ASEN 4018 Senior Projects Fall 2018

Critical Design Review

ARGUS

Auto-Tracking RF Ground Unit for S-Band

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Advisor: Professor Dennis Akos

Customer: Raytheon

ARGUS

Purpose and Objective

Project Motivation

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- 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: ≈$50,000

Project Objective

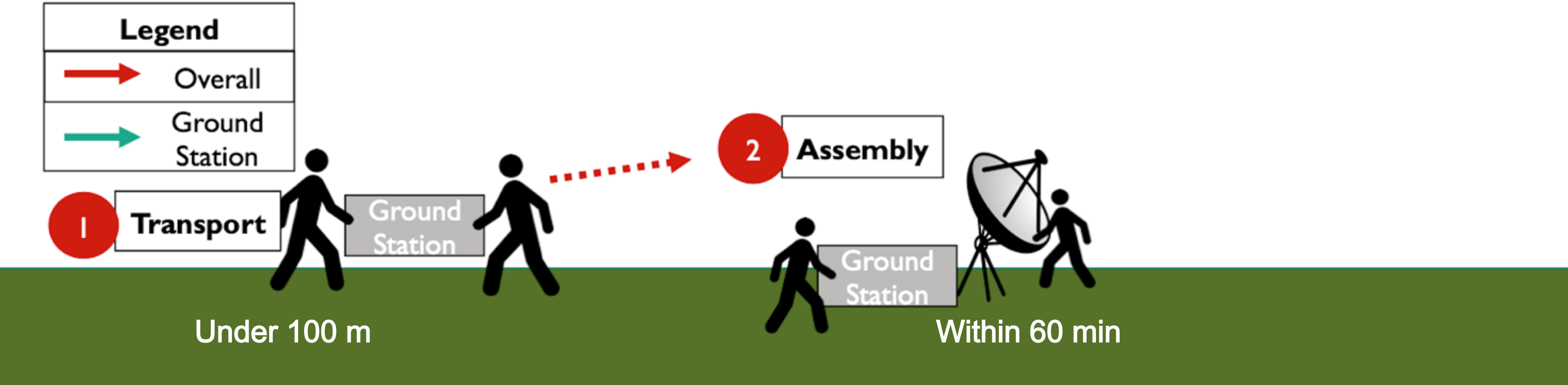
Mission Statement: The ARGUS ground station is designed to be able to track a LEO satellite and receive a telemetry downlink using a platform that is both portable and more affordable than current S-Band ground stations.

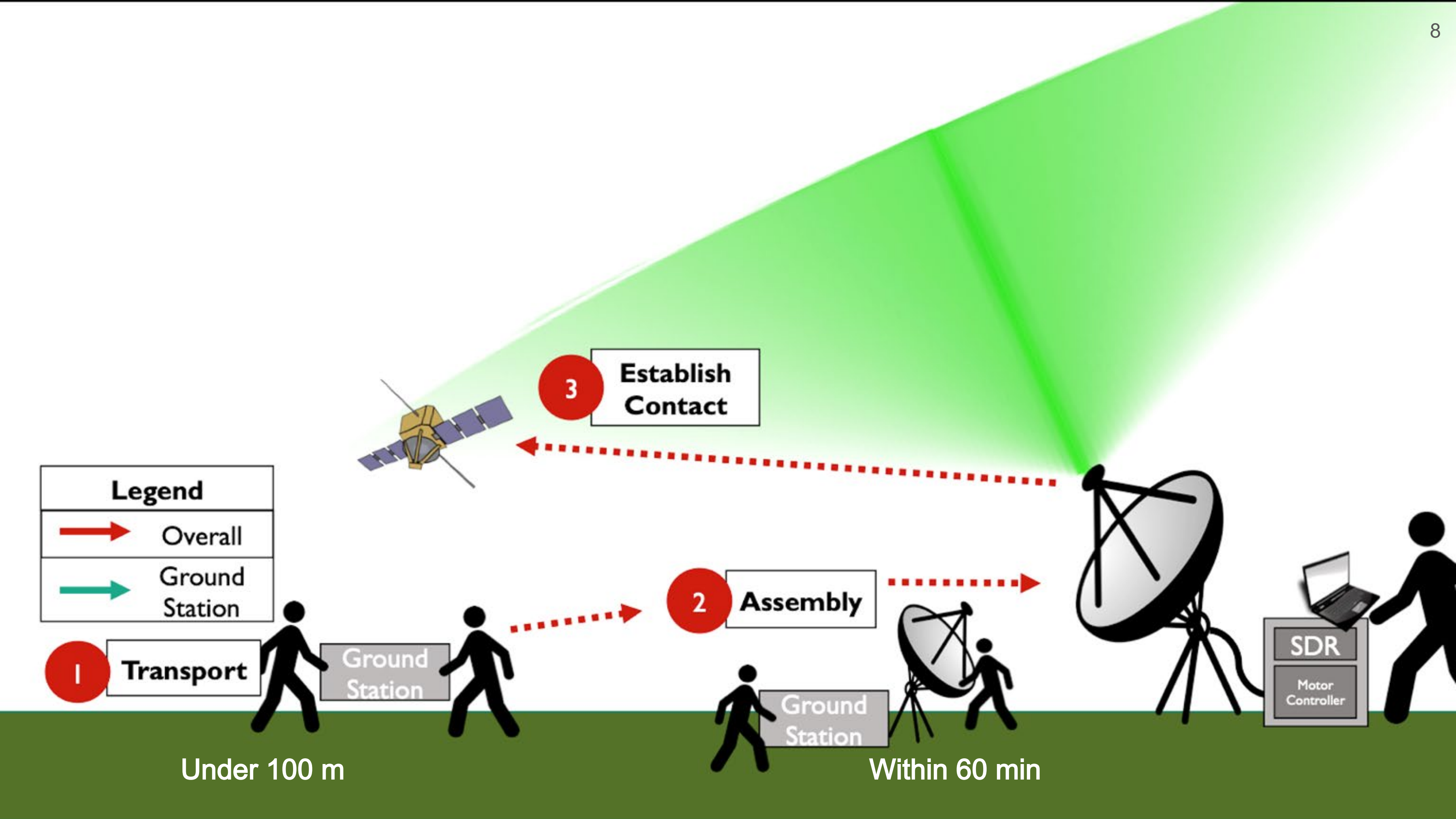
- Commercial-off-the-shelf (COTS) where possible
- Interface with user laptop (monitor)
- Portable: 46.3 kg (102 lbs), able to be carried a distance of 100 meters by two people

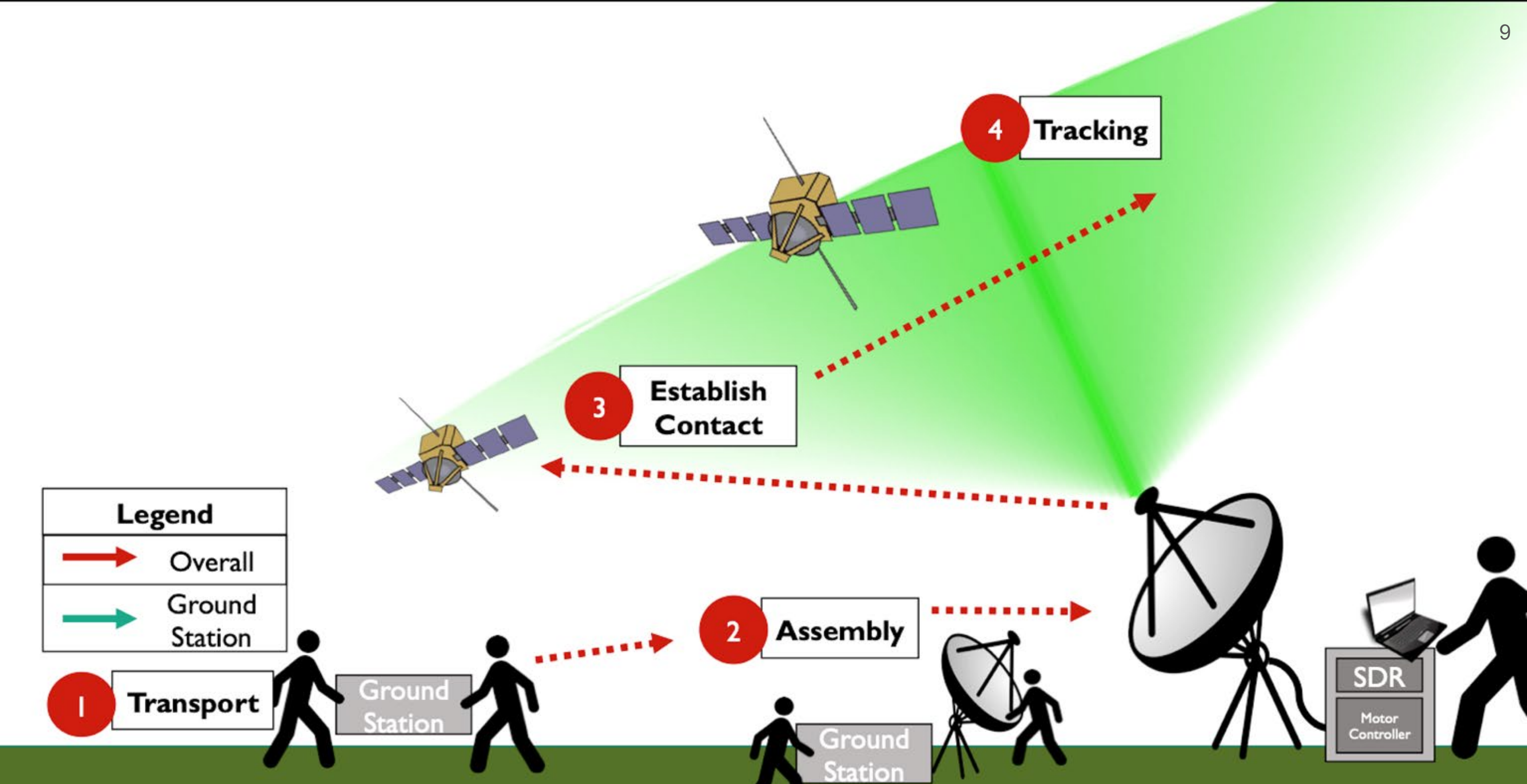
ARGUS

CONOPS


Legend
Overall
Ground Station
1
Transport
Ground Station
Under 100 m

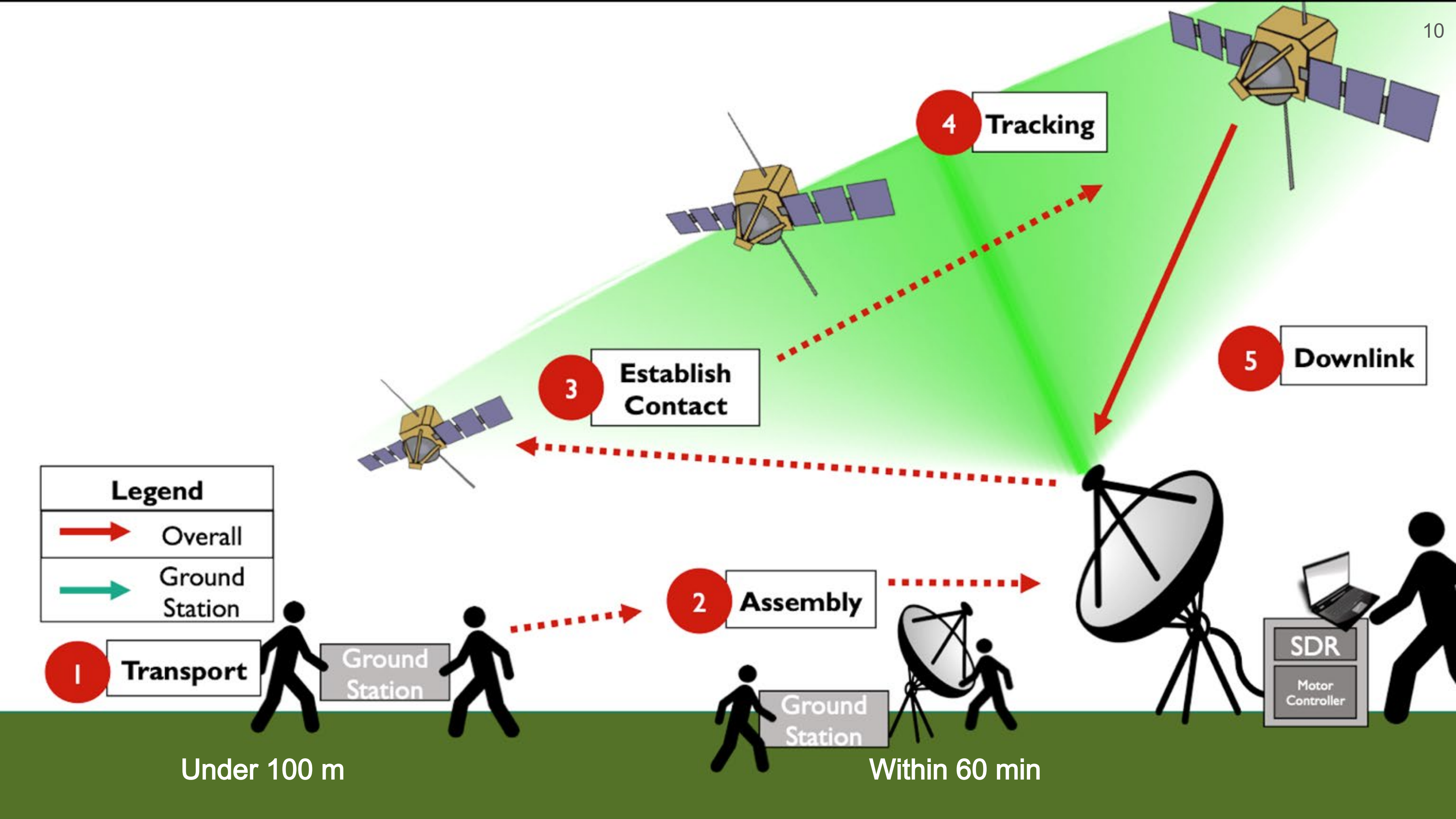

Legend
Overall
Ground Station
1 Transport
Ground Station
2 Assembly
Ground Station
Under 100 m
Within 60 min

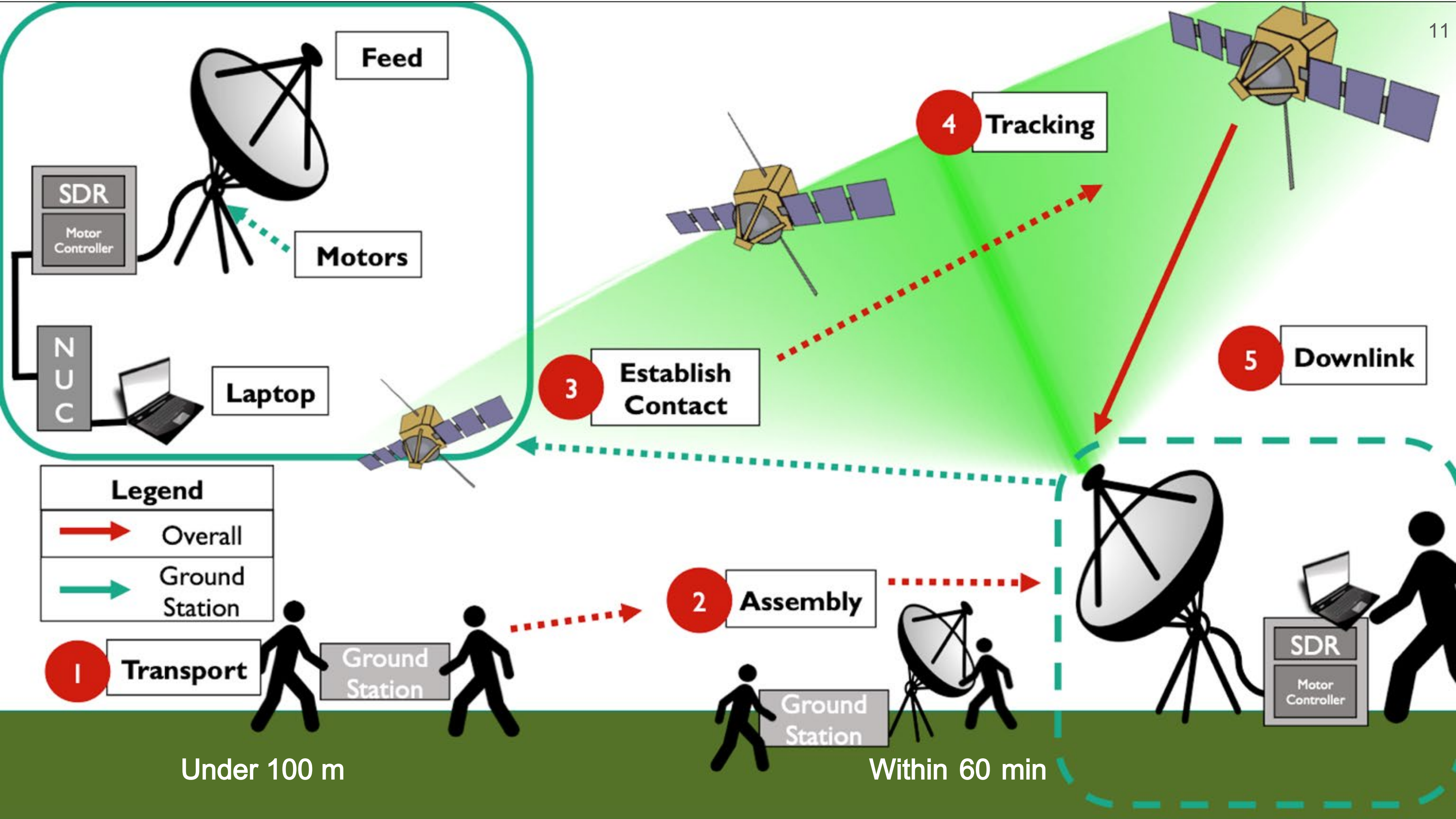

3
Establish Contact
Legend
Overall
Ground Station
2
Assembly
1
Transport
Ground Station
Ground Station
SDR
Motor Controller
Under 100 m
Within 60 min



Under 100 m

Within 60 min


4 Tracking
3 Establish Contact
5 Downlink
Legend
Overall
Ground Station
2 Assembly
1 Transport
Ground Station
Ground Station
SDR
Motor Controller
Under 100 m
Within 60 min


Feed
SDR
Motor Controller
Motors
N U C
Laptop
4 Tracking
3 Establish Contact
5 Downlink
Legend
Overall
Ground Station
1 Transport
Ground Station
2 Assembly
Ground Station
SDR
Motor Controller
Under 100 m
Within 60 min

Functional Requirements

ARGUS

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.
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 ° and 170° local elevation.
3.0	The ground station shall be reconfigurable to be used for different RF bands.
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.
5.0	The ground station onboard computer shall interface with a laptop using a Cat-5 ethernet cable.

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Design Solution

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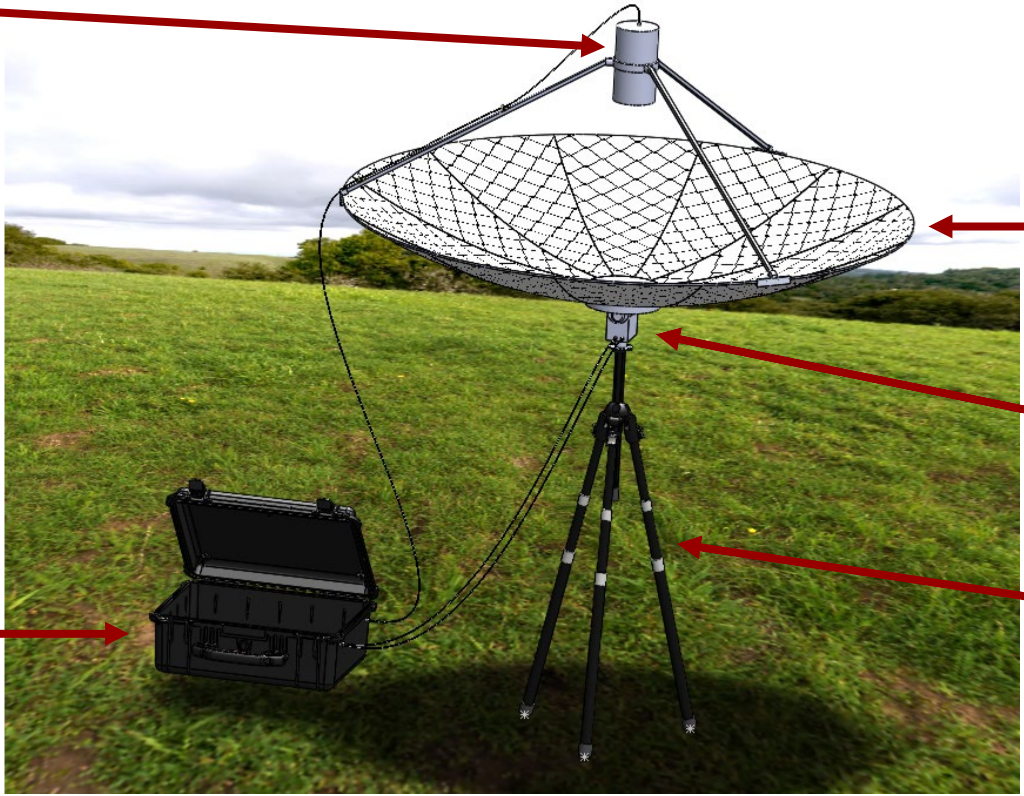
Helical Antenna Feed



