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Dual Circular Polarization with Reduced Mutual Coupling Among Two Orthogonally Placed CPW-Fed Microstrip Antennas for Broadband Applications

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Abstract

In this communication, a design of Coplanar Waveguide-fed Dual Circularly Polarized Broadband Antenna (CPW-DCPBA) has been proposed. Here, a square slot consists of two orthogonal T-shaped asymmetric microstrip antennas protruded from a signal line of CPW feed has been presented. The microstrip antennas are isolated with an inverted-L type grounded strip embedded at the left corner, followed by a square strip. A modified meandered line (MML) is embedded with the square strip to achieve circular polarization at the lower frequency. An SRR is placed at the back of the antenna to enhance the 3-dB axial ratio bandwidth (ARBW). Measurements of the fabricated antenna show an impedance bandwidth of 88% and the 3-dB ARBW of 75%, in which return loss is better than 10 dB and the isolation among the antennas are better than 15 dB. A peak gain of 3.1–5.6 dBi is achieved within the axial ratio band. The antenna is fabricated on FR-4 substrate of 60 mm × 60 mm × 1.6 mm with an antenna area of $0.359\lambda_0^2$. The simulated results are in good agreement with the measured results which verified its usage for broadband applications.

Keywords Axial ratio bandwidth (ARBW) · Axial ratio · Circularly polarized (CP) · Coplanar waveguide (CPW) · Mutual coupling · Slot antenna

1 Introduction

In today's world circularly polarized (CP), antennas are getting more advantageous over linearly polarized antennas in wireless communication, due to its ability to overcome polarization mismatch when acting as a transmitter and as a receiving antenna. Also, the CP

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antennas have better weather penetration and mobility than linear polarized (LP) antennas [1]. Wide bandwidth antennas are the most popular choice for high-speed wireless communication. Recently, much research has been done on CP square slot and ring slot antennas as shown by research papers tabulated in Table 1 because of wider bandwidth, low profile and easy embedding with monolithic microwave integrated circuits.

Mostly, CPW feed is preferred over microstrip feed due to less dispersion, low radiation loss and easy integration with solid-state devices. As represented in Table 1, wide 3-dB axial ratio bandwidth (ARBW) and impedance bandwidth (IBW) have been realized due to several techniques mentioned as follows: rectangular slot with horizontal stub protruded from the ground plane [1], two embedded inverted-L shaped grounded strips around two opposite corners of the slot [2, 3], three inverted-L shaped grounded strips at the corners [4], an inverted-L type stub extended from the signal line of the asymmetric-CPW feed [5], embedding an asymmetric inverted T-shaped grounded metallic strip that is perpendicular to the axial direction of the CPW feed line [6], using slot composed of multiple circular sectors [7], an open slot at the lower left of the slot [8], E-shaped slits are embedded at opposite corners of the ground plane [9], two linked annular slots [10], a slot antenna with lightening-shaped feed line and inverted-L grounded strips [11], angular-ring slot antenna with truncated corners and a pair of slits [12], a novel four-feed technique with circular radiating patch [13] and a rectangular slot antenna fed by four CPW port [14] are used for achieving circular polarization.

In this communication, a CPW-fed square slot antenna, having dual circular polarization, has been proposed on FR-4 substrate. Two orthogonally placed microstrip antennas protruded from signal line of CPW feed have been proposed to generate orthogonal E-fields required to achieve circular polarization. These E-fields has been favourably directed in horizontal and vertical directions using inverted-L grounded strip structure to obtain circular polarization. The 3-dB ARBW has been increased with the square strip embedded with the inverted-L grounded strip and shifted towards lower frequency by increasing the current

Table 1 Comparison table of some of the existing CP antennas with the proposed CPW-fed antenna

