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# A Compact Circularly Polarized Multiband Microstrip Patch Antenna with Defective Ground Structure

Ashish Kumar Singh, Ankit Sharma*, Lakshmanan. M., and Deepak Gangwar

***Abstract*—In this paper, a novel double-layer multiband circularly polarized microstrip patch antenna is proposed. The design employs the concept of slotted patch fed with proximity coupled feed having defected ground plane (DGS). The proposed antenna achieves multiple operating frequency bands including FB1 (11.15 GHz), FB2 (4.17 GHz), FB3 (4.87 GHz) and FB4 (1.98 GHz). The proposed antenna has obtained bandwidth of 12.98%, 4.7%, 4.69% and 5.39% at FB1, FB2, FB3 and FB4 bands, respectively. The proposed antenna also exhibits circular polarization in the frequency band FB4. The 3dB ARBW of the antenna is 9.23% at 11.2 GHz. Finally, a metallic cavity is used with the antenna to achieve a unidirectional radiation pattern. The designed antenna radiation characteristics are verified with the experimental results.**

***Keywords*—Multiband, circularly polarized and defective ground structure (DGS), axial ratio**

## I. Introduction

IN the present, scenario, the demand of wireless communication system is increasing day by day. Especially, the demand of mobile phone or wireless local area networks (WLANs) have increased due to the increase in the number of users having these services [1]. Multifunction has become one of the most important trade mark for the antennas required in the modern wireless communication system. Due to this, lots of researches have gone into designing multiband dual polarized antennas along with various radiating elements, feeding structures. In recent years, polarization diversity has been receiving much more attention than space-diversity in wireless communication system, due to its advantage in reducing the number and size of antenna [2-3].

In modern wireless communication systems dual-polarize antennas are used for polarization diversity or MIMO schemes [4]. In [5] a tri-band antenna using meandering split-ring slot is presented for WLAN/WiMAX application. Similarly, a triple-band antenna is designed using three circular arc shaped strips for both WLAN and WiMAX application [6]. At the same time, a dual band CP antenna is proposed by creating an asymetric slit in the patch and truncating the corners of patch of antenna [7]. Mathew et al. have proposed a dual polarized CP antenna using V slit in the circular patch of the microstrip antenna [8]. A CPW-fed dual-band dual-polarized antenna for short-range communication applications is designed. The proposed antenna exhibits linear polarization (LP) at lower frequency and circular polarization (CP) at higher frequency [9]. In [10], a dual-band dual-polarized antenna is designed for terrestrial and satellite communication. Furthermore, a dielectric resonator antenna with dual-band CP is designed for radiolocation applications. The designed antenna have impedance bandwidth of 26.25% and 11.17% with 3 dB axial ratio bandwidth (ARBW) of 15.8% and 5.02% respectively [11]. Dual-band CP microstrip antenna operating at 1555 MHz and 2500 MHz band with spiral slots is presented in [12]. Goel et al. presents proximity coupled square shaped antenna with dual-band circular polarization for Wi-Max and WLAN systems [13]. A single feed dual band composite cavity-backed four-arm curl antenna has been developed by Ta et al. In this design a cavity backed reflector is used to improve the radiation characteristics of the antenna [14]. Furthermore, an H shaped slot antenna consist of one main slot fed by CPW and the two side slot fed by microstrip line is proposed. The designed antenna is having impedance bandwidth of 17% and 32 dB isolation is obtained over the entire bandwidth [15]. A simple and compact microstrip fed circularly polarized wide slot antenna is proposed with impedance bandwidth of 90.2% and 3 dB ARBW of 40% [16]. Similarly, H-shape slot truncated patch short back fire antenna (SBA) is designed to achieve CP excited. The SBA also consist of parasitic circular ring at the height of sub-reflector to increase the gain of the antenna [17]. A wideband circularly polarized H-shaped dielectric resonator antenna is proposed wherein CP is generated by using cross slot feed of two unequal length [18]. Recently, shah et al. have designed a dual layer rectangular multiband antenna using DGS and frequency selective surface (FSS). The resonant frequency of the multiband antenna is 5.5 GHz, 6.81 GHz and 9.3 GHz [19]. The antenna designs discussed in the literature are either linearly polarized or circularly polarized and also has issue of larger size. So, we have proposed a compact multi-band antenna which is linearly polarized at lower bands and circularly polarized at higher frequency band. The comparison of proposed antenna with other related antennas discussed in literature is shown in Table I. It can be observed from Table I that the proposed antenna is compact in size as compared to other listed reference antennas. It also has wider 3-dB ARBW as well as more number of frequency bands spread from 1 to 14 GHz. The paper is organized as follows. The detailed design of the proposed antenna is discussed in Section 2. Section 3 describes evolution of the proposed antenna geometry. The explanation of results is given in Section 5 followed by brief conclusion in Section 6.

