A Dual-Band Dual-Polarized Coupled Asymmetric T-Shaped Monopole Antenna for Linear and Circular Polarization Applications

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1 Introduction

Nowadays, dual-band dual-polarization (DBDP) antennas fulfill the multiple demand for wireless communication network. On the other side, antennas that have omnidirectional radiation pattern pose very useful for global positioning systems (GPSs) and for personal mobile system. On the contradictory side, antennas having unidirectional radiation pattern had become a very pivotal for the wireless communication technology in the likes of point-to-point communication, satellite systems.

Dual-band antennas having linear polarization and circular polarization properties are considered to be very popular among antenna technologies, and to fulfill the two bands design, distinct antenna designs are considered [1–6]. Researchers have been working on important methods that guarantee the linear polarization requirement [1–5]. And for dual-band dual-polarization (DBDP), the various research papers are mentioned in [1–5].

Inspired by the above research work and acknowledging the scope of DBDP, a coupled asymmetric T-shaped antenna is proposed in this paper and has a dimension of $50 \times 50 \times 50$ mm^3. The antenna is engraved into an FR4 epoxy material.

Here, the proposed antenna poses both circular polarization and linear polarization. And to achieve this polarization, a gap of 0.5 mm is introduced in the coupled asymmetric T-shaped radiating patch.

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The proposed design in this paper has applications like it can be used for WiMAX, WLAN, and the higher resonating frequency can be used for C-band like broadcasting and fixed mobile communication application. The T-shaped antenna shows right-hand circular polarization (RHCP) characteristics as well as linear polarization. Given that the suggested antenna has dual-band dual-polarization, its lower resonating band is linearly polarized (LP), while its higher resonating band is right-handed circularly polarized (RHCP).

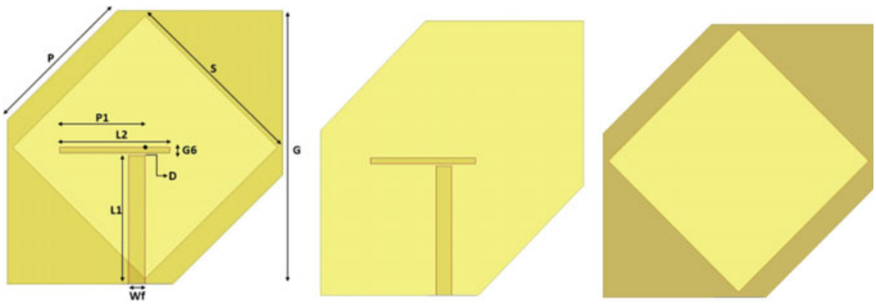
As a result, the suggested antenna is simulated and optimized with electromagnetic simulation software Ansys HFSS software, and the simulated results are observed and examined further in the software.

2 Antenna Design

The top and the bottom view of the suggested coupled asymmetric T-shaped antenna are shown in Fig. 1b, c. The simulated overview dimensions of the suggested antenna are being shown in Fig. 1a. The coupled asymmetric T-shaped antenna is excited with 50 Ω lumped port in the Ansys HFSS simulator. It is implemented on FR4 substrate. The antenna is resonating at lower band 2.2 GHz, having dielectric constant (ε_r) 4.4 and loss tangent (tan δ)0.02 (Figs. 2 and 3; Table 1).

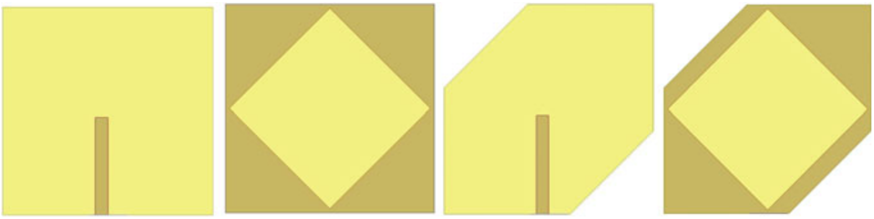
A 50 Ω microstrip line is used to feed the proposed linked asymmetric T-shaped antenna for signal transmission. Antenna operates on inset microstrip line feedline in this instance. The antenna is designed to have a coupled asymmetric T-like shape to achieve the desired dual-band dual-polarization (DBDP) characteristics. The coupled line T-shape, $L_1 = 20$ mm and $L_2 = 20$ mm, is placed 0.5 mm apart to achieve DBDP, and $L_2 = 20$ mm is shifted a little bit left side to get the desired result.

