ASEN 4018 Senior Projects Fall 2018

Critical Design Review

Auto-Tracking RF Ground Unit for S-Band

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Advisor: Professor Dennis Akos

Customer: Raytheon
Purpose and Objective
Project Motivation

- Ground stations consist of a motorized antenna system used to communicate with satellites
- Current ground stations are expensive and stationary
- Mobile ground stations could be used to provide instantaneous communication with small satellites in remote locations
- Communication is real-time and direct to the user

Current stationary S-Band ground station: \( \approx $50,000 \)
Mission Statement: The ARGUS ground station is designed to be able to track a LEO satellite and receive a telemetry downlink using a platform that is both portable and more affordable than current S-Band ground stations.

- Commercial-off-the-shelf (COTS) where possible
- Interface with user laptop (monitor)
- Portable: 46.3 kg (102 lbs), able to be carried a distance of 100 meters by two people
CONOPS
Under 100 m

Within 60 min
Under 100 m
Within 60 min
Under 100 m

Within 60 min
### Functional Requirements

<table>
<thead>
<tr>
<th>FR</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>The ground station shall be capable of receiving signals from a Low Earth Orbit satellite between 2.2 - 2.3 GHz, in Quadrature Phase Shift Keying (QPSK) modulation with a Bit Error Rate (BER) of $10^{-5}$, a bit rate of 2 Mbit/s, and a G/T of 3 dB/K.</td>
</tr>
<tr>
<td>2.0</td>
<td>The ground station shall mechanically steer a dish/antenna system to follow a LEO satellite between 200 km to 600 km between 10° and 170° local elevation.</td>
</tr>
<tr>
<td>3.0</td>
<td>The ground station shall be reconfigurable to be used for different RF bands.</td>
</tr>
<tr>
<td>4.0</td>
<td>ARGUS shall weigh less than 46.3 kg (102 lbs) and be capable of being carried a distance of 100 meters by two people.</td>
</tr>
<tr>
<td>5.0</td>
<td>The ground station onboard computer shall interface with a laptop using a Cat-5 ethernet cable.</td>
</tr>
</tbody>
</table>
Design Solution
Helical Antenna Feed

Transportable Case

1.5m Parabolic Reflector

Azimuth/Elevation Motors

Tripod
Functional Block Diagram

Legend
- Power
- Satellite Bit Stream
- Pointing Control

- Outside Project Scope
- To be developed
- To be purchased

Power Source 120 V AC
Power Regulation (AC-DC and regulators)
12 V DC
19 V, 120 W AC-DC

Satellite
LH-13XL Feed
Motor Controller: Rot2Prog
Az/El Motors + Position Sensors: SPX-01

Antenna Unit
N-SMA Adapter
USB
12 V DC
3.0 V DC
2 m SMA

Intel Nuc Computer
Pointing Control Software
Pluto Software (GNU Radio)
External Computer

GPS (GlobalSat BU-353-S4)
Micro USB

SDR (Airmav Pluto)

Purpose Design Solution CPEs Design Reqs. Project Risks Validation Project Planning
Antenna Unit Subsystem
● Antenna Feed
  ○ **Purpose:** Collect incoming signal
  ○ **Model:** RFHam Design H-13XL
  ○ **Specs:** LCHP at 2.1 - 2.6 GHz, 110° beamwidth

● Antenna Dish
  ○ **Purpose:** Magnify and focus incoming signal
  ○ **Model:** RFHam Design 1.5 m
  ○ **Specs:** Metal mesh, aluminum struts, 6 kg

● Antenna Base
  ○ **Purpose:** Support antenna system and motors
  ○ **Model:** RFHam Design
  ○ **Specs:** 670mm – 830mm height, 30 kg max load
Motor System

SPX-01: az/el motors + position sensors + controller

- $655.78
- 0.5 deg resolution
- Interfaces with onboard computer
- Manual/auto control
- Designed for continuous tracking

Az/El motors + position sensors
Motor controller
Signal Conditioning and Processing

Legend:
- **Power**
- **Satellite Bit Stream**
- **Pointing Control**
  - Outside Project Scope
  - To be developed
  - To be purchased

- **Power Source 120 V AC**
- **Power Regulation** (AC/DC and regulators)
  - 12 V DC
  - 19 V, 120 W AC-DC

- **Intel Nuc Computer**
  - Pointing Control Software
  - Pluto Software (GNU Radio)
  - External Computer
    - GPS (GlobalSat BU-353-S4)
    - Wi, θ, t, text file

- **Antenna Unit**
  - LH-13XL Feed
  - Motor Controller: Rot2Prog
  - Az/El Motors + Position Sensors: SPX-01

- **LNA** (LNA-050400A00)
- **SDR** (ArgoX Pluto)

- **Satellite**
- **QPSK**

Connections:
- 12 V DC
- 3.0 V DC
- 2 m SMA
- Micro USB
- USB

**Purpose**
**Design Solution**
**CPEs**
**Design Reqs.**
**Project Risks**
**Validation**
**Project Planning**
● **Low Noise Amplifier (LNA)**
  ○ **Purpose:** Increase signal gain
  ○ **Model:** Minicircuits ZX60-P33ULN+
  ○ **Specs:** 14.8 dB Gain, 0.38 dB Noise

● **Software Defined Radio (SDR)**
  ○ **Purpose:** Process incoming RF data
  ○ **Model:** Adalm Pluto
  ○ **Specs:** 325 MHz to 3.8 GHz Frequency Range, 12 bit ADC, 20 MHz max RX data rate

● **Onboard Computer**
  ○ **Purpose:** Process incoming RF data and control tracking
  ○ **Model:** Intel NUC Kit NUC7I7DNKE
  ○ **Specs:** i7 Processor, 16gb RAM, 512gb SSD
Critical Project Elements
Design Requirements and Satisfaction
Antenna Subsystem

| FR 1.0 | The ground station shall be capable of receiving signals from a Low Earth Orbit satellite between 2.2 - 2.3 GHz, in Quadrature Phase Shift Keying (QPSK) modulation with a Bit Error Rate (BER) of $10^{-5}$, a bit rate of 2 Mbit/s, and a G/T of 3 dB/K. |
| FR 4.0 | ARGUS shall weigh less than 46.3 kg (102 lbs) and be capable of being carried a distance of 100 meters by two people. |
RF Ham Design Reflector

