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High gain wideband circularly polarized antenna with modified ground plane

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ABSTRACT

In this study, a high-gain wideband circularly polarized (CP) printed monopole antenna for wireless local-area network (WLAN), worldwide interoperability for microwave access or WiMAX, C-band, and multiple input, multiple output (MIMO) applications was proposed and demonstrated. The proposed antenna structure has an octal-shaped monopole antenna tilted by 20° from its longitudinal axis, excited by coaxial probe feeding, and partial ground plane. To achieve broadband CP performance, the ground plane was redesigned with etching slots. A 1.6-mm-deep FR-4 (Ɛr = 4.3) substrate with dimensions of 70x55 mm2 is used to create and test a prototype of the suggested antenna. The proposed antenna's measurement results satisfy requirements for a broad ARBW of 107% (1.83-6.05 GHz), a broad impedance bandwidth of 139.39% (2-11.2 GHz), and a maximum gain of 7.28 dBi.

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1. INTRODUCTION

With the development of current systems for communication, the need for circularly polarised (CP) antennas is growing overwhelming. Because of their many benefits, such as their ability to suppress polarization, reduce conflict across two antennas, and establish reliable communication linkages during bad weather [1], [2]. The fast expansion of communication via wireless networks coupled with portable mobiles and other handheld electronics has boosted the need for a circularly polarized (CP) antenna with broad impedance and axial ratio bandwidth (ARBW) [3]. Ultra-wideband antennas of CP are commonly employed for military-related uses, including radar devices, medical equipment, and electronic defense systems [4], [5]. The performance of contemporary communication technologies, including mobile, GPS, and satellite uses, is additionally enhanced by utilizing the CP radiation pattern [6], [7].

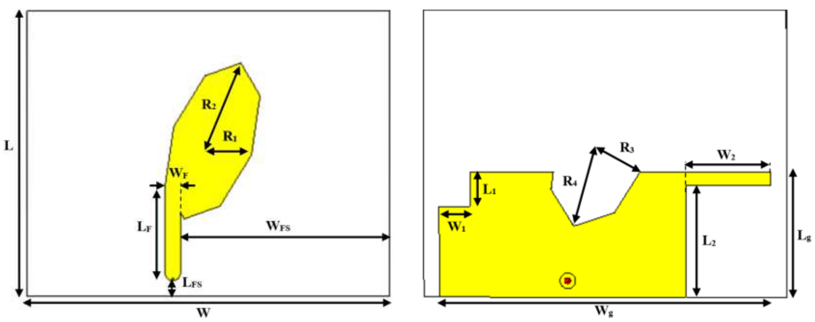
The majority of CP monopole antennas have a narrower band and less gain. An important challenge for researchers is the creation of a wideband impedance and high-gain CP antenna. As a result, numerous researchers have been developing unique methods for creating a small CP monopole with a broad ARBW [8]–[10]. To achieve 23% CP bandwidth, [8] utilized an inexpensive C-shaped feed and L-shaped slot monopole antenna. A CP monopole antenna in the form of a Y with two uneven monopole arms was used [9]. This antenna has a 3-dB ARBW of 4.3% over the 2.25–2.35 GHz frequency range. A trapezoidal monopole antenna for both linear and circular polarization that is supplied via a coplanar waveguide (CPW) with an ARBW of 8% is described in [10]. However, the ARBW of the mentioned antennas [8]–[10] has restrictions and making them unsuitable for many wireless applications. Additionally, because these antennas are very large, it is difficult to place the other electronic components in tiny form factor devices. Consequently, several methods became reported to increase the CP bandwidth (3-dB ARBW) and modify the ground plane by using both stubs and slots [11]–[13]. To achieve 64.7% bandwidth [14], a parasitic spiral patch was linked to each side of the monopole. 72.4% bandwidth was achieved in [15] using an asymmetric ground plane and several extended stubs. Alsariera *et al*. [16] described a monopole antenna fed by an L-shaped CPW to obtain 98% ARBW. Wang *et al*. [17] achieved 85.5% ARBW by monopole with a reversed L-shape, L-shaped strip, and uneven U-shaped strip as parasitic components. A small sickle-shaped antenna that has a slotted ground layer was indicated to realize 126.85% IBW and 73.33% ARBW [18]. A single feed with CPW of monopole produces an IBW of 76.9% and a 3-dB ARBW of 39.8% by a bent L-shaped stub and an asymmetric ground plane [19]. In this paper, we are interested in obtaining a circularly polarized antenna with as broad an ARBW as possible. We were able to get 139.39% IBW, 107% ARBW, and a high gain of 7.28 dBi. This indicates that the IBW, ARBW, and gain of some of the antenna parameters previously reported in the literature have been enhanced.

