Broadband CPW-Fed Circularly Polarized Compact Planar Monopole Antenna with Half-Elliptical slot for C and X band Applications

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Abstract

A new coplanar-waveguide (CPW)-fed monopole antenna with broad impedance bandwidth (IBW) and axial ratio bandwidth (ARBW) is presented. A half-elliptical slot and a rectangular slot with a compact size of 23 x 22 x 1.6 mm^3 make up the planned structure. The design stages of the planned antenna are presented by optimizing the various design parameters using parametric analysis. It has a -10 dB IBW of about 71.74 percent from 4.38 GHz to 9.28 GHz, with a 46.19 percent ARBW from 5.71 GHz to 9.14 GHz. It is appropriate for wireless communication applications in the C- and X-bands and entirely covers the wireless locan area network (WLAN) band (5.725-5.85 GHz). The surface current distribution investigates the circular polarisation (CP) rotation process. The developed antenna has good gain and has steady radiation characteristics within the operational band. The antenna measured results are in perfect accordance with the simulations.

Keywords: Broadband, Circular polarization, Compact planar antennas, Coplanar waveguide, Half-elliptical slot.

1. Introduction

In recent decades, the need for miniature antennas with broadband capabilities has increased due to the necessity for high data rate communication. Because of their multiple advantages, planar antennas are the most popular radiating element for wireless transmission [1], including low production cost, small size, ease of design, great flexibility, and easy integration with other devices. CP antennas provide several appealing features [2], including reduced multipath effects during CP propagation, better flexibility in transmitter and receiver orientations, and more excellent resistance to signal loss due to adverse weather. The superiority of CP antennas over linearly polarized (LP) antennas has led to their widespread use in [3]several wireless communication technologies, including radio frequency identification systems (RFID), mobile satellite communication systems, onboard airplanes, high-speed trains, WLAN, global system for mobile communications (GSM) and global navigation satellite systems (GNSS) remote sensing.

Several planar antennas [4]-[15] to realize CP were reported in the literature. IBW 13.33 GHz was developed via an L-shaped parasitic element inside a hexagonal ring-shaped monopole [4]; It covered the entire UWB band, but the ARBW is only 1.9 GHz. On the ground plane, an L-shaped branch and a rectangular branch with an asymmetric T-shaped feed line [5] covered IBW of 7.5 GHz ARBW of 3.1 GHz with overall dimensions of 48 x 31 x 1 mm^3. The combined effect of a parasitic strip around monopole, parasitic Hilbert strip, and defected ground [6] produced broadband characteristics.

The inverted-L stripe and asymmetric ground plane are paired with two consecutive CP modes in [7], resulting in a massive 3-dB ARBW. An etched U-shaped slot antenna with two L-shaped radiation patches on a square ground plane [8] realized IBW of covering the entire ultra-wideband (UWB) with ARBW of 4 GHz with dimensions of 48 x 48 x 1 mm^3. A structure of three combined loops, two asymmetric U-shaped strips, and two L-shaped slots generated three circularly polarized frequency bands with good broad IBW [9]. Metamaterial inspired quad-band CP antenna [10], dual-band circular slot antenna [11], ring slot antenna with capacitive-load [12], [13] substitutes a wide strip for a thin dipole, resulting in two degenerated orthogonal modes that allow CP to operate. The inclusion of a slot, U-shaped slot, and a cross-shaped monopole ensured broad ARBW by vertically extending one side of the ground plane [14], [15].

A literature survey demonstrates that scholars have put a lot of work into developing numerous strategies [16]–[26] to realize CP antennas with compact size and broad bandwidth. The primary radiating source is truncated corner patches, while the second radiating element is periodic metallic plates [16], sandwiched metasurfaces, and partially reflecting surface [17] offered CP around 1 GHz. A crossed dipole inside an octagonal ring [18], folded E-Shaped and folded T-shaped dipoles [19], four-slot type split ring resonators (SRR) etched on each of the elliptical arms [20], modified rectangular patch based on metamaterial (MTM) with two sets of spiral strips and vias [21], a novel [22] composite right/ left-handed transmission-line (CRLH-TL), antenna inspired by the CRLH-TL with a closed ring slot [23], based on a high impedance surface (HIS), an asymmetrical semi-circular fractal boundary patch antenna [24] was developed and s-shaped metasurface (MTS) based CP antenna [25] realized circularly polarized antennas. In CP antennas, the sequential phase rotation (SPR) approach [26]–[30] was employed to improve the ARBW.

This article proposes a wide -10 dB IBW of nearly 71.74 percent from 4.38 GHz to 9.28 GHz and a 3-dB ARBW of 46.19 percent from 5.71 GHz to 9.14 GHz. A CPW line with a monopole and ground with rectangular slot, half-elliptical slot, and strips feeds this antenna. This antenna is smaller than several previously reported antennas, comprising 23 x 22 x 1.6 mm^3 and having a broad IBW 4.9 GHz and ARBW 3.43 GHz.

