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Bat Shaped Circularly Polarized Antenna for X and Ku Band Applications

Sweta Singh[1], Karunesh Srivastava[2, *], Farha Usman[1], and Ram S. Yadav[1]

Abstract—A bat-shaped micro-strip patch antenna is proposed with tri-band characteristics (11.0–11.5 GHz), (11.8–12.3 GHz), (13.0–14.3 GHz) and impedance bandwidth 4.4%, 4.1%, and 9.5% at resonant frequencies 11.36 GHz, 12.14 GHz, and 13.4 GHz, respectively. The proposed antenna exhibits peak gain of 2.6 dBi. The proposed micro-strip patch antenna shows the dual band circularly polarized characteristics with two axial ratio bands (11.0–13.0 GHz) and (13.2–14.0 GHz) and 3-dB axial-ratio (AR) impedance bandwidths 15% and 5.2%, respectively. Investigation of the proposed antenna is done using evolution technique. The results are verified experimentally in terms of reflection coefficient, gain, axial ratio, and radiation pattern.

1. INTRODUCTION

Since inception micro-strip patch antennas have played a vital role in the advancement of wireless communication systems, micro-strip patch antennas with high gain, large impedance bandwidth, and small planar area are desired in communication systems. Additional characteristics like small size, light weight, polarization and multiband characteristics encourage researchers to explore micro-strip patch antenna for higher frequency band applications. In new trend, micro-strip patch antenna with multiband characteristics is preferred over separate antennas used for different frequency bands.

Micro-strip patch antenna covers almost every field of day-to-day life like textiles, biomedicine, defense, wireless communication, space craft, etc. Low bandwidth and low gain are limiting characteristics of micro-strip patch antenna. Several methods to enhance the bandwidth and gain of micro-strip patch antenna have been reported [1, 2]. Comprehensive reviews of broadband, multiband, and ultra-wideband (UWB) antennas including effect of geometries, materials, design solutions and numerical tools are reported [3] for evaluating the performance of micro-strip patch antenna. Various methods are illustrated in literature to increase the gain and bandwidth of microstrip patch antenna [4–7]. Slot and stacking [4] are used to increase the gain and bandwidth whereas gap-coupled structure [5] is used to increase the bandwidth. Annular ring, shorting pin, and gap coupled patch are explained for enhancing the bandwidth and gain [6]. Defected ground structure with slit, notch, square strip, and stub is analysed [7]. Slit, notch, and square strip are responsible for better gain and bandwidth [7].

Linearly polarised micro-strip patch antenna suffers from bandwidth limitations [8]. Demand of a multiband circularly polarized antenna on single patch has increased in manifolds as it is desired to design multiband antenna rather than single band circularly polarized antenna on single patch. Numerous single/multi band circularly polarized antenna with different shapes has been reported for various applications.

A semi-arc-shaped defect in ground and a tilted hexagon by an angle of 25° with asymmetrical feed are used to generate an orthogonal mode wave for S, C, and X-band applications [9]. A novel single

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* Corresponding author: Karunesh Srivastava (karunesh.ec@gmail.com).
[1] Department of Electronics & Communication, University of Allahabad, Prayagraj, India. [2] Department of Electronics & Communication Engineering, Ajay Kumar Garg Engineering College, Ghaziabad, India.

feed wideband circularly polarized antenna with high gain is capable of harvesting ambient energy [10]. An asymmetric-circle-shaped slotted microstrip antenna with slits is proposed for circular polarization and RFID applications. A slotted square patch is used to generate circular polarization by varying the radius of the circular-slots in diagonal directions of a square patch [11].

A compact single-feed circularly polarized micro-strip antenna with a symmetric and wide-beamwidth radiation pattern is designed to achieve a symmetric radiation pattern over a wide range of observation angle for L-band applications [12], and a U-slot wideband circularly polarized patch antenna with truncated square patch for wireless communication system [13] is reported in literature. Different patch shapes of antenna like C shape, split ring, parasitic patches, and strips are reported to obtain circular polarization [14–17]. Antennas with dual bands [18, 19], triple bands [20–23], and multibands [24–26] are reported for different applications. Circularly polarized antenna is useful for lowering the multipath interferences, polarization loss, and limited bandwidth. A compact circularly polarized patch antenna with multiple asymmetrical V shaped slits and cross slots for X and Ku band frequency range is reported in [27].

