CUBESAT-TO-GROUND COMMUNICATION AND MOBILE MODULAR GROUND-STATION DEVELOPMENT

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ABSTRACT

A mobile modular ground station is described for direct communication and tracking of CubeSats from various locations. The ground station operates in the UHF range and employs a circularly polarized Yagi-Uda antenna. A two-piece wooden antenna base with a telescoping mast was constructed for mounting the antenna. For an orbit height of 600 km, satellite transmit power of 27.0 dBm, satellite antenna gain of 5 dB, and ground station antenna gain of 19.1 dBic, the calculated signal power at the ground station is -89.9 dBm and the calculated signal power at the transceiver is -70.9 dBm. The mobile modular ground station successfully tracked three CubeSats named CubeSat XI-IV, Cute-1, and Quakesat.

INTRODUCTION

Nanosatellites are a class of small satellites that have a mass between 1-10 kg [1]. Within this class is the so-called CubeSat that is a 10-cm cube with a mass of up to 1 kg [2]. Most of these satellites can fit in the palm of your hand and perform sensing missions or technology demonstrations. Typically, CubeSats are launched as secondary payloads into a circular sun-synchronous low-earth orbit at 500-600 km [2]. Eventually the satellite de-orbits due to Earth's gravity and burns up in the atmosphere. Compared to conventional large satellites, CubeSats are easily deployable and can potentially be used for natural disaster evaluation and for battle line assessment. The development time for a CubeSat is roughly one year with constant improvements in each generation. Distributed networks of CubeSats are also promising alternatives to conventional large single satellites.

The ground station is of primary importance for mission success as it is the first and final piece in the communication link. Its main purpose is to track and receive data from CubeSats for data analysis. Since all communication with CubeSats is done wirelessly, the ground station serves as the access point on Earth. A simple example is the cellular phone. As long as you are in the range of a base station, you can make and receive calls. Going out of that range means that you have no reception and are cutoff from communication. Therefore, without a ground station, the CubeSat is useless.

A basic ground station consists of hardware and software to transmit and receive data reliably. The components include transmit and receive antennas, a computer programmed with orbital-prediction software compatible with the hardware for auto- tracking, and a transceiver to transmit and receive data. The antenna's input return loss should be measured with a network analyzer to ensure that the maximum amount of the transmitted power transfers to the antenna. Conventional ground stations are stationary and therefore can only be used in a single location. This makes the station useless if it is needed at another location. Mobility of a ground station is important because it allows for use in remote locations. With a mobile ground station, the ground station operator is able to access the satellite at different points on earth to analyze the data that is received.

GROUND STATION DESIGN

The design of the ground station is based on the Friis Transmission formula, the physical constraints that the University of Hawaii's location, and the design of the University of Hawaii's first CubeSat, named Mea Huaka'i or Voyager.

By using the Friis Transmission Formula, a simplified model of the CubeSat-to- ground station communication link can be calculated.

$$P_r\,[\text{dBm}] = P_t\,[\text{dBm}] + G_t\,[\text{dB}] + G_r\,[\text{dB}] - 20*\log_{10}(4\pi R / \lambda) \qquad (1)$$

The transmit power (P_t) of the ground station and satellite, the receive power (P_r) at the ground station and satellite, and the gain of the ground station and satellite antenna (G_t,G_r) can be determined for a certain frequency of operation and distance (R) of the communication channel. The frequency of operation determines the wavelength (λ).

Mea Huaka'i was designed to work at a frequency of 436 MHz, with a transmit power of 27.0 dBm, a quarter-wavelength whip monopole antenna gain of 5 dB [3], and have a circular sun-synchronous orbit at an altitude of 600 km. The maximum distance that can be experienced in a single pass is 2,830.9 km, at the horizon, and the minimum distance is 600 km, at a location directly above the ground station. The free space loss, which is the last term in (1), is -154.3 dB at 2,830.9 km and -140.8 dB at 600 km. The ground station antenna was chosen to be a commercial-off-the-shelf M2 436CP42 U/G which is a circularly-polarized Yagi-Uda antenna with a gain of 19.1 dBic. Therefore, the maximum power received at the ground station location is -89.9 dBm and the minimum power received at the ground station is -103.4 dBm. The Friis Transmission Formula is a simplified model that does not include the effective noise temperature, pointing losses, and coaxial cable losses. The coaxial cable chosen for the ground station was Belden 8214 RG-8 with a loss of 1 dB per 25 feet. Therefore a SP-7000 Super Amp GaAsFET Series 432/435 MHz mast-mounted low-noise amplifier (LNA) was included immediately after the Yagi-Uda antenna for a minimum signal to noise ratio of 9 dB and a signal amplification of 20 dB. The antenna's input return loss was measured with a Hewlett Packard network analyzer at a center frequency of 435 MHz to ensure a low input return loss.