References	$\lvert S_{11} \rvert <$ − 10 dB (GHz)	IBW (%)	f_c (GHz)	3-dB ARBW (%)	Gain (dBi)	Ant. area (mm × mm), (λ_0^2)
[1]	3.5–9.25	90.20	6.38	40.00	0.8–4.5	25 × 25, 0.230
[2]	1.72–2.94	52.36	2.41	28.80	3–4	60 × 60, 0.233
[3]	2.67–13.12	132.3	5.97	32.20	3–4.2	60 × 60, 1.425
[4]	2–7.07	111.8	3.58	86.43	–	60 × 60, 0.511
[5]	1.77–2.59	36.89	2.22	30.60	4.1max	60 × 60, 0.197
[6]	1.53–1.61	5.2	1.58	3.81	1.8max	60 × 60, 0.099
[7]	2.08–4.01	63.4	3.05	57.40	8.3max	$(106.4)^2$, 1.170
[8]	2.13–7.46	111.2	4.8	27.00	5.3max	50 × 50, 0.381
[9]	1.51–2.65	54.80	2.08	32.80	3.5–5	60 × 60, 0.187
[10]	2.25–4.25	61.53	3.25	46.70	–	65 × 35, 0.228
[11]	2.07–3.41	51.40	2.75	48.80	2.6–4.2	60 × 60, 0.301
[13]	0.93–2.71	97.8	1.8	83.8	6max	$(124)^2$, 0.560
[14]	1.19–2.6	74.4	1.90	70.80	7.4max	$(124)^2$, 0.640
Our's	1.68–4.31	87.78	3.00	74.62	3.2–5.6	60 × 60, 0.359

path length by using Modified Meandered Line (MML), which also helps in increasing the gain of the antenna at higher frequency. A Square Split Ring Resonator (SSRR) has been placed at the back side of the proposed antenna, which acts as a wave trap, and hence, helps in further increasing the 3-dB ARBW without disturbing the other parameters except a dip in return loss, isolation and gain around 2.6 GHz. Modified Meandered Line and SSRR had been also used to reduce the mutual coupling among microstrip antennas in [15, 16] respectively. The proposed antenna shows a better IBW than [2, 5–7, 9–11, 14] and a better 3-dB ARBW except [4, 13] as shown in the Table 1. Also λ_0^2, the antenna area is less than [3, 4, 7, 8, 13, 14] as shown in Table 1.

2 Antenna Structure with MML and SRR

The geometry of the proposed CPW-fed microstrip antenna has been illustrated in Fig. 1. The antenna has been fabricated on the FR-4 substrate of dimension 60 mm × 60 mm × 1.6 mm having dielectric constant (ε_r) = 4.3, and a loss tangent of 0.025. Here, a square slot has two orthogonally placed, asymmetric T-shaped microstrip antennas protruded from a signal line of CPW feed. One of the orthogonal microstrip antennas will act as a T-shaped feed line, and hence, will work as a stub in the time slot when the excitation signal is applied to the other microstrip antenna.

The microstrip antennas are isolated from each other by an inverted-L type grounded strip embedded in the left corner (as shown in Fig. 1a), followed by a square strip. This inverted-L grounded strip of length, L_3 = 9.75 mm has reduced mutual coupling among the microstrip antenna by almost 28 dB and attained circular polarization at the upper frequency. The MML has been embedded with the square strip as shown in Fig. 1a to achieve circular polarization at the lower frequency. The length of MML, along with square strip area, has been optimized for better gain and circular polarization. A SSRR is embedded at the back of the antenna as shown in the Fig. 1c.

3 Design and Analysis of the Antenna

In this section, we will discuss the development phase of the proposed antenna. The development of the proposed antenna has been divided into five phases, i.e. Ant. 1 to Ant 5. As shown in Fig. 2, Ant. 1 has two orthogonally placed, T-shaped asymmetric microstrip antennas protruded from the signal strip line of the two CPW-feed. The antennas are shifted by 0.85 mm from their midpoint towards − x and − y-axis. These two orthogonally placed asymmetric T-shaped lines help in generating orthogonal E-fields, which are required for circular polarization. Ant. 1 has a narrow isolation bandwidth and is linearly polarized as shown in Fig. 3a–c. The two E-fields generated due to the two antennas are further redirected along the horizontal and vertical components with the help of inverted-L grounded strips at the left corner as shown in Ant. 2 of Fig. 2, which results in a 3-dB ARBW of 36.30% as shown in Fig. 3c.