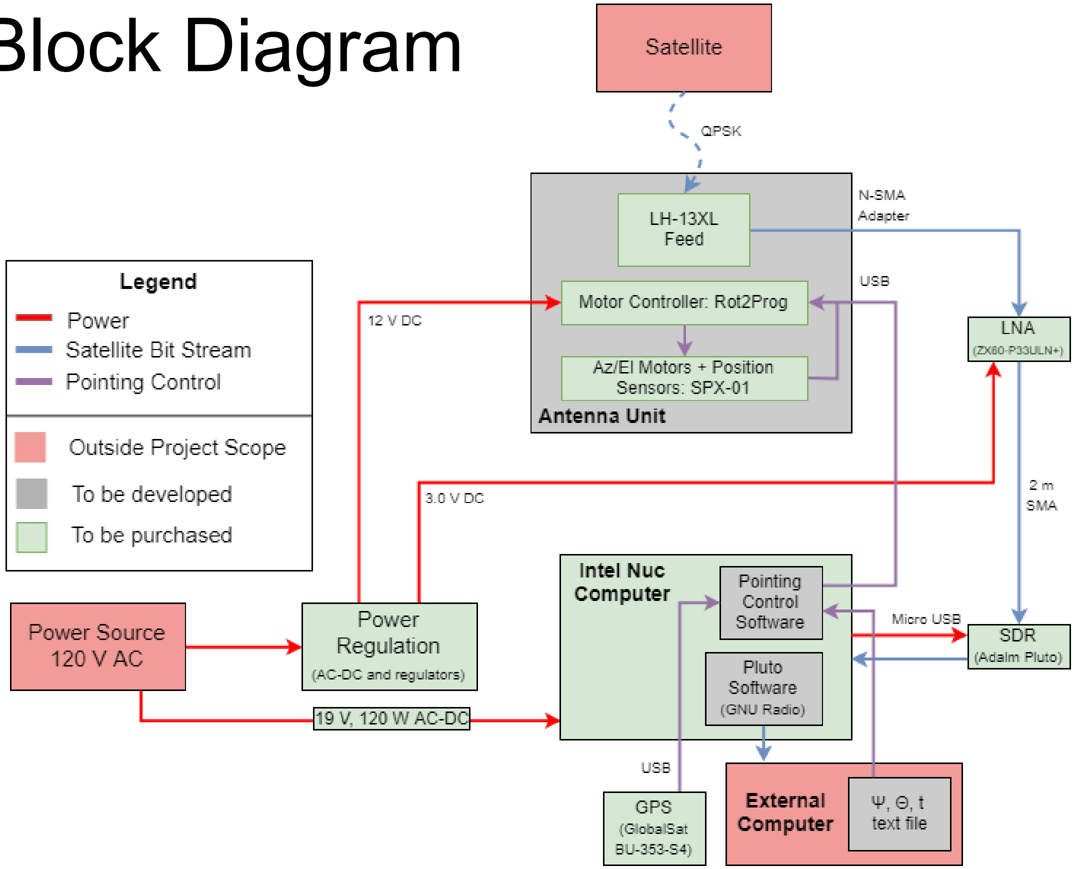
1.5m Parabolic Reflector

Azimuth/Elevation Motors

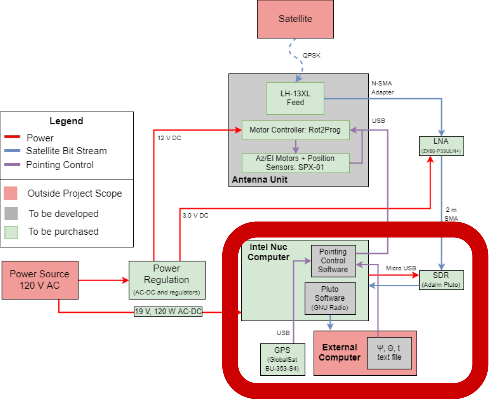
Tripod

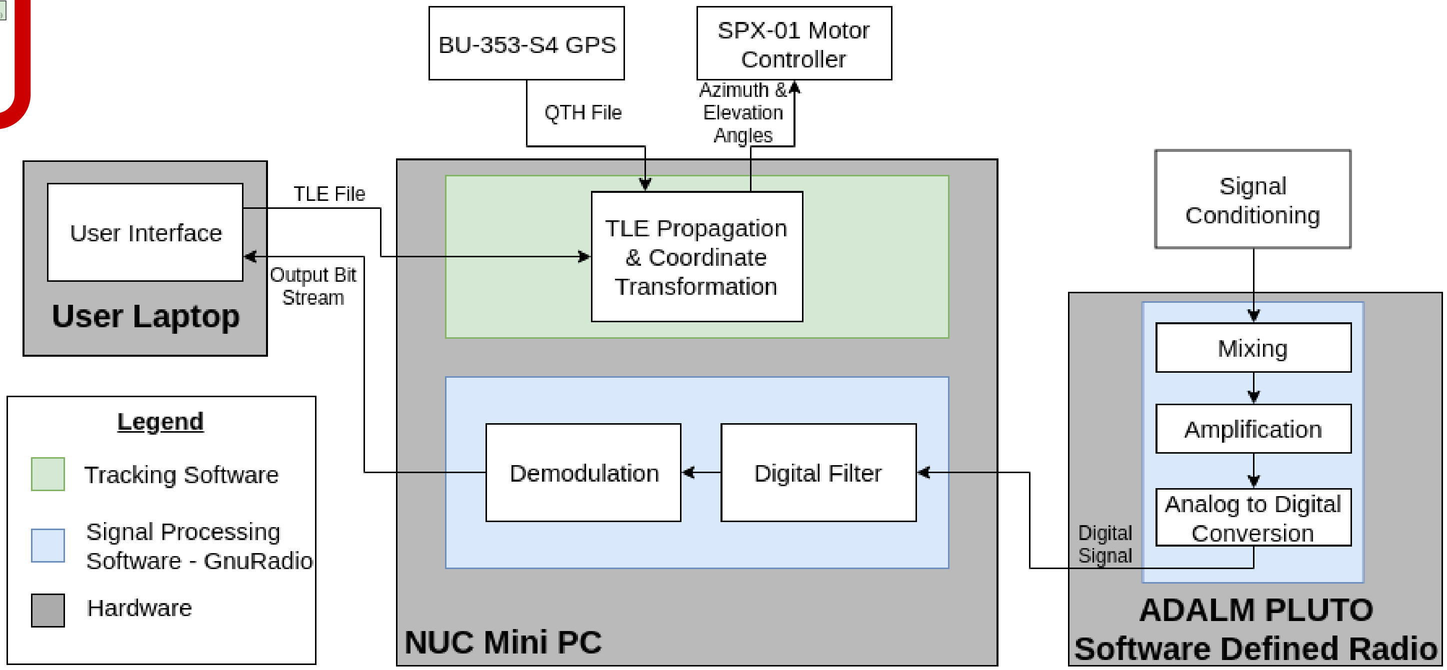
Transportable Case

Functional Block Diagram

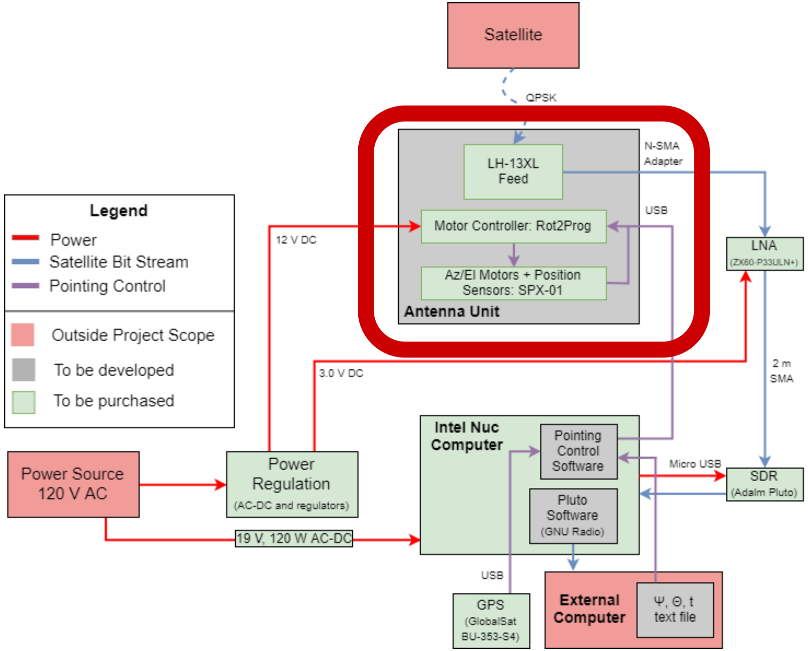


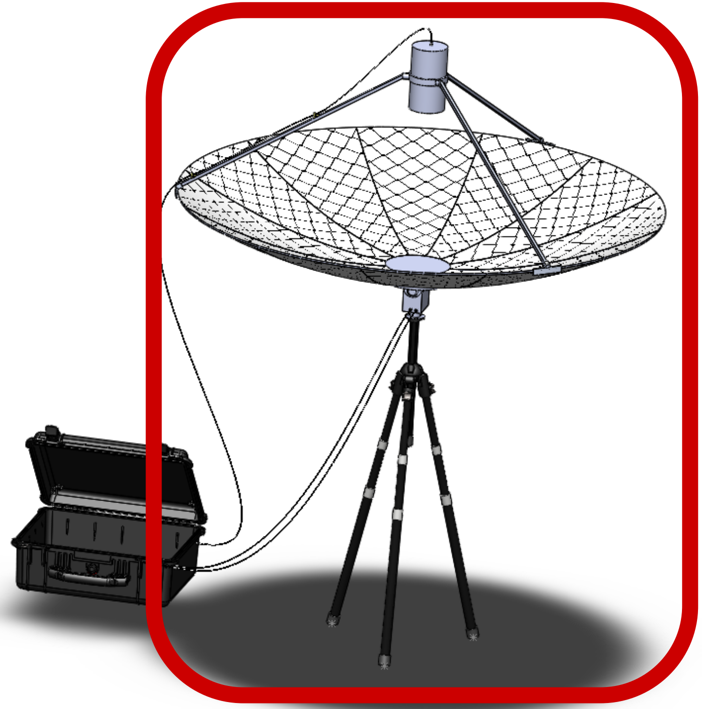
Software Flow Chart



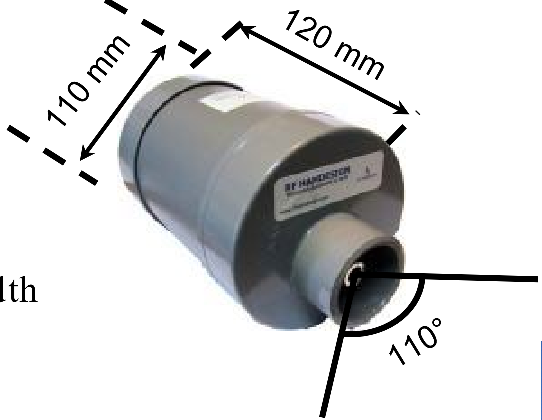


Antenna Unit Subsystem

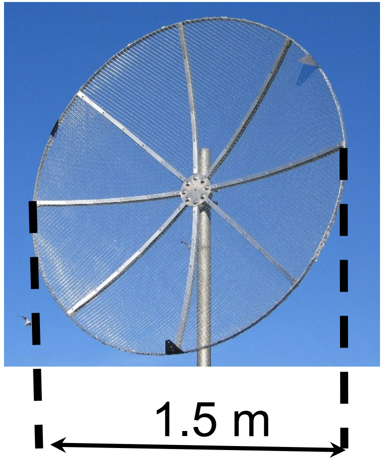




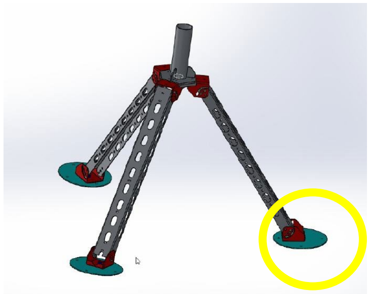
- Antenna Feed
  - **Purpose:** Collect incoming signal
  - **Model:** RFHam Design H-13XL
  - **Specs:** LCHP at 2.1 - 2.6 GHz, 110° beamwidth



- 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

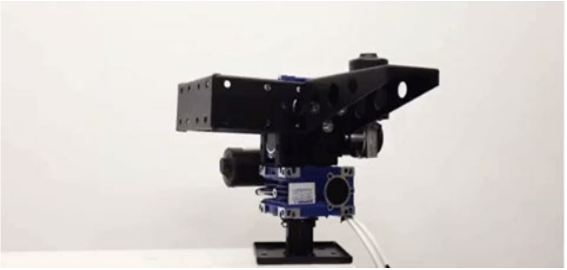


Motor System

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

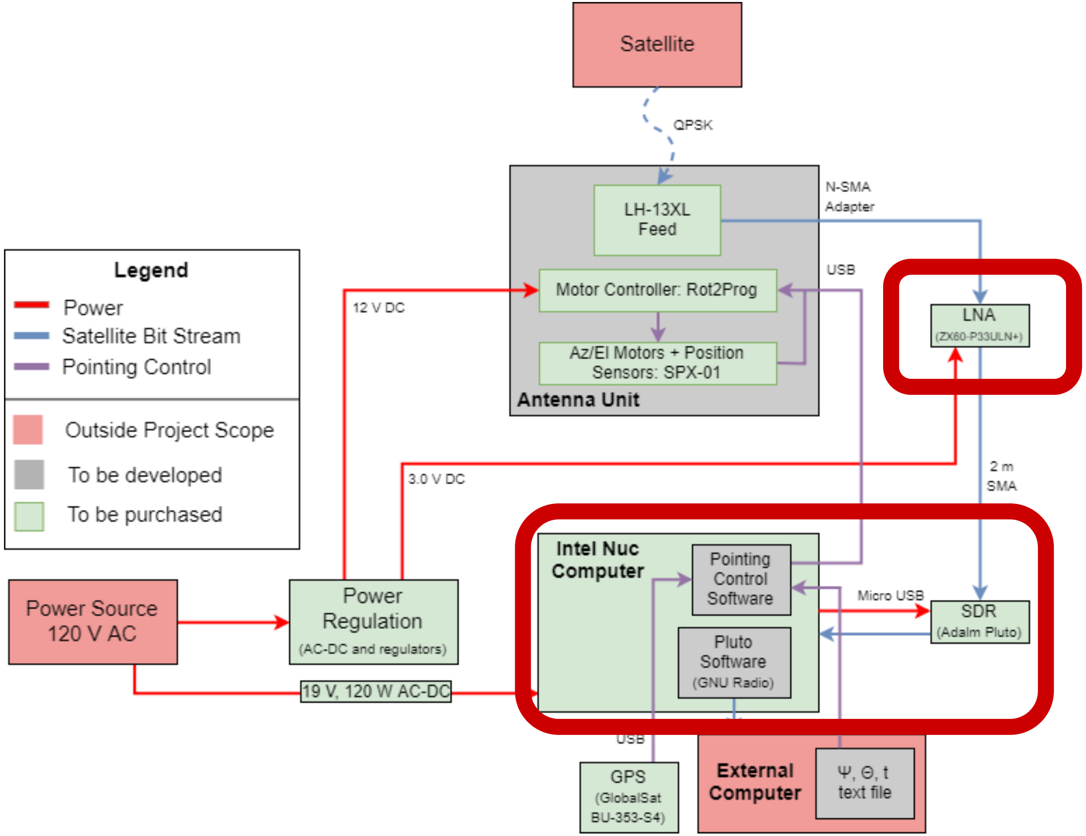
- $655.78
- 0.5 deg resolution
- Interfaces with onboard computer
- Manual/auto control
- Designed for continuous tracking

Az/El motors + position sensors



Motor controller

Signal Conditioning and Processing



ARGUS

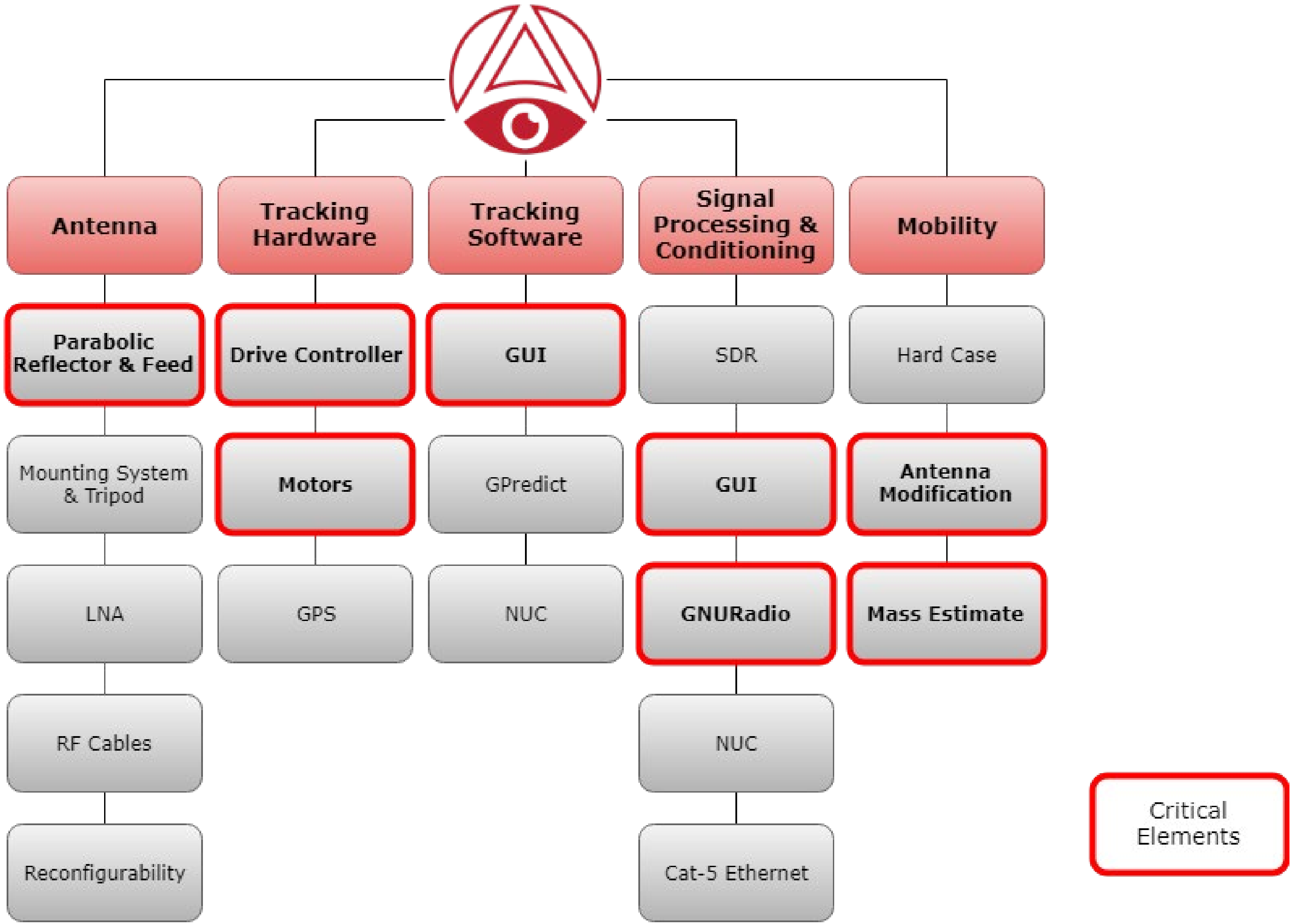
- Low Noise Amplifier (LNA)
    - **Purpose:** Increase signal gain
    - **Model:** Minicircuits ZX60-P33ULN+
    - **Specs:** 14.8 dB Gain, 0.38 dB Noise

- 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

ARGUS

Critical Project Elements


Antenna
Tracking Hardware
Tracking Software
Signal Processing & Conditioning
Mobility
Parabolic Reflector & Feed
Drive Controller
GUI
SDR
Hard Case
Mounting System & Tripod
Motors
GPredict
GUI
Antenna Modification
LNA
GPS
NUC
GNURadio
Mass Estimate
RF Cables
NUC
Reconfigurability
Cat-5 Ethernet
Critical Elements

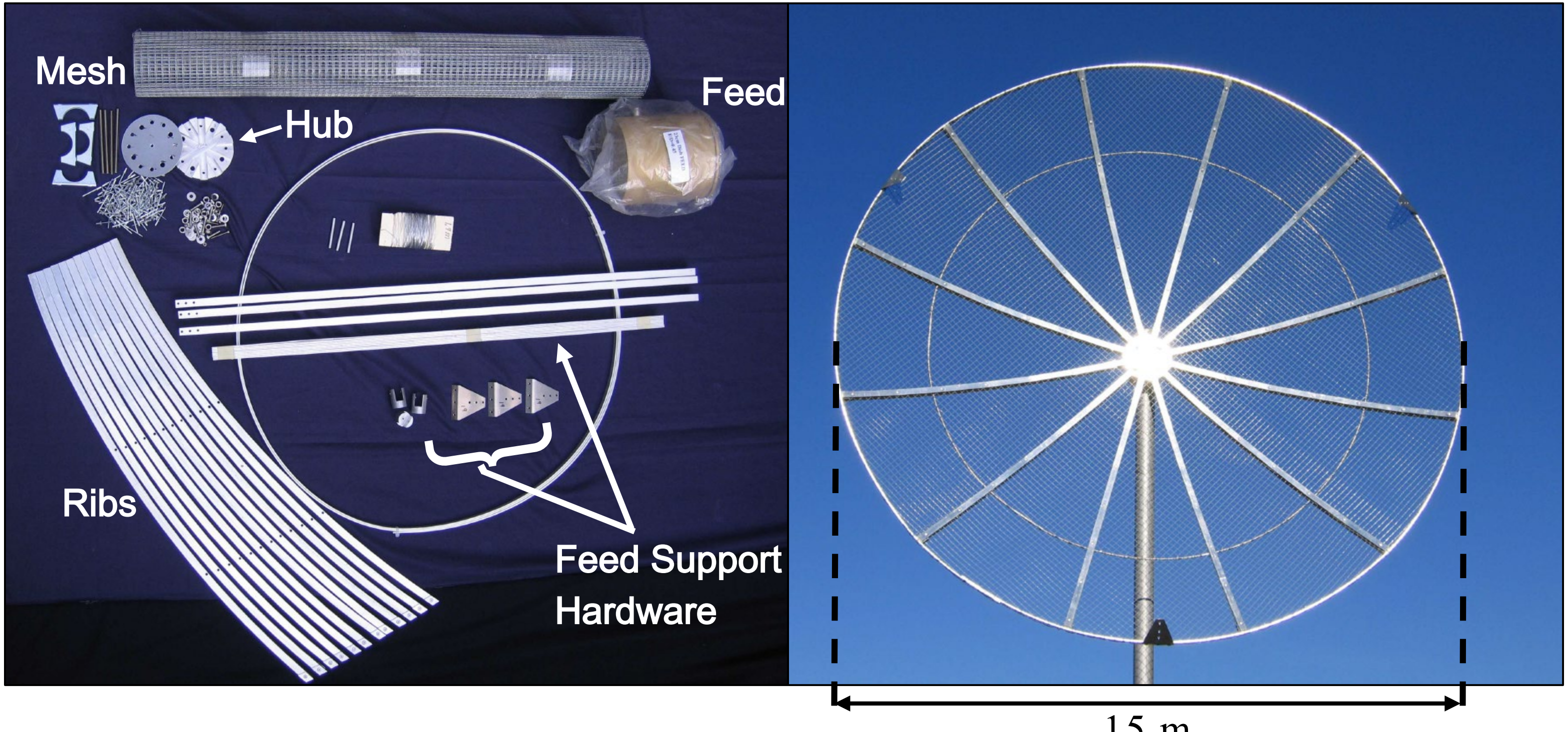
Design Requirements and Satisfaction

ARGUS

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:

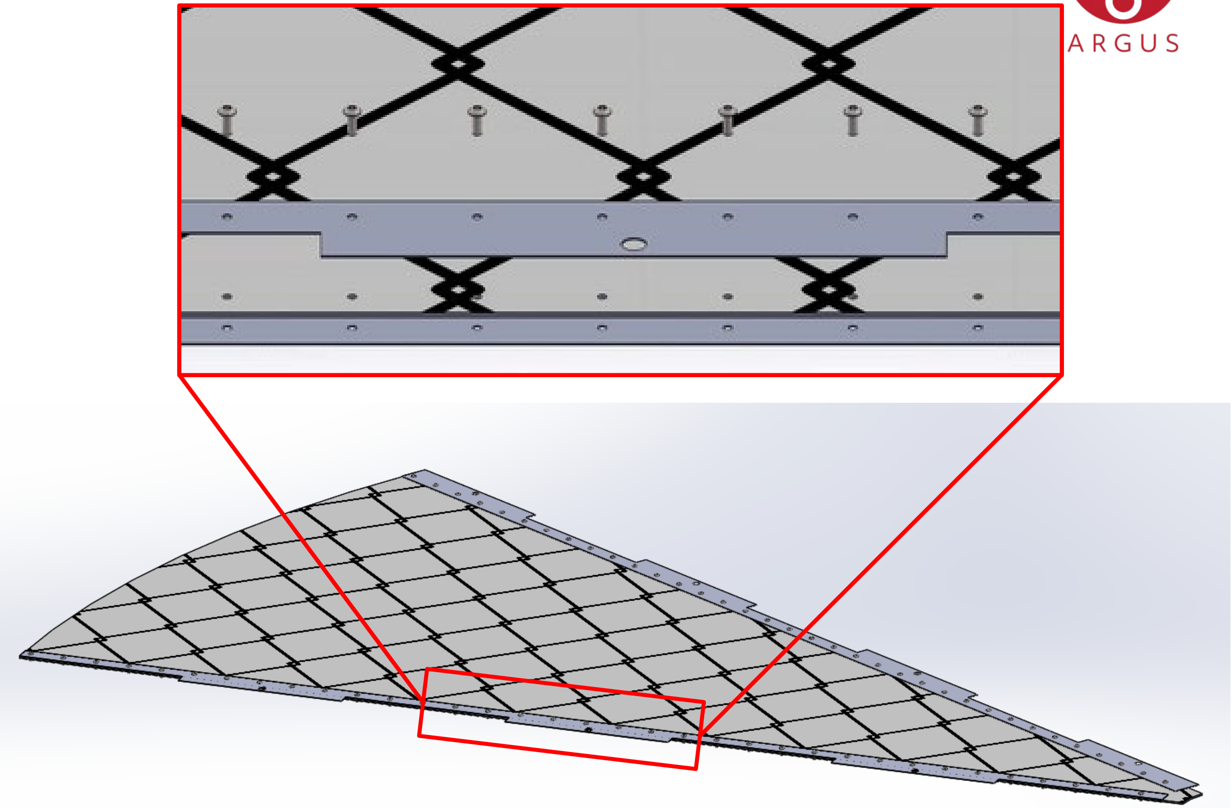
- Assembly time 6+ hours
- Single continuous mesh
- Multiple tools

Modifications:

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

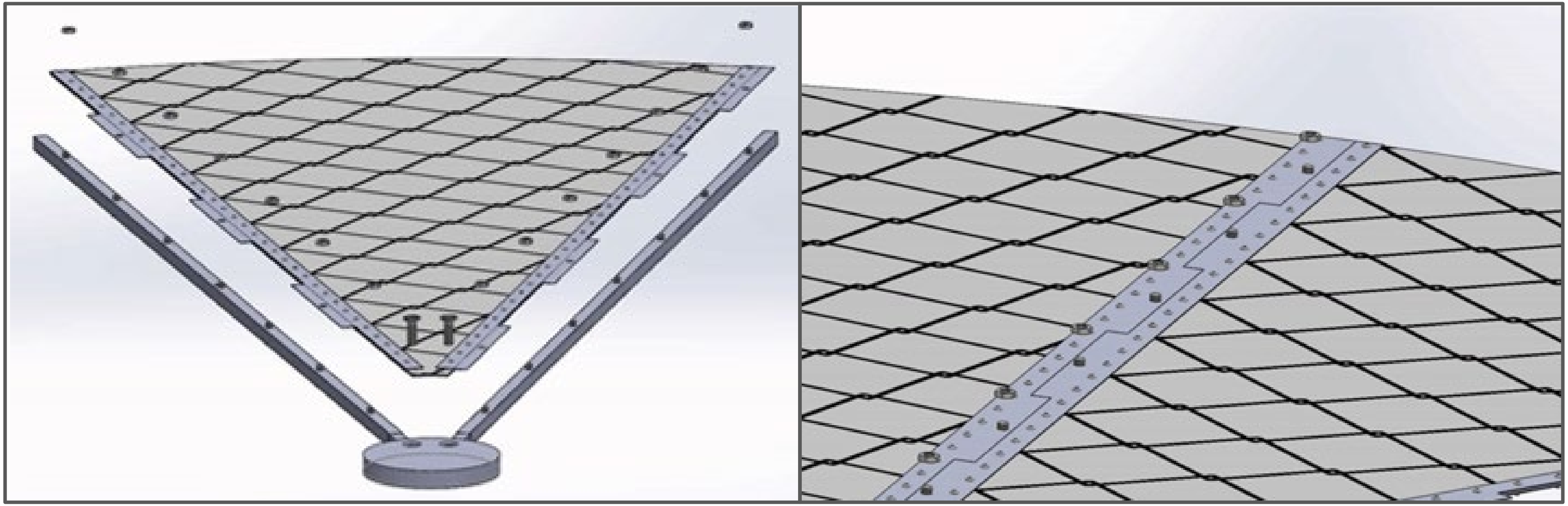
Modularity:

- 22 gauge aluminum sheet attaches to ribs
- Petals attach to central hub



Modification of Reflector

ARGUS



✔ Meets mobility requirements (FR.4)

Antenna Gain Calculation

Pasternack SMA Male to N Male Adapter

- $L_1 = 0.07\ dB$

ZX60-P33ULN+ MiniCircuits LNA

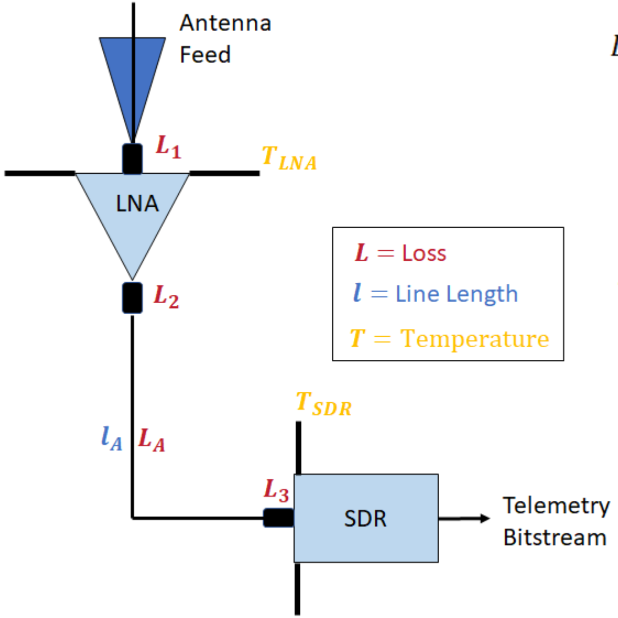
- $T_{LNA} = 44\ K$
- $G_{LNA} = 11.3\ dB$

Pasternack SMA to SMA Cable

- $l_A = 2\ m, 0.7\ \frac{dB}{m} \Longrightarrow L_A = 1.4\ dB$
- $L_2 = L_3 = 0.45\ dB$

Adalm-Pluto SDR

- $T_{SDR} = 288.6\ K$



L = Loss
l = Line Length
T = Temperature

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

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

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

$$\Rightarrow T_s = 140K$$

Requirement: $\frac{G}{T_s} = 3\frac{dB}{K}$

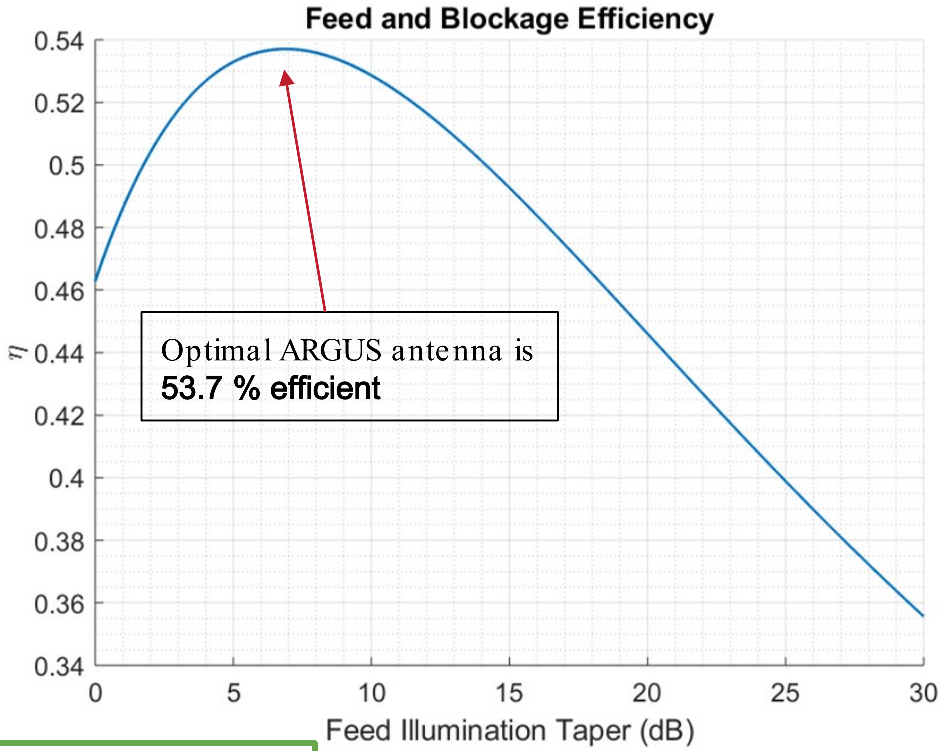
$$G_{required} = 26.2\ dBi$$

Estimated Efficiency

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

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

Gain at **53.7%** efficiency	28.08 dBi
Gain at **35%** efficiency	26.22 dBi
Required gain	26.2 dBi



✔ ☐Meets bandwidth and gain requirements (FR.1)

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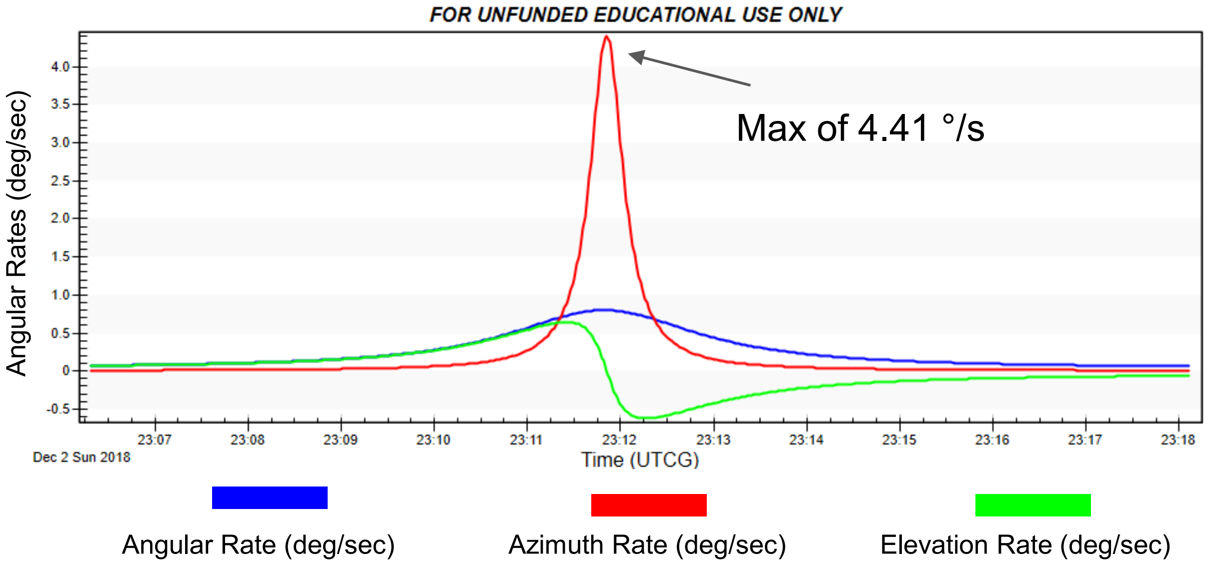
Tracking Hardware Subsystem

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.

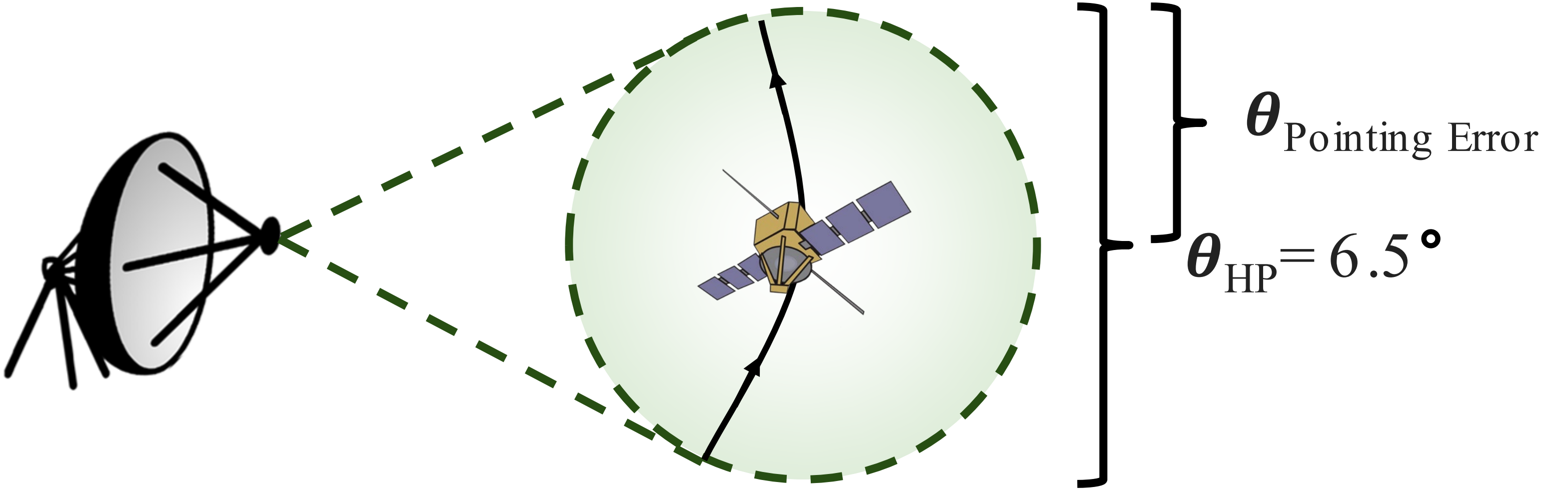
STK: Tracking Rate Verification

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



Worst Case Pointing Error



$$\theta_{\text{Pointing Error}} = \theta_{\text{TLE, Error}} + \theta_{\text{Motor, Error}} + \theta_{\text{Tracking, Error}} < 3.25°$$

$$\theta_{\text{Motor, Error}} < 3.25° - 1.10° - 1.43°$$

$$\theta_{\text{Motor, Error}} < 0.72°$$

$$\theta_{\text{TLE, Error, Max}} = 1.43°$$

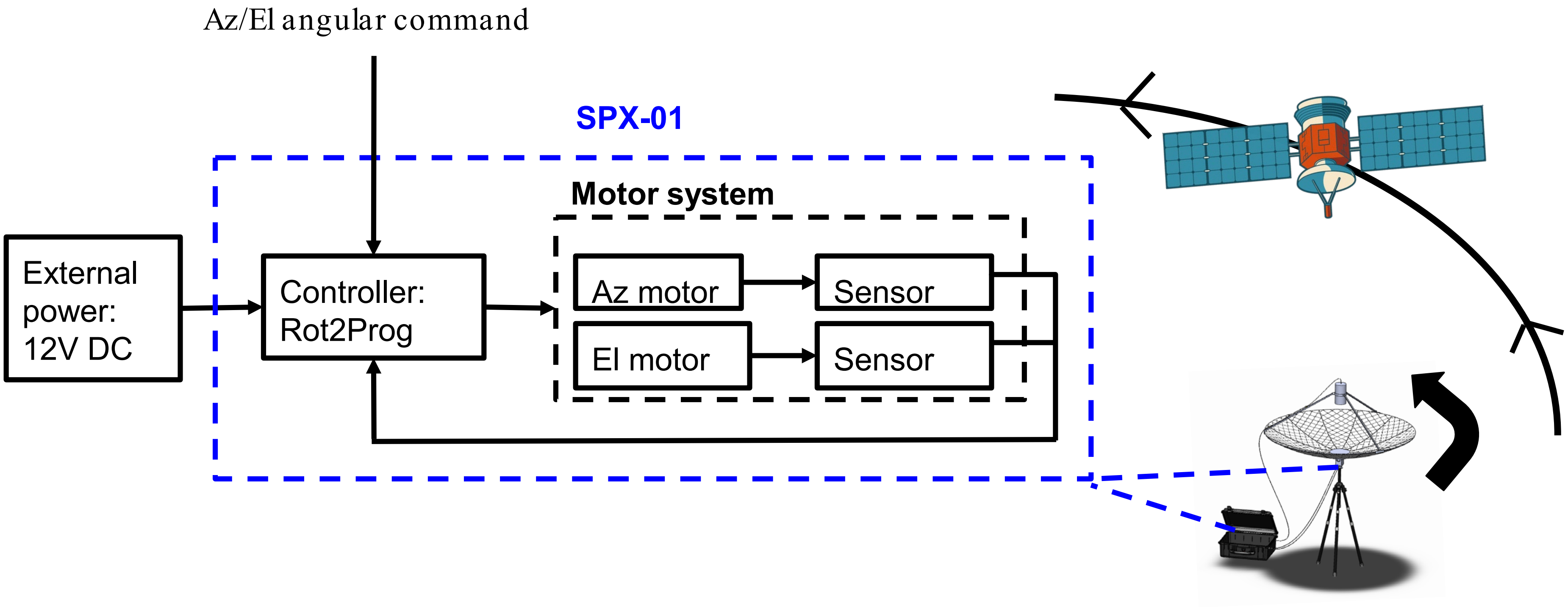
$$\theta_{\text{Tracking, Error, Max}} = 1.10°$$

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°

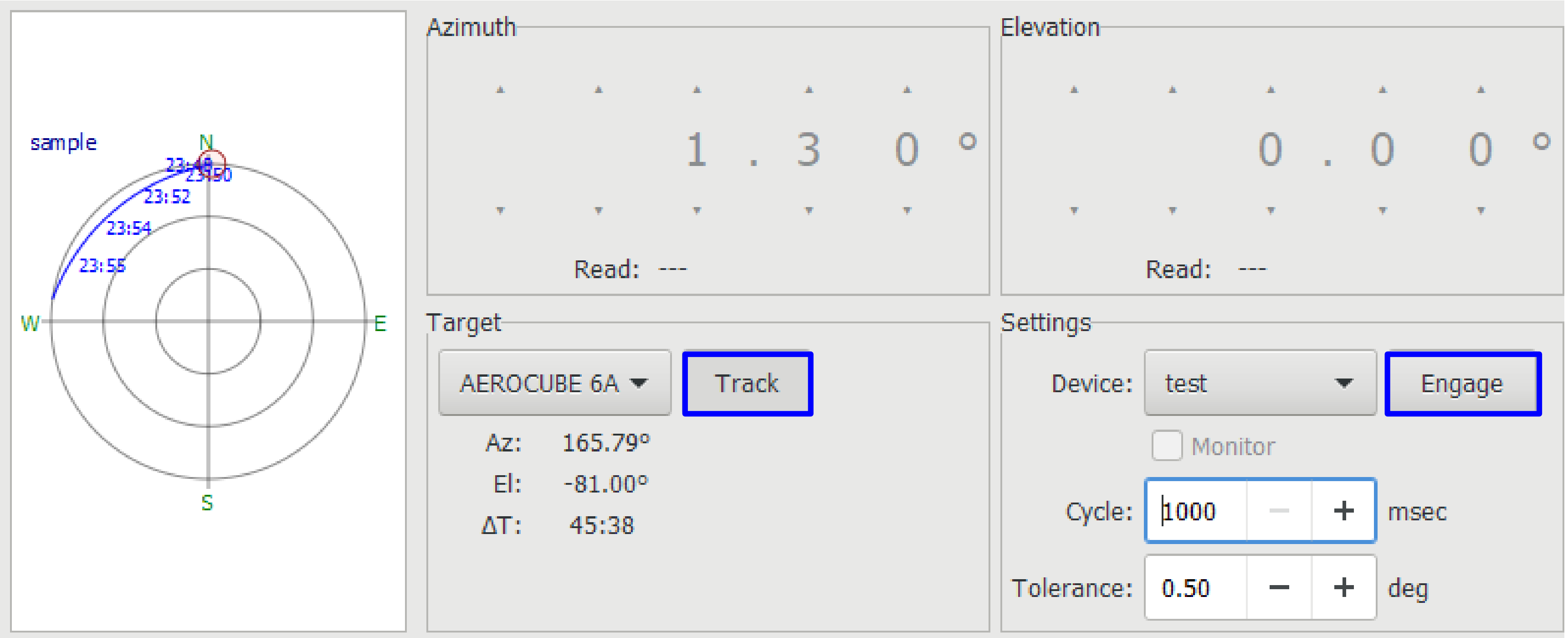
✓ ☐	DR 2.3	The antenna motor shall be able to move the antenna at a slew rate of **5.0 °/s**
✓ ☐	DR 2.4	The antenna motor shall have a pointing accuracy greater than **0.72°**

Tracking Overview



Software Interface

Enable serial communication ➡ Input lat/long ➡ Calibrate ➡ Select target ➡ Engage

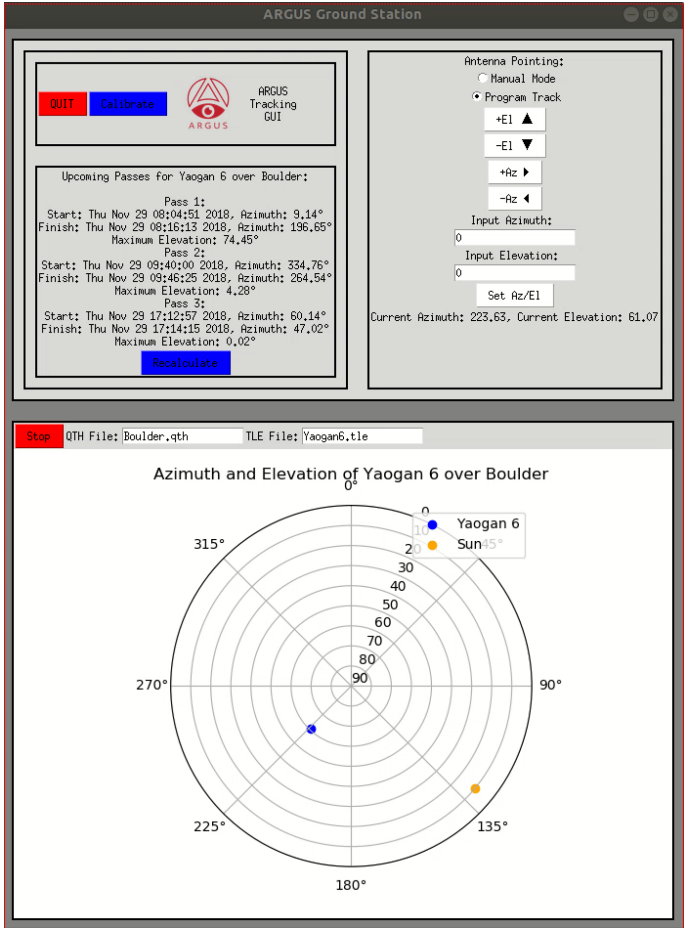


Tracking Software Subsystem

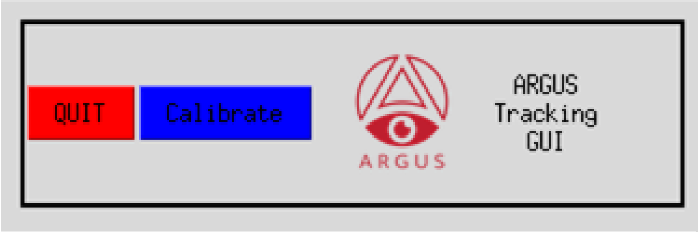
FR 2.0	The ground station shall mechanically steer a dish/antenna system to follow a LEO satellite between 200 km to 600 km between 10° elevation and 170° elevation.