2. Proposed Antenna Design

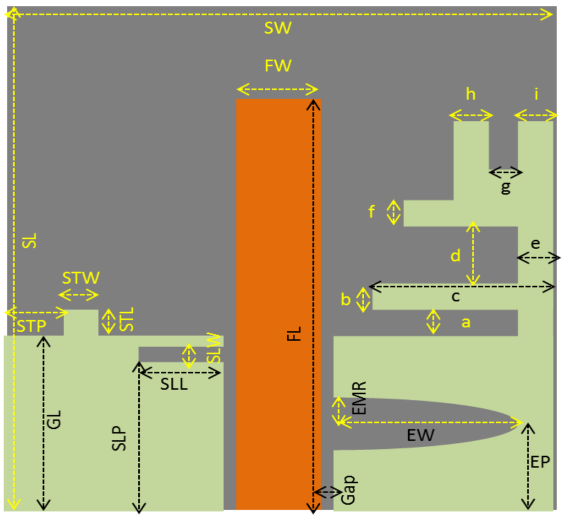


Fig. 1. Antenna structure

Fig. 1 shows suggested CPW - fed monopole antenna geometry. The radiating patch is a simple monopole. On the right side of the monopole, two horizontal and two vertical asymmetric strips make up the ground plane. Whereas on the left side, a small strip is protruded. A rectangular slot in the ground plane is left to a monopole; right side to the ground, a half-elliptical shaped area is created. The antenna configuration is excited through 50 Ω CPW. The overall dimensions of the antenna are 23 x 22 x 1.6 mm^3. The measurements of the planned antenna are shown in Table 1.

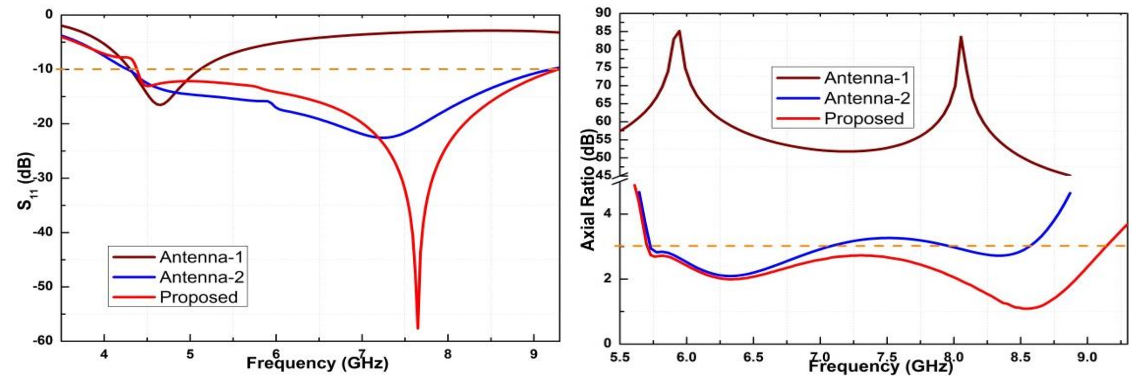
Table 1. Antenna dimensions

Dimension	Value (mm)	Dimension	Value (mm)	Dimension	Value (mm)
SL	23	EP	3	b	1.2

SW	22	SLL	3.375	c	6.8
FL	18.8	SLW	0.5	d	2.3
FW	2.8	SLP	5.8	e	1.05
G	0.25	STW	1.5	f	1.2
GL	6.6	STL	0.85	g	1
EMR	1.85	STP	3	h	1
EW	8	a	1.25	i	1

(a)Ante.1 (b) Ante. 2 (c) Ante. 3

Fig. 2. The Antenna's evolution



(a) (b)

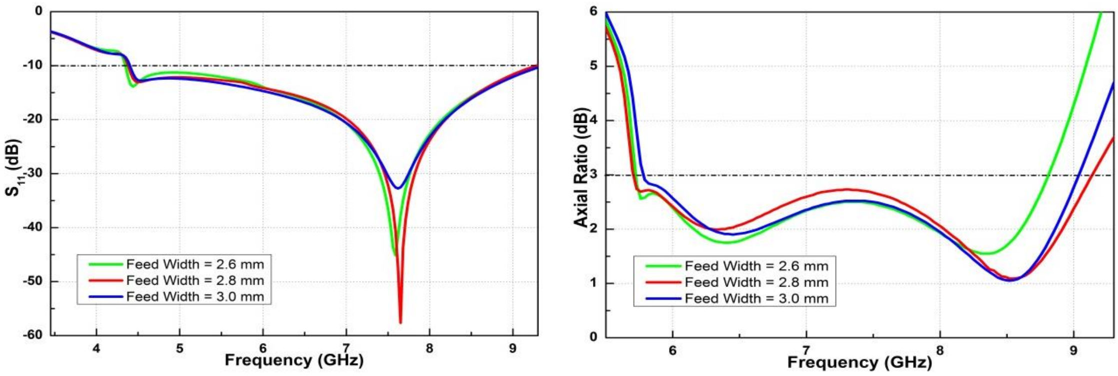
Fig. 3. (a) S_{11} (b) Axial Ratio

As illustrated in Fig. 2, the antenna design idea involves three steps. Antenna 1 has a monopole and ground with IBW 4.30 GHz to 4.65 GHz with a return loss of -16.53 dB. Antenna 2 has a half-elliptical slot, two horizontal stripes, and two vertical strips right to the monopole, as in Fig. 2(b). It has a 4.27 GHz to 9.2 GHz IBW (4.93 GHz bandwidth), a -22 dB return loss, and can produce circular polarisation. The ARBW ranges from 5.73 GHz to 7.07 GHz and 7.13 GHz to 8.56 GHz, having a total ARBW of 5.73 GHz to 8.56 GHz (1.89 GHz). The proposed antenna (antenna 3) uses a rectangular slot and a small strip, as shown in Fig. 2(c). This antenna yields an extensive -10 dB IBW from 4.38 GHz to 9.28 GHz of around 71.74%, and ARBW from 5.71 GHz to 9.14 GHz of 46.19%. Fig. 3 shows the comparison plot of the three antennas.

