NON-DEPLOYABLE MINIATURIZED QUADSLOT ANTENNA FOR CUBESATS

Samantha Romano, Dr. Martin Kaliski, Dr. Jordan Puig-Suari, Dr. Bellardo
California Polytechnic State University
1st Grand Ave San Luis Obispo, CA 93401; 425-444-1213
sam.romano18@gmail.com

ABSTRACT

The combination of the structural panels of a 1U cubesat and their air gaps can form a quadslot antenna. This type of antenna eliminates the need for a deployment mechanism and reduces the risk of a disconnection from the satellite. The electrical field constructs in an air gap at the corner of two panels, and when all four panels are powered the antenna emits a semi-omnidirectional radiation pattern similar to a dipole. Unlike a dipole, it can radiate up to 5dB of gain instead of 2.15dB. Another benefit to this antenna is its ability to have sensors and or solar cells on the panels without interfering with the radiation pattern. This is because each panel serves two electrical purposes: increasing the electrical length to reduce frequency and providing space for miscellaneous electrical hardware. Overall, this type of antenna provides the same capability as an L-dipole or patch antenna without sacrificing space, increasing cost, or cumulating more risk. The design allows for a variety of flexibility in frequency, bandwidth, physical size, or construction. This was designed and developed at California Polytechnic State University.

INTRODUCTION

CubeSats are nanosatellites that the space community utilizes to test, research, and validate new ideas instead of investing in a large satellite. The need for CubeSats over the last decade has increased because more experiments can be conducted at a lower cost and reduced development time[1]. These satellites perform a multitude of tasks. Some examples include: examine weather data, analyze the scintillation in the atmosphere, or test a miniaturized mass spectrometer. Developers range from high school students to full-time employees in this industry.

CubeSats require a reliable antenna to transmit and receive telemetry to a ground station. The launch pod limits the size of the antenna, and anything that extends beyond the dimensions of a launch pod, such as a Poly Picosatellite Orbital Deployer (PPOD), requires that the antenna be stored[2]. Engineers solve this issue by integrating a deployment mechanism to release the stored antenna. This incurs a large risk if the release mechanism does not function properly, and it could compromise the mission. This antenna disclosed herein solves this issue and the concomitant deployment risk.

The antenna developed is categorized as a quadslot antenna. This antenna utilizes the gaps created between each of the panels of a CubeSat to be a slot. Two methods were developed from this basic structure: The Solar Cell Method and The Meander Line Method. Both methods work in the UHF frequency range.

The Solar Cell Method uses separate ground planes to allow an electrical path for the antenna and a path for the electronics.

The Meander Line method uses Koch fractals to reduce the frequency without having to change the physical dimension of the antenna[4].

These antennas radiate additional gain compared to the traditional dipole, 2.15dB versus 5dB. These applications have immediate effects on current development. Companies, such as Fleet in Adelaide, Australia, are in the midst of creating cubesat constellations[1]. This means that the increased power from each cubesat will bolster the interlinked communication systems within these constellations. This also will eliminate the risk of one of satellites losing communications from deployment failure. These are some of the benefits from these methods.

BACKGROUND

Some CubeSats at the amateur radio UHF range use a half wavelength L-dipole antenna and others may use a patch antenna. The problem with a patch antenna is that it can only radiate from one side, and removes space for a solar cell. For CubeSats that use a dipole, these devices extend far beyond the CubeSat physical structure and require the engineers to fold the antenna into the satellite in order to meet requirements[2]. An example of a deployment mechanism is a burn resistor circuit. An engineer wraps and ties down the antennas with non-stretchable fishing wire. A low ohm resistor is placed underneath the wire to allow a large amount of current and to increase the temperature of the resistor. Once the resistor reaches a high enough temperature, the wire then snaps and releases the antenna. The main issue is the risk of the wire not breaking and causing a mission failure due to no communication.

