Circularly Polarized Dual-Band Cylindrical Dielectric Resonator Antenna for Cubesat Applications

Mandovi Borthakur, Taimoor Khan and Sounik Kiran Kumar Dash
Department of Electronics and Communication Engineering, National Institute of Technology Silchar, Assam, India

Abstract

A new circularly polarized dielectric resonator antenna (DRA) is reported for dual-band operation. A 50Ω-microstrip line feed and an optimized inclined plus-shaped slot are utilized to excite the resonator at 7.4 GHz and 11.1 GHz, respectively with an axial ratio below to 3 dB. A 40^0 beamwidth gains at both the resonant frequencies are observed as > 5 dBi. The simulated and measured results are fairly matched. The performance of this antenna signifies it's suitability for Cubesat applications.

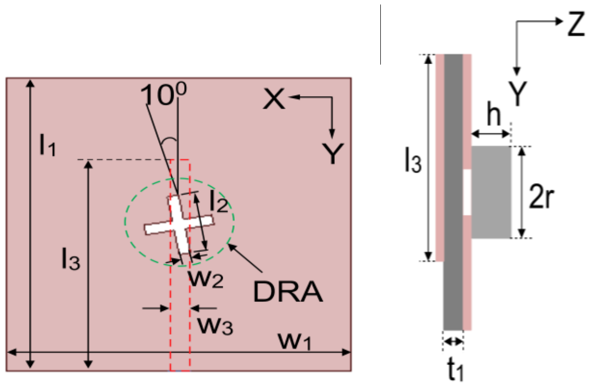
1. Introduction

The investigation on cubesat has been widely done in last two decades intending for both civil and military requirements. In 2003, the first cubesat was launched in Russia [1-2] and since then the research on cubesat development is being continuously increased because of several attractive features like lesser development time, lighter weight and lesser complex, etc. [3]. The cubesat communication is very much important in view of setting communication link between the satellite and ground station. For this purpose, the design and optimization of antenna in view of ultra-compactness is quite challenging. In addition to the compactness, it should be less complex, light weight and compactable with the cubesat form factor [4]. The literature on cubesat antennas is very much limited [5-8]. Leao et al. [5] have developed single monopole antenna operating at 146 MHz and 438 MHz. Apart from this, the printed antennas [6-7], helical antenna [8] have also been reported for the same purpose. The cubesat antennas described in [5-8] are basically metallic antennas operating ~400MHz/2.4GHz/3.0GHz, respectively. Further, these antennas are expected to be less efficient while operating at higher frequencies like 8GHz/11GHz (i.e. X-band). So to fill-up this lacuna, the dielectric resonator antenna can be considered as an alternative because of its several attractive features like wide bandwidth, high radiation efficiency, low loss as well as geometrical specifics i.e. much more design flexibility than the conventional antennas i.e. microstrip antenna, horn antenna, etc. [9], [10] which is rarely investigated for cubesat applications.

Here, in this communication, the authors have proposed an inclined plus-shaped slot fed circularly polarized cylindrical DRA resonating at 7.4 GHz and 11.1 GHz, simultaneously. The simulated axial-ratio is found to be below 3 dB at both the resonant frequencies with 5.22 dBi and 5.6 dBi peak gain, respectively. The proposed antenna configuration is shown in Section 2 followed by design flow in Section 3. Prototype measurement and conclusion are discussed in Section 4 and Section 5, respectively.

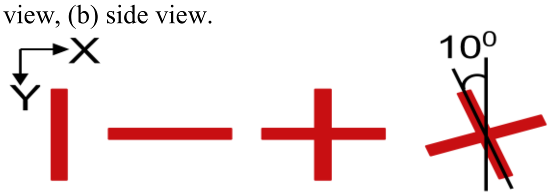
2. Proposed Antenna Design

The optimized antenna geometry is depicted in Fig. 1. A FR4 Epoxy sheet ($l_1 \times w_1 \times t_1 = 30 \times 30 \times 1.6$) mm^3 of ($\varepsilon_r = 4.4$) is used as a ground plane substrate. A 10^0 rotated (along Y-axis) plus-shaped slot ($l_2 \times w_2 = 6 \times 0.5$) mm^2 is made on the top-side with a 50Ω running microstrip feed line ($l_3 \times w_3 = 6 \times 0.5$) mm^2 on the back-side. A dielectric resonator of radius (r) = height (h) = $5mm$ is placed centrally above the plus-shaped slot. This geometry is modeled using HFSS v13.0.



