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A Dual-Band Antenna With Dual-Circular Polarization for Nanosatellite Payload Application

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ABSTRACT A Compact dual-band circular polarized antenna is proposed for a small satellite payload communication system. The antenna consists of a pentagonal radiator and a stacked rectangular parasitic element to achieve lower and higher axial ratio, respectively. The antenna exhibits two −10 dB impedance bandwidth of 380 MHz (2.44–2.82 GHz) and 770 MHz (3.05–3.83 GHz) with a compact size of $0.33\lambda \times 0.33\lambda \times 0.03\lambda$ (with respect to lower end frequency). Average antenna peak gain of nearly 4.4 dB at lower band and 6.5 dB at higher band has been achieved with directional radiation patterns. The antenna performance has been investigated using 1U nanosatellite structure to realize the operation in a real-time environment.

INDEX TERMS Antenna, dual-band, dual-CP, nanosatellite, payload communication.

I. INTRODUCTION

Every year numerous short-term payloads are launched into space for several purposes such as earth observation, communications, military surveillance and intelligence functions. Nanosatellites or CubeSats come into play to launch the short-term payloads with reduced cost, size and building time. These satellites are in form of unit size of 10 cm × 10 cm × 10 cm and could consist of multiple units. So, it is expected and considered that these satellites operate and communicate at very low power levels near to few watts with high gain effective antenna [1]. Antenna is a key element for remote sensing, establishing communication link between satellite and earth or satellite to satellite. The antenna size and performance proportionality relation compel antenna researchers to compromise antenna performance for compliance with CubeSat standard. However, multiple frequency bands with good gain and broad bandwidth are highly desired to enhance the wireless communication capacity. Moreover, CP antenna facilities antenna orientation, mobility and reduce multipath effects [2]. Circular polarized (CP) antenna is also desired to increase communication reliability.

During the past decade, several types of research have been performed on dual-circular polarized for multiband satellite applications [3]–[5]. However, in context of nanosatellite with limited space, multiband circular polarized antenna with compact and simple structure is highly desired [6]. Considering these constrains, several techniques have been adopted to achieve dual circular polarization like stacked configuration [7], [8], alternative feeding [9], dual port [4], etc.

In [10], dual-feed multi-layered stacked dual CP antenna was proposed for S- and C-band application, but the proposed multiple layers and feeding line fabrication make the antenna complex and expensive. To avoid dual feeding technique, a single feed stacked antenna was proposed in [5], the problem almost remains same due to use of multiple shorting vias. Another approach of achieving dual CP is shared feed array [3], but the antenna size increased with array number.

In this paper, a dual band dual polarized antenna is proposed. The antenna has been fabricated and investigated for nanosatellite payload communication application. RHCP and LHCP are achieved using two-layered structure and dual port technique. Though the antenna utilized dual port configuration with stack structure the efficiency can be reduced. To mintage this limitation a parasitic rectangular patch was inserted between the substrate. The measured efficiency was achieved about 55% and 80% at lower and higher operating band respectively.

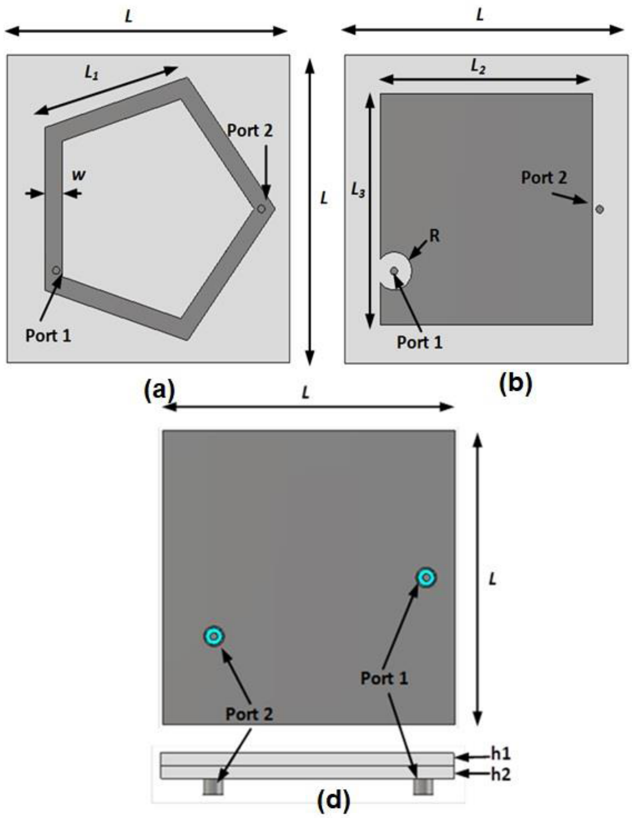


FIGURE 1. Geometric layout of the proposed dual circular polarized antenna- (a). top layer, (b). middle layer and (c). bottom layer.