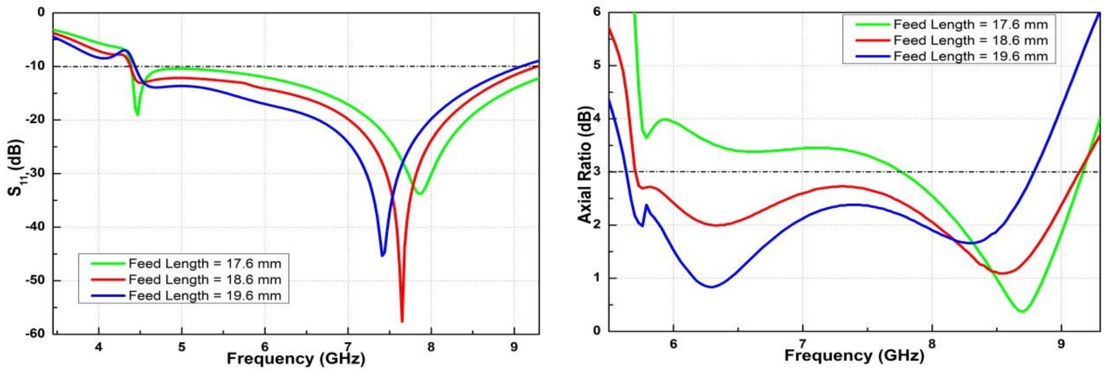
3. **Parametric Analysis**

The influence of the change of some parameters is powerful on the overall performance of the antenna. Different parameter changes have been simulated and then investigated for good performance for broadband CP operation. There are few parameters in this broadband circularly polarized antenna which influence the antenna's overall performance. In this section, the analysis of variations in monopole width (FW), monopole length (FL), gap between monopole and ground (G), ground length (GL), ellipse major radius (EMR), strip length, and stripe width are studied with respect to return loss and axial ratio.

The modest effect of is shown in Fig. 4(a). At FW=2.8 mm, impedance matching is improved when ARBW is increased. The profound effect of FL is shown in Fig. 4(b). The CP operation is deteriorated at FL=17.8 mm. The ARBW is more at FL=18.8 mm. The upper cut-off frequency is decreased as FL increases. Here FL= 18.8 mm is an optimum value.



(a)



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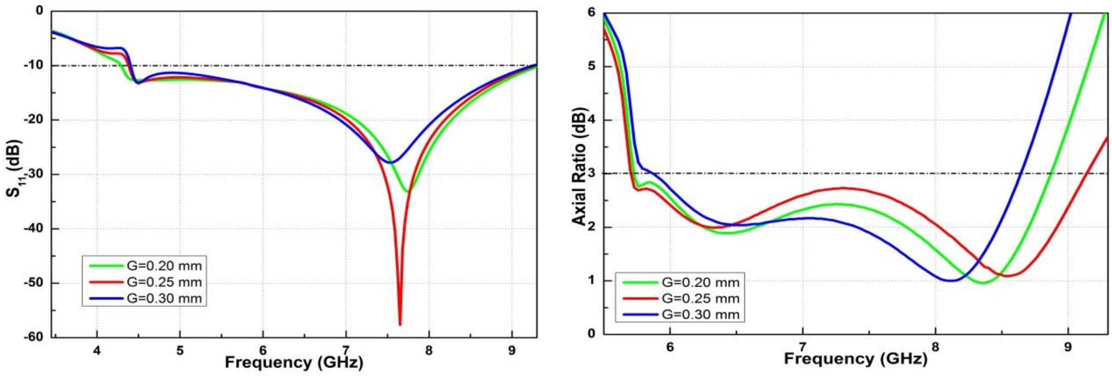

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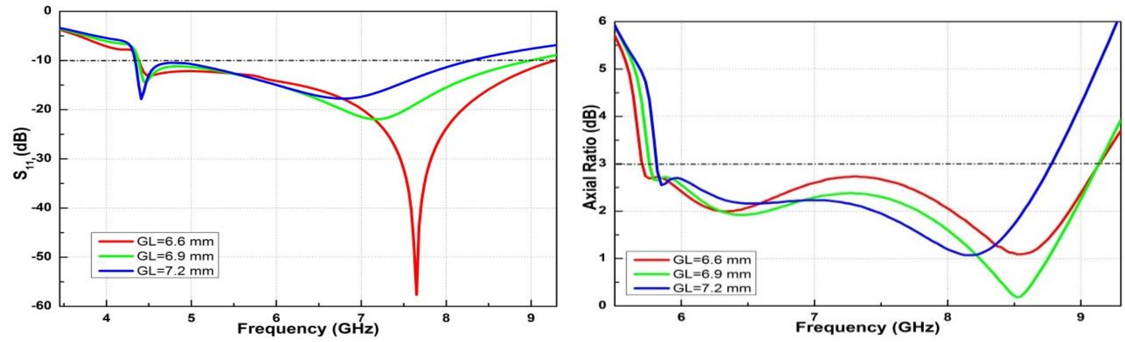

