Utilization of a Portable Ground Station to Conduct Site Surveys in the S-Band Frequency for CubeSat at MSU's Mission

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CubeSat at MSU is an undergraduate student-led design team working to construct, launch, and operate Mississippi's first satellite. The 1-Mississippi mission is focused on wildfire detection through hyperspectral imaging and thus requires a ground station that will accommodate a large bandwidth at a high frequency. An efficient ground station operating in the s-band frequency (2.1 GHz) is vital to downloading the large image files for a successful mission. A simplified and portable ground station was constructed to conduct site surveys on and around the Mississippi State University campus to test the feasibility of a permanent location, the Line of sight (LOS), possible radio interferences, and the noise floor. The system consists of a 1.76 GHz 6.5 turns Helicone antenna, 2.4 GHz Grid antenna, Yaezu 5500 Elevation-Azimuth Dual Controller, counterbalanced boom, 4ft mast, linux based base station, G-Predict antenna and satellite tracking software, SDR++ SDR software, CaribouLite dual channel 6GHz sub 1GHz transceiver, and custom Arduino based RS232 controller to interface to the G5500. This paper details the design and construction of the test ground station within the constraints of the mission, the site survey test procedure, and the results of the experimentation.

I. Nomenclature

GS = ground station
GSI = ground station interface
LOS = line of sight
RF = radio frequency
SA = spectrum analyzer
SDR = software defined radio

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II. Introduction

CubeSat at MSU is an undergraduate student design team working to construct, launch, and operate Mississippi's first satellite. The "1-Mississippi" mission will be a 3U CubeSat submitted to NASA's CubeSat Launch Initiative (CSLI) and will contain a hyperspectral imaging payload capable of detecting wildfires. To download the anticipated large image files, a ground station that can operate effectively in the s-band frequency (2-4 GHz range) is required. S-band has a longer transmission range than many frequency bands below it, and is on the lower end for frequencies capable of satellite communications. It is easier to acquire an s-band license in comparison to other acceptable frequency bands capable of satellite communication such as X-Band [1]. S-band is a common frequency band for satellite communications missions, meteorological radar systems, and CubeSat communication systems. A common advantage s-band has to other potential space communication frequencies is its low signal loss due to weather fluctuations. It has an average loss of less than 5% compared to the Ka band which has a typical loss range of 30% to 70% [2]. A suitable location for a permanent s-band ground station with a clear line of sight (LOS), easily accessible facilities, little to no radio interference, and a low noise floor is vital to the success of the ground station and subsequent mission. To determine the best location to permanently install the team's ground station, site surveys were conducted with a portable communication system to mimic the final product. Locations tested included the roof of on campus buildings, university research fields, and other accessible locations on campus. Each site was consistently evaluated by established criteria and then compared to one another.

III. Objectives

The objective of this experiment is to determine the most viable site for a permanent ground station that will meet the needs of the CubeSat at MSU team. The results of this testing as well as the testing procedure can be used by other university satellite design teams considering an on-campus large communication system. An affordable testing system was designed and constructed within the 1-Mississippi mission criteria, operating in s-band frequency. Experimental procedures were created and followed at each viable location. Both qualitative data, assessed on a pre-defined scale, and quantitative data were recorded and then compared. The conclusion reached through this project will be presented to Mississippi State University and the Aerospace Engineering Department to request permanent access to the chosen location.

IV. Design and Construction

The portable ground station design was composed of three main sub systems. The Antenna Stand, the Ground Station Interface (GSI), and the Workstation. The antenna stand was composed of a 2.4 GHz grid antenna, a 1.7 GHz 6.5 turns helicone antenna, a Yaezu G5500 Rotator, a Yaezu 5500 Elevation-Azimuth Dual controller, a custom-built counter-balanced boom arm, and a 4ft. mast. The GSI was composed of an Arduino uno, a custom Arduino based RS232 controller, a CaribouLite dual channel 6GHz sub 1GHz transceiver, and a Raspberry Pi 4. The workstation was composed of a monitor, keyboard, and mouse.

