Enhancing Communication Range of Student Satellites Using Ground Station Antenna Systems

Maman Ali[1], Danial Babar[1], M. Mannan Chishti[1], Bilal Ahmad Khan[1], M. Kamran Saleem[1], Awais Ahmad Khan[2].
[1]Electrical Engineering Department, University of Central Punjab, Lahore.
[2]Mechanical Engineering Department, University of Engineering and Technology, Lahore
*Correspondence: maman.ali@ucp.edu.pk

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Student-made satellites have a prominent position in contemporary STEM education; however, the usefulness of the technology is constrained due to the constraints associated with traditional radio communication ranges. In order to solve this issue, high gain antennas for 2.4 GHz were designed using simulations on ANSYS HFSS along with SolidWorks modeling, followed by 3D-printing of antennas made from PLA material and copper rods. As per the simulation data obtained, the Yagi-Uda and Corner Reflector designs had a gain of 10.23 dB and 12.45 dB, respectively. The experiments conducted using drones proved that the custom-designed antennas can enhance the telemetry range to distances greater than 800 meters and 1000 meters, respectively, thus far exceeding the traditional antenna range of 100 meters to 200 meters. Thus, this work proves the effectiveness of these inexpensive antennas for path loss compensation in ground segment communication.

Keywords: Student Satellite, STEM, Yagi Uda Antenna, Corner Reflector Antenna, Gain

Introduction:

Student Satellites play an important role in the field of innovation and research. Educational satellites are low-cost and compact and can be used for various purposes. STEM education provides hands-on experience to students interested in space technology and space education. These small satellites [1] are important in analyzing various types of mission simulations, like an actual satellite. The actual satellites are costly, and the equipment is not accessible to everybody, even for researchers. For this specific purpose, these satellites, which are CANSAT and CUBESAT, are built using various types of electronics and mechanical mechanisms. They have their ground stations [2], which are developed for satellite communications. [3].

CANSAT [4] is a can-shaped satellite in which all the electronics are wrapped in the size of a soda can. This type of student satellite is used for CanSat competitions [5][6] worldwide. The CANSAT is used for the simulation of the launching and landing mission of a satellite on the moon. The satellite is loaded in a rocket. At a specific altitude, the rocket deploys the satellite, and it comes to the ground using the attached parachute. Like an actual satellite, it consists of subsystems stacked up in it. [7] Like the onboard computer, which consists of a microprocessor which is used for data processing. The Altitude Control System comprises different sensors and a communication subsystem for data communication on the ground station.

CUBESAT [8] is a 10x10 cm3 cube-shaped satellite. It is the standard size of a small satellite [1] that is launched into orbit. CubeSat can be launched in space using space-qualified components. These satellites are used for different types of missions, which defines their payload subsystem. For which specific purpose is CubeSat designed. The CUBESAT for which this satellite system is designed serves the purpose of remote sensing. The payload consists of a camera which sends a live feed to the ground station as shown in Figure 1(a).