In this paper, a dual band circularly polarized micro-strip patch antenna for X and Ku band applications is presented. The proposed antenna is compared with the existing patch antennas (useful for either Ku or X/Ku band applications) in terms of size, % IBW (impedance bandwidth), ARBW (axial ratio bandwidth), and gain (cf. Table 1). It is clear from Table 1 that [22, 26] and proposed antenna exhibit circular polarization whereas [23, 28, 29] exhibit linear polarization. It is clearly established in Table 1 that the proposed antenna is smaller than other reported circular polarized antennas except [26] with better % ARBW and good gain. These qualities enable the proposed antenna to be a suitable candidate for X and Ku band applications.

Table 1. Comparison between proposed patch antenna and existing different patch antennas.

Ref.	Size (mm × mm)	Operating band/BW (GHz)	M/S	% IBW	% IARBW	Max. Gain (dBi)	Application
22	35 × 30	(4.39–4.95)/0.56 (6.4–14.5)/8.1	M	12%, 77.8%	2.03% 1.58% 0.90%	4.45	X and Ku band
23	20 × 11	(11.13–11.82)/0.69 (15.77–16.89)/1.12	M	6% 6.8%	NR	5	X and Ku band
26	16 × 16	(10.82–11.89)/1.07	S	17.6%	2.1%	7.05	X and Ku band
28	20 × 18	(10.8–13.55)/2.75	M	22.6%	NR	4.91	X and Ku band
29	34.6 × 14.1	(11.59–15.75)/4.15	S	30.35%	NR	6.31	Ku band
[*]	20 × 20	(11.0–11.5)/0.5 (11.8–12.3)/0.5 (13.0–14.3)/1.3	M	4.4% 4.1% 9.5%	15% 5.2%	2.6	X and Ku band

M: Measured, NR: Not Reported, S: Simulated, [*] — Proposed Structure

2. EVOLUTION OF ANTENNA DESIGN

The evolution of the proposed micro-strip patch antenna is shown in Fig. 1. The proposed bat-shaped micro-strip patch antenna is obtained using Ansoft HFSS v13 in simple three steps. Dimensions of each antenna (A_1–A_3) are well labeled in Fig. 1. Antenna-1 (A_1) is designed and simulated on an FR-4 substrate (height 1.6 mm) of size $(20 \times 20)\,\text{mm}^2$ with coaxial feeding. A simple micro-strip patch

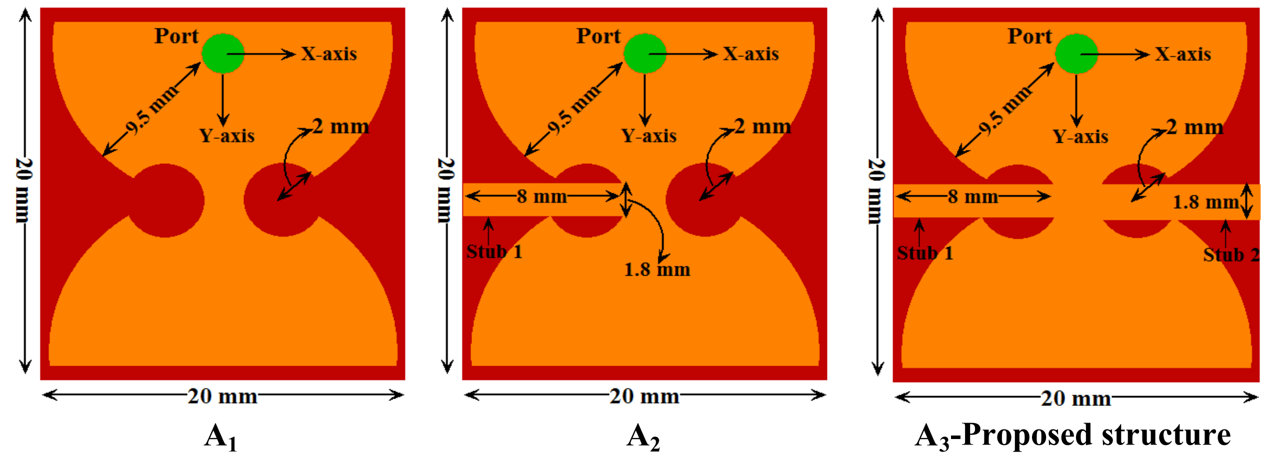


Figure 1. Antenna growth with its top (orange) and bottom (red) view.