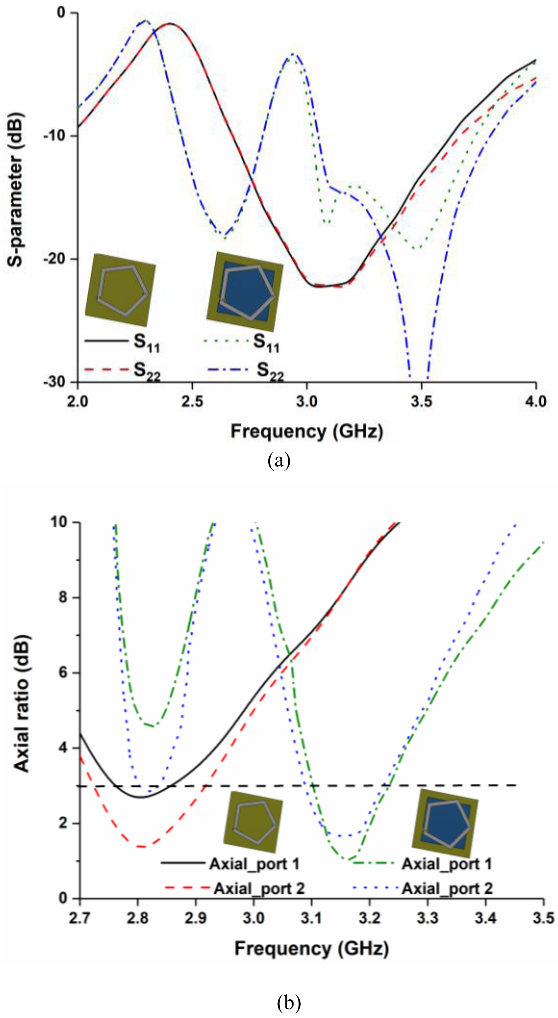


FIGURE 2. Simulated S-parameter and axial ratio with and without parasitic layer.

II. DUAL CP-ANTENNA DESIGN

The proposed antenna has been designed based upon the 1-Unit CubeSat standard, like space, weight and power. Moreover, the key consideration was stable dual-CP over operating bandwidth and simple design structure. Therefore, dual feeds technique has been adopted to achieve CP characteristics and dual-polarization. The design layout of the antenna is illustrated in Figure 1. The antenna consists of two layered of Rogers 5880 substrate material having a thickness of 1.575 mm. The top layer is pentagonal shaped radiating patch, which is formed from a five-segmented circular shaped patch having outer radius R_1 and inner radius R_2. The middle layer is a parasitic rectangular patch for enhancing the operating bandwidth and isolated from the feed with a hole (R). the bottom layer is ground plane with the same size of the substrate material. The fundamental resonant frequency was calculated comparing with conventional annular-ring slot antennas [11], where the wavelength in the ring slot approximately corresponds to the mean circumference of the ring slot.

$$f_0 = \frac{c\varepsilon}{2\pi R_2} \tag{1}$$

$$\varepsilon = \sqrt{\frac{1+\varepsilon_r}{2\varepsilon_r}} \tag{2}$$

Where c is the velocity of light, ε_r is permittivity of the substrate material.

The pentagon radiator has been fed using two orthogonal coaxial feeds to produce circular polarization and the position were chosen by trial and error methods based on desired operating frequency. The parasitic middle layer helps to achieve dual operating band with 3dB axial ratio [4], presented in Fig. 3. It is seen from Fig. 3 that the middle parasitic layer perturbs the fundamental operating bandwidth into two desired operating bands as well as split the AR bandwidth into dual CP bands. The operating band can be shifted by manipulating the middle layer.

Moreover, the antenna working mode can be explained by the surface current distribution at different time instants. When the port is exciting the antenna shows 3dB axial ratio from 3.1 to 3.23 GHz and it can be seen from the surface current at 3.15 GHz that the majority current flow through the middle rectangular parasitic patch, shown in Fig. 3. Furthermore, it can be observed that at $\omega t = 0°$ the predominant current is oriented towards −y-axis, while +x and −x-axis

