System Design Document

For

Microwave Tracking Ground Station

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SYSTEM DESIGN DOCUMENT

1 INTRODUCTION

The System Design Document describes the system requirements, operating environment, system and subsystem architecture, files and database design, input formats, output layouts, human-machine interfaces, detailed design, processing logic, and external interfaces.

1.1 Purpose and Scope

As an ongoing project within the Embry-Riddle Aeronautical University WiDE Laboratory, the STMGS aims to innovate on the work of the previous team. By manipulating existing hardware, this iteration of the project introduces new tracking software, a complete RF block design, and utilizes the SDR to effectively record satellite signals.

The Satellite-Tracking Microwave Ground Station (STMGS) is designed to autonomously track satellites operating on S-band frequencies, and then analyze and record their signals using software-defined radio (SDR). This project focuses on the challenges of radio frequency (RF) communication systems by improving several critical components, including antennas, combiners, filters, and amplifiers. One of the key challenges we are addressing is the need to design these components to be both compact and efficient, ensuring they fit within strict size limitations. Additionally, the project involves implementing tracking software for a dual-rotor positioner, which is essential for communication. To maintain the reliability and stability of the system, we are using a pole mount. This mount is designed to secure the system and prevent any misalignment or movement that could disrupt communication.

1.2 Project Executive Summary

1.2.1 System Overview

The system is composed of several key components: an antenna, a positioner, a positioner controller, RF/Receiving (RX) modules, tracking software, and RF SDR software, as depicted in Figure 1, a high-level system diagram. This configuration enables the system to actively track a satellite using the onboard software in conjunction with the positioner and its controller. The antenna dish facilitates the RX between the satellite and the system. Figure 1 below illustrates the general architecture of the integrated system.

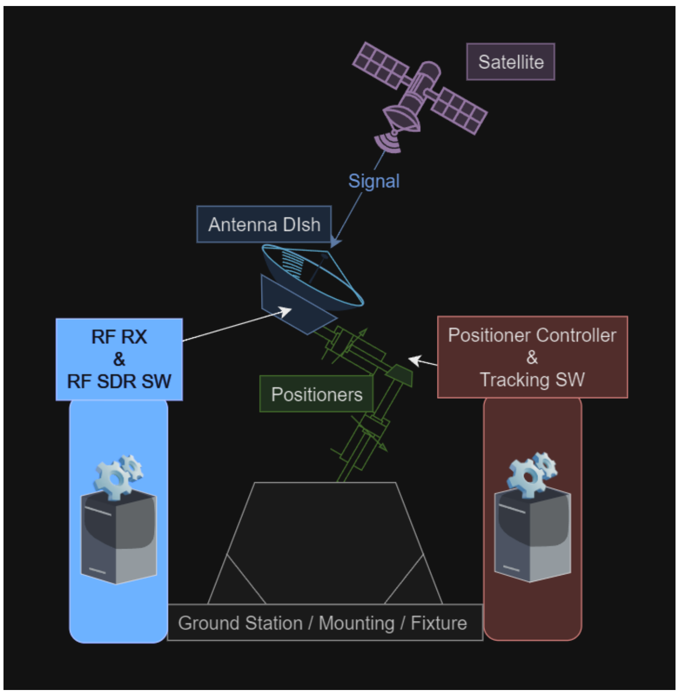

Figure 1 (Microwave Tracking Ground Station Systems Diagram)

1.2.2 Design Constraints

1. <u>Regulatory Compliance:</u>

   The system must adhere to all relevant regulations and standards, which may include frequency usage, power emissions, and safety standards.

2. <u>Size and Deployability:</u>

The system must be compact, enabling deployment in a variety of locations. This necessitates a design that maximizes space efficiency.

3. Signal Strength Compensation:

   Due to the compact size, the system may experience limitations in signal strength. To address this, enhancements such as amplified antenna gain will be implemented to ensure optimal performance.

4. Power Requirement:

   The system's power supply must be both compact and capable of efficiently powering the entire system. It should conform to the United States standard of 120V at 60Hz.

5. Keplerian Coordinate System Utilization:

   Keplerian coordinates will be the foundational elements in all positioning calculations, ensuring precision and consistency in tracking.

6. Positioner Software Selection:

   The choice of positioner software remains undecided. The system is designed to be compatible with various positioners, many of which come with their own built-in software. The selected software will be adaptable to meet our specific requirements.

7. Frequency Range Limitation of Software Defined Radio:

   Our system incorporates a Pluto software-defined radio, which inherently limits the operational frequency range. The maximum frequency capability of the Pluto SDR is a critical constraint in our design. This limitation necessitates careful consideration in the system's design and operation, ensuring that all functionalities and performance metrics are aligned with the achievable frequency range of the Pluto SDR. Strategies will be implemented to optimize performance within this frequency constraint, including the selection of compatible components and the development of software algorithms specifically tailored to operate efficiently within the defined frequency limits.

8. Budgetary Limitations:

   No budget is allotted for this project. All hardware and software components must be borrowed from the WiDE Laboratory.

9. Compatibility with Existing Systems:

   The system must be compatible with existing infrastructure and technology, including communication protocols and data formats associated with the satellites that are emitting the microwaves we are trying to track.

10. User Interface and Accessibility:

    The system should have a user-friendly interface, and be accessible and easy to operate, even for users with limited technical expertise.

11. Adaptability to Diverse Weather Conditions:

    The system is engineered to function effectively across a range of environmental scenarios. However, it is important to note that certain extreme weather conditions, such as excessive moisture, high wind levels, or dense cloud cover, could impact operational efficiency. This necessitates the implementation of robust design features and protective measures to mitigate the adverse effects of such environmental challenges, ensuring reliable performance even under less than optimal weather conditions. The system's resilience to these environmental factors is a key consideration in its design and operational planning.