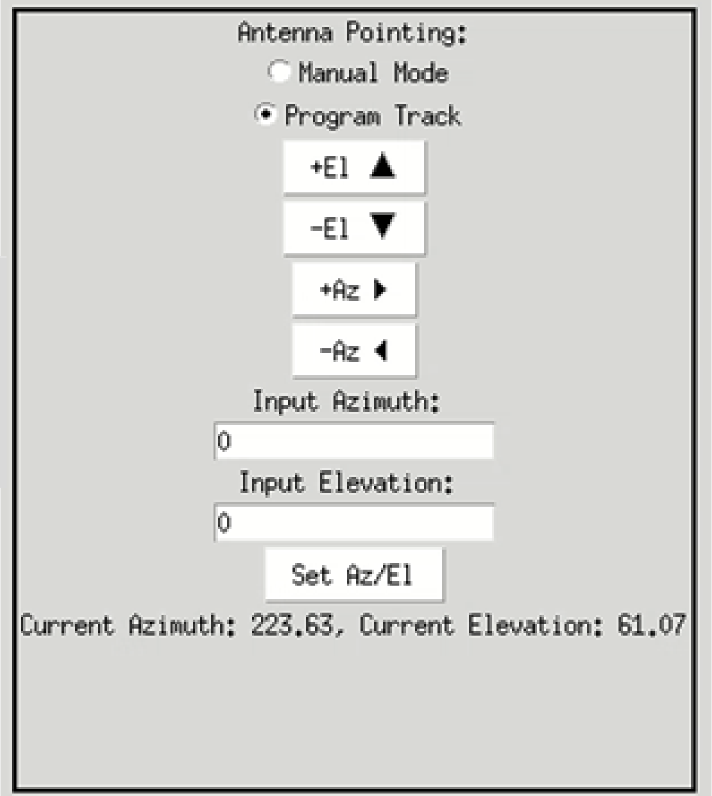
Tracking Software Demonstration

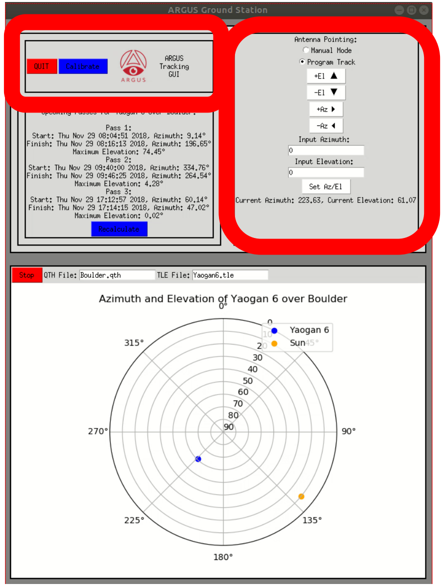
FR 2.0	The ground station shall mechanically steer a dish/antenna system to **follow a LEO satellite** between 200 km to 600 km between 10° elevation and 170° elevation.



Calibration & Manual Control Frames



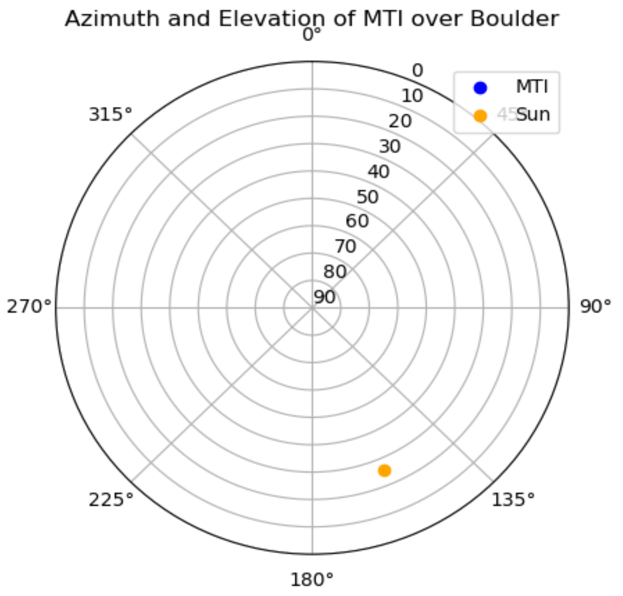




Azimuth and Elevation Calibration

DR 2.2	The pointing control accuracy must be within **3.25°** to maintain downlink capabilities throughout the entire pass.

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



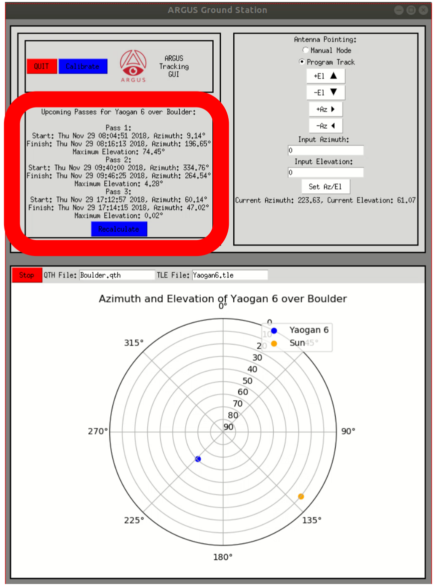
Ground Station Latitude/Longitude (GPS) → ARGUS GUI → Sun Azimuth and Elevation → Point in Predicted Location and Dither

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°
Finish: Mon Nov 26 19:45:50 2018, Azimuth: 195.04°
Maximum Elevation: 82.28°
Pass 3:
Start: Mon Nov 26 21:09:20 2018, Azimuth: 330.76°
Finish: Mon Nov 26 21:14:42 2018, Azimuth: 266.4°
Maximum Elevation: 3.22°

Recalculate



STK: Upcoming Pass Verification

DR 2.2	The pointing control accuracy must be within **3.25°** to maintain downlink capabilities throughout the entire pass.

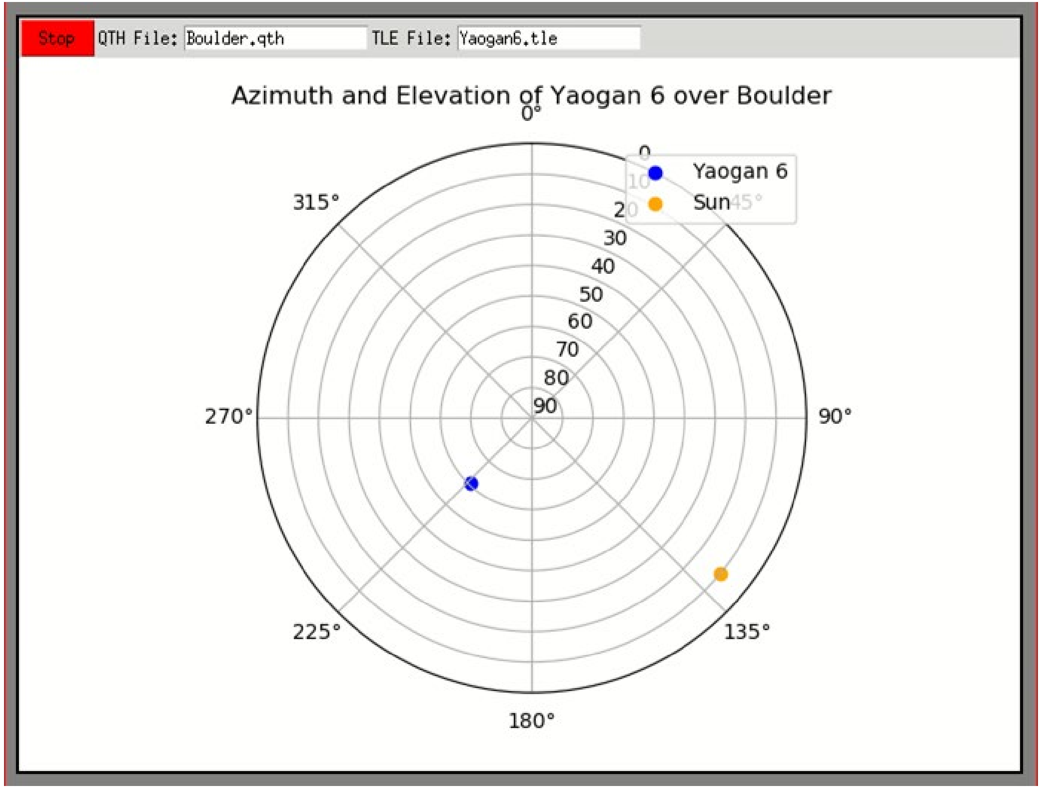
ARGUS (Mountain Time)

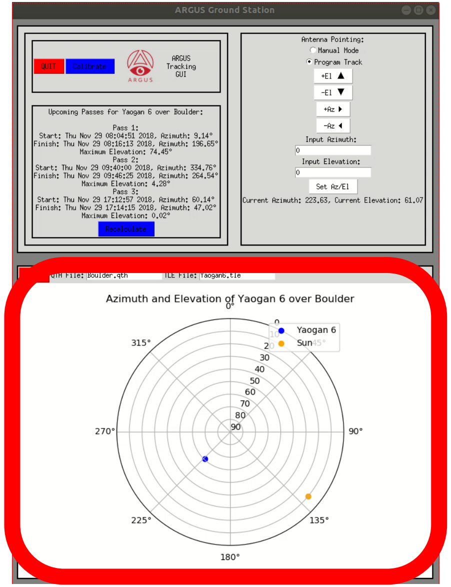
```
Upcoming Passes for MTI over Boulder:

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:
Start: Sun Dec  2 19:32:59 2018, Azimuth: 12.35°
Finish: Sun Dec  2 19:43:11 2018, Azimuth: 192.14°
Maximum Elevation: 84.43°
Pass 3:
Start: Sun Dec  2 21:06:27 2018, Azimuth: 333.89°
Finish: Sun Dec  2 21:12:18 2018, Azimuth: 262.7°
Maximum Elevation: 4.08°
Recalculate
```

```
Place1-To-Mti_26102
--------------------
             Access      Start Time (UTCG)           Stop Time (UTCG)
             ------
                  2      3 Dec 2018 02:32:58.799     3 Dec 2018 02:43:11.240
```

✔ ☐Verified

Az/El Plot Frame

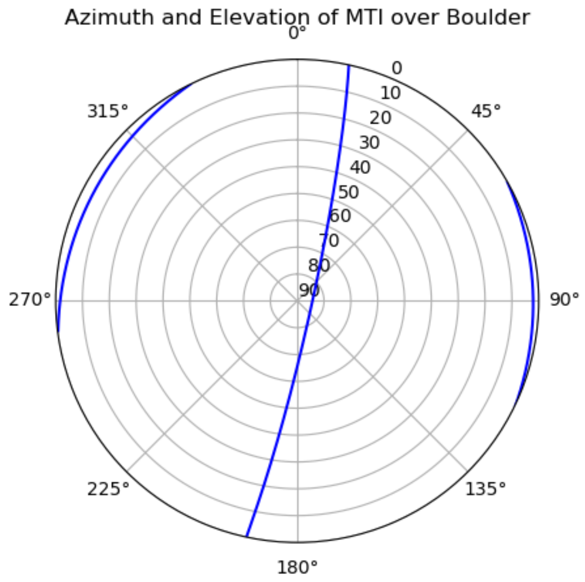




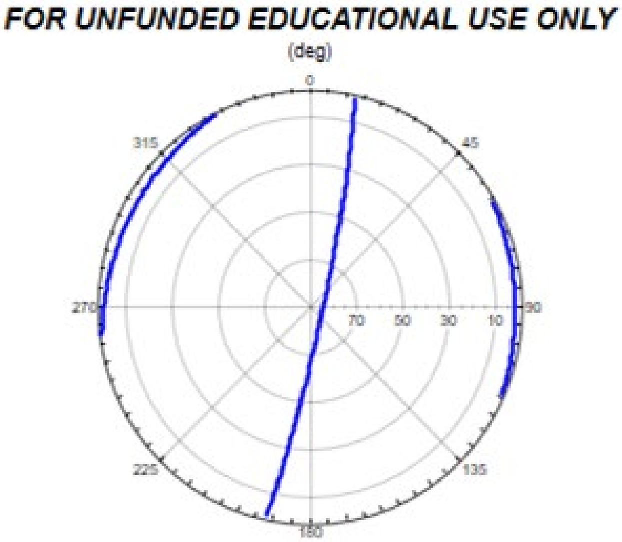
STK: Azimuth/Elevation Verification

DR 2.2	The pointing control accuracy must be within **3.25°** to maintain downlink capabilities throughout the entire pass.

ARGUS



STK



ARGUS

Signal Conditioning & Processing

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 Diagram

ARGUS

Adalm Pluto SDR → Digital Filtering → Demodulation → GUI

Adalm Pluto SDR
- Frequency: 2.2-2.3 GHz
- Bit Rate: 2 MHz
- Mixing
- Amplify
- ADC

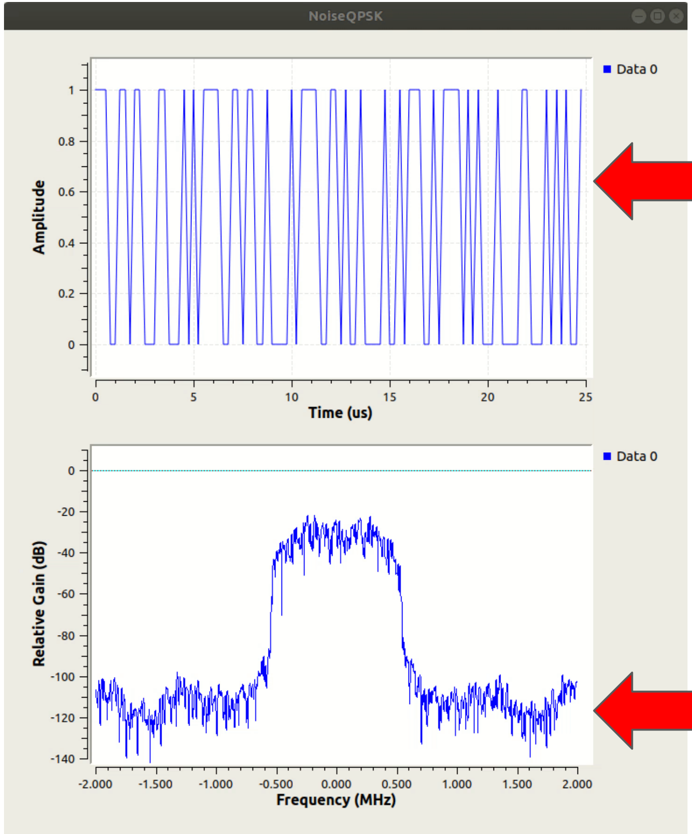
Digital Filtering
- Low Pass

Demodulation
- QPSK

GUI
- FFT Plot
- Bit Plot

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



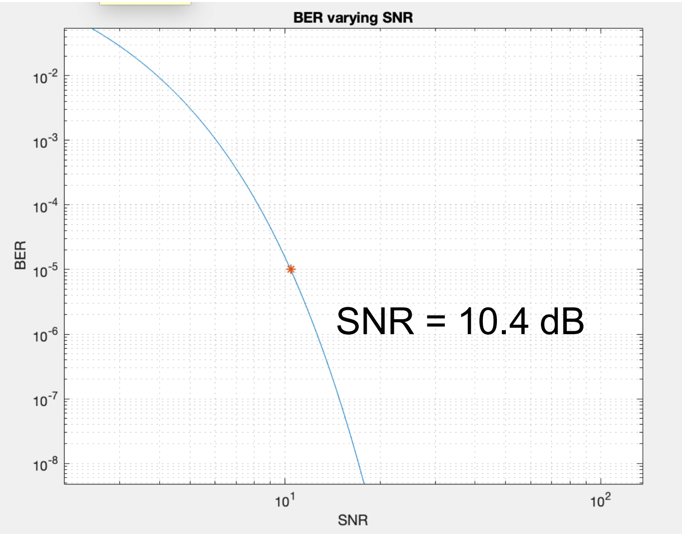
DR 1.4	The ground station shall be capable of demodulating a signal using the QPSK modulation scheme.
DR 1.10	The ground station shall be able to receive a data rate of at least 2 million bits per second.

Bit Error Rate

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) of10^{-5}**, a bit rate of 2 Mbit/s, and a G/T of 3 dB/K.

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

- Must have SNR ≥ 10.4dB to achieve BER of 10^{-5}
- Current system SNR ≅ 17.21dB
  - BER ≅ 8.9e-9
  - Determined using ASEN 3300 link budget and typical transmit values



✔ ☐Meets Requirement

ARGUS

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

ARGUS

Components	Mass	Components	Mass
Feed	1 kg	Tripod	1.9 kg
Dish	6 kg	SDR	0.12 kg
Az/El motors	12.8 kg	Electronics	2.2 kg
Motor Controller	2 kg	Case	15.4 kg
NUC	1.2 kg	Mounting Bracket	1.6 kg
Total	**44.2 kg < 46.3 kg**	✔ ☐Meets Mass Requirement **(FR4.0)**	

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Risk Management

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Risk Matrix

Gain	Blockage and efficiency calculations flawed, too little gain to get satellite signal
Manufacturing	Modifications to dish result in incorrect parabola, unaccounted for blockage
TLE	Accuracy dependent on source and age of TLE
Motor	Motor resolution and limits cause error in tracking satellite
Mobility	Violate OSHA standards
Calibration	Inaccurate calibration of Az/El causes inaccurate pointing and tracking
BER	High BER causes data to be erroneous and unusable
Full Integration	Failure between subsystem interfaces causes entire system failure

Severity →

Likelihood ↑

	1	2	3	4	5
5	Mobility				
4					
3			1. Motor Error 2. Calibration	Full Integration	
2		Manufacturing		BER	Dish Gain
1		TLE Error			

Legend
Low (1-4)
Moderate (5-9)
High (10-14)
Critical (15-25)

ARGUS

Risk Mitigation

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

Legend	
(green)	Low (1-4)
(yellow)	Moderate (5-9)
(orange)	High (10-14)
(red)	Critical (15-25)

Severity →

Likelihood ↑

	1	2	3	4	5
5					
4	Mobility				
3			Full Integration		
2		Manufacturing	1. Motor Error 2. Calibration	Dish Gain	
1	TLE Error			BER	

