CubeSat Planar Turnstile UHF Antenna

James Allen Morrison

Rice University

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The OWLSAT team designed a 4-element planar turnstile antenna based on the Oresat canted turnstile design. The original design is derived from a NASA technical document on the design of miniaturized satellite antennas. The antenna is designed for a center frequency of 435 MHz in the UHF band with a 50 ohm coax-fed feed circuit, three Mini-circuits QBA-07+ 90 degree hybrid couplers, and then four /4 monopoles made out of stainless-steel measuring tape.

Diagram, schematic

Description automatically generated

Figure 1. Schematic and line lengths

The feed circuit operates by creating 4 antenna feeds that are successively 90 degrees apart. This is accomplished by splitting the radio input by 0 and 90 degrees, then shifting the 90 degrees path by an additional 90 degrees via a co-planar waveguide (CPWG). From there the 0 and 180-degree paths are split again, which produces a 0, 90, 180, and 270 degree output to each element, respectively. The derivation for the delay line lengths is detailed in figure 2, which are based on an FR4 thickness of 62 mils and a 50 ohm CPWG calculation for propagation delay in Altium Designer (PCB design software). From this, the propagation velocity can be found from the inverse of propagation delay, which leads to the direct theoretical values for “perfectly electrically conductive” elements as well as a very accurate estimate of the delay line lengths since the Altium simulation takes into many of the parasitics aspects. Note that the schematic includes extra components such as the right-angled MMCX jack to accommodate future assembly issues if a straight jack is no longer suitable.

Diagram

Description automatically generated

Figure 2. Derivation of Element Length and Delay Lines

A final simulation in HFSS pictured in figure 4 confirmed that a much shorter element length of 132 mm is more realistic assuming the feed circuit is perfect and lossless. The expected slightly directed omni-directional pattern is cross-confirmed with MATLAB in figure 3 at a peak directivity of 2.2 dBi.