1.2.3 Future Contingencies

1. Antenna Modification for Future Adaptability:

    a. Size Adjustments for Signal Optimization:

    In response to potential future scenarios, there may be a need to modify the dimensions of the dish or antenna. Such alterations could become essential to counteract unforeseen signal loss or to adapt to changes in transmission requirements. Proactive considerations will be made for adjusting the antenna size to ensure continuous optimization of signal strength and overall system efficiency. Mainly, an antenna with a higher gain will be needed if it is unable to receive signals from certain satellites, specifically those that are farther away.

    b. Adaptation to Frequency Constraints and Satellite Tracking:

    Modifications to the antenna may also be necessitated by the limitations in frequency range imposed by the software-defined radio (SDR) and the specific satellites targeted for tracking. The antenna design will be evaluated and potentially revised to align with the frequency capabilities of the SDR and to optimize the tracking of available satellites. This will involve an assessment of both current and anticipated satellite constellations, ensuring the system's antenna remains effective and relevant in the evolving landscape of satellite communications.

2. Software Interface Overhaul:

    The system's software graphical user interface (GUI) may undergo significant revisions to maintain compatibility with evolving hardware components. These changes will aim to enhance user experience and interface efficiency, aligning with any new operational demands or technological advancements.

3. Deployment Location Constraints:

   The geographical location and specific satellite targets may impose limitations on where the system can be effectively deployed. Future deployments will consider geographical and orbital factors to maximize operational effectiveness.

4. Contingencies:

   Possible contingencies are having to change the size of the dish or antenna as to compensate for loss of signal. Software GUI may need to be significantly changed to operate with the components. Location and satellite may affect where the system can be deployed for operation. May need to adjust operations based on given laws and or approvals of the local area.

1.3 Document Organization

This SDD is organized with headings and sections. The citations, figures, and references will be in American Psychological Association (APA) format or a link reference where applicable.

The major sections of this document are as follows:

1. INTRODUCTION

   This section contains the purpose, scope, executive summary, system overview, constraints, and contingencies.

2. SYSTEM ARCHITECTURE

   This section discusses the build of software, hardware, and integration of the system.

3. HUMAN-MACHINE INTERFACE

   This section discusses how users utilize the system via inputs and receive outputs from the system.

4. DETAILED DESIGN

   This section explains in detail the design of the software, hardware, and communication functions of the system.

5. EXTERNAL INTERFACES

   This section explains the build and design of the external interfaces of the system.

6. SYSTEM INTEGRITY CONTROLS

   This section shows how the integrity of this system is controlled.

1.4 Project References

This section provides a bibliography of key project references and deliverables that have been produced before this point.

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1.5 Glossary

Terms (A-Z)	**Meaning**
GHz	Gigahertz
GUI	Graphical User Interface
Ka-Band	Frequencies between 27-40 GHz
K-Band	Frequencies between 18-27 GHz
Ku-Band	Frequencies between 12-18 GHz
LEO	Low Earth Orbit
RF	Radio Frequency
RX	Received Signal
S-Band	Frequencies between 2-4 GHz
SDR	Software Defined Radio *(a radio communication system utilizing software to modulate and demodulate received signals)*
STMGS	Satellite-Tracking Microwave Ground Station
TLE	Two Line Elements - A set of numbers which provides the details needed to calculate the position of an object in space given the current time.

2 SYSTEM ARCHITECTURE

The ground station is composed of five main subsystems that are essential for successfully tracking and receiving microwave signals from satellites (Refer to Figure 1). These subsystems include: the positioner, positioner software, SDR, antenna, and tracking software. The tracking software calculates the current and future positions of the desired satellite using GPS coordinates. This information is then relayed to the positioner software, which adjusts the positioner accordingly. The positioner, equipped with azimuth and elevation rotors, precisely aligns the antenna to optimize signal reception from the satellite. Finally, the SDR processes and records the signals emitted by the target satellite.

2.1 System Hardware Architecture

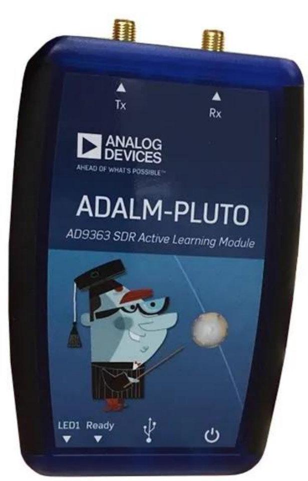
The structure of this system mainly includes the positioning system fixed on top of a rolling cart so that the system can be more easily deployed at a wide variety of locations. One end of the positioner has a counterweight and at the other end is a S-band antenna. The signal from this antenna is passed through a coaxial cable which can be interfaced with the SDR receiver.

Antenna: Ubiquiti RocketDish RD-2G24

Positioner- Yaesu G-5500DC with RT Az-El Controller

Positioner Controller- (Yaesu Azimuth Dual Controller G-5500 with Yaesu GS-232B Computer)

Radio Receiver- an SDR receiver to interface between the antenna and a computer (SDR Pluto)



2.2 System Software Architecture

There are three main software components to this product. The tracking software accepts user input to determine which satellite to begin tracking. The tracking software then interfaces with the motor controlling software to maintain antenna alignment with the desired satellite. The tracking software user input includes Keplerian elements for the satellite and the location of the ground station when operating. The third software is the SDR receiver which will identify and record our desired signal, if possible. The SDR will display signals received by the antenna and may be adjusted by the user to monitor different frequencies (Figure 2).

2.3 Internal Communications Architecture

There are two main lines of communication in this system: the antenna feed and the positioner control. The antenna feed comes straight from the dish antenna with distinct vertically polarized and horizontally polarized ports. These are combined into a circularly polarized signal which is passed through a bandpass filter and amplifier. This final signal is fed into the SDR where it is interpreted and displayed through the SDR software. The positioner control signal is sent from the control software to an accessory module of the motor controller. This accessory module is natively designed to interface with the motor controller to aid in computer control.

3 HUMAN-MACHINE INTERFACE

This machine is mainly interfaced digitally through a computer, but there are a few physical considerations. To improve the transportability and maneuverability of this system, it could be easily moved to optimal locations on a mobile surface, greatly reducing the required work needed to move it. The digital interface is both the SDR software and the positioner control software; both are accessed with a computer. The softwares is designed with human usability as the primary focus.