(a) (b)

Figure 1. Schematic diagram of the proposed antenna; (a) top view, (b) side view.



(a) (b) (c) (d)

Figure 2. Development of the optimized slot; (a) vertical slot (Antenna #1), (b) horizontal slot (Antenna #2), (c) plus slot (Antenna #3), and (d) 10^0 rotated plus slot (Antenna #4).

3. Design Flow

From, a qualitative understanding point of view, the entire design and developments are well discussed in separate stages with the respective slot-geometries as shown in Figure 2. The resonant frequency of the antenna (as per dimensions in Section 2) can be estimated as 7.7 GHz and 11.4 GHz as per eqn. (1) and eqn. (2). This also indicates the mode of operation as $HEM_{11\delta}$ and $TM_{01\delta}$ respectively for both the resonant frequencies.

$$f_{r(HEM_{11\delta})} = \frac{c}{2\pi r} \times \frac{6.324}{\sqrt{\varepsilon_{rd}+2}} \times \left[0.27 + 0.36\left(\frac{r}{2h}\right) + 0.02\left(\frac{r}{2h}\right)^2\right] \quad (1)$$

$$f_{r(TM_{01\delta})} = \frac{c}{2\pi r} \times \frac{1}{\sqrt{\varepsilon_{rd}+2}} \times \sqrt{3.83^2 + \left(\frac{\pi r}{2h}\right)^2} \quad (2)$$

Stage 1:

The design of this proposed antenna begins with a cylindrical DRA placed above a vertical-slot [Fig. 2 (a)] made on the top- side of the ground plane and considered as Antenna #1. Here the slot doesn't allow the antenna to resonate because of heavy reflection (S11 > -5 dB) as shown in Fig. 3. Then rotating the slot by 90^0 (considered as Antenna #2), the S11 comes down ~ -20dB and the antenna yields dual-band 7.15-7.5 GHz and 10.7-11.2 GHz [Fig. 3]. The respective peak-gain at resonance 7.4 GHz and 11.1 GHz are found as 5.6 dBi and 5.4 dBi, respectively [Fig. 4]. It can be noted that these two type antennas deal with an axial-ratio more than 8 dB (results are not shown for brevity).

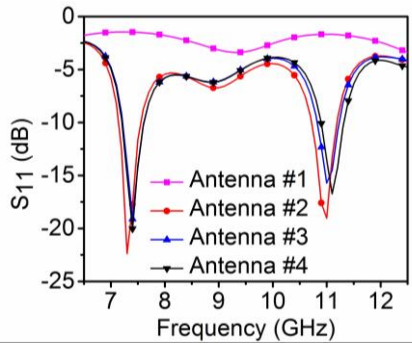


Figure 3. S_{11} comparison of all antennas.

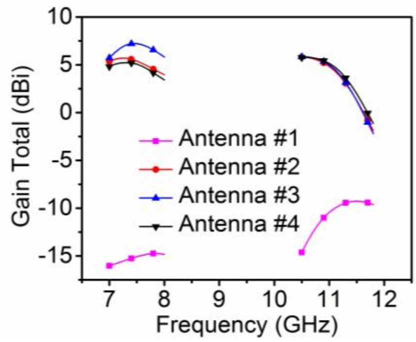


Figure 4. Gain total comparison of all antennas.