Amateur frequency CubeSats in PolySat, the CubeSat organization at California Polytechnic State University, operate in the 70cm amateur band at around 437MHz[2]. Typical CubeSats use either a half wavelength or quarter wavelength dipole. The quadslot must adhere to these resonant properties.

$$\lambda = \frac{c}{f} = \frac{3e8\left[\frac{m}{s}\right]}{437[\mathrm{MHz}]} = 0.68\mathrm{m} \tag{1}$$

For this invention to be universal, its size is limited to 0.1m in each direction when inserted into a launch pod[2]. Both methods previously mentioned meet this requirement. The performance of these antennas is determined by a few variables for a 1U CubeSat.

- The size of the gaps determines the bandwidth but can degrade S11 performance.

- The size of the panels and the electronics planes are, see Figure 1. These are critical because the size of the cutout of the antenna plane determines frequency.

- The feed location also determines frequency. Its location can provide either half wavelength or quarter wavelength depending on the desired frequency. For both antennas disclosed here, the feed must be in the center of the panel. See Figure 1.

The edge of each slot is positively charged or negatively charged. The electric field is horizontally polarized as the charge flows from one edge to the other. This defines the antenna as H-Pol. The central feed divides into four separate feeds to inject into each side of the slot. The feed splits where the conductor supplies one edge of the slot and the ground supplies the other.

Many other applications can use this new nondeployable quadslot to reduce circuit complexity. Applications can range from small self-powered beacons to integrating into geo-satellite structures.

SIMULATIONS

All simulations were done in either High-Frequency Simulation Structure (HFSS) or in Advanced Design Systems (ADS)

Solar Cell

The solar cell design integrates the flexibility of a non-deployable UHF antenna, and exploit most of the panel for electronics and solar cells. Figure 1 displays the HFSS model of the solar cell antenna and where the electronics can be held. The panel is 90x100mm and the electronics panel is 69x83mm in order to fit two UTJ solar cells. There lies a nonconductive path between the antenna plane and the electronics plane to maintain isolation. It is shown in purple, which represents FR4, in Figure 1. The gaps from outer corner to outer corner measure approx. 4.2mm.

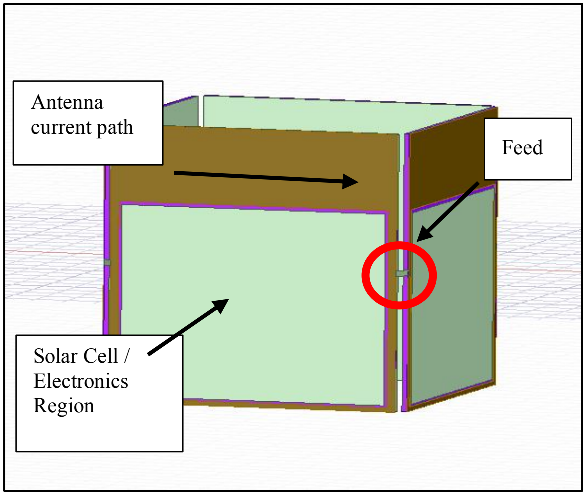


Figure 1 HFSS Model of Solar Cell Prototype.

An E-Field simulation was done to ensure that the antenna was radiating out of the gaps and that the electronics planes were not affecting the pattern. Figure 2 proves that the radiation occurs at the air gaps.
The quadslot antenna produces a semi-omnidirectional radiation pattern similar to a dipole. There are stronger nulls at 0° and 270° but its gain is more than double that of a dipole. An ideal half-wavelength dipole radiates at 2.15dB and this antenna emits 5dB. Reference Figure 3.

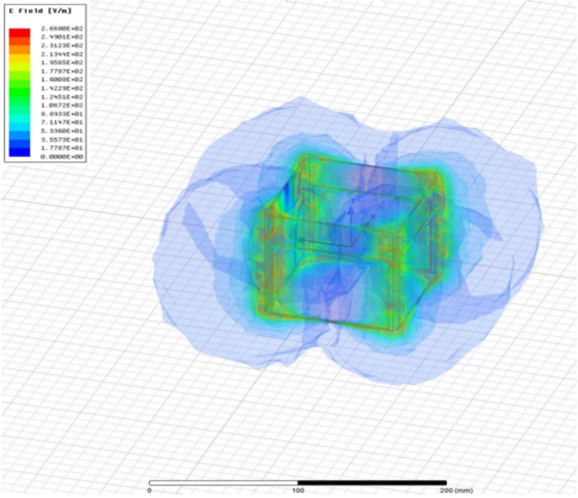


Figure 2 HFSS E-Field Pattern of Solar Cell Prototype.

