Comparison of Omnidirectional VHF Antenna Construction and in situ Performance for LEO Satellites

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Abstract

Lowering the barriers of entry with regards to building a satellite ground station is central to why a comparative analysis of easy-to-build antennas is needed. Easing access to the experience of setting up a ground station and observing passing satellites is a valuable asset to any community, and allows those who are interested in the data being transmitted, more opportunities to receive said data. The study compares the receive performance of two omnidirectional VHF antennas. Antenna performance metrics include SWR, return loss, decoded images, impedance in the VHF band, and more. Understanding which antenna performs best with minimal tedium during setup can be accounted for as a significant barrier lowering factor. As such, the study also compares the ease and practicality of each antenna build, considering skill level, cost, access to materials, and other relevant factors. The antennas under test include the crossed-dipole and quadrifilar helix (QFH), both of which are omnidirectional VHF and relatively easy to build. Both of these antennas were to operate in the two-meter band, between 146-148 MHz. Preliminary results suggest the QFH receive performance is stronger than the crossed-dipole.

Background

Assessing antenna performance and constructability are the fundamental criteria by which completion of our objective will be measured, therefore, the ensuing analysis considers the performance of two antennas operating in the two-meter band that were constructed using materials purchasable at any hardware store and tested using a VNA as well as other equipment and techniques. A quantitative comparison of homemade, LEO reception antennas is not present in any existing published material, therefore, data acquisition for the purposes of comparing the antennas had to be done. This was accomplished by ensuring that both antennas operated in the same conditions, these include location, environment, builders, measuring devices and receive parameters such as gain, orientation in space, and reception frequency.

The missions of SatNOGS, an open source hardware platform for networking satellite ground stations, the Libre Space Foundation, and our own objective of accessibility informed our choice of which antennas to build. To be in compliance with our objective, the chosen antennas had to be omnidirectional, as this is the most cost effective, and require minimal construction experience on the part of the builder. Thus, the chosen antennas were the crossed-dipole or turnstile antenna and the quadrifilar helix (QFH or QHA) antenna. Our intended receive frequency was to be at 146 MHz. This frequency would allow us the flexibility to downlink data from the NOAA weather satellites at 137 MHz, the Fox satellites, and many others operating in the two-meter amateur band.

Crossed-Dipole – Characteristics & Construction

The first antenna to be considered will be the half-wave crossed-dipole (or turnstile) antenna. The materials needed for construction included 1¼” PVC, 13 feet of ¼” aluminum rod, ¼” nuts, ring terminals, terminal blocks, LMR-195 coaxial cable, and terminating coaxial connectors. The desired reception frequency of 146 MHz dictated the length of each half of the dipoles to be 18.4” and reflectors to be 36.94”. The construction process consisted of creating four through-holes perpendicular to each other in the PVC pipe through which the halves of the driven elements were secured. Then, four more holes were drilled into the PVC, a quarter wavelength or 18.4” from the driven elements; each pair of holes were drilled in planes offset by a quarter-inch such that the two reflectors could pass through the PVC without coinciding. Next, the driven elements had to be wired. This was done by separating the inner and outer conductors and connecting them to the driven elements 180° apart. Then, the 90° phase line was cut to 18.4", where one end was spliced with the feedline and the other end was connected to the remaining driven elements [1]. The manner in which these connections were made resulted in the intended left-handed polarization [2]. The challenge of this build was with respect to the congestion of the feed point. Feed point congestion, as seen in Figure 1, is a challenging problem to remedy because antenna theory requires that the dipole is continuous from end to end despite the obvious impossibility of this in reality. Perhaps, the feed point could be a separate assembly which could be coupled to the main post in future builds.