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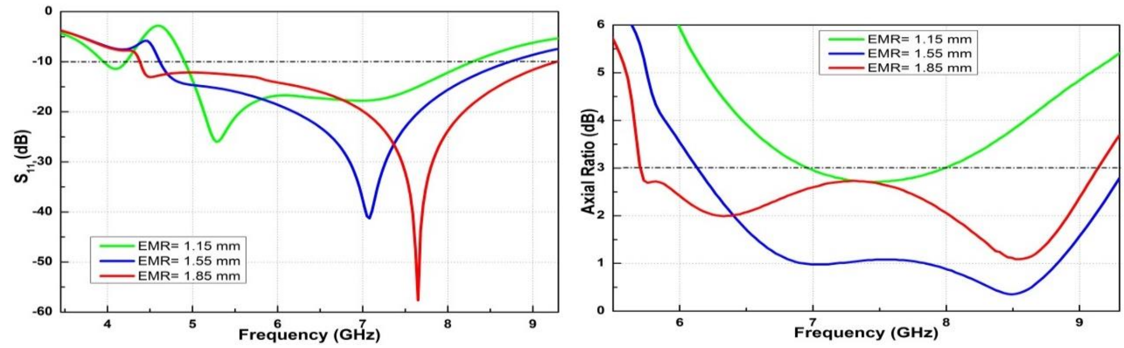
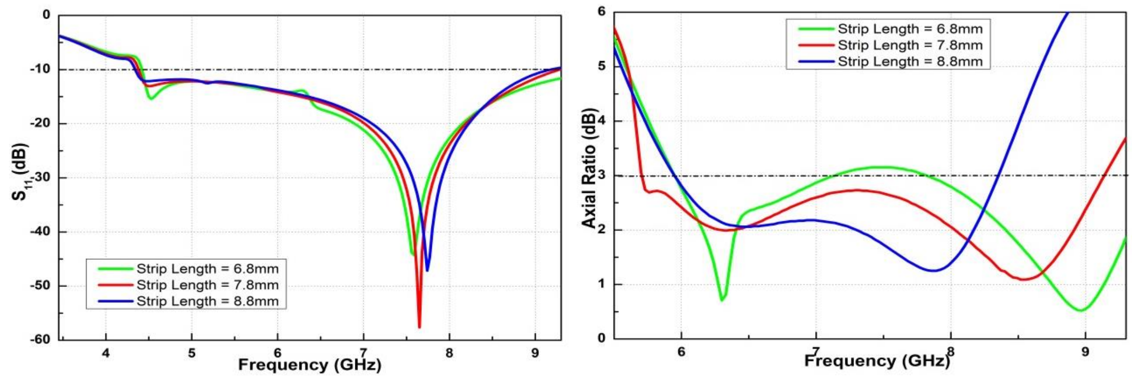
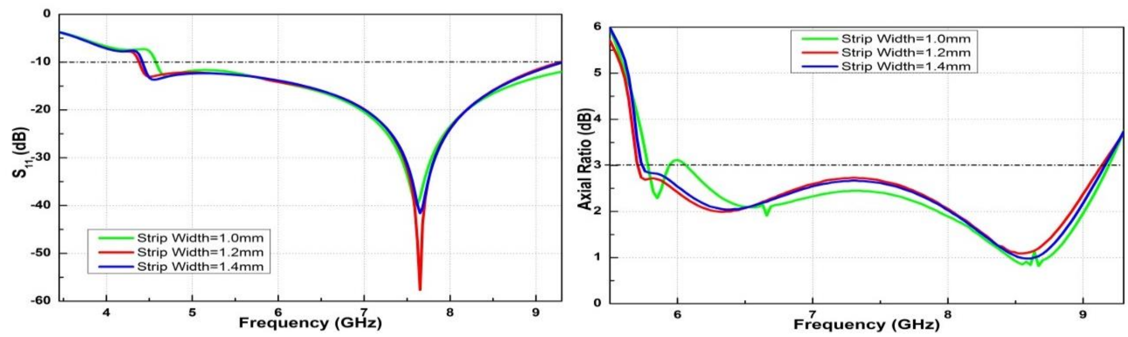


(e)



(f)



(g)

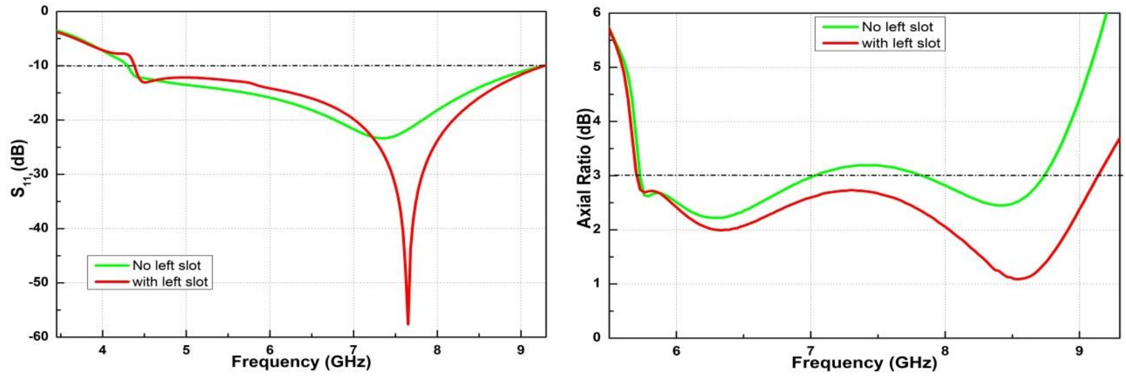
Fig. 4. (a) monopole width (FW) (b) monopole length (FL) (c) gap (G) (d) ground length (GL) (e) ellipse major ratio (EMR) (f) strip length (g) strip width - Parametric analysis