The entire ground station system had the ability to operate in both S-Band and L-Band frequencies. As indicated in blue in Figure 1, when utilizing the L-Band (1.7 GHz) configuration, the helicone antenna was connected to the CaribouLite Dual Transceiver via a RGAX coax cable. The Yaezu Dual Controller was connected to the GSI via a custom 8-pin connector (C8pC) via the Arduino controller. This allowed the digital Raspberry Pi 4 to interface with the analog dual controller. This capability enabled G-predict, a satellite tracking software to control the azimuth and elevation of the antenna when tracking satellites. While these capabilities are essential to the 1-Mississippi mission, they were not used during the site surveys conducted.

In the s-band (2.4 GHz) configuration, indicated in red on Figure 1, the grid antenna was connected to the CaribouLite transceiver via a RGAX coax cable. The radio signals were received and then processed by the SDR ++ software on the Raspberry Pi 4 to calculate the noise floor. These results were then displayed on the workstation. In this configuration, the azimuth and elevation were controlled by using the analog switches on the Yaezu Dual Controller. This configuration was used to perform the site surveys and collect noise floor data. A Tiny Spectrum Analyzer (SA) was used to get additional noise readings from the 5 sites surveyed.

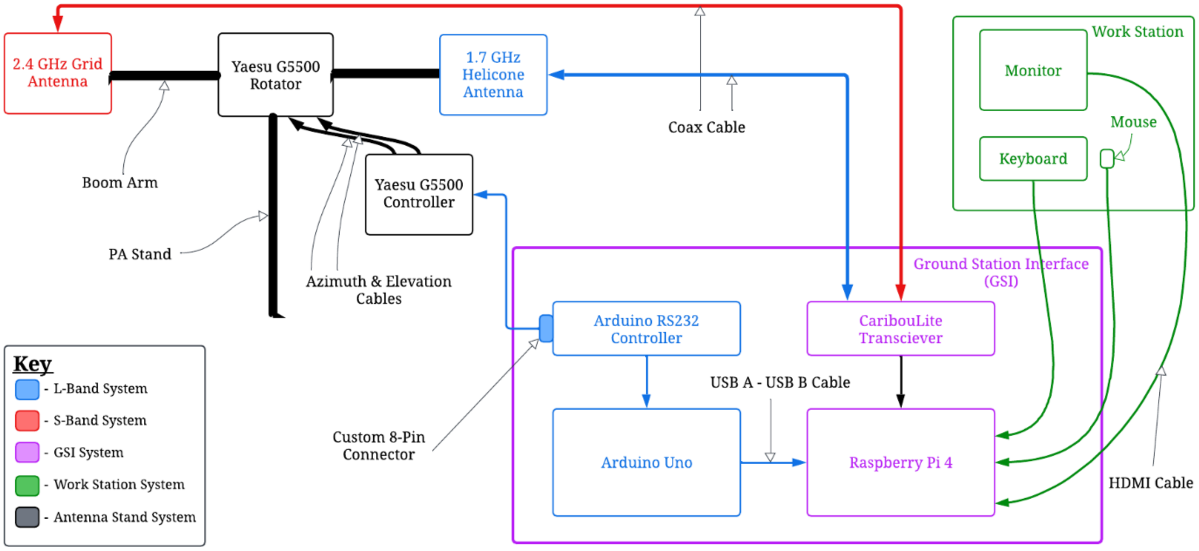

Fig. 1 Portable Ground Station Schematic

The ground station was primarily composed of affordable and easy to acquire components (see Table A1). To integrate all the components, custom components were required in place of expensive specialized hardware. The custom counter-balanced boom arm was composed of steel tubing with mounting plates welded on. The antennas and counterweights were attached via nuts and bolts. CaribouLite is an open source Software Defined Radio (SDR) that operates in a wide range of bandwidth (30-6000 MHz) including s-band range (2GHz-4GHz). A typical s-band transceiver costs upwards of $1,000 [3], while the CaribouLite costs only $140, plus a $35 RPi 4 for a total of $175. The Yaezu G-5500 rotator was selected because it has proven extremely effective in the cost effective SatNOGS system. SatNOGS is an open-source, affordable ground station design by Libre Space Foundation [4] which the team used as a reference when designing the portable system.To digitally control the rotor, typically a $650 controller (GS-232B) is required. Instead, an Arduino based RS232 controller was used to interface to the G5500 for significantly less. This created a cost-effective system that still allows operation with full azimuth and elevation control. SDR++ is a cross-platform and open source SDR software [5]. It is free to use and compatible with a long list of SDRs, including the CaribouLite and was used throughout testing. Overall, these components total to less than $1325, compared to the Portland State Aerospace Society “U.N.I.C.L.O.G.S.” s-band $20,000 ground station design [6].