This article proposes a wideband CP-printed monopole antenna with a partial ground plane. The presented work is explained in four sectors. In the first section, “The proposed design of a circularly polarized antenna,” the antenna design with dimension is covered. The section 2, “Method,” discusses a methodology for achieving CP radiation performance and parametric analysis. In the section 3, titled “Results and Discussion” the proposed antenna's prototype is created, and measured results are contrasted with predicted outcomes. The final section, “Conclusion,” is completed.

2. THE PROPOSED DESIGN OF A CIRCULARLY POLARIZED ANTENNA

The suggested broadband CP antenna appears in Figure 1 and is fabricated from a low-cost FR4 dielectric substrate that has a relative permittivity of 4.3, a dielectric loss tangent of 0.025, and a total volume of 70x55x1.6 mm^3. A 50-ohm microstrip transmission feedline connects the octal monopole antenna to an SMA coaxial probe connector. The final lengths of the proposed antenna, which were adjusted with the CST microwave studio suite, are shown in Table 1.

Figure 1 shows the suggested printed monopole antenna's optimized design, where the octal monopole is printed above the upper metallic layer of the FR-4 substrate as shown in Figure 1(a). The modified monopole is tilted (Θ =20°) from the vertical axis to achieve broadband matching and satisfy CP performance, as demonstrated by the parametric study. The monopole’s place is not at the center of the substrate, but it shifts in the vertical axis (y-axis) by 4.5 mm and in the horizontal axis (x-axis) by 0.8 mm, and this affects the antenna properties. The monopole is fed by a 50-ohm microstrip line terminated with coaxial probe feeding, which begins (L_{FS} = 5 mm) before the end of the substrate. Figure 1(b) shows an etching on the bottom metallic layer where a modified ground plane is printed with some edges. As presented in the parametric studies section, these modified edges extend the 3-dB ARBW.



(a) (b)

Figure 1. Layout of the proposed antenna with dimensions (a) top view and (b) bottom view

Table 1. The designed antenna's dimensions

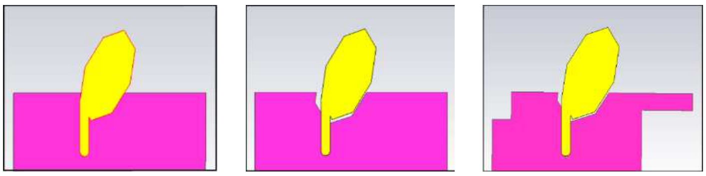
Parameter	Value (mm)	Parameter	Value (mm)
W	70	W_g	64
L	55	L_g	26
R_1	8	W_1	6
R_2	16	L_1	9
W_F	3	W_2	16.3
L_F	18.3	L_2	20.5
W_{FS}	42	R_3	9.2
L_{FS}	5	R_4	17.4

3. METHOD

The approach for achieving CP radiation performance and parametric analysis is covered in this section. To provide a greater range in impedance bandwidth (IBW) and ARBW, three models with different ground planes are used. Parametric analysis is required while deciding on the most suitable dimensions to increase the properties of the recommended antenna.

