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RESEARCH ARTICLE

Dual Sense Circularly Polarized Compact Slot Antenna for CubeSat Applications

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ABSTRACT A dual feed dual sense circular polarized (CP) slot based wideband UHF antenna is proposed. The proposed structure is very compact which makes the design a suitable candidate for Cube-Sat applications. It consists of a hexagonal thin slot and two feeding transmission lines. In order to achieve CP, the two transmission lines are placed symmetrically with respect to the slot. The shape and location of transmission lines and slot structure are critical and achieved using a parametric analysis. To achieve wideband characteristics with a compact size, the slot is constructed with a capacitive loading. The design is fabricated on Rogers RO4350 with an overall board size of $60 \times 60 \times 1.52$ mm^3. The simulated and measured results have verified that the proposed antenna design operates over a wide frequency range from 360 MHz to 470 MHz.

INDEX TERMS Circular polarization, cube satellite, electrically small antenna, slot antenna.

I. INTRODUCTION

Cubesat has been emerged as a key solution to advances the future technology for low earth orbit satellite communications and satellite missions. The size of a 1 Unit CubeSat is generally $10 \times 10 \times 10$ cm^3 [1], [2]. Moreover, CubeSat requires circular polarized (CP) antenna with wide impedance matching bandwidth. The CP antenna offers more orientation flexibility and matching compared to linear polarized in many wireless communication applications including satellites, 5G millimetre-wave and radio frequency identification [3], [4]. Nevertheless, the CP antenna is always challenging to built especially with wideband and compact size characteristics [5] at UHF spectrum, which are the core requirements in CubeSat communication.

Due to physical and structure requirements by CubeSat, electrically small antennas with CP and wideband characteristics are good candidates. Recently, many compact and electrically small antennas have been presented in [6], [7], and [8] using meta-material technology. However, most of them are single linearly polarized antenna designs. Some other designs based on split-ring resonator method have also been proposed in [9] and [10] to make a compact CP antenna.

The CP antennas for CueSats based on leaky wave and loop concepts were proposed in [2], [11], and [12]. However, those designs did not operate at UHF band. A miniatured UHF band slot antennas were reported in [13], [14], and [15]. Nevertheless, the designs were complicated and comparatively large in size.

In this works, a capacitive loaded thin slot based antenna is presented. The proposed design is very compact and wide band with circular polarization characteristics which are the main contributions of the proposed work. The design has both the Right and left hand circular polarizations. It shows good impedance matching bandwidth from 360 MHz to 470 MHz with 3 dB axial ratio.

II. PROPOSED CIRCULAR POLARIZED SLOT ANTENNA

The aim of the proposed work is to design a very compact antenna at 435 MHz frequency band which satisfy the size

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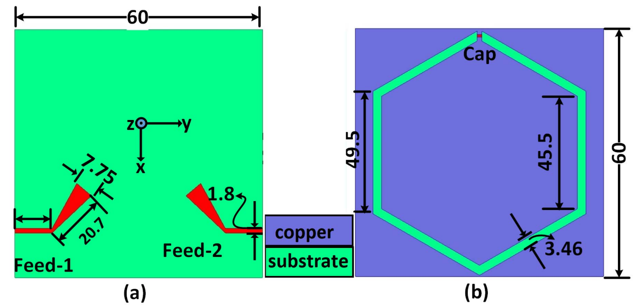

FIGURE 1. The geometry of a proposed antenna. (a) Top view, (b) bottom view - All values are in millimeter (mm).