Verification and Validation

Test Plan

ARGUS

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

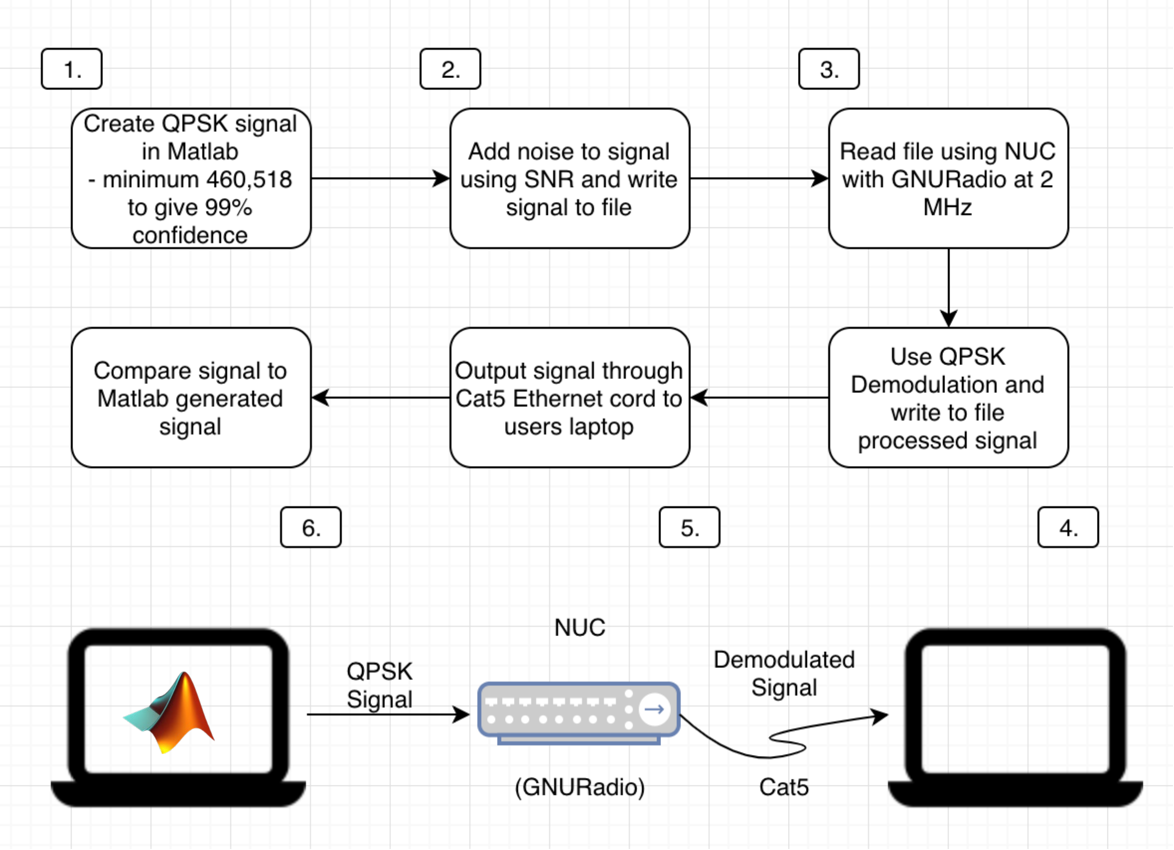
Antenna System:
- S-Band satellite signal reception

Signal Processing Test:
- S-Band signal processed

Motor System Test:
- MTI + Yaogan 6 tracking

Mobility:
- Transport and assembly > 100m

Signal Processing System Level Test



Equipment Needed	Procurement
Laptop	Owned
GNURadio	Open Source

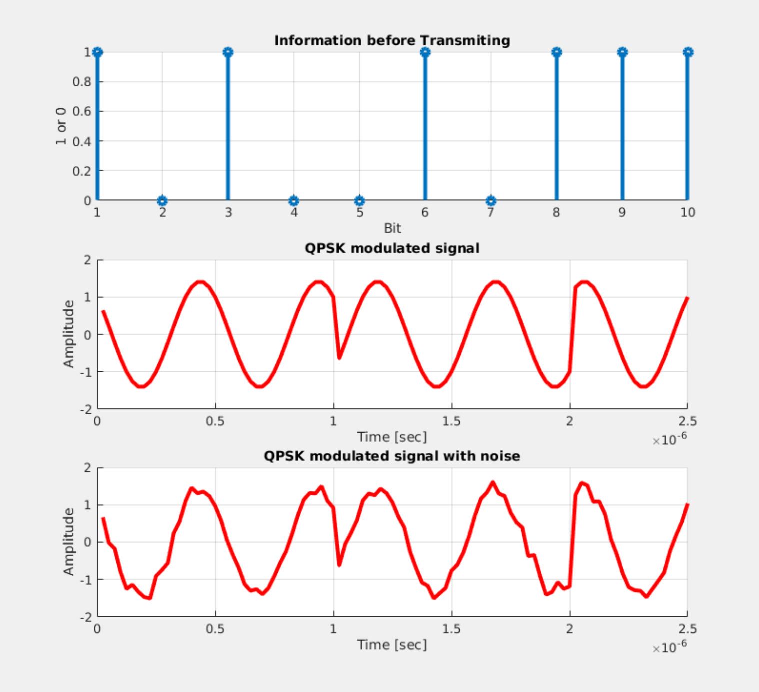
Possible Measurement Errors
• NUC Processing Speed • Reconfigurability • Length of test (time)

Signal Processing System Level Test

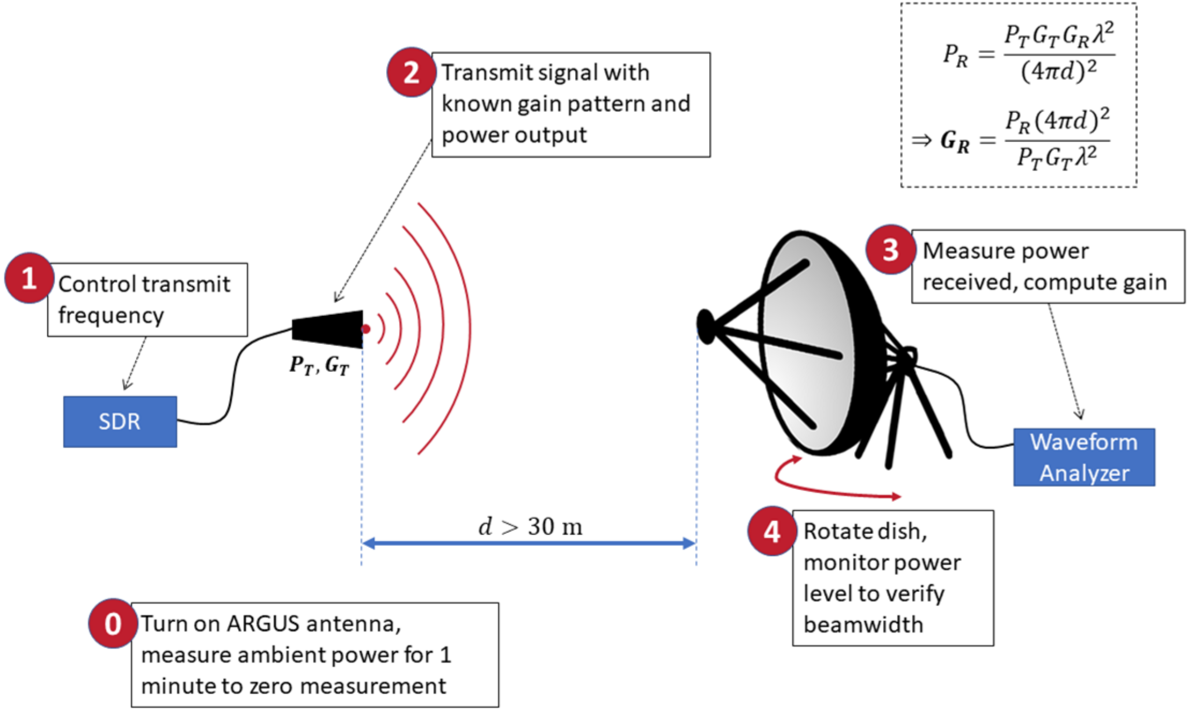
ARGUS

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

Data Needed	Compared To	Expected
BER	Matlab estimation	8.9E-9
QPSK Signal	Matlab generated signal	Matlab generated signal



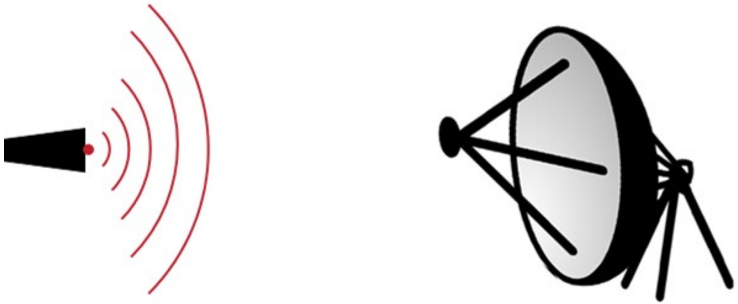
Antenna Gain/Beamwidth Test



Equipment Needed	Procurement
SDR	Purchase
Transmit Antenna	Borrow/Purchase
Waveform Analyzer	Borrow
Measuring wheel	Borrow

Antenna Gain/Beamwidth Test

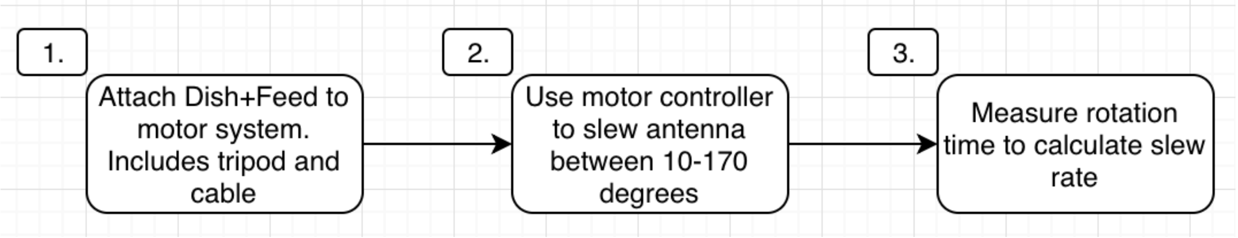
Objective	• Verify antenna gain • Verify half power beam width (HPBW)
Location	Rural location or RF test range
FR Verified	FR 1: Gain, Beamwidth

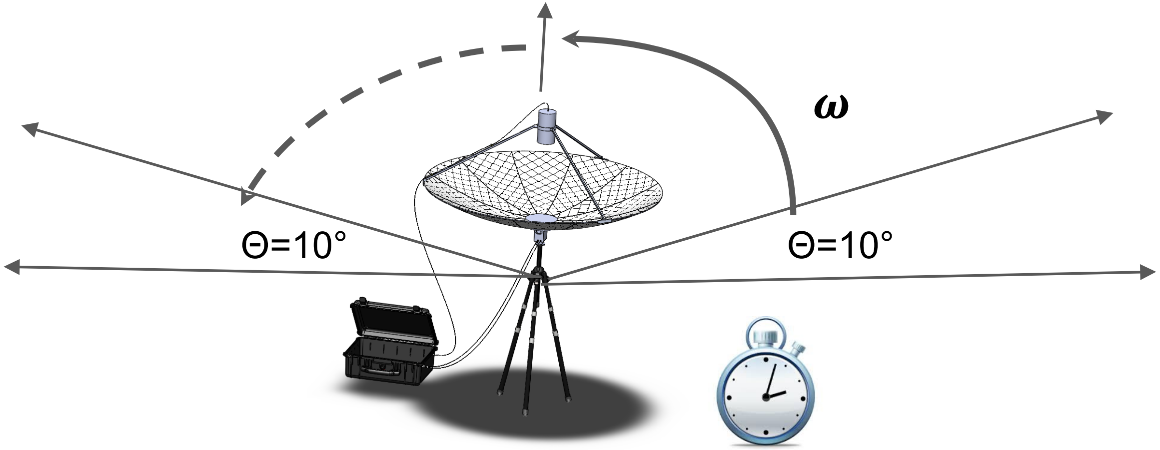


Data Needed	Compared To	Expected
Gain	Efficiency model, dish kit specs	29.5dBi at 2.4GHz
Beamwidth	Idealized estimates, dish kit specs	6.5°

Potential Measurement Issues
• External signal noise • Signal reflection from ground • Incorrect feed placement • Pointing accuracy

Motor System Level Test





Equipment Needed	Procurement
Timer	Owned
Protractor	Borrow
Power Supply	Borrow

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	Resolution	Expected
Rotation Rate	0.5°/s	7.2 °/s
Rotation Angle	1°	10°-170°

Possible Measurement Errors
• Timing accuracy • Angle measurement accuracy

Mobility System Level Test

Equipment Needed	Procurement
Scale	Borrow
Measuring wheel	Borrow
Stopwatch	Borrow/Owned

1 All ARGUS components packed in carrying case

2 Weigh disassembled system

3 Carry 100m

4 Assemble ARGUS

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

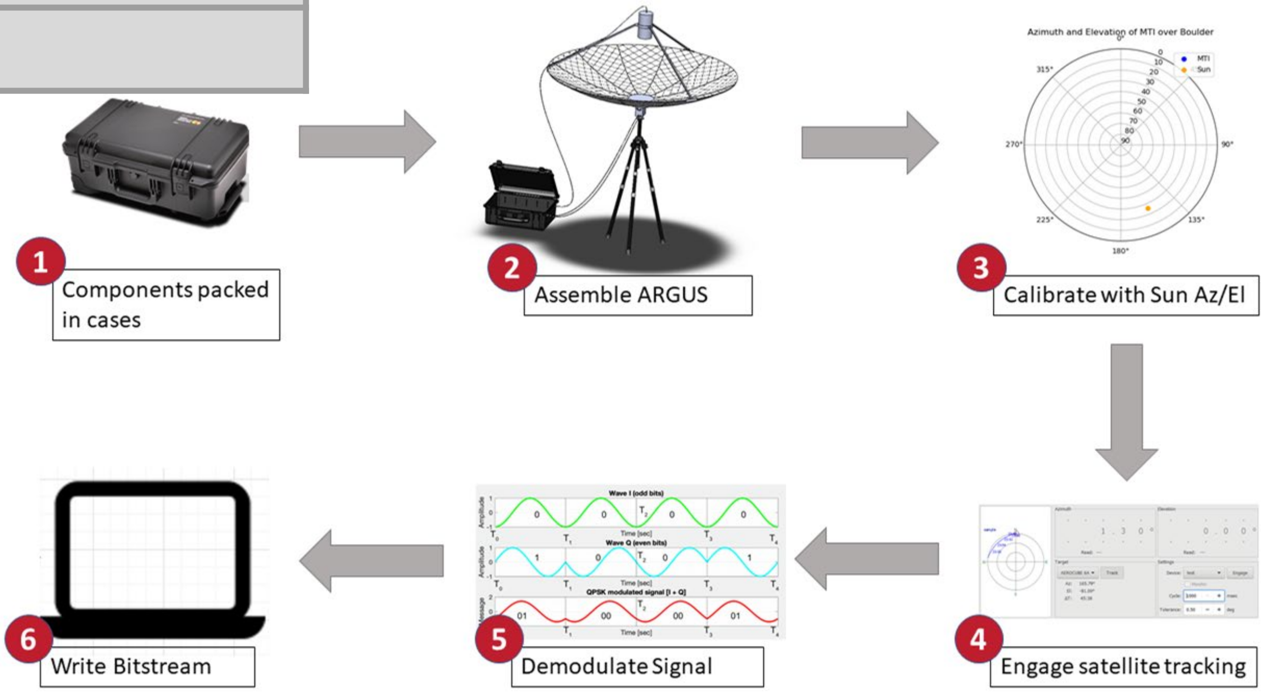
Mobility System Level Test

Objective	• Verify weight requirements • Demonstrate mobility • Show assembly is under 60min
Location	Business field
FR Verified	FR 4: Mass, assembly time

Data Needed	Requirement	Expected
Weight	46.3 kg	42.6 kg
Assembly Time	60 min	35 min

Objective	• Test ARGUS portability • Receive signal from satellite
Location	Business Field
FR Verified	All FR