Table 2. Simulation values of variations in EMR

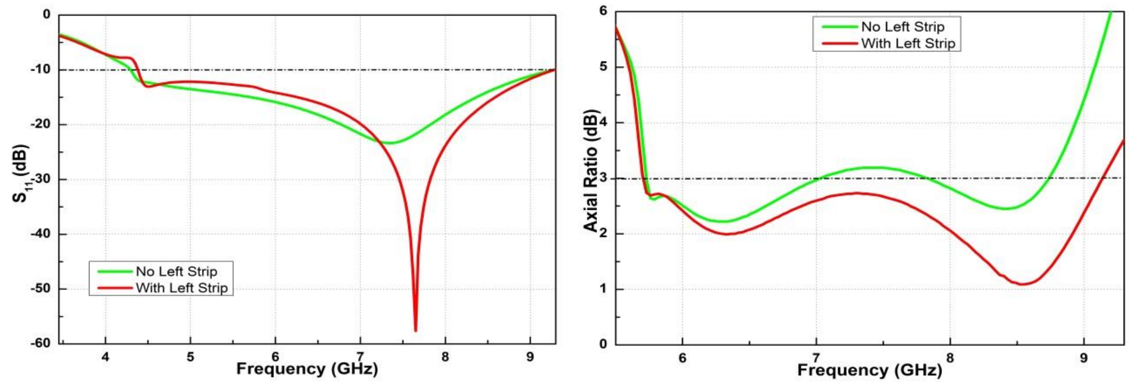
EMR (mm)	Frequency range (GHz)	IBW (GHz)	Frequency range (GHz)	ARBW (GHz)
1.15	4.9 – 8.2	3.3	7.16 – 7.32	0.16
1.55	4.6 – 8.6	4	6.2 – 8.7	2.5
1.85	**4.38 – 9.28**	**4.9**	**5.71- 9.14**	**3.43**

As seen in Fig 4(c), the gap G has an impact on both S_{11} and axial ratio. The impedance matching is affected intensely at G=0.2 mm, 0.3 mm. It yields good matching at G=0.25 mm. Meanwhile, there is an effect on CP operation in the upper-frequency band for variations in G value. There is a fall in impedance matching at GL=6.9 mm and 7.1 mm. It crops good matching at GL=6.6 mm. The CP operation in the upper-frequency band is observed for variations in GL value.

The persuasive effect of the EMR is shown in Fig. 4(e). The IBW is improved from 3.3 GHz to 4.9 GHz, whereas the ARBW is enlarged from 0.16 GHz to 3.43 GHz. The detailed simulation values of variations in EMR are presented in Table 2. The slight variations of S_{11} and axial ratio with respect to changes in strip length and strip width are shown in Fig. 4(f) and Fig. 4(g). Optimized values are 6.8 mm and 1.2 mm strip length and strip width, respectively. All other parameters are kept constant while one parameter is changed.



(a)