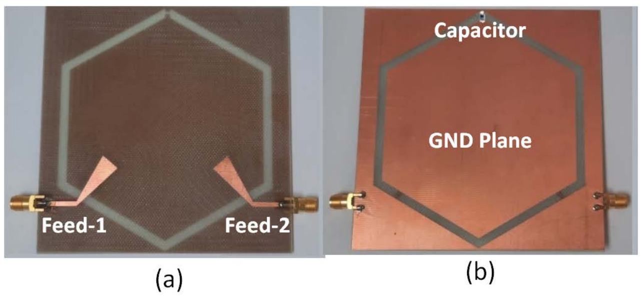

FIGURE 2. The fabricated prototype of the proposed antenna. (a) Top view and (b) bottom view.

and bandwidth requirements for CubeSat applications. Thus, the used slot is meandered like a hexagonal shape and then loaded with a capacitor which makes the overall antenna size very small. The total length or width is only $0.08\lambda_o$ at 435 MHz which is very compact compared to the existing literature [13], [14], [15].

The geometry of the whole antenna design is shown in Figure 1. The antenna is implemented on a double sided (top and bottom) Rogers RO4350 with an overall board size of $60 \times 60 \times 1.52$ mm^3. The slot and its feeding (Feed-1 & Feed-2) are manufactured on the bottom and top sides of the substrate, respectively.

A. DUAL FEED SLOT ANTENNA

In this work, a 435 MHz frequency is chosen for UHF band CubeSat communications. The proposed resonating structure is a slot based antenna as shown in Figure 1. The conventional slot antenna is very popular for its easy fabrication, integration, planar structure, wideband characteristics, and omnidirectional radiation patterns which are suitable for UHF band CubeSat communications.

The proposed slot is meandered to make compact in size. It looks like a hexagonal shape as shown in Figure 1. It is also very thin with a width of 3.46 mm. It is excited with two transmission lines (TL); left feed (Feed-1) for left hand CP and right feed (Feed-2) for right hand CP. The TL are modified and optimized to achieve wideband impedance matching bandwidth. The optimized dimensions of the TL are given in Figure 1. Additionally, the thin slot is loaded

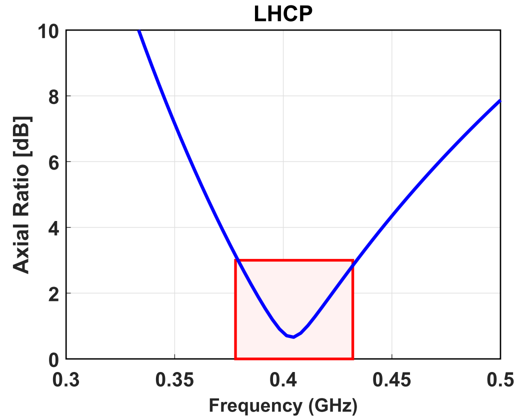

FIGURE 3. Axial ratio vs. frequency curve for left hand circular polarization (LHCP).

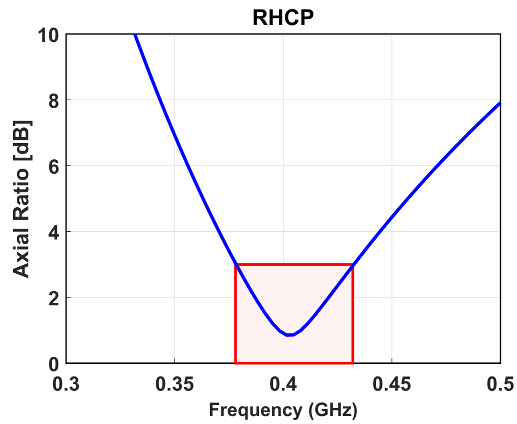

FIGURE 4. Axial ratio vs. frequency curve for right hand circular polarization (RHCP).

with a capacitor (Cap), see in Figure 1(b) to reduce the electrical size of the slot and improves the impedance matching bandwidth. The final optimized design covers 550 MHz to 650 MHz frequency band without capacitive loading. While it covers 360 MHz to 470 MHz frequency band with capacitive loading. The results are presented in next section. The most effective parameter in controlling the AR bandwidth was the location of feeding structure. Several parametric sweeps were performed to obtain the optimal AR bandwidth.