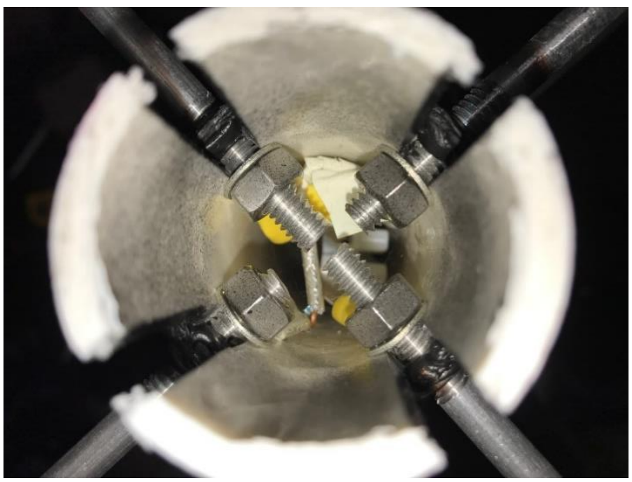


Figure 1: Crossed-dipole feed point

Crossed-Dipole – Performance

Antenna elements for the turnstile were tested with a VNA at particular steps during the building process. Since a turnstile is comprised of two dipoles 90° out of phase, each dipole was tested to verify if it was working at 146 MHz. For the first dipole to undergo VNA testing, the VNA plot of return loss vs. frequency revealed a dip at 138.4 MHz instead at 146 MHz. This result provided the realization that theoretical conditions make assumptions that cannot be ignored in application; frequency has a linear relationship with the length of the dipole, hence the concept of proportionality was used to make the dipole resonant at 146 MHz. I was determined that the dipole should be shortened by 5.2% after calculating the percent difference in the frequencies. After cutting down the length, the dipole was tested again with the VNA, and successfully obtained a dip at 146 MHz. Then the cross dipole was cut to the same length and verified with the VNA to ensure resonance at 146 MHz. After adding the quarter wavelength phase line and reflector the newly assembled turnstile was tested. The return loss vs frequency plot for the turnstile revealed a dip at 146MHz. Although the dip's position was right, it was not as deep as the dips of the individual dipoles. The return loss was -6.73 dB, as seen in Figure 2, for the turnstile, while the dips of individual dipoles were -27.09 dB. SWR for the turnstile at 146 MHz was 2.71; whereas, resistance and reactance at 146 MHz for the turnstile were 31.2 Ω and 36.4 Ω respectively. After this we scheduled observations through SatNOGS for weather and amateur satellites to obtain the waterfall spectrum and decoded images.

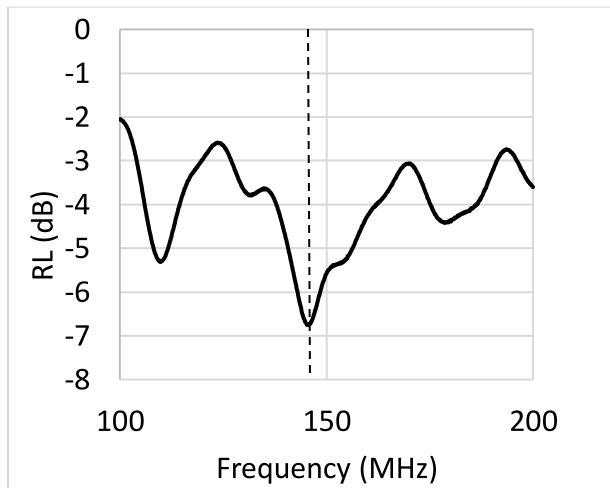


Figure 2: Measure of turnstile return loss over 100 MHz frequency sweep (dashed line denotes 146 MHz).

QFH – Characteristics & Construction

Constructing the QFH antenna was done by following instructions written in the journal QST by David P. Finell, N7LRY, titled *Build a 2-Meter Quadrifilar Helix Antenna* [3]. The materials required for this build included 2¼" PVC, 2" PVC, 2¼" to 1¾" adapter, 2' of ¼" aluminum rod, 12' of ½"-width aluminum strips, ¼" nuts, and ring terminals. The desired reception frequency of 146 MHz dictated the physical parameters of the antenna, like helix diameter and length. Two sets of four holes were drilled 18.4" apart, this set the length of each helix. The helices were made by cutting two 10" aluminum rods and securing them to each end of two of the aluminum strips. This formed a rectangle which was then twisted by stepping on one end of the assembly and turning the other end 180° by hand. This formed one of the helices, and was repeated to form the other helix. The feed point of the antenna consisted of a 1” PVC cap which was affixed concentric with a coupler at the bottom end of the helix, as seen in Figure 3. Each of the conductors of the LMR-195 coaxial cable were then separated and connected to the elements 90° offset from each other. A 90° phase line was then spliced to the feedline connections on one end, and connected to the remaining two elements on the other end. The challenge in constructing the QFH had to do with screwing the nuts onto the aluminum rods onto which threads were cut using a tap and die set. The softness of aluminum would yield to the hardness of the steel nuts when screwed on, this made fine adjustments of the nuts (which maintain the helix diameter) difficult.