- Meets specified 27 dB at 2.3 GHz requirement; however, fails to meet mobility requirement
Modification of Reflector

Current RFHam dish:
- Assembly time 6+ hours
- Single continuous mesh
- Multiple tools

Modifications:
- Assembly time less than 1 hour
- Split into 12 connectable pieces
- Fewer than 4 tools

Modularity:
- 22 gauge aluminum sheet attaches to ribs
- Petals attach to central hub
Modification of Reflector

✔️ Meets mobility requirements (FR.4)
Antenna Gain Calculation

ZX60-P33ULN+ MiniCircuits LNA
- $T_{LNA} = 44\, K$
- $G_{LNA} = 11.3\, dB$

Pasternack SMA Male to N Male Adapter
- $L_1 = 0.07\, dB$

Pasternack SMA to SMA Cable
- $I_A = 2\, m, 0.7\, dB\/m \Rightarrow L_A = 1.4\, dB$
- $L_2 = L_3 = 0.45\, dB$

Adalm-Pluto SDR
- $T_{SDR} = 288.6\, K$

$L = \text{Loss}$
$l = \text{Line Length}$
$T = \text{Temperature}$

$L_{ttl} = L_1 + L_2 + L_3$

$a = 10^{-L_{ttl}/10}$

$T_S = aT_a + (1-a)T_0 + T_{LNA} + \frac{T_{SDR}}{G_{LNA}/L_A}$

$\Rightarrow T_S = 140\, K$

Requirement: $\frac{G}{T_S} = 3\, dB/K$

$G_{\text{required}} = 26.2\, dBi$
Estimated Efficiency

$$\eta = \eta_{feed} \eta_{bl}$$

$$G_{parabolic} = \eta \left( \frac{\pi D}{\lambda} \right)^2$$

<table>
<thead>
<tr>
<th>Efficiency</th>
<th>Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>53.7%</td>
<td>28.08 dBi</td>
</tr>
<tr>
<td>35%</td>
<td>26.22 dBi</td>
</tr>
<tr>
<td>Required</td>
<td>26.2 dBi</td>
</tr>
</tbody>
</table>

Optimal ARGUS antenna is 53.7% efficient

✔ Meets bandwidth and gain requirements (FR.1)
## Tracking Hardware Subsystem

| FR 2.0 | The ground station shall mechanically steer a dish/antenna system to follow a LEO satellite between 200 km to 600 km between 10° elevation and 170° elevation. |
STK: Tracking Rate Verification

DR 2.3  The antenna motor shall be able to move the antenna at a slew rate of **5.0 °/s**

- Worst case pass
  - Elliptical orbit
  - Pass directly overhead
  - Retrograde
- Max Rate: 4.41 °/s

Max of 4.41 °/s

Angular Rates (deg/sec)  Azimuth Rate (deg/sec)  Elevation Rate (deg/sec)
Worst Case Pointing Error

\[ \theta \text{Pointing Error} = \theta \text{TLE, Error} + \theta \text{Motor, Error} + \theta \text{Tracking, Error} < 3.25^\circ \]

\[ \theta \text{Motor, Error} < 3.25^\circ - 1.10^\circ - 1.43^\circ \]

\[ \theta \text{Motor, Error} < 0.72^\circ \]

\[ \theta \text{TLE, Error, Max} = 1.43^\circ \]

\[ \theta \text{Tracking, Error, Max} = 1.10^\circ \]

\[ \theta_{HP} = 6.5^\circ \]
Antenna Motor System

- **specs:**
  - Azimuth
    - Range: 0° to 360°
    - Speed: 7.2°/sec
  - Elevation
    - Range: ± 90°
    - Speed: 7.2°/sec
  - Maximum Load: 30 kg
  - Position sensors with accuracy: 0.5°

| ✓ | DR 2.3 | The antenna motor shall be able to move the antenna at a slew rate of 5.0 °/s |
|   |        |                                                          |
| ✓ | DR 2.4 | The antenna motor shall have a pointing accuracy greater than 0.72° |
Tracking Overview

Az/El angular command

External power: 12V DC

Controller: Rot2Prog

Motor system

Az motor → Sensor

El motor → Sensor

SPX-01
Software Interface

Enable serial communication ➔ Input lat/long ➔ Calibrate ➔ Select target ➔ Engage
Tracking Software Subsystem

FR 2.0 The ground station shall mechanically steer a dish/antenna system to follow a LEO satellite between 200 km to 600 km between 10° elevation and 170° elevation.
The ground station shall mechanically steer a dish/antenna system to follow a LEO satellite between 200 km to 600 km between 10° elevation and 170° elevation.
Calibration & Manual Control Frames

Purpose Design Solution CPEs Design Reqs. Project Risks Validation Project Planning

Antenna Pointing:
- Manual Mode
- Program Track
  +El ▲
  -El ▼
  +Az ▶
  -Az ◀

Input Azimuth:
0
Input Elevation:
0
Set Az/E1

Current Azimuth: 223.63, Current Elevation: 61.07
Azimuth and Elevation Calibration

- Manual Control Frame - Dither around Sun, find strongest signal strength
- Calibration Frame - Set current pointing angles to predicted Sun location

**Ground Station Latitude/Longitude (GPS)**

- **ARGUS GUI**
- **Sun Azimuth and Elevation**
- **Point in Predicted Location and Dither**

The pointing control accuracy must be within 3.25° to maintain downlink capabilities throughout the entire pass.
Upcoming Pass Frame

Upcoming Passes for MTI over Boulder:

Pass 1:
Start: Mon Nov 26 18:05:36 2018, Azimuth: 55.65°
Finish: Mon Nov 26 18:11:00 2018, Azimuth: 120.54°
Maximum Elevation: 3.04°

Pass 2:
Start: Mon Nov 26 19:35:38 2018, Azimuth: 10.82°
Maximum Elevation: 82.28°

Pass 3:
Finish: Mon Nov 26 21:14:42 2018, Azimuth: 266.4°
Maximum Elevation: 3.22°

Recalculate
The pointing control accuracy must be within $3.25^\circ$ to maintain downlink capabilities throughout the entire pass.