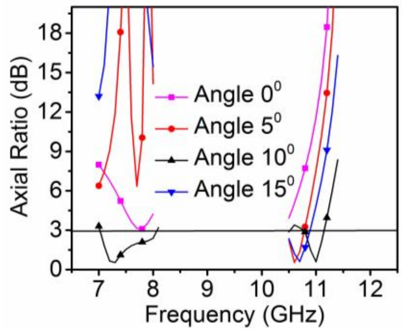
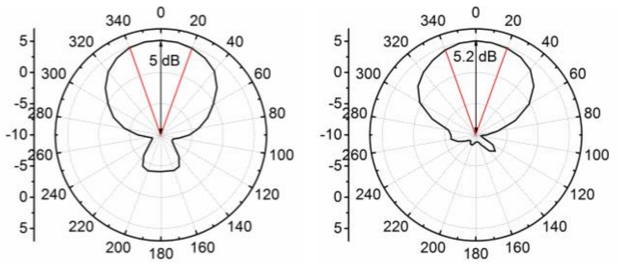


Figure 5. Axial ratio comparison of all antennas.

Stage 2:

Hence to impose circular polarization, certain changes are made on the slot type without disturbing the standard of operation. i) First both the slots (horizontal and vertical) are combined to create '+' (plus) shaped slot [Figure 2(c)]. This configuration (Antenna #3) found effective in bringing down the axial ratio near 6 dB at first and 1 dB at second resonances, with negligible effect on the resonance deep. The observed bandwidth and gain near the first resonance are found as 7.15-7.55 GHz with 7.21 dBi peak gain, respectively. Whereas near second resonance, 10.8 - 11.3 GHz with 5.5 dBi peak gain is observed. This antenna is be noted as Antenna #3. ii) Next, the plus-shaped slot is rotated. The angle of rotation of the plus- shaped slot is gradually increased from 0 degree to 15 degree (along xy-plane) in steps of 5 degrees. At each step, the axial- ratio result was verified [Fig. 5]. At each angle of rotation, the authors have observed circular polarization near angle 10 degree. This configuration is considered as Antenna #4. It can be noted that, though this configuration yields circular polarization, the gain at the lower resonance drops to 5.22 dBi, while at upper resonance it is constant i.e. ~ 5.5 dBi [Figure 4]. The gain radiation pattern are depicted in Figure 6. At 7.4 GHz this antenna deals with 5 dB gain with 40 degree beamwidth whereas it is observed as 5.2 dB at 11.1 GHz. Finally, this Antenna #4 is considered as the optimized antenna.



(a) (b)

Figure 6. Gain total radiation pattern of Antenna #4 in E-plane; (a) 7.4 GHz, (b) 11.1 GHz.

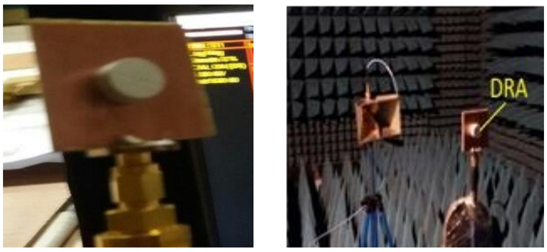
4. Measurement and Validation

The fabricated prototype is depicted in Figure 7. The required dielectric resonator of optimized dimension is tailored out from an Eccostock HiK dielectric rod of εrd= 10 and loss tangent = 0.002. Photolithography etching process is applied to create appropriate slot and feed at respective surfaces of the FR4 sheet (εr = 4.4 and loss tangent = 0.04). The cylindrical DR is placed over the slot using adhesive gum. An automatic anechoic chamber and Network analyzer are used for characterization of the model. The comparison of simulated and measured S11 [Figure 8] and axial ratio [Figure 9] shows little frequency shifting in the upper resonance while good matching at the lower resonance. Similarly the measured gain total is also well agreed with its simulated counterpart [Figure 10]. The simulated radiation patterns at 7.4 GHz and 11.1 GHz are shown in Figure 11. A comparison of simulated and measured performances are shown in Table 1. The observed variation between the simulated and measured results are because of the unconsidered deposited soldering material and invisible air gap between the DR and the ground plane sheet.