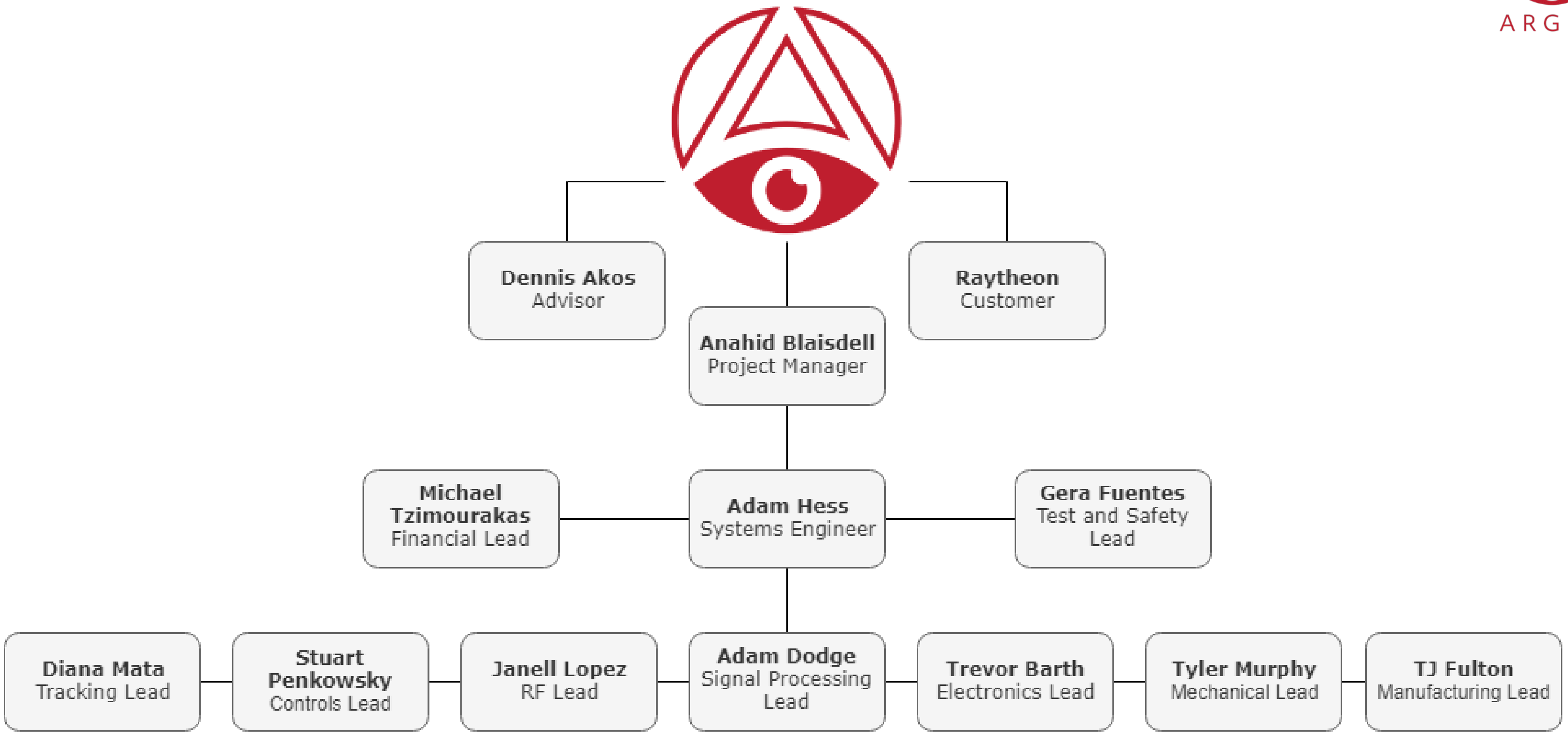
Full System Test



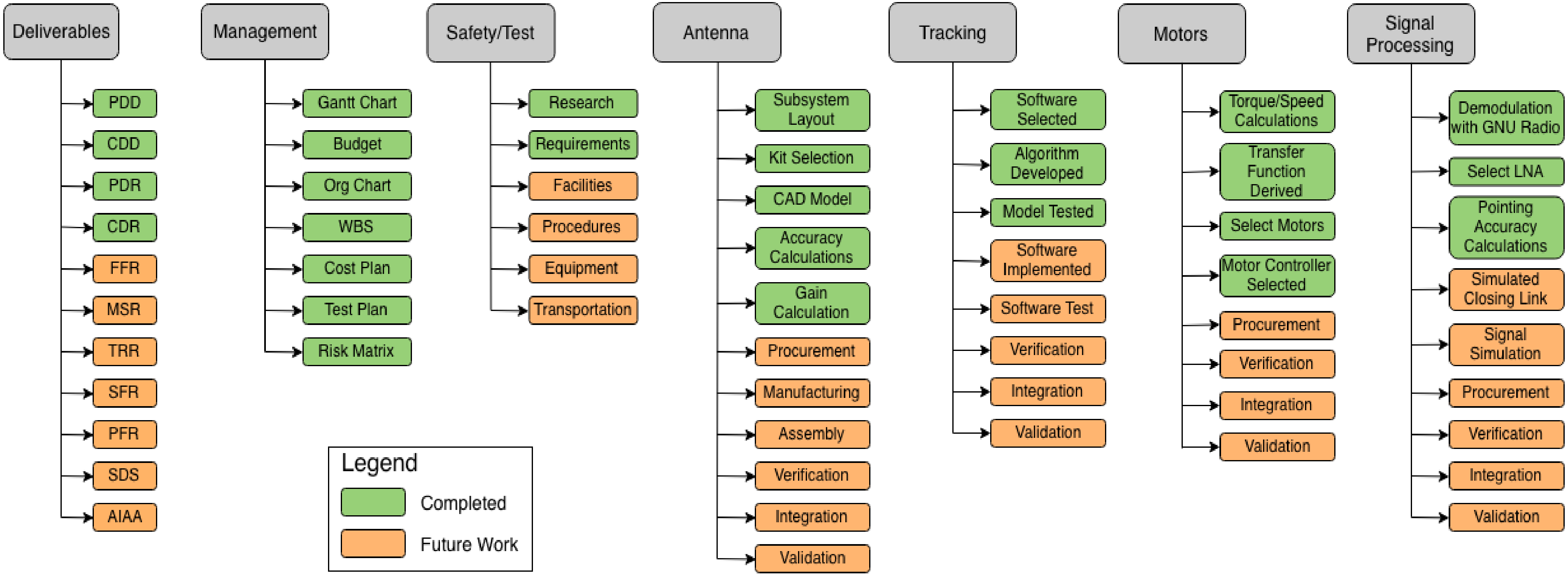
ARGUS

Project Planning

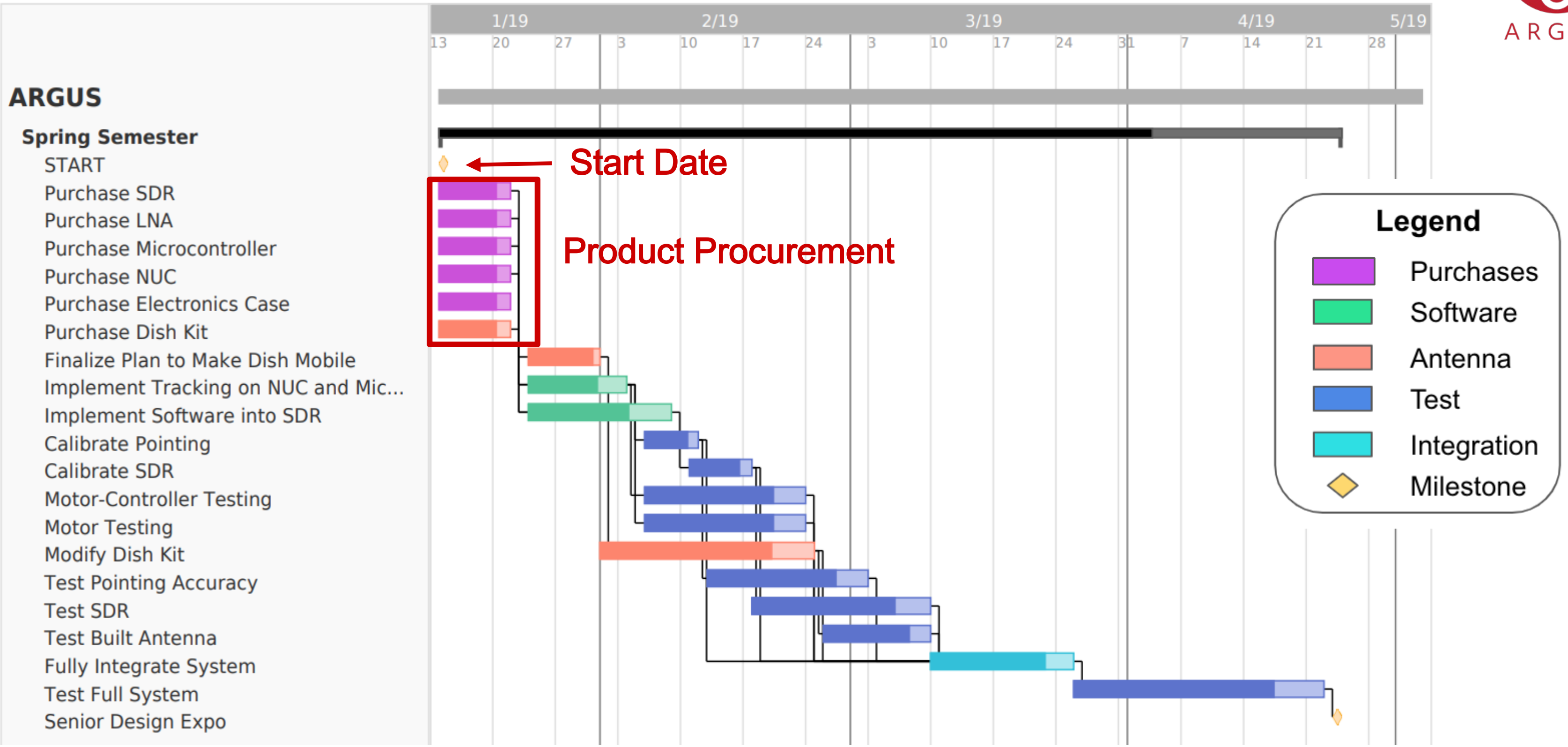
Organizational Structure



Work Breakdown Structure



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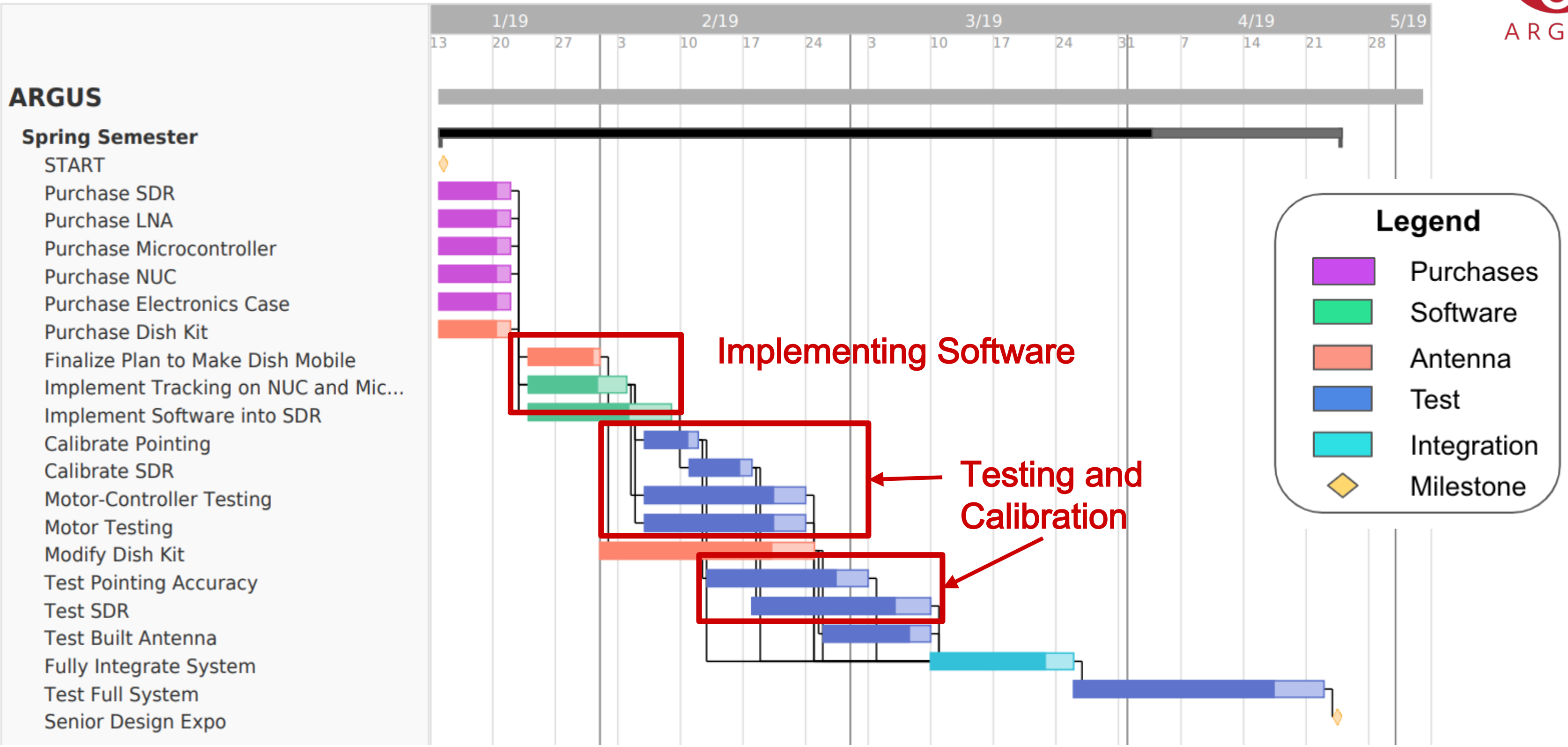
ARGUS
Spring Semester
START
Purchase SDR
Purchase LNA
Purchase Microcontroller
Purchase NUC
Purchase Electronics Case
Purchase Dish Kit
Finalize Plan to Make Dish Mobile
Implement Tracking on NUC and Mic...
Implement Software into SDR
Calibrate Pointing
Calibrate SDR
Motor-Controller Testing
Motor Testing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

Work Plan



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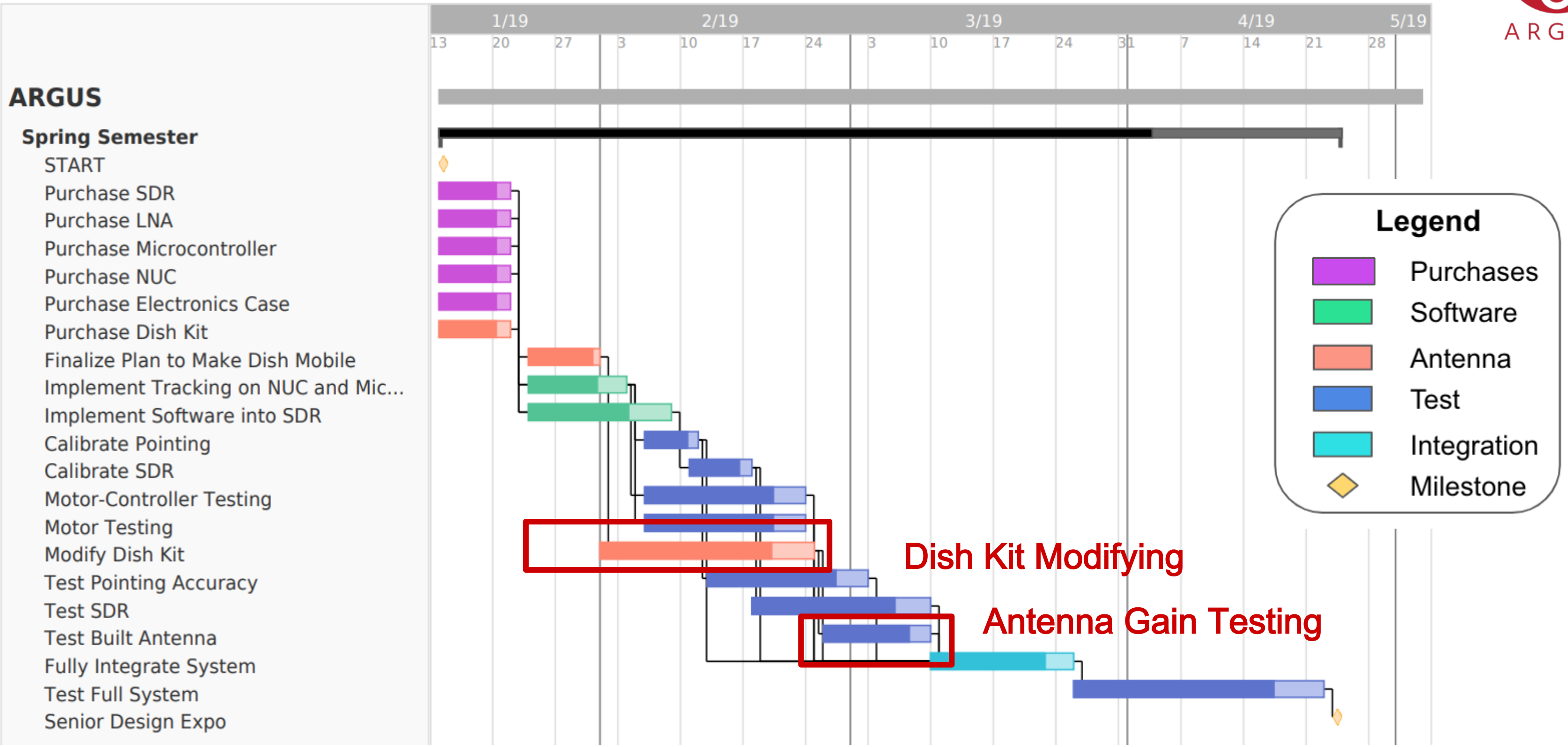
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Dish Kit Modifying
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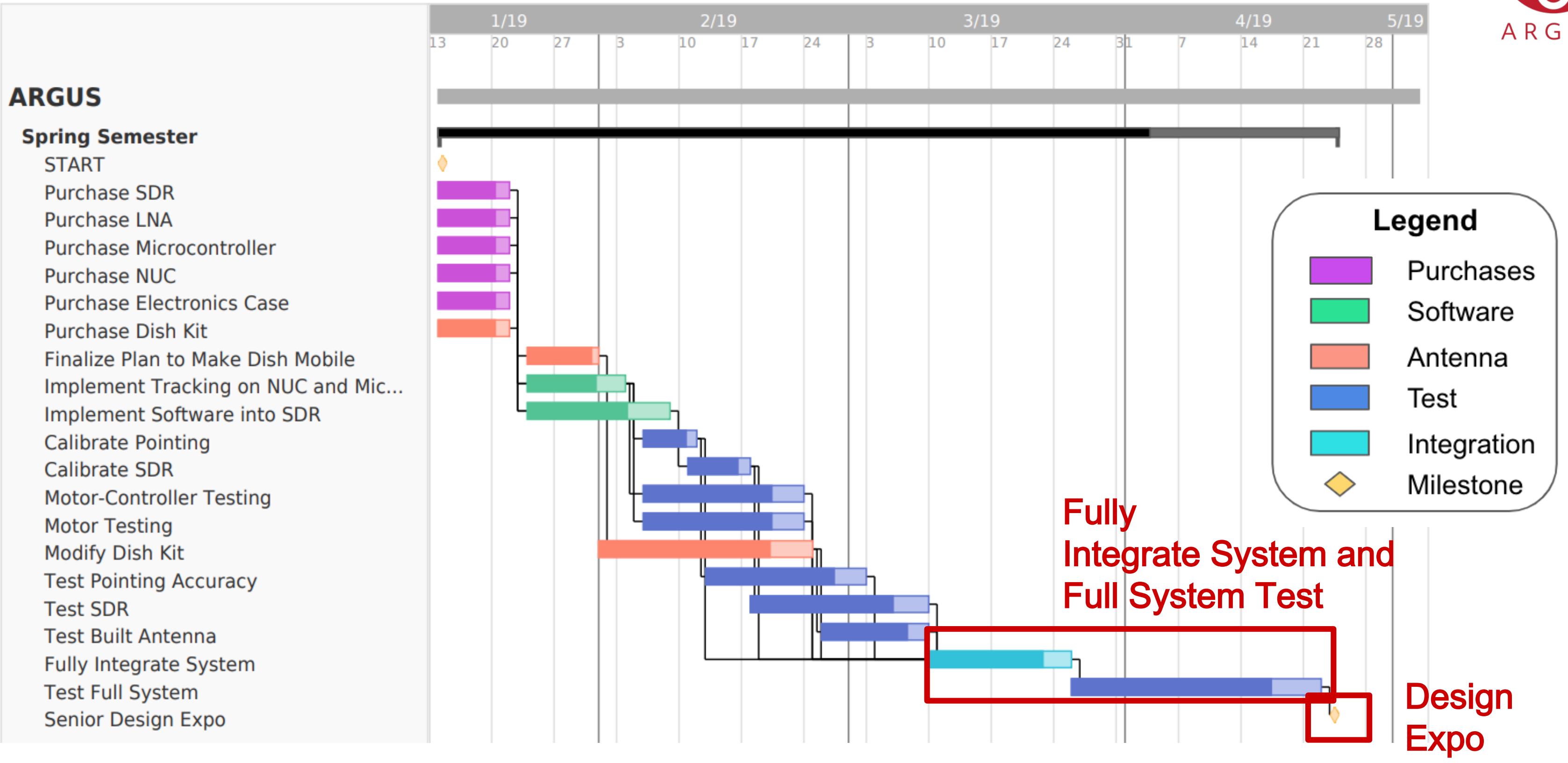
Work Plan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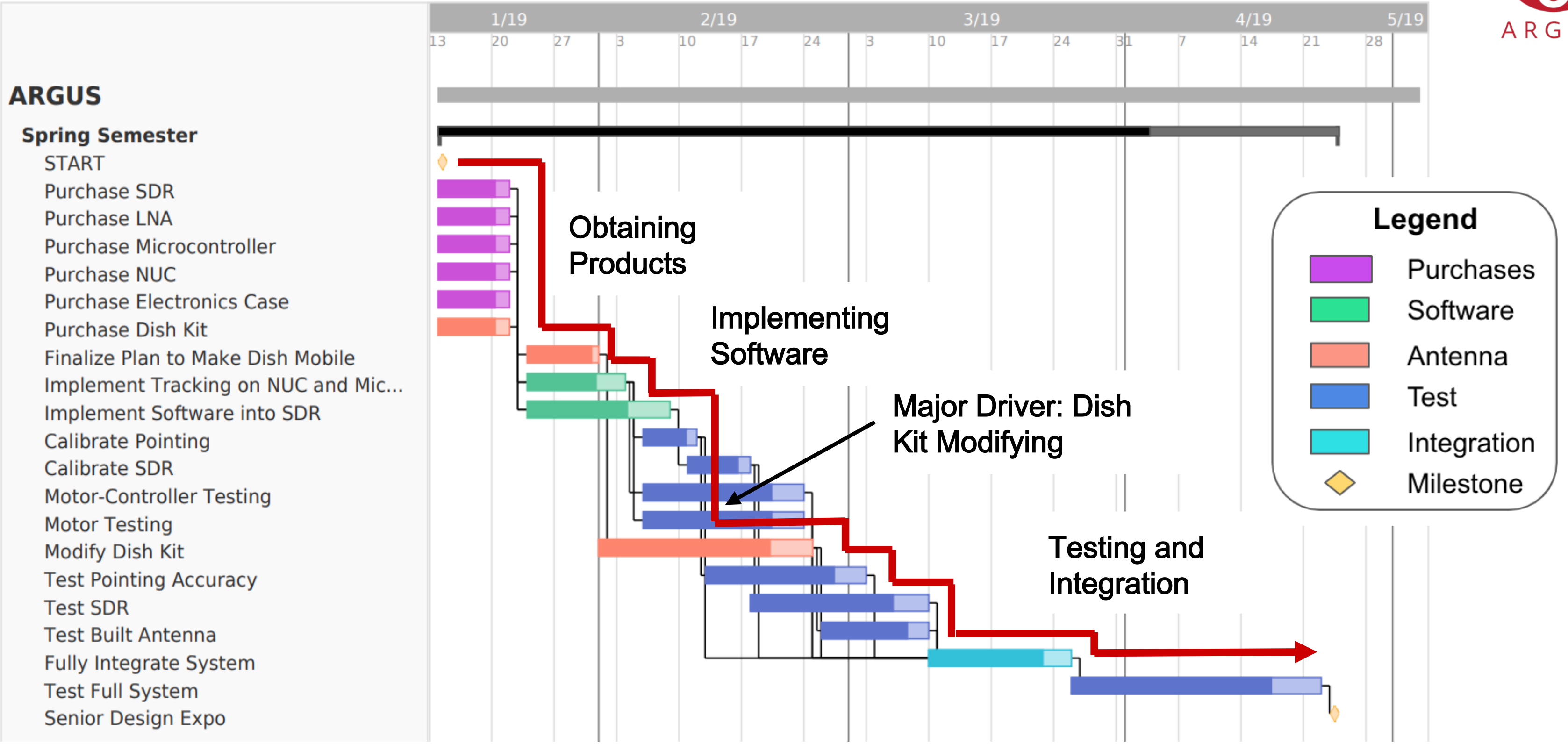
Milestone
Fully
Integrate System and
Full System Test
Design
Expo

Work Plan

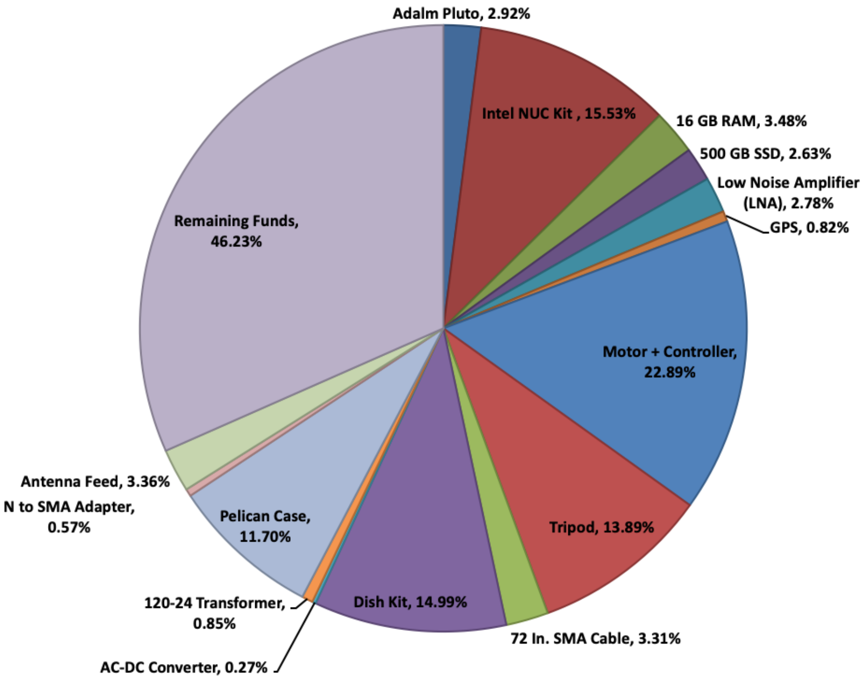
Critical Path



Budget

Total: $3419.25

Item	Cost ($)
Motor + Controller	782.58
Electronics	1134.10
Dish + Feed	627.67
Tripod	475.00
Pelican Case	400.00
Remaining Funds	1580.65
Total	5000.00



References

1. Mason, James. "Development of a MATLAB/STK TLE Accuracy Assessment Tool, in Support of the NASA Ames Space Traffic Management Project." August, 2009. https://arxiv.org/pdf/1304.0842.pdf
2. *Splatalogue*, www.cv.nrao.edu/course/astr534/Equations.html.
3. *STK*, help.agi.com/stk/index.htm#training/manuals.htm?TocPath=Training|_____0.
4. Kildal, Per-Simon. *Foundations of Antenna Engineering: a Unified Approach for Line-of-Sight and Multipath*. Kildal Antenn AB, 2015.
5. "Cables, Coaxial Cable, Cable Connectors, Adapters, Attenuators, Microwave Parts." *Pasternack*, www.pasternack.com/.
6. "Tools for Spacecraft and Communication Design." *Amateur Radio in Space*, www.amsat.org/tools-for-calculating-spacecraft-communications-link-budgets-and-other-design-issues/.
7. http://www.rfhamdesign.com/index.php
8. Hamlib rotator control command library: http://manpages.ubuntu.com/manpages/xenial/man8/rotctld.8.html
9. *RF Hamdesign- Mesh Dish Kit 1.5m* "Specifications Sheet". PDF file. 2018. www.rfhamdesign.com/downloads/rf-hamdesign-dish-kit_1m5_kit_spec.pdf.
10. *SPX-01 Azimuth & Elevation Rotor Including Control* "SPX-01 Specifications Sheet". PDF file. 2018. www.rfhamdesign.com/downloads/spx-01-specifications.pdf.

Questions?

Backup Slides

Total List

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

Changes Made Since PDR

ARGUS

Change	Reasoning
Purchase and modify dish kit	Cost effectiveness due to amount of man hours necessary to build dish from scratch
Purchase motor gimbal	Difficulty in accuracy and efficiency. Out of scope
More precise gain number	Specific components chosen, thus, accurately calculated losses
Removal of auto-track	Out of scope due to difficulty, processing constraints, and strain on motors

Requirement		Verification Method
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 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
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.**	Slew rate and pointing accuracy testing of integrated gimbal/antenna assembly, tracking satellite during pass monitoring signal strength
3.0	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
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.**	Weight budgeting, mobility and assembly demonstrations
5.0	The ground station onboard computer shall interface with a laptop using a Cat-5 ethernet cable.	Passage of required data between laptop and NUC

Reconfigurability

FR 3.0	The ground station shall be reconfigurable to be used for different RF bands.

