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Conformal Circularly Polarized UHF Slot Antenna for CubeSat Missions

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Abstract—A conformal circularly polarized UHF antenna integrated on the body of a CubeSat is presented. The antenna operates at 485 MHz and provides at least 10 MHz impedance bandwidth. Traditional UHF antennas for CubeSat have been wire or tape measures that require mechanical deployment, whereas the antenna reported in this paper does not need such treatment and therefore has a potential application in CubeSat mission by promising a more reliable communication link and reduced cost. The measurements showed good agreements with the design data, validating frequency response, bandwidth, and circular polarization level of the proposed antenna.

1. INTRODUCTION

Integrating antennas with the solar panels of small satellites, especially CubeSats, without competing for the extremely limited surface real estate, has enormous merits in a successful space mission. Such an integration not only reduces payload of the aircraft by replacing deployed wire antennas, but also promises a more reliable communication link. As the standards and classification of CubeSats are well documented, this paper follows the terminology defined in [1] without repeating them in the introduction. Several research groups have reported different types of antennas integrated with solar cells on CubeSat surface [2–6], but all of those antennas were for GHz frequencies. The UHF band, which remains the major interest in most CubeSat launching, however, has limited studies, and the technology in this band still utilizes deployed antennas such as helical or dipoles [7–10]. The reason for limited solution and lack of conformal UHF CubeSat antennas is fairly straightforward. An antenna operating at a UHF band requires larger footprint, and it is challenging to fit it within a CubeSat solar panel. For example, a 3U CubeSat is among larger CubeSats, and one of its panel is only 10 by 30 cm^2. The challenge further magnifies when the communication link requires a circular polarization (CP) and reasonable bandwidth to satisfy both up and down links. To resolve the limited panel size issue, unlike previous work that used only one side of a CubeSat or one flat panel for antenna integration, this paper presents a design that utilizes all four sidewalls of a CubeSat to fit a conformal cavity-backed slot antenna. The width of the slot is only 3 mm, and solar cells can be conveniently placed around the antenna. By adjusting the design parameters, the proposed antenna topology can easily support a lower UHF operation (such as 350 MHz). Furthermore, the antenna design is independent of the solar cell production, and the solar cells do not have to be custom designed as in [2, 3]. This trait enables payload reduction by allowing off-the-shelf solar cells. This paper is built on a prior conference paper [11] where simulation of one band was presented. The extension includes the design of up- and down-links, circular polarization, measurements, and the isolation between the two bands.

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2. ANTENNA DESIGN

2.1. Antenna Geometry

The antenna geometry is as illustrated in Fig. 1 where a meander-line shaped slot antenna was wrapped around the sidewalls of CubeSat, and the solar cells were integrated around the antenna. As CubeSats often use printed circuit boards as base panels for mounting solar cells, a Rogers' high frequency laminate was chosen to host solar cells and the antenna, due to the laminate's high RF quality and easy access. The design basis of the antenna is a cavity backed slot antenna excited by a microstrip line as described by Wong et al. [12] and Han [13]. The detailed antenna geometry and layer information are presented in Fig. 2, where a Roger's laminate and a metallic plate were assembled together to house the antenna on the top and the feedline on the bottom layer of the laminate. A meander line loop slot (Fig. 2(a)) was etched on the top layer, leaving the metal cladding everywhere else but the slot. A microstrip feedline was printed on backside of the laminate (Fig. 2(b)). A dielectric layer is necessary to function as the substrate for the microstrip line, and then the substrate was backed with a metal layer as the ground plane. The ground and top layers of the Rogers' laminate were connected to form a cavity for the slot antenna. In this study, the dielectric between the feedline and the ground was chosen to be air for practical considerations in building the CubeSat, but other materials such as Teflon or polyamide can be adopted as long as the material and geometry satisfy the CubeSat assembly and system requirements. When prototyping the antenna and solar panel, it was easier to first create the ground layer, which is a metallic square cylinder. Then shape the Roger's laminate into a bigger concentric cylinder, leaving a space that can be air or vacuum in between. The two cylinders can be fastened in place by using plastic spacers at corners. The spacers do not have significant effect on the antenna design at UHF band, especially when the permittivity of the spacer was chosen to be close to 1. Finally, two metal lids were placed on the top and bottom of the cylinders to complete the cube and to short the ground and antenna layers. The lids and the innermost layer also create a grounded Faraday cage that helps to isolate the electronics inside the CubeSat from the antenna and any external radiation. In order to keep the design simple, the geometry of the meander line was kept the same on each of the four walls of the CubeSat.