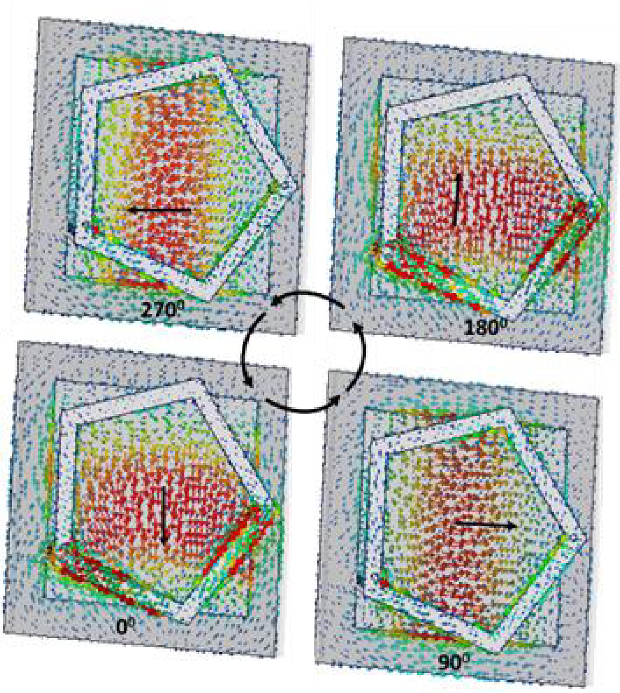


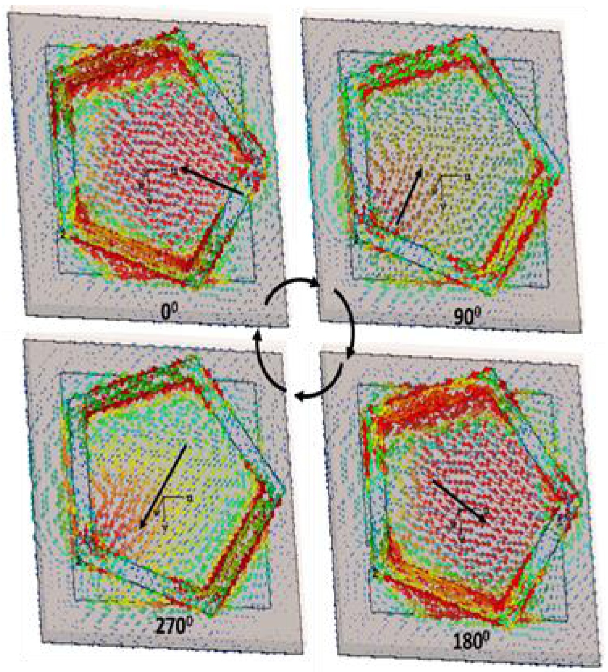
FIGURE 3. Surface current distribution when exciting port 1 (RHCP).

TABLE 1. Antenna design parameters.

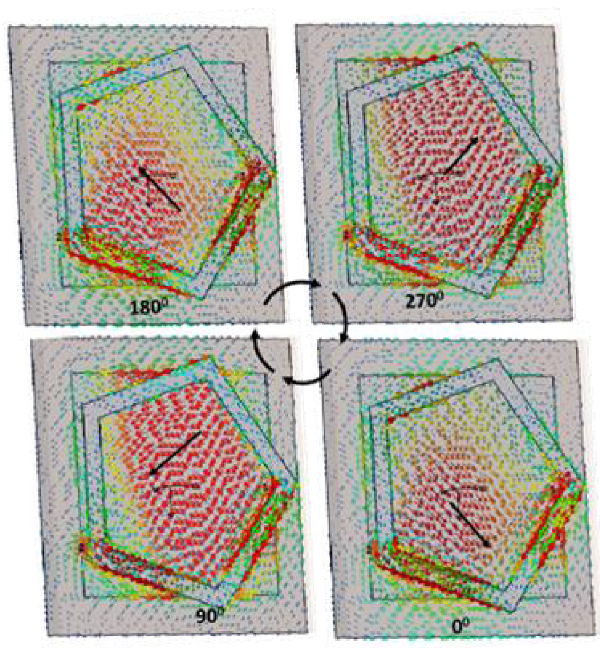
Parameter	Value (mm)
L	40
L_1	21.16
L_2	30
L_3	22.65
h_1	1.575
h_2	1.575
w	2.43
R	2.5
R_1	20
R_2	15

direction is nullified. After that when time instant of $\omega t = 90°$, the majority electric current in the rectangular patch is oriented towards +x axis and the total current in +y and −y-axis direction is cancelled accordingly. Similarly, the current direction at $\omega t = 180°$ and 270° is just opposite to 0° and 90°, respectively. So, the vector sum of majority current travels in the anti-clockwise direction and results in RHCP wave propagation.

Additionally, when the port 2 is excited as feed and port 1 is terminated with 50Ω, the antenna achieved two 3dB AR bands. One is 2.80 to 2.83 MHz and another one is 3.08 to 3.22 MHz. In Fig. 4, the current distribution at 2.81 GHz and 3.15 GHz for port 2 are depicted. According to Fig. 4, with respect to the time phase, the vector sum of the majority current for port 2 rotates in the clockwise direction and results LHCP wave propagation. Therefore, the proposed antenna is capable to generate dual-CP simultaneously. The optimized design parameter of the proposed antenna is tabulated in Table 1.



at 2.81 GHz

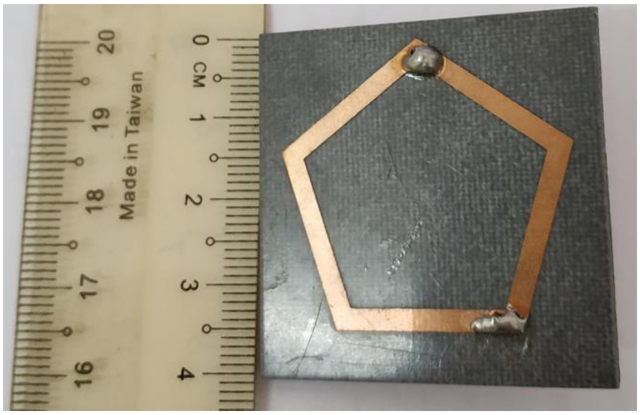


at 3.15 GHz

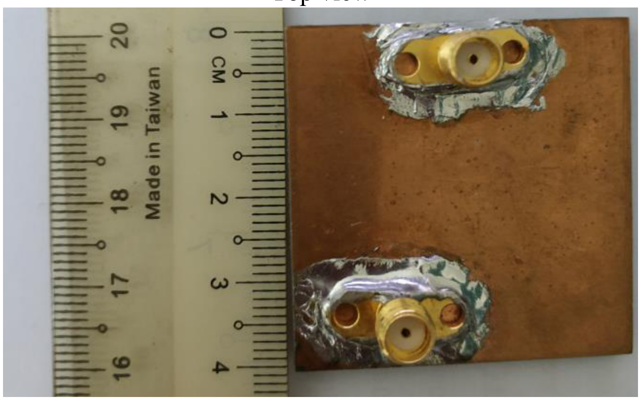
FIGURE 4. Surface current distribution when exciting port 2 (LHCP): (a) at 2.81 GHz and (b) at 3.15 GHz.

