A Low Cost Ground Station Setup for Introducing Undergraduate Students to Satellite Reception and Radio Astronomy

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Abstract

A satellite ground station, being the only point of contact with satellites, needs to be receptive over a large frequency range. It also has to be efficient enough for clear and continuous data reception. Hence, antennas form an essential part of a ground station. Therefore, we have strategically chosen six specific antennas and analysed them to obtain seamless reception as well as scanning of signals over HF, VHF, UHF, L band, and S band, along with one horn antenna to detect the H I (1420.4 MHz) frequency. The antennas can also receive linear as well as circularly polarised signals. In this paper, we discuss the design of the ground station along with its results with an aim to serve as a succinct reference for beginners in the field.

1. Introduction

The six antenna ground station at MIT-WPU campus is designed to introduce students to wireless communication through laboratory assignments for undergraduate and graduate courses where students transmit, receive, and process analog and digital signals in multiple bands (HF, VHF, UHF, L band, S band) as well as introduce students to fundamentals of radio astronomy by using a horn antenna for receiving the 21 cm hydrogen line at a low cost of $4000 for the entire six antenna setup including all electronics components [4]. In this paper we discuss the design of our ground station along with simulations of all six antennas along with their results and we have also described the entire ground station setup in detail along with receptions from the International Space Station and the Meteor-M-2 satellite using our ground station.

The antennas are connected to various frequency-band specified low noise amplifiers (LNA) and band pass filters connected via LMR400 coaxial cables followed by HackRF One SDR connected to the mission PC for providing better attenuation and reduction in noise. The HackRF One SDR covers 1 MHz to 6 GHz operating frequencies thus enabling it to support a variety of satellite receptions using open-source hardware, thus making it a software-driven satellite ground station. [3] The modular design of the ground station facilitates reconfigurability using different software frameworks [5-9]. The three antennas: dish, cross-yagi and horn are mounted on an automatic antenna rotator which can track satellites using the ASCOM driver. The antenna rotator attached to the horn antenna is used to point the antenna at a specific point in the sky.

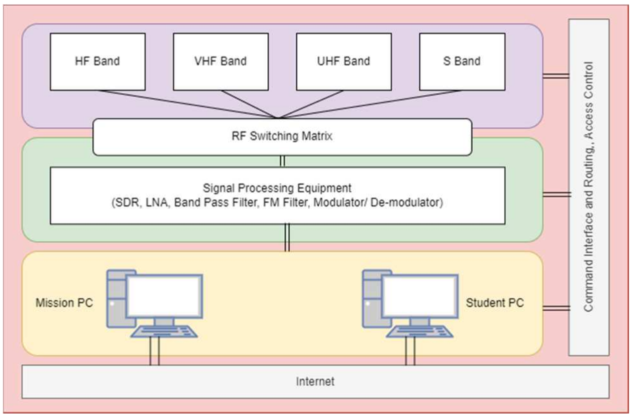

Figure 1. Overview of Satellite Ground Station Architecture

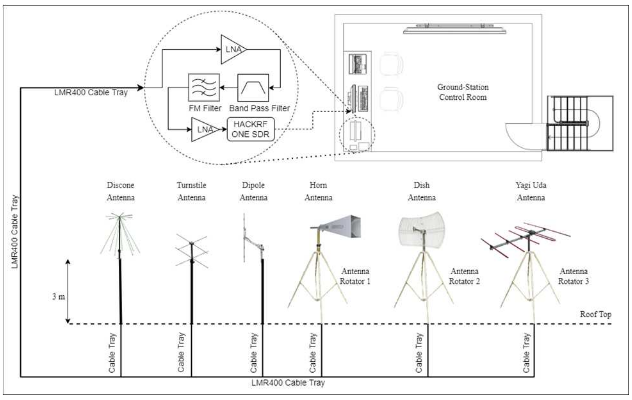

Figure 2. Layout of MIT-WPU Satellite Ground Station

2. Computational Details

Simulations were performed using MMNAGAL-Basic [10], a software based on the MININEC-3 [11] computation engine. MININEC is an independent implementation of Numerical Electromagnetics Code (NEC). All antennas were simulated with a real ground plane, an added height of 3m and with aluminium pipes.