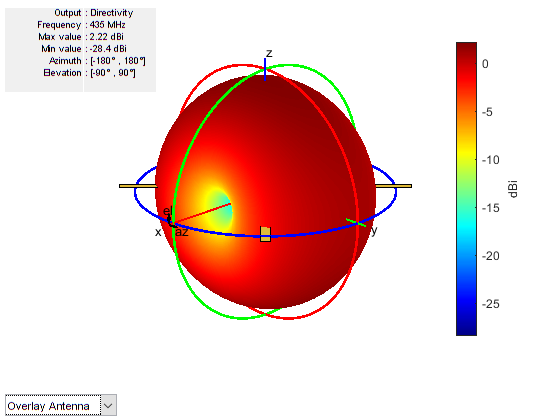


Figure 3. MATLAB Simulation

.A picture containing bubble chart

Description automatically generated

Figure 4. HFSS Radiation Pattern with Spacecraft Model

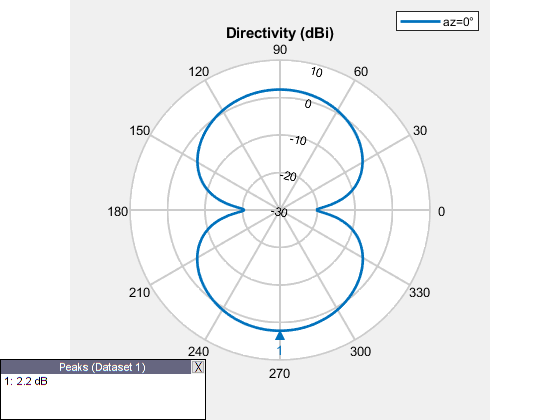
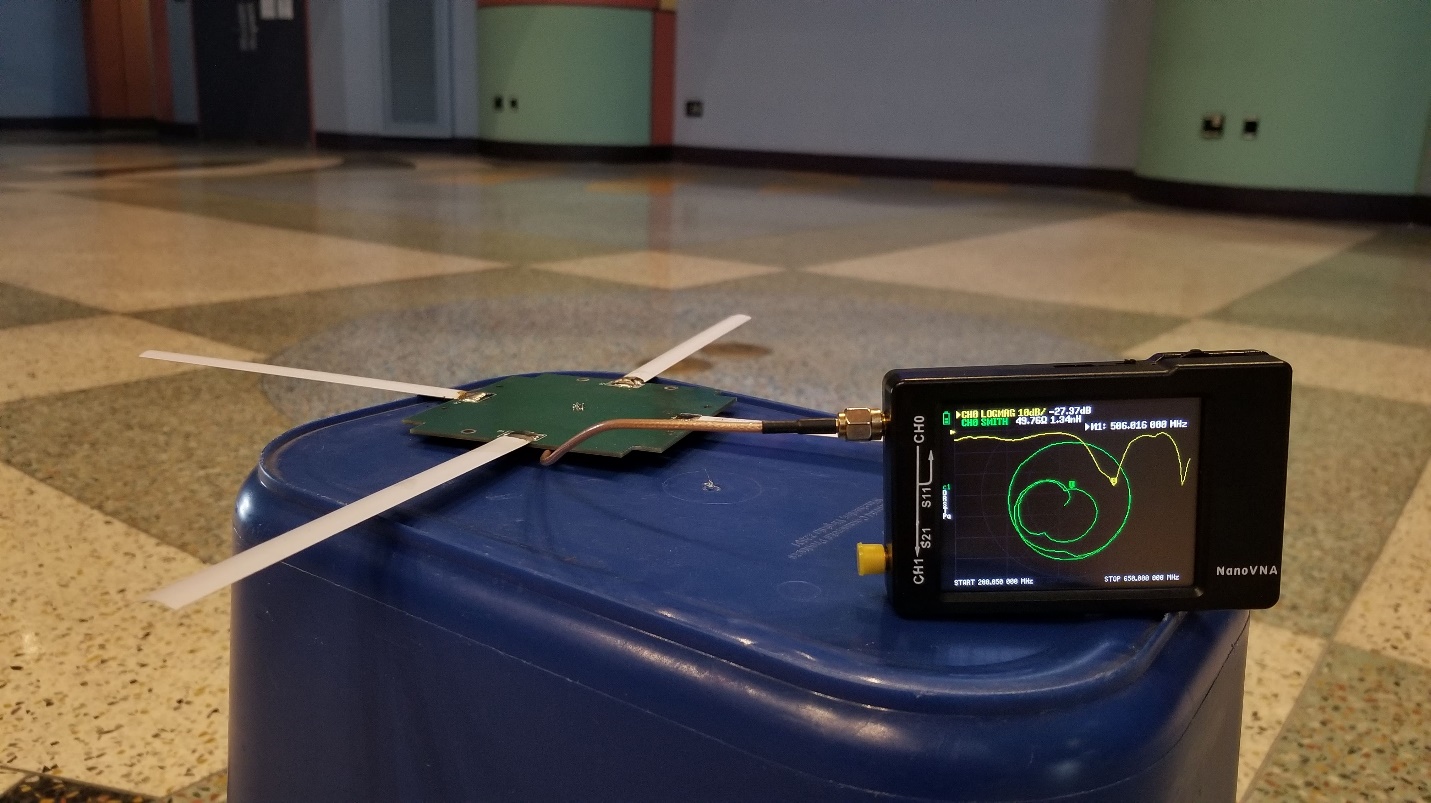