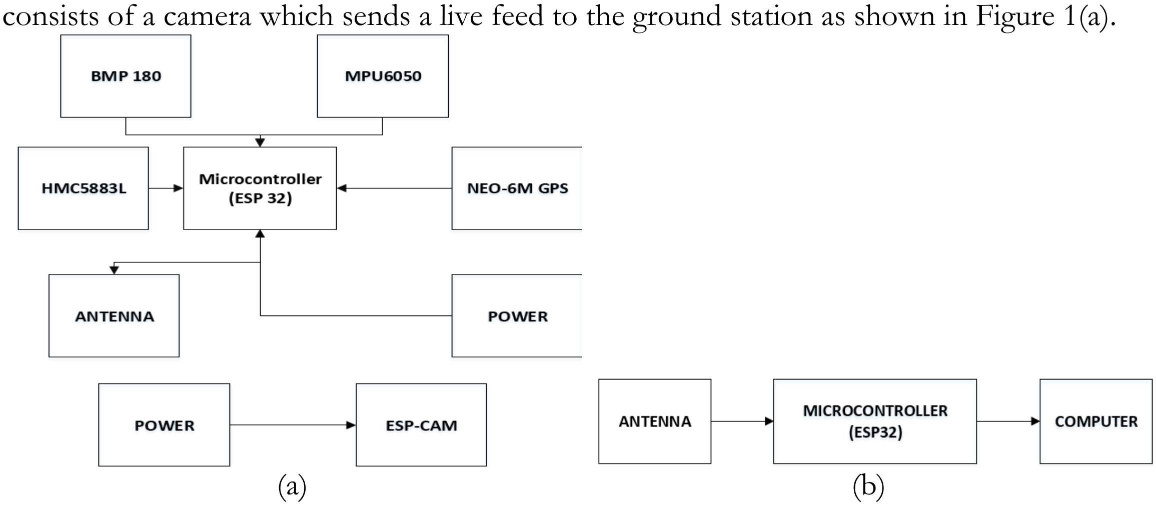

Figure 1. (a) Block Diagram of Student Satellite (b) Ground Station Block Diagram

The satellite sends data through its antenna to the ground station. Ground Station [9] consists of an antenna and a microcontroller to decode the data, and then it is shown on the display, whether it is any software or a graphic user interface. The block diagram of the ground station is shown in Figure 1(b).

The progress made towards ground station developments forms an important aspect of aerospace education today, being the essential bridge connecting space components to earth-based researchers. An equally significant aspect of this topic relates to student ground stations [10], which create an ideal educational platform that allows hands-on learning through satellite tracking, telemetry collection, and operations management. In line with academic endeavors, there has been considerable attention paid to the development of a low-cost GS for receiving data [11] by means of utilizing available open architecture designs, softwaredefined radios, and specialized antennas to track satellites while bypassing the costliness of commercial systems. Apart from receiving telemetry data, such locally established stations play a highly important role in promoting space sciences [12]. This is due to their capacity to bring the real-time information about atmosphere conditions and orbits into the classroom environment, inspiring new students to become involved in related projects and research endeavors. Regardless of purpose, each ground station is designed in accordance with the requirements it needs to fulfill – be it real satellite data reception or a purpose-designed satellite for multiple tasks and communications at different frequencies.

Objective:

The primary objective of the proposed antennas is to enhance the gain as well as range of communication between satellite and the ground station. This enhancement will help the students to study the environment more effectively.

Novelty:

The novelty of proposed antennas is discussed below:

The study achieved reproducible results through their 3D-printed PLA and copper antenna fabrication method. The drone tests demonstrated that the system achieved a range increase of 3.5 to 5 times compared with standard modules. The system allows low-cost student missions to access the extended range.

The antennas provide high gain and directional radiation pattern which improves communication reliability and signal strength.

It enables longer flight tests and helps in data acquisition from higher altitudes, which helps advanced research, especially in machine learning and artificial intelligence.

These antennas are used for communication between satellite and ground station. Due to this the communication is compromised. It means the antennas restrict the work because of the range limit. These antennas are used for communication between satellite and ground station.

Firstly, the on-board ESP32 [13] antenna is used. The satellite microcontroller communicates with the ground station microcontroller through the protocol of ESP-NOW [14]. It is a wireless communication. The mac address of ground station microcontroller is added to the student satellite, and then they communicate with each other.

Nrf24l01 [15] is the 2.4 GHz transceiver module, that is used in both satellite and ground station. It operates on entire ISM band. This increases the range of communication between both entities. It consists of a dipole antenna with an RF module that communicates with the microcontroller. The dipole antennas have an omnidirectional [16] radiation pattern. The microcontroller communicated with this nrf module using the SPI Protocol.

On ground station custom based antennas are integrated. These antennas improve the range of communication. Different types of Yagi Antennas [17] are used for the communication. Yagi Uda antenna is a directional antenna in which metallic rods are used which amplifies the signal and direct it to any direction. The dipole antenna itself has an omnidirectional radiation pattern. By using the reflector and directors as shown in Figure 2. the radiation is directed towards a specific direction.

Moreover, Corner Reflector antenna shown in figure 3, is type Yagi Antenna which use the metallic strip instead of rod as the reflector. This increases the gain of antenna. The corner reflector has two metal strips which are at a specific angle.

Simulation and Theoretical Background:

Two antennas are proposed, Yagi Uda and Corner Reflector antenna.

These antennas are simulated using ANSYS HFSS. The researchers used radiation boundary conditions to create an open-space environment which absorbs outgoing electromagnetic waves and prevents any unwanted reflections. The antenna feed used a lumped port which operated at 50 Ω reference impedance through the dipole gap to simulate the built coaxial cable while adaptive solving achieved its target through 2.4 GHz testing which required 6 passes until reaching $\Delta S \leq 0.02$ to obtain accurate S-parameters and gain measurements through HFSS automatic tetrahedral mesh refinement.