Aluminium provides good structural strength, conductivity, low cost and resistance to oxidation. The simulation study targets a source impedance of 50 ohms, SWR < 2, and Gain >= 8 dBi. Due to the limitations of the basic version and implementation of MMNAGAL Horn antenna was simulated in the Simulink-Matlab simulation package [12].

3. Antenna Designs

Here we present the design of all six antennas.

3.1] Dipole Antenna : The Dipole designed for the ground-station is a simple half wavelength dipole with a reflector with a changeable length for reception over a larger frequency range [1]. The dipole for the frequency of 137 MHz has a length of 1.03 m. The distance separating the reflector and the dipole is 0.53 m, that is, the quarter wavelength distance. The source for the dipole is placed at its centre.

3.2] Dish Antenna : The parabolic grid antenna consists of two reflectors, namely, a parabolic reflector and a grid reflector. The dipole antenna acts as the exciter which is placed between two bowtie antennas [1]. Use of two reflectors maximise the signal towards the dipole exciter. [4] The parabolic reflector has a focal distance of 0.2 m. The grid reflector has a ground plane length of 0.072 m, ground plane width of 0.062 m and a spacing of 0.028 m from the antenna element. There are two triangular bowtie antennas having a flare angle of 20.6° and a length of 0.062 m each. They are separated by a distance of 0.05 m. The dipole antenna is of length 0.013 m and width of 0.604 m. There are four wire stacks each of length of 0.021 m, width of 0.604 m, tilt angle of 5.71° and title axis of Z. The grid antenna and the parabolic reflector are 0.2 m apart.

3.3] Horn Antenna : The pyramidal horn antenna is a radio telescope made from aluminium sheet metal simulated for 1420.4 MHz [1]. The flare length is 0.695 m, flare width is 0.744 m, flare height is 0.590 m. The length of the waveguide is 0.251 m, width is 0.169 m and the height is 0.105 m. The feed height is 0.053 m and the feed offset is 0.067 m.

3.4] Turnstile Antenna : The proposed turnstile antenna is a crossed dipole antenna simulated for the central frequency of 145 MHz, the length of each dipole being 0.968 m. The turnstile antenna is also accompanied by a reflector each of length 0.968 m parallel to the antenna along the negative side of the Z-axis separated by a distance of 0.549 m.

3.5] Discone Antenna : The discone has a mast of diameter 35 mm and height 0.581 m. It consists of 6 lower radials of 0.353 m each and 8 upper radials of 0.113 m each. The upper radials are normal to the mast and the lower radials have a zenith angle of 135°. The angle of separation between the upper radials is 45° and that of the lower radials is 60°. It is made completely of stainless steel.

3.6] Cross-Yagi Antenna : The Cross-Yagi antenna is designed with 4 directors placed along the positive x-axis and with a single reflector placed behind the dipole for receiving dual band (VHF, UHF) signals. [5] The leftmost element is the reflector which is also the biggest element of our antenna with a length of 0.34 m. The dipole antenna of length 0.728 m is placed to the right of the reflector spaced at a distance of 0.08 m. The 4 directors to the dipole antenna are at a distance of 0.047 m, 0.153 m, 0.286 m and 0.459 m respectively. The lengths of these 4 directors are 0.323 m, 0.294 m, 0.288 m and 0.275 m.