Figure 5. Simulated Elevation Pattern

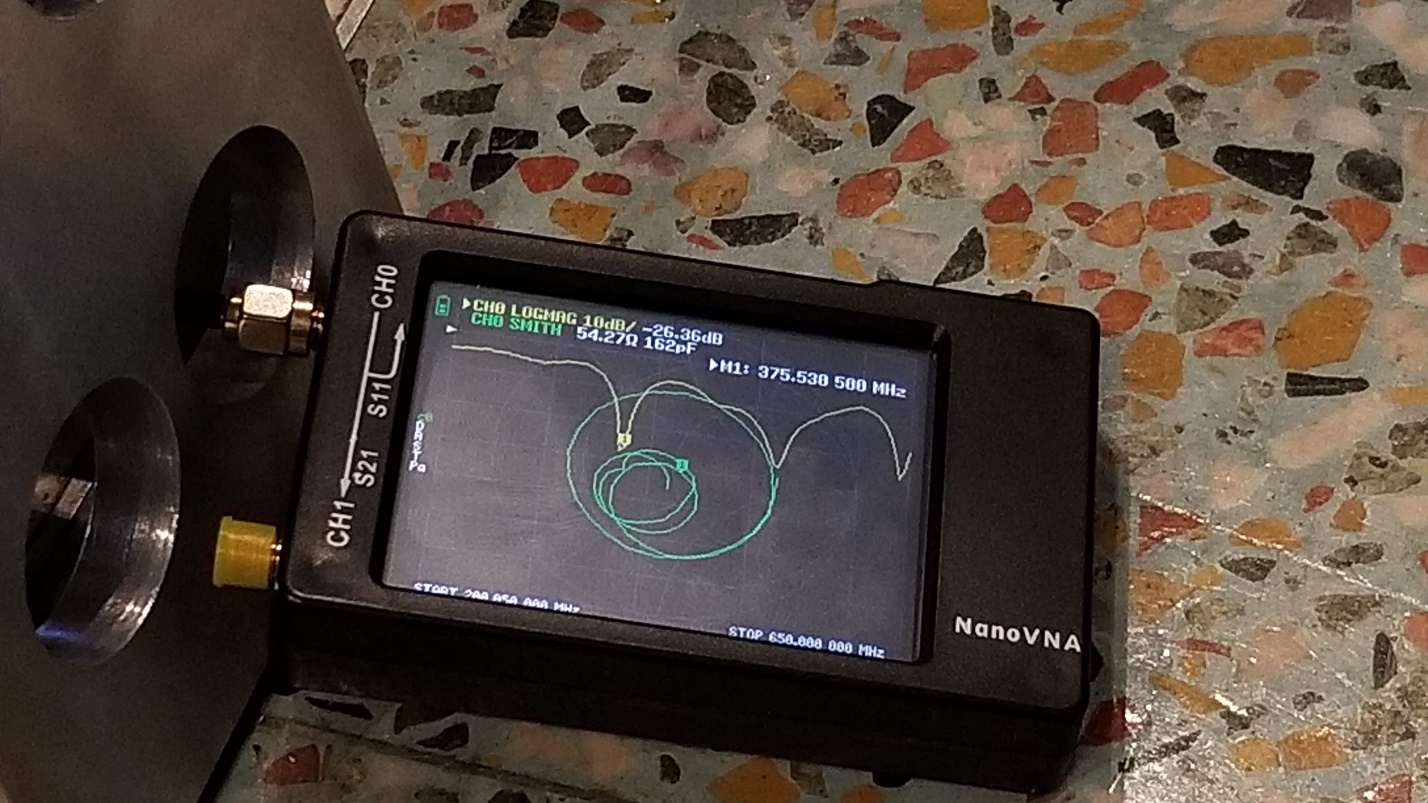
**Testing**

**Design Issue:** The board files had a mistake such that 4 circles were accidentally place on the mechanical layer of the board and were interpreted by the automated fabrication process through Advanced Circuits to be non-plated through holes (except for one hole that is plated!). Thankfully, this simply adds to the flexibility of the mounting options, but could have been disastrous. The cause of the circles is unclear at this time.