The Yagi Uda Antenna consists of three parts; one is dipole which is active element, the directors and reflectors illustrated in Figure 2. The dipole is driven element because it is connected to transmitter or receiver. The reflector is placed behind the driven element at a certain distance. The length of dipole is set to $\lambda/2$. In result the length of each arm will be $\lambda/4$. The directors are placed in front of the active element. They are slightly shorter than the dipole. In yagi-uda antenna, a metallic rod is used as the reflector. The directors enhance the gain of antenna by suppressing side lobes.

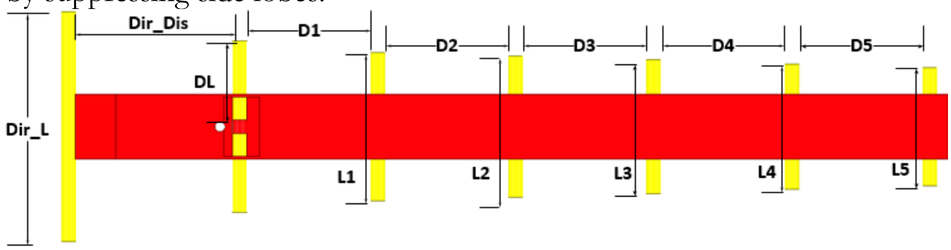

Figure 2. Description of reflector and director of Yagi-Uda Antenna

The overall length of the antenna is shorter due to high frequency. In simulated antenna, 5 directors are used. The gain of antenna depends on the spacing between elements. Hypothetically, this distance is set in between 0.1λ to 0.25λ. Then it is optimized using software. In Ansys HFSS, the antenna is simulated and initial results are obtained. To optimize the results, the Parametric sweep is used. In this sweep, a range of value is set for each variable which is required to optimize. For example, to optimize the dipole length, minimum and maximum points are determined and then analyze the parametric. This parametric sweep will analyze each variable and provide result according to each value. The benefit of this parametric is that, response trend can be observed easily. The response for each variable can be seen individually. At the end, when results are optimized, the final variables are saved and can be seen in Table 1.

Where, Dir_L is the length of reflector which is placed at a distance, Dir_L from the dipole, DL is the length of Dipole and D1,L1 are distance between directors and lengths of directors respectively. The Ref_L and Ref_W are length and width of the reflector sheet for Corner Reflector Antenna, as shown below.

Table 1. This table describes the dimension parameters of the Proposed antennas

Description	Length(mm)	Description	Length(mm)
Dir_L	70	L3	41
Dir_Dis	44	D4	34.75
DL	24	L4	38
D1	34.75	D5	34.75
L1	45	L5	36
D2	34.75	Ref_L	100
L2	43	Ref_W	62.5
D3	34.75	TL	292.5

Corner Reflector antenna has two metallic sheets which act as reflector and placed behind the driven element as shown in figure 3. The two sheets are set at an angle theta, θ. This change in angle shows the variation in side lobes level. For proposed antenna it is set as 120°. The length of dipole is set as $\lambda/2$. The length of each arm will be $\lambda/4$. The directors are placed at the distance as in Yagi-Uda antenna. This distance is typically between 0.1λ to 0.25λ. This wavelength (λ), is determined by the frequency at which the antenna operates. The higher the frequency, the shorter the wavelength. The variables are explained in Table 1.

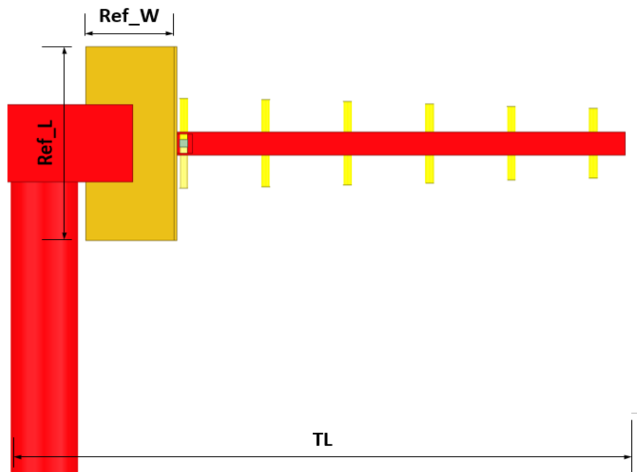

Figure 3. Corner Reflector Yagi Antenna with sheet reflector.