ARGUS (Mountain Time)

Upcoming Passes for MTI over Boulder:

Pass 1:
- Start: Sun Dec 2 18:03:20 2018, Azimuth: 60.53°
- Finish: Sun Dec 2 18:08:01 2018, Azimuth: 115.76°
- Maximum Elevation: 2.1°

Pass 2:
- Maximum Elevation: 84.43°

Pass 3:
- Start: Sun Dec 2 21:06:27 2018, Azimuth: 333.89°
- Maximum Elevation: 4.08°

Recalculate
Az/El Plot Frame

Azimuth and Elevation of Yaogan 6 over Boulder

0°
315°
30°
20°
270°
225°
20°
180°
135°
90°
60°
50°
40°
30°
20°
0°
Sun 45°
80°
90°

Purpose  Design Solution  CPEs  Design Reqs.  Project Risks  Validation  Project Planning
The pointing control accuracy must be within $3.25\degree$ to maintain downlink capabilities throughout the entire pass.
FR 1.0 | The ground station shall be capable of receiving signals from a Low Earth Orbit satellite between 2.2 - 2.3 GHz, in Quadrature Phase Shift Keying (QPSK) modulation with a Bit Error Rate (BER) of $10^{-5}$, a bit rate of 2 Mbit/s, and a G/T of 3 dB/K.
FR 1.0 The ground station shall be capable of receiving signals from a Low Earth Orbit satellite between 2.2 - 2.3 GHz, in Quadrature Phase Shift Keying (QPSK) modulation with a Bit Error Rate (BER) of $10^{-5}$, a bit rate of 2 Mbit/s, and a G/T of 3 dB/K.
GNURadio Software Demonstration

**DR 1.4** The ground station shall be capable of demodulating a signal using the QPSK modulation scheme.

**DR 1.10** The ground station shall be able to receive a data rate of at least 2 million bits per second.
Bit Error Rate

**BER** is governed by the system Signal to Noise Ratio (SNR)

- Must have SNR ≥ 10.4 dB to achieve BER of 10⁻⁵
- Current system SNR ≈ 17.2 dB
  - BER ≈ 8.9e⁻⁹
  - Determined using ASEN 3300 link budget and typical transmit values

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**FR 1.0**

The ground station shall be capable of receiving signals from a Low Earth Orbit satellite between 2.2 - 2.3 GHz, in Quadrature Phase Shift Keying (QPSK) modulation with a **Bit Error Rate (BER) of 10⁻⁵**, a bit rate of 2 Mbit/s, and a G/T of 3 dB/K.

- SNR = 10.4 dB
  - Meets Requirement

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*Purpose | Design Solution | CPEs | Design Reqs. | Project Risks | Validation | Project Planning*
# Mobility

| FR 4.0 | ARGUS shall weigh less than 46.3 kg (102 lbs) and be capable of being carried a distance of 100 meters by two people. |
## Mobility: Mass Estimate

<table>
<thead>
<tr>
<th>Components</th>
<th>Mass</th>
<th>Components</th>
<th>Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed</td>
<td>1 kg</td>
<td>Tripod</td>
<td>1.9 kg</td>
</tr>
<tr>
<td>Dish</td>
<td>6 kg</td>
<td>SDR</td>
<td>0.12 kg</td>
</tr>
<tr>
<td>Az/El motors</td>
<td>12.8 kg</td>
<td>Electronics</td>
<td>2.2 kg</td>
</tr>
<tr>
<td>Motor Controller</td>
<td>2 kg</td>
<td>Case</td>
<td>15.4 kg</td>
</tr>
<tr>
<td>NUC</td>
<td>1.2 kg</td>
<td>Mounting Bracket</td>
<td>1.6 kg</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>44.2 kg &lt; 46.3 kg</strong></td>
<td>✓ Meets Mass Requirement (FR4.0)</td>
<td></td>
</tr>
</tbody>
</table>
Risk Management
<table>
<thead>
<tr>
<th>Issue</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gain</td>
<td>Blockage and efficiency calculations flawed, too little gain to get satellite signal</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>Modifications to dish result in incorrect parabola, unaccounted for blockage</td>
</tr>
<tr>
<td>TLE</td>
<td>Accuracy dependent on source and age of TLE</td>
</tr>
<tr>
<td>Motor</td>
<td>Motor resolution and limits cause error in tracking satellite</td>
</tr>
<tr>
<td>Mobility</td>
<td>Violate OSHA standards</td>
</tr>
<tr>
<td>Calibration</td>
<td>Inaccurate calibration of Az/El causes inaccurate pointing and tracking</td>
</tr>
<tr>
<td>BER</td>
<td>High BER causes data to be erroneous and unusable</td>
</tr>
<tr>
<td>Full Integration</td>
<td>Failure between subsystem interfaces causes entire system failure</td>
</tr>
</tbody>
</table>

**Risk Matrix**

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Mobility</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>TLE Error</td>
<td>Manufacturing</td>
<td>BER</td>
<td>Dish Gain</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1. Motor Error</td>
<td>2. Calibration</td>
<td>Full Integration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Legend**

- Low (1-4)
- Moderate (5-9)
- High (10-14)
- Critical (15-25)
### Risk Mitigation

<table>
<thead>
<tr>
<th>Risk</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gain</td>
<td>Larger dish gives bigger margin of error</td>
</tr>
<tr>
<td>TLE</td>
<td>Download most recent TLE’s for testing</td>
</tr>
<tr>
<td>Motor</td>
<td>Buy more precise motors</td>
</tr>
<tr>
<td>Mobility</td>
<td>Purchase a case with less mass</td>
</tr>
<tr>
<td>Calibration</td>
<td>Antenna point at strongest signal from sun during calibration</td>
</tr>
<tr>
<td>BER</td>
<td>LNA, short cable lengths, specific frequency band</td>
</tr>
<tr>
<td>Full Integration</td>
<td>Interfaces tested incrementally/thoroughly for proper function</td>
</tr>
</tbody>
</table>