The ground plane and the substrate are truncated with triangle of length $P =$ 31.2 mm at two of the corners and also a square shape length of $S = 34$ mm which



(a) (b) (c)

Fig. 1 Suggested antennas dimension, top view and bottom view in Ansys HFSS (**a**) views of the planned antenna are shown in (**b**), respectively (**c**)



(a) (b)

Fig. 2 Top and bottom view of antenna1 (**a**), top and bottom view of antenna2 (**b**)

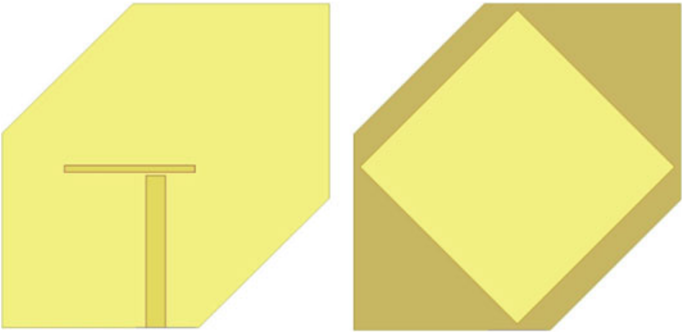


Fig. 3 Top and bottom view of antenna3

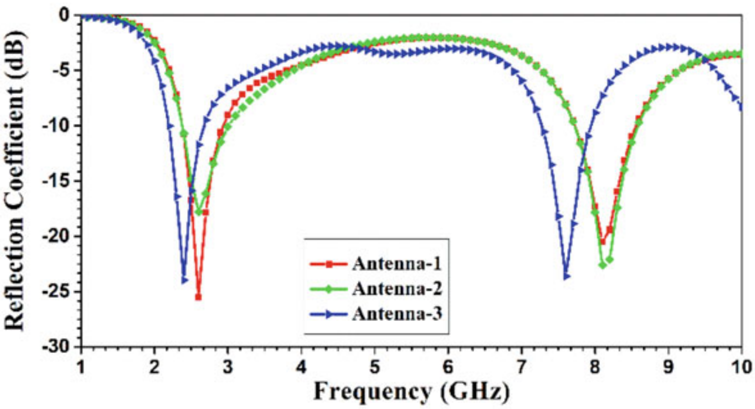
Table 1 Suggested antenna's size

Parameter	Value (mm)	Parameter	Value (mm)
G	50	L_1	20
P	31.2	G_6	1
S	34	P_1	15.5
W_f	3	L_2	20
L_{off}	1.5	D	0.5

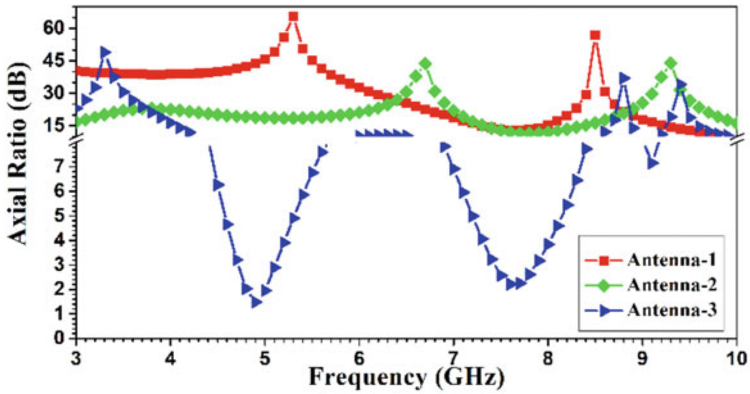
is inclined at 45° is etched in the middle of the ground plane and doing so the result of the antenna improved gradually.