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TABLE I
COMPARISON OF PROPOSED ANTENNA WITH OTHER DUAL-POLARIZED ANTENNAS

| **Antenna** | **Centre Frequency (GHz)** | **3dB ARBW (GHz)** | **Polarization** | **Peak Gain (dBi)** | **Size (mm$^2$)** |
|---|---|---|---|---|---|
| Proposed | 1.98, 4.17,4.87, 11.15 | 1.0 | LP & CP | 4.6 | 30x38 |
| Ref [6] | 1.18, 1.23, 1.57 | 0.013, 0.01, 0.04 | CP | 6.3 | 80x80 |
| Ref [11] | 2.54, 3.46, 5.72 | - | LP | 2.82 | 23x36.5 |
| Ref [12] | 2.58, 3.52, 5.46 | - | LP | 3.51 | 18x37 |
| Ref [13] | 2.39, 3.85 | 0.04, 0.011 | CP | 9.17 | 31.6x31.6 |
| Ref [14] | 2, 3.5, 5.6 | 0.046 | LP & CP | 4.4 | 50x50 |
| Ref [15] | 1.95, 2.16 | 0.02 | LP & CP | -1.1 | 22×24.8 |
| Ref [16] | 0.85, 1.85 | 0.074 | LP & CP | 8.9 | 155.4x166.67 |
| Ref [17] | 5.12, 8.86 | 0.76, 0.63 | CP | 5.8 | 100×100 |
| Ref [18] | 1.56, 2.50 | 0.85, 0.23 | CP | -1.9 | 50×50 |
| Ref [19] | 3.35, 5.5 | 0.1, 0.2 | CP | 6 | 80×80 |
| Ref [20] | 1.23, 1.59 | 0.01, 0.035 | CP | 6.7 | 90×90 |

## II. ANTENNA DESIGN

The schematic diagram of the proposed multi-band circularly polarized antenna is shown in Fig. 1(a). The proposed antenna consists of two substrates, a ground plane, a rectangular patch and a metal cavity. The overall size of the proposed antenna is 30×38 mm$^2$. It can be seen from Fig. 1(b) that the proposed antenna is fed with 50Ω microstrip line printed just above the top of the substrate1 (FR4 lossy, €r = 4.3, loss tangent = 0.025). The length and width of microstrip line is 14.5 mm and 2.917mm, respectively. Ground plane of the proposed antenna is depicted in Fig. 1(c). The ground plane of the proposed design is just below the substrate1 and is defected by etching a 'step shape' slot for the purpose of generating two orthogonal electric field components to achieve circular polarization. A small slot of dimension Lcut×Wcut is also etched on the ground plane just below the starting point of microstrip line to reduce coupling between the microstrip line and the ground plane. The radiating patch of the proposed antenna printed on the Substrate2 (FR4 lossy, €r = 4.3,   = 0.025, thickness = 0.76 mm) can be seen from Fig. 1(d). The patch has been unequally truncated from two opposite corners and an 'unequal arm cross' slot is created on the patch. Truncated corners along with the 'unequal arm cross' slot on the patch, and 'step shape' slot in the ground plane help to generate CP. A metal-cavity is placed below the ground plane of the proposed design to reflect the radiation going in backward direction. The type of feeding technique used in the proposed antenna is proximity coupled feed. Dimensional measurements of the proposed antenna are shown in Table II.