#### Risk Evaluation

<table>
<thead>
<tr>
<th>Severity</th>
<th>Likelihood</th>
<th>Risk</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Low (1-4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Moderate (5-9)</td>
<td>Mobility</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>High (10-14)</td>
<td>Full Integration</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>TLE Error</td>
<td>BER</td>
</tr>
</tbody>
</table>
Verification and Validation
Test Plan

Component Test:
Jan. 15th - Feb. 11th

Antenna:
- Dish manufacturing
- Motor calibration
- Feed functionality

Signal Processing:
- GNURadio
- Predict
- GPS

Hardware:
- Power Transformer
- Capacitor
- Motor Functionality
- Component weights

Integration Test:
Feb. 11th - Mar. 11th

Antenna System:
- Gain
- Beamwidth

Signal Processing Test:
- QPSK demodulation
- BER
- Cat5 connection

Motor System Test:
- Rotation rate
- Rotation range

Systems Test:
Mar. 11th - April 21st

Antenna System:
- S-Band satellite signal reception

Signal Processing Test:
- S-Band signal processed

Motor System Test:
- MTI + Yaogan 6 tracking

Mobility:
- Transport and assembly > 100m
Signal Processing System Level Test

1. Create QPSK signal in Matlab - minimum 460,518 to give 99% confidence
2. Add noise to signal using SNR and write signal to file
3. Read file using NUC with GNURadio at 2 MHz
4. Use QPSK Demodulation and write to file processed signal
5. Output signal through Cat5 Ethernet cord to users laptop
6. Compare signal to Matlab generated signal

Possible Measurement Errors
- NUC Processing Speed
- Reconfigurability
- Length of test (time)

<table>
<thead>
<tr>
<th>Equipment Needed</th>
<th>Procurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laptop</td>
<td>Owned</td>
</tr>
<tr>
<td>GNURadio</td>
<td>Open Source</td>
</tr>
</tbody>
</table>
Signal Processing System Level Test

**Objective**
- Verify NUC Processing speed
- Cat5 data port connection
- GNURadio on S-Band signal

**Location**
ITLL

**FR Verified**
FR 1: BER, QPSK Demodulation, Bandwidth
FR 3: Reconfigurability
FR 5: Cat5 Connection

<table>
<thead>
<tr>
<th>Data Needed</th>
<th>Compared To</th>
<th>Expected</th>
</tr>
</thead>
<tbody>
<tr>
<td>BER</td>
<td>Matlab estimation</td>
<td>8.9E-9</td>
</tr>
<tr>
<td>QPSK Signal</td>
<td>Matlab generated signal</td>
<td>Matlab generated signal</td>
</tr>
</tbody>
</table>
Antenna Gain/Beamwidth Test

1. Control transmit frequency
   - Turn on ARGUS antenna, measure ambient power for 1 minute to zero measurement

2. Transmit signal with known gain pattern and power output
   - Transmit signal with known gain pattern and power output

3. Measure power received, compute gain
   - Measure power received, compute gain

4. Rotate dish, monitor power level to verify beamwidth
   - Rotate dish, monitor power level to verify beamwidth

\[ P_R = \frac{P_T G_T G_R \lambda^2}{(4\pi d)^2} \]
\[ G_R = \frac{P_R (4\pi d)^2}{P_T G_T \lambda^2} \]

Equipment Needed

<table>
<thead>
<tr>
<th>Equipment Needed</th>
<th>Procurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDR</td>
<td>Purchase</td>
</tr>
<tr>
<td>Transmit Antenna</td>
<td>Borrow/Purchase</td>
</tr>
<tr>
<td>Waveform Analyzer</td>
<td>Borrow</td>
</tr>
<tr>
<td>Measuring wheel</td>
<td>Borrow</td>
</tr>
</tbody>
</table>

Related to:

- Purpose
- Design Solution
- CPEs
- Design Reqs.
- Project Risks
- Validation
- Project Planning
Antenna Gain/Beamwidth Test

**Objective**
- Verify antenna gain
- Verify half power beam width (HPBW)

**Location**
Rural location or RF test range

**FR Verified**
FR 1: Gain, Beamwidth

<table>
<thead>
<tr>
<th>Data Needed</th>
<th>Compared To</th>
<th>Expected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gain</td>
<td>Efficiency model, dish kit specs</td>
<td>29.5 dBi at 2.4GHz</td>
</tr>
<tr>
<td>Beamwidth</td>
<td>Idealized estimates, dish kit specs</td>
<td>6.5°</td>
</tr>
</tbody>
</table>

**Potential Measurement Issues**
- External signal noise
- Signal reflection from ground
- Incorrect feed placement
- Pointing accuracy
Motor System Level Test

1. Attach Dish+Feed to motor system. Includes tripod and cable
2. Use motor controller to slew antenna between 10-170 degrees
3. Measure rotation time to calculate slew rate

Equipment Needed

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Procurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timer</td>
<td>Owned</td>
</tr>
<tr>
<td>Protractor</td>
<td>Borrow</td>
</tr>
<tr>
<td>Power Supply</td>
<td>Borrow</td>
</tr>
</tbody>
</table>
Motor System Level Test

**Objective**
- Test cable wrap
- Show motor control system
- Test encoders

**Location**
ITLL

**FR Verified**
FR 2: Slew rate, range of motion

**Data Needed**

<table>
<thead>
<tr>
<th>Data Needed</th>
<th>Resolution</th>
<th>Expected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotation Rate</td>
<td>0.5°/s</td>
<td>7.2 °/s</td>
</tr>
<tr>
<td>Rotation Angle</td>
<td>1°</td>
<td>10°-170°</td>
</tr>
</tbody>
</table>

**Possible Measurement Errors**
- Timing accuracy
- Angle measurement accuracy
# Mobility System Level Test

<table>
<thead>
<tr>
<th>Equipment Needed</th>
<th>Procurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scale</td>
<td>Borrow</td>
</tr>
<tr>
<td>Measuring wheel</td>
<td>Borrow</td>
</tr>
<tr>
<td>Stopwatch</td>
<td>Borrow/Owned</td>
</tr>
</tbody>
</table>

1. **All ARGUS components packed in carrying case**
   - Weigh disassembled system