Table 1. Comparison of All Three Antennas

Antenna		Bandwidth (GHz)	Gain (dBi)	AR (dB)
#2		(7.15-7.5), (10.7-11.2)	5.6, 5.4	NA
#3		(7.15-7.55), (10.8-11.3)	7.21, 5.59	NA
#4	Sim.	(7.15-7.55), (10.9-11.35)	5.22, 5.6	0.8, 0.5
	Mea.	(7.16-7.7), (9.8-10.6)	5.2, 4.8	2.1, 2.4

*Antenna #1 is not considered as it was not resonating at all.



(a) (b)

Figure 7. Fabricated prototype; (a) connected with the VNA, (b) anechoic chamber set up.

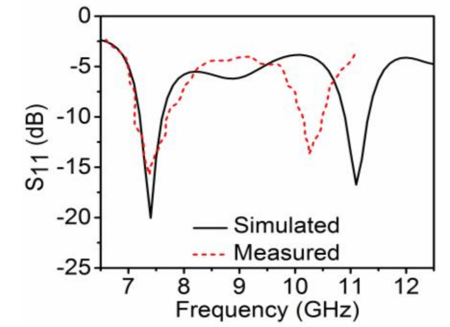


Figure 8. Comparison of simulated and measured S_{11}.

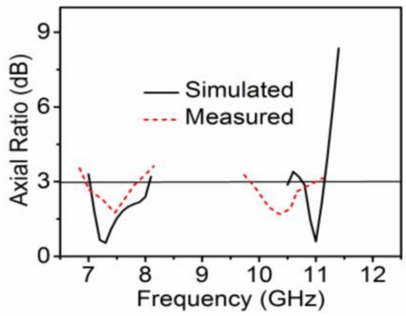


Figure 9. Comparison of simulated and measured axial ratio.

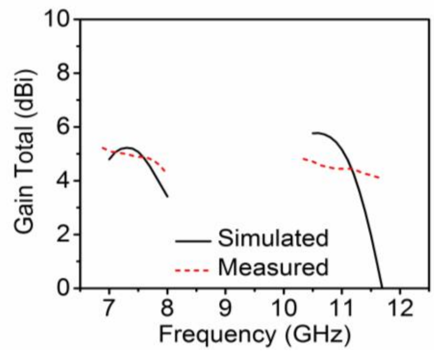
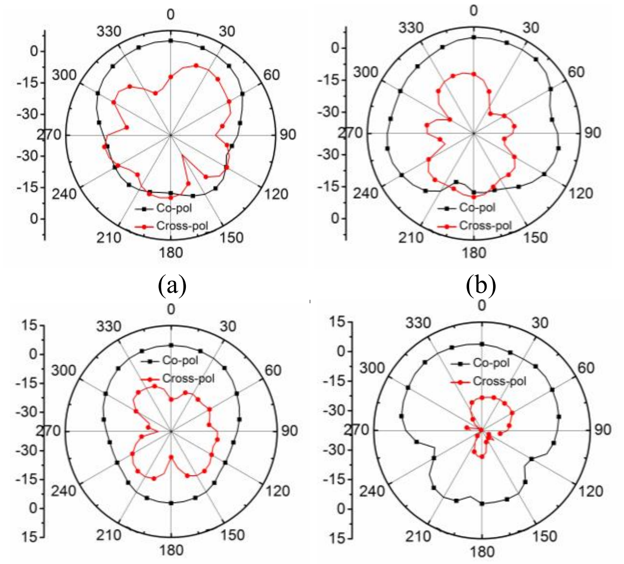


Figure 10. Comparison of simulated and measured gain total.



(a) (b)

(c) (d)

Figure 11. Simulated radiation pattern; (a) E-plane, (b) H-plane at 7.4 GHz and (c) E-plane and (d) H-plane at 11.1 GHz respectively.

5. Conclusion

A circularly polarized, dual band, cylindrical dielectric resonator antenna is proposed and characterized here. A 100 rotated plus-slot is actualized on one of the ground plane to impose circular polarization. This antenna operates at 7.4 GHz and 11.1GHz with AR < 3dB. A 40 degree beamwidth of 5 dBi gain at 7.4 GHz and 5.2 dBi at 11.1 GHz is observed. These performance characteristics along with the overall physical dimension of the proposed DR satisfies its suitability for Cubesat applications.

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