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A Miniaturized and Circularly Polarized L-Shaped Slot Antenna for Ultra-wideband Applications

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Abstract: ***A miniaturized microstrip-fed, wideband and circularly polarized L-shaped slot antenna is designed for ultra-wideband applications. To realize L-shaped slot antenna with wide impedance bandwidth, a stub of size 10.7 mm^2 is added to a rectangular shaped slot of the ground plane. The position of the feedline is optimized to attain wide circular polarization bandwidth. The proposed antenna size is very small i.e., 25×25 mm^2. A prototype of the design is fabricated and measured. The axial ratio bandwidth (ARBW< 3 dB) of 2.2 GHz (from 6.2 GHz to 8.4 GHz) and the impedance bandwidth (S11<-10 dB) of 7.4 GHz (from 2.5 GHz to 9.9 GHz) is achieved by the proposed design. Moreover, the antenna achieves a stable radiation pattern and a gain of more than 2.8 dBi over the complete ARBW. The advantages of the structure are miniaturized design, having wide impedance bandwidth, and broad ARBW.***

Keywords: ***axial ratio bandwidth, circular polarization, slot antenna, ultra-wideband antenna.***

I. INTRODUCTION

The circular polarization (CP) is an essential feature for ultra-wideband (UWB) antennas. But it is rather difficult to achieve general polarization such as linear polarization. Traditionally, for point to point satellite communication, the circularly polarized antennas were employed but they are bulky and not having space constraint for eg. Archimedean Spiral, Yagi-Udas, and Crossed dipoles antennas, etc. Now the researchers have started adapting microstrip patch antennas due to its low profile, compact in size, conformal, ease of designing, compatible with PCB fabrication technology accompanied by the rapid growth in wireless communication and other portable device technologies [1-5]. Moreover, the spectrum released by the Commission of Federal Communication (FCC) for the operations of Personal Area Network (PAN) has raised the demand of the microstrip patch antennas,

Interestingly, the circularly polarized microstrip patch antennas emerged due to its capability to deal with multipath fading, data rate, and receiver orientation. Since for ideal circular polarization, the patch antennas have opted. Also, the slotted antenna with microstrip-feed can be considered as an excellent and potential candidate because it has a good radiation pattern and easily compatible with MMIC (monolithic microwave integrated circuits).

In the recent past, a variety of CP slot antennas have appeared. Such as, in [6], a CP antenna with asymmetric slits loaded irregular-shaped, a wide square slot for CP operation [7], two-arm slots for dual-polarization [8], and asymmetrical ground and monofilar spiral antenna [9] have been proposed. Also, in [10], a trapezoidal shape slot antenna is designed to achieve a CP band of 1.77 GHz. A CP antenna with a slot has been investigated which provides resonance at 1575 MHz of CP band [11]. Furthermore, in [12], an antenna with stair shaped slot has been designed which gives a CP band at 850 MHz of the resonant frequency. In [13] a square slot is used to design an antenna that gives a CP band of 1.4 GHz. But in [14], a hexagonal shaped antenna is proposed which gives a CP band of 1.6 GHz. Finally, a comparison list of the CP slot antenna from the literature is given in Table I.

In this research work, a miniaturized slot antenna of size 25×25 mm^2 has been designed and verified. The proposed antenna prototype achieves the impedance bandwidth (BW) and axial ratio bandwidth (ARBW) of 7.4 GHz (2.5 GHz to 9.9 GHz), and 2.2 GHz (6.2 GHz-8.4 GHz), respectively. The design comprises of a rectangular slot and a microstrip feed-line on either side of the substrate. Furthermore, in order to achieve the enhanced impedance BW, a rectangular-shaped slot is modified by adding a stub of size 10.7 mm^2 from the right side toward the center of the ground plane of the structure. Moreover, the radiation pattern of the design is stable over the complete CP frequency band. A comparison of the proposed design with the reference antennas is listed in Table I in terms of the resonant frequency band, size, ARBW, and BW, respectively.