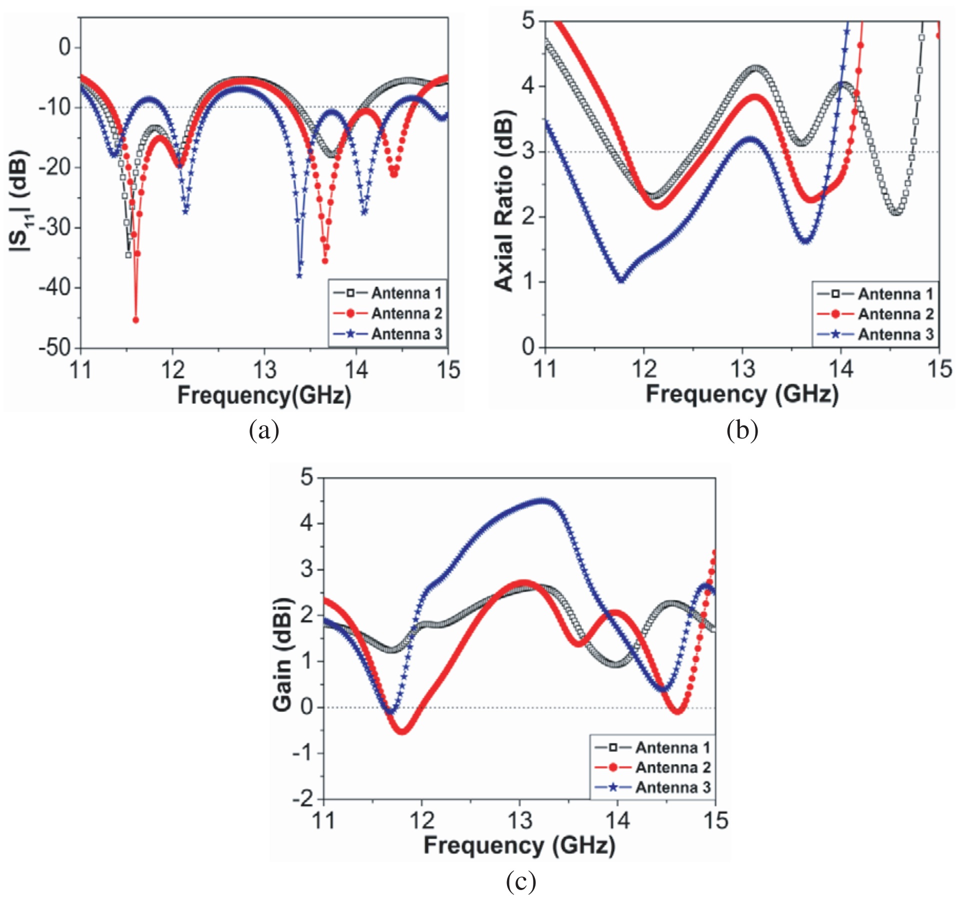
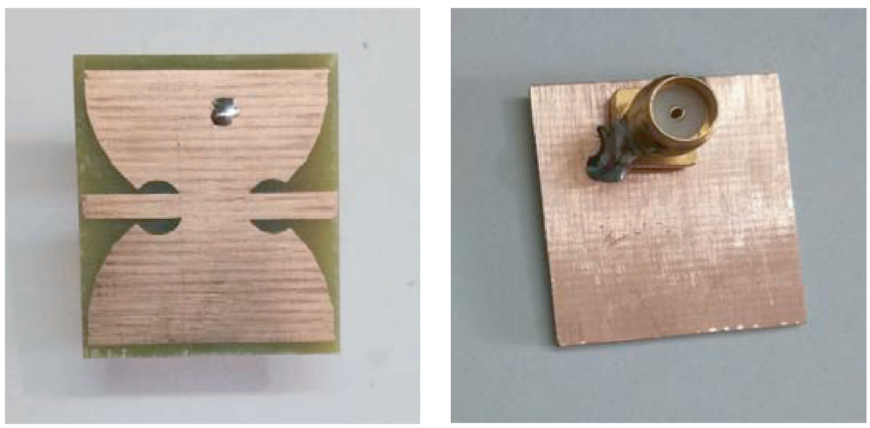