Further enhancement of circular polarization and gain has been attained by the introduction of a square strip of dimension 10.7 mm × 10.7 mm as depicted in Ant. 3 of Fig. 2. The axial ratio bandwidth has been significantly improved as shown in Fig. 3c; however, the impedance bandwidth has been disturbed in the middle as shown in Fig. 3a.

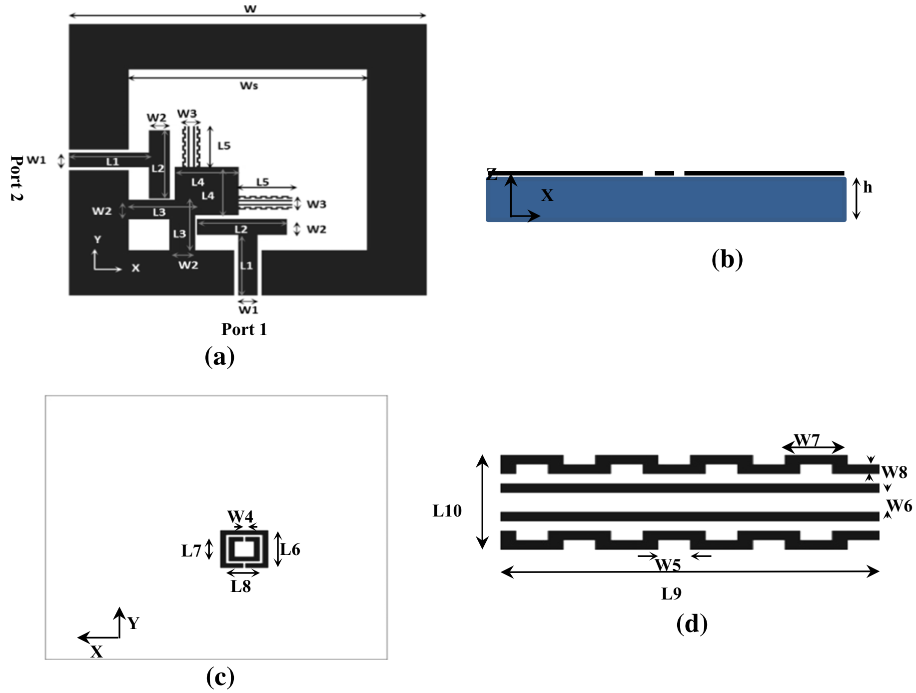


Fig. 1 Proposed antenna structure and dimensions. **a** Front view, **b** side view, **c** back view, **d** MML structure. [W = 60, Ws = 40, W = 3.2, W2 = 3.5, W3 = 9.75, W4 = 0.4, W5 = 0.6, W6 = 1, W7 = 1.2, W8 = 0.3, L1 = 13.4, L2 = 15.1, L3 = 9.75, L4 = 10.7, L5 = 9, L6 = 8.4, L7 = 5.4, L8 = 6.4, L9 = 9, L10 = 3] (Unit: millimeter)

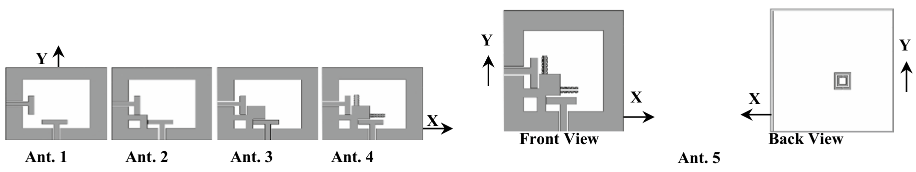


Fig. 2 Steps of improvement in proposed antenna

But this problem has been removed in Ant. 4, where an MML of length L5 = 9 mm, which is at a distance of 2.1 mm from the orthogonally placed microstrip antennas, has been introduced. The complete dimension of the MML has been shown in Fig. 1d. The introduction of MML, embedded with the square strip as shown in Ant. 4 in Fig. 2, helps in increasing the current path length due to which the return loss and 3-dB ARBW starting frequency has been lowered down to 1.67 GHz from 2 GHz (in case of Ant. 3) with a significant increase in ARBW to 73.96% in the frequency range, where the return loss is more than 10 dB as shown in Table 2.