As seen from Table I, the proposed design has overall good performance over the referenced designs in terms of size, ARBW and, impedance bandwidth. The proposed CP antenna design offers miniaturization as compare to the rest of the structures.

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Although [17] offers better ARBW as compared to proposed structure while structures [13],[14], [15],[16], [18],[19], [20],[21], [22],[23], [24],[26], and [27] have lower ARWB value. This is also observed that the structures [13], [16], [17], [18], [19], [21], [22], [24], and [26]

Table-I: CP Antenna design with resonant frequency band, size, ARBW, and BW

CP Antenna	Publishing Year	Resonant Frequency band (GHz)	Antenna Size (mm^2)	ARBW (GHz)	Impedance BW (GHz)
Sze et al. [13]	2010	2.0-3.4	60 × 60	1.40	1.40
Zhou et al. [14]	2011	1.8-4.5	62 × 62	1.60	2.70
Jan et al. [15]	2013	2.13-7.46	50 × 50	1	5.33
Luo et al. [16]	2015	1.17- 2.25	60 × 60	0.70	1.08
Saini et al. [17]	2016	2.0-4.76	60 × 60	2.76	1.70
Chu et al. [18]	2013	1.5-2.65	60 × 60	0.71	1.15
Row et al. [19]	2014	2.2-2.80	56 × 23	0.11	0.60
Guo et al. [20]	2018	2.49-6.42	53 × 44.7	1.77	3.93
Ko et al. [21]	2018	2.25 to 2.87	45 × 45	0.17	0.62
Cao et al. [22]	2017	4.55-6.52	40 × 40	1.50	1.97
Hu et al. [23]	2015	3.06-5.52	67 × 67	1.80	2.46
Xue et al. [24]	2015	1.73-3.11	120 × 100	0.97	1.38
Van et al. [25]	2018	1.68–3.97	54 × 54	2.06	2.29
He et al. [26]	2016	1.9-2.8	50 × 50	0.79	0.90
Nasimuddin et al. [27]	2012	2.0-5.0	60 × 60	1.48	3.00
Proposed design	2019	2.5- 9.9	25 × 25	2.2	7.4

shows impedance BW below 2 GHz, whereas structures [14], [15],[20],[23],[25], and [27] offer impedance BW above 2 GHz. However, the impedance BW offered by the proposed structure is 7.4 GHz, which is higher among all. Hence, the proposed structure, exhibits miniaturization, offer broader bandwidth, and better impedance matching compared to the referenced structures.

The research work has been organized as follows: Introduction and the review of the literature are presented in section I. Section II, describes the proposed antenna design. The result and discussion are given in Section III. Finally, the conclusion of the work is presented in Section IV.

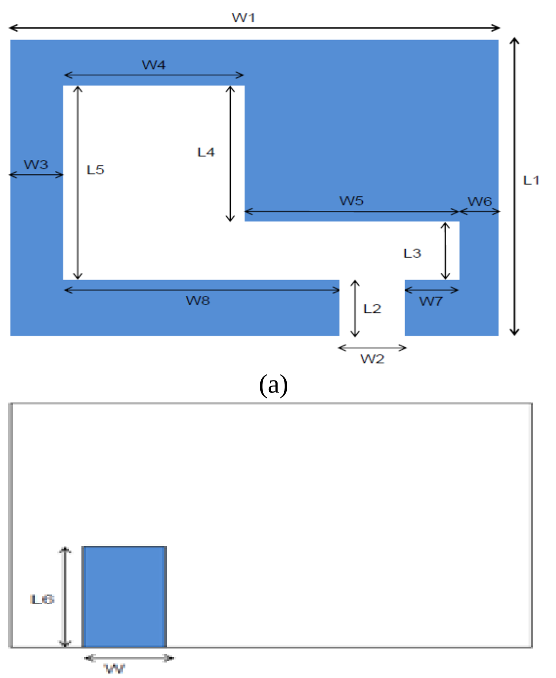
II. ANTENNA DESIGN

A. Antenna design and parameters

The configuration of the design is given in Fig. 1. The top view of the design has been given in Fig. 1(a) while its bottom view is presented in Fig. 1(b). The prototype is designed on a commercially cheap FR4 substrate. The