3.1 Inputs

The system software requires a variety of human inputs to get the full functionality of the system. The SDR software requires the user to input certain radio settings and adjust the operating frequency to match it to the desired signal. For the tracking software, the user must input the station location and select their desired satellite. If the satellite they wish to track is not in the program's database, the user is required to add their satellite's information including its TLE. The positioner can also take manual input from the user allowing the user to make quick adjustments to the ground station's configuration without using the software. Once in use, the ground station will be receiving RF signals, one of the most important inputs to this system.

3.2 Outputs

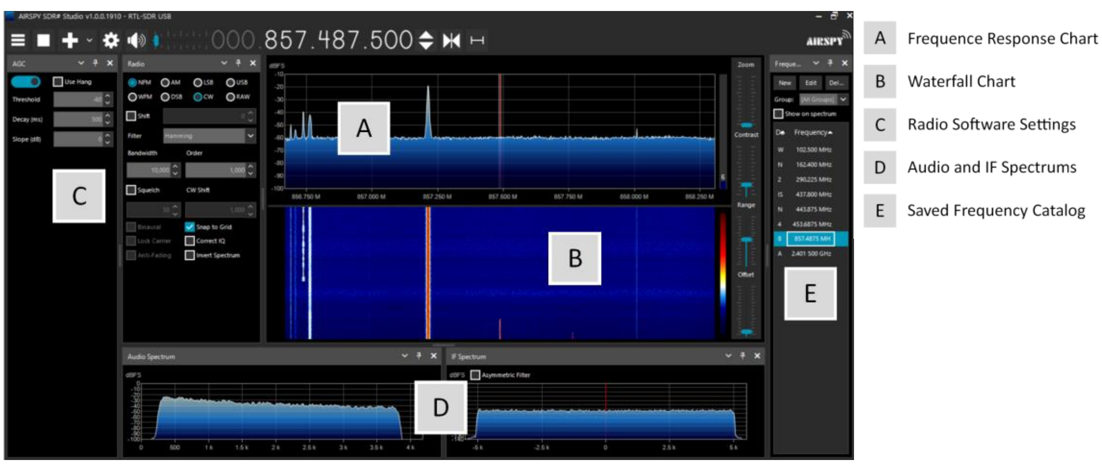


Figure 2 (SDR Sharp Software)

The system's main output is the display of the SDR software as seen in Figure 2. This is how the signals are received and made into meaningful information. Another output of the system will be the results from the positions software that will move the positioner via the GUI into position actively tracking the satellite.

4 DETAILED DESIGN

The ground station consists of three main modules: a satellite communication module (SCM), a mount and positioning module (MPM), and a positioner controller and tracking module (PCTM). The SCM and MPM are connected by fixing the Ubiquiti RocketDish RD-2G24 antenna to the Yaesu G5500 positioner motors via a pole mount for the dish. The motors are controlled by the tracking software inputting to the GS-232B computer and the G-5500 controller. The antenna has two coaxial output cables which will send any received RF signals through the RF feed to obtain usable data for the SDR software SDR Sharp.

4.1 Hardware Detailed Design

4.1.1 Satellite Communication Module:

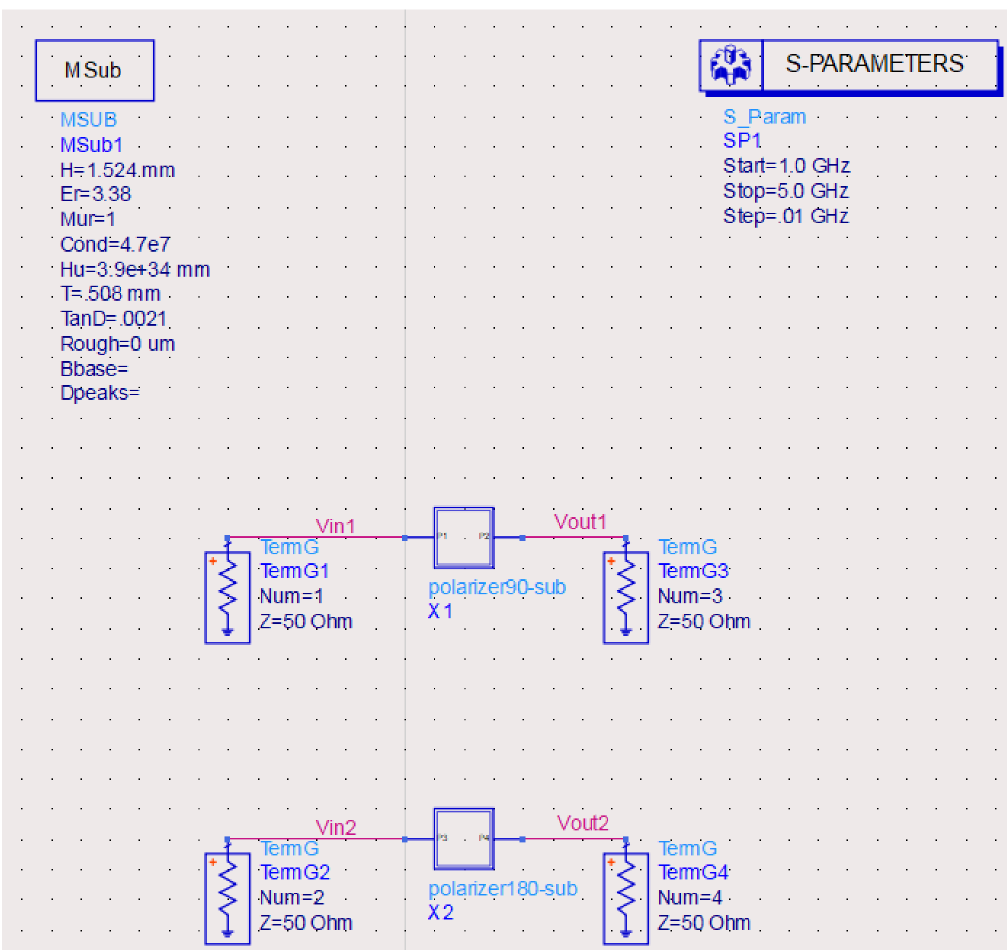
This module is responsible for receiving the raw RF transmission from the satellite at the antenna and processing the signal into usable data in the SDR. This system includes a parabolic antenna dish, RF conversion feed, and SDR software. The RocketDish antenna is designed for high-gain reception of microwave signals from satellites and operates between 2.3 - 2.7 GHz with a gain of 24 dBi. The RF feed is custom made using microstrip transmission lines and is designed to take the received RF signal at the antenna from two coaxial RF connectors, depolarize the signal, run the signal through a bandpass filter to eliminate unnecessary signals outside of the bandwidth, and send the signal through a low noise amplifier for output and further analysis and processing in the SDR.