The University of Hawaii at Manoa has several physical obstructions that can hinder wireless communication. They include wide-tall buildings made from concrete, glass, and other types of materials, and Manoa Valley to the north, which consists of high mountains and thick cloud cover. This eliminates the options of placing a permanent ground station at ground level because the window for communication would be too small. Therefore, a higher elevation for a ground station was needed. A permanent on- campus ground station placed on the top of Holmes Hall was initially proposed, but the rules and regulations prevented the construction of student-designed structures on top of buildings. This eliminated the possibility of a permanent ground station at a suitable height. Therefore, a mobile modular ground station was designed to achieve the option of possibly using a higher location for tracking.

The mobile modular ground station hardware consists of a collapsible quad-pod which is connected to a foldable square base, as shown in Figure 1 and 2, respectively.

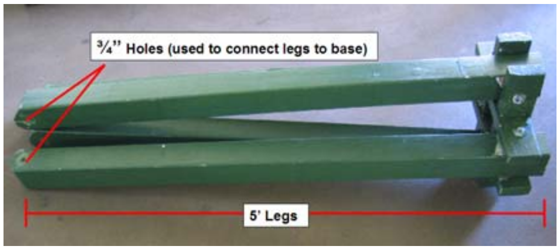

Figure 1: Quad-pod of antenna base

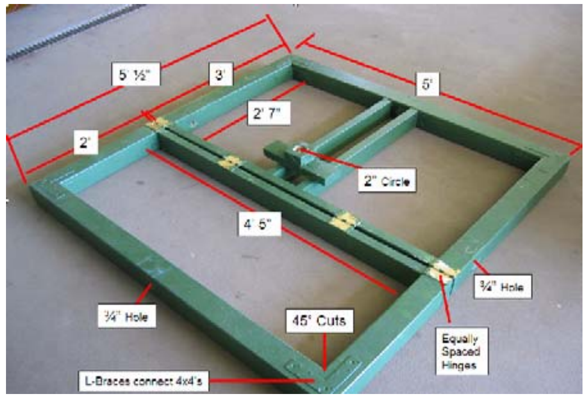

Figure 2: Square bottom of antenna base

The quad-pod and square base were chosen to be constructed out of wood because it is heavy enough to support the rotator, fiber glass boom, and antennas in light winds, but not so heavy that it would be too hard to move. The telescoping mast is provided to obtain unobstructed rotation of the antenna-boom assembly. The fully assembled mobile modular base is shown in Figure 3.

Figure 3: Fully assembled ground station set up

The mobile modular ground station software consists of a laptop computer that is programmed with NOVA for Windows (NOVA), a Yaesu G-5500 elevation-azimuth dual rotator controller, and a Yaesu GS-232A computer interface. The main reason why NOVA is chosen as the primary software is because it is compatible with the computer interface and rotator controller and provides auto tracking. This program allows us to automatically track CubeSats and predict the time, elevation and azimuth level for satellite passes. This program uses Keplerian elements to make all of the calculations. The total system block diagram is shown in Figure 4.