Table-II: Parameters with size in mm

Parameters	Dimension (mm)	Parameters	Dimensions (mm)
W1	25	W8	13.5
W2	3	L1	25
W3	4.3	L2	4.8
W4	10	L3	5.25
W5	9.5	L4	10.75
W6	1	L5	15
W7	3	L6	9.75



(b)

Fig. 1. Configuration of the design (a)Top view and (b) Bottom view

plane of the antenna. Furthermore, to overcome the coupling between

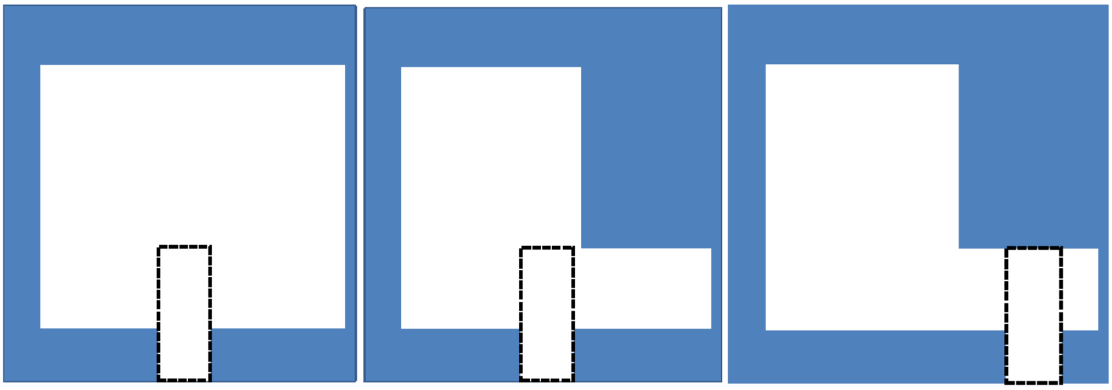

(a) (b) (c)

Fig. 2.Enhancement in proposed design (a) Ant1, (b) Ant2, and (c) Ant3

the ground plane and feedline, a small slot of W2 is made at the bottom part of the standard thickness of FR4 is 1.6 mm with loss tangent value of 0.0019 and dielectric constant (ε_r) of 4.4. Firstly, the rectangular slot of 15 × 19.5 mm^2 is made on the ground plane of the design and then to achieve the enhanced impedance bandwidth, a stub of length 10.75 mm is added from the right side of the ground plane toward its center which forms the L-shape slot in the ground plane as shown in Fig. 1. With parametric optimization and tuning of microstrip line position in order to achieve wideband circular polarized operation. The parameter dimensions of the design in millimeters have been given in Table II.

B. Parametric analysis

Fig. 2 shows the different modifications in the antenna design which provides the improvement in the bandwidth and ARBW of the design. The design of the three antennas is being shown in Fig. 2. The Antenna1 (Ant1) with a rectangular slot and a centered positioned microstrip feedline on either side of the substrate is shown in Fig. 2(a) and then to enhance the impedance BW, a stub is added from the right side of the ground plane toward its center, as shown in the curve of Antenna2 (Ant2) in Fig. 2(b).

Furthermore, to achieve wide bandwidth and ARBW, the feedline is shifted towards the right edge from the center of Antenna 2, as shown in the curve of Antenna 3 (Ant3) in Fig. 2(c).