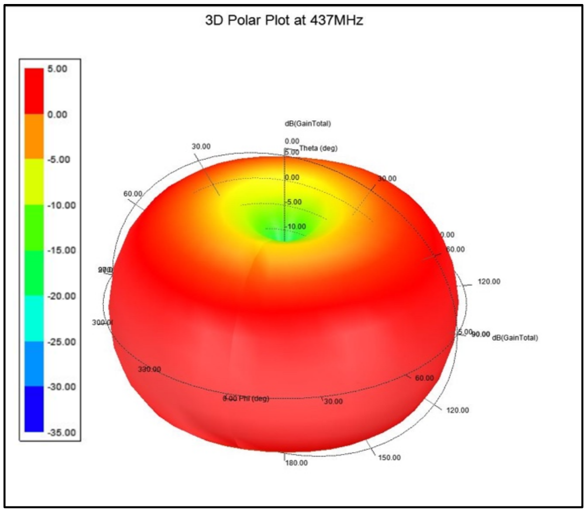
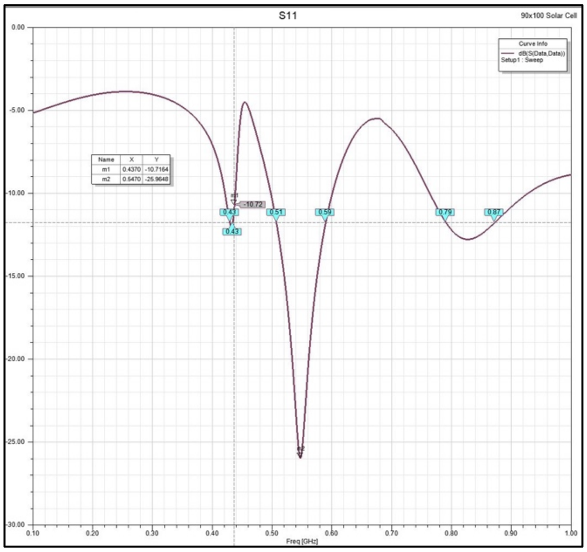


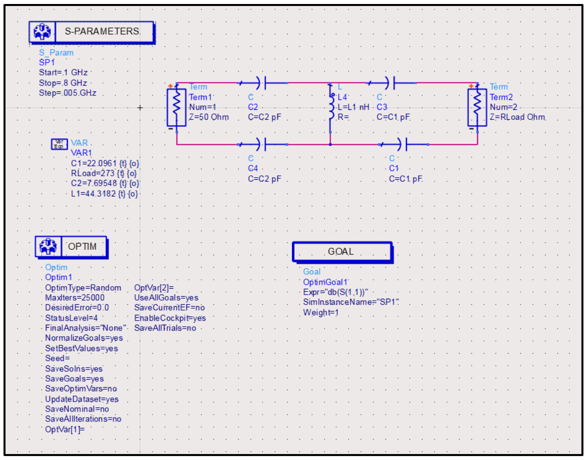
Figure 3 HFSS 3D Polar Plot of Solar Cell Prototype.

Another important parameter to view is the S11. This antenna performed -8dB or less between 390MHz and 450MHz as shown in Figure 4. The S11 needs to be -10dB in order to obtain a VSWR equal or less than 2. The last simulation solves what kind of tuning circuitry to develop since the impedance of a quadslot is 273Ω[3]. ADS optimization feature resulted in four capacitors in series with one inductor in parallel with values of 22.1pF, 7.69pF, and 44.3nH respectively. See Figure 5.



Name	X	Y
m1	0.4370	-10.7164
m2	0.5470	-25.9648

Figure 4 HFSS S11 Result of Solar Cell Prototype With -10.72dB at 437MHz.