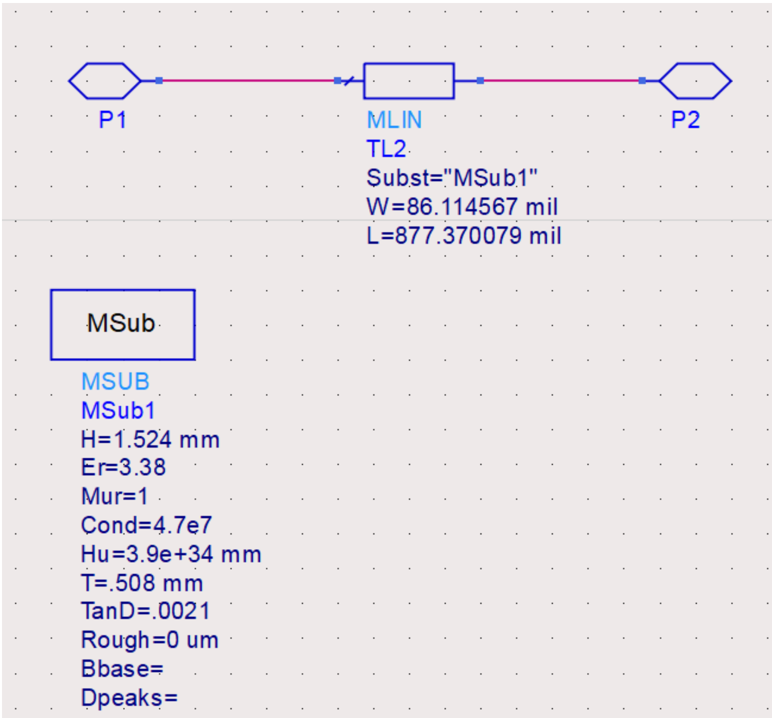
4.1.1.1 Radio Frequency Block:

This section examines the design details and decisions relating to components for the RF Block (polarizer, combiner, filter, and amplifier).

4.1.1.1.1 Polarizer (Delay Line):

The first step for a received signal to travel from the antenna to the SDR is the polarizer. Consisting of two transmission lines of different electrical lengths of a quarter-wavelength (90 deg). To be exact our polarizer will have 179.926-89.963 = 89.963 degrees (within 1 degree of 90 degrees)