III. RESULTS AND DISCUSSIONS

The simulated reflection coefficient (S_{11}) and ARBW of Ant1, Ant2, and Ant3 are represented in Fig. 3 and 4, respectively. It has been observed from Fig. 3 that the Ant3 achieved resonance at 2.5 to 9.9 GHz with impedance bandwidth of 7.4 GHz and ARBW of 2.2 GHz. Ant3 is having a greater impedance bandwidth comparatively to Ant1 and Ant2. For Ant 1, it has achieved two resonant frequency peaks at 3.2 GHz and 7.1 GHz with poor impedance bandwidth. Then we modified this design to form Ant2, by adding a stub from the right side of the ground plane toward its center, it results in a wideband response and better results with enhanced impedance bandwidth. Finally, the feedline is shifted towards the right edge from the center of Antenna 2 to make our final Ant3 design in order to achieve wide bandwidth and ARBW.

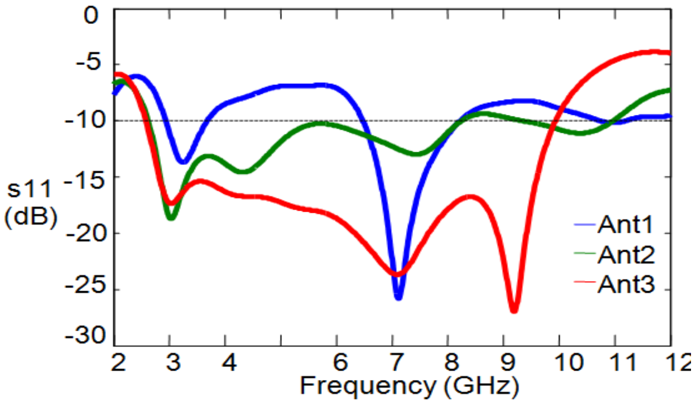


Fig. 3. S_{11} of Ant 1, Ant 2, and Ant 3

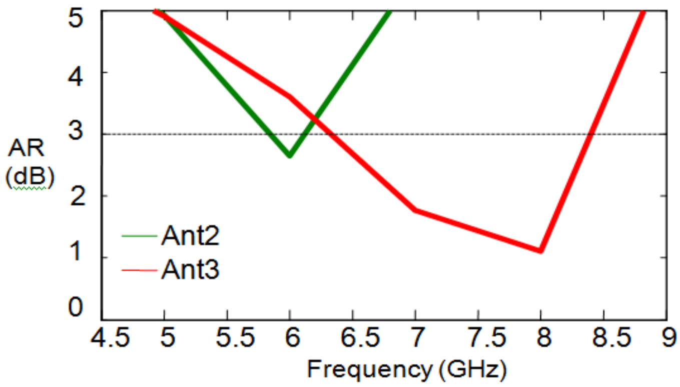
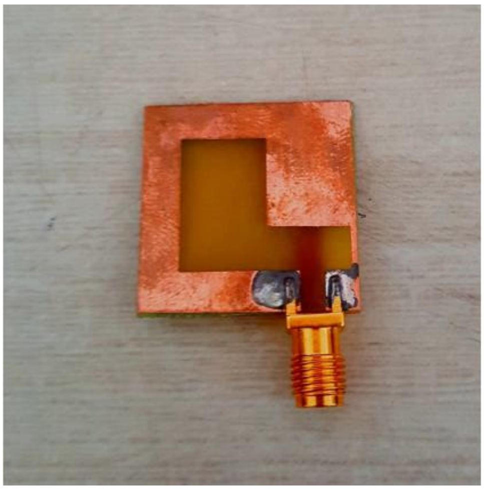
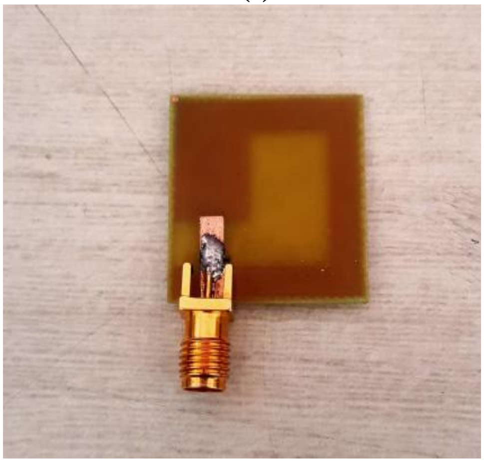