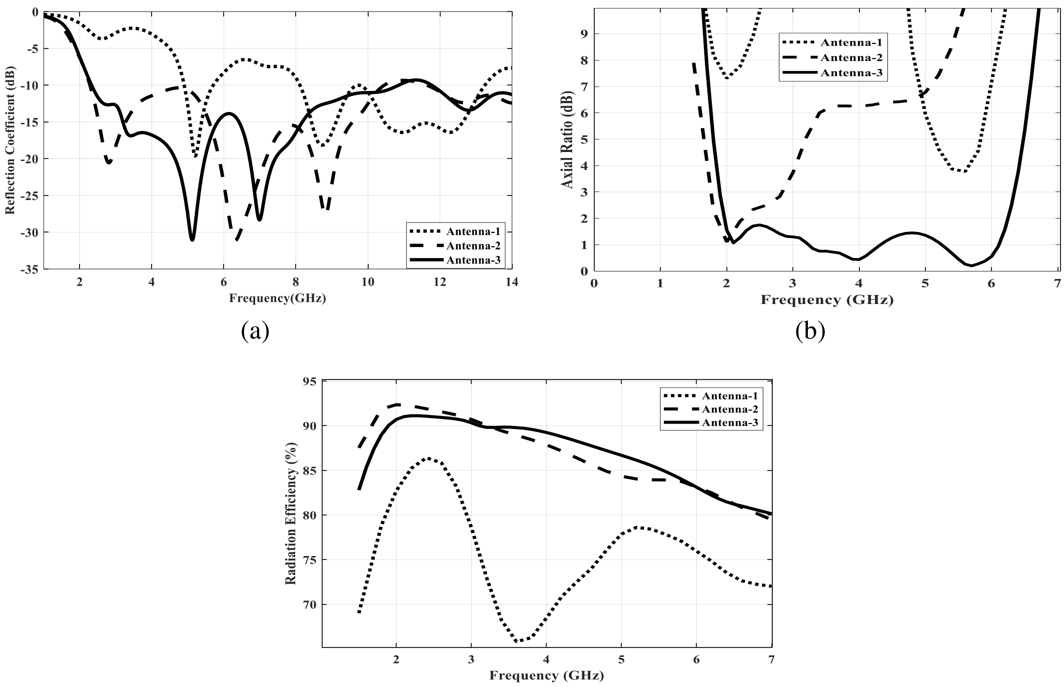
3.1. Methodology for achievement CP radiation performance

To evaluate the design process, three antennas (Antennas 1–3) are examined. The detailed analogy is depicted in Figures 2–3 (in terms of structure and performance potential). One possibility for enhancing the performance of various antenna characteristics is the use of the implicit technique in Antenna-3. Antenna design starts with an octal monopole antenna and a partial rectangle ground plane, which is Antenna-1 as shown in Figure 2(a), which results in a bandwidth of (8.1–13.25 GHz) illustrated in Figure 3(a), which is not a CP as shown in Figure 3(b). Then it truncates the octal-shaped (R3, R4) radius from the ground plane to obtain Antenna-2, as shown in Figure 2(b), which improves the impedance matching band (2.2–10.45 GHz) illustrated in Figure 3(a), while ARBW (1.8–2.8 GHz) is displayed in Figure 3(b). The other two truncating rectangles in the ground plane from the edges yield Antenna-3 (the final design), as shown in Figure 2(c), which significantly enhances the impedance matching band (2.32-10.85 GHz), as shown in Figure 3(a), and the axial ratio band (1.86-6.37 GHz) (the generation of wideband CP antenna), as displayed in Figure 3(b). The radiation efficiency for the three models of the antenna shown in Figure 3(c) shows that the highest efficiency is from the third model, where its value is 91%.