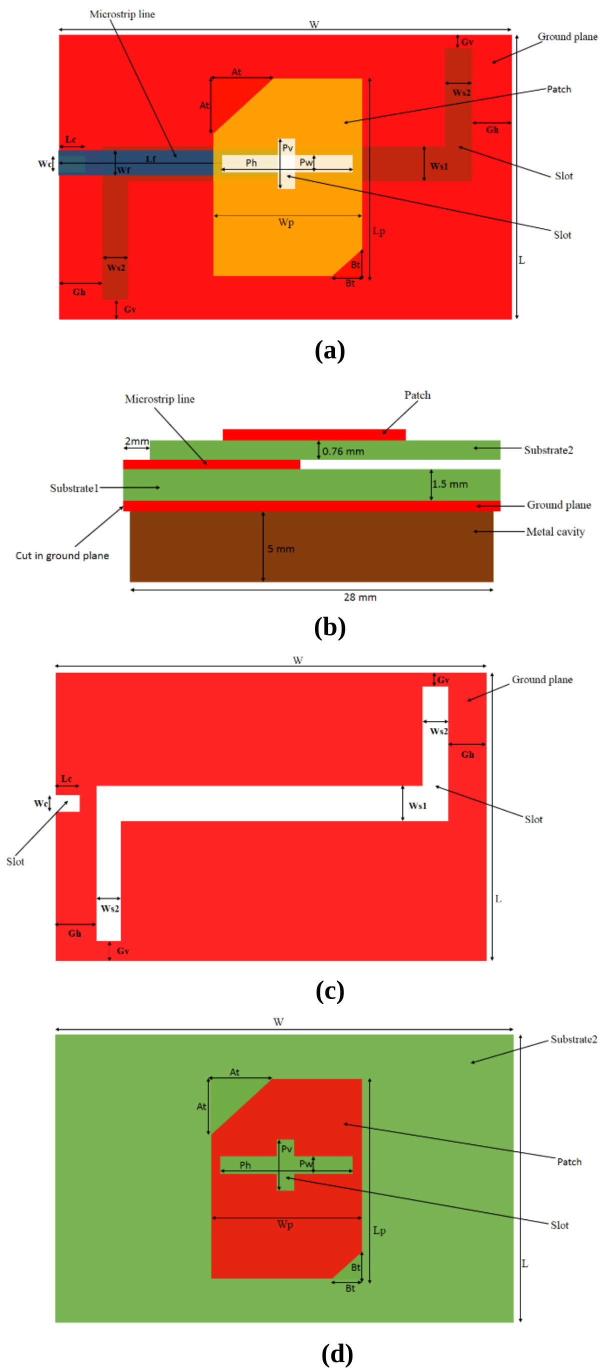


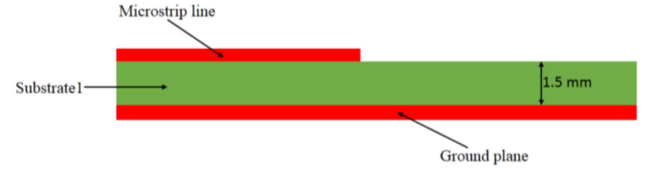

Fig.1. Geometry of the proposed antenna (a) Top view (b) Side view (c) Ground plane (d) Patch of proposed antenna

TABLE II
DIAMENSIONS OF THE PROPOSED ANTENNA PROTOTYPE

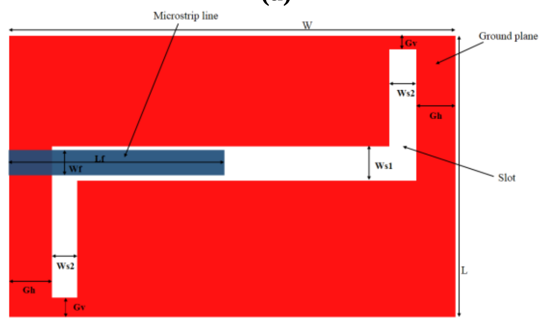
| **Parameters** | **Values (mm)** | **Parameters** | **Values (mm)** | **Parameters** | **Values (mm)** |
|---|---|---|---|---|---|
| L | 38 | Wc | 2.2 | At | 4.5 |
| W | 30 | Lf | 14.5 | Bt | 2 |
| Gh | 3 | Wf | 2.917 | Ph | 10 |
| Gv | 1 | Tsub1 | 1.5 | Pv | 4 |
| Ws1 | 4 | Tsub2 | 0.76 | Pw | 2 |
| Ws2 | 2 | Lp | 15 | Sc | 2 |
| Lc | 2 | Wp | 11 | - | - |

## III. Evolution of Proposed Antenna Geometry

In this section, proposed antenna evolution is explained. Five antennas is discussed and analyzed here, i.e. antenna1, antenna2, antenna3, antenna4, and antenna5. Antenna5 is the proposed antenna in this letter. At first stage, Antenna1 with slotted ground plane with microstrip line is designed. The side view and top view of Antenna1 are shown in Fig. 2(a) and Fig. 2(b), respectively.Antenna1 works in single band and it is linearly polarized as shown in Fig. 3 and Fig. 6. Moreover, radiation pattern of Antenna1 has large magnitude back and side lobes as seen in Fig.4. In Antenna2, substrate2 is placed above microstrip line and a rectangular patch is printed on the top surface of substrate2. The patch is unequally truncated from opposite corner and 'unequal arm cross' shape slot is created and optimized at the center of the rectangular patch as shown in Fig. 2(c) and Fig. 2(d). The S11-plot in Fig. 3 shows that Antenna2 works in multiple bands. However, it is linearly Polarized (LP). Its radiation pattern in Fig. 4 shows reduction in side lobe level, but it has a wide angular 3 dB beam width of 133.4˚. Also, the main lobe is in backward direction (towards the ground plane i.e. along –Z-axis direction). A Metal-cavity is introduced below ground in Antenna3. The side view of Antenna3 is shown in Fig. 2(e) and top view of Antenna3 is shown in Fig. 2(f). In Fig. 3, S11-plot shows that Antenna3 works in multiple bands but impedance bandwidth is not so good. More importantly, the AR drops below 3 dB in upper frequency band (10.50 to 11.26 GHz) making Antenna3 circularly polarized in nature as shown in Fig. 6. Due to metal-cavity, radiation pattern main lobe shifts toward forward direction (towards the patch i.e. along +Z-axis direction) and angular 3 dB beamwidth is also reduced to 85.7˚. Above all, main-lobe magnitude has been significantly increased along with significant reduction of side-lobe level as hsown in Fig. 4. Metal-cavity increases the gain and front-to-back ratio of the antenna and gain of the antenna increases as shown in Fig.5. The Antenna4 is shown in Fig. 2(g) and Fig. 2(h). A small slot is created on the ground plane just below the starting point of microstrip line. Due to this coupling between the microstrip line and the ground plane is reduced, which results in improvement of S-parameter. The Side view and top view of Antenna5 is shown in Fig. 2(i) and Fig. 2(j), respectively. In Antenna5 width of substrate2 is reduced by 2 mm from the microstrip line side edge. This is done basically for ease of attaching and soldering SMA connector with microstrip line. However, the S11-plot shows slight improvement in impedance bandwidth. Also, there is improvement in 3 dB AR bandwidth. Comparison of reflection coefficient of Antenna1, Antenna2, Antenna3, Antenna4 and Antenna5 is shown in figure 3. It can be seen that Antenna5 (proposed antenna) gives better result than other antennas. Comparison of radiation pattern of various evolving step antennas is shown in Fig. 4. It is seen that radiation pattern of Antenna5 has directive pattern with angular 3 dB beam-width of 85.7°. Gain comparison of Antenna1, Antenna2, Antenna3, Antenna4, and Antenna5 is given in Fig. 5. It is observed that peak gain is better in Antenna5. Whereas, Fig. 6 gives comparison of axial-ratio of Antenna1, Antenna2, Antenna3, Antenna4, and Antenna5. It is seen that Antenna5 gives best axial-ratio with peak point value of 0.89 dB at 11.2 GHz. Thus we can say that Antenna5 is the final optimized antenna for our work.