4. Results

Table 1. Antenna simulation results

Antenna	F(MHz)	R(Ohm)	SWR	Gain (dB)
Dipole	137	51.11	1.02	7.9
Turnstile	145	50.49	1.06	8.27
Cross Yagi-Uda	435	42.31	1.18	15.16
Dish	2400	356.2	1.21	25.29
Discone	1090	54.67	1.09	6.79
Horn	1420.4	72.18	1.46	18.6

5. Receptions and Simulations

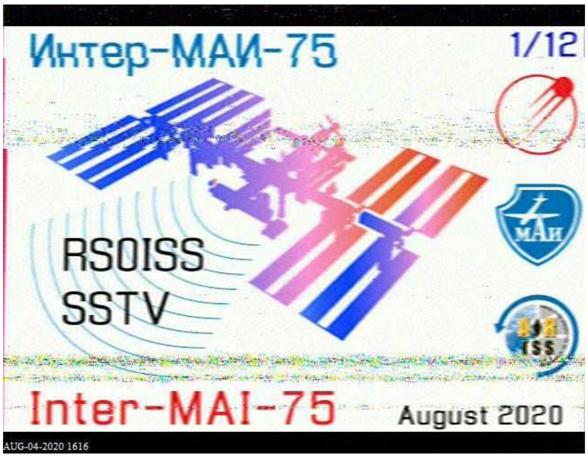

Figure 3. International Space Station ARISS SSTV reception by using our ground station dipole antenna.