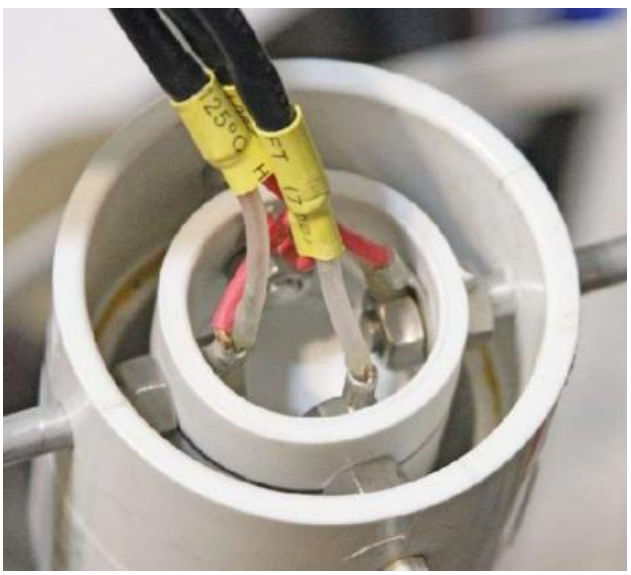


Figure 3: QFH feed point assembly

QFH – Performance

The QFH cannot be assembled in a piece-wise fashion as the turnstile was, so the QHF was tested only once everything was assembled. Once the QFH was put together, it was tested with the VNA. The return loss vs. frequency plot revealed a dip of -6.08 dB at 146 MHz, as seen in Figure 4. Also, the .csv file from the VNA test revealed a real impedance of 18 Ω, SWR of 2.97, and a reactance of -12.5 Ω.The impedance matching technique of using a choke balun apparently did not prove to be very effective. After the VNA testing, observations were then scheduled through SatNOGS for weather and amateur satellites to obtain the waterfall spectrum and decoded images.

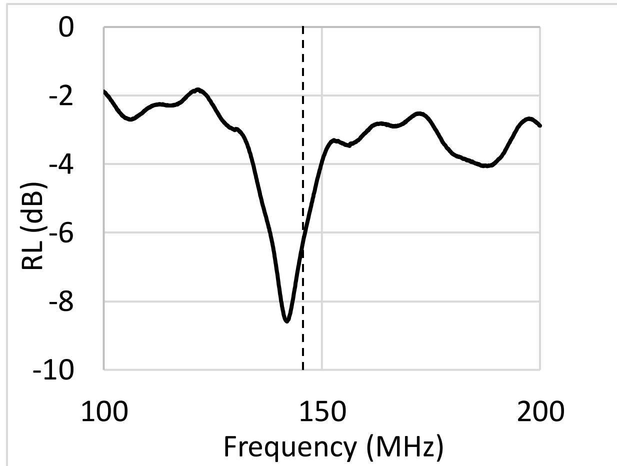
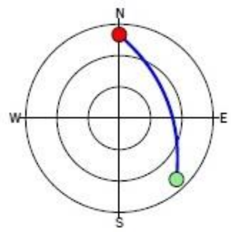


Figure 4: Measure of QFH return loss over 100 MHz frequency sweep (dashed line denotes 146 MHz).

The waterfalls in Figures 5a and 5b illustrate the disparity in the receive quality between the turnstile and QFH antennas upon reception from a NOAA-18 weather satellite. It can be seen that the turnstile's downlink strength was weaker than the QFH which maintained a reception quality of about -35 dB throughout most of the pass. This comparison, however, is an ongoing process, as neither antenna is equipped with a LNA or band-pass filter.