III. ANTENNA RESULT AND DISCUSSION

The proposed antenna has been fabricated according to the listed parameter in Table 1. The S-parameter and farfield characteristics of the fabricated prototype have been



Top view



Bottom view

FIGURE 5. Fabricated prototype of the dual cp antenna.

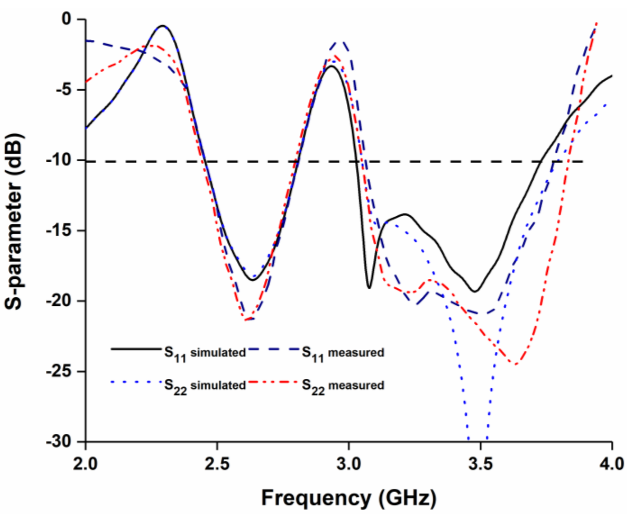


FIGURE 6. Simulated and measured reflection coefficient of the dual cp antenna.

measured using Performance network analyzer (PNA) Agilent N5227A and Satimo nearfield measurement system, respectively. The measured reflection coefficient for both ports has been measured, shown in Fig. 6. From Fig. 6, it is depicted that the operating bandwidths of the proposed

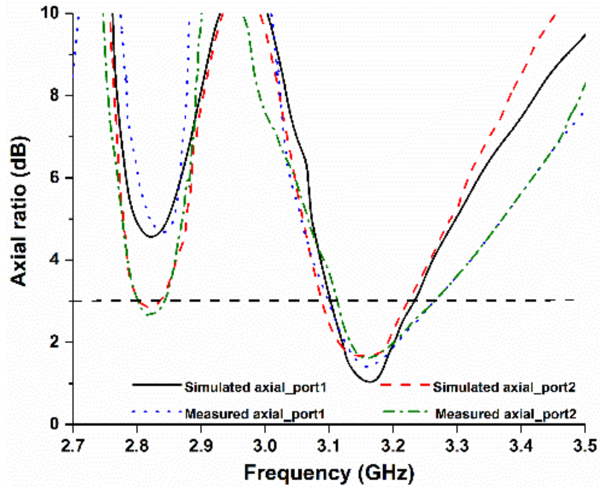
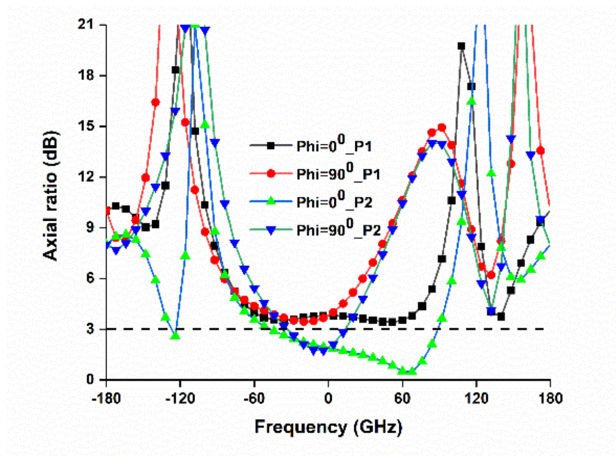
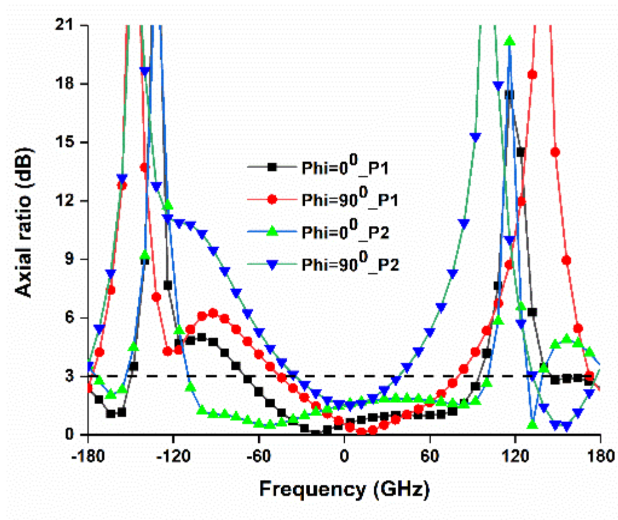


FIGURE 7. Simulated and measured axial ratio of the proposed dual CP antenna.



at 2.81 GHz



at 3.15 GHz

FIGURE 8. AR beamwidth of the proposed antenna.