A SSRR of dimension 8.4 mm × 8.4 mm has been introduced at the back of the antenna as shown in the back view of Ant. 5 of Fig. 2, for further improving the 3-dB ARBW. The SSRR will act as a wave trap, and hence, will help in increasing the 3-dB

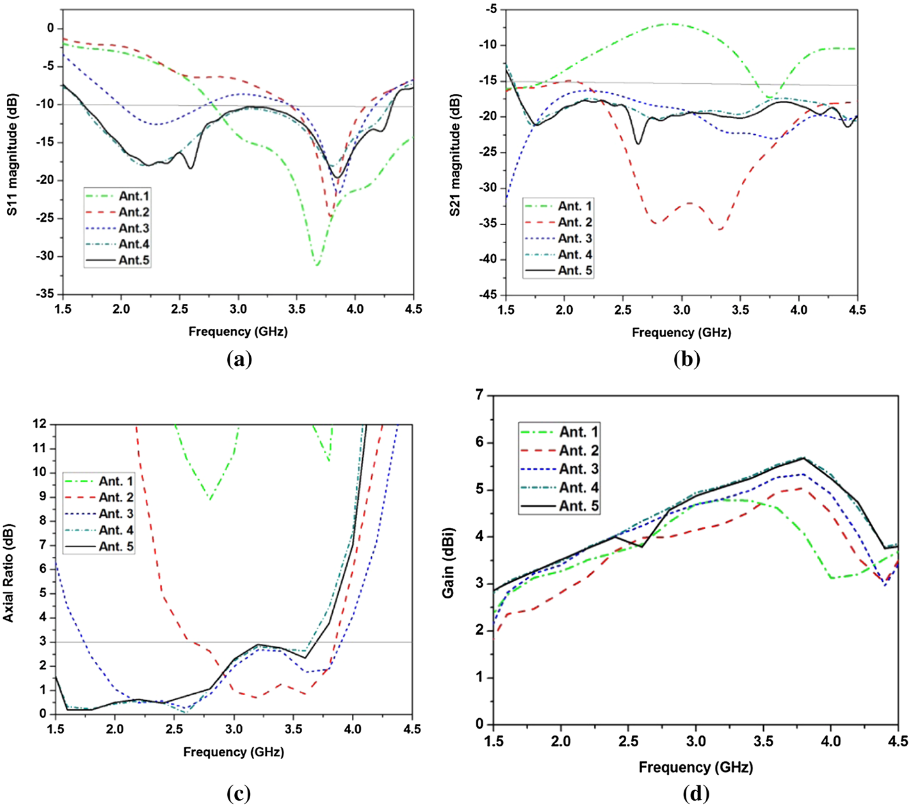


Fig. 3 Simulated results of **a** S_{11} versus frequency, **b** S_{21} versus frequency and **c** axial ratio versus frequency, **d** gain for Ant. 1–5

Table 2 Comparison table of antenna performance from Ant. 1 to Ant. 5

	$\lvert S_{11}\rvert < -10$ dB (GHz)	$\lvert S_{21}\rvert < -15$ dB (GHz)	3-dB AR band (GHz)	3-dB ARBW (%)	Gain (dBi) (1.68–3.68 GHz)
Ant. 1	2.78–4.5	3.63–3.88	–	0.0	2.9–4.8
Ant. 2	3.44–4.09	2.1–4.5	2.66–3.84	36.30	2.4–5.0
Ant. 3	2–2.68, 3.5–4.16	1.5–4.5	2–2.68, 3.5–3.9	29, 10.81	3–5.30
Ant. 4	1.66–4.3	1.56–4.5	1.67–3.63	73.96	3.14–5.6
Ant. 5	1.68–4.31	1.55–4.5	1.68–3.68	74.62	3.14–5.6

ARBW by 40 MHz without affecting any other parameters of the antenna. The square SRR position has been optimized for improving 3-dB ARBW.