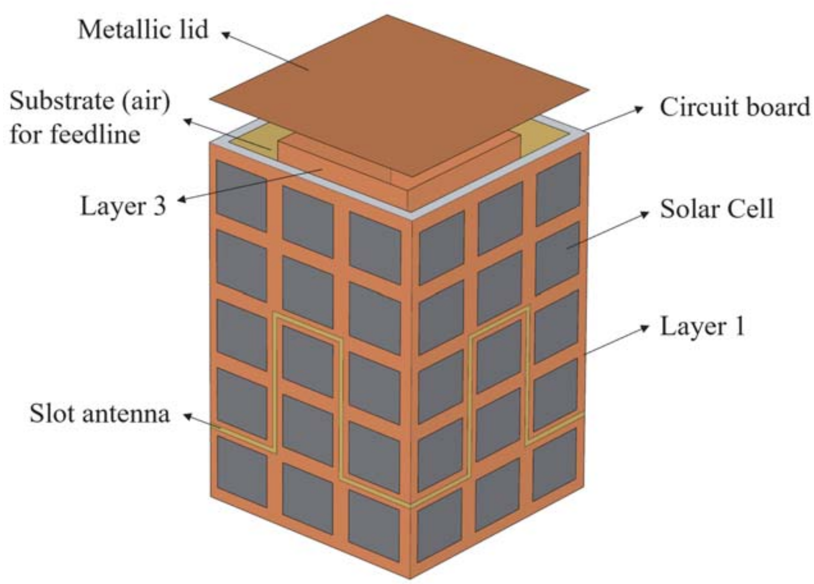


Figure 1. A UHF slot antenna on the solar panel of 1.5U CubeSat.

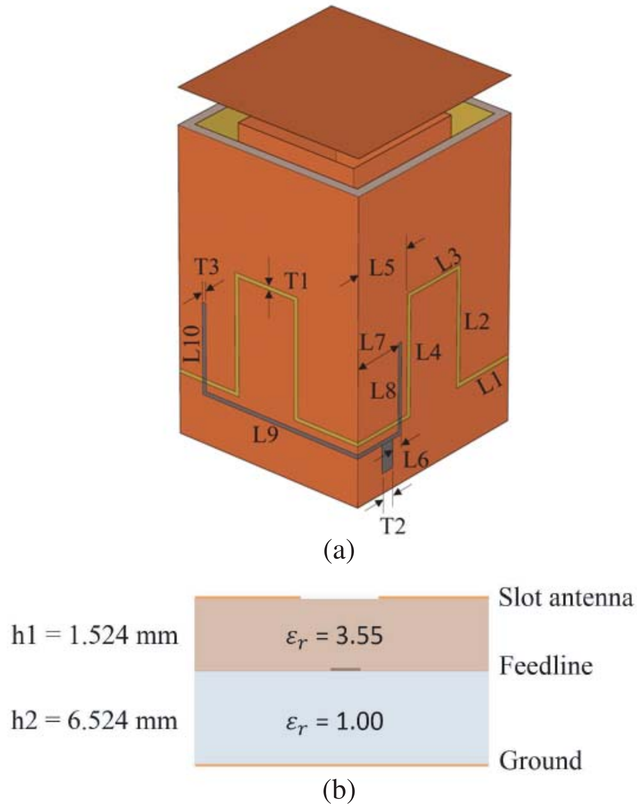


Figure 2. Details of the antenna geometry and layer information. (a) Antenna and feedline. (b) Layer information.