Fig. 4. ARBW of Ant 2 and Ant 3

The axial ratio bandwidth comparison plot of Ant1, Ant2, and Ant3 has been given in Fig. 4. It has been observed that the Ant3 possesses greater ARBW than Ant1 and Ant2. The Ant1 possess poor ARBW response, whereas, for Ant2, it is roughly equal to 0.5 GHz. Ant3 own axial ratio bandwidth of 2.2 GHz, which is a significant improvement over Ant2 design. Therefore, it is concluded that the impedance bandwidth and axial ratio bandwidth are remarkably improved by shifting the feed-line towards the right edge from the center of Ant2. This is due to the fact that the horizontal electric field vector (EHOR) of the stub has a phase difference (PD) of nearly 90^0 with the vertical electric field



(a)



(b)

Fig. 5. Fabricated prototype (a) Top view (b) Bottom view

vector (EVER) of slot radiator and the CP wave is developed for a large range of frequency. Therefore, finally, Ant 3 has achieved the broadband ARBW of 2.2 GHz from the frequency range of 6.2 to 8.4 GHz and also achieves the wide impedance bandwidth (BW) of 7.4 GHz ranges from 2.5-9.9 GHz as depicted in Fig. 3 and Fig. 4, respectively. Moreover, for the indicative purpose, the Ant1 axial ratio (> 9 dB) is not given in Fig. 4.

For the experimental verification of the design, the prototype of antenna 3 has been fabricated and measured with Vector Network Analyzer (MS46322A) are shown in Fig. 5 and Fig 6, respectively. The top view of the fabricated design of ant3 is shown in Fig. 5(a), whereas the bottom view of the fabricated design of ant3 is shown in Fig. 5(b). To feed the antenna a female edge-mounted SMA connector is connected to the prototype of Ant3.

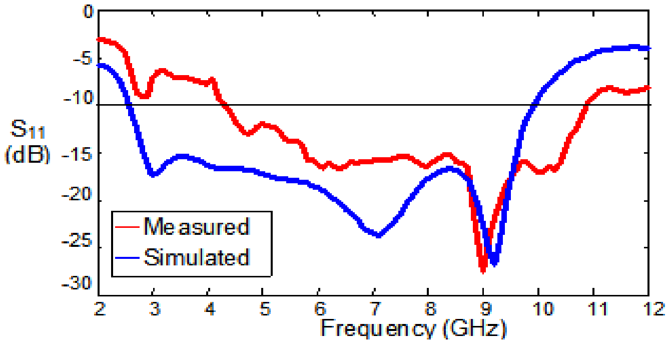
The measured axial ratio and reflection coefficient (S_{11}) of Ant3 is illustrated in Fig. 7 (a) and 7 (b), respectively and seems to be in good agreement with each other. It has been found that due to fabrication and SMA connector losses, the -10 dB measured impedance bandwidth of design is slightly shifted towards the higher region of the frequency as depicted in Fig. 7(a), whereas 3dB measured axial ratio bandwidth moves a little towards the lower frequency region as shown in Fig. 7(b). Hence, the measured results are in good agreement with the simulated results.

To validate the Ant3 design further, the analysis for surface current distribution has been made. The simulated

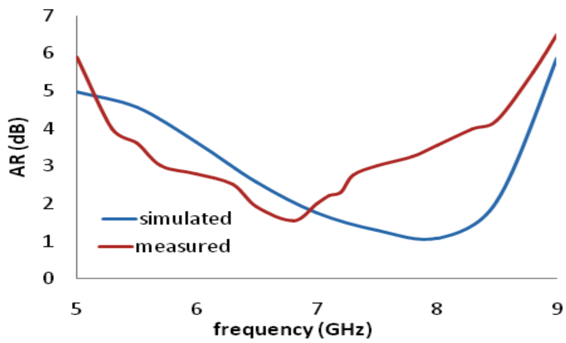
Fig. 6.Measurement of prototype performance with MS46322A vector network analyzer

the surface current distribution of Ant 3 design has been taken at a resonant frequency of 7 GHz and illustrated in Fig. 8. It can be clearly observed from Fig. 8 that the time-varying surface current distribution is similar at a phase angle of 180^0 and 270^0 whereas inverse in phase at 0^0 and 90^0. Therefore, it is evident that the design is LHCP (Left Hand Circularly Polarized) in the +z-direction and RHCP (Right Hand Circularly Polarized) in –z-direction.