The surface current distributions at the resonant frequency, 3 GHz has been shown in Fig. 4a, which clearly shows the RHCP in +z direction due to the anticlockwise movement of surface current from phase 0° to 270° for excitation from port 1. Similarly, we can see

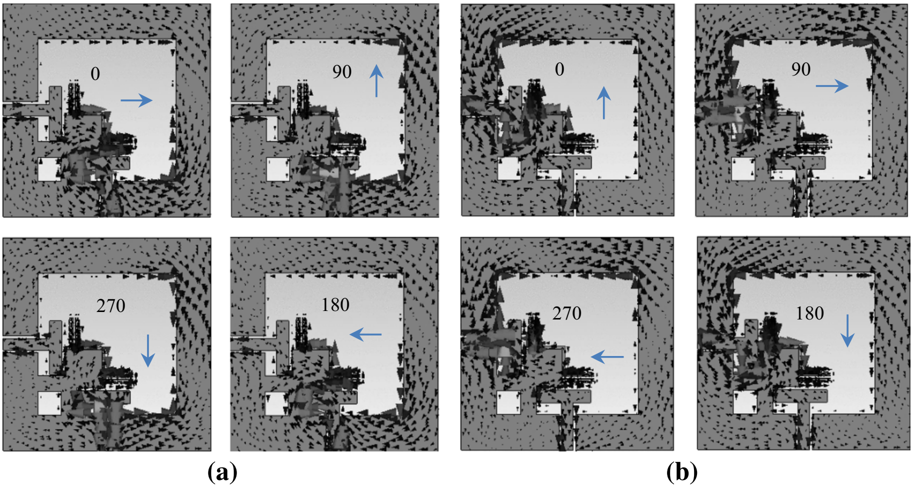
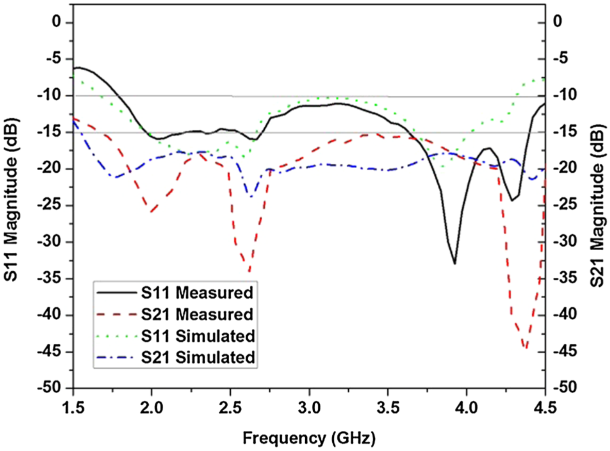


Fig. 4 Surface Current distributions for Phase 0°, 90°, 180° and 270° for **a** Port 1-RHCP, **b** Port 2-LHCP

Fig. 5 Measured and simulated results of S_{11} and S_{21} parameter for the proposed Ant. 5



the clockwise movement of surface current from phase 0° to 270° for excitation from port 2 in Fig. 4b resulting in LHCP in the +z direction. Concentrate on the square strip area in Fig. 4 to closely monitor the direction of the surface current.

So, it can be said that we have dual circular polarization at the resonant frequency 3 GHz due to the two orthogonal ports. The measured results, such as return loss and isolation, have been shown in the Fig. 5, which clearly shows a good agreement with the simulated results.

Figure 6 represents the comparison of simulated 3-dB ARBW with the measured one, which shows that the axial ratio BW is 75%, ranging from 1.68 to 3.68 GHz—where our proposed antenna is having a return loss of more than 10 dB and an isolation loss of more than 15 dB. Figure 7 shows that the measured gain of the fabricated antenna is in good agreement with the simulated results.