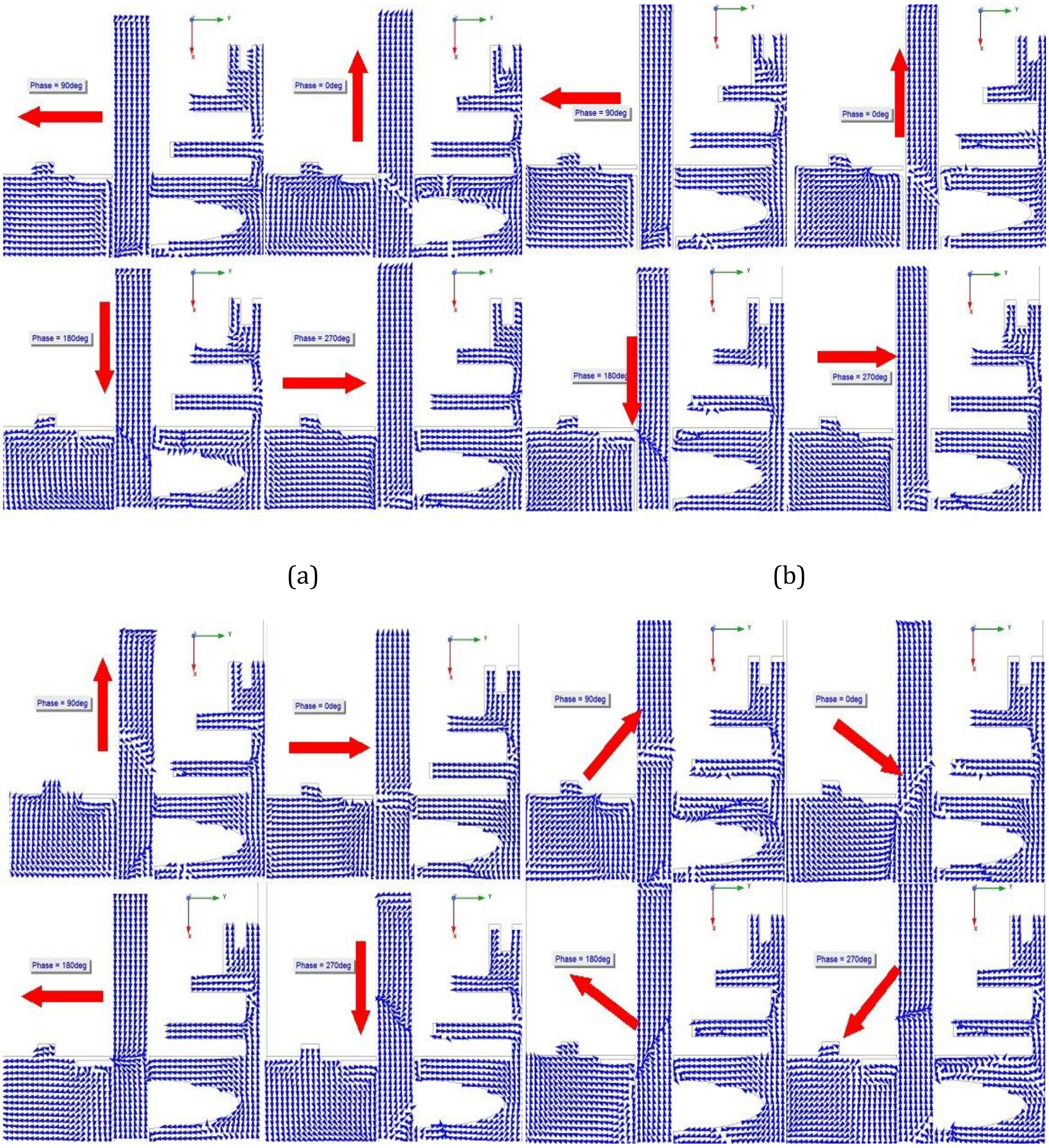
(b)

Fig. 5. S_{11} and axial ratio analysis (a) with and without slot (b) with and without strip

The ground plane's left slot is also crucial for achieving adequate IBW and the possibility of circular polarisation. Fig. 5(a) shows the improvement in IBW and making broadband in the CP operation from 5.71- 9.14 GHz with 3.43 GHz ARBW using the slot. As illustrated in Fig. 5 (b), a thin strip was put in the ground plane to improve the IBW and ARBW.

4. Circular Polarization Mechanism

The CP mechanism demonstration is in Fig. 6. The surface current distribution at regular time instances of $\varphi=0^0, 90^0, 180^0, 270^0$ at different frequencies of 5.7 GHz, 6.3 GHz, 7.6 GHz, and 9 GHz are shown. The time-varying observations indicate the rotation of E-field vectors in an anti-clockwise direction. Thus Right-hand circular polarization (RHCP) is possible in the order of z > 0 plane.

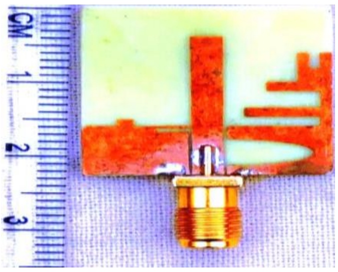


(a) (b) (c) (d)

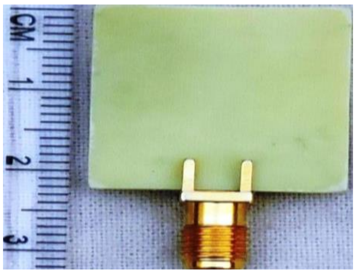
Fig. 6. Surface current distribution showing time phases 0^0, 90^0, 180^0, 270^0 at frequencies (a) 5.7 GHz (b) 6.3 GHz (c) 7.6 GHz (d) 9 GHz

5. Results and discussion

Ansys high-frequency structural simulation (HFSS) version 18.2 is used for the simulation of antenna. To verify the reliability, the optimized antenna is fabricated shown in Fig. 7. The antennas simulated and measured S_{11} are illustrated in Fig.8; a close match of measured values with simulated values of 71.74% (4.38 GHz to 9.28 GHz) is observed. The simulated and measured CP results are plotted in Fig. 9; the measured values with simulated values of 46.19% (5.71 GHz to 9.14 GHz) are observed.



(a)



(b)

Fig. 7. A fabricated prototype (a) top view; (b) bottom view

The xoz-plane and yoz-plane 2-D far-field patterns at frequencies of 5.76 GHz, 6.33 GHz, and 8.52 GHz are displayed. Fig. 10 depicts the RHCP and Left-Hand circular polarisation (LHCP) of modeled and measured radiation patterns. With RHCP in the +z direction and LHCP in the –z direction, the antenna exhibits a bidirectional radiation response.