2. **Carry 100m**
   - Assemble ARGUS
Mobility System Level Test

**Objective**
- Verify weight requirements
- Demonstrate mobility
- Show assembly is under 60min

**Location**
Business field

**FR Verified**
FR 4: Mass, assembly time

**Data Needed**

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Expected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>46.3 kg</td>
</tr>
<tr>
<td></td>
<td>42.6 kg</td>
</tr>
<tr>
<td>Assembly Time</td>
<td>60 min</td>
</tr>
<tr>
<td></td>
<td>35 min</td>
</tr>
<tr>
<td>Objective</td>
<td></td>
</tr>
<tr>
<td>--------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>● Test ARGUS portability</td>
<td></td>
</tr>
<tr>
<td>● Receive signal from satellite</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business Field</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FR Verified</th>
</tr>
</thead>
<tbody>
<tr>
<td>All FR</td>
</tr>
</tbody>
</table>

### Full System Test

1. Components packed in cases
2. Assemble ARGUS
3. Calibrate with Sun Az/El
4. Engage satellite tracking
5. Demodulate Signal
6. Write Bitstream
Project Planning
Work Breakdown Structure

Legend
- Green: Completed
- Orange: Future Work

Deliverables
- PDD
- CDD
- PDR
- CDR
- FFR
- MSR
- TRR
- SFR
- PFR
- SDS
- AIAA

Management
- Gantt Chart
- Budget
- Org Chart
- WBS
- Cost Plan
- Test Plan
- Risk Matrix

Safety/Test
- Research
- Requirements
- Facilities
- Procedures
- Equipment
- Transportation

Antenna
- Subsystem Layout
- Kit Selection
- CAD Model
- Accuracy Calculations
- Gain Calculation
- Procurement
- Manufacturing
- Assembly
- Verification
- Integration
- Validation

Tracking
- Software Selected
- Algorithm Developed
- Model Tested
- Software Implemented
- Software Test
- Verification
- Integration
- Validation

Motors
- Torque/Speed Calculations
- Transfer Function Derived
- Select Motors
- Motor Controller Selected
- Procurement
- Verification
- Integration
- Validation

Signal Processing
- Demodulation with GNU Radio
- Select LNA
- Pointing Accuracy Calculations
- Simulated Closing Link
- Signal Simulation
- Procurement
- Verification
- Integration
- Validation

Purpose  Design Solution  CPEs  Design Reqs.  Project Risks  Validation  Project Planning
Work Plan

ARGUS

Spring Semester
START
Purchase SDR
Purchase LNA
Purchase Microcontroller
Purchase NUC
Purchase Electronics Case
Purchase Dish Kit
Finalize Plan to Make Dish Mobile
Implement Tracking on NUC and Mic...
Implement Software into SDR
Calibrate Pointing
Calibrate SDR
Motor-Controller Testing
Motor Testing
Modify Dish Kit
Test Pointing Accuracy
Test SDR
Test Built Antenna
Fully Integrate System
Test Full System
Senior Design Expo

Legend
- Purchases
- Software
- Antenna
- Test
- Integration
- Milestone

Implementing Software
Testing and Calibration
Work Plan

ARGUS
Spring Semester
- START
- Purchase SDR
- Purchase LNA
- Purchase Microcontroller
- Purchase NUC
- Purchase Electronics Case
- Purchase Dish Kit
- Finalize Plan to Make Dish Mobile
- Implement Tracking on NUC and Mic...
- Implement Software into SDR
- Calibrate Pointing
- Calibrate SDR
- Motor-Controller Testing
- Motor Testing
- Modify Dish Kit
- Test Pointing Accuracy
- Test SDR
- Test Built Antenna
- Fully Integrate System
- Test Full System
- Senior Design Expo

Legend
- Purchases
- Software
- Antenna
- Test
- Integration
- Test
- Milestone

Dish Kit Modifying
Antenna Gain Testing
Work Plan

ARGUS

Spring Semester
START
Purchase SDR
Purchase LNA
Purchase Microcontroller
Purchase NUC
Purchase Electronics Case
Purchase Dish Kit
Finalize Plan to Make Dish Mobile
Implement Tracking on NUC and Mic...
Implement Software into SDR
Calibrate Pointing
Calibrate SDR
Motor-Controller Testing
Motor Testing
Modify Dish Kit
Test Pointing Accuracy
Test SDR
Test Built Antenna
Fully Integrate System
Test Full System
Senior Design Expo

Legend
- Purchases
- Software
- Antenna
- Test
- Integration
- Integration
- Milestone

Fully Integrate System and Full System Test

Design Expo
Work Plan

ARGUS

Spring Semester
- START
- Purchase SDR
- Purchase LNA
- Purchase Microcontroller
- Purchase NUC
- Purchase Electronics Case
- Purchase Dish Kit
- Finalize Plan to Make Dish Mobile
- Implement Tracking on NUC and Mic...
- Implement Software into SDR
- Calibrate Pointing
- Calibrate SDR
- Motor-Controller Testing
- Motor Testing
- Modify Dish Kit
- Test Pointing Accuracy
- Test SDR
- Test Built Antenna
- Fully Integrate System
- Test Full System
- Senior Design Expo

Legend
- Purchases
- Software
- Antenna
- Test
- Integration
- Test
- Integration
- Milestone

Critical Path

Obtaining Products
Implementing Software
Major Driver: Dish Kit Modifying
Testing and Integration
# Budget

## Item

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor + Controller</td>
<td>782.58</td>
</tr>
<tr>
<td>Electronics</td>
<td>1134.10</td>
</tr>
<tr>
<td>Dish + Feed</td>
<td>627.67</td>
</tr>
<tr>
<td>Tripod</td>
<td>475.00</td>
</tr>
<tr>
<td>Pelican Case</td>
<td>400.00</td>
</tr>
<tr>
<td><strong>Remaining Funds</strong></td>
<td><strong>1580.65</strong></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>5000.00</strong></td>
</tr>
</tbody>
</table>