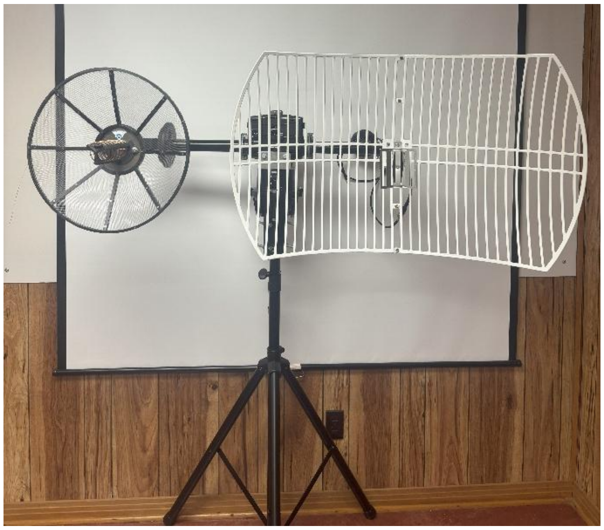

Fig. 2 Antenna Stand Configuration

V. Experiment Procedure

A. Location Criteria

Before any testing and data collection could take place, possible locations for a permanent site were chosen in advance. For a location to be deemed feasible for the 1-Mississippi mission, a baseline set of criteria, decided on by the team, needed to be met. The location first needed the infrastructure to support a ground station long term. This included having enough space for equipment, having safety precautions against harsh weather, having internet and power access, and the ability to make repairs or upgrades fairly easily [7]. This eliminated locations which were too small, too remote, and lacked suitable existing structures. For example, the intermural/recreational sports fields were considered but were opted against due to not having an accessible structure with power and internet access. The regulatory requirements, such as licensing standards [8], and Mississippi State University policies were also considered when choosing possible locations to conduct testing.

B. Ground Station Testing Configuration

Once a location was decided, the testing procedure consisted of transporting necessary equipment, assembling the mobile ground station, recording observations about the site, collecting data with the ground station, and interpreting the data. The equipment used in each site survey included equipment listed in Table A1 along with a digital Spectrum Analyzer (SA) and additional surveying equipment.

Assembling the ground station on-site required the antenna, rotor, and stand to be placed in an area clear of obstructions, with at least enough space to rotate without interference. Using a compass placed directly on the antenna feed horn, the system was rotated to point directly north and horizontally flat. This was used as a baseline for all noise tests as it is equivalent to 0º elevation and 0º azimuth. The azimuth is the angular distance measured from the north point of the horizon on an azimuth circle, consisting of 360º. [9]. Depending on the site, a folding table was set out to hold the remaining equipment. Next, the G-5500 Elevation-Azimuth Dual Controller was connected to the rotor, powered on, and both the elevation and azimuth were zeroed out by ensuring all dials reach zero using the manual switches. The G-5500 Controller was interfaced into the GSI through an 8-pin cannon plug from the Arduino hat in the GSI. A keyboard, mouse, monitor, and power were then connected to the Raspberry Pi in the GSI. The final testing configuration can be seen in Figure 1. The Tiny Spectrum Analyzer (SA), a device that measures and displays Signal amplitude (strength) as it varies by frequency within its frequency range (spectrum) [10] was also powered on and ready to be plugged into the antenna for the second round of testing. General surveying equipment was also set up at this time, including a GPS unit, a compass, an altimeter, and an anemometer for determining wind speed.