(a) (b) (c)

Figure 2. Design procedures of the proposed monopole antenna with modified ground (a) Antenna-1, (b) Antenna-2, and (c) Antenna-3 (final proposed structure)



(a) (b)

(c)

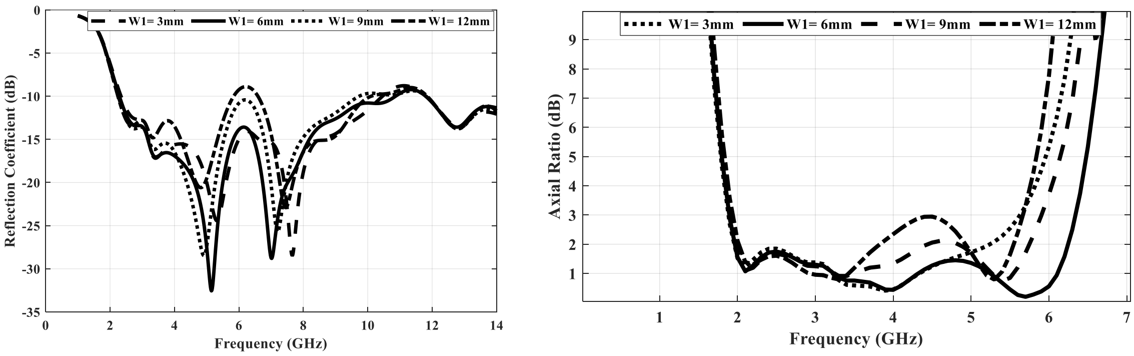
Figure 3. Simulated performances of different design procedures (a) reflection coefficient (dB), (b) axial ratio (dB), and (c) radiation efficiency (%)

3.2. Parametric analysis

This section presents parametric research to examine the impact of the suggested antenna's geometrical characteristics on the magnitude of the reflection coefficient (S11) and ARBW. To comprehend the impact on the axial ratio and S11, several values of the aperture (W_1, L_1), angle (ϴ), and monopole position (x, y) are being used as dominating parameters. Through this study, the dimensions of the antenna were chosen.

3.2.1. Effect of the dimension of slot (W_1)

Figure 4 depicts the effects of varying the length of W_1 in S11 and the 3-dB AR bandwidth. When the horizontal length (W_1) is increased from 3 to 12 mm with a step of 3 mm, the lower side of the frequency remains unaffected in S11 but slightly affects the high frequencies, as shown in Figure 4(a). 3-dB AR bandwidths improve on the upper side of frequency until 6 mm, then they deteriorate, as shown in Figure 4(b). W_1 has been optimized to 6 mm based on a study.

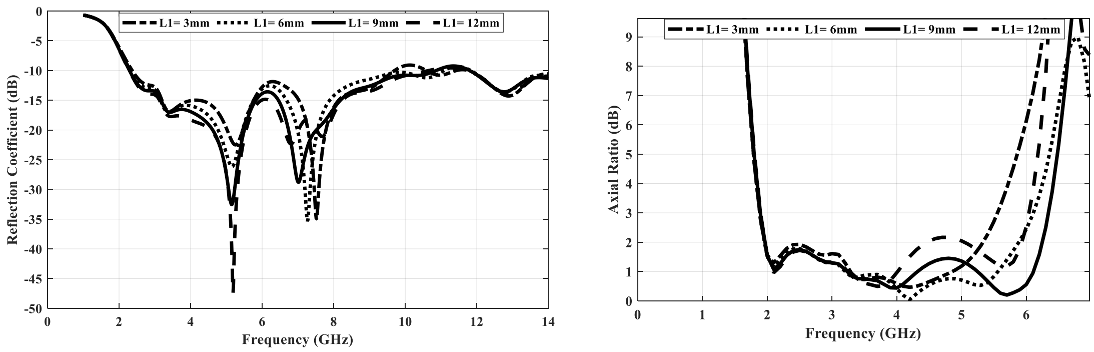


(a) (b)

Figure 4. Effect of the length (W_1) on (a) reflection coefficient (dB) and (b) axial ratio (dB)

3.2.2. Effect of the dimension of slot (L_1)

Figure 5 depicts how length (L_1) affects the S-parameter and ARBW. The length of L_1 changes from 3 to 12 mm with a step of 3 mm. The effect of length (L_1) has a slight change in the lower frequencies but affects the high frequencies. When increasing the length (L_1) from 3 to 12 mm, the bandwidth will improve slightly, as shown in Figure 5(a). While the ARBW gets better by increasing the length up to 9 mm and gets worse after that, as indicated by Figure 5(b). According to the study's results, (L_1 = 9 mm) is superior to other values in terms of obtaining wide matching and AR bandwidths.