The axial ratio curves for the proposed design are shown in Figure 3 & Figure 4 for left hand and right hand polarizations. The design has stable axial ratio below 3 dB from 360 MHz to 470 MHz frequency band in both cases. The stability of the axial ratio can also be verified from Figure 5 and Figure 6.

Moreover, the current distributions for the proposed structure are also plotted in Figure 7. The current distributions are plotted at 430 MHz with the phase values of 0°, 30°, 90°, and 150°.

Finally, a parametric analysis is also discussed here which helps in achieving a better performance in terms of size reduction and widening the bandwidth. The capacitor (Cap)

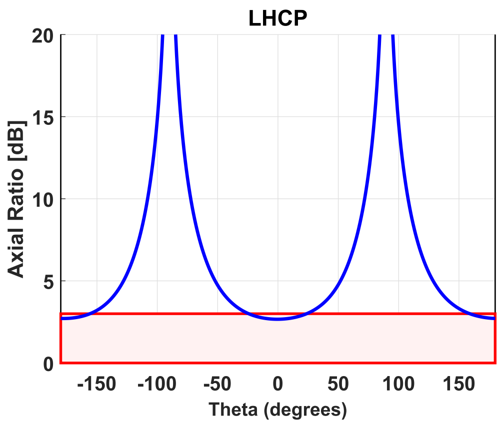

FIGURE 5. Axial ratio vs. theta curve for left hand circular polarization (LHCP).

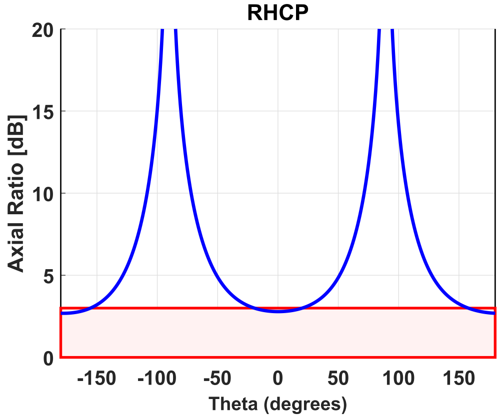

FIGURE 6. Axial ratio vs. theta curve for right hand circular polarization (RHCP).

is loaded with the thin slot antenna as shown in Figure 1. The values of the capacitance of the capacitor are varied to see the effect of the antenna. The reflection coefficient S_{11} curves for Feed-1 are shown in Figure 8. It can be seen that the S_{11} are dependent on the capacitance values. It can be also seen from the Z_{in} curves provided in Figure 9. As we increase the values from 3pF to 16pF, the resonance frequency shifts to the lower frequency. This is because, increasing the capacitance values will increase the electrical length of the antenna that will ultimately lower down the resonance. The figure shows curves for 3pF, 5pF, 8pF, 12pF, 14pF, and 16pF. Nevertheless, we have chosen 12pF capacitance value for the proposed design to operate at 435 MHz. It can also be observed that the 12pF capacitance also improves the impedance matching bandwidth compared to without capacitor loading structure.

B. ANTENNA DESIGN PROCEDURE

The design procedure of the proposed antenna structure is summarized below:

- Select the resonating frequency, i.e. 435 MHz.
- Initially, a hexagonal slot can be selected as a resonating structure.

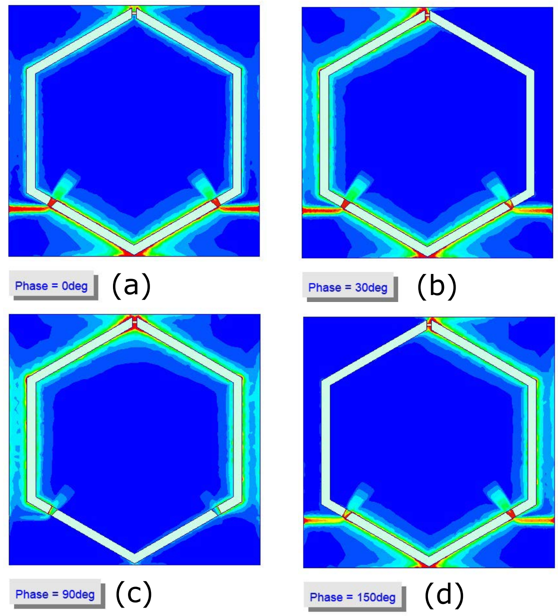

FIGURE 7. The surface current distributions at different phase angles.