Figure 2. Simulated (a) reflection coefficient, (b) axial ratio, (c) gain of Antenna 1, 2 and 3.

structure is obtained by combining two semi-circles (radius 9.5 mm) back to back. Further two small size circles of radius (2 mm) are etched from the patch antenna. Antenna-1 resonates with two bands, i.e., (11.2–12.2 GHz) and (13.4–14.0 GHz) with peak gain of 4.6 dBi. We are observing two axial ratio bands ((11.6–12.5 GHz) and (14.3–14.7 GHz)) for Antenna-1, but only one axial ratio band (11.6–12.5 GHz) is covering the operating band (cf. Fig. 2(b)).

A stub of size $(8 \times 1.8)\,\text{mm}^2$ is added to the left side of meeting point of semicircles of Antenna-1 (A_1) for getting Antenna-2 (A_2). It is observed that the return loss for (13.2–14.6 GHz) band improves, and axial ratio band of higher frequency side shifts towards lower frequency side (cf. Figs. 2(a) & (b)). In the next step, one more stub of size $(8 \times 1.8)\,\text{mm}^2$ is added on the right side of Antenna-2 (A_2) in order to get Antenna-3 (A_3). It can be observed that resonating band and axial ratio band shift towards lower frequency side by adding another stub in Antenna-2. Antenna-3 has three simulated resonating bands (11.1–11.6 GHz), (11.9–12.4 GHz), and (13.0–14.4 GHz) with peak gain of 2.4 dBi (cf. Figs. 2(a) & (c)). Gain in the frequency range (11.6–11.9 GHz) drops below 0 dBi in two consecutive bands. Gain of the third resonating band (13.0–14.4 GHz) starts falling down from the point where return loss starts decreasing. Due to maximum IBW (impedance bandwidth), IARBW (Impedance axial ratio bandwidth) with notable gain characteristics, Antenna-3 (A_3) is chosen as the proposed antenna. Result and discussion section elaborates more about Antenna-3 (A_3) characteristics. Prototype of the proposed antenna with top and bottom views is shown in Fig. 3, and its performance is tabulated in Table 2 in terms of bandwidth, impedance bandwidth (% IBW), impedance axial ratio bandwidth (% IARBW), and maximum gain.



(a) (b)

Figure 3. Antenna prototype with its (a) top and (b) bottom view.

Table 2. Performance analysis of antenna evolution.

Antenna	Resonating bands (GHz) /BW (GHz)	% IBW	ARBW (GHz)	% IARBW	Max. Gain (dBi)
Antenna-1	(11.3–12.3)/1 (13.4–14.0)/0.6	8.5 4.4	(11.7–12.5)/0.8 (14.3–14.7)/0.4	6.6 2.8	4.6
Antenna-2	(11.3–12.3)/1 (13.3–14.6)/1.3	8.5 9.3	(11.8–12.6)/0.8 (13.4–14.0)/0.6	6.6 4.4	2.4
Antenna-3 **Proposed Structure**	(11.1–11.6)/0.5 (11.9–12.4)/0.5 (13.0–14.4)/1.4	4.4 4.1 10.2	(11.1–12.9)/1.8 (13.2–13.9)/0.7	15 5.2	2.6

BW: Bandwidth, IBW: Impedance Bandwidth, ARBW: Axial Ratio Bandwidth, IARBW: Impedance Axial Ratio Bandwidth

3. RESULTS AND DISCUSSION

The proposed structure has been fabricated. The measurement of return loss, axial ratio, gain, and radiation pattern has done. It is observed from Fig. 4 that simulated and measured results are in good agreement (cf. Fig. 4). We observe three resonating bands (11.0–11.5 GHz), (11.8–12.3 GHz), and (13.0–14.3 GHz) below −10 dB emission point with two axial ratio bands (11.0–13.0 GHz) and (13.2–14.0 GHz). It is clear from Fig. 4(a) that antenna is circularly polarized and covers almost all resonating bands. Fig. 4(b) shows the simulated and measured plots of return loss and gain with the variation of frequency. Similarly, Fig. 4(c) shows the simulated and measured axial ratio and gain with variation of frequency. It is clear from Fig. 4(d) that simulated radiation efficiency of proposed antenna is more than 80% for the entire resonating bands and axial ratio bands. Fig. 5 clearly demonstrates that directivity of the antenna is 7.76 dBi, 5.25 dBi, and 6.5 dBi at resonating frequencies 11.36 GHz, 12.14 GHz, and 13.4 GHz, respectively.