2.2. Design Parameters

Two sets of slot antennas were meandered on two 1.5U CubeSats to provide up- and down-links, respectively. Then the two 1.5U CubeSats can be cascaded into a 3U CubeSat as illustrated in Fig. 3. Both antennas provide CP, and the center frequencies were 485 MHz and 500 MHz for the up- and down-links. The metallic lids (Fig. 2) as described in Section 2.1 not only serve as mechanism to short the ground of the antenna and feedline, but also isolate the up and down links. This is essential due to the close proximity of the two UHF bands. Although it might be feasible to integrate a slot antenna similar to previous work [2] on a 3U panel, it is nearly impossible to achieve both links and CP. The proposed method resolves the issue and isolates the two bands effectively, which means that the two

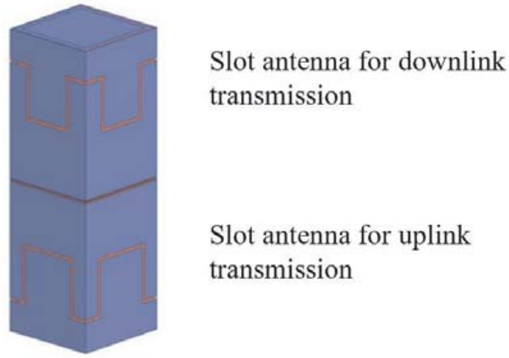


Figure 3. Proposed design of circularly polarized slot antenna for 3U CubeSat.

Table 1. Design parameters of the uplink.

Slot Parameter	**L1**	**L2**	**L3**	**L4**	**L5**	**T1**
Value (mm)	17	57	66	57	17	3

Feedline Parameter	**L6**	**L7**	**L8**	**L9**	**L10**	**T2**	**T3**
Value (mm)	10	3	30	98	30	.5	.3

Table 2. Design parameters of the downlink.

Slot Parameter	**L1**	**L2**	**L3**	**L4**	**L5**	**T1**
Value (mm)	17	52.6	66	52.6	17	3

Feedline Parameter	**L6**	**L7**	**L8**	**L9**	**L10**	**T2**	**T3**
Value (mm)	10	3	30	98	30	.5	.3

bands can be tuned independently. The design parameters marked in Fig. 2 are listed in Tables 1 and 2 for the up- and down-links, with L and T denoting the length and thickness of a slot or microstrip line. The thickness of the air layer ($h2$ in Fig. 2(b), i.e., the space between the microstrip line and the layer 3, which is the ground) has been optimized to yield the best balance between the antenna properties and the CubeSat payload. A thicker dielectric layer results in wider bandwidth, but it also occupies extra space and casts difficulty for modular design of CubeSats. The 90 degree phase shift needed for a CP was achieved by adjusting the length of $L7$ and $L9$.

3. FABRICATION AND ASSEMBLY

After verifying the design using Ansys' HFSS, the uplink slot antenna and the feedline were created on a Rogers 4003C panel using an LPKF ProtoMat S62 milling machine. The board was then cut into four pieces to constitute each wall of the CubeSat. The final prototype contains three main parts as shown in Fig. 4: two frames, four walls cut from Rogers 4003C that has the antenna and feedline printed on it, and an inner sleeve made from a piece of brass sheet. The cubic structure was then closed with two aluminum square sheets as the top and bottom. Detailed fabrication process and assembly are listed as follows.