Figure 4 compares the three antennas' axial ratios and reflection coefficients (a). For all the three antennas the difference in result in impedance bandwidth is minimal but for axial ratio bandwidth for antenna1 the result is not good. After improvement in antenna2, the axial ratio bandwidth is slightly improved but still not satisfy the 3db requirement. In antenna3, the 3db requirement is met as it can be seen in Fig. 4b.

The desired result of the proposed antenna we got by optimizing three antenna design one after another. In antenna1, the radiating patch of $L_1 = 20$ mm was only considered without the coupled $L_2 = 20$ mm, and for the ground plane, the two opposite corners were not etched as is shown in Fig. 2a.



(a)



(b)

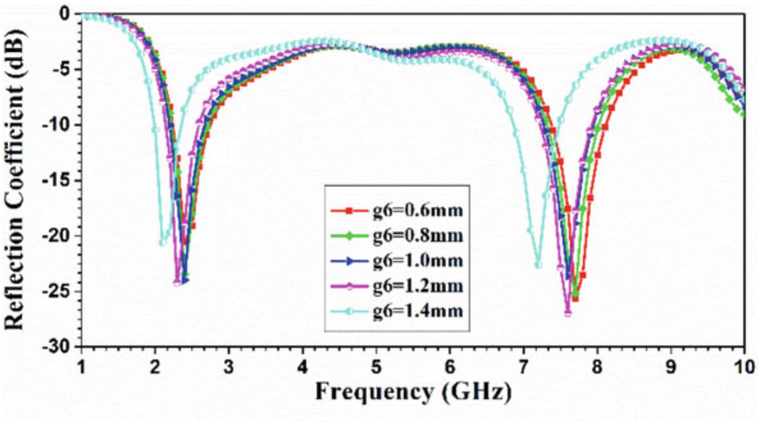
Fig. 4 Simulated impedance bandwidth (**a**), and ARBW (**b**) of antennas 1–3

For antenna2, the radiating patch was as same as antenna1, but the only change was in the ground plane, where two opposite edges of $P = 31.2$ mm are etched as it is shown in Fig. 2b. To meet the required DBDP parameter, the length P_1 and the width G_6 are varied. After setting $P_1 = 15.5$ mm and $G_6 = 1$ mm, the desired result for DBDP is observed. As dual-band dual-polarization characteristics are still no achievable in antenna1 and antenna2, as a result in the third antenna the coupled asymmetric T-shaped radiating patch was designed, and the desired results have been observed.

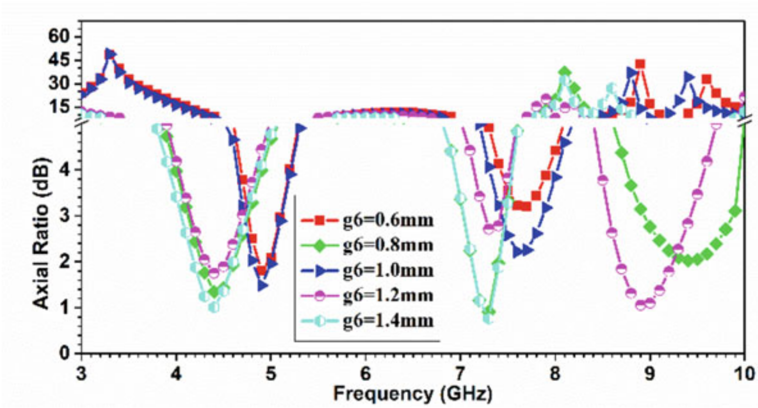
3 Parametric Optimization

The variation of width (G_6) of the coupled T-shaped patch is informed below. Five different values for G_6 are taken. From the result, it can be understood that there is minimal variation in impedance bandwidth but a huge change in axial ratio bandwidth. And from the result, it can be found that $G_6 = 1$ gives the best result in Fig. 5.