(a)

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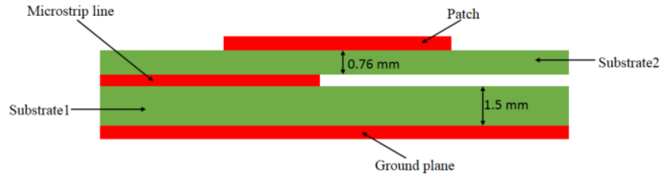
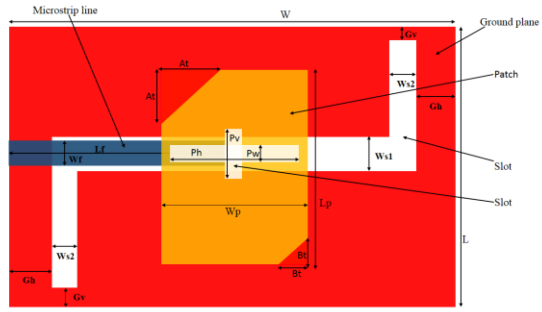



(c)

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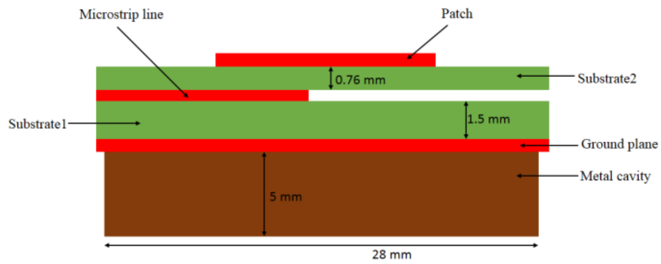
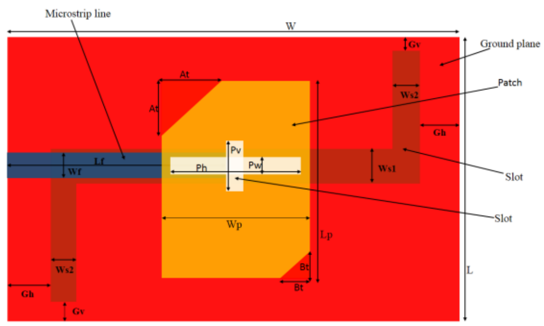



(e)




(f)