(a) (b)

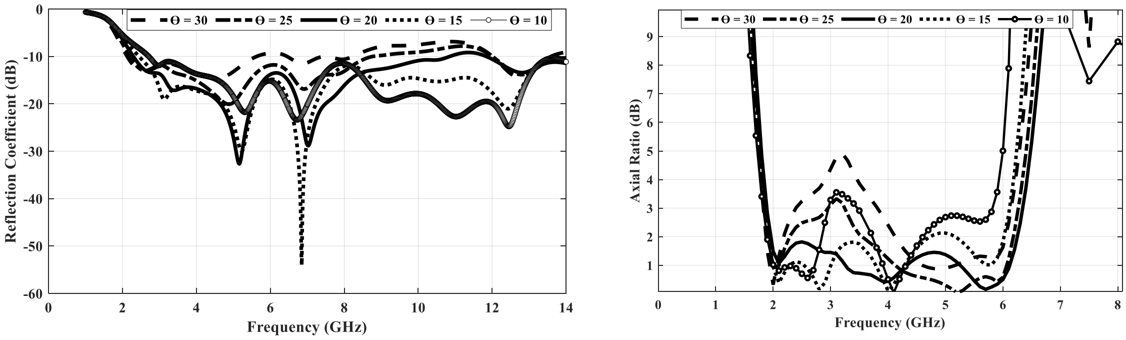
Figure 5. Effect of the length (L_1) on (a) reflection coefficient (dB) and (b) axial ratio (dB)

3.2.3. Effect of variation in angle (ϴ)

The effect of changing the angle values on the reflection coefficient and the axial ratio is illustrated in Figure 6. The bandwidth is greatly affected by changes in angle values. As shown in Figure 6(a), the lower the angle, the greater the bandwidth. When the angle decreases from 30 to 20 degrees, the ARBW improves and then worsens. For a wider ARBW, this is at an angle Ɵ = 20°, as shown in Figure 6(b), so it was chosen to obtain a wider ARBW.

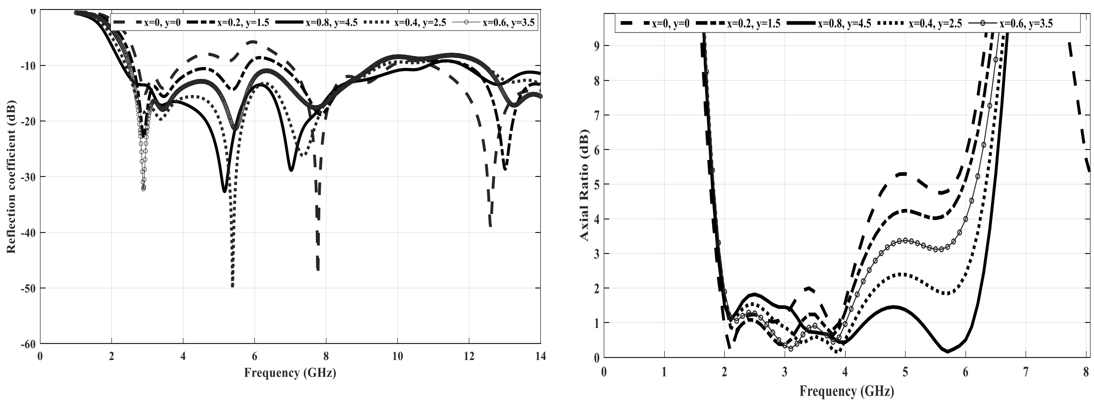
3.2.4. Effect of position of monopole (x, y)

Impedance bandwidth (IBW) and ARBW are affected by the monopole site. There are some values for the monopole site, as shown in Figure 7, where the best monopole site is x = 0.8 and y = 4.5 mm, which achieves the best results in S11 as demonstrated in Figure 7(a) and ARBW as displayed in Figure 7(b). Therefore, it was chosen because it works to improve results.