S_Param
SP1
Start=.1 GHz
Stop=.8 GHz
Step=.005 GHz

VAR
VAR1
C1=22.0961 {t} {o}
RLoad=273 {t} {o}
C2=7.69548 {t} {o}
L1=44.3182 {t} {o}

Optim
Optim1
OptimType=Random
MaxIters=25000
DesiredError=0.0
StatusLevel=4
FinalAnalysis="None"
NormalizeGoals=yes
SetBestValues=yes
Seed=
SaveSolns=yes
SaveGoals=yes
SaveOptimVars=no
UpdateDataset=yes
SaveNominal=no
SaveAllIterations=no
OptVar[1]=
OptVar[2]=
UseAllGoals=yes
SaveCurrentEF=no
EnableCockpit=yes
SaveAllTrials=no

Goal
OptimGoal1
Expr="db(S(1,1))"
SimInstanceName="SP1"
Weight=1

Figure 5 ADS Schematic of Antenna Tuning Circuit.

Meander Line

The meander line antenna serves the same purpose as the solar cell however it cannot hold electronics and radiate together. This design is a proof of concept to prove that a UHF antenna can fit the cubesat standard[2]. The meander lines shown in Figure 6 are known as Koch Patterns[4]. These lines force the electrical path to be longer without having to increase the physical size. Since the antenna feed views these as slots, it will radiate through the fractals which means no electronics can cover the panels.

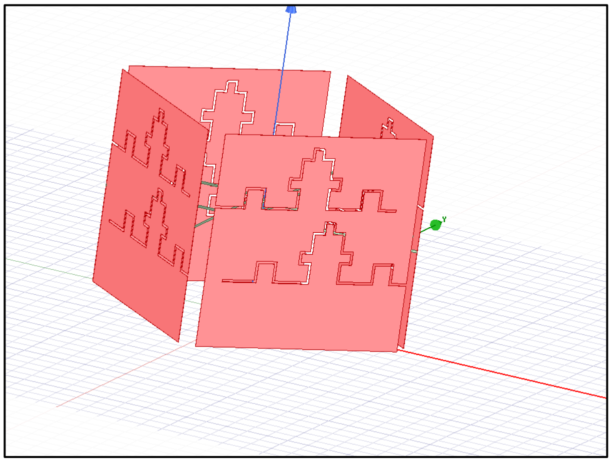


Figure 6 HFSS Meander Line Prototype.

PROTOTYPES

Solar Cell

Two prototypes were built for testing purposes. Since manufacturing plays a large role in signal integrity, a second prototype was built to measure these effects and confirm repeatability against simulation design. The first prototype shown in Figure 7 tested the radiation pattern with and without power to the electronics panel. These results prove the electronics panel has no effect on the antenna. A resistor was placed on the electronics panel with 2W of power applied to mimic a solar cell while measurements were taken in the anechoic chamber. There was a small offset in the chamber positioner hence the tilt in the pattern even though every test was normalized to 0°. The nulls should be located at 0° and 180°.

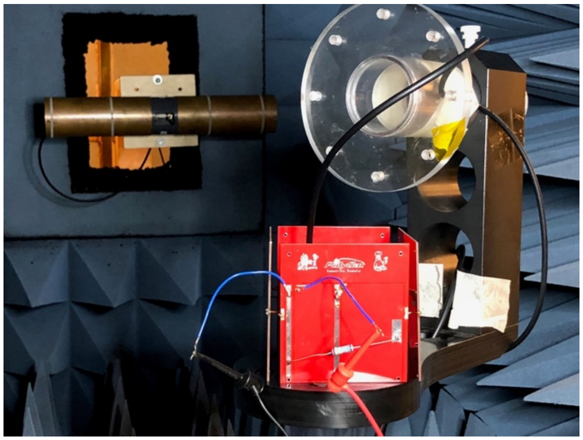


Figure 7 Prototype 1 in the Anechoic Chamber at Cal Poly SLO.