Reconfigurability to Other Frequency Bands

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

Laptop Interface

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

Power Budget

Component	Voltage	Max Power Draw
Motor Assembly	24 VAC, 50/60 Hz	45.6 W
NUC Computer	19 V	120 W
LNA	3.0 V	0.5 W

*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

ARGUS

GPS Module

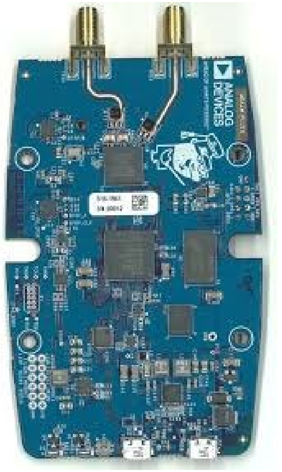
- Purpose:
  - Determine precise location of ground station used for calibration and timing
- Model:
  - Globalsat BU-353
- Specs:
  - Stationary Accuracy of +/- 3 meters
  - $30

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

ARGUS

- 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

$$CL = 1 - e^{-N_{errors}} = e^{-N_{bits} * BER}$$

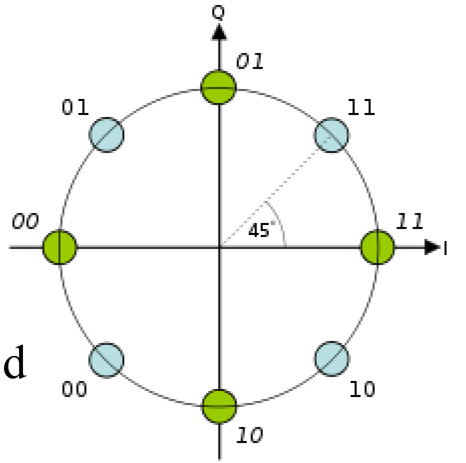
$$N_{bits} = \frac{-\ln(1-CL)}{BER} = \frac{-\ln(1-0.99)}{10^{-5}} = 460517.0186$$

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

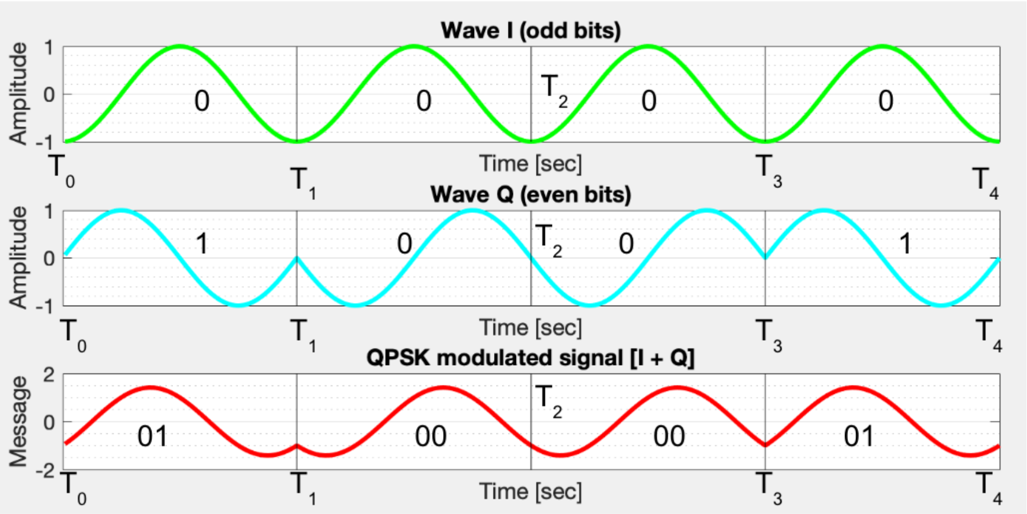
ARGUS

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

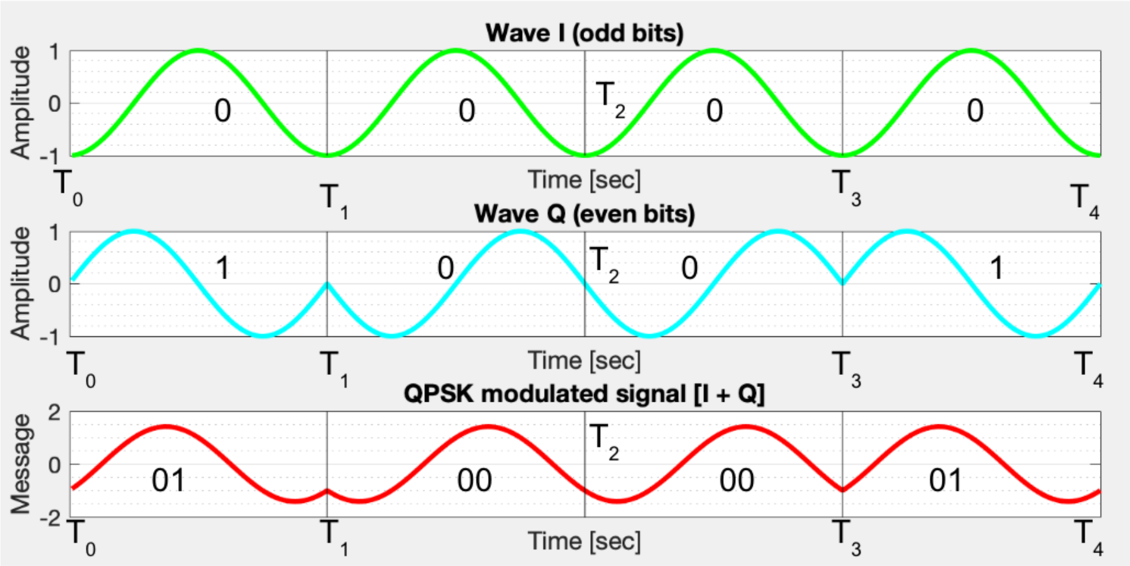


QPSK Modulation

$$s_n(t) = \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f t + \pi(1 - n)), \quad n = 0, 1.$$

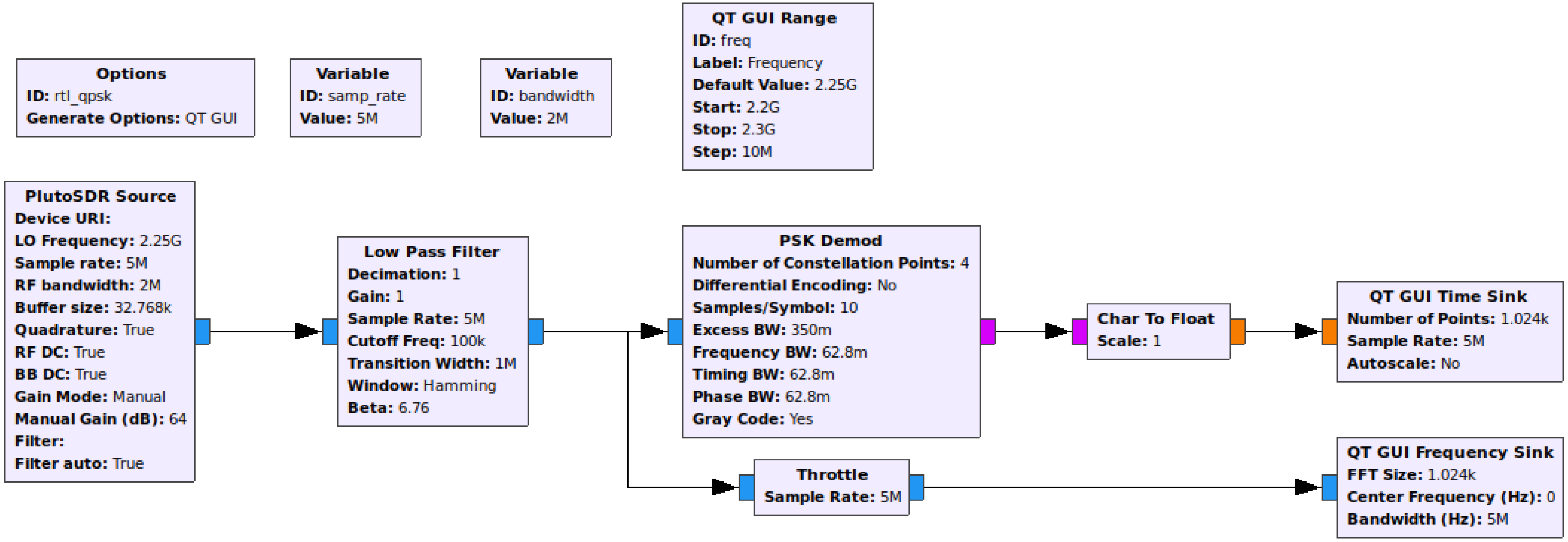
Reception:

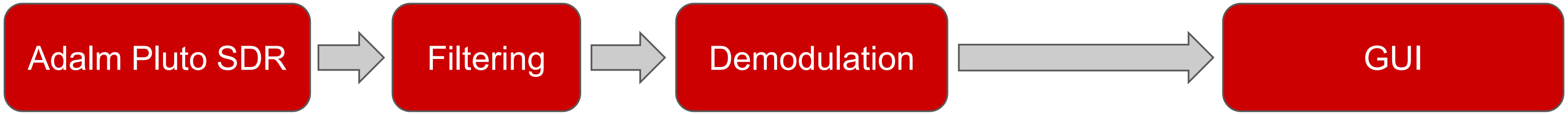
- Final wave is received containing 2 bits per Period
- Results in 2 times faster data rate
- Or half the BER with same data rate



Received the letter “A”: 01000001

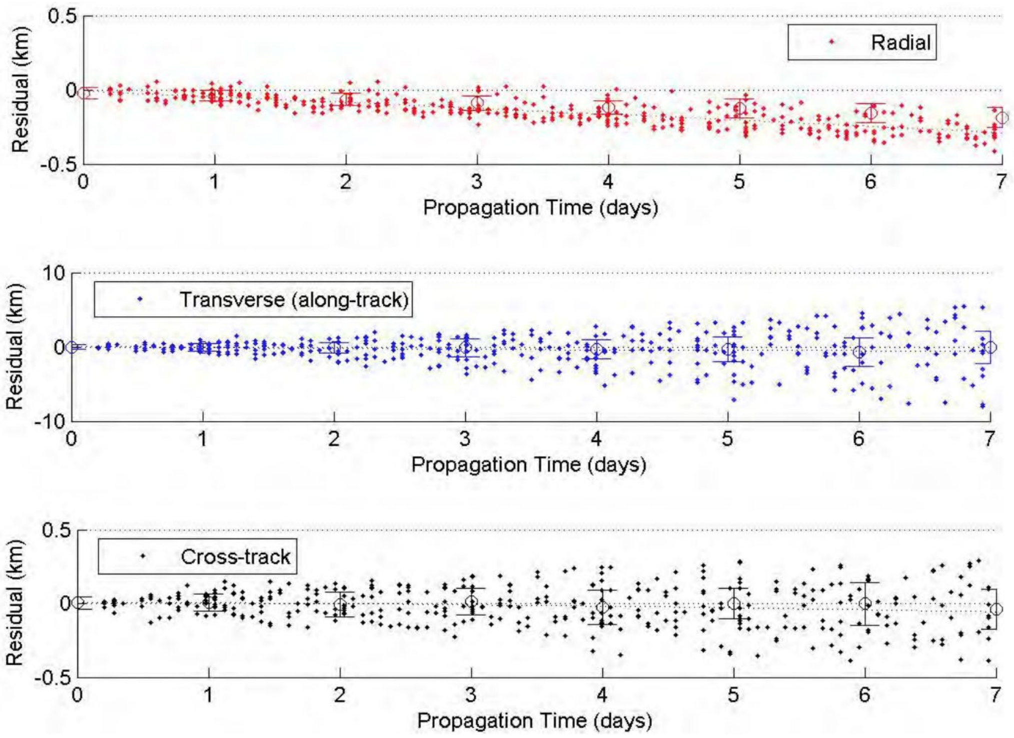
GNURadio Software Diagram





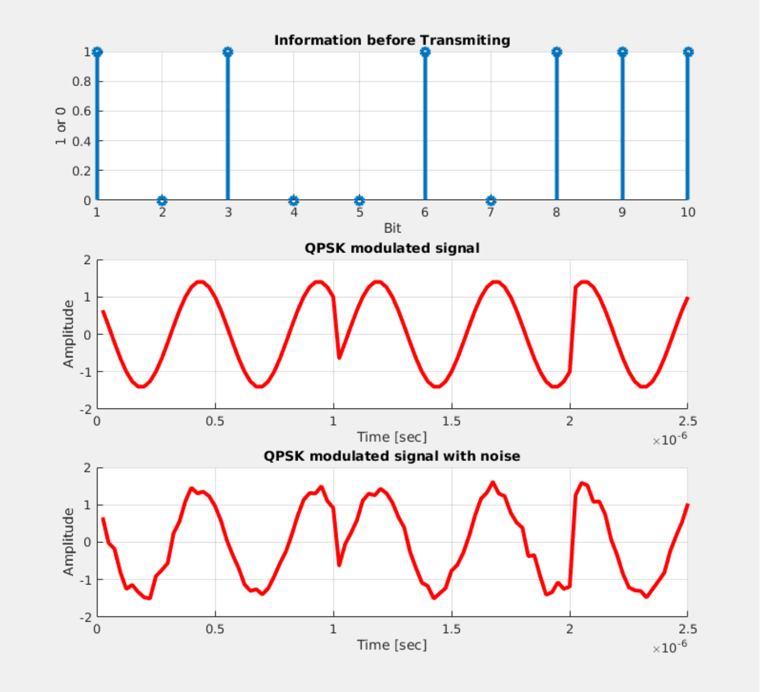
TLE Predicted Error

- 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

Rot2Prog motor controller (back)

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

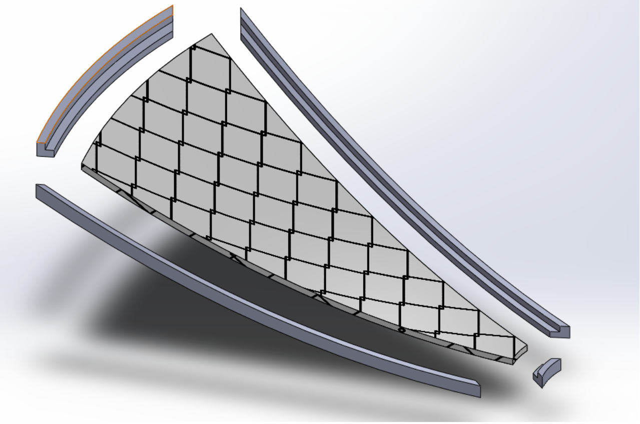
Elevation motor connector:
Motor drive (2 pins)
Impulse sense (2 pins)

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

Reflector Design Choice

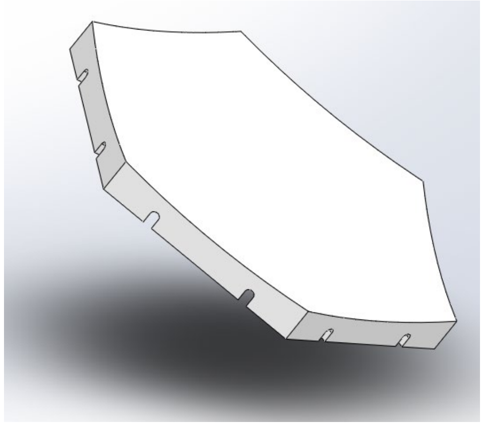
- 3 Materials and Dish Styles Explored

Aluminum Ribs with Aluminum Mesh



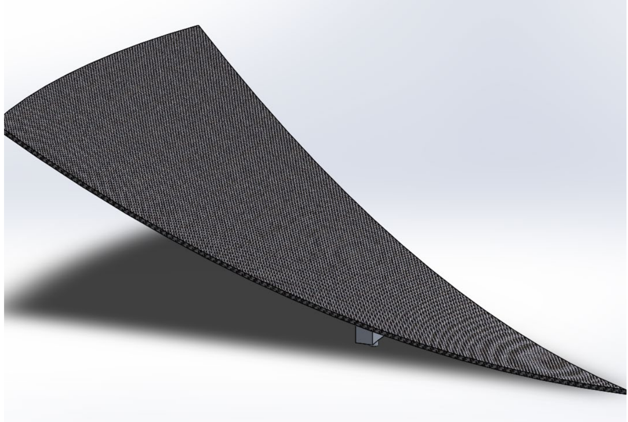
❌Difficult to Manufacture
❌Not Cost/Time Effective

3D Printed Hexagonal Design



❌Not Time Efficient
❌Heavy

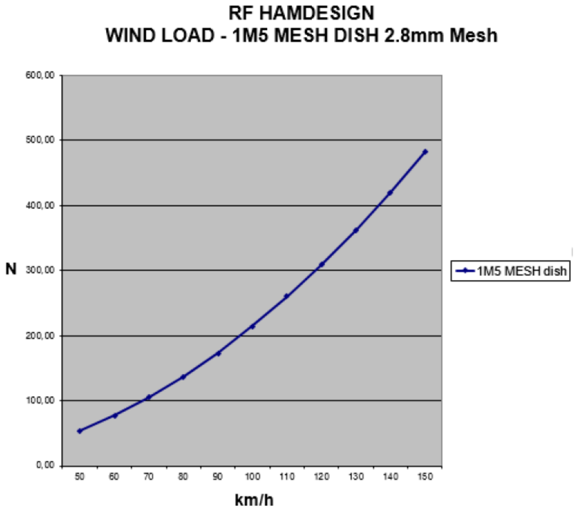
Carbon Fiber Panels

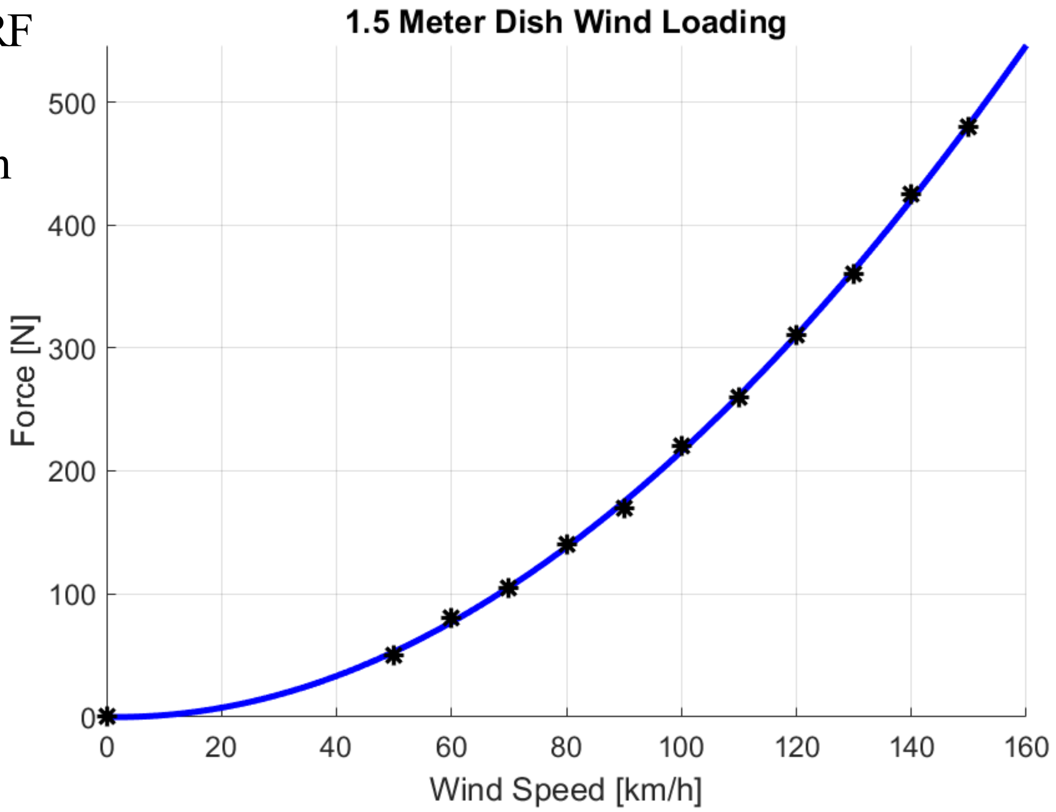


❌Over Budget
❌Difficult to Verify

Dish Wind Loading Estimation

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





Antenna Efficiency

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

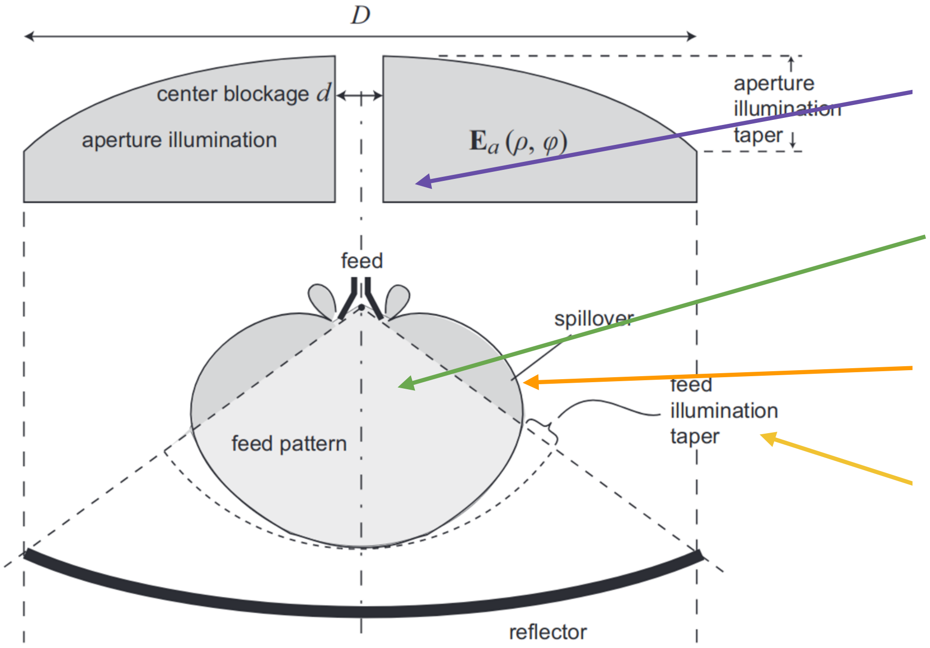
$$\eta = \eta_{sp}\eta_{ill}\,\eta_{pol}\,\eta_{\phi}\eta_{bf}\eta_{bs} = \eta_{feed}\eta_{bl}$$