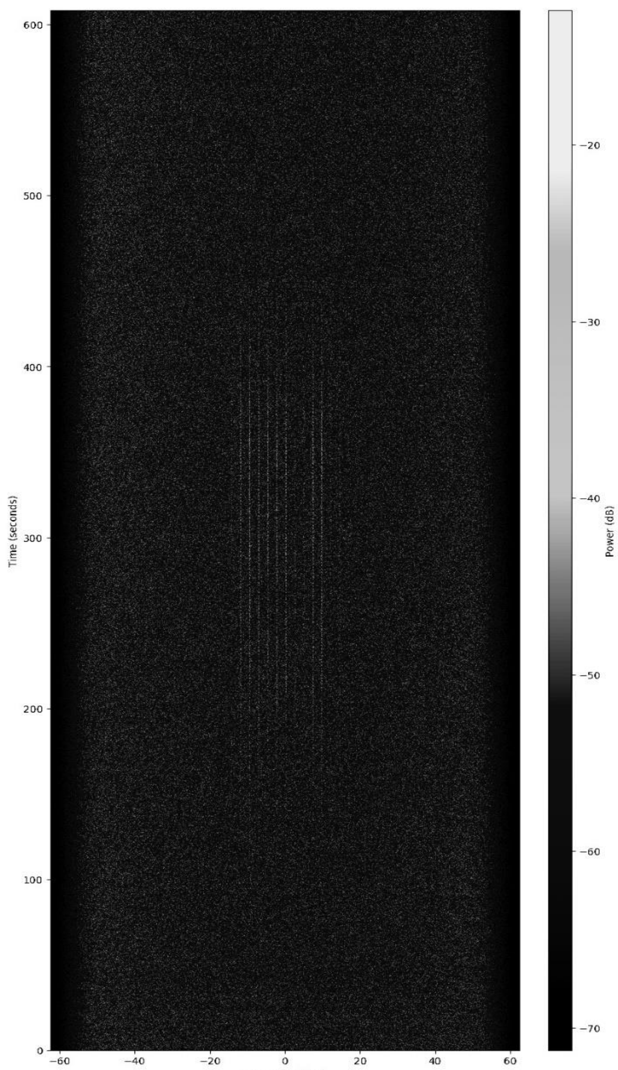


Figure 5a: Crossed-dipole waterfall representation of observation taken during a NOAA-18 pass.

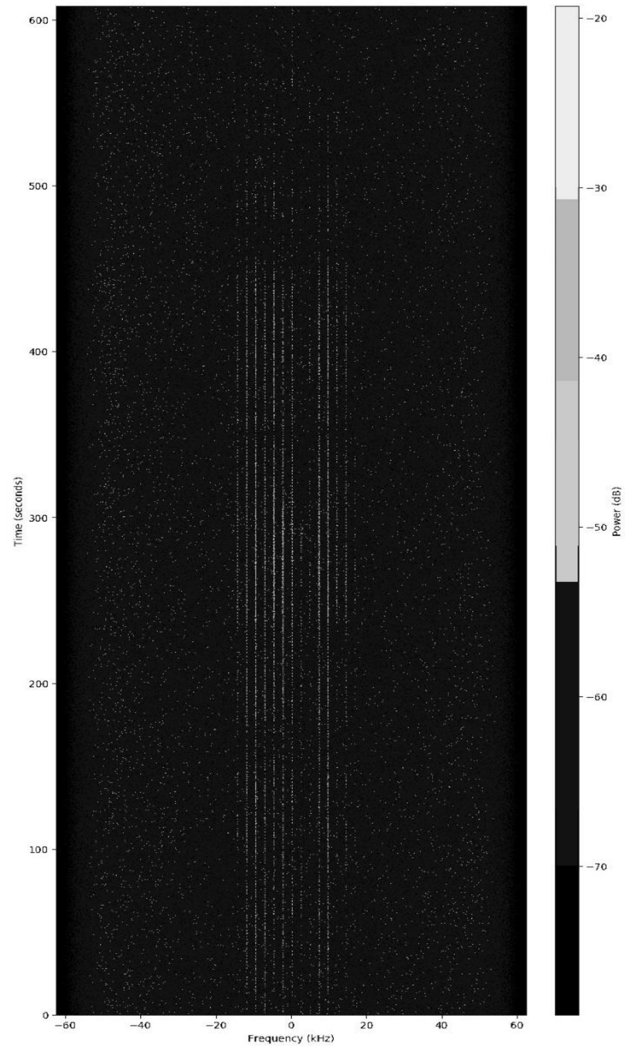


Figure 5b: QFH waterfall representation of observation taken during a NOAA-18 pass.

Conclusion

This study provides a comprehensive analysis of the ease of construction and preliminary performance of the omnidirectional VHF crossed-dipole turnstile antenna and QFH antenna. To provide a standardized analysis we maintained conditions and operating environment. Difficulties during construction were experienced during both antenna builds; an iterative approach will be taken to solve these issues to improve constructability. The initial data suggests that, through VNA plots and waterfall spectrums, the QFH exhibits better receptivity. It must also be noted that this study is ongoing and that any substantial claim on the performance of either of the antennas is dependent on the completion of a satisfactory number of test observations.

References

[1] Cebik, L.B. "A Simple Fixed Antenna for VHF/UHF Satellite Work." *QST*, QST, Aug. 2001.

[2] Adam. *DIY 137 MHz APT Weather Satellite Antenna – Or, Do We Need a Circular Polarization?* DIY 137 MHz APT Weather satellite antenna – Or, do we need a circular polarization?

[3] Finell, David P. *Build a 2-Meter Quadrifilar Helix Antenna*. QST, May 2018. Accessed 9 July 2019.