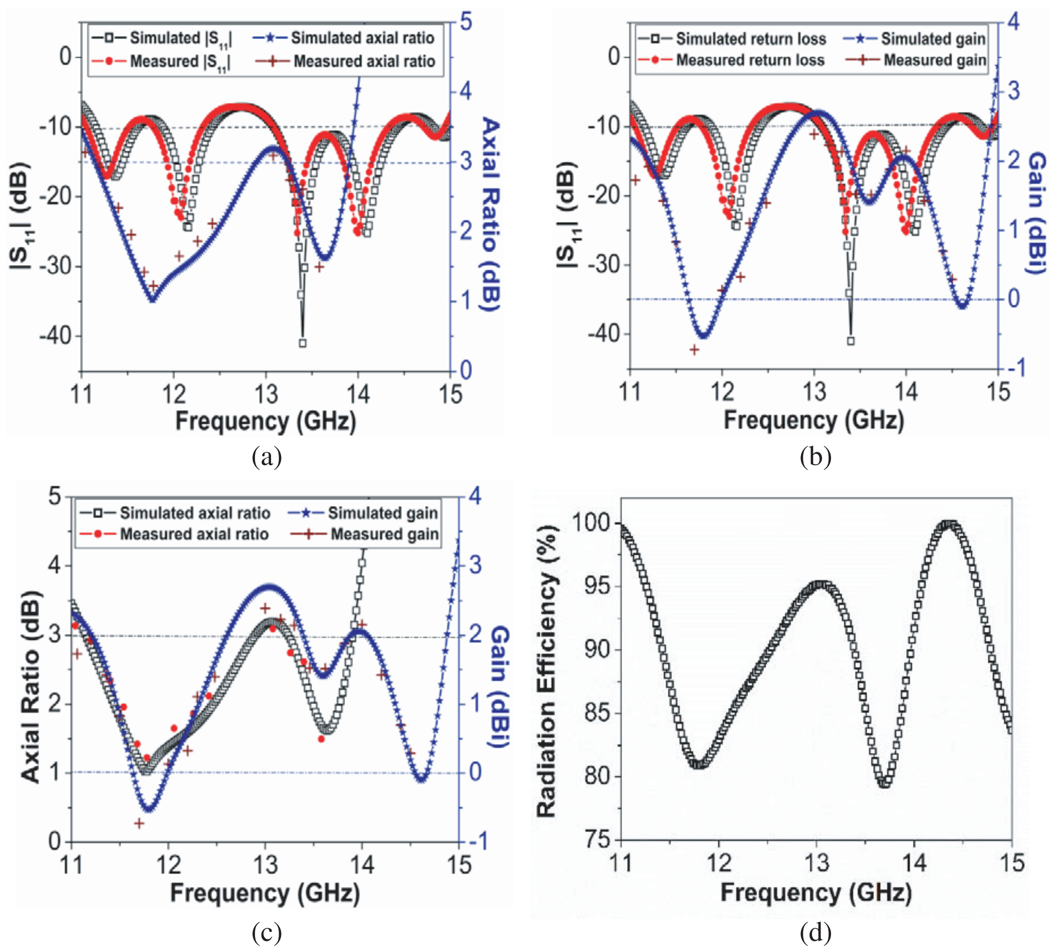


Figure 4. Simulated and measured (a) return loss and axial ratio, (b) return loss and gain, (c) axial ratio and gain with frequency variation, (d) radiation efficiency (only simulated).