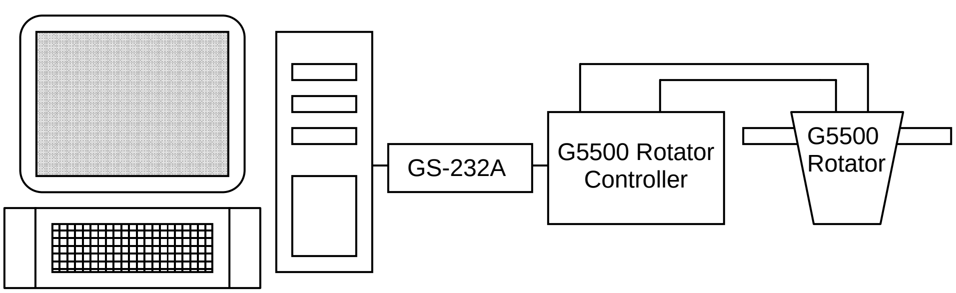

Figure 4: System block diagram

FABRICATION AND ASSEMBLY

The mobile modular base was constructed using wood from a local hardware store. The quad-pod was made from 4x4 beams and the square bottom was made from 2x4 beams. With the help of Kaneohe City Mill and other CubeSat students we measured and cut the wood to meet the specified design. Each section was connected using straight and L-brackets, nails, and wood glue. The folded portion of the wood base was connected with copper door hinges. The extendable mast was constructed using two fence posts, one with a larger diameter than the other and both having the same length. Three holes were drilled through the larger diameter post. The first hole was drilled 5.5 inches above the bottom and two are drilled 4.25 and 7.5 inches from the top of the post. Two holes are drilled at the bottom of the inner post. These two holes were drilled inline with the two in the outer post. To connect the quad-pod to the square base post holders, 6-inch long, 0.5-inch diameter bolts and nuts were used. The telescoping mast is than inserted in the connected base, as shown in Figure 6. On top of the mast a Yaesu G-5500 rotator is connected and finally two fiber glass booms are attached to the rotator at the two opposite ends the VHF and UHF Yagi-Uda antennas are placed. A Yaesu FT-847 dual VHF/UHF input/output transceiver is connected to the 435 MHz antenna by using type-N connectors and 25 feet of RG-8 coaxial cables.

Figure 5: Complete raised VHF/UHF mobile-modular ground station

EXPERIMENTAL RESULTS

The UHF Yagi-Uda antenna's input return loss was measured using a network analyzer at two different antenna lengths to ensure that it had a lowest nominal value. The antenna's input return loss was first measured for its entire length of 21 elements. The value was measured to be -17 dB after tuning and the measured input return loss for 13 elements of the antenna was -21 dB after tuning.

The mobile-modular ground station was tested on four separate occasions. During the final three occasions four signals were received from three different CubeSats; they where Cute-1, CubeSat X-IV, and QuakeSat. The operating frequencies of these CubeSats were 436.837.500 MHz and 436.675 MHz.

ANALYSIS AND DISCUSSION

A mobile-modular ground station was designed and built. The ground station was designed to provide reliable communications with CubeSats, while being mobile. The ground station was tested for its operation in the UHF range and the results were good. As mentioned in the preceding section, an antenna length of 21 elements has a higher input return loss than an antenna length of 13 elements. Although the shorter antenna has a lower input loss, the gain of the antenna decreased because the number of elements of the antenna decreased [4]. I decided to use the shorter portion of the Yagi-Uda antenna because the gain of the antenna does not decrease linearly with the number of elements and the gain curve flattens out as the number of elements exceeds 10 elements [4]. Therefore, I was able to decrease the input return loss by over two times while maintaining a high gain of the antenna. As stated the ground station was able to receive signals from three different satellites during four different attempts. The first attempt failed because we did not account for Doppler shift, which is a change in the observed frequency of a wave occurring when the source and observer are in motion relative to each other, as seen in Figure 6, with the frequency increasing when the source and observer approach each other and decreasing when they move apart. In the final three tries we accounted for the Doppler shift and were successful in tracking Cute-1, CubeSat XI-IV, and QuakeSat.

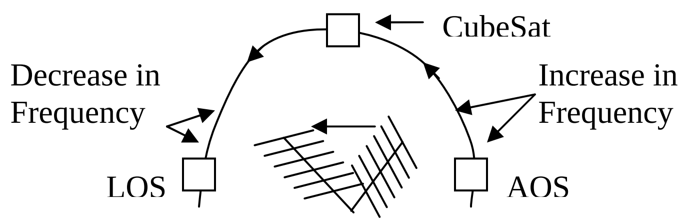

Figure 6: Diagram of Doppler shift

CONCLUSION

A mobile modular ground station was designed and built for CubeSat tracking and communication. Through measured data it can be seen that the input return loss is lower with an antenna length of 13 elements of the Yagi-Uda antenna. Therefore, this portion of the antenna is used instead of the entire section. The modularity of the ground station allowed the CubeSat team to test the ground station at different locations and allowed us to track at locations that would not have been available to us if we were to have a permanent ground station. We were able to successfully track three CubeSats.

Future improvements for this project would be to upgrade the tracking software to one that automatically account for the Doppler shift. Also, the VHF antenna could be measured and calibrated for a low input return loss and could be tested similarly to the UHF antenna. Once these improvements are done the mobile ground station would be able to join the CubeSat community set forth by Cal Poly San Luis Obispo.

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