C. Software Testing Configuration

SDR++ software was used for measuring the noise floor for each site survey. SDR++ is an open-source, free program that creates a software defined radio (SDR) on a computing device. The software was downloaded and executed on the ground station controller to confirm working status prior to testing. Upon booting the pi for testing, the software was executed. In the software interface, the gain was set to 50.4 decibels, and the bandwidth was set to 250 kHz. These values were kept constant throughout the testing and were confirmed to be the same values at every survey site. The play button was then clicked and a live graph of the noise floor was displayed.

D. Data Collection

A formal site survey document was created to ensure results were recorded consistently across all locations and when overseen by different team members. The report was sectioned into different categories, each containing specific questions to be answered, blanks to be filled in, and instructions on how to exactly gather both observational and numerical data. The categories were:

1. General Information
2. Geographical and Environmental Assessment
3. RF Environment Analysis
4. Infrastructure Assessment
5. Visual Documentation
6. Summary and Initial Impressions
7. Survey Notes and Additional Instructions

General Information data included the site name/identifier, exact coordinates recorded using the GPS unit, and the elevation recorded with the altimeter. Higher elevations are preferred for communication systems as they typically provide a clearer LOS and signal strength to the satellite [8].

For the Geographical and Environmental Assessment, obstructions which could cause interference such as trees, buildings, powerlines, etc. were listed and the distances to each were recorded. A brief description of the terrain, such as urban/rural and flat/hilly, was recorded in this section as well. The temperature, humidity, and wind speed, recorded using local weather data and the anemometer on site, were noted. Extreme winds could affect the antenna's stability while temperature could cause the antenna to expand or contract slightly, and moisture in the air could cause interference. This information may explain weaker signals and is therefore important to consider when comparing the RF data of each of the site surveys conducted on different days in different conditions [11].

The RF Environment Analysis section first assesses the line of sight (LOS). LOS is defined as a direct path between two points, or what you would see directly in front of you at that point. In many communication systems, especially for low earth orbit (LEO) satellites which have a smaller area of coverage, a clear LOS is vital to receiving and transmitting a strong signal during short timeframes [12]. Physical obstructions, such as buildings, trees, powerlines, etc., also cause significant radio interference and prevent a successful mission. The site survey document prompted the surveyors to determine if the LOS was clear. A "clear" LOS was described as having no significant obstructions to seeing the horizon in a full 360º azimuth rotation. "Significant" was defined as covering a large area of the visual landscape in any direction. As a part of the RF analysis, a Spectrum Scan was conducted to record the noise level. Noise level is the amount of "noise" caused by nearby signals that would affect the RF environment. Wi-Fi signals, power lines, cellphones, etc. would raise the noise level and cause potential interference to the ground station. First, using the complete ground station system set-up [Figure 1] a baseline noise floor was measured at 0º N and 0º azimuth (elevation). Tests were conducted at various bearings running across the horizon directly North to South and then East to West. The data was recorded at elevations between 0 degrees and 180 degrees in increments of 22.5 degrees. The number of decibels (dB) at each bearing were determined with the SDR++ software graphical reading. The software displayed data with an accuracy of 5dB, thus the ones-place significant figure was estimated by the lead surveyor. The test was then repeated using the SA. The antenna was disconnected from the Caribou Lite Hat and plugged into the Tiny SA. The noise level at each of the same bearings were recorded with this device, which provided data to one decimal place. All data was recorded in a table to be evaluated [Table A2]. Lower noise level equates to lower radio interference and would therefore offer more consistent and clear communication. During testing, as the antenna rotated to each of the testing positions, the SDR++ was monitored by a team member to determine if there were any interference concerns that fell outside of the pre-set bearings for testing. If a significant amount of noise was found, the bearing and noise floor at that location was noted.

For the Infrastructure Assessment a simple yes/no checklist and specific short answer questions were utilized to determine the following characteristics of the site: power availability, internet availability, space availability, and ground stability. These characteristics are all vital to having a successful and easily operable permanent ground station.

Visual Documentation gave specific instructions on pictures to take of the site and the test setup for later comparison.

Summary and Initial Impressions prompted the lead surveyor to describe major strengths and concerns for the site that may be outside the scope of the previous sections in the document. Examples of information listed here included "difficult power accessibility," "no buildings in LOS," and "not significantly better than previous site."