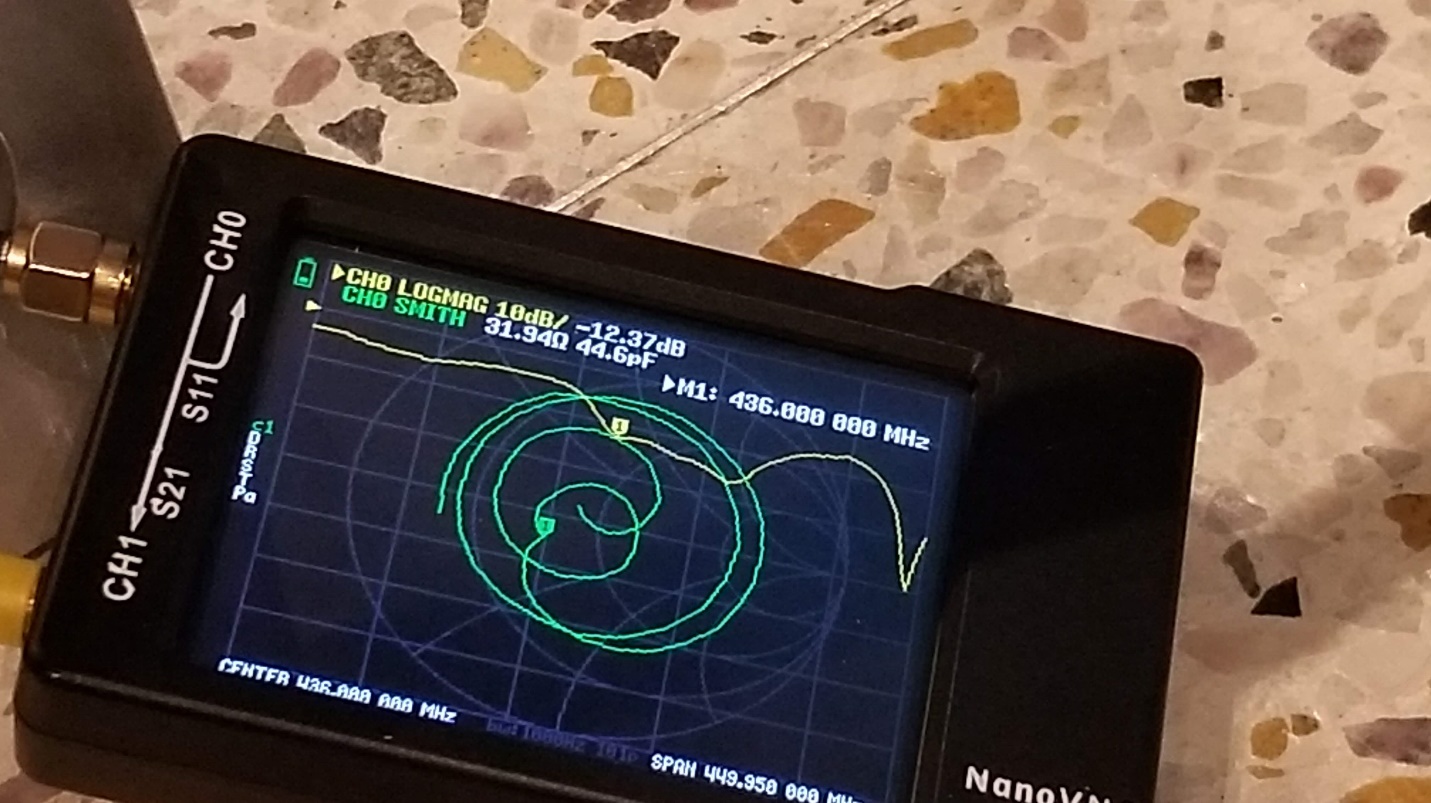
The first test used the theoretical element length of 163 mm since it is much longer than the HFSS simulated optimal value. However, as seen below, the circuit resonated at 506 MHz. The best explanation so far is that the pads added extra capacitance and the parallel traces that make up the serpentine length tuning segment, boosted the resonant frequency even after parasitics and non-idealities that should have lowered the resonant frequency.



After adding scraps to the elements to increase the length to 220 mm each, the resonant frequency dropped to 375 MHz, which confirmed that the circuit is linearly transforming with element length.



New elements were then cut to match 220 mm, then incrementally trimmed down until the 3rd fundamental resonance approached the 2nd resonance, which created a region of resonance large enough to include the 436 MHz center frequency of our transmissions (-10 dB is acceptable – meaning 90% of power is passed to antenna circuit).



It was noted here that significant VHF reflections were only noticed within a few inches of the elements and that the PCB should NOT be grounded to the structure directly through the through holes, instead grounding through the connector is desired.

The design mistake that caused difficulty in tuning and grounding is that it was assumed that since the Oresat design did not require L-Matching to the 75-ohm quarter-wavelength monopole elements, our design would greatly improve with the inclusion of a simple matching network to step the 50-ohm output of the circuit to the 75-ohm impedance of the elements. This would most likely merge the 1st and 2nd resonance regions together such that it would be easier to match the antenna to 436 MHz.