Total: $3419.25
References


3. STK help.agi.com/stk/index.htm#training/manuals.htm?TocPath=Training|____0.


Questions?
Backup Slides
# Total List

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
<th>Percentage</th>
<th>Remaining Funds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adalm Pluto</td>
<td>$99.99</td>
<td>2.92%</td>
<td>$1,580.65</td>
</tr>
<tr>
<td>Intel NUC Kit</td>
<td>$530.98</td>
<td>15.53%</td>
<td></td>
</tr>
<tr>
<td>16 GB RAM</td>
<td>$118.99</td>
<td>3.48%</td>
<td></td>
</tr>
<tr>
<td>500 GB SSD</td>
<td>$90.00</td>
<td>2.63%</td>
<td></td>
</tr>
<tr>
<td>Low Noise Amplifier (LNA)</td>
<td>$94.95</td>
<td>2.78%</td>
<td></td>
</tr>
<tr>
<td>GPS</td>
<td>$27.97</td>
<td>0.82%</td>
<td></td>
</tr>
<tr>
<td>Motor + Controller</td>
<td>$782.58</td>
<td>22.89%</td>
<td></td>
</tr>
<tr>
<td>Tripod</td>
<td>$475.00</td>
<td>13.89%</td>
<td></td>
</tr>
<tr>
<td>72 in. SMA Cable</td>
<td>$113.08</td>
<td>3.31%</td>
<td></td>
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<tr>
<td>Dish Kit</td>
<td>$512.67</td>
<td>14.99%</td>
<td></td>
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<tr>
<td>AC-DC Converter</td>
<td>$9.33</td>
<td>0.27%</td>
<td></td>
</tr>
<tr>
<td>120-24 Transformer</td>
<td>$29.18</td>
<td>0.85%</td>
<td></td>
</tr>
<tr>
<td>Pelican Case</td>
<td>$400.00</td>
<td>11.70%</td>
<td></td>
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<tr>
<td>N to SMA Adapter</td>
<td>$19.63</td>
<td>0.57%</td>
<td></td>
</tr>
<tr>
<td>Antenna Feed</td>
<td>$115.00</td>
<td>3.36%</td>
<td></td>
</tr>
<tr>
<td>Remaining Funds</td>
<td>$1,580.65</td>
<td>46.23%</td>
<td></td>
</tr>
<tr>
<td>Total Income</td>
<td>$3,419.35</td>
<td>100.00%</td>
<td></td>
</tr>
</tbody>
</table>
## Changes Made Since PDR

<table>
<thead>
<tr>
<th>Change</th>
<th>Reasoning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purchase and modify dish kit</td>
<td>Cost effectiveness due to amount of man hours necessary to build dish from scratch</td>
</tr>
<tr>
<td>Purchase motor gimbal</td>
<td>Difficulty in accuracy and efficiency. Out of scope</td>
</tr>
<tr>
<td>More precise gain number</td>
<td>Specific components chosen, thus, accurately calculated losses</td>
</tr>
<tr>
<td>Removal of auto-track</td>
<td>Out of scope due to difficulty, processing constraints, and strain on motors</td>
</tr>
<tr>
<td>Requirement</td>
<td>Verification Method</td>
</tr>
<tr>
<td>-------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>1.0</td>
<td>The ground station shall be capable of receiving signals from a Low Earth Orbit satellite between 2.2 - 2.3 GHz, in Quadrature Phase Shift Keying (QPSK) modulation with a Bit Error Rate (BER) of $10^{-5}$, a bandwidth of 2MHz, and a G/T of 3 dB/K. Verification of conditioning and processing QPSK signal in lab setting, power reception test of LEO satellite with integrated system</td>
</tr>
<tr>
<td>2.0</td>
<td>The ground station shall mechanically steer a dish/antenna system to follow a LEO satellite between 200 km to 600 km between 10° elevation and 170° elevation. Slew rate and pointing accuracy testing of integrated gimbal/antenna assembly, tracking satellite during pass monitoring signal strength</td>
</tr>
<tr>
<td>3.0</td>
<td>The ground station shall be reconfigurable to be used for different RF bands. All band specific components are accessible and interfaced with industry standard connectors</td>
</tr>
<tr>
<td>4.0</td>
<td>ARGUS shall weigh less than 46.3 kg (102 lbs) and be capable of being carried a distance of 100 meters by two people. Weight budgeting, mobility and assembly demonstrations</td>
</tr>
<tr>
<td>5.0</td>
<td>The ground station onboard computer shall interface with a laptop using a Cat-5 ethernet cable. Passage of required data between laptop and NUC</td>
</tr>
</tbody>
</table>
Reconfigurability

| FR 3.0 | The ground station shall be reconfigurable to be used for different RF bands. |
## Reconfigurability to Other Frequency Bands

<table>
<thead>
<tr>
<th>Components Dependent upon Frequency</th>
<th>Reason</th>
<th>Reconfigurable Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed</td>
<td>Picks up specific band and made for specific focal length to diameter ratio; diameter depends on frequency</td>
<td>Modular ring clamp makes it possible to swap out feed at other band, provided F/D ratio is similar</td>
</tr>
<tr>
<td>SDR</td>
<td>SDR has maximum frequency and sampling rate, upgrade may be required at higher frequencies.</td>
<td>Change defined frequency window and sampling rate according to new band OR insert new SDR using the same connections</td>
</tr>
<tr>
<td>Parabolic dish material</td>
<td>Must use material smaller than 1/10th of wavelength</td>
<td>None needed; current mesh is valid up to 11 GHz</td>
</tr>
<tr>
<td>LNA</td>
<td>Made for specific frequency bands</td>
<td>Replace LNA to accommodate new band</td>
</tr>
</tbody>
</table>
Laptop Interface

| FR 5.0 | The ground station onboard computer shall interface with a laptop using a Cat-5 ethernet cable. | -5 |
## Power Budget

<table>
<thead>
<tr>
<th>Component</th>
<th>Voltage</th>
<th>Max Power Draw</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor Assembly</td>
<td>24 VAC, 50/60 Hz</td>
<td>45.6 W</td>
</tr>
<tr>
<td>NUC Computer</td>
<td>19 V</td>
<td>120 W</td>
</tr>
<tr>
<td>LNA</td>
<td>3.0 V</td>
<td>0.5 W</td>
</tr>
</tbody>
</table>

