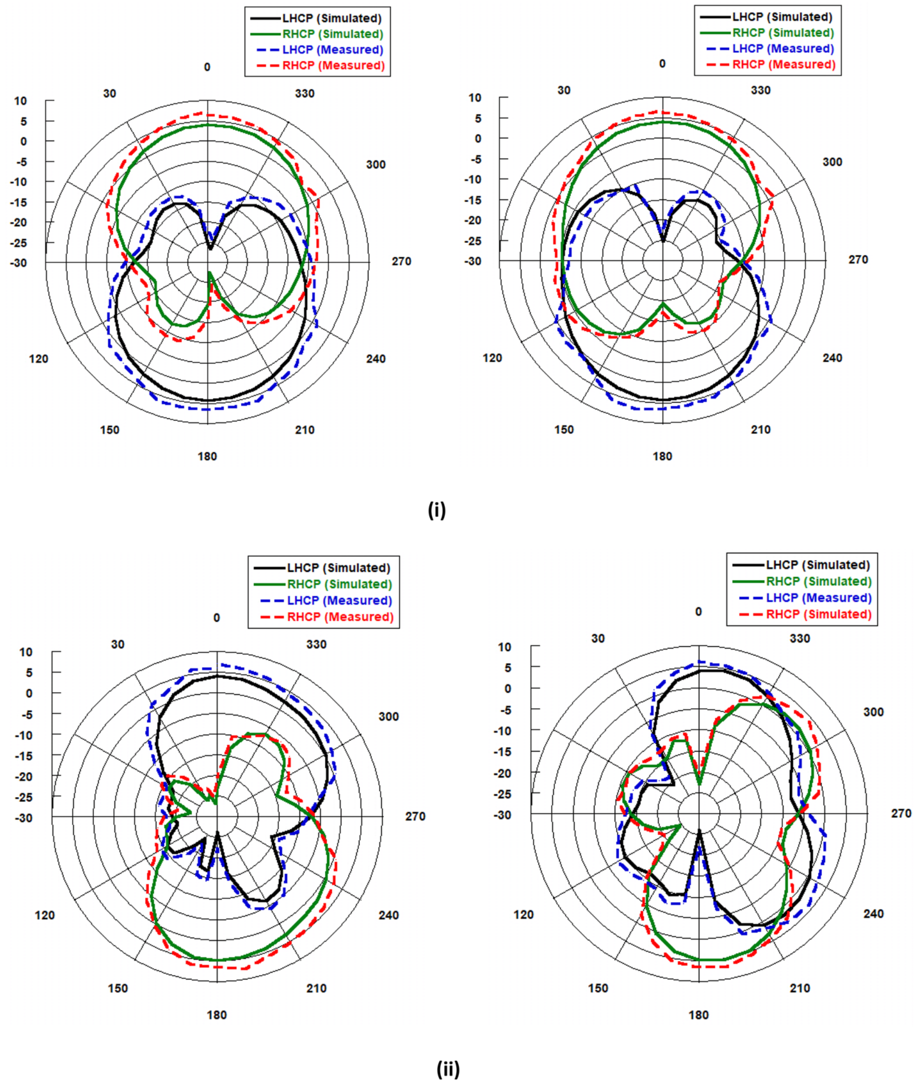


Fig. 9 Radiation patterns (Simulated and measured) at **i** 3 GHz and **ii** 6 GHz

the simulated value of lower IBW ranges from 2.6 to 3.6 GHz (32.25 %) and that of upper IBW ranges from 5.1 to 7.5 GHz (38 %) whereas the measured value of lower IBW lies from 2.4 to 3.8 GHz (45.16%) and upper IBW lies from 5 to 7.8 GHz (43.75 %) respectively. Similarly, from Fig. 4ii it is observed that the simulated lower ARBW lies in the range of 2.6–3.6 GHz (32.25%) and the upper ARBW falls in the range of 5.1–7 GHz (31.5%) whereas the measured ARBW comes in the range from 2.4–3.8 GHz (45.16 %) to 5–7.3 GHz (37.4 %) in lower and upper part respectively.

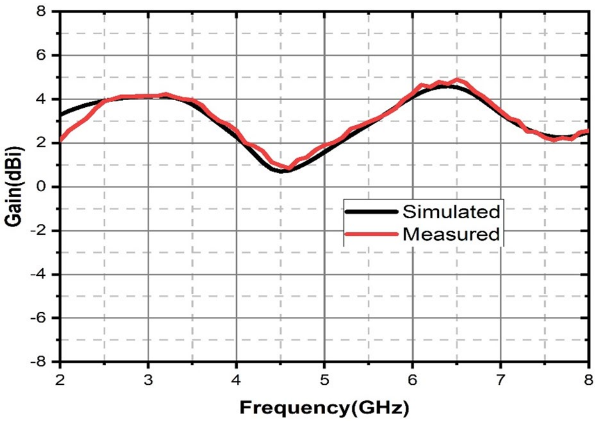


Fig. 10 Designed antenna's simulated and measured gain within the AR band

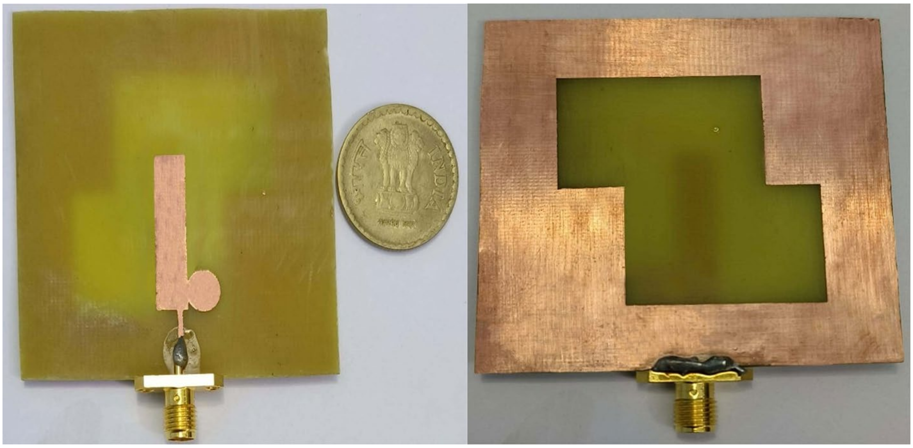


Fig. 11 Antenna model **i** Top view **ii** Bottom view

7 Conclusion

In this communication, a dual-band circular polarized square slot radiator is designed which is simulated by Ansys HFSS and successfully fabricated. The antenna covers a good range of bandwidth. Measurement results depict that the antenna achieves a 10 dB loss of 45.16% from 2.4 to 3.8 GHz range and 43.75 % from 5 to 7.8 GHz in both the bands. Similarly, it attains a 3dB AR of 45.16 % from 2.4 to 3.8 GHz and 37.4% from 5 to 7.3 GHz in both bands. The simulation and measurement results are in good agreement and it can be concluded that the antenna can indeed operate in both S-band (2–4 GHz) and C-band (4–8 GHz).

Acknowledgements We would like to express our sincere gratitude to all the individuals and organizations who have contributed to the publication of this research paper.

Author Contributions Hirak Keshari Behera: Conceptualization, Methodology, Software, Validation, Writing—original draft. Manas Midya: Validation, Formal analysis, Investigation, Writing—review and editing. Laxmi Prasad Mishra: Investigation, Project administration, Supervision.

Funding Not applicable

Data Availability Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical Approval Not applicable.

Consent for Publication We, the undersigned, give our consent for the publication of identifiable details, which can include pictures and details within the text to be published in the above journal.

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