The radiation patterns of the Ant3 design have been given in Fig. 9. The simulated and measured LHCP and RHCP of E and H planes are given at two frequencies i.e., 7.5 GHz and 8.5 GHz. E-plane radiation at 7.5 GHz performance has been



(a)



(b)

Simulated and measured results (a) S_{11} (Reflection co-efficient) and (b) Axial ratio bandwidth for Ant3

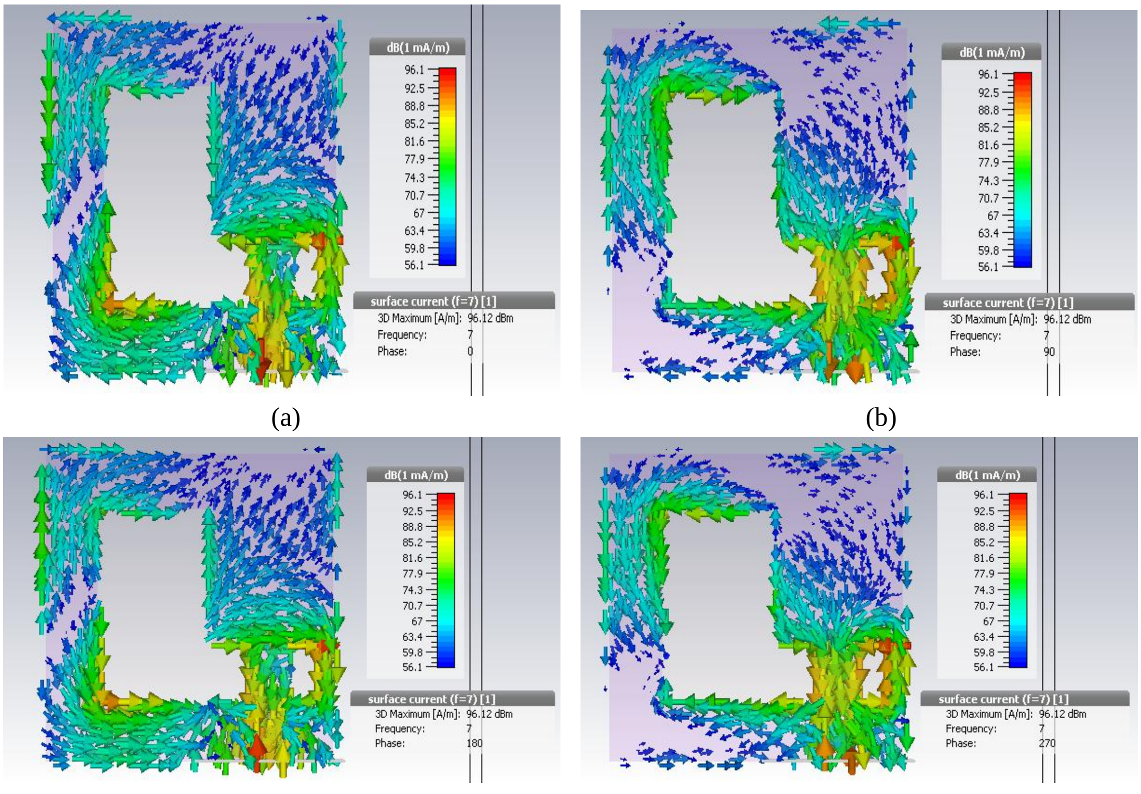


Fig. 7. Surface current distributions of the design of Ant3 at 7 GHz for (a) 0^0 (b) 90^0 (c) 180^0 and (d) 270^0