The final section of the document, Survey Notes and Additional Information, is a record of how the specific site survey was conducted. This includes who was leading the survey, who helped and recorded information, and what specific equipment was used. This section also provides more details on how to properly use and make edits to the document to ensure that no data or information is lost.

VI. Results

The locations tested included the Walker Aerospace Engineering Laboratories rooftop, Mississippi State University Utilities Pump House, the Howell Observatory in South Farm at MSU, the front lawn of Patterson Engineering Laboratories, and the MSU North Farm.

Walker Rooftop, directly above the Aerospace Engineering Department, provided a large, flat, and empty space for the potential ground station. With an elevation of 435ft, the ground station was eye-level or above the surrounding buildings and had a relatively clear LOS. Power was easily fed onto the roof through an existing extension cord running through a pipe into an unused closet. CubeSat at MSU would have access to the closet for additional equipment, instruments, and wired connections. One major interference at this location was detected when facing Hilbun Hall (MSU Physics Department) at approximately 19º East and between 6-10º in elevation [Figure 3].

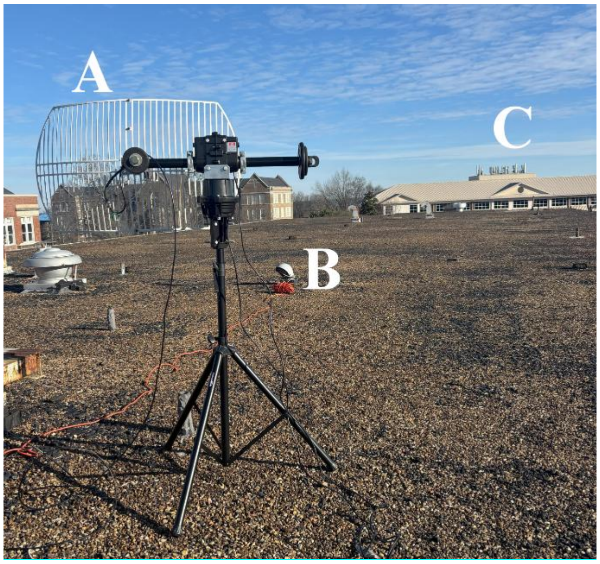

Fig. 3 Walker Rooftop Site Survey Configuration. (A) Antenna Stand, (B) power source, and (C) Hilbun Hall

The Pump House is located in the middle of the parking lot behind the MSU Industrial Education Building. The area was flat and stable, had an elevation of 392ft above sea level, and was surrounded by trees and buildings approximately 1,000ft away. An outside outlet was available for use and a small patch of grass was just big enough to house all the testing equipment. Concerns raised at this location included, passing cars causing interference, tall tree line, and limited space.

The South Farm Observatory is located approximately 10 minutes away from CubeSat at MSU's laboratory space and in the middle of MSU research farmland. The LOS was very clear, with only the small observatory as an obstruction. Power was easily available from the observatory, but internet access was practically nonexistent. A sidewalk was available for ground stability, the elevation was 331ft, and no significant interferences were detected.

The front lawn of Patterson Laboratories provided easy access to power, strong internet access, enough of a flat surface, and an elevation of 390ft. The LOS was not clear with buildings surrounding the location and cars passing on the road in front of the potential site. The proximity of Hilbun Hall was also a concern for this location.

The North Farm site is approximately 5 minutes off campus and is located on MSU research farmland. The elevation of the site was 255ft above sea level, the tree line was approximately 30ft away, the terrain was not flat, and the LOS was generally clear. Power was not easily accessible, and a portable generator (Chevy Silverado 2500HD) was needed to ultimately conduct this test. Internet access was extremely limited as well. A major interference in the signal was detected coming from a radio tower at 18º East and 12º in elevation.