Similarly, for P_1, five values are taken, and it is found that $P_1 = 15.5$ gives the best result as it is seen in Fig. 6. When $P_1 = 15.5$, it creates asymmetric in geometry. For that reason, *Ex*/*Ey* magnitude is nearly equal to 90 which is desired for creation for circular polarization at higher frequency region.

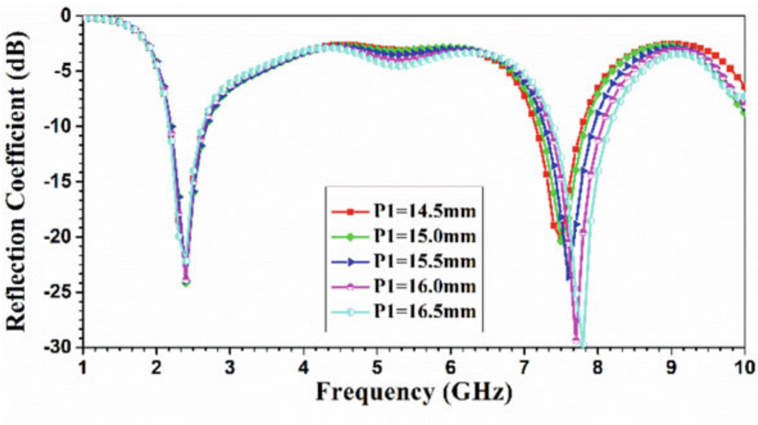


(a)

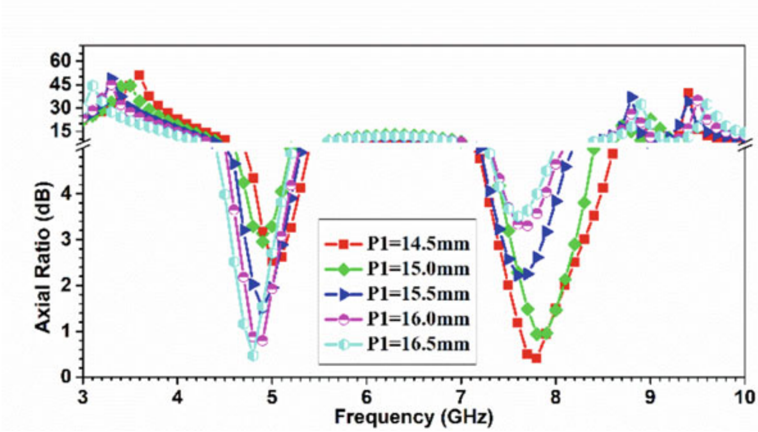


(b)

Fig. 5 Comparison of different values of G_6 for reflection coefficient (**a**), ARBW (**b**)



(a)



(b)

Fig. 6 Comparison of different values of P_1 for reflection coefficient (**a**), ARBW (**b**)

4 Result and Discussion

Optimization and simulation are done in Ansys HFSS. The antenna poses dual-band dual-polarization characteristics. Here for the lower resonating band, the antenna is linearly polarizing, and for the higher resonating band, the antenna is circularly polarizing. The simulated IBW at low frequency and higher frequency region are 2.17–2.66 GHz and 7.15–7.78 GHz which are resonating at 2.41 GHz and 7.46 GHz frequency. And they are 20.28% and 8.43%. The simulated 3 dB axial ratio bandwidth at higher resonating frequency is 7.38–8.3 GHz which is 11.73% at center resonating frequency 7.84 GHz.

Figure 8a depicts the simulated gain, with the two modes' greatest gains equaling 1.73 dB (linear polarized mode) and 4.06 dB (circular polarized mode). Figure 7 displays the simulated radiation efficiency (b). This antenna's maximum radiation efficiency is 95%, and its radiation efficiency is higher than 85% across the whole impedance bandwidth range.

Figure 9 depicts the surface current distribution of the proposed antenna at 7.88 GHz for Phase 0°, 90°, 180°, and 270°. Here, the surface current rotates counter-clockwise. It is for this reason that the polarization is described as having a right-hand circular polarization (RHCP).