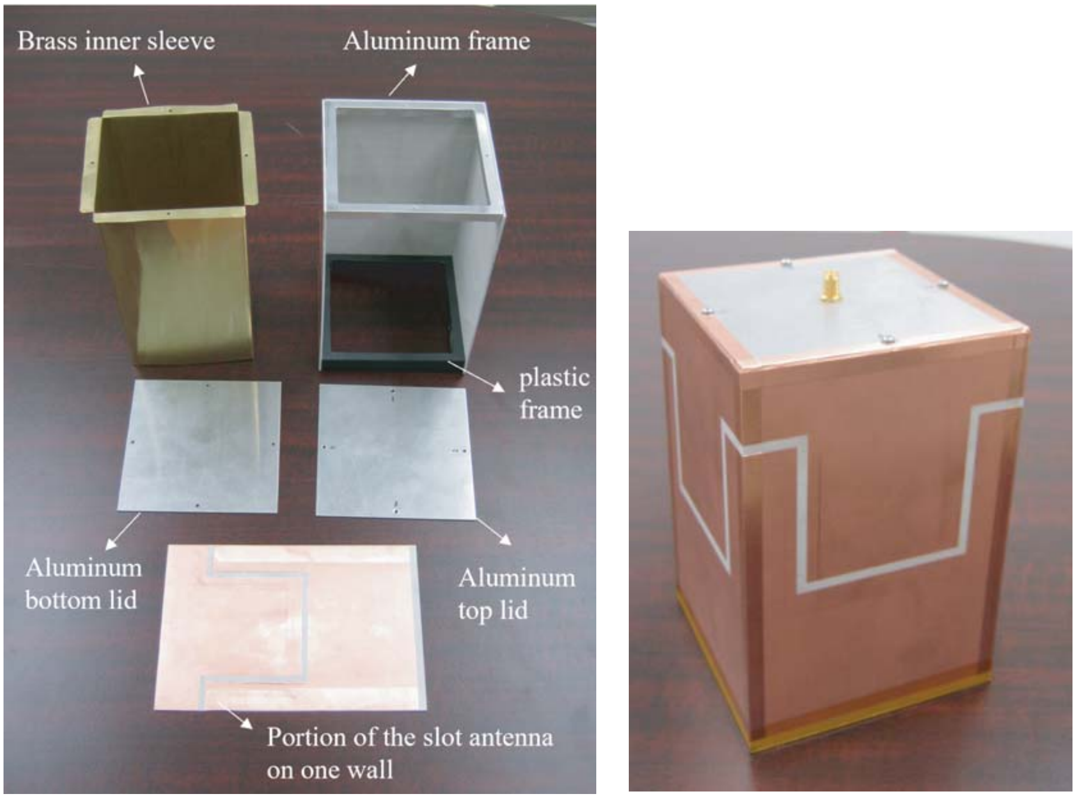
(1) Top and bottom frames for the cube were machined from a 6.35 mm thick aluminum sheet and a 12.7 mm thick plastic sheet, respectively. Each frame provides the exact spacing of $h2$ (Fig. 2(b)) between the outer Rogers 4003 wall and inner brass sleeve. Both frames can be machined from aluminum, but use plastic for the bottom yields a lighter design.

(2) Four walls cut from the Rogers 4003C that had the antenna and feedline printed on were attached to the frames with double-sided adhesive tapes. Special care was taken to ensure that the slots and feedline were aligned. In addition, a piece of adhesive copper tape was used to ensure the connection of the feedline at the corner (Fig. 2(a)).

(3) The top and bottom lids of the cube assembly were machined from a piece of 1.016 mm thick aluminum sheet. A hole was drilled on the bottom lid to bring in the excitation for the antenna, which was a RG316 coax cable, and to solder an SMA connector (Fig. 5(a)).

(4) The inner sleeve, which is also the ground for the antenna and the feedline, was machined from a .127 mm brass sheet. The top end of the sleeve was machined and bent so that it sits seamlessly on the frame and to create a grounded cavity needed for the slot antenna. A hole was drilled on the brass sleeve to bring in the inner pin of the feedline, and the sleeve was grounded to the outer conductor of the RG316 (Fig. 5(b)).