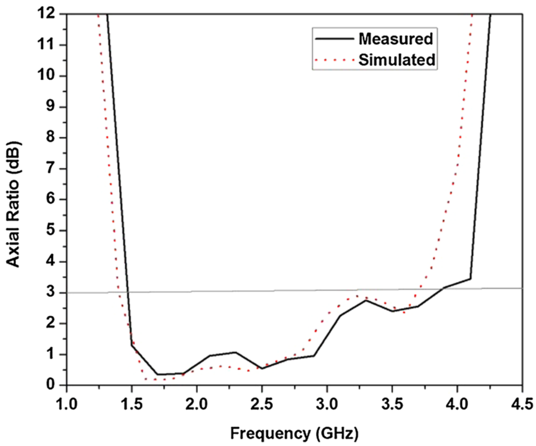


Fig. 6 Measured and simulated 3-dB ARBW for the proposed Ant. 5

In the Figs. 5, 6 7, slight variations in the measured and simulated results are due to fabrication errors, attached SMA connector and experimental environments. The fabricated antenna has been shown in Fig. 8, depicting (a) Top view and (b) Back view of the antenna. The polar plot of the radiation patterns at 3 GHz have been shown in Fig. 9 for excitation from both port 1 and port 2 separately. The left and right-hand circular polarization have been plotted in the XZ plane (E-plane) and the YZ plane (H-plane) due to excitation from port 1 and termination of port 2 in Fig. 9a. Clearly, we can see RHCP in +z direction and LHCP in − z direction with a cross polarization level of > 20 dB in the broadside direction. Similarly, we can see the same results for the XZ and the YZ plane in the case of excitation from port 2, depicting LHCP in + z direction and RHCP in − z direction in Fig. 9b.

The Mutual Coupling reduction results have been verified using the computed result of Envelope Correlation Coefficient (ECC) of the final proposed Ant. 5 as shown in Fig. 10. The ECC has been computed through scattering parameters using the following equation [15, 17–19].

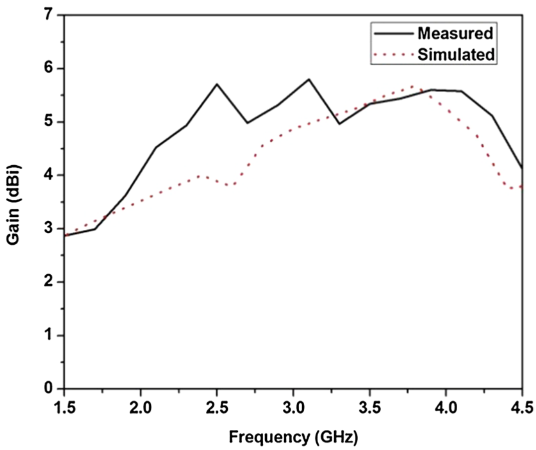
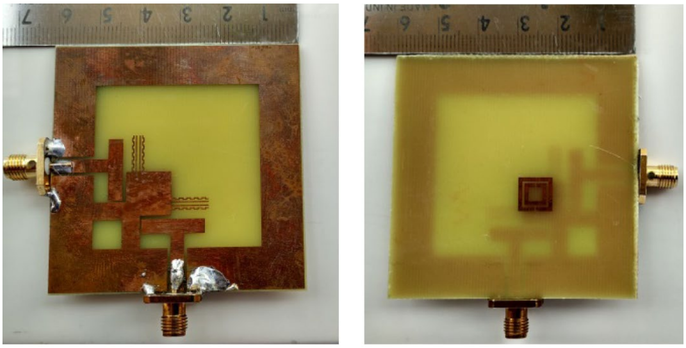