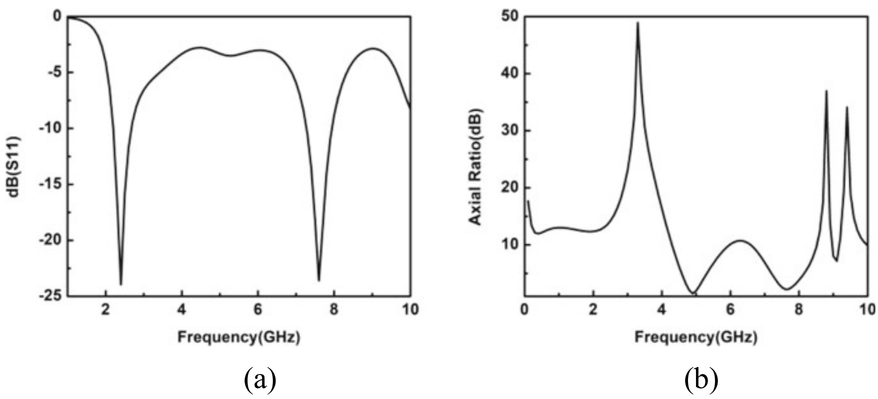


Fig. 7 Impedance bandwidth (**a**) and ARBW (**b**) of the proposed antenna

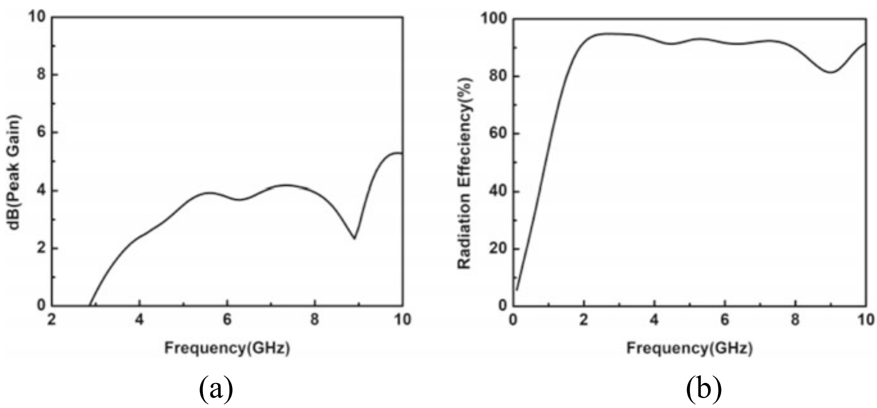


Fig. 8 Peak gain (**a**) and radiation efficiency (**b**) of the proposed antenna

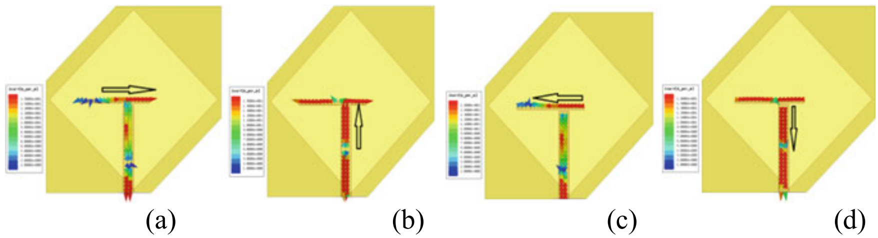


Fig. 9 Simulated surface current distribution at 7.84 GHz for Phase 0° (**a**), Phase 90° (**b**), Phase 180° (**c**), Phase 270° (**d**)