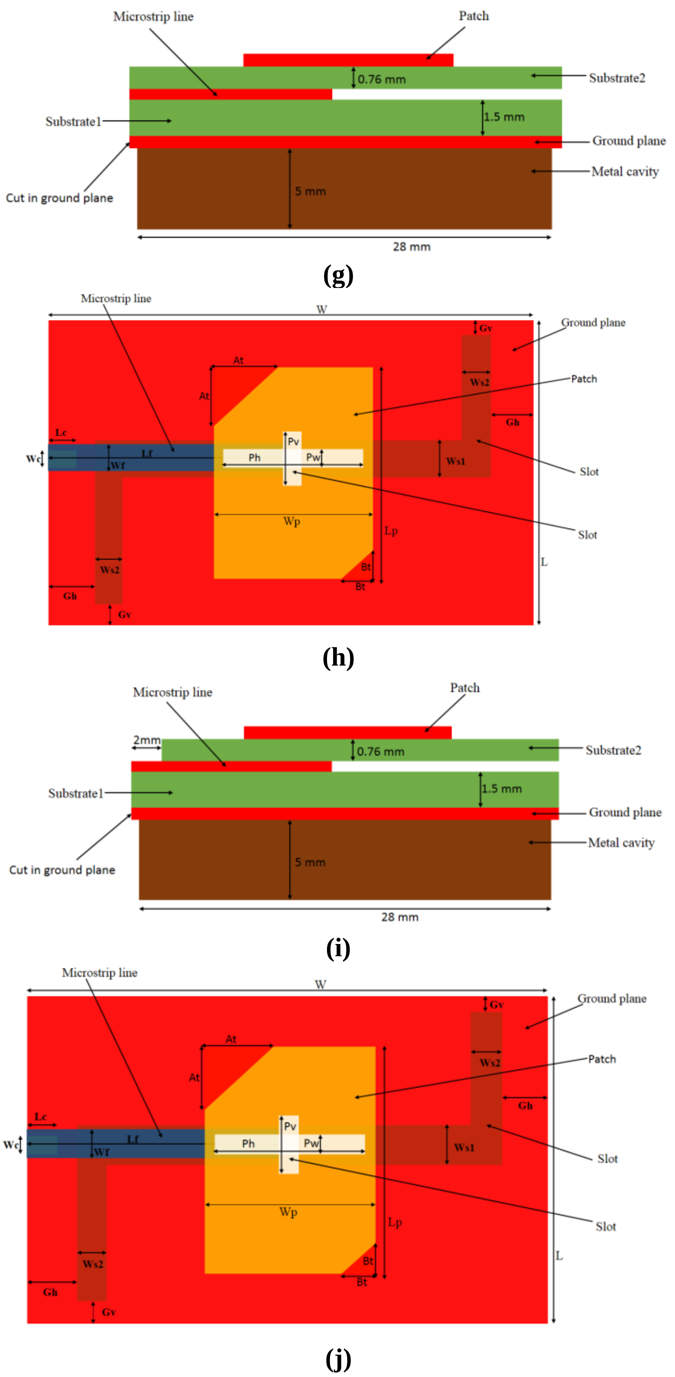



Fig. 2. Evolution of the proposed antenna (a) side view of Antenna1 (b) top view of Antenna1 (c) side view of Antenna2 (d) top view of Antenna2 (e) side view of Antenna3 (f) top view of Antenna3 (g) side view of Antenna4 (h) top view of Antenna4 (i) side view of Antenna5 (j) top view of Antenna5

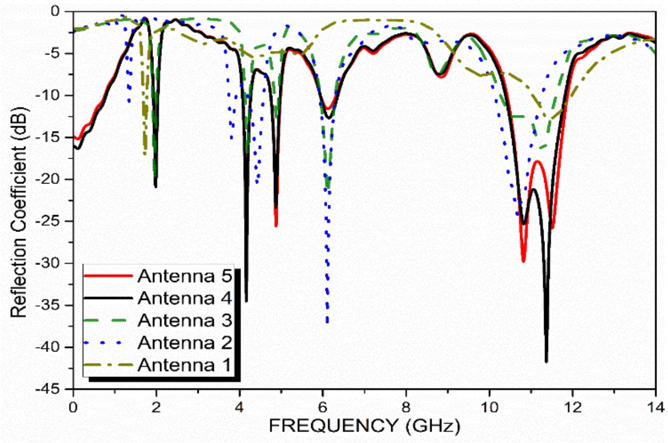



Fig.3. Comparison of reflection coefficient of Antenna 1, Antenna2, Antenna3, Antenna4 and Antenna5

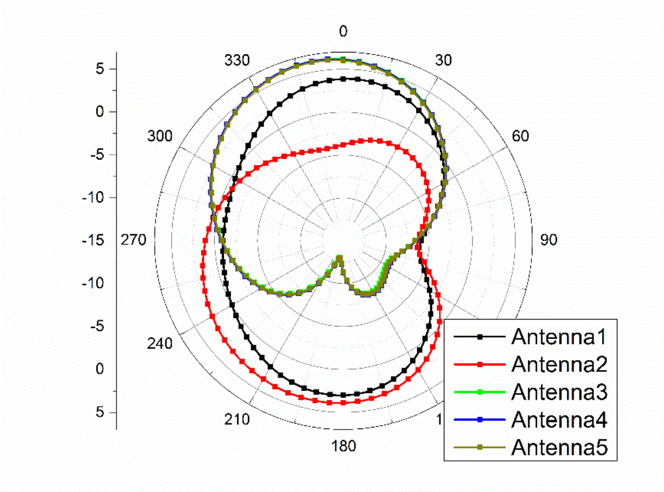



Fig.4. Comparison of radiation patterns of Antenna 1, Antenna2, Antenna3, Antenna4 and Antenna5

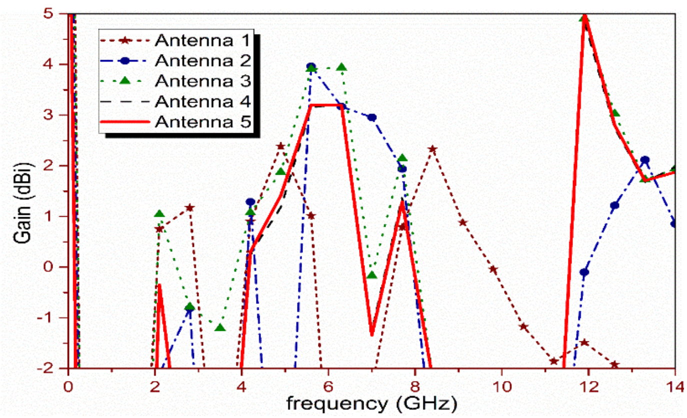



Fig.5. Comparison of gain of Antenna 1, Antenna2, Antenna3, Antenna4 and Antenna5

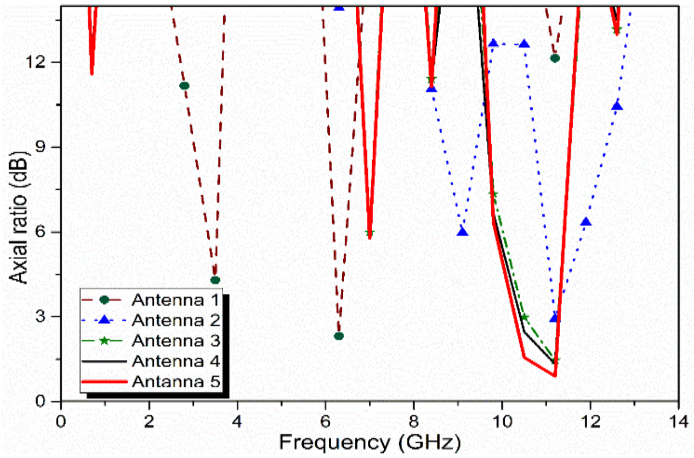



Fig.6. Comparison of axial ratio of Antenna 1, Antenna2, Antenna3, Antenna4 and Antenna5

## IV. Result and Discussion

The simulated and measured results of the proposed antenna are presented in this section. The antennas were simulated by using 'CST Studio Suite 2016' software. The proposed antenna is fabricated and measured using Agilent's Vector Network Analyzer. The gain, AR, and radiation pattern measurement have been carried out inside the anechoic chamber. A good agreement between simulated and measured results is achieved. The prototype of the antenna is shown in Fig. 7.