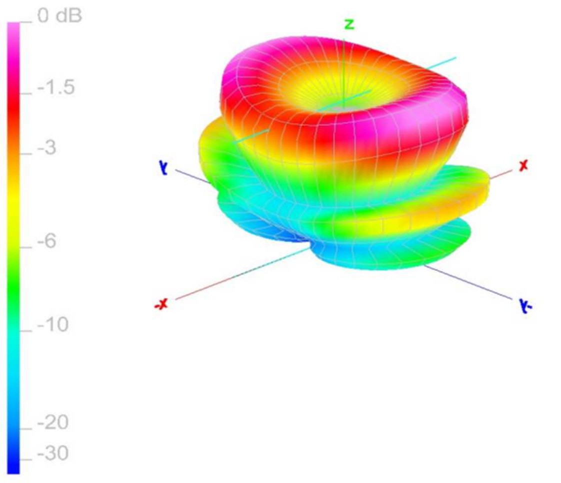

Figure 4. Dipole Reflector Antenna Radiation Pattern

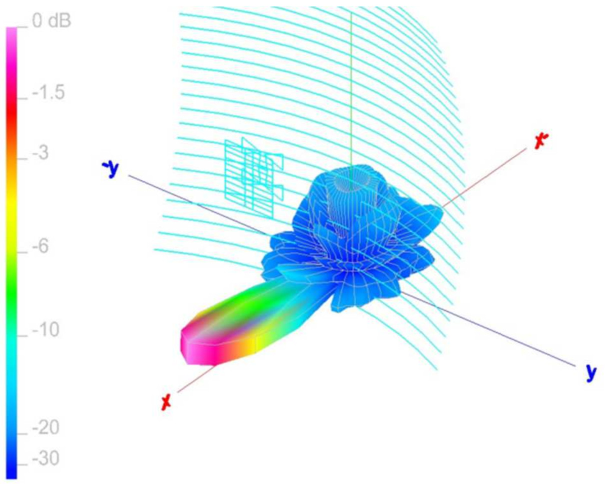

Figure 5. Parabolic Dish Antenna Radiation Pattern

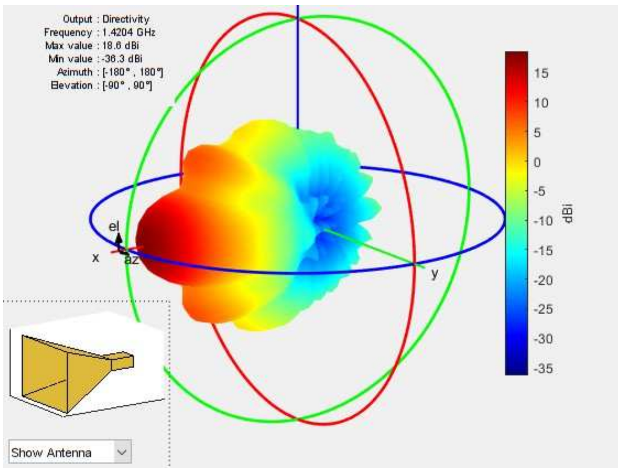

Figure 6. Horn Antenna Radiation Pattern

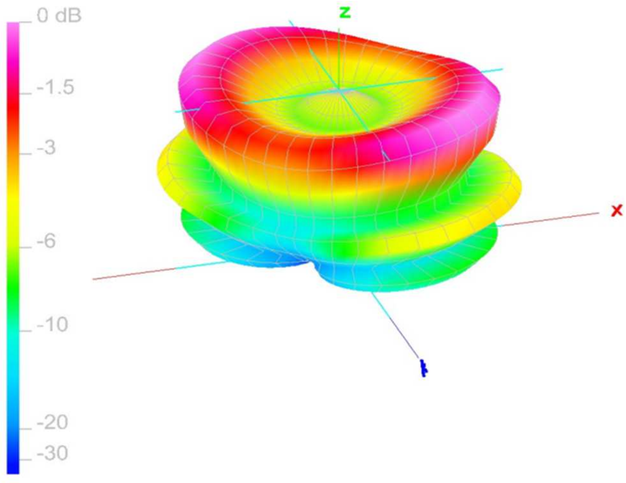

Figure 7. Turnstile Reflector Antenna Radiation Pattern

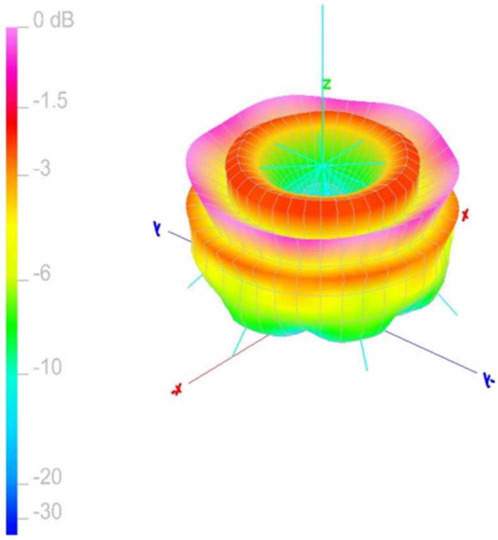

Figure 8. Discone Antenna Radiation Pattern

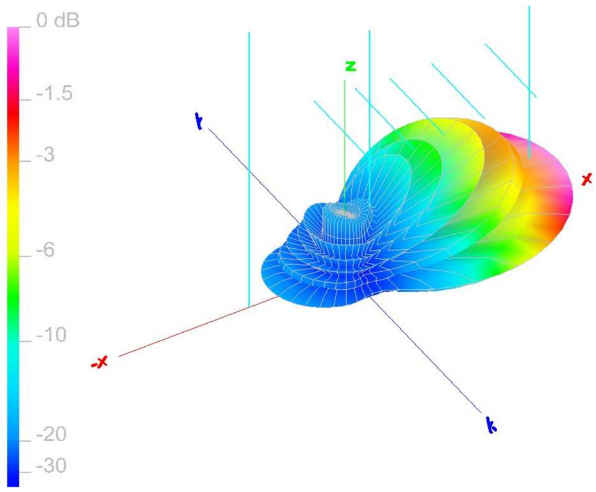

Figure 9. Cross Yagi-Uda Antenna Radiation Pattern

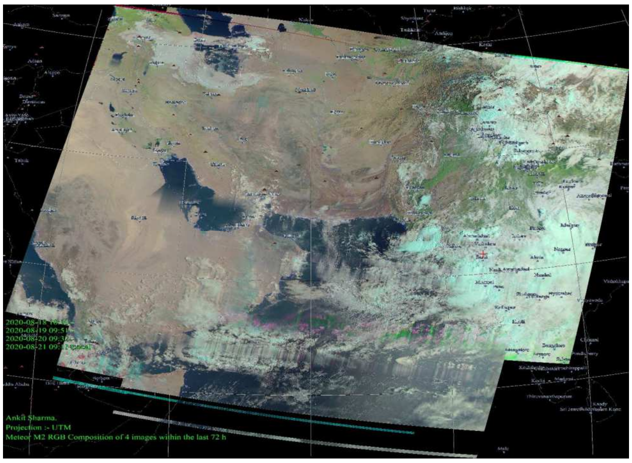

Figure 10. Meteor-M-2 reception at 137.9 MHz using our ground station turnstile antenna.

6. Conclusion

The proposed ground station has a simple, highly efficient design (SWR <= 1.5 and Gain (in dB) ranging from 6.5 dB to 25.29 dB) and with its multi-reception capabilities, the ground station can receive from a multitude of sources like satellites, terrestrial radio signals within the HF/VHF/UHF (L-band, S-band, and C-band) as well as X-band and K-band (i.e. using down converters) and the 21 cm line in radio astronomy. Custom-designed antennas provide flexibility to target specific sources with high efficiencies. The aim of the paper is to provide an excellent source for individuals and groups to build their custom-designed antenna ground stations at a low cost. It aims to make ground stations and radio telescopes as prevalent as optical telescopes at Universities.

7. Acknowledgements

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8. References

1. Balanis, C., n.d. *Antenna theory*. 3rd ed. New Jersey: Wiley-Interscience, pp.182-800.

2. D. Loranz, J. Detweiler, J. LaCombe and E. Wang, "Starting a student satellite program", *2005 Annual Conference*, June 2005