CP antenna are 380 MHz (2.44 to 2.82 GHz) and 720 MHz (3.06 to 3.77 GHz) for port 1, and 380 MHz (2.44 to 2.82 GHz) and 770 MHz (3.05 to 3.83 GHz) for

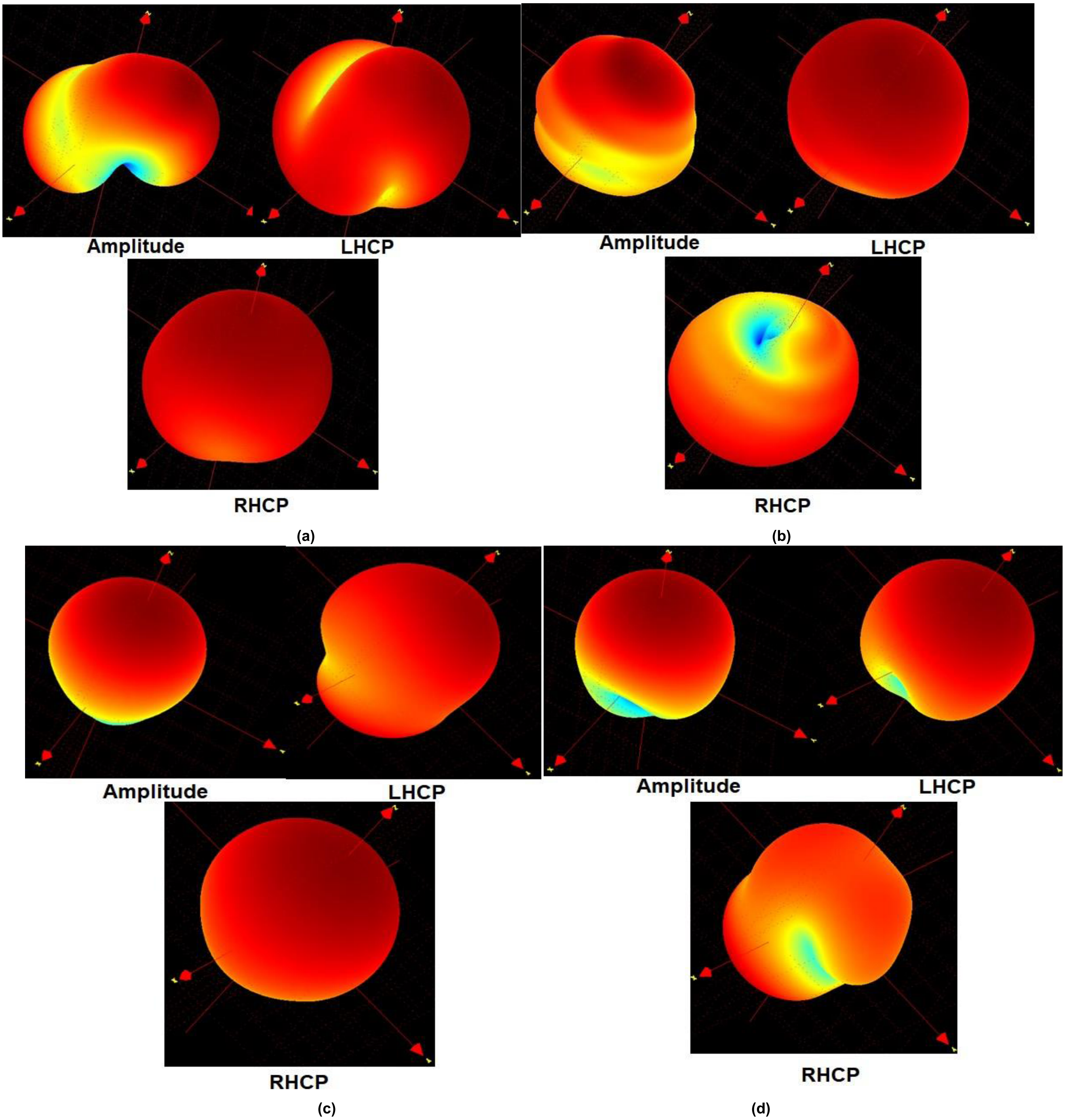


FIGURE 9. Measure 3D-radiation patter (a) at 2.81 GHz for port 1, (b) at 2.81 GHz for port 2, (c) at 3.15 GHz for port 1, and (d) at 3.15 GHz for port 2.

port 2. The accomplished average port isolation is about 5.8 dB and 5dB throughout the lower and upper the operating region, respectively. The good consistency of the simulated and measured results validates the fabricated antenna. Fig. 7 shows the simulated and measured axial ratio of the developed antenna. The antenna achieved single 3dB AR band from 3.10 to 3.23 GHz (FBW=4.1%) for port 1 and two CP bands for port 2, one is 2.80 to 2.84 GHz (FBW=1.42%) and other is 3.11-3.26 GHz (FBW=4.70). A slight discrepancy between simulated and measured result is observed, which may be attributed to the fabrication and measurement tolerances. So, the antenna can be used for dual band dual CP polarization simultaneously.