**Fig. 7: Photograph of the fabricated antenna**

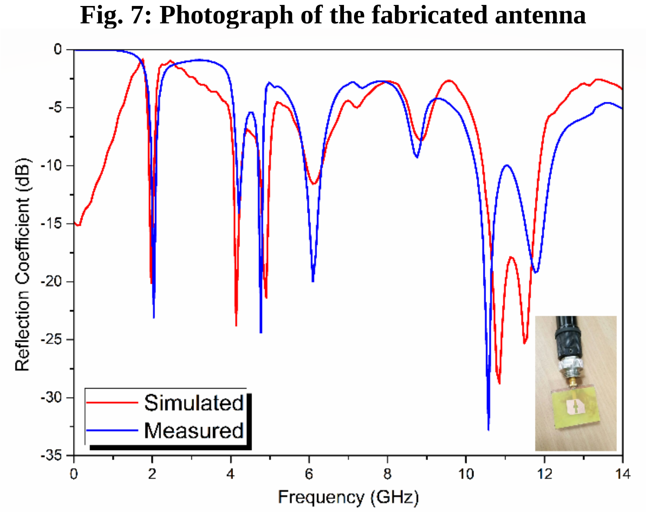



Fig. 8. Measured S-parameter characteristics ($S_{11}$) of the proposed antenna (inset photograph of the measurement)

Comparison of simulated and measured reflection coefficient (S11-plot) is shown in Fig. 8. It can be seen from the S11 plot that the proposed antenna is working in multiple frequency bands (four bands). The bands are FB1 (10.426-11.874 GHz), FB2 (4.072-4.268 GHz), FB3 (4.752-4.980 GHz), and FB4 (1.929-2.036 GHz). The proposed antenna has obtained bandwidth of 12.98% (1.448 GHz), 4.7% (0.196 GHz), 4.69% (0.228 GHz), and 5.39% (0.107 GHz) at FB1, FB2, FB3, and FB4 bands respectively. The center frequencies are 11.15 GHz, 4.17 GHz, 4.87 GHz, and 1.98 GHz for bands FB1, FB2, FB3, and FB4 respectively. The measured results are nearly in good agreement with the simulated data.

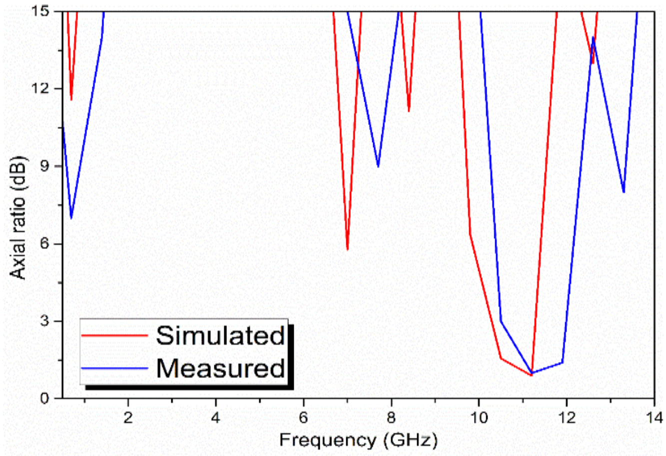



Fig. 9. Simulated and measured axial ratio of proposed antenna

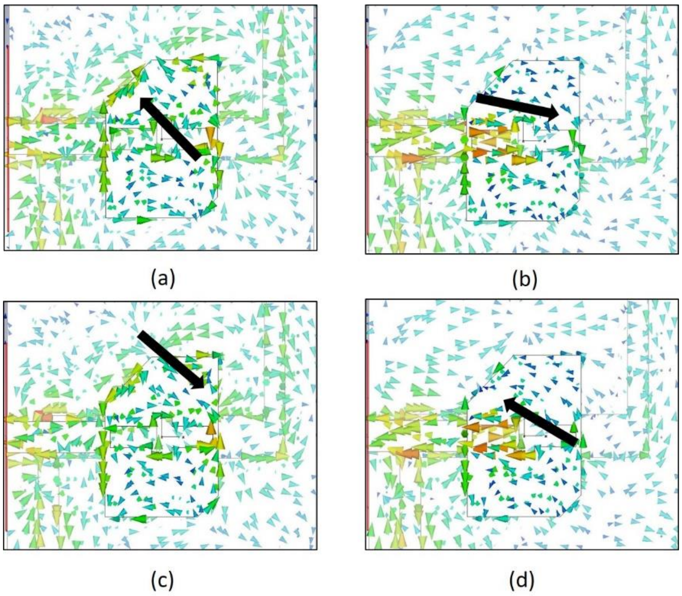



Fig. 10. Surface current distribution of the antenna with phase angle (a) 0° (b) 90° (c) 180° (d) 270° at 11.2 GHz

The simulated and measured AR (axial ratio) of the proposed antenna is shown in Fig. 9. The 3 dB ARBW is found to be 1 GHz (from 10.284 to 11.285 GHz). The measured axial-ratio is slightly shifted towards higher frequency band, but peak point of axial-ratio is same (at 11.2 GHz) with value of 0.89 dB. Fig. 10, shows surface current distribution of the proposed antenna at 11.2 GHz and at different phase angles. The sense of surface current is clockwise, thus the proposed antenna is left-hand circularly polarized (LHCP) in the +Z-direction. Fig.