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MLIN
TL2
Subst="MSub1"
W=86.114567 mil
L=877.370079 mil
P2
MSub
MSUB
MSub1
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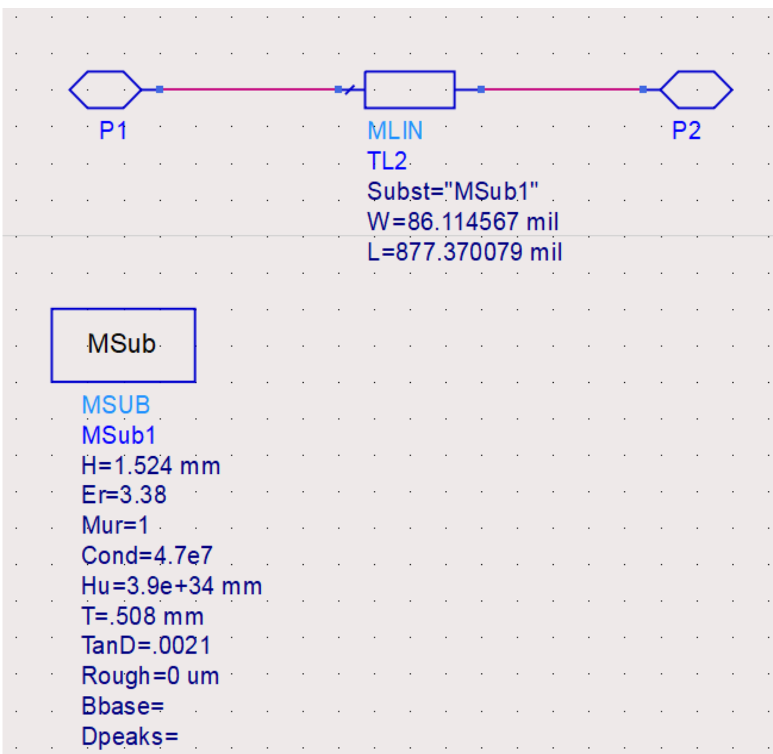
Dpeaks=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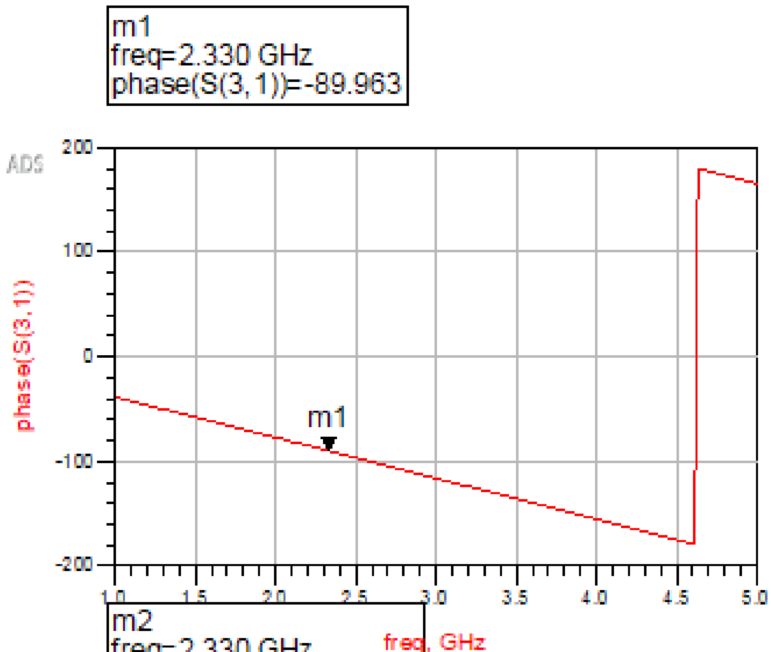
Dpeaks=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ADS
phase(S(3,1))
200
100
0
-100
-200
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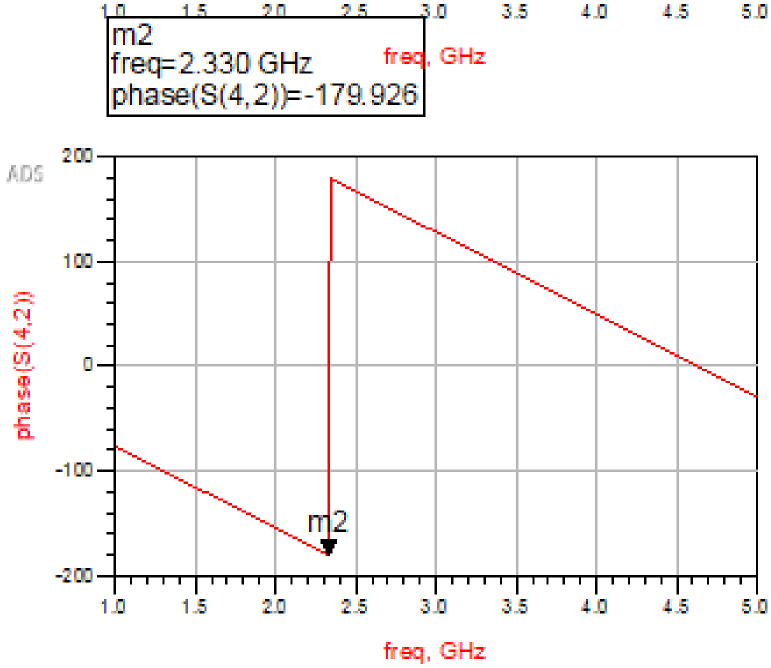
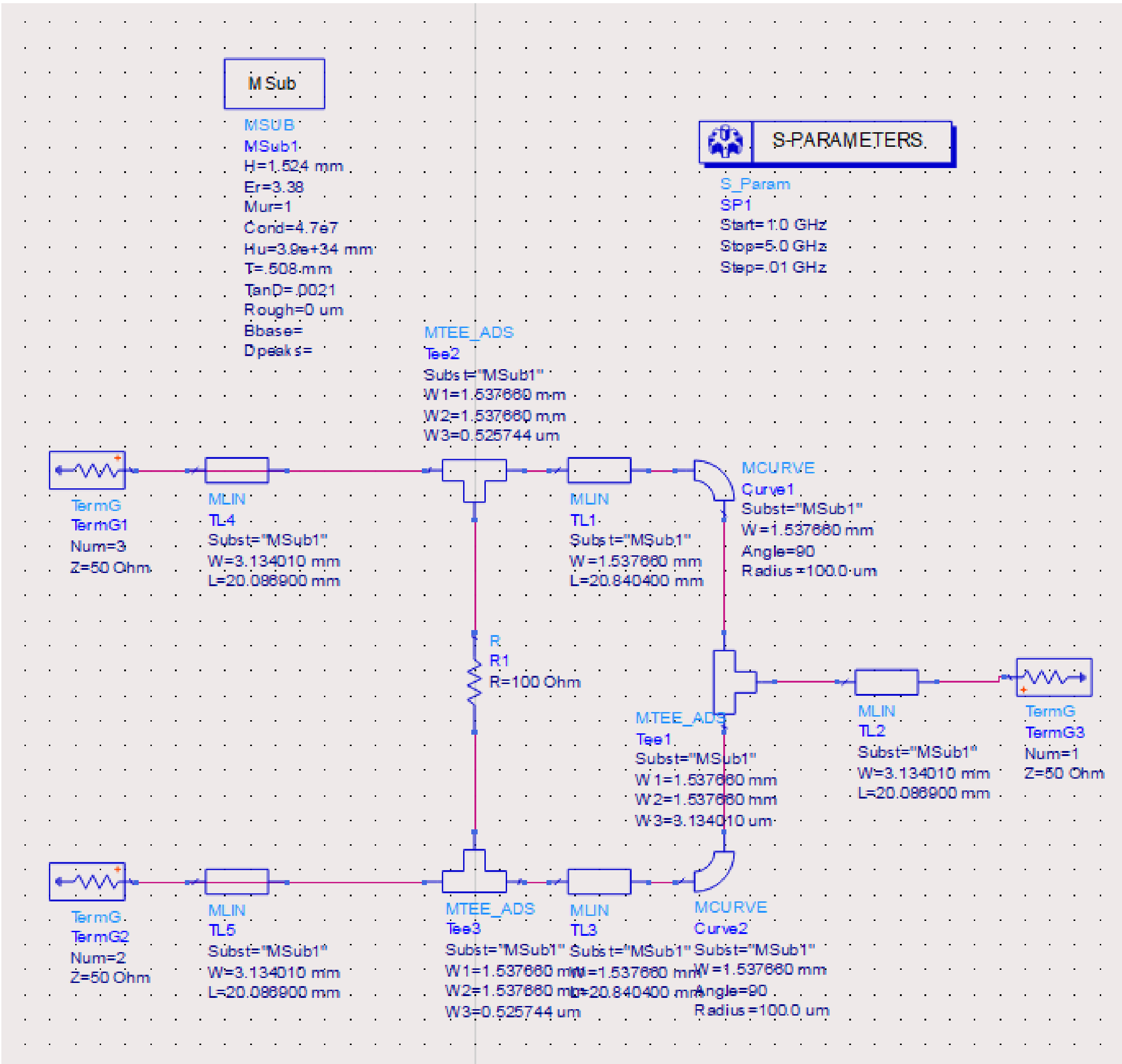
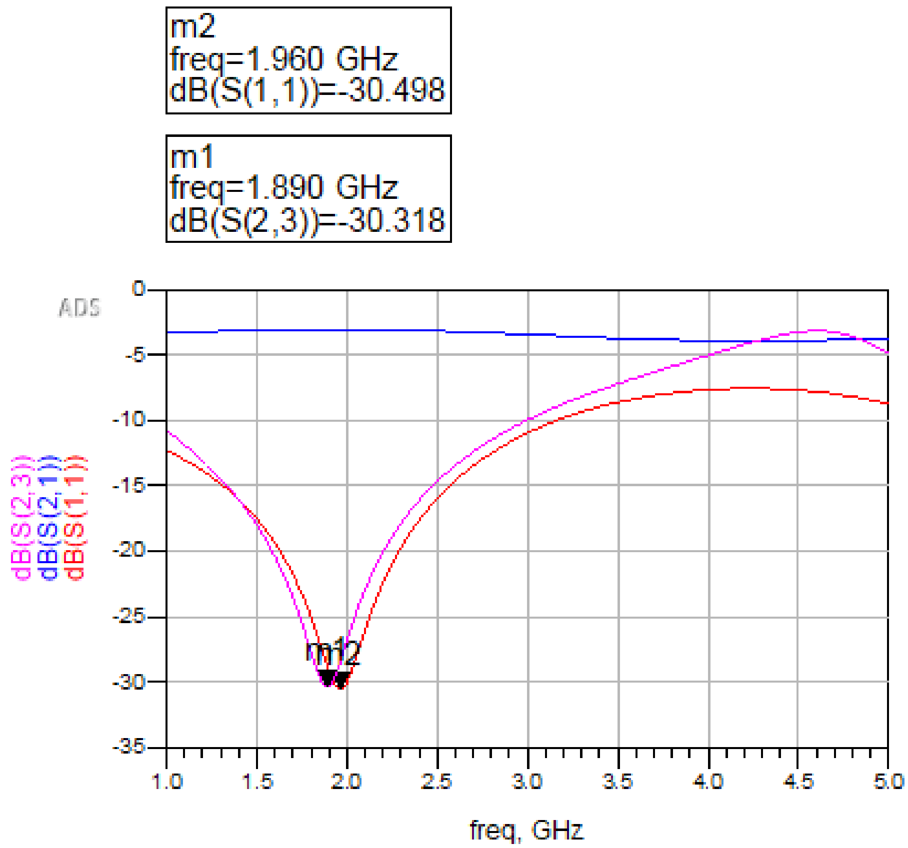
2.0
2.5
3.0
3.5
4.0
4.5
5.0
freq, GHz