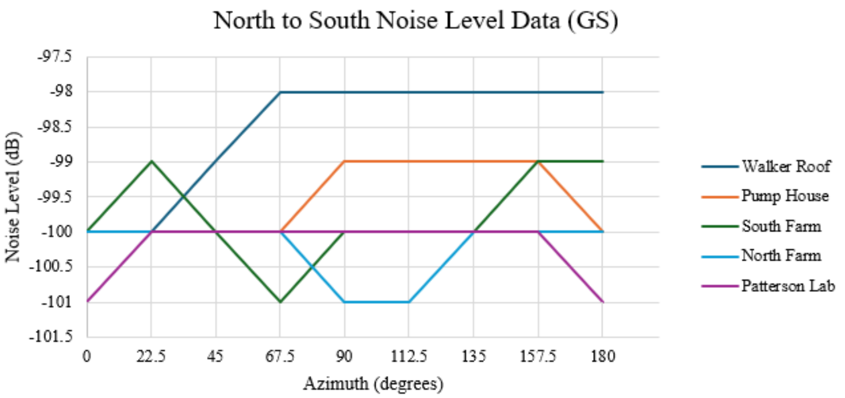

Fig. 4 Noise Level Data Recorded with the Ground Station Configuration Running North to South

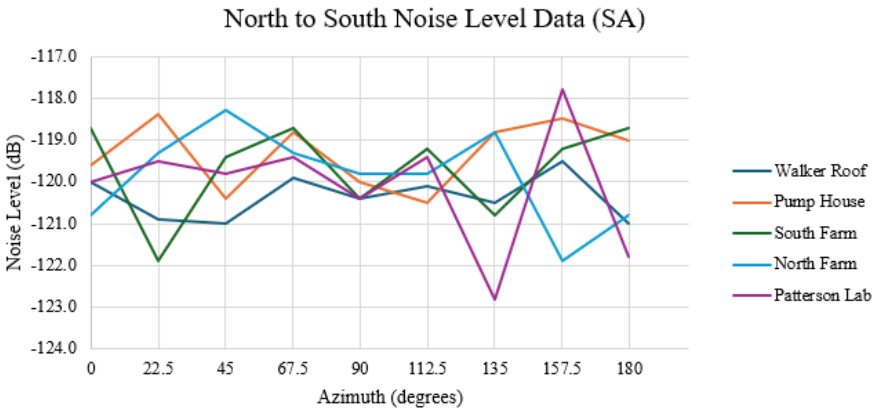

Fig. 5 Noise Level Data Recorded with the Spectrum Analyzer Configuration Running North to South

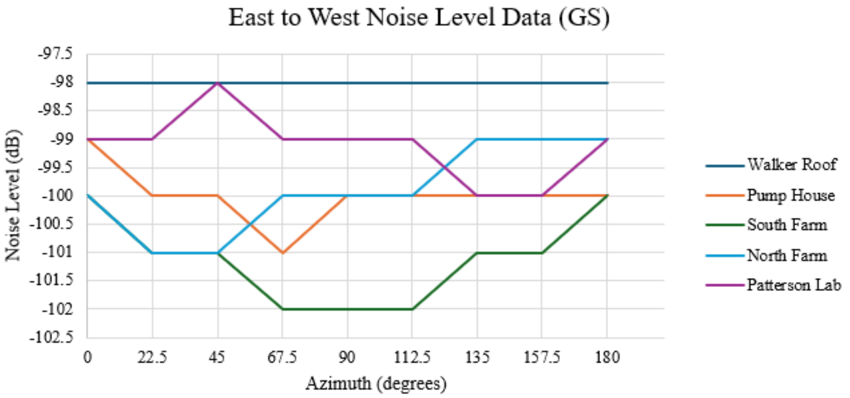

Fig. 6 Noise Level Data Recorded with the Ground Station Configuration Running East to West

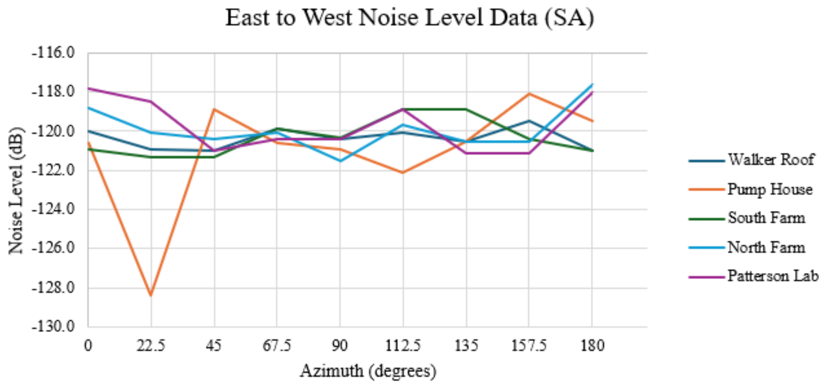

Fig. 7 Noise Level Data Recorded with the Spectrum Analyzer Configuration Running East to West