(5) After inserting the brass sleeve and soldering the coax cable to the feedline, the cubic assembly was closed by fastening the aluminum top and bottom lids on the frame with screws. Then the walls



(a) (b)

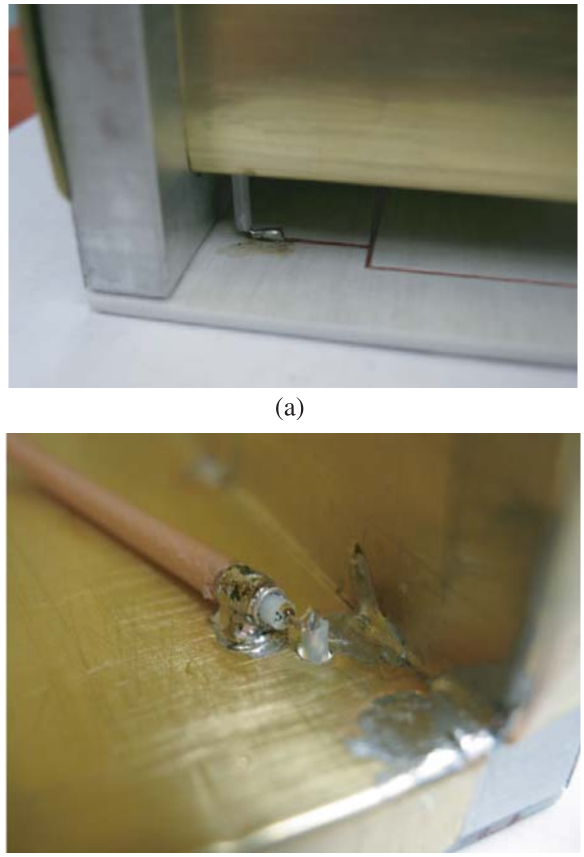
Figure 4. The antenna assembly. (a) Major arts. (b) Finished prototype.

(i.e., the antenna panel) were sealed at corners and edges with copper tape to yield a finished prototype (Fig. 4(b)).

4. SIMULATION RESULTS AND MEASUREMENTS

4.1. Simulated Results and Discussions

Two meander-line slot antennas operating at up and down links, respectively, were designed to suit integration with two 1.5 CubeSats and then cascaded to form a 3U CubeSat (Fig. 4, Fig. 3). Because there is an isolating aluminum sheet (i.e., bottom lid in Fig. 4(a)), the two bands have little interference. Fig. 6 shows the S_{11} response of the two bands after being integrated on a 3U CuebSat. The simulation was performed using Ansys's HFSS, and both bands promised about 15 MHz bandwidth for above 10 dB return loss. Radiation patterns for the two bands were plotted in Fig. 7. It is seen that both bands promise a generally omnidirectional E-field pattern that resembles the field pattern of a dipole antenna. H-field pattern shows some shift in the direction of the field maximum and distortion of the pattern for the uplink. This is understandable because the antenna was designed by meandering a square slot antenna, and those bent portions affect the H-field pattern as a slot is essentially a magnetic dipole. The meandering effect is more severe for the uplink because of the lower operating frequency and a resulting longer slot antenna to be bent to fit on the CubeSat. Fig. 8 is the simulated S_{21} parameter between the two feed ports for the up- and down-links. It is seen that the isolation between the two bands is more than 10 dB. This is within a common CubeSat link budget and is comparable with or better than the isolation between two wire antennas mounted on the corners of a CubeSat. Because of the sufficient isolation between the two bands, only a 1.5U CubeSat with an integrated uplink was prototyped for measurements since the two bands are effectively independent, and the design methods are the same in nature.



(a)

(b)

Figure 5. Excitation of the antenna. (a) Coax pin soldered to the feedline. (b) Brass sleeve and coax cable.