These antennas are used for communication between ground station and student satellite. Both antennas are integrated on ground station.

For calculation of received power on receiver end, link budget analysis is implemented using Friis Equation. This equation calculates the received power from antenna. In this study, the equation is used to calculate the range of communication between both antennas, the antenna on ground station and the antenna integrated on the student satellite. The equation can be seen below.

$$Prx\ (dB) = Ptx(dB) + Gtx\ (dBi) + Grx\ (dBi) - FSPL\ (dB) - Lother$$

Where Ptx is the transmitter power output from the satellite transceiver module, Gtx as the transmitter antenna gain of the aircraft, and Grx as the directional gain of the receiver antenna at the ground station system. The effects of system degradation are included in the equation by the removal of the FSPL, that is the free space path loss due to the spreading of signal energy in geometric proportions through the separation distance, as well as Lother which includes all other forms of signal degrading effects. Lother takes care of all other secondary losses such as hardware loss due to RF signal absorption in cables and connectors, among others. FSPL is calculated based upon the distance and operating frequency.

The design stage consists of calculation of lengths and widths of dipole and directors, simulation is implemented. After the simulation and results verification of Antenna using simulation software, these antennas move to the fabrication.

The boom and mechanical frame is designed using CAD software. The software used to design these is Solidworks. Compact designs can be easily designed in the software. When clicking on solidworks icon, it opens the window where the type of work is asked whether part design or assembling of different parts together. The boom is designed using part. When it is designed the software default setting is sldprt which means part. To use for manufacturing stl, step or. stp file is used. Software allows to export any type of format. These formats are used by CNC machines or 3d Printers.

Results and Discussion:

In this section, both antennas were simulated and results were obtained. The gain of corner reflector is higher than the yagi uda antenna. Corner Reflector suppressed side lobe levels which increased the gain of antenna making it more efficient and reliable.

The bandwidth of yagi antenna is 170MHz and fractional bandwidth of 7.04%. The S11 shows the minimum reflections at the center frequency, which indicates excellent impedance match at 2.4GHz.

The bandwidth of Corner Reflector antenna is 230MHz and fractional bandwidth of 9.64%.

The realized gain of antenna is 12.45dBi. The return loss in both antennas can be seen in figure 4.

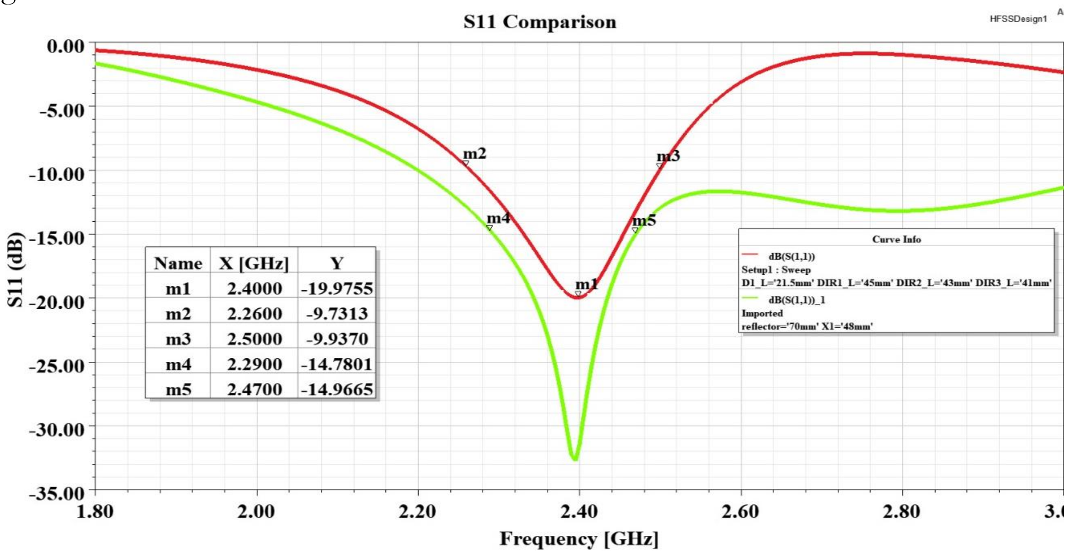

Figure 4. Comparison between Yagi Uda and Corner Reflector Antenna showing return loss for both antennas at 2.4GHz

The realized gain of yagi-uda antenna is 10.23 dBi. The lower side and back lobes can be seen in Figure 5. While, the realized gain of corner reflector antenna is 12.45 dBi. Maximum gain is in the direction of the directors. In yagi antenna the side lobe level can be seen between -2 and 2 dB. When corner reflector is introduced, the side lobe level shifted to below -15dB as shown in figure 5. This is the noticeable reduction. The side lobe level shows the unwanted radiation which is wasted in other direction. So it is reduced to achieve maximum radiation in the single direction. The graph shows good front to back ratio. Thus the interference is minimized and communication improves.