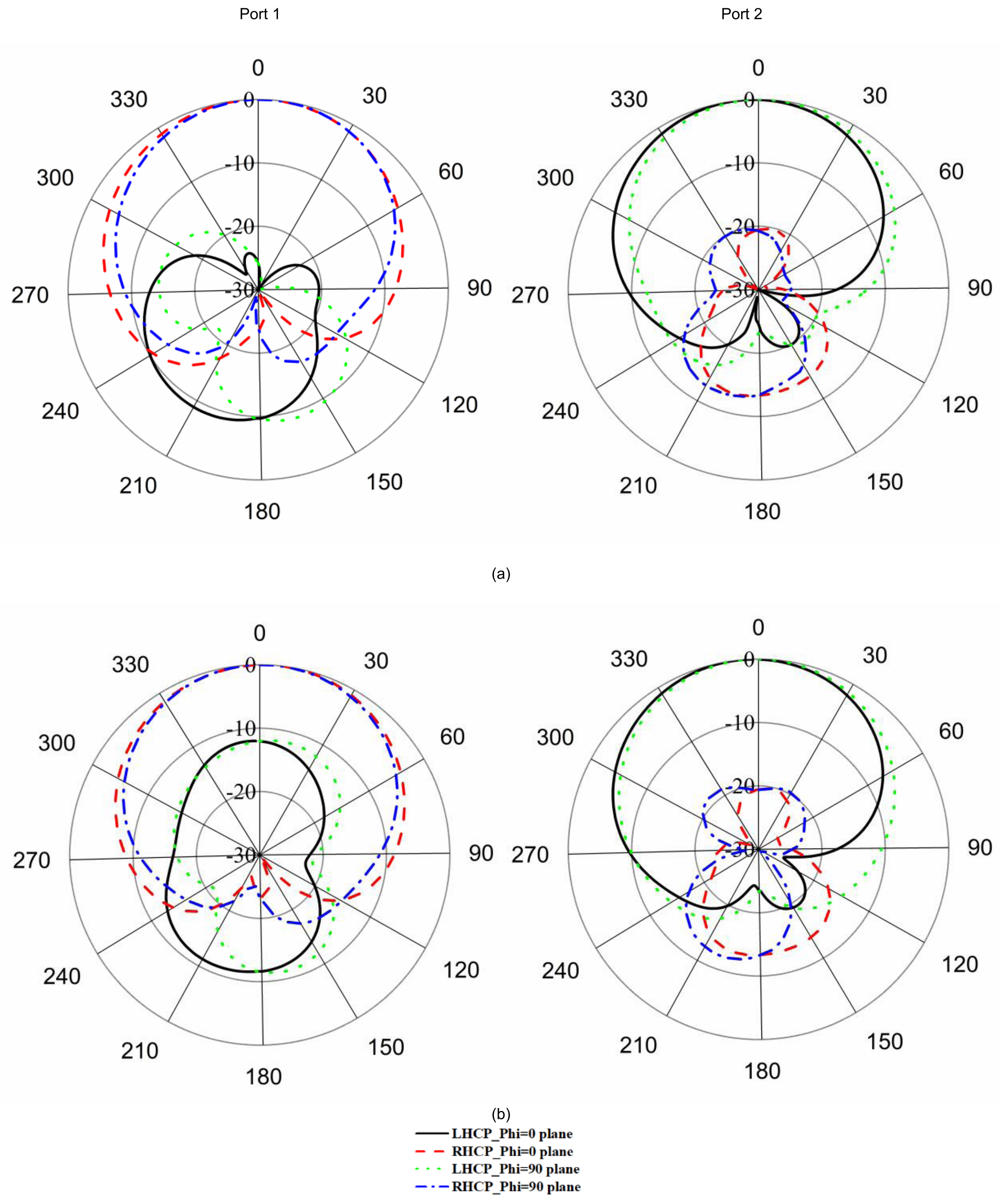


FIGURE 10. **Measure 2D-radiation patter (a) 2.81 GHz and (b) at 3.15 GHz.**

The AR beamwidth at 2.81 GHz and 3.15 GHz are illustrated in Fig. 8, where the antenna achieved wide 3dB axial beamwidth for both ports and listed in Table 2. As to establish sufficient satellite communication link the antenna should an axial ratio beamwidth more than 120° [12], the proposed dual port CP antenna is very prominent for satellite communication.

The 3-D radiation pattern of the proposed CP antenna for both ports is illustrated in Fig. 9. It is seen from Fig. 9 that when port 1 is excited, RHCP is the principle polarization, whereas LHCP corresponds to the pattern excited by port-2 and the corresponding 2-D patterns are depicted in Fig. 10. Simulated and measured peak gain of the proposed CP antenna in Fig. 11.