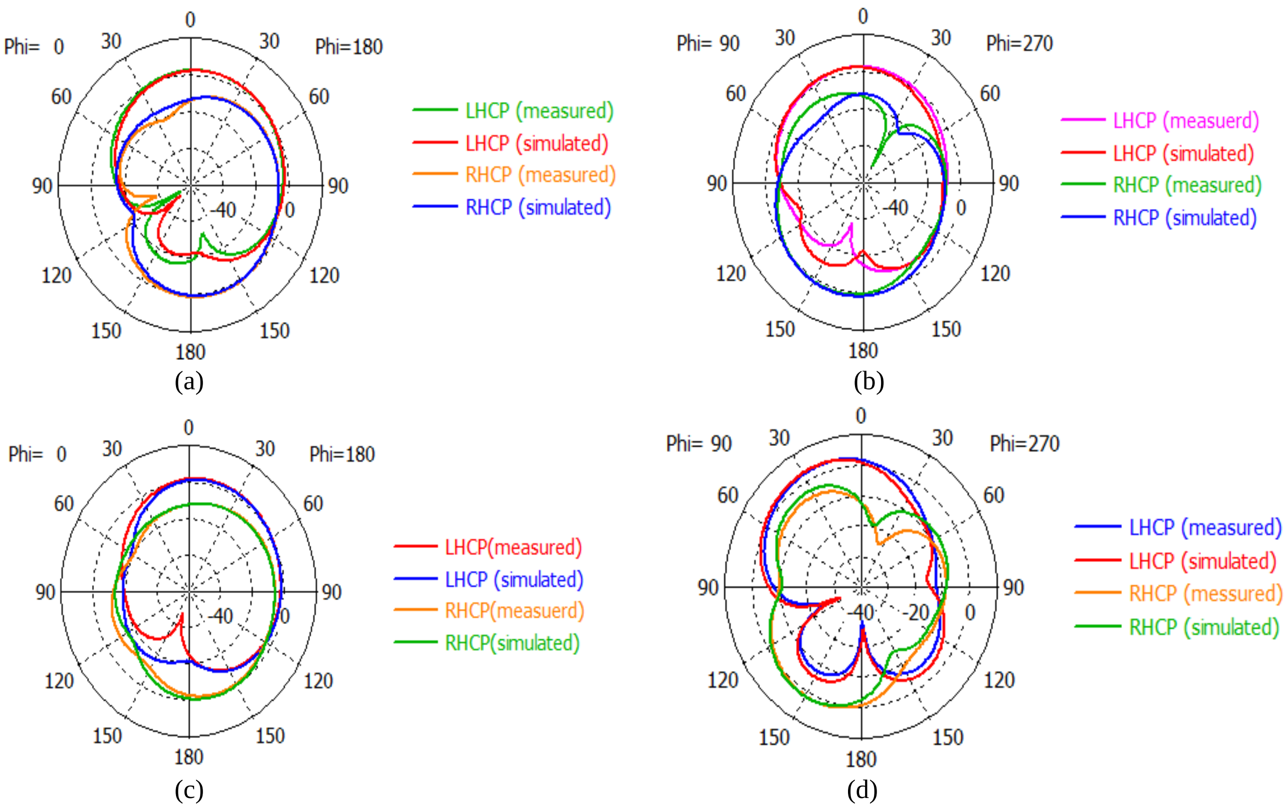
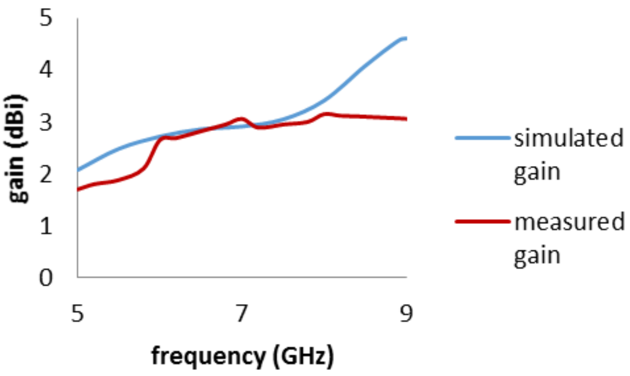
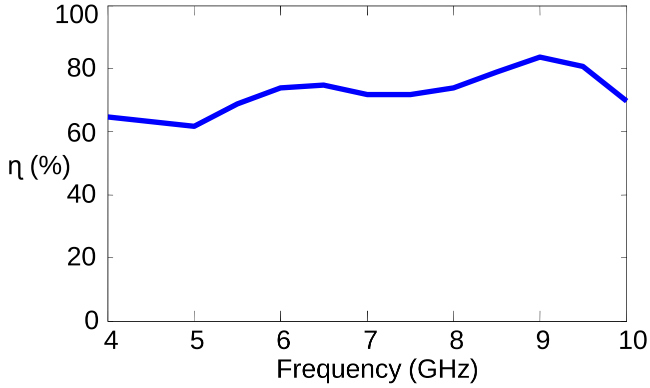