*All other components powered through USB connections to NUC computer*
Power Components

- **120-24 VAC Transformer**
  - Used for providing 24 VAC to pointing motors
  - Rated for 100 W (45.6 W required)
  - Verification: Multimeter reading of input and output for voltage and frequency

- **120 VAC to 3.3 VDC AC-DC Converter**
  - 3.3 VDC required for LNA
  - Rated for 9.9 W (0.5 W required)
  - Verification: Multimeter reading of DC output
GPS Module

- **Purpose:**
  - Determine precise location of ground station used for calibration and timing

- **Model:**
  - Globalsat BU-353

- **Specs:**
  - Stationary Accuracy of +/- 3 meters
  - $30
Low Noise Amplifier

- **Purpose:**
  - Increase signal gain

- **Model:**
  - Minicircuits ZX60-P33ULN+

- **Specs:**
  - Gain: 14.8 dB
  - Noise: 0.38 dB
  - Max Power Draw: 0.2 Watts
  - $94.95
Software Defined Radio

- **Purpose:**
  - Process incoming RF data

- **Model:**
  - Adalm Pluto

- **Specs:**
  - Up to 20 MHz Bit Rate
  - 12 bit ADC
  - Frequency Range: 325 MHz to 3.8 GHz
  - $100
Onboard Computer

- **Purpose:**
  - Process incoming RF data and control tracking
- **Model:**
  - Intel NUC Kit NUC7I7DNKE
- **Specs:**
  - Intel i7 Processor
  - 3.6 GHz Clock Speed
  - $750
BER Equation

Using QPSK Modulation, BER is calculated by:

- Varying SNR (E/N) gives BER

\[ P_s \approx 2Q \left( \sqrt{\frac{E_s}{N_0}} \right) \]

https://en.wikipedia.org/wiki/Phase-shift_keying#Bit_error_rate_2
BER Confidence Level Calculation

\[ CL = 1 - e^{-N_{\text{errors}}} = e^{-N_{\text{bits}} \times \text{BER}} \]

\[ N_{\text{bits}} = \frac{-\ln \left( 1 - CL \right)}{\text{BER}} = \frac{-\ln \left( 1 - 0.99 \right)}{10^{-5}} = 460517.0186 \]

https://www.keysight.com/main/editorial.jspx?ckey=1481106&id=1481106&nid=-11143.0.00&lc=eng&cc=US
What is QPSK Modulation?

1.0 The ground station shall be capable of receiving signals from a Low Earth Orbit satellite between 2.2 - 2.3 GHz, in Quadrature Phase Shift Keying (QPSK) modulation with a Bit Error Rate (BER) of $10^{-5}$, and a G/T of 3 dB/K.

- QPSK Modulation is a method of encoding bits within a waveform
- Slice transmitted signal into four parts by varying phase;
  - 45°, 135°, 180°, 225°
- Shape of wave indicates what pair of bits are being transmitted
- Piece received signal back together
QPSK Modulation

Transmission:

- Bit stream broken up into 2 parts
  - Odd Bits = Inphase Component (I)
  - Even Bits = Quadrature Phase Component (Q)

- 2 waves created composed of 4 periods
  - Certain shape of cosine = 0
  - Certain shape of sine = 1

- Waves combined with 2 bits per period of transmitted signal

Sending the letter “A”: 01000001
QPSK Modulation

Reception:

- Final wave is received containing 2 bits per period
- Results in 2 times faster data rate
- Or half the BER with same data rate

Received the letter “A”: 01000001
GNURadio Software Diagram

Adalm Pluto SDR → Filtering → Demodulation → GUI
TLE Predicted Error

- In the absence of truth data, Two Line Element text files can be propagated and compared to the positions assumed to be the most accurate, the epoch.
- The positions of the satellite are then propagated and compared to the original position.
Bit Error Rate & QPSK Verification

- **Purpose:** Ensure received bit stream will be accurate and software can successfully demodulate QPSK signals.

- **Procedure:**
  - Create QPSK modulated signal in MATLAB of at least 460,518 bits to give 99% confidence
  - Add noise to signal (assume Additive White Gaussian) using signal to noise ratio of 17.21
  - Write to file
  - Read file using GNURadio and Demodulate
  - Write output bit stream to file and compare to original bit stream in MATLAB
Controller Interface

Azimuth motor connector:
Motor drive (2 pins)
Impulse sense (2 pins)

Elevation motor connector:
Motor drive (2 pins)
Impulse sense (2 pins)

USB computer control connector: built-in tracking interface or popular tracking programs
Reflector Design Choice

- 3 Materials and Dish Styles Explored

Aluminum Ribs with Aluminum Mesh
- Difficult to Manufacture
- Not Cost/Time Effective

3D Printed Hexagonal Design
- Not Time Efficient
- Heavy

Carbon Fiber Panels
- Over Budget
- Difficult to Verify
Dish Wind Loading Estimation

- Based on information by RF Ham Design spec sheet
- 1.5 Meter dish with 2.8 mm Mesh

1.5 Meter Dish Wind Loading

![Graph showing force vs wind speed for a 1.5 meter dish with 2.8 mm Mesh.](image)
Antenna Efficiency

\[ G_{\text{parabolic}} = \eta \left( \frac{\pi D}{\lambda} \right)^2 \]

\[ \eta = \eta_{sp} \eta_{ill} \eta_{pol} \eta_{\phi} \eta_{bf} \eta_{bs} = \eta_{\text{feed}} \eta_{bl} \]
Feed Loss Sources

$$\eta_{feed} = \eta_{sp} \eta_{ill} \eta_{pol} \eta_{\phi}$$

- $\eta_{\phi}$: Phase Efficiency
- $\eta_{pol}$: Polarization Sidelobe Efficiency
- $\eta_{sp}$: Spillover Efficiency
- $\eta_{ill}$: Illumination Efficiency
Feed Efficiency \[ \eta_{\text{feed}} = \eta_{\text{sp}} \eta_{\text{ill}} \eta_{\text{pol}} \eta_{\phi} \]
Blockage Loss

\[ \eta_{bl} = \eta_{bf} \eta_{bs} \]
Antenna Surface Efficiency

Assume surface errors $\epsilon$ have Gaussian distribution with an rms of $\sigma$. Surface efficiency is then

$$\eta_s = \exp\left[-\left(\frac{4\pi \sigma}{\lambda}\right)^2\right]$$

Varying the error-to-wavelength ratio results in the following efficiency distribution:
Signal to Noise Ratio (SNR) Verification