(a) (b)

Figure 6. Effect of the angle (Ɵ) on (a) reflection coefficient (dB) and (b) axial ratio (dB)



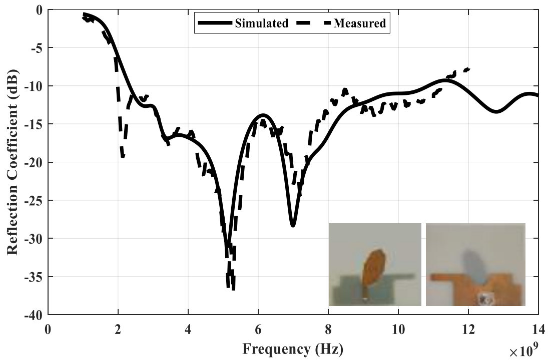
(a) (b)

Figure 7. Effect of position of monopole on (a) reflection coefficient (dB) and (b) axial ratio (dB)

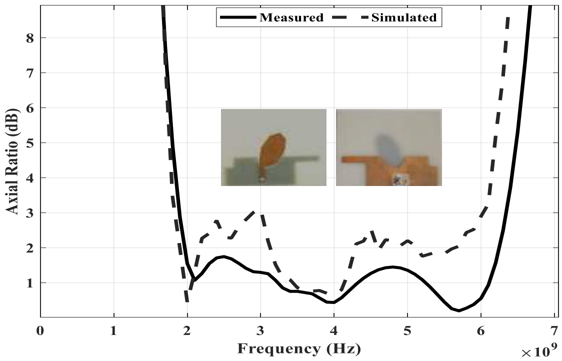
4. RESULTS AND DISCUSSION

An anechoic chamber (Satimo StarLab-18/Star007-A0019) was utilized to measure the prototype's gain, axial ratio, and radiation parameters, whereas the S11 was measured using a PNA (E8363B Agilent Network Analyzer). The simulation's results are validated using a manufactured and characterized broadband CP antenna. Simulated and measured results values are compared in Figure 8. Figure 8(a) displays the measured value and simulated data of 10-dB IBW at 2-11.2 GHz (139.39%) and 2.32-10.85 GHz (129.53%), respectively. Accordingly, the 3-dB ARBW is 1.83-6.05 GHz (107%) and 1.86-6.37 GHz (109.6%), as displayed in Figure 8(b). The measurement and simulation peak gain of the proposed antenna is 7.28 dBi and 5.5 dBi within the ultra-wideband (UWB) spectrum, as shown in Figure 8(c).

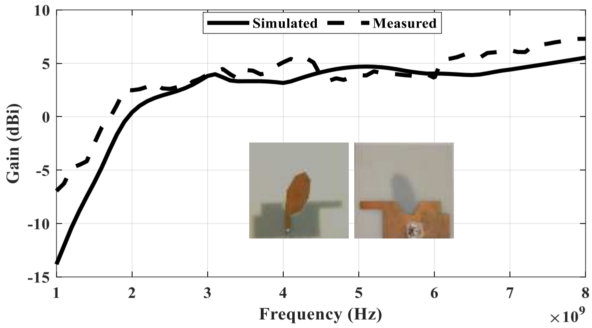
Figure 9 depicts the radiation patterns at 2 GHz and 5.5 GHz. The normalized radiation patterns in the yz-plane and xz-plane at 2 GHz as displayed in Figure 9(a) and 5.5 GHz as shown in Figure 9(b). The findings demonstrate that for the + Z direction, an RHCP is achieved, while for the – Z direction, the realization of an LHCP. This antenna's bidirectional radiation properties make it suitable for both point-to-point and point-to-multipoint communications. Nevertheless, a great agreement is demonstrated between simulation and testing findings, with just a little modification necessary due to fabrication tolerances and SMA connection losses.