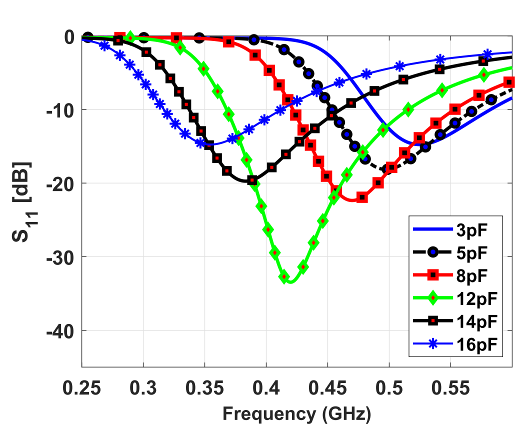

FIGURE 8. S_{11} for different values of capacitor.

- Add and optimize the location of the feeding structure.
- Add an appropriate capacitor to the slot.
- Do the parametric analysis for the whole antenna structure to achieve wideband axial ratio bandwidth.

III. PROTOTYPING, RESULTS AND COMPARISON

The proposed antenna design is modelled and optimized in High Frequency Structured Simulator (HFSS). It is fabricated using LPKF S103 at KFUPM. The fabricated prototype is shown in Figure 2.

The S-parameters are measured using vector network analyser. The simulated and measured S_{11} without capacitor loading are shown in Figure 10. The design covers 550 MHz to 650 MHz for both left and right handed circular polarizations cases. The simulated and measured S_{11} with capacitor loading are shown in Figure 11. The design covers 360 MHz to 470 MHz for both left and right handed circular polarizations cases. The -10 dB impedance matching bandwidth is

TABLE 1. The comparison of proposed and other CubeSat antenna designs.

References	Frequency band	Size (mm^2)	S_{11} BW	Polarization Sense	CP BW	Antenna type
[2]	28 GHz	98×6	$\approxeq$ 10 GHz	LHCP & RHCP	10 GHz	Leaky wave
[11]	24 GHz	26×33	$\approxeq$ 3 GHz	Linear	NA	Leaky wave
[14]	300 MHz	55×55	$\approxeq$ 2 MHz	Linear	NA	Slot
[15]	800 MHz	335×230	Not given	Linear	NA	Slot
This Work	**435 MHz**	**60×60**	**110 MHz**	**LHCP & RHCP**	**100 MHz**	**Slot**

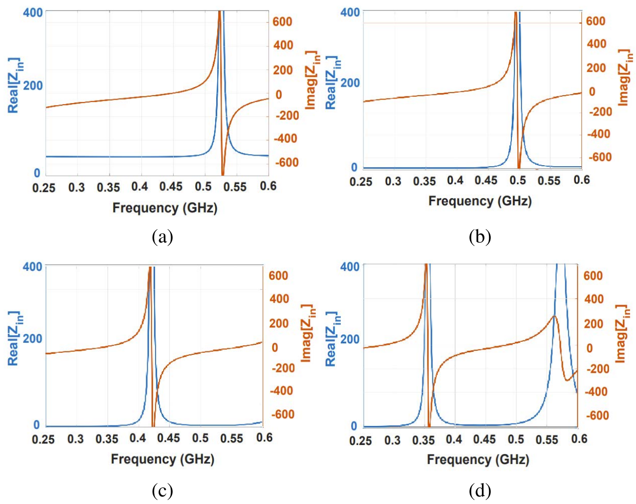

FIGURE 9. Z_{in} curves. (a) 3pF, (a) 8pF, (a) 12pF, and (a) 16pF.