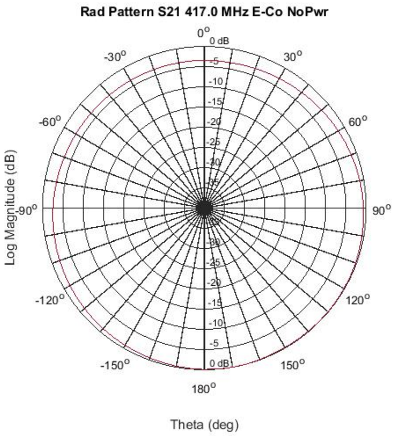


Figure 8 E-Co Radiation Pattern With No Power

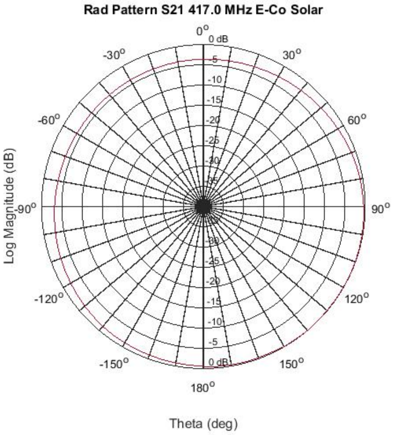


Figure 9 E-Co Radiation Pattern with Power

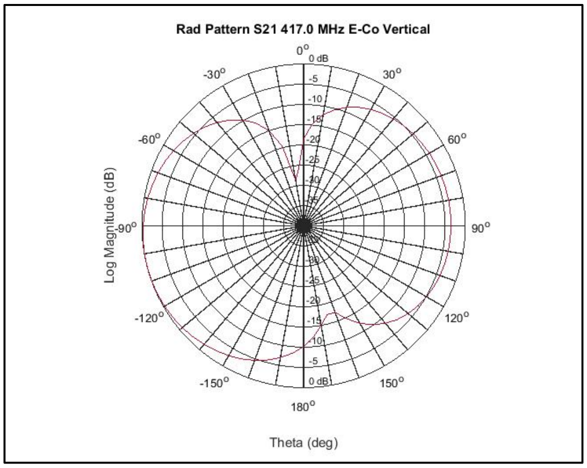


Figure 10 E-Cross of the Solar Cell Prototype 1.

The second prototype was used to test the gain of the antenna. Two broadband dipoles were measured to obtain a reference point as shown in Figure 12 and the model in Figure 14. The two dipoles have a S21 of -1.1533dB at 469MHz. The quadslot has an S21 of a -2.2975dB. However, the quadslot has an RF feed network that introduces insertion loss that the dipole does not have. The power dividers, baluns, and RF taps introduce 2.2dB insertion loss alone. Figure 14 is the dipole antenna used to test S21. Its RF feed is directly placed whereas the quadslot has a tuning stage at each slot before transmitting.

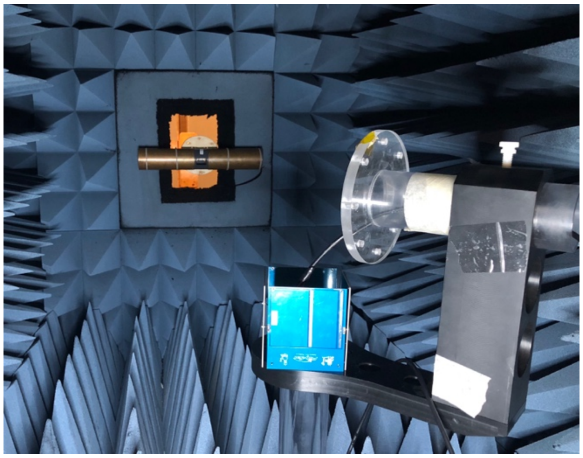


Figure 11 Prototype 2 in the Anechoic Chamber at Cal Poly SLO.

Below shows the loss between two of the dipole antennas. These antennas were built at Cal Poly for a previous project, but provides the correct frequency to test the quadslot. This also proves that these antennas have approximately -3dB loss when compared to an ideal dipole. This shows that manufacturing plays a large role. If professionally done, both antennas would be closer to ideal.