Simulated surface current distributions for phases 0°, 90°, 180°, 270° are observed at different frequencies 11.75 GHz and 13.4 GHz (where axial ratio is minimum in resonating bands), respectively. Clockwise rotation of current distribution with respect to $-Z$ axis corresponds to right hand circular polarization (RHCP) with advancement of 90° phase shift and vice versa. It is clear from Figs. 6 & 7 that the proposed antenna exhibits left hand circular polarization (LHCP) for frequency 11.75 GHz and right hand circular polarization (RHCP) for frequency 13.4 GHz. Simulated and measured radiation

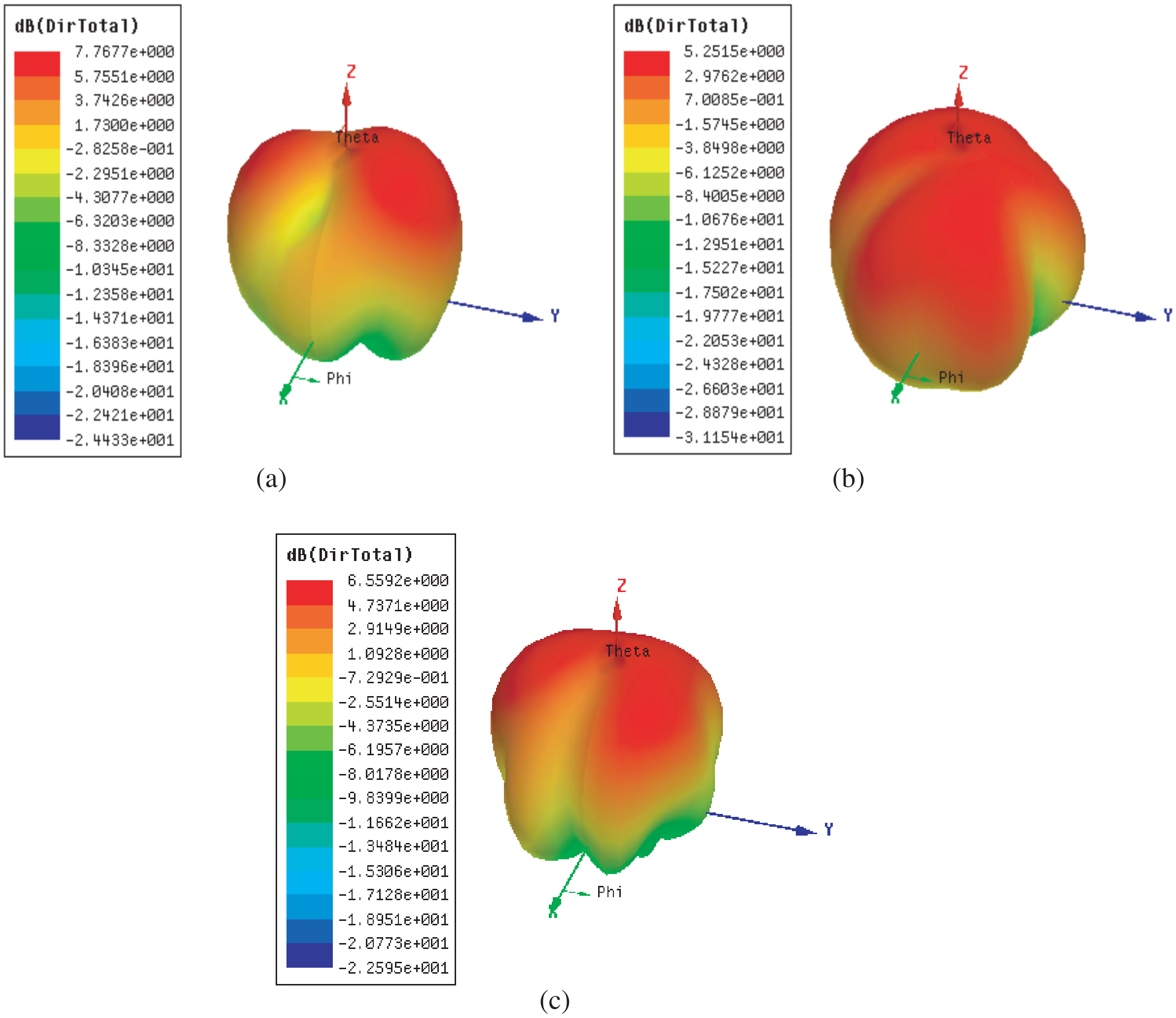


Figure 5. Directivity at different frequency. (a) 11.36 GHz. (b) 12.14 GHz. (c) 13.4 GHz.