(a)

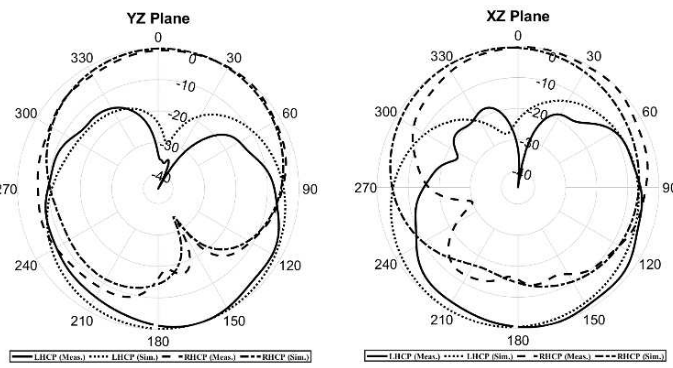


(b)

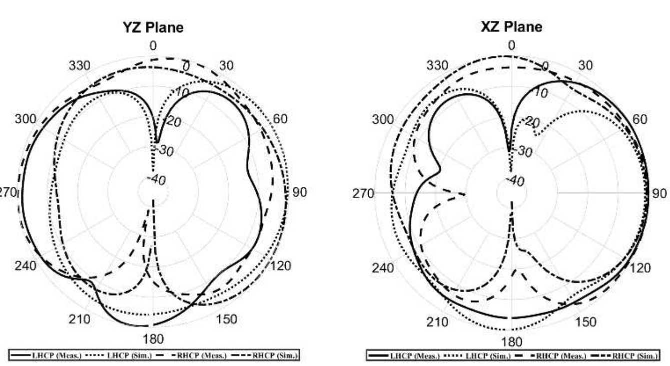


(c)

Figure 8. Simulated and measured results of the proposed antenna (a) reflection coefficient (dB), (b) axial ratio (dB), and (c) gain (dBi)



(a)



(b)

Figure 9. Measurement and simulation antenna radiation patterns at (a) 2 GHz and (b) 5.5GHz

Table 2 compares the proposed antenna's size, IBW, 3-dB ARBW, and gain to those of a different previously published circularly polarised antenna. It means that the proposed antenna benefits from having a broad IBW and ARBW. In comparison to other reported antennas, it also has a larger peak gain.

Table 2. Comparing the proposed antenna to other similar antennas

Ref.	Antenna size (mm3)	IBW (GHz, %)	3-dB ARBW (GHz, %)	Gain (dBi)
Alsariera *et al*. [16]	33.5 × 34.5 × 1.6	(2–6.2), 103	(1.9– 5.8), 98	3.6
Saraswat *et al*. [20]	30 × 50 × 1.56	(2.13–3.47), 47.91	(2.22–3.25), 37.6	NA
Manohar and Chaudhary [21]	20 × 25 × 0.8	(2-9), 127.3	(2-9), 127.3	6.3
Behera *et al*. [22]	79.4 × 59 × 1.3	(3.27–5.89), 57.21	(4.21–5.42), 25.25	4.92
Mondal [23]	28 × 23.9 × 1.6	(3.64–15.30), 123	(3.85–10.52), 93	3.3
Tao *et al*. [24]	25× 25 ×1	(4.5–9.7),73.2	(5.3–9.4), 55.8	3.47
Peddakrishna *et al*. [25]	22 × 30 × 0.8	(3.1-10), 104	(3.3-4.0), 18.5	3.2
Proposed work	70 x 55 x 1.6	(2-11.2), 139.39	(1.83-6.05), 107	7.28

5. CONCLUSION

High gain circularly polarized monopole antenna with UWB matching and broadband CP performance has been suggested and fabricated. According to the experiment's findings, the suggested antenna achieves an impedance bandwidth (IBM) of 139.39%, and an AR bandwidth (ARBW) of 107%. Modifications to the partial ground plane were made to obtain the CP antenna by truncating the octal-shaped and other two rectangles from the ground plane. The proposed design is characterized by ease of manufacture, in addition to obtaining the best results in ARBW, IBW, and a high gain compared to previous literature. It is a candidate for WLAN, WiMAX, IEEE C-band, and ISM. It can be used in the MIMO application.

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