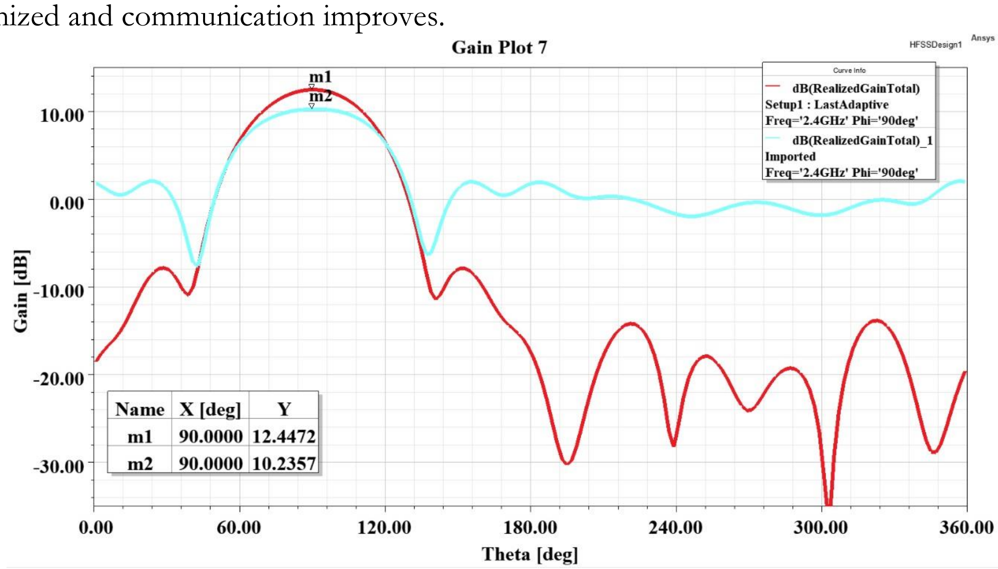

Figure 5. Gain comparison at 2.4GHz and Phi at 90 deg.

Radiation pattern of Yagi antenna and corner reflector antenna is shown in figure 6. The Yagi antenna has a HPBW measures 80° between 70° and 110°. Half Power beamwidth (HPBW) is precisely the angular measurement of the main lobe spread between the two directions wherein the emitted power is reduced to 50% of its maximum value, which is equivalent to -3 dB down from the top. The Corner Reflector antenna has a narrower HPBW which measures 40° between 70° and 110° to achieve better directivity for specific satellite communication purposes.

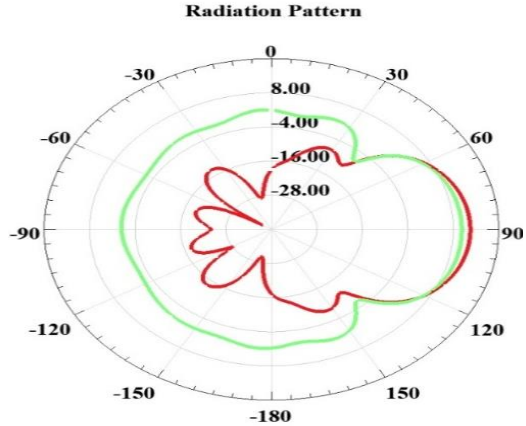

Figure 6. Radiation Pattern Comparison for both antennas at 2.4GHz and phi=90 deg.

Using the friis equation, range is calculated and by testing these antennas the range is measured. The equation provided a hypothetical determination of range. The measured ranges exceeded theoretical free-space predictions for some setups, likely due to favorable propagation conditions and environmental effects not fully captured by the Friis model as shown in Table 2.