The results from each site survey were compiled and analyzed. To compare locations fairly with consideration to both the observational and numerical data, the sites were each ranked against one another in each category previously described in the Experiment Procedure. The sites were ranked 1-5 with 5 being the best location for that category and 1 being the worst. Weights were applied to categories to account for more mission critical criteria. Noise floor and accessibility were given a weight of 3 because they are both essential to permanent ground station operations and very difficult/impossible to work around. Without consistent access to the test location, it will be extremely difficult to continuously operate a large ground station. Without a low enough noise floor, it will be impossible to distinguish the signal from a satellite from the RF background. LOS, power, and internet were all weighted the second heaviest because they are critical, but a deficiency can be worked around with significant effort. LOS, which is required to create a link with a satellite, could be improved by constructing a platform for the ground station to operate on. If a location lacks power, a generation method can be added or powerlines can be run to the area. Elevation, terrain, obstructions, and space are all given the least weight as they have the least impact on the performance of the ground station in comparison to other categories. The scores were then added for each site, with the highest total value determining the most feasible location for a permanent station. For any sites that were deemed to perform the same in a category, the tie was broken based on overall accessibility.

Table 1: Site Rankings

		Possible Locations				
Category	**Weight**	**Walker Roof**	**Pump House**	**South Farm**	**Patterson Lab**	**North Farm**
Elevation	1	**5**	2	4	1	3
Terrain	1	2	4	1	**5**	3
Obstructions	1	4	4	**5**	1	3
LOS	2	4	4	**5**	1	3
Noise Floor	3	1	3	**5**	2	4
Power	2	**5**	3	4	2	1
Internet	2	**5**	3	2	4	1
Space	1	**5**	1	4	2	3
Accessibility	3	**5**	3	2	4	1
Weighted Totals		**62**	49	54	40	35

VII. Analysis

The noise level data revealed that each location had little noise pollution overall, with a loudest recorded signal of -78 dB (Hilbun Hall interference) and lowest of -102 dB when testing using the ground station. Measurements with the SA determined the site to be even quieter, with a minimum value of -128.4 dB. The discrepancy between the GS and SA values were likely due to different gains between the SA's antenna and the GS's antenna. It can also be attributed to the longer coaxial connections between the GSI and GS when compared to the SA's connection to the GSI. Both are common culprits for noise floor differences between devices. When comparing locations with the GS, Walker Rooftop recorded the highest average noise level of -98.3 dB and South Farm with the lowest average of -100.4 dB. As seen in Figure 4 and Figure 6, Walker Rooftop is noticeably above the other locations but well within the other data collected with the SA in Figure 5 and Figure 7. The Pump House has the largest range and standard deviation of its data, whereas Walker Rooftop was most consistent.

Although the Walker Rooftop was measured to have the most noise when using the ground station, when considering its performance in the other categories necessary for a successful mission, it was the clear winner. The accessibility, infrastructure, and elevation the site provides would be invaluable to CubeSat at MSU and compensate for the relatively small amount of additional noise. The final concern with using the Walker Rooftop was the detected interference from Hilbun Hall. The interference was only detectable in a small area and could therefore be mitigated or avoided by potentially using a narrower bandwidth. In the event that this interference or another unforeseen issue arises, South Farm was decided to be a more than suitable alternate site. Having the lowest noise floor and clearest LOS, South Farm would provide a strong communication signal with some infrastructure inconveniences.

VIII. Conclusion and Next Steps

Through experimentation, the roof of Walker Aerospace Engineering Laboratories was determined to be the most suitable location for CubeSat at MSU's ground station to be used in the 1-Mississippi mission. The site's noise level measured was determined to be adequate for operations in the s-band frequency and its existing infrastructure was found to be exceptional for the mission. Future testing, including analyzing the effect of narrower bandwidths or testing the noise floor with a different antenna under different gain settings, may be conducted to confirm the findings and ensure the final mission is successful. CubeSat at MSU intends to begin construction of a permanent ground station in accordance with the findings of this experiment.