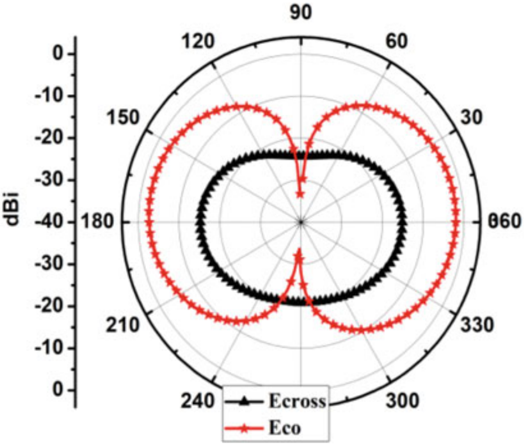
Figure 10 depicts the simulated electric field radiation pattern for Eco (elevation plane, *XZ* plane, = 90°) and Ecross (azimuthal plane, *XY* plane, = 0°) for the linked asymmetric T-shaped antenna operating at the frequency of 7.84 GHz. (a) It suggests that, like a traditional dipole mode antenna, the radiation pattern for the *E*-field is omnidirectional. Figure 10 depicts the suggested antenna's predicted magnetic field radiation pattern for the H_{co} plane (azimuthal plane, *XY* plane, = 0°) and H_{cross} plane (elevation plane, *XY* plane, = 90°). (b) Cross-polarization radiations are similarly strong in this area, but they are 15 dB less intense than co-polarization radiations.

Figures 11a and b show the radiation patterns for the suggested antenna for LHCP and RHCP at frequencies of 7.84 GHz and = 0° (*XZ* plane) and = 90° (*YZ* plane), respectively. Cross-polarization levels are 17 dB smaller than co-polarization levels in the broadside direction at the given frequency, and the steady radiation pattern at that frequency is obtained.

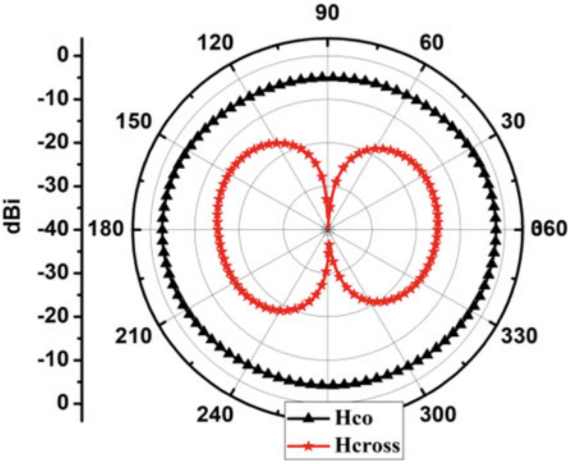
The simulated IBW at low frequency and higher frequency region are 2.17–2.66 GHz and 7.15–7.78 GHz which are resonating at 2.41 GHz and 7.46 GHz frequency. And they are 20.28% and 8.43%. The simulated 3 dB axial ratio bandwidth at higher resonating frequency is 7.38–8.3 GHz which is 11.73% at center resonating frequency 7.84 GHz. RHCP characteristics are exhibits by using this design.

The highest peak gain is 4.31 dBi at 7.4 GHz. The maximum radiation efficiency of this implemented antenna is 95%, and throughout the impedance bandwidth region, the radiation efficiency is greater than 85%.

The proposed antenna in this work has the highest axial ratio bandwidth (ARBW) when compared to other relevant papers, as can be seen in Table 2. The proposed antenna was also found to have an excellent impedance bandwidth (IBW).



(a)



(b)

Fig. 10 Simulated radiation pattern of suggested antenna for E_{co} ($\varphi = 90°$) plane and E_{cross} ($\varphi = 0°$) plane (**a**) and H_{co} ($\varphi = 0°$) plane and H_{cross} ($\varphi = 90°$) plane (**b**)