11 shows simulated and measured gain plot of the proposed antenna. It can be seen that gain is positive from 4.1 GHz to 6.8 GHz, and from 11.56 to 11.87 GHz. The peak gain is 4.6 dBi at 11.87 GHz. Peak gain in frequency bands FB1, FB2, FB3, and FB4 are 4.60 dBi, 0.43 dBi, 1.65 dBi, and -0.50 dBi respectively. Fig. 12 shows simulated radiation patterns of the proposed antenna at 1.98 GHz and 4.2 GHz. The simulated and measured radiation pattern of antenna at 4.87 GHz is shown in Fig. 13. It can be seen that the antenna is directive in nature and radiates in forward direction (along +Z-axis direction). Proposed antenna performance parameters are summarized in Table III.

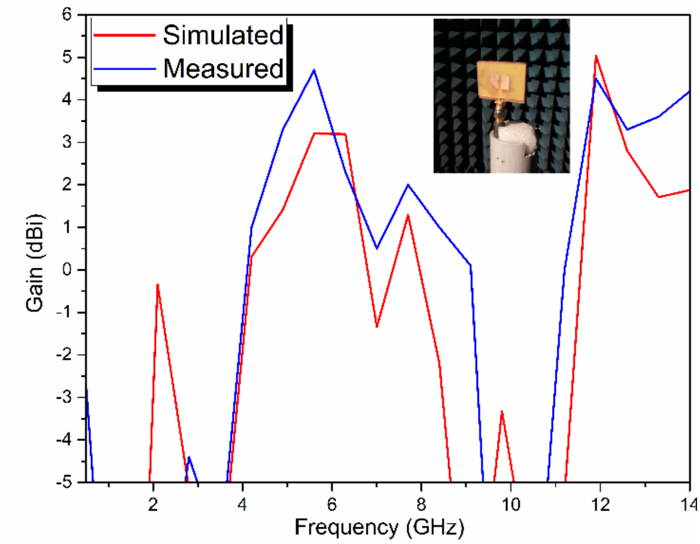
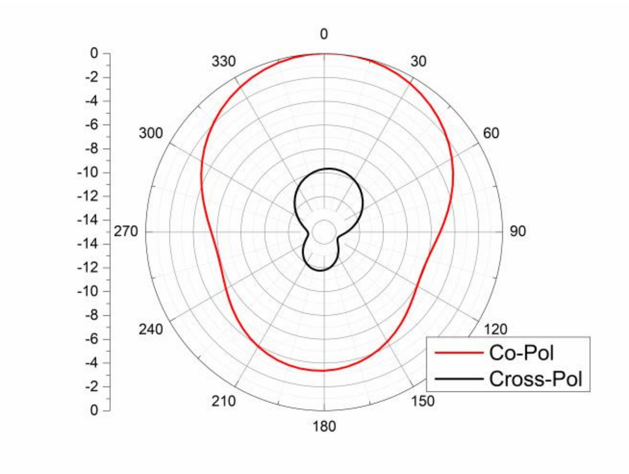
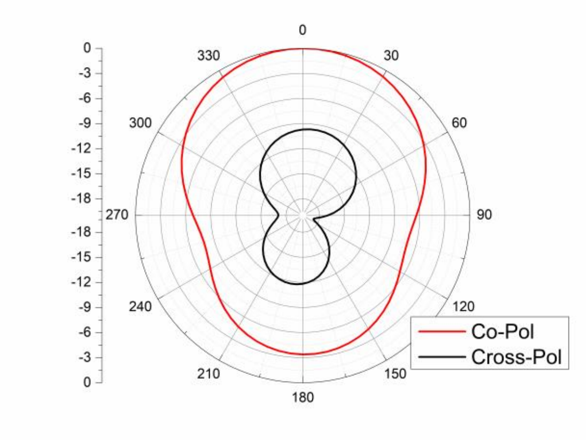



Fig. 11. Simulated and measured gain of proposed antenna (inset photograph of the anechoic chamber)




**(a)**

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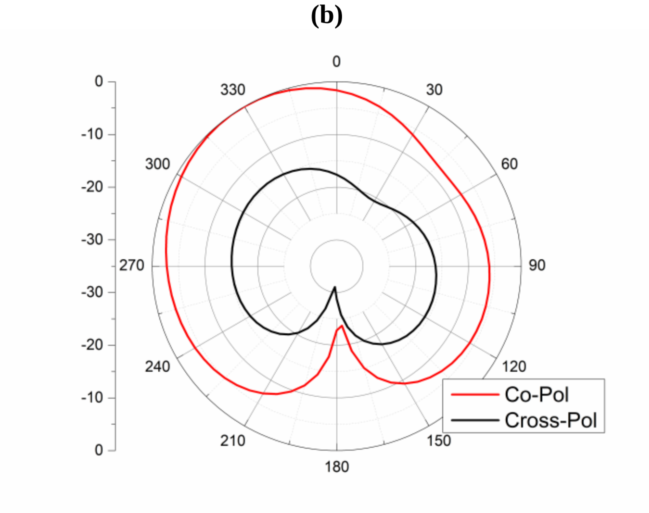