Appendix

Table A1: Ground Station Parts List and Pricing

Part	Sub System	Total Cost
PA Stand	Stand	$28.99
Custom Boom (2 1/2 ft.)	Stand	$30.00
5lb Counter Weight	Stand	$5.99
1.25lb Counter Weight	Stand	$12.00
Yaezu G-5500 Rotator	Stand	$759.95
Azimuth Cable	Stand	$0.00
Elevation Cable	Stand	$0.00
20 ft. RGAX Coax Cable	Stand	$18.99
Yaezu G-5500 Controller	Stand	$0.00
Power Cord	Stand	$0.00
2.4 GHz Grid Antenna	Stand	$92.99
Raspberry Pi 4	Controller	$61.95
Arduino Uno	Controller	$27.60
Custom Arduino Hat	Controller	$30.00
Caribou Lite Hat	Controller	$140.00
8-Pin connector	Controller	$0.00
14 Gauge Wire	Controller	$9.99
USB A - USB B Cable	Controller	$8.99
Monitor	Work Station	$69.99
Wireless Keyboard	Work Station	$18.99
Wireless Mouse	Work Station	$0.00
6 ft. HDMI Cable	Work Station	$8.49
	Total	**$1,324.91**

Table A2: Site Survey Noise Floor Data

	Walker Roof				**Pump House**			
	North-South		East-West		North-South		East-West	
Elevation (degrees)	GS (dBW)	SA (dBW)	GS	SA	GS	SA	GS	SA
0	-100	-120.0	-98	-120.0	-100	-119.6	-99	-120.6
22.5	-100	-120.9	-98	-120.9	-100	-118.4	-100	-128.4
45.0	-99	-121.0	-98	-121.0	-100	-120.0	-100	-118.9
67.5	-98	-119.9	-98	-119.9	-100	-118.8	-101	-120.6
90.0	-98	-120.4	-98	-120.4	-99	-120.0	-100	-120.9
112.5	-98	-120.1	-98	-120.1	-99	-120.5	-100	-122.1
135.0	-98	-120.5	-98	-120.5	-99	-118.8	-100	-120.5
157.5	-98	-119.5	-98	-119.5	-99	-118.5	-100	-118.1
180.0	-98	-121.0	-98	-121.0	-100	-119.0	-100	-119.5
Average	-98.6	-120.4	-98.0	-120.4	-99.6	-119.3	-100.0	-121.1

	South Farm Observatory				**Patterson Laboratories Lawn**				**North Farm**			
	North-South		East-West		North-South		East-West		North-South		East-West	
Elevation	GS	SA	GS	SA	GS	SA	GS	SA	GS	SA	GS	SA
0	-100	-118.7	-100	-120.9	-101	-120.0	-99	-117.8	-100	-120.8	-100	-118.8
22.5	-99	-121.9	-101	-121.3	-100	-119.5	-99	-118.5	-100	-119.3	-101	-120.1
45.0	-100	-119.4	-102	-121.3	-100	-119.8	-98	-121.0	-100	-118.3	-101	-120.4
67.5	-101	-118.7	-102	-119.9	-100	-119.4	-99	-120.4	-100	-119.3	-100	-120.1
90.0	-100	-120.4	-102	-120.3	-100	-120.4	-99	-120.4	-101	-119.8	-100	-121.5
112.5	-100	-119.2	-102	-118.9	-100	-119.4	-99	-118.9	-101	-119.8	-100	-119.7
135.0	-100	-120.8	-101	-118.9	-100	-122.8	-100	-121.1	-100	-118.8	-99	-120.5
157.5	-99	-119.2	-101	-120.4	-100	-117.8	-100	-121.1	-100	-121.9	-99	-120.5
180.0	-99	-118.7	-100	-121.0	-101	-121.8	-99	-118.0	-100	-120.8	-99	-117.6
Average	-99.8	-119.7	-101.1	-120.3	-100.2	-120.1	-99.1	-119.7	-100.2	-119.9	-99.9	-119.9

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