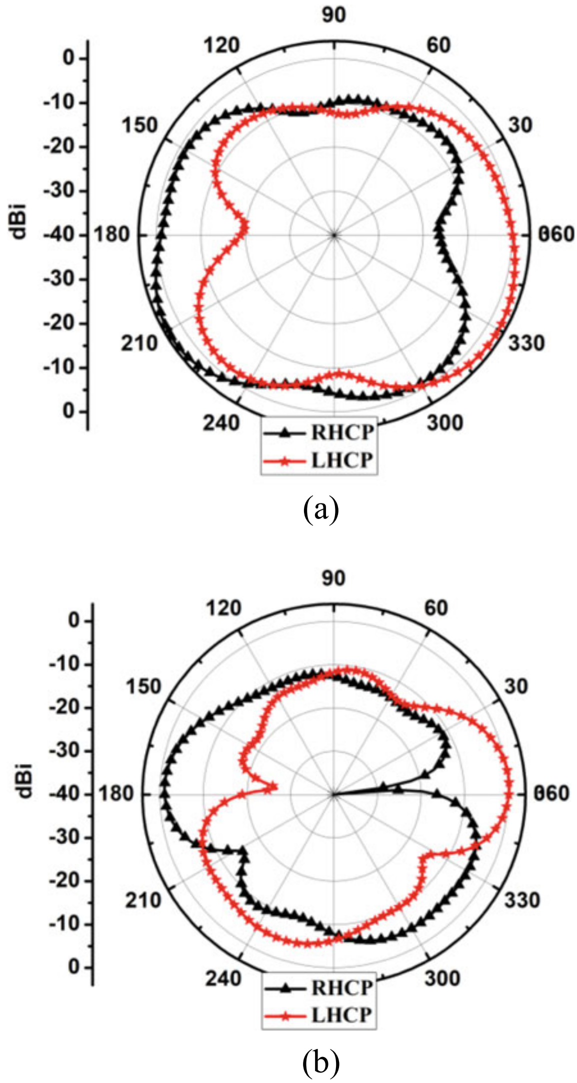


Fig. 11 Simulated radiation patterns (LHCP and RHCP) in *XZ* ($\varphi = 0°$) (**a**) and *YZ* ($\varphi = 90°$) (**b**) planes

Table 2 Comparison between recommended antennas with related DBDP antenna

Ref. (year)	Antenna size (mm^3)	Polarization	IBW (%)	Freq. (GHz)	ARBW (%)	fc (GHz)
1 (2016)	40 × 40 × 3	LP, RHCP	5.1, 14.9	4.42, 5.74	8.8	5.815
2 (2017)	$R = 23.5$, $H = 6.508$	LP, RHCP	2, 1	1.38, 1.57	1.39	1.576
3 (2017)	40 × 40 × 3	LP, LHCP	4.81, 23	4.72, 5.78	8.81	5.815
4 (2019)	50 × 50 × 2.325	LP, LHCP	8, 5.8	2.5, 5.92	5.91	5.75
5 (2021)	25 × 20 × 1.6	LP, LHCP	7.72, 14.26	9.45, 11.56	10.74	12.13
Proposed work	50 × 50 × 1.6	LP, LHCP	20.28, 8.43	2.4, 7.78	11.73	7.84

5 Conclusion

To accomplish the dual-band dual-polarized (DBDP) characteristics, the coupled asymmetric T-shaped antenna is fed with an inset microstrip feed line in this paper. A coupled asymmetric T-shaped microstrip feeding line which is having asymmetric characteristics is connected to a 50 Ω microstrip line. A quadratic groove is cut out of the ground plane and the substrate to provide the dipole mode's bandwidth. The circular polarization (CP) is produced by introducing linked asymmetric T-shaped design, while the dipole's linear polarization (LP) properties are unaltered. A small gap is introduced in the coupled T-shaped to attain impedance matching in two of the frequency bands. The simulated IBW at lower and higher frequency regions is 2.17–2.66 GHz, 20.28% and 7.15–7.78 GHz, 8.43% which are resonating at 2.41 GHz and 7.46 GHz frequencies. The simulated 3 dB axial ratio bandwidth at higher resonating frequency is 7.38–8.3 GHz, 11.73% at center resonating frequency 7.84 GHz. Right-hand circular polarization (RHCP) characteristics are exhibited by using this design. The highest peak gain is 4.31 dBi at 7.4 GHz. The maximum radiation efficiency of this implemented antenna is 95%, and throughout the impedance bandwidth region, the radiation efficiency is greater than 85%. The proposed design in this paper has multiple applications like it can be used for at lower resonating frequency linearly polarized band WiMAX, WLAN application, and higher resonating frequency band can be used for C-band: broadcasting and fixed mobile communication application.

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