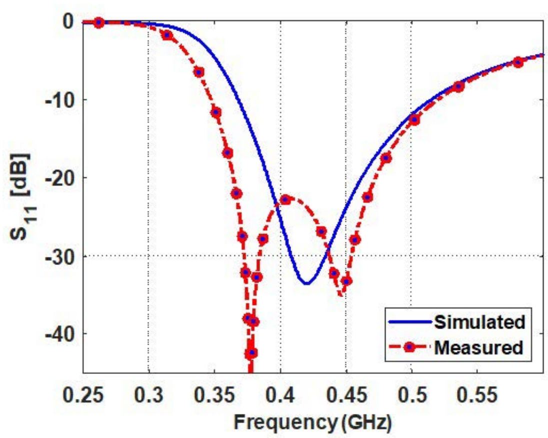

FIGURE 11. The simulated and measured S_{11} with capacitor loading.

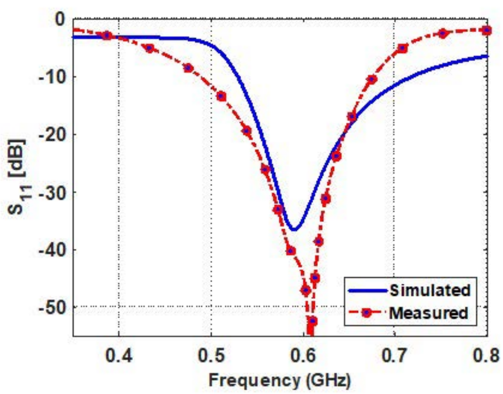

FIGURE 10. The simulated and measured S_{11} without capacitor loading.

110 MHz which is very wide at UHF band. The results show a good agreement between simulated and measured curves. Due to the symmetry of the design the S_{11} and S_{22} are similar and not shown here.

The antenna is also characterize for far-field radiation patterns in an anechoic chamber. The simulated 3D radiation patterns are given in Figure 12 showing omnidirectional patterns at 435 MHz. While, the simulated and measured 2D radiation patterns for Feed-1 are shown in Figure 13 at 435 MHz. The cross pol (black & blue curves) are lower than the Co pol. (green & red curves). Again, a good agreement is observed between simulated and measured results. The Feed-2 has similar patterns and not shown here. For LHCP and RHCP gain observations, when Feed-1 excited and Feed-2 is terminated with matched load, the design operates as a left hand polarized antenna as Figure 14. The Left handed gain is much higher than the right handed gain which verify that the antenna is circular polarized. When Feed-2 is excited and Feed-1 is terminated with matched load, the design operates as a right hand polarized antenna as shown in Figure 15. The right handed gain is much higher than the left handed gain which verify that the antenna is also a circular polarized. Overall, the antenna has -8 dBi to -10 dBi gain in the covered band. The proposed slot is loaded reactively to bring down the resonance frequency to lower bands. As capacitive loading is accompanied with antenna miniaturization, the same aperture area would operate at lower frequencies. Hence it is expected to have lower efficiency by capacitive loading. For the proposed antenna, the efficiency was varied about 11% without and with capacitive loading while operating at

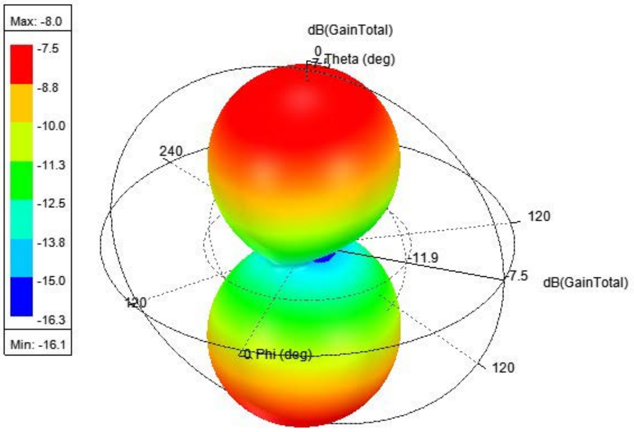

FIGURE 12. The 3D realized gain in dBi.