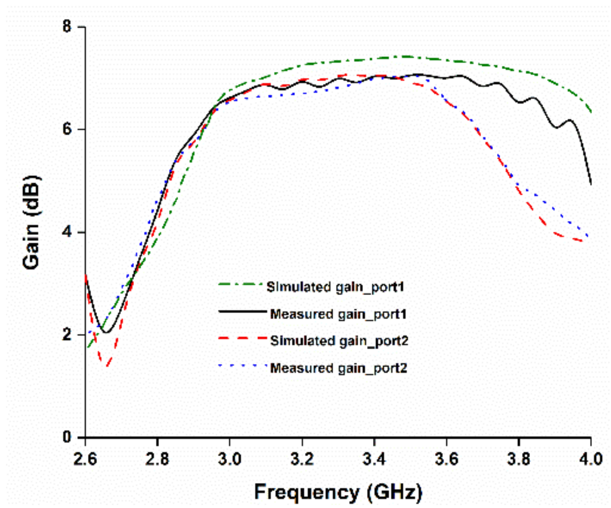
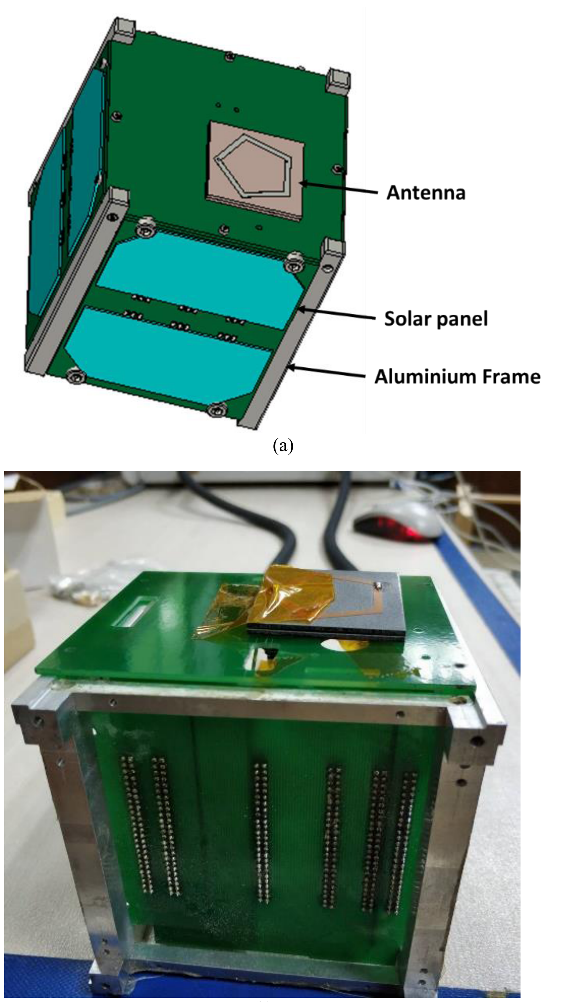


FIGURE 11. Simulated and measured peak gain of the CP antenna.



(a)

(b)

FIGURE 12. Antenna mounted with 1U nanosatellite structure.

The average peak gain at the lower operating frequency is about 4.4 dB and 6.5dB at higher frequency band.

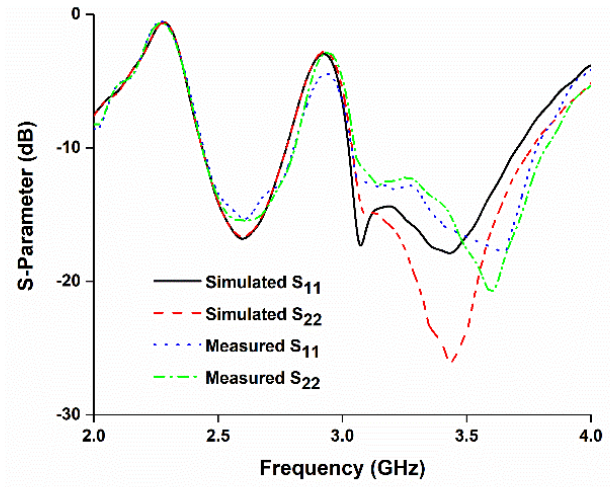
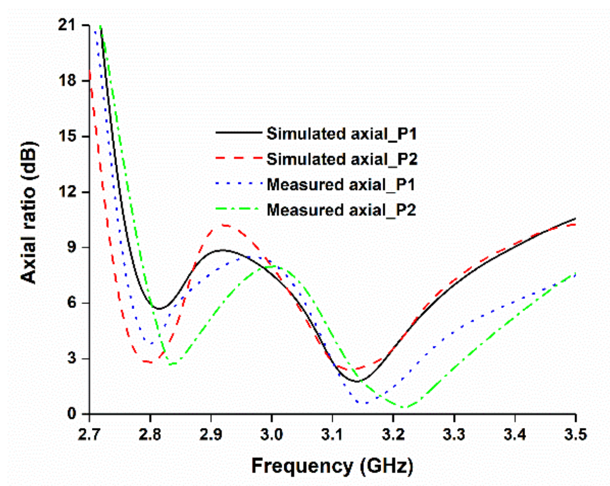


FIGURE 13. S-parameter of the proposed antenna with nanosatellite structure.



(b)

FIGURE 14. Axial ratio of the proposed antenna with nanosatellite structure.