The Return Loss of antennas is measured using pocket VNA. For testing with the satellite ground station, a drone is used. The drone carries the satellite with it to the altitude and the data transmission is tested. The parameters communicated at the ground station shows that at specific altitude, the communication stops and the altitude is recorded. Thus we are able to find the range of both antennas with our satellite system.

Table 2. Calculated and Measured range of antennas

Antenna Configuration	Pt (dBm)	Gtx (dBi)	Grx (dBi)	Calculated Range(m)	Measured Range(m)
On Board Esp-32	0	2.0	2.0	352	200
NRF24L01 module	0	2.15	2.15	260	300
Yagi Uda Antenna	0	2.15	10.23	658	700
Corner Reflector Antenna	0	2.15	12.45	848	>1000

All antenna comparison tests were conducted under identical RF transmission conditions to ensure fair evaluation. The satellite module used the ESP32-WROOM-DA (30-pin) microcontroller which communicated through ESP-NOW protocol that operates on 2.4 GHz Wi-Fi radio using default transmit power of 0 dBm according to the ESP32-WROOM-DA datasheet from Espressif Systems version 0.7. The satellite hardware which included microcontroller and RF module and power supply system maintained its physical state throughout all testing periods while ground station antennas were used for different tests. All tests were performed in the same open-field environment under end-of-summer conditions which the experimental methodology section described to maintain identical environmental conditions during antenna testing.

Antenna structural elements, such as the boom and mechanical fastening elements, were manufactured through FDM 3D printing utilizing standard PLA filament material. Structural elements were 3D printed at a layer thickness of 0.2 mm, wall thickness of 1.2 mm (3 wall perimeters), and top/bottom layer thickness of 0.8 mm (4 solid layers). In order to maximize structural rigidity while minimizing the load on the payload, honeycomb (hexagon) fill was used at a density of 40%. The print profile set the infill feed rate at 50 mm/s, wall feed rate at 30 mm/s, nozzle temperature of 210°C, and heated bed temperature of 60°C. After structural manufacturing was completed, all passive elements, such as directors, reflectors, and driven dipole element, were fully manufactured with high purity (E-Cu) copper rods with an outer diameter of 3.0 mm in order to ensure optimal conductivity.

The step file or stl file is imported into slicing software which converts the drawing into machine code which is then sent to the 3D printer. 3D printer manufacture the physical model. For dipole feed, a 50Ω coaxial cable which is connected to the dipole and then connected to the sma connector of RF module with microcontroller as discussed above. Manufactured antennas are shown in figure 9a and figure 9b.

(a) (b)

Figure 9. (a) Yagi Uda Antenna at 2.4GHz center frequency (b) Corner Reflector Yagi Antenna at 2.4GHz center frequency

The fabricated antennas are tested using pocket VNA and then for testing with the satellite ground station, a quadcopter drone is used. Field validation was conducted using a quadcopter drone with a maximum payload capacity of 3 kg, carrying the CanSat module (total payload mass: 500 g). The researchers conducted 15 to 20 flight tests which examined communication reliability under different environmental conditions. Five trials were conducted under clear sunny conditions at noon in an open field, four trials were performed on overcast cloudy days, and the remaining trials were carried out during evening hours. All testing was performed during the end of summer season. The drone ascended to various heights in each trial while the ground station recorded the data it received. The effective communication range for each trial was determined by recording the altitude at which communication signals stopped working. The open-field test environment minimized multipath interference and physical obstructions.

Conclusion:

Student Satellites are an important part of Space technology and STEM education. These educational satellites help in the field of research and innovation. It is observed that the by developing the Yagi antennas, the range of satellite communication has been extended. The range recorded from Corner Reflector Yagi antenna is more than 1km. This opens a gateway for the professionals to study remote sensing and acquire environmental data using these educational satellites which leads to advancement in machine learning and artificial intelligence.

References:

[1] C. Humberd, C. MacEo, and J. Kang, “Small Satellites as a Gateway to Hands-On Space Systems Education,” *2024 IEEE Integr. STEM Educ. Conf. ISEC 2024*, 2024, doi: 10.1109/ISEC61299.2024.10664885.

[2] M. Fischer and A. L. Scholtz, “Design of a multi-mission satellite ground station for education and research,” *2nd Int. Conf. Adv. Satell. Sp. Commun. SPACOMM 2010*, pp. 58–63, 2010, doi: 10.1109/SPACOMM.2010.13.