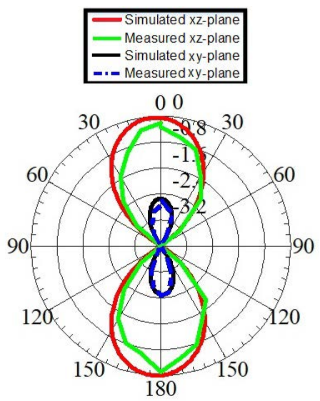

FIGURE 13. The 2D simulated and measured radiation patterns at 435 MHz.

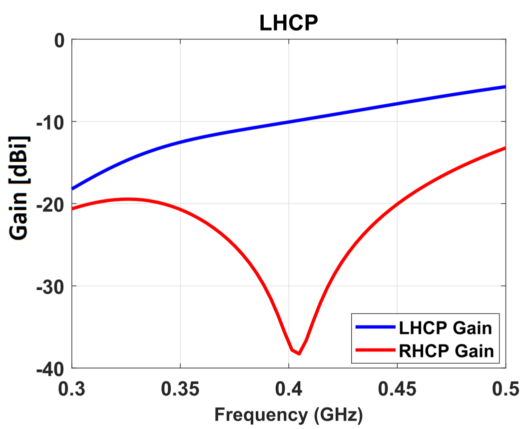

FIGURE 14. Gain vs. frequency curve for left hand circular polarization (LHCP).

different frequency bands. The radiation efficiency obtained was from 75% ∼78% over the entire band of operation.

Finally, the proposed design is compared with the existing antenna designs in the literature in Table 1. It can be noticed that the proposed design is very compact in size and provides wideband characteristics at 435 MHz UHF band. Moreover, the proposed design is a right and left hand

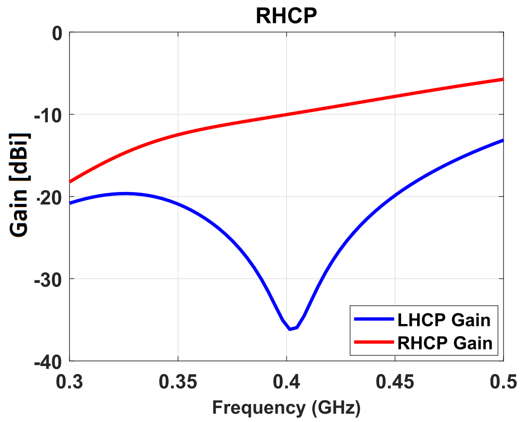

FIGURE 15. Gain vs. frequency curve for right hand circular polarization (RHCP).

circular polarized while others are only linear polarized [11], [14], [15].

IV. CONCLUSION

In this work, a very compact antenna has been presented for CubeSat communication at UHF band. The antenna was structured using thin hexagonal slot and two transmission lines. The thin slot was loaded with a capacitor to further reduce the antenna size. The final antenna design operates at 435 MHz from 360 MHz to 470 MHz band with −10 dB impedance matching bandwidth. The planar and very compact structure with circular polarization and wideband band characteristics make the design a good candidate for CubeSat communication.

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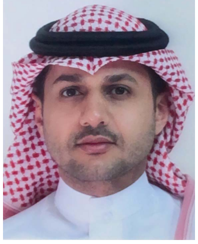

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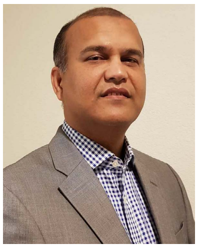

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