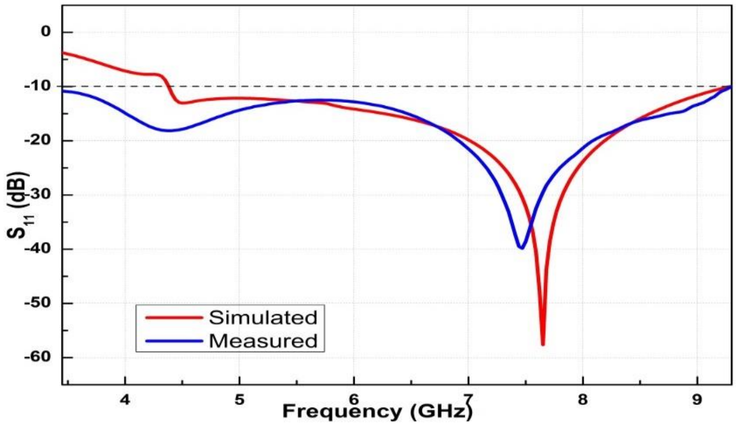


Fig.8. Comparison plot of return loss

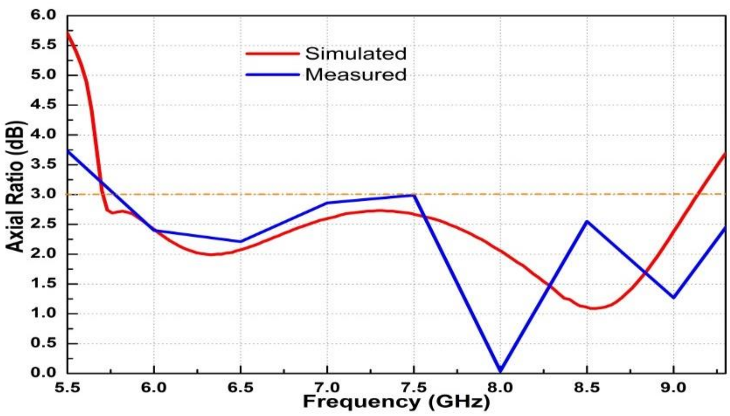
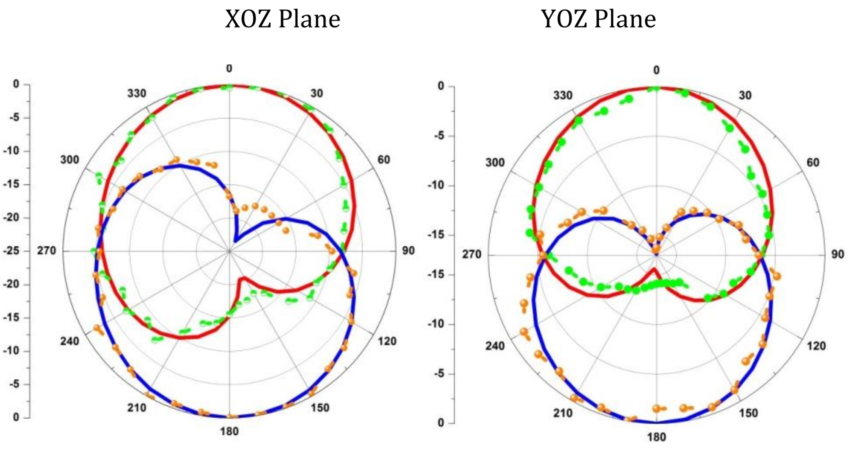
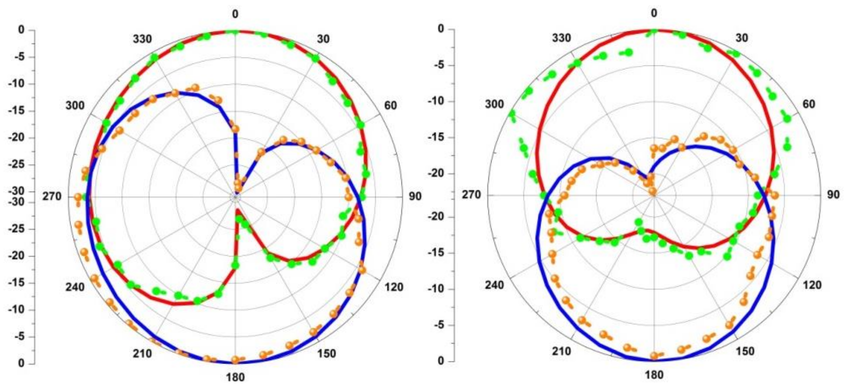


Fig. 9. Comparison plot of Axial Ratio



(a)



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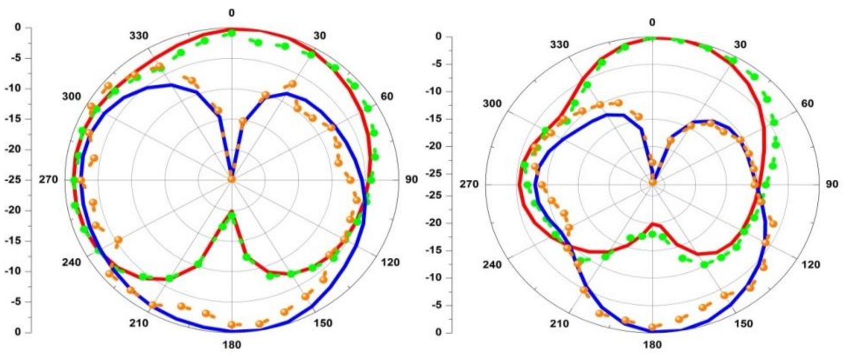