Fig. 7 Measured and simulated gain for the proposed Ant. 5



(a) Front View **(b)** Back View

Fig. 8 Photograph of fabricated proposed Ant. 5

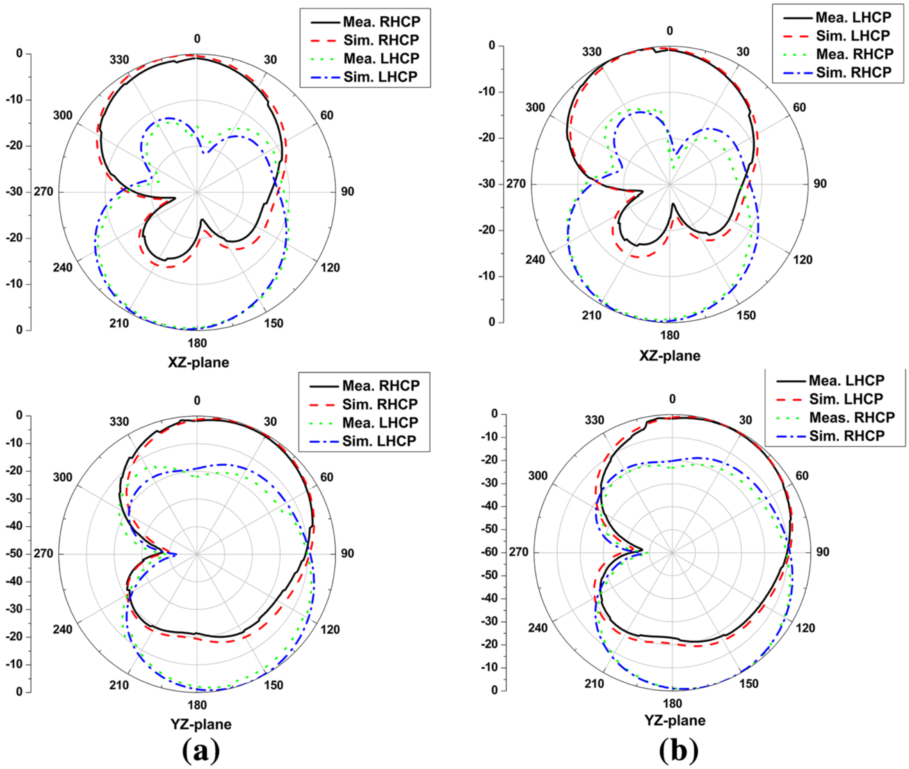


Fig. 9 Measured and simulated radiation patterns at 3 GHz in XZ and YZ plane for excitation in **a** Port 1 and **b** Port 2

$$\rho_e = \frac{\left|S_{11}^* S_{12} + S_{12}^* S_{22}\right|^2}{\left(1 - \left|S_{11}\right|^2 - \left|S_{21}\right|^2\right)\left(1 - \left|S_{12}\right|^2 - \left|S_{22}\right|^2\right)}$$

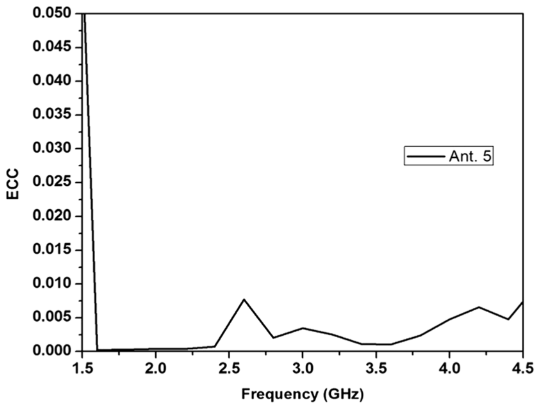


Fig. 10 Computed ECC of proposed Ant. 5

The ECC is way below the acceptable limit of 0.05 [19], ranging from 0.021×10^{-2} to 0.771×10^{-2} for the proposed Ant. 5. This computed ECC is much better than [17–19].

4 Conclusion

A CPW-DCPBA has been proposed. The measured results show shifting of 3-dB ARBW towards the lower frequency of 1.68 GHz as compared to 2 GHz (achieved in Ant. 3), due to the introduction of MML. A 3-dB AXBW of 2 GHz i.e. 74.62% has been achieved in the frequency range (1.68–3.68 GHz) with a peak gain of 3.1–5.6 dBi, where the return loss is more than 10 dB. A good isolation of 15 dB has been achieved throughout the operating frequency range. The proposed antenna is suitable for both LTE bands (1.7 and 2.7 GHz), which include 13 FDD (Frequency Division Duplex) LTE bands and 10 TDD (Time Division Duplex) LTE bands. The antenna is also suitable for WiMAX (2.5–2.69 GHz, 3.2–3.8 GHz), WLAN/Bluetooth (2.4–2.484 GHz) and for IEEE 802.11y-2008 (3.65–3.7 GHz).

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