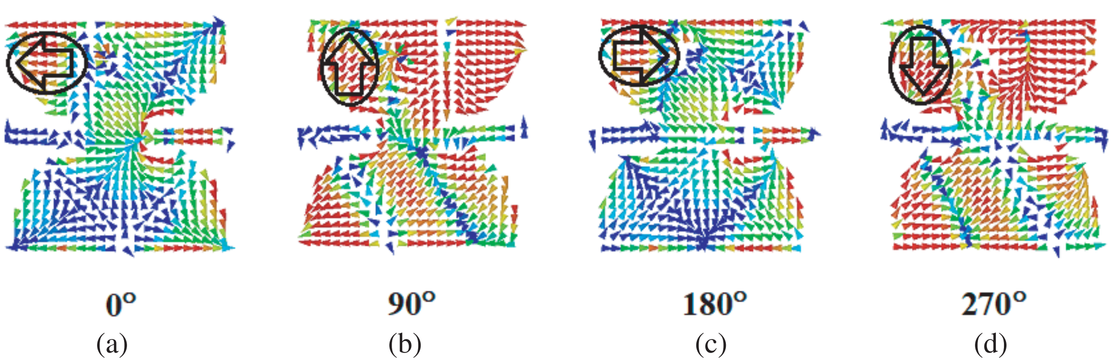


Figure 6. Surface current distribution at 11.75 GHz.

patterns with RHCP and LHCP components in XZ and YZ planes are shown in Fig. 8. It is clear that the magnitude of LHCP component is greater than RHCP component (Fig. 8(a)), and the magnitude of RHCP component is greater than LHCP component (Fig. 8(b)). The measurement setup for obtaining gain, axial ratio, and radiation pattern is shown in Fig. 9. Agilent N5230C network analyzer with

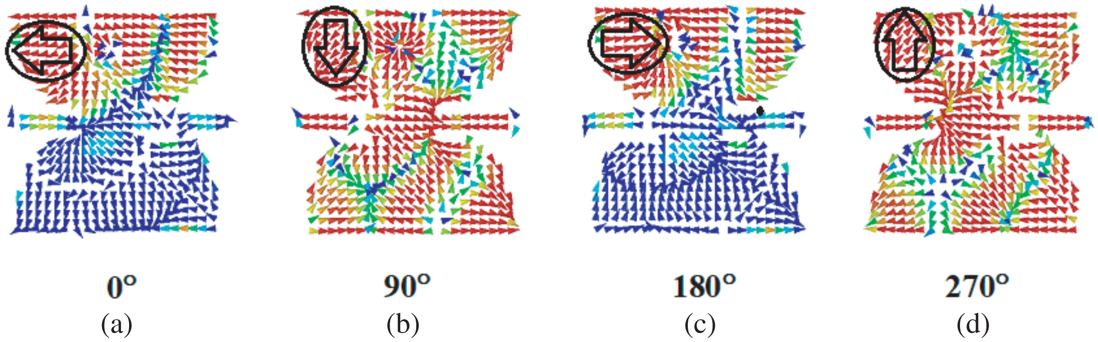


Figure 7. Surface current distribution at 13.4 GHz.