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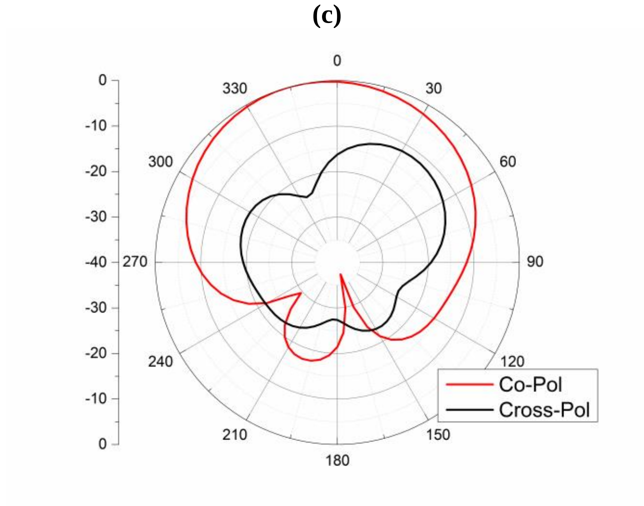
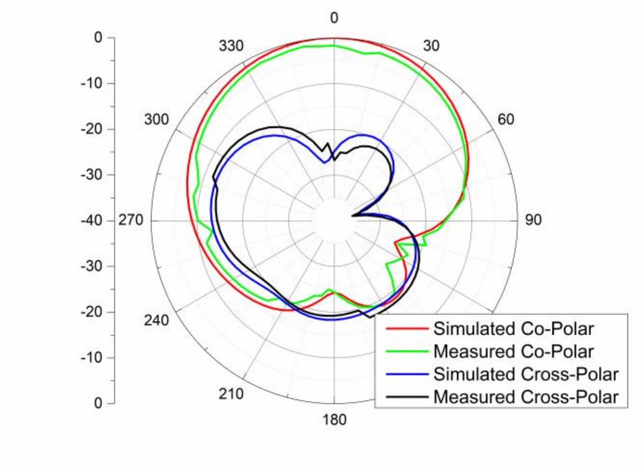
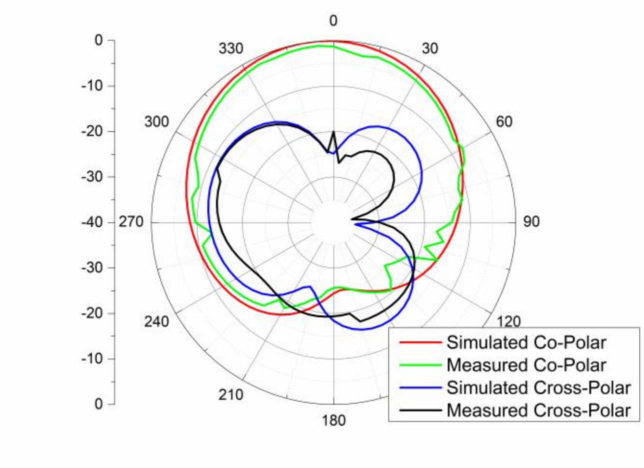



**(d)**

Fig. 12. Simulated and normalized radiation patterns of the proposed antenna in (a) xz plane (b) yz plane at 1.98 GHz, (c) xz plane (d) yz plane at 4.2 GHz




**(a)**




**(b)**

Fig. 13: Simulated and measured normalized radiation patterns of the proposed antenna in (a) xz plane (b) yz plane at 4.87 GHz.

TABLE III
ANTENNA PERFORMANCE PARAMETERS

| Parameters | FB1 | FB2 | FB3 | FB4 |
|---|---|---|---|---|
| Frequency (GHz) | 10.426-11.874 | 4.072-4.268 | 4.752-4.980 | 1.929-2.036 |
| -10 dB impedance bandwidth | 12.98% | 4.70% | 4.69% | 5.39% |
| Polarization | Circular | Linear | Linear | Linear |
| Peak Gain (dBi) | 4.60 | 0.43 | 1.65 | -0.50 |
| 3 dB ARBW | 9.23% (1 GHz) | - | - | - |

## V. CONCLUSION

A novel and compact multiband dual polarized antenna is presented in this work. The proposed antenna works in three frequency bands for linear polarization (LP) and at one frequency band for circular polarization (CP). The proposed antenna has S11 ≤ -10 dB impedance bandwidth of 1.448 GHz (from 10.426 to 11.874 GHz), 228.3 MHz (from 4.752 to 4.9803 GHz), 196 MHz (from 4.072 to 4.268 GHz), and 106.9 MHz (from 1.929 to 2.036 GHz). It also has 3 dB ARBW of 996 MHz (from 10.289 to 11.285 GHz). The simulated and measured results are well in accordance with each other. The proposed antenna is compact in size and has applications in satellite communication, aircraft surveillance and maritime navigation.

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