Fig. 8. Measured and simulated results of LHCP and RHCP (a) E-plane at 7.5 GHz, (b) H-plane at 7.5 GHz, (c) E-plane at 8.5 GHz, and (d) H-plane at 8.5 GHz, respectively.



(a)



(b)

Fig. 9. The results showing (a) simulated and measured the gain of the design and (b) Antenna efficiency (η).

shown in Fig. 9(a), whereas H-plane radiation performance at 7.5 GHz has been given in Fig. 9(b). Similarly, E-plane radiation at 8.5 GHz performance has been shown in Fig. 9(c), while H-plane radiation performance at 8.5 GHz has been given in Fig. 9(d), respectively. It is observed from Fig. 9 that the LHCP and RHCP of E-plane and H-plane are found to be nearly Omni-directional. Due to the fabrication losses, the small difference is observed between the measured and simulated results of LHCP and RHCP.

The gain of the Ant3 design has been given in Fig. 10(a). From the figure, it is clear that the simulated directive gain of the antenna is varied from 2.1 dBi to 4.8 dBi whereas the range of measured directive gain varies from 1.7 dBi to 3.1 dBi within ARBW. A graph for Ant3 design has been also plotted for antenna efficiency varies within a range of frequency from 4GHz to 10 GHz and is given in Fig. 10(b). This indicates that the percentage efficiency (η) of the antenna remains above 60% throughout the entire frequency range. The maximum efficiency of the ant3 design is 83 % observed at a frequency of 9.1 GHz.

IV. CONCLUSION

A miniaturized, wideband, circularly polarized L-shaped slot antenna has been discussed in this paper. In order to obtain the design of the final proposed structure, Ant1 has been designed first, this shows dual-band resonant behavior with poor impedance bandwidth and axial ratio BW. This structure is modified to Ant2 by inserting a stub of length 10.75 mm, which is added from the right side of the ground plane toward its center resulting in improved impedance bandwidth and axial ratio BW. Finally, to achieve wide bandwidth and ARBW, the feedline is shifted towards the right edge from the center of Ant2 to form Ant3 design. The modified design has got a wideband frequency response between 2.5 GHz to 9.9 GHz. The wide -10dB impedance bandwidth of 7.4 GHz is achieved by introducing a stub to a rectangular slot of the ground plane whereas the position of the feedline is used to achieve 3dB axial ratio BW of 2.2 GHz. Moreover, the proposed design has a stable directive gain, efficiency, and radiation pattern over a complete ARBW.

The final product is a miniaturized and circularly polarized L-Shaped Slot Antenna which finds its usefulness for ultra-wideband Applications. The compactness and miniaturization nature of this antenna also makes it very much appropriate for the indoor wireless application.

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