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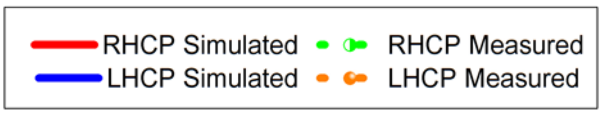

Fig.10. Radiation patterns (a) 5.76 GHz (b) 6.33 GHz (c) 8.52 GHz

Table 3. Comparison of the intended antenna's performance to that of previously published works

Ref.	Impedance Band (GHz)	IBW (GHz)	Axial Ratio Band (GHz)	ARBW (GHz)	Size (mm^3)
2	3.4-11	7.6	3.4-7.6 8.65-9.5	5.05	37 x 33 x 1.6

4	0.17-13.5	13.33	4.9-6.8	1.9	68 x 33 x 1.6
5	3.1-11.9	8.8	3.4-6.5	3.1	48 X 31 X 1
6	2.04-7.95	5.91	3.6-6.84	3.24	60 x 60 x 0.8
7	4.8-8.8	4	5.375-8.75	3.375	24 x 24 x 1
8	1.9-14.3	12.4	1.9-5.9	4	48 X 48 X 1
9	4.484-10.121	5.637	not given	0.095, 0.186, 0.149	55 X 55 X 1.6
10	2.4-2.6,2.9-3.1 3.3-3.5,4-8.3	0.2,0.2 0.2,4.3	2.39-2.55,3.05-3.1 4-5,6.3-6.64	0.16,0.05 1,0.34	32 x 38 x 1.6
11	1.25-2.75	1.5	1.54-2.65	1.11	95 X 50.5 X 1.6
12	1.527-1.917 2.598-3.248	0.058 0.152	1.579-1.637 2.67-2.822	0.058 0.152	55 X 66 X 1.6
13	0.7-3.1	2.4	1.45-2.45	1	102 X 40 X 23
14	4.3-7.71	3.35	4.8-7.4	2.6	16 x 22 x 1
15	1.8-6.61	4.8	1.83-6.35	4.52	48 X 48 X 1
16	5.08-5.92	0.84	5.08-5.92	0.84	31 x 32 x 3
17	3.08-4.41	1.33	3.55-4.56	1.01	60 x 88 x 4.8
18	3.6-6	2.4	3.28-6.71	3.43	28 X 28 X 15
19	3.0-5.2	2.2	3.0-5.2	2.2	200 X 200 X 0.8
20	2.58-3.42, 2.92-3.44	0.84,.0.5 2	2.78-3.16 3.06-3.44	0.38,0.38	30.3 X 51.4 X 0.5
21	1.58-6.20 (3.58-3.75 Notched)	4.62	2.54-5.79	3.25	62 x 32 x 1
22	5.3-5.95	0.65	5.8-5.61	0.13	20 X 20 X 2.4
23	1.94-1.965 2.545 2.685	0.025,0. 140	2.58- 2.64	0.06	24.8 X 22 X 1.5
24	5.33-5.86	0.53	5.33-5.79	0.46	19.5 X 12 X 1.52
25	2.32-2.70	0.38	2.38-2.48	0.1	38 X 38 X 1.6
26	4.05-6.6	2.55	5.3-6.6	1.3	34 X 34 X 1.6
27	8.93-12.82	3.89	9.23-12.47	3.24	28 X 28 X 1.6
28	4.46-5.5	1.04	4.52-5.4	0.88	90 X 90 X 0.5
29	2.8-3.95	1.15	2.8-3.95	1.15	85 X 85 X 1.6
30	5.1-8.9	3.8	5.15-7.9	2.75	70 X 70 X 1.6
This Work	**4.38-9.28**	**4.9**	**5.71-9.14**	**3.43**	**23 X 22 X 1.6**

The proposed antenna's performance is compared to that of similar works published previously in the literature, as shown in Table 3.This work focus on the compact broadband CP antenna, which produced an IBW of 4.9 GHz from 4.38 to 9.28 GHz. The CP band covers 5.71 to 9.14 GHz with a bandwidth of 3.43 GHz. When compared to previous works, the proposed antenna has a wider ARBW [4-7,9-14,16-17,19-30]. There are few antennas with ARBW above the 3.43 GHz band [2,8,15,18]. As compactness is the major challenge in modern wireless communications, the proposed work has more compactness than these antennas [2,8,15,18], offering more ARBW.

6. Conclusion:

A novel monopole CPW-fed CP antenna with broad ARBW is presented, using various parametric optimizations for antenna design modifications, the IBW obtained from 4.38 GHz to 9.28 GHz (71.74%), and ARBW reached from 5.71 GHz to 9.14 GHz (46.19%). The antenna structure contains a rectangular slot, A half-elliptical-shaped slot, and protruded strips determine the simplicity in the design with a compact size of 23 x 22 x 1.6 mm^3. The surface current distribution is used to investigate the CP rotation process. The designed antenna is fabricated, and performance is measured. There is a good match between measured and modeled results. The antenna completely covers the WLAN (5.725-5.85 GHz) spectrum and can be used for C and X band wireless communications.

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