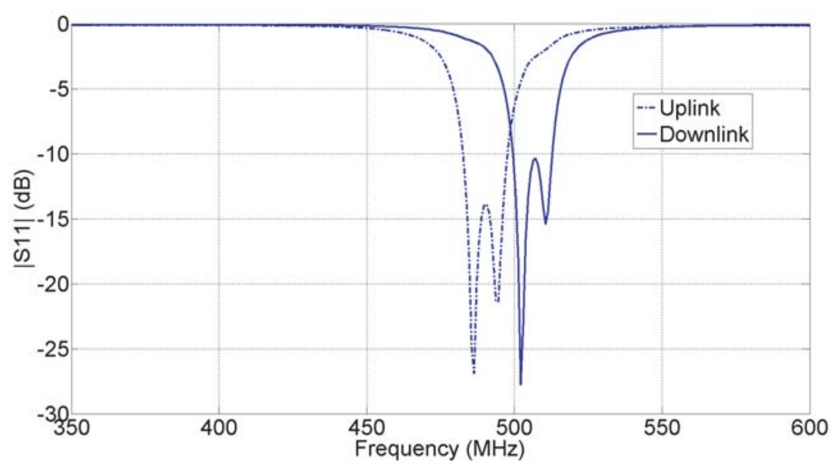


Figure 6. Reflection coefficient for uplink and downlink channel slots.

4.2. Measurement Setup and Results

After the uplink prototype was fabricated following the procedure in Section 3, the reflection coefficient was measured with an Agilent N5225A Vector Network Analyzer, and the results were plotted in Fig. 9. It is seen that return loss at 485 MHz is 13.6 dB, and overall the measured results agree well with the

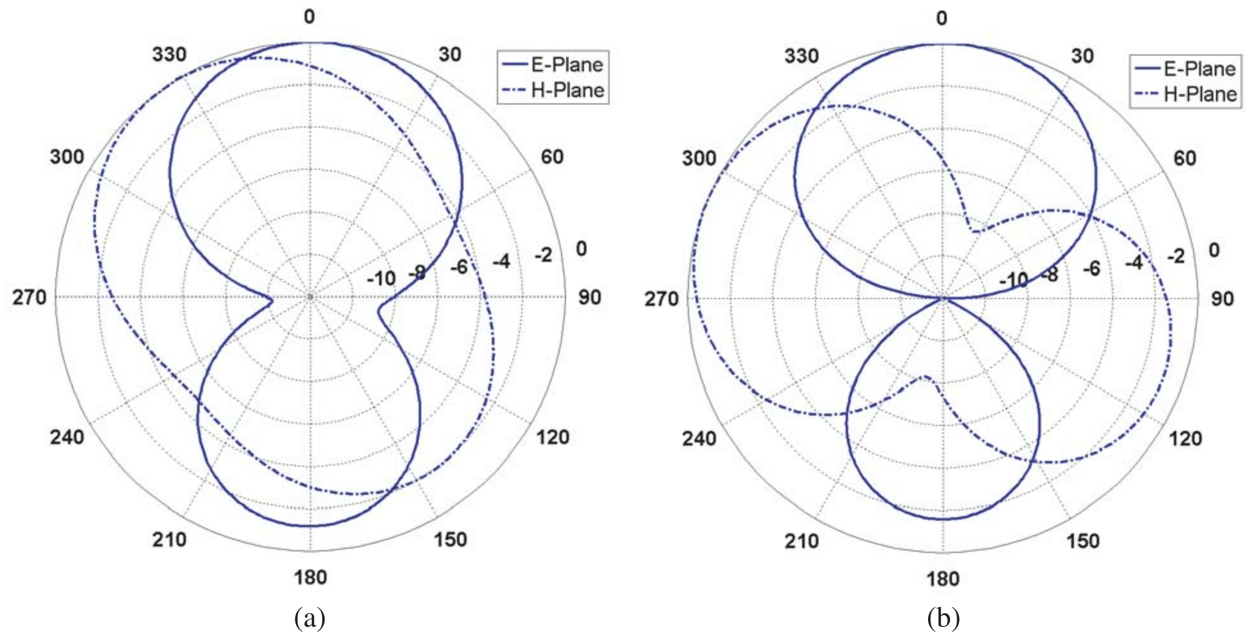


Figure 7. Radiation patterns. (a) Uplink. (b) Downlink.