m2
freq=2.330 GHz
phase(S(4,2))=-179.926
ADS
phase(S(4,2))
200
100
0
-100
-200
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
freq, GHz

4.1.1.1.2 Combiner (Wilkinson Power Combiner):

The second step is to combine both lines into one singular line.

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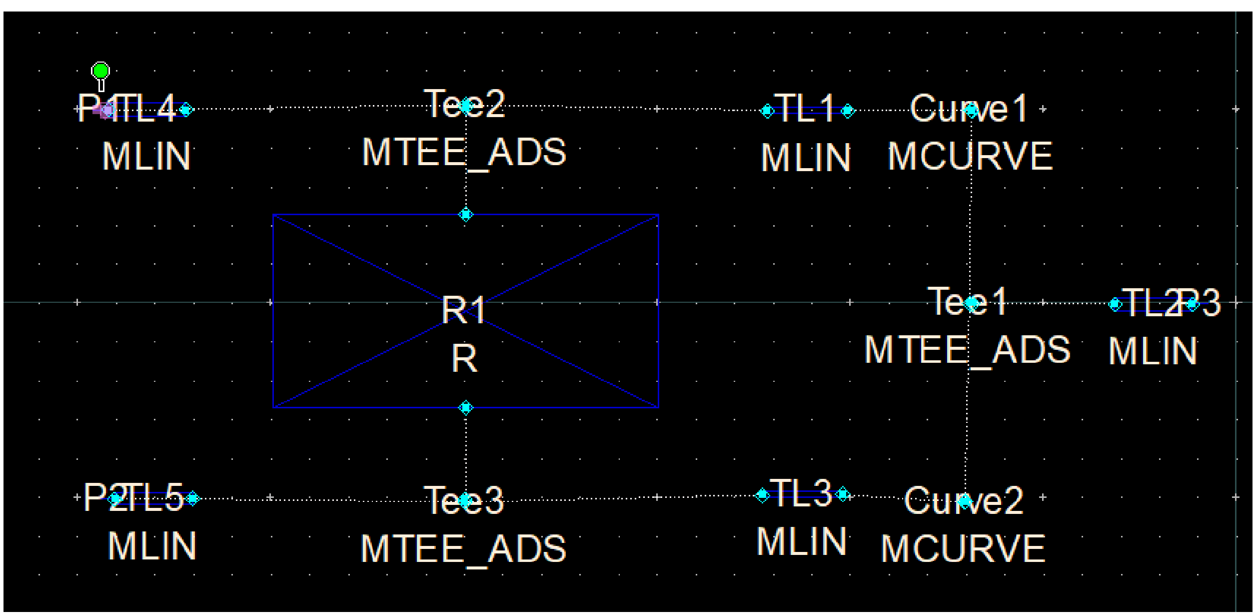
dB(S(1,1))=-30.498
m1
freq=1.890 GHz
dB(S(2,3))=-30.318
ADS
dB(S(2,3))
dB(S(2,1))
dB(S(1,1))
m1
m2
freq, GHz


P1
TL4
MLIN
Tee2
MTEE_ADS
TL1
MLIN
Curve1
MCURVE
R1
R
Tee1
MTEE_ADS
TL2
P3
MLIN
P2
TL5
MLIN
Tee3
MTEE_ADS
TL3
MLIN
Curve2
MCURVE

4.1.2 Mount and Positioning Module:

This module is responsible for supporting the ground station and performing the physical movement and tracking to keep the antenna in line of sight with the satellite. The mount and positioning module has the antenna fixed to a pole which inserts into the positioner motors. The positioner motor assembly itself is affixed to the wooden base and allows adjustment of the antenna's azimuth and elevation angles, controlled via an electronic controller box. This controller is operated via software from the PCTM.