TABLE 2. AR properties of the proposed antenna.

		Port 1	Port 2
3dB AR bandwidth	Simulated	- 3.10-3.237	2.80-2.84 3.08-3.225
	Measured	- 3.09-3.26	2.80-2.83 3.11-3.26
AR beamwidth	1.81 GHz	-	Phi=0°: -47° to 89.8° (136°) Phi=90°: -34° to 14.6° (48.6)
	3.15 GHz	Phi=0°: -69° to 96° (165°) Phi=90°: -47° to 80° (137°)	Phi=0: -180° to 102° (210°) Phi=90°: -35° to 40° (75°)

The proposed antenna performance has been investigated with 1U nanosatellite structure. The antenna reflection coefficient has been simulated and measured with nanosatellite structure. The operating bandwidth is almost identical with free space antenna through a little change in s-parameter is observed, shown in Fig. 13. The axial ration bandwidth also

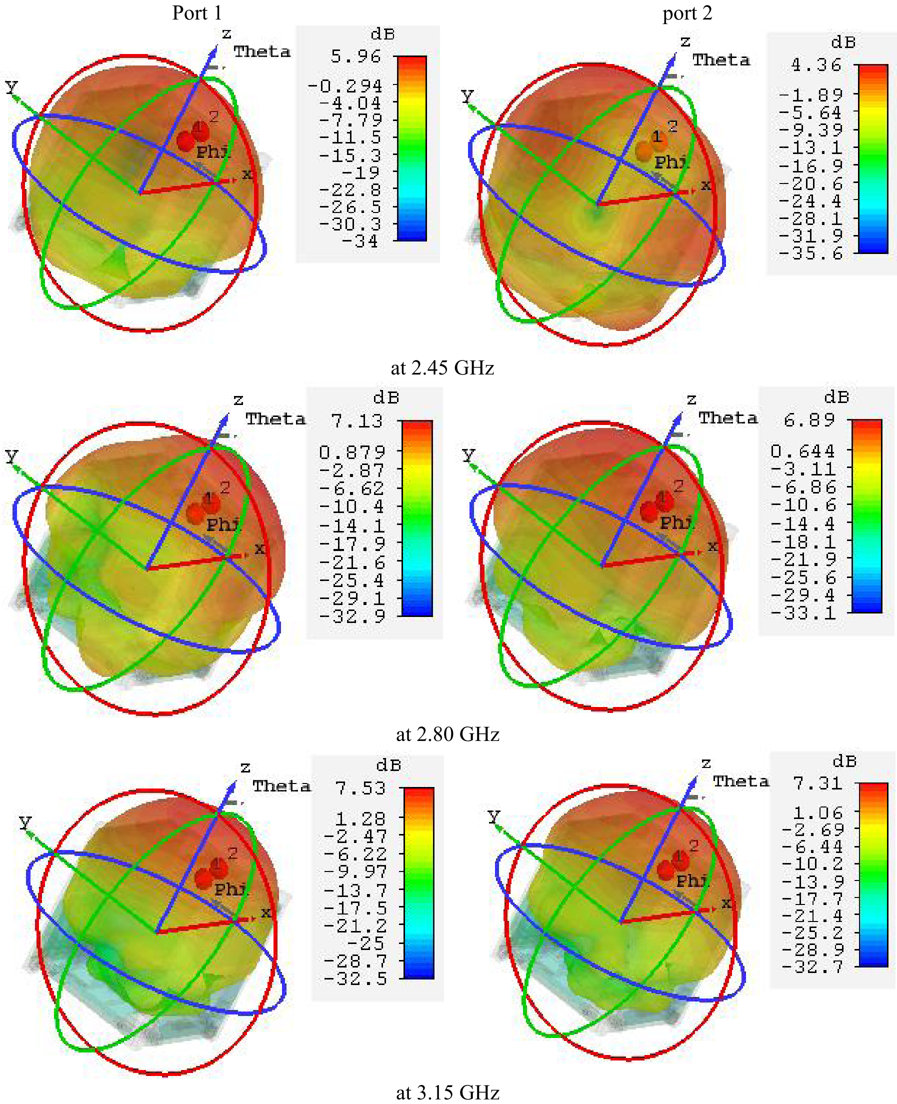


FIGURE 15. **3D-farfield radiation pattern of the CP antenna with 1U nanosatellite structure.**

remains approximately similar to free space antenna, shown in Fig. 14. However, a slight shifting is found due to proximity with 1U nanosatellite structure. Antenna farfield radiation at three different frequency 2.45 GHz, 2.81 GHz, and 3.15GHz are presented in Fig. 15. It is shown from Fig. 15 that the antenna shows consistent radiation pattern with high gain.

IV. CONCLUSION

In this paper, a dual-band CP antenna has been proposed for nanosatellite communication system that does not require deploy externally. The antenna exhibits two wide impedance bandwidths of 380 MHz and 770MHz, two 3dB AR bandwidths, high gains with compact size. The antenna prototype has also been developed and integrated with 1U nanosatellite structure. The measured antenna performance complies with the simulated result within operating frequency bands. The simulated and measured performance investigation confirm that it can be a good candidate for nanosatellite payload communication system.

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