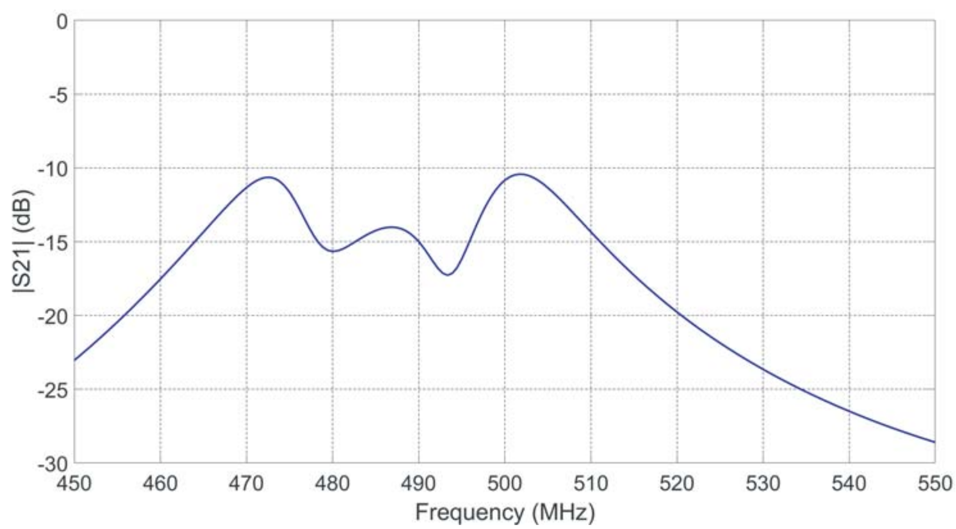


Figure 8. Proposed design of circularly polarized slot antenna for 3U CubeSat.

simulation. From the measured results, one could read about 1 dB loss outside the resonant band, which is understandable considering the loss in the material, fabrication precision, and the effect of soldering. The radiation patterns were manually measured outdoor in a field because the frequency was too low for our indoor antenna range. A two-monopole array antenna resonating at 485 MHz was constructed to be the transmitter antenna. The ground plane of the monopoles has a size of 20 by 24 inch^2, and the gain of the antenna is approximately 6 dB considering loss and the size of the ground plane. The transmitter antenna and CubeSat were mounted on top of the two 12 feet poles, and the two poles were separated by 7 feet to place the two antennas in their far zones and not to cause severe multipath reflection from sounding farms and trees. The final measurement setup is as pictured in Fig. 10, where the transmitter antenna is connected to a signal generator and the CubeSat antenna to a spectrum analyzer. The cables to the two antennas were measured to have a 4.5 dBm loss. The CubeSat antenna was rotated to full 360

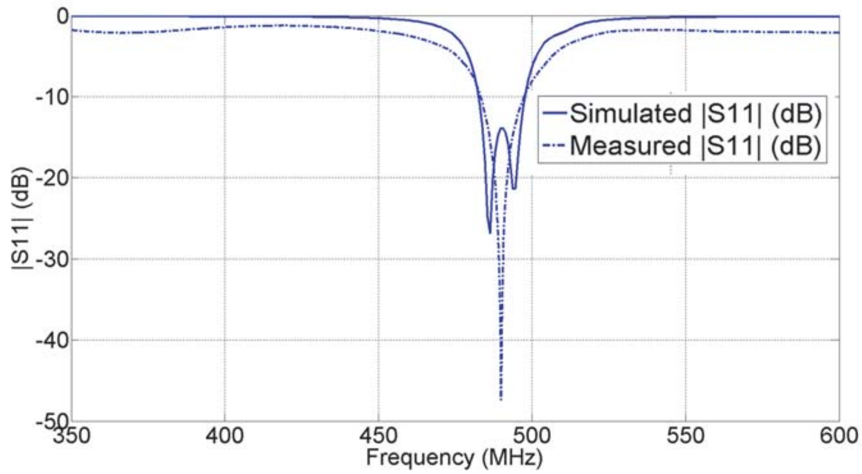


Figure 9. Simulated and measured reflection coefficient for lower slot (uplink).