4.1.3 Positioner Controller and Tracking Module:

This module is responsible for controlling the positioners to align the antenna with the satellite via an orbital tracking software. The tracking software is responsible for calculating the position of the satellite using its TLE, and sending commands to the positioner controller box to adjust the positioner motors and track the satellite's movement.

Future Options

The current ground station will be using the aforementioned RocketDish antenna and Yaesu positioner. While these components may be sufficient for the scope of this project, different antennas and positioners could be utilized in future iterations of the ground station for better results. These options were considered but ultimately decided against in the interest of time and cost.

Postioners	**Angle Resolution**	**Rotation Speed**	**Weight (kg)**	**Dimensions (mm)HxLxW**	**Max Load (kg)**	**Software Included**	**Cost**
SPX-01*	0.5°	3.5°/s	12.8	487x174x174	11-30	Yes	**$778.31**
SPX-01/HR*	0.1875°	5.3°/s	12.8	487x174x174	11-30	Yes	**$1026.44**
CURRENT WIDE LAB MODEL: Yaesu G5500***	Not specified	AZ: 2.7°/s EL:6.2°/s	9	Roughly the same	200	Yes	**Minimal**
PTS06	0.005°	AZ: 60°/s EL: 30°/s	6	279x173x178	36	Controlled via software on Windows 10	**Not Specified**

Table 1 (Azimuth and Elevation Rotor/Positioners)

Table 1 summarizes the positioner options. Both SPX-01 and SPX-01/HR come equipped with a power supply, controller, and pole mounting bracket. SPX-01/HR shares the same physical and electrical composition but offers improved angle resolution, rotation speed, and features a TCP/IP module for wireless control. On the other hand, the Current WiDE Lab model from the previous group was available at no cost, and required only the creation of a new mount.

Antennae	Weight	Diameter	Beamwidth	Gain	Band/Frequency	Cost
Current Antenna	9.8 kg	65 cm	3.8°	24 dB	2.3-2.7 Ghz	**Minimal**
223-18/ .XXX/419	Not Specified	46 cm	3.0°	33 dB	Ku-Band 12.4 to 18 GHz	**Not Specified**
223-24/ .XXX/419	Not Specified	61 cm	2.0°	36.5 dB	Ku-Band 12.4 to 18 GHz	**Not Specified**
223-36/ .XXX/419	Not Specified	92 cm	1.5°	40.5 dB	Ku-Band 12.4 to 18 GHz	**Not Specified**
223-48/ .XXX/419	Not Specified	1220 cm	1.0°	43 dB	Ku-Band 12.4 to 18 GHz	**Not Specified**

Table 2 (S-band and K-band Dish Antennas)

Table 2 summarizes possible future antenna options. The previous team's antenna was available at no cost and only required a modification to the mount design. The Millimeter Wave antennas are built to order; exact specifications can vary, though the cost is likely to be a significant limitation for future groups.

4.2 Software Detailed Design

4.2.1 RF SDR Software:

- The RF SDR software is responsible for tuning to different frequencies, demodulating received signals, and performing digital signal processing. It's likely to be Pluto with a maximum operating frequency of 3.8 GHz (max 6 GHz when amplified).
- The software will include a graphical user interface (GUI) for user interaction, allowing operators to select frequencies, track signal strength, and configure the SDR parameters.

4.2.2 Positioner Controller and Tracking Software:

- The tracking software calculates the antenna's required position using Keplerian coordinates and real-time tracking algorithms. It sends control signals to the positioner motors to adjust the dish's orientation.
- Includes fault detection and diagnostics to ensure accurate tracking and to handle any errors or malfunctions in the positioner mechanism.

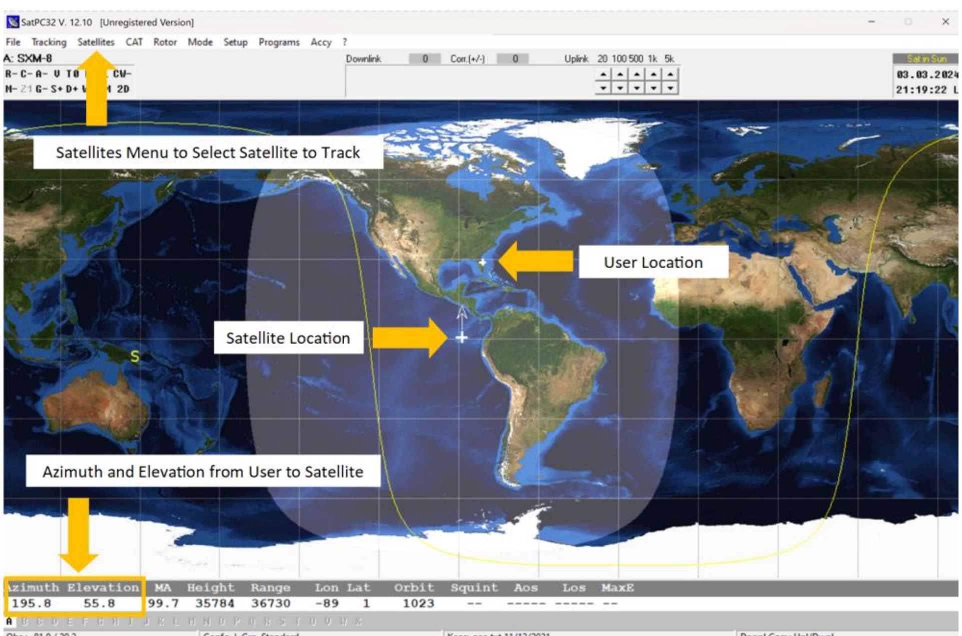


Figure 3 (Sat32PC Tracking Software)

4.3 Internal Communications Detailed Design

4.3.1 Control Signals:

- A control bus or communication system transmits commands from the positioner controller to the motor drivers within the positioners. This may use standard protocols such as Ethernet for reliable data transfer.