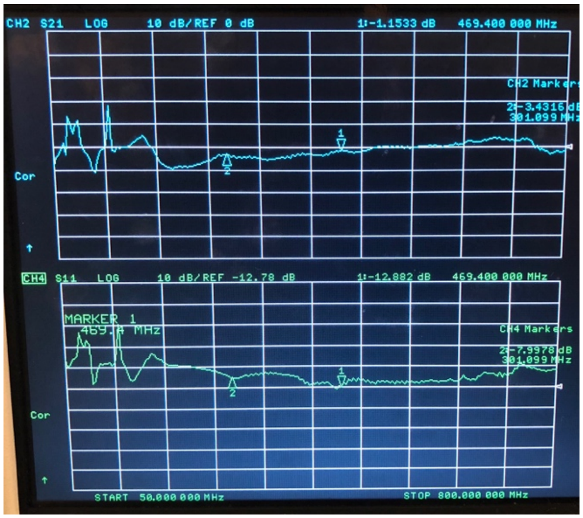


Figure 12 S21 and S11 of The Broadband Dipole Antennas.

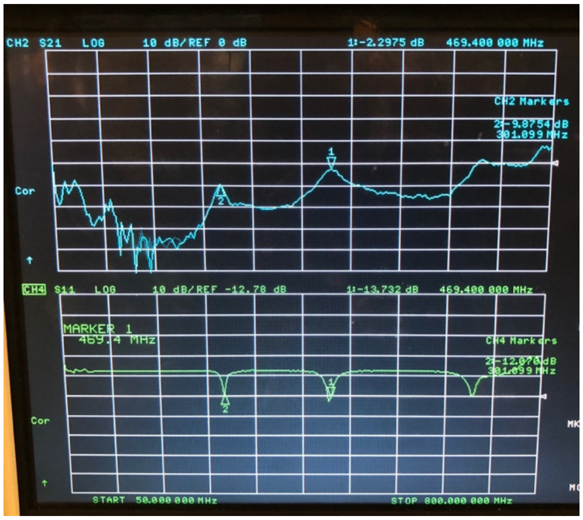


Figure 13 S21 of Solar Cell Prototype 2.

Figure 14 Broadband Dipole Viewing the RF Feed Built at Cal Poly.

Meander Line

The meander line prototype helped prove that a nondeployable UHF antenna is possible. Shown in Figure 16, the antenna has an S11 of -6.9dB at 427MHz.

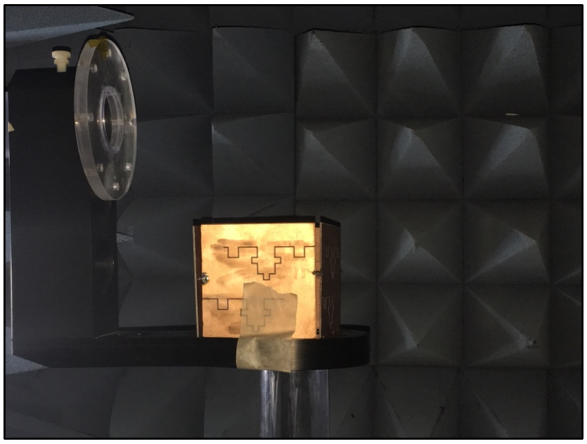


Figure 15 Meander Line Prototype.

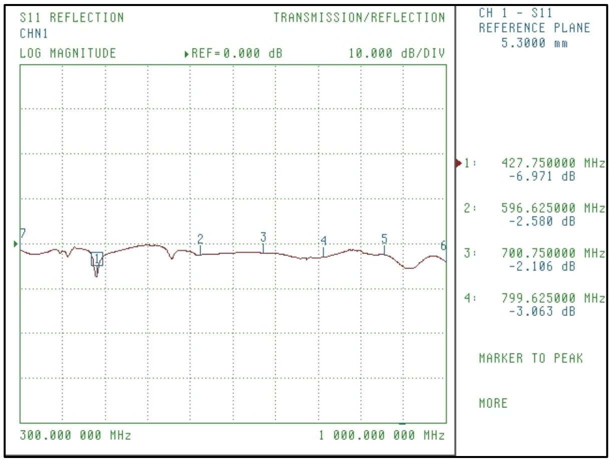


Figure 16 S11 of First Meander Line Prototype.

CONCLUSION

The success of these simulations and prototypes will reduce risk in future missions and provide a foundation for advances in antenna development. These antennas will also ease the requirements in pointing since the antennas are omnidirectional, provide higher downlink data rate, and still allow the space for solar cells and sensors.

Acknowledgments

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