[3] O. Kodheli, “Satellite Communications in the New Space Era: A Survey and Future Challenges,” *IEEE Commun. Surv. Tutorials*, vol. 23, no. 1, pp. 70–109, 2021, doi: 10.1109/COMST.2020.3028247.

[4] M. Celebi *et al.*, "Design and navigation control of an advanced level CANSAT," *RAST 2011 - Proc. 5th Int. Conf. Recent Adv. Sp. Technol.*, pp. 752–757, 2011, doi: 10.1109/RAST.2011.5966942.

[5] Carrington Chun, M. Hassan Tanveer, "The CanSat Compendium: A Review of Scientific CanSats," *Mathematics*, vol. 11, no. 7, p. 675, 2023, doi: https://doi.org/10.3390/machines11070675.

[6] S. Soyer, "Small space can: CanSat," *RAST 2011 - Proc. 5th Int. Conf. Recent Adv. Sp. Technol.*, pp. 789–793, 2011, doi: 10.1109/RAST.2011.5966950.

[7] K. Ahmad, W. Afzal, M. Kamran Saleem, and A. A. Khan, "Design and Development of Multi-Stage CANSAT for Measuring Attitude and Atmospheric Parameters," *2023 25th Int. Multi Top. Conf. INMIC 2023 - Proc.*, 2023, doi: 10.1109/INMIC60434.2023.10466003.

[8] R. Nugent, R. Munakata, A. Chin, R. Coelho, and J. Puig-Suari, "The CubeSat: The picosatellite standard for research and education," *Sp. 2008 Conf.*, 2008, doi: 10.2514/6.2008-7734.

[9] K. Harshavardhini, V. K. Ghanathey, S. S. Ryali, and S. Chilukuri, "Implementation of Antenna in Satellite Ground Station for Cubesat," *Lect. Notes Inst. Comput. Sci. Soc. Telecommun. Eng. LNICST*, vol. 601, pp. 33–41, 2025, doi: 10.1007/978-3-031-81168-5_4.

[10] M. Choudhary, R. Tambekar, and S. Saranjame, "Design and Implementation of a Student-Built Ground Station Antenna in CanSat," *2025 IEEE Space, Aerosp. Def. Conf. Sp. 2025*, 2025, doi: 10.1109/SPACE65882.2025.11171358.

[11] A. Deokar, R. Sanghai, A. Gadekar, and A. Sharma, "A Low Cost Ground Station Setup for Introducing Undergraduate Students to Satellite Reception and Radio Astronomy," *2022 URSI Reg. Conf. Radio Sci. USRI-RCRS 2022*, 2022, doi: 10.23919/URSI-RCRS56822.2022.10118461.

[12] J. Soliz, M. Cuiza, and P. Carvajal, "Implementation of a ground station to encourage space science in developing countries," *2024 Int. Conf. Glob. Aeronaut. Eng. Satell. Technol. GAST 2024 - Proc.*, 2024, doi: 10.1109/GAST60528.2024.10520801.

[13] M. Babiuch, P. Foltynek, and P. Smutny, "Using the ESP32 microcontroller for data processing," *Proc. 2019 20th Int. Carpathian Control Conf. ICCC 2019*, May 2019, doi: 10.1109/CarpathianCC.2019.8765944.

[14] S. M. Koushik, M. Srinivasan, R. Lavanya, S. Alfred, and S. Setty, "Design and Development of Wireless Sensor Network based data logger with ESP-NOW protocol," *2021 6th Int. Conf. Converg. Technol. I2CT 2021*, Apr. 2021, doi: 10.1109/I2CT51068.2021.9417914.

[15] B. Babusiak and M. Smondrk, "Building a Wireless Sensor Network with nRF24 Module for Home Security: Design and Implementation," *2024 47th Int. Conf. Telecommun. Signal Process. TSP 2024*, pp. 315–319, 2024, doi: 10.1109/TSP63128.2024.10605919.

[16] Rao Shahid Aziz, Slawomir Koziel & Anna Pietrenko-Dabrowska, "A compact tri-band omnidirectional antenna design for CubeSat applications," *Sci. Rep.*, 2025, [Online]. Available: https://www.nature.com/articles/s41598-025-96628-w

[17] D. Arceo and C. A. Balanis, "A compact Yagi-Uda antenna with enhanced bandwidth," *IEEE Antennas Wirel. Propag. Lett.*, vol. 10, pp. 442–445, 2011, doi: 10.1109/LAWP.2011.2150730.