Figure 10. Field setup for range test of 1.5U CubeSat antenna.

degrees with a step size of 10 degrees, and the received power was measured at each rotation. Then, the Friis transmission equation was used to calculate the CubeSat antenna's gain using transmitted power from the signal general, cable loss, distance, and the gain of the transmitter antenna. The measured radiation pattern (Fig. 11) was normalized to its maximum value and was plotted to compare with the simulation. From Fig. 11(a), it can be seen that the shape of measured pattern agrees reasonably well with the simulation, considering a relative rough measurement environment. The peak gain of the CubeSat antenna was calculated to be 2.73 dB and is only 0.1 dB less than the simulation. The overall gain difference from the simulation is within 0.2 dB at different angles. These results were satisfactory, and the properties of the UHF slot antenna were well within the CubeSat link budget. For verifying the CP property, the CubeSat was rotated by 90 degrees around the mounting pole axis, and then the pattern measurement was repeated. The radiation patterns for the CubeSat facing two directions (90 degrees apart) were plotted in Fig. 11(b), and it is clear that radiation patterns for two different directions are almost identical, predicting a satisfactory CP.

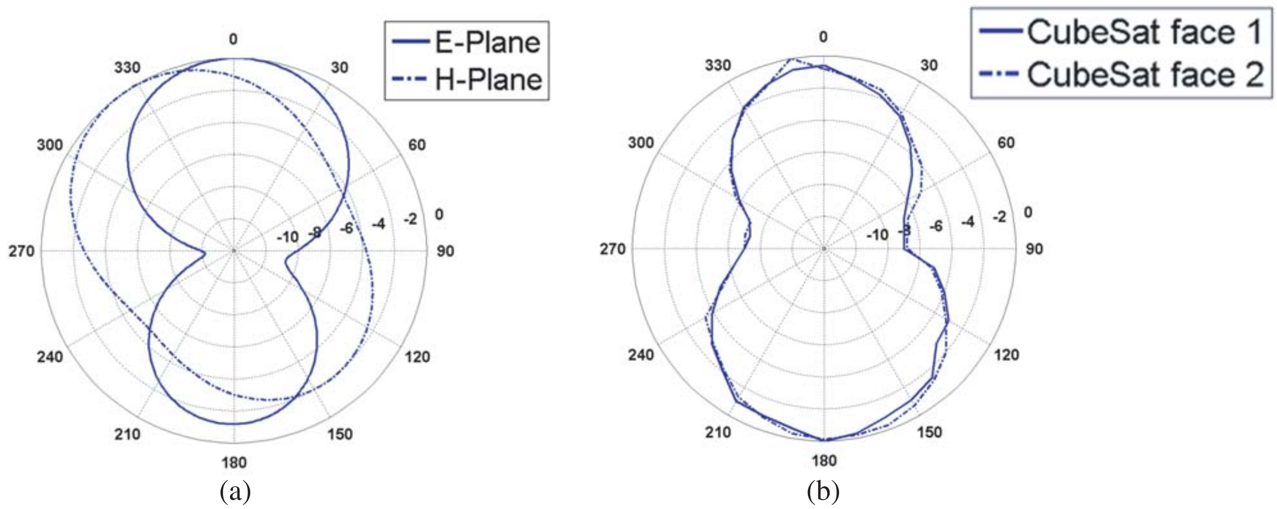


Figure 11. Measured results (uplink). (a) Pattern. (b) Axial ratio.

5. CONCLUSION

This paper presents a creative solution for integrating a CP UHF antenna on the solar panels of a CubeSat for a cheaper and safer space mission since no mechanical deployment is needed for the antenna. The design is based on a cavity backed slot antenna, where a square loop was meandered to fit the circumference of a 1.5U CubeSat. The loop antenna is then fed from two sides with a 90 degree phase shift to achieve a CP. The antenna parameters were optimized to satisfy the frequency and bandwidth requirements of a CubeSat communication at 485 MHz. The measured frequency response, bandwidth, and CP level all match the simulation data, and the design can be flexibly extended to other frequencies when necessary by adjusting the meander geometry. As the antenna design is independent from the solar cells, and the solar cells can be fit around the antenna, such an integration of antenna and solar panel contributes to payload reduction, promising great potential in future CubeSat missions.

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