- **Purpose:** Determine if signals received from orbit are distinguishable from noise floor

- **Procedure:**
  - Track transmitting LEO satellite
  - Perform Fourier transform on signals
  - Compare signal power to average noise floor power
  - Compare actual SNR to SNR range for acceptable bit error rate
  - Pure tone transmit. Low power. Sinusoid
RFHamDesign Predicted Gain

**RFHamDesign 1.5m Dish Kit**

- Polyfit Function
- RFHamDesign Reported Gain

**Argus Design Operation**

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>Gain (dBi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.2</td>
<td>28.85</td>
</tr>
<tr>
<td>2.22</td>
<td>28.9</td>
</tr>
<tr>
<td>2.24</td>
<td>28.95</td>
</tr>
<tr>
<td>2.26</td>
<td>29.05</td>
</tr>
<tr>
<td>2.28</td>
<td>29.1</td>
</tr>
<tr>
<td>2.3</td>
<td>29.15</td>
</tr>
</tbody>
</table>
Antenna Radiation Pattern

Unblocked Reflector Pattern

Total Radiation Pattern

Feed Taper

- 10 dB
- 15 dB
- 20 dB
Gain Verification

Two possibilities:
- Anechoic chamber test
- Far-field radiation test

Estimated Far-Field distance:

\[ d > \frac{2D^2}{\lambda} = 33.02 \text{ m} \]

Anechoic chamber not feasible
Motor Modeling

\[ \Sigma F = I \ddot{\theta} \]  
Newton’s 2nd law for rotational motion

\[ T - b\dot{\theta} = I \ddot{\theta} \]  
Torque proportional to current, \( C \) by constant \( a \)

\[ aC - b\dot{\theta} = I \ddot{\theta} \]  
Friction opposes torque, proportional to angular velocity by constant \( b \)
Transfer Function Modeling

- Commanding position:
  \[
  \frac{\theta(s)}{C(s)} = \frac{a}{I s^2 + b s}
  \]

  \[
  \frac{\theta(s)}{\theta_d(s)} = \frac{a(K_D s^2 + K_P s + K_I)}{I s^3 + (b + aK_D)s^2 + aK_I}
  \]

- Commanding angular rate:
  \[
  \frac{\dot{\theta}(s)}{C(s)} = \frac{a}{I s + b}
  \]

  \[
  \frac{\dot{\theta}(s)}{\dot{\theta}_d(s)} = \frac{a(K_D s^2 + K_P s + K_I)}{(I + aK_D)s^2 + (aK_P + b)s + aK_I}
  \]
PID Block Diagram

Desired position or angular rate

Error

Controller

$KP + \frac{KI}{s} + sKD$

Control signal

Plant

$\frac{a}{Is^2 + bs}$

Position

Angular rate

Actual position or angular rate

Encoder

Feedback
Simulink and Arduino Controls
Signal Reception

- According to ASEN 3300 Lab 11 link budget, current signal to noise ratio figure is $17.21\,\text{dB}$ prior to amplification.
- Chosen LNA has a gain of $14\,\text{dB}$ and a noise figure of $0.4\,\text{dB}$
  - Signal to noise ratio will barely be reduced by amplification.

Calculation Assumptions:
- TX Antenna Gain: $6.0\,\text{dBi}$
- TX Pointing Error: $\pm 6^\circ$ (-$12\,\text{dB}$ loss)
- TX Power: $5\,\text{Watts}$
- RX Diameter: $1.5\,\text{m}$
- RX Antenna Efficiency: $50\%$
- RX Beamwidth: $9^\circ$
- RX Pointing Accuracy: $0.5^\circ$
- Range: $400\,\text{km}$
- Frequency: $2.3\,\text{GHz}$
Control Interface

1. Connect controller to computer via USB
2. Enable communication to controller with TCP using Hamlib’s rotctl library

   Example Linux command: “rotctl -m 202 -s 19200 -r /dev/ttyUSB0”

Model

Baud       Port

1. Input current lat/long
2. Perform manual sun calibration
3. Select satellite to track
4. Engage tracking
## Requirements & Their Satisfaction

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Satisfaction</th>
</tr>
</thead>
</table>
| 1.0 | The ground station shall be capable of receiving signals from a Low Earth Orbit satellite between 2.2 - 2.3 GHz, in Quadrature Phase Shift Keying (QPSK) modulation with a Bit Error Rate (BER) of $10^{-6}$, a bit rate of 2 Mbit/s, and a G/T of 3 dB/K.  
- The dish, LNA, and SDR are designed to handle signals between 2.2-2.3 GHz  
- The software is capable of QPSK demodulation of the signal, as well as handling signals with high bandwidth  
- The MATLAB simulation showed the BER will be well below $10^{-5}$  
- The dish is designed with a minimum gain of 27 dBi, which satisfies the G/T requirement |
| 2.0 | The ground station shall mechanically steer a dish/antenna system to follow a LEO satellite between 200 km to 600 km between 10° elevation and 170° elevation.  
- The software is capable of tracking a LEO satellite from 0° to 90° elevation  
- The motors will use PID control to ensure that they are pointing as close to the desired position as possible |
## Requirements & Their Satisfaction

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Satisfaction</th>
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<tbody>
<tr>
<td>3.0 The ground station shall be reconfigurable to be used for different RF bands.</td>
<td>● Components can be swapped out; dish needs no adjustment</td>
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</table>
| 4.0 ARGUS shall weigh less than 46.3 kg (102 lbs) and be capable of being carried a distance of 100 meters by two people. | ● The mass estimate is 45.32 kg, which is less than the requirement.  
● The carrying case and dish disassembly will allow for easy transport. |
| 5.0 The ground station onboard computer shall interface with a laptop using a Cat-5 ethernet cable. | ● Linux Secure Shell with X11 Forwarding |
Disassembled and Packaged System
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