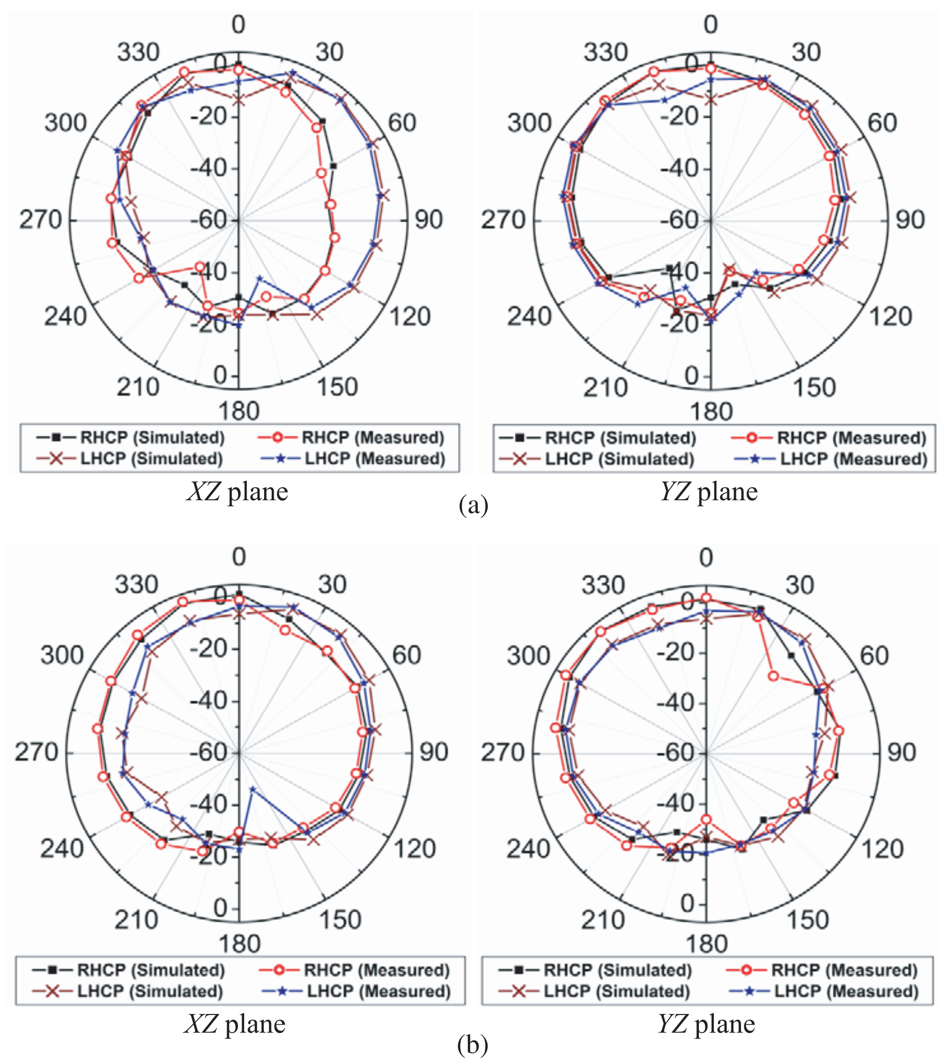


Figure 8. Measured and simulated radiation pattern at (a) 11.75 GHz and (b) 13.4 GHz.

Amkom horn antenna is used for the measurements (cf. Fig. 9). Simulated and measured results are in good agreement with small deviation. Minor deviation between simulated and measured results is due to fabrication and connectors used during measurement.

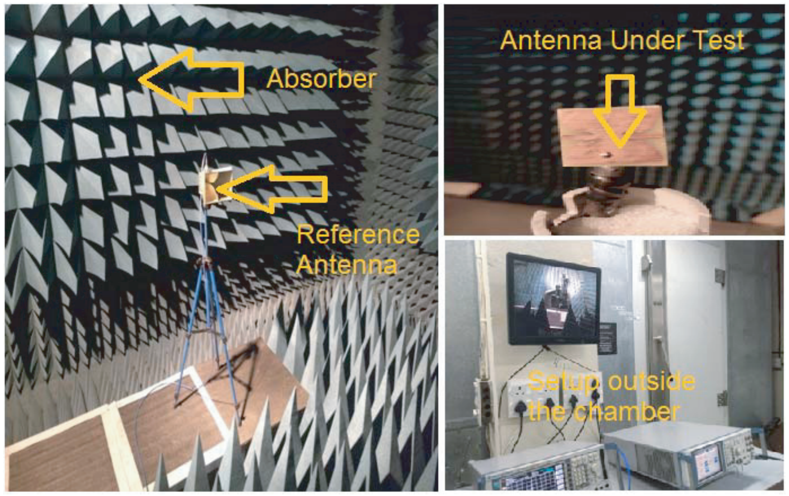


Figure 9. Measurement setup for gain, axial ratio and radiation pattern.

4. CONCLUSION

A dual-band bat-shaped circularly polarized micro-strip patch antenna has been designed, fabricated, and measured. With two simple stubs in the bat-shaped patch antenna, dual-band circular polarization was achieved. The measured impedance bandwidths are 4.4%, 4.1%, and 9.5% for three bands, and impedance axial ratio bandwidths are 15% and 5.2% for dual bands. The antenna obtains good circularly polarized characteristics and is well suited for DBS (direct broad cast service) application weather monitoring, air traffic control, maritime vessel traffic control, defense, radar applications, and many more in the frequency range of X and Ku bands.

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