4.3.2 Data Flow:

- The RF signal received by the antenna dish is converted to a digital format by the RF receiver and fed into the SDR software for processing.

4.3.3 Monitoring and Feedback Loops:

- Sensor feedback from the positioners (such as encoders or potentiometers) is relayed back to the positioner controller to confirm that the dish has reached the commanded orientation.
- Monitoring systems are in place to check the health and status of the hardware components.

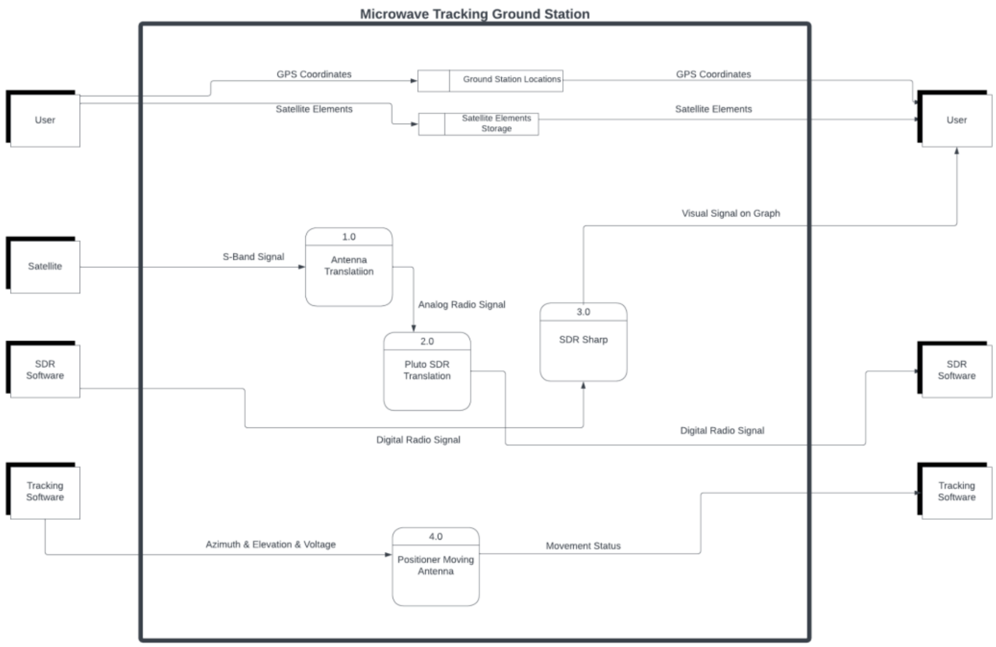


Figure 4 (Data Flow Diagram)

5 EXTERNAL INTERFACES

The external interfaces of the Microwave Tracking Ground station have two main architectures and can be split into two main categories of interfaces: hardware and software.

5.1 INTERFACE ARCHITECTURE

There are two major architectures for the interfaces of the Microwave Tracking Ground Station. The first is the connection between the antenna and the SDR software. This progresses with the received signal moving from the antenna, through the RF block, to the SDR Pluto, and finishing at the SDR software to be displayed visually. The second connection of interfaces lies between the tracking software and the positioner. The tracking software interfaces with the motor controller of the positioner to tell the positioner where to point the antenna to align with the orbit of the desired satellite.

5.2 INTERFACE DETAILED DESIGN

The hardware interfaces for this system comprise two key communication pathways: the antenna feed and the positioner control. The antenna feed is sourced directly from the dish antenna, featuring separate vertical and horizontal polarization ports. These signals are amalgamated into a circularly polarized signal, which subsequently passes through a coupled-line filter and low-noise amplifier . The resultant signal is then directed into the Software-Defined Radio (SDR) for interpretation and visualization via the SDR software. Conversely, the positioner control signal is transmitted from the control software to an auxiliary module integrated with the motor controller. This specialized module is inherently designed to seamlessly interface with the motor controller, facilitating computer-based control. Both pathways require interfacing with an external computer that can run the software.

The software interface requirements for this product revolve around two primary software components. The initial software component interacts with the positioner controller, ensuring precise alignment of the antenna with the satellite's orbit. It relies on input data, specifically the Keplerian elements of the satellite and the receiver's location, to regulate the positioner and achieve antenna alignment. This software has a built in database of these elements for easy satellite lookup and selection. It displays a map of the world and indicates both the satellite's and the user's locations. The second software component is the SDR receiver software, which serves as the intermediary between the system's Software-Defined Radio (SDR) and a computer. This software is responsible for visualizing the signals received by the antenna and fine-tuning the frequencies monitored by the SDR.

6 SYSTEM INTEGRITY CONTROLS

The system features an open user interface that remains accessible as long as it is connected to the GUI software and the manual controls. It's noteworthy that the information used to track satellites is publicly available and not deemed security-critical. Satellite signals, accessible to anyone with a capable ground station, contribute to the system's non security critical nature. Accurately tracking a satellite using its unique orbit data serves to help ensure that the received signal is from the desired source.

Access to the software is granted solely through the ground control station, following clearance by the user authentication system. Physical security measures entail secure storage practices for the system, accompanied by power-down procedures during periods of inactivity. Additionally, a pre-operation test is conducted to ensure proper motion functionality before initiating satellite tracking. The user operating the system will have access to a kill switch powering down the system hastily if any movement is perceived as unsafe.

Given the non-disruptive nature of the system, as it solely receives signals, primary emphasis is placed on limiting access to maintain full control in the hands of the product owner. This focus on controlled access ensures the system's operational integrity and aligns with the overall non-invasive character of its functionalities.