3. S. Hitefield, Z. Leffke, M. Fowler and R. W. McGwier, "System overview of the Virginia Tech Ground Station," *2016 IEEE Aerospace Conference*, 2016, pp. 1-13, doi: 10.1109/AERO.2016.7500716.

4. M. Bazdresch, S. Velayudhan and W. Johnson, "A satellite ground station for teaching digital and wireless communications," *2016 IEEE Frontiers in Education Conference (FIE)*, 2016, pp. 1-4, doi: 10.1109/FIE.2016.7757672.

5. M. Fischer and A. L. Scholtz, "Design of a Multi-mission Satellite Ground Station for Education and Research," *2010 Second International Conference on Advances in Satellite and Space Communications*, 2010, pp. 58-63, doi: 10.1109/SPACOMM.2010.13.

6. J. Cutler and A. Fox, "A framework for robust and flexible ground station networks", *Journal of Aerospace Computing Information and Communication*, vol. 3, Mar. 2006.

7. "Global educational network for satellite operations", *21st Annual AIAA/USU Conference on Small Satellites*, 2008.

8. M. Schmidt and K. Schilling, "Ground station networks for distributed satellite systems" in Distributed Space Missions for Earth System Monitoring, New York:Springer, vol. 31, pp. 355-371, 2013.

9. P. David, S. Hitefield, Z. Leffke, W. C. Headley and R. W. McGwier, "Implementation of an actor framework for a ground station", *Aerospace Conference 2016 IEEE*, March 2016.

10. DL2KQ, I.G., Mmana-gal download. *MMANA-GAL basic*. Available at: http://gal-ana.de/basicmm/en/ [Accessed August 26, 2022].

11. J. Logan and J. W. Rockway, "The new mininec (version 3). a mini-numerical electromagnetic code." NAVAL OCEAN SYSTEMS CENTER SAN DIEGO CA, Tech.Rep., 1986.29

12. MATLAB, version 7.10.0 (R2010a). Natick, Massachusetts: The MathWorks Inc.,2010