Feed Efficiency

Blockage Efficiency

Feed Loss Sources

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



η_{ϕ} Phase Efficiency

η_{pol} Polarization Sidelobe Efficiency

η_{sp} Spillover Efficiency

η_{ill} Illumination Efficiency

Feed Efficiency

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

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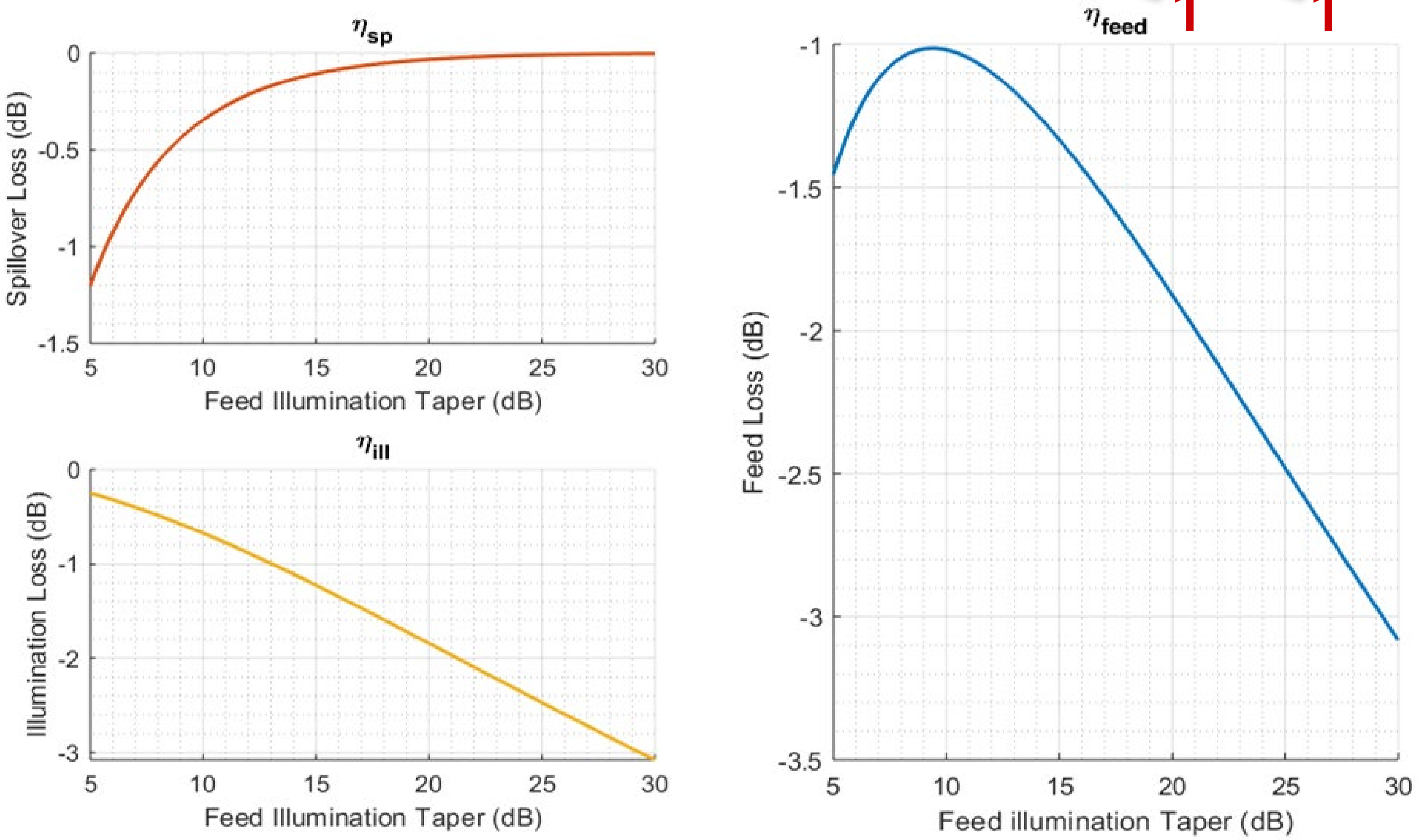
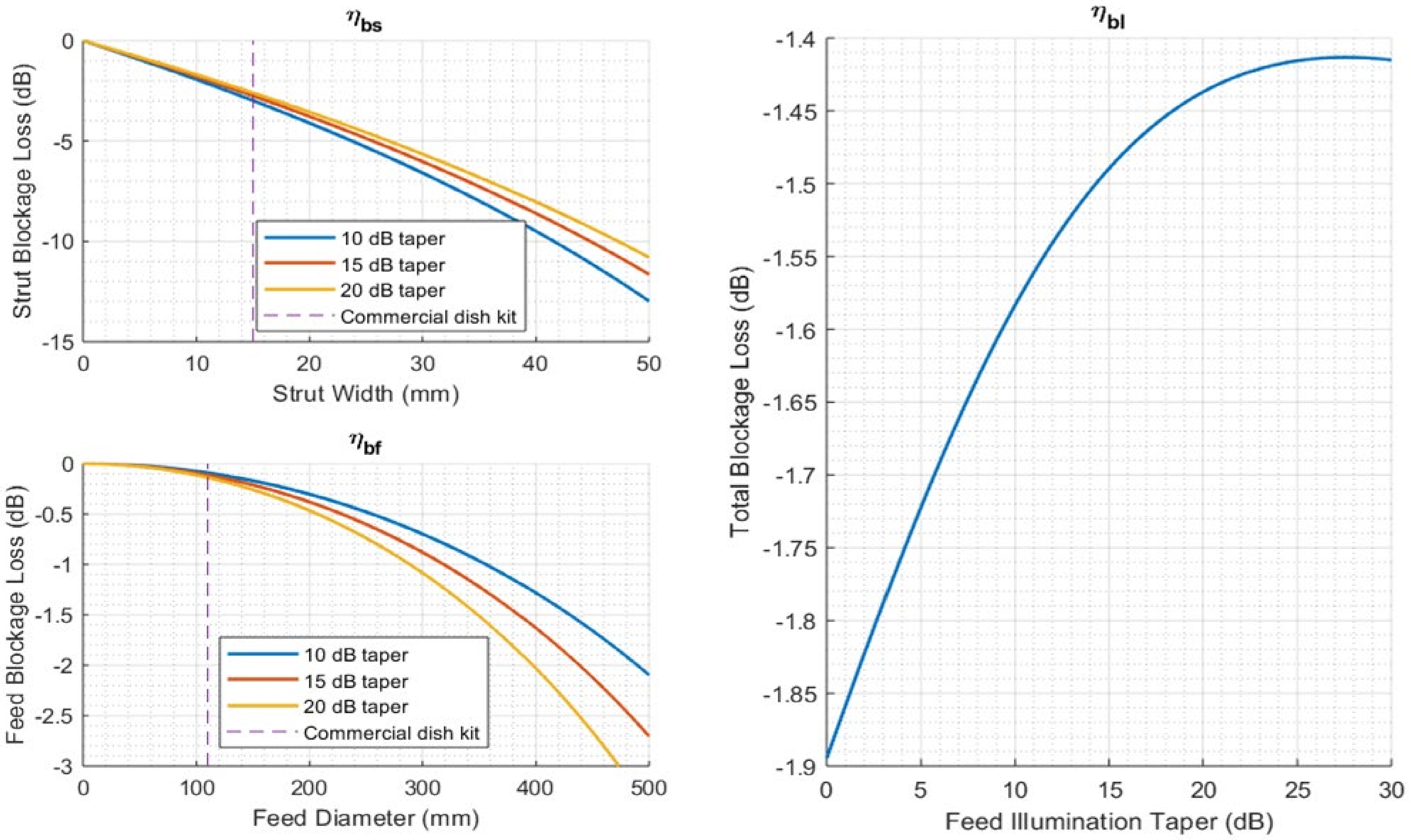


Blockage Loss

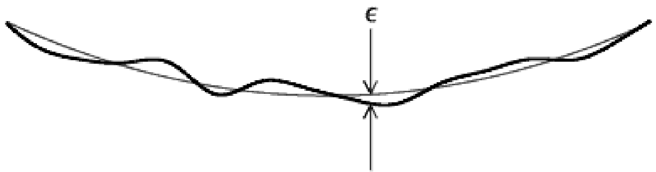
$$\eta_{bl} = \eta_{bf}\eta_{bs}$$



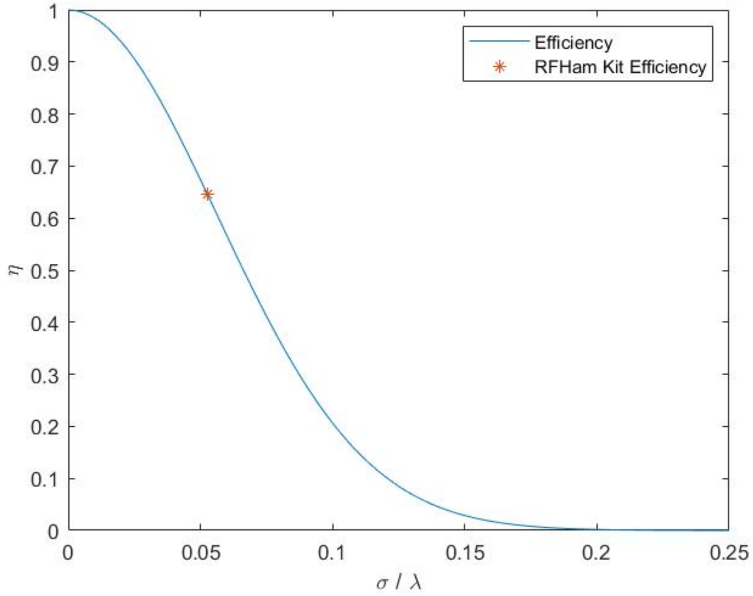
Antenna Surface Efficiency

Assume surface errors ϵ have Gaussian distribution with an rms of σ. Surface efficiency is then

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

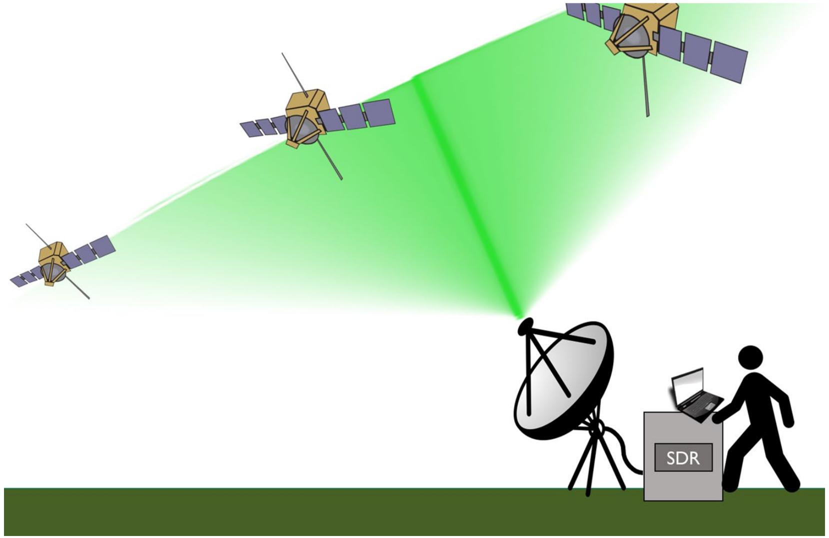


Varying the error-to-wavelength ratio results in the following efficiency distribution:

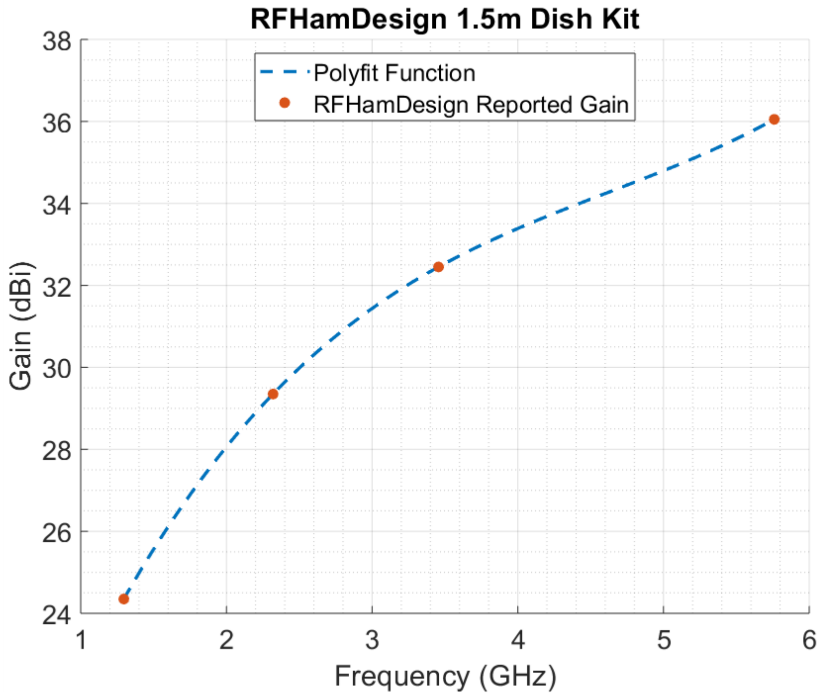


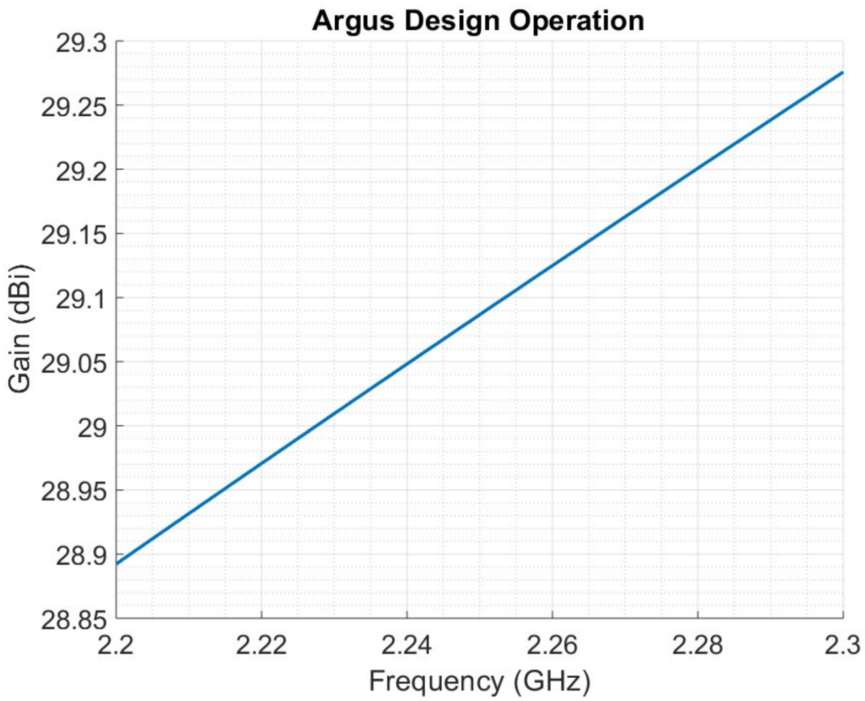
Signal to Noise Ratio (SNR) Verification

- **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

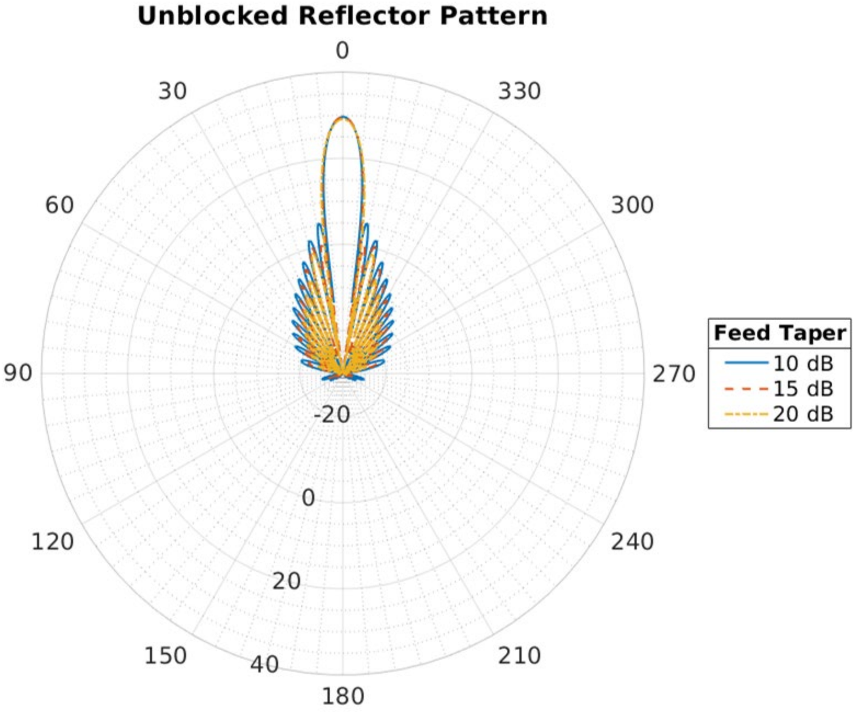


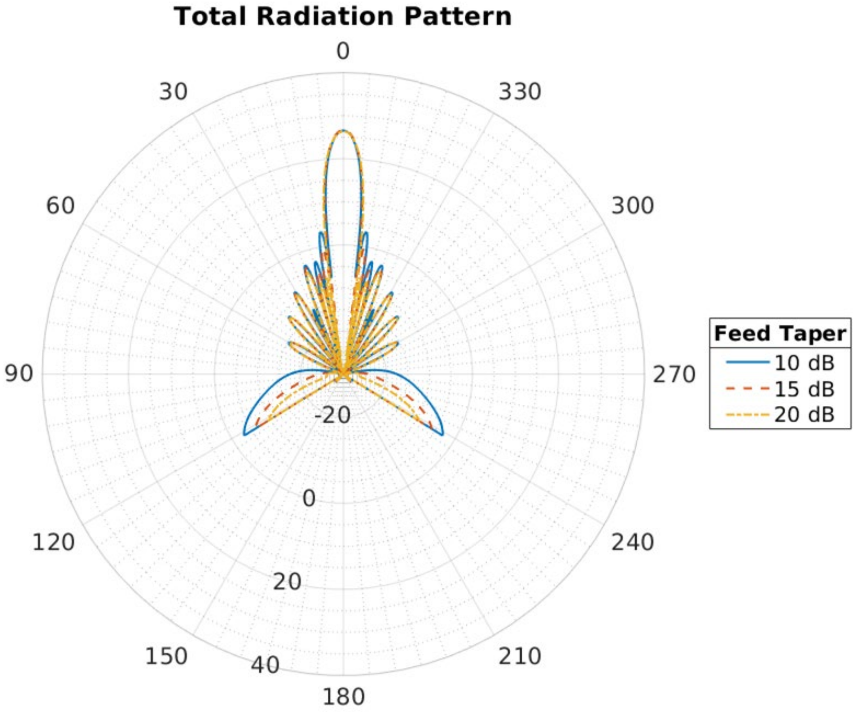
RFHamDesign Predicted Gain





Antenna Radiation Pattern

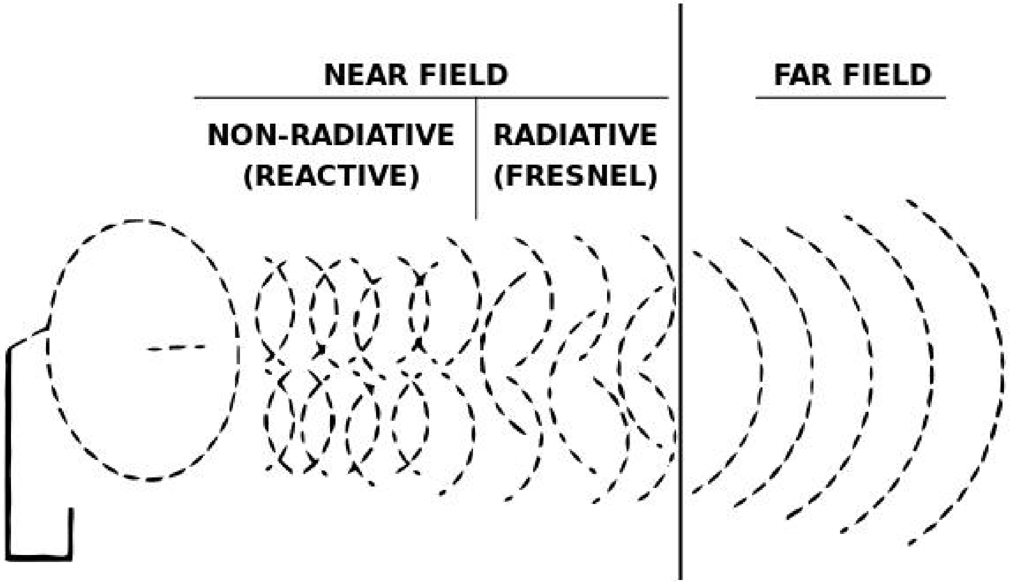




Gain Verification

Two possibilities:

- Anechoic chamber test
- Far-field radiation test



Estimated Far-Field distance:

$$d > \frac{2D^2}{\lambda} = 33.02\, m$$

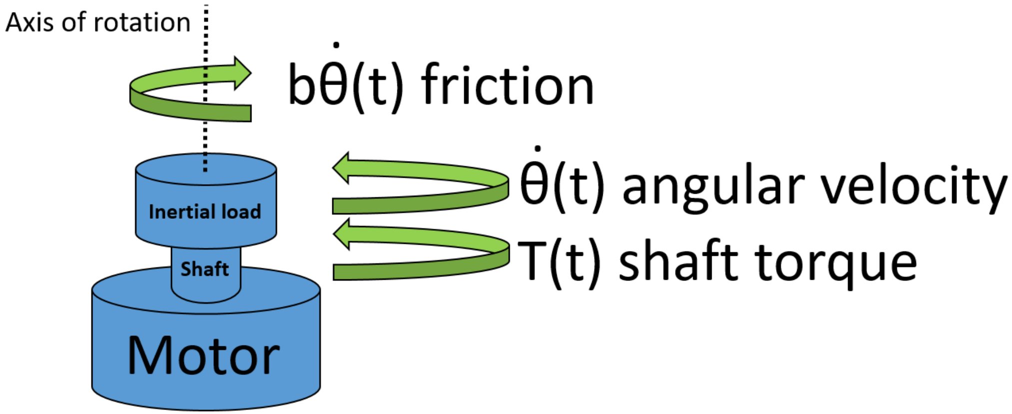
Anechoic chamber not feasible

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 ang vel by constant b



Transfer Function Modeling

- Commanding position:

$$\frac{\theta(s)}{C(s)} = \frac{a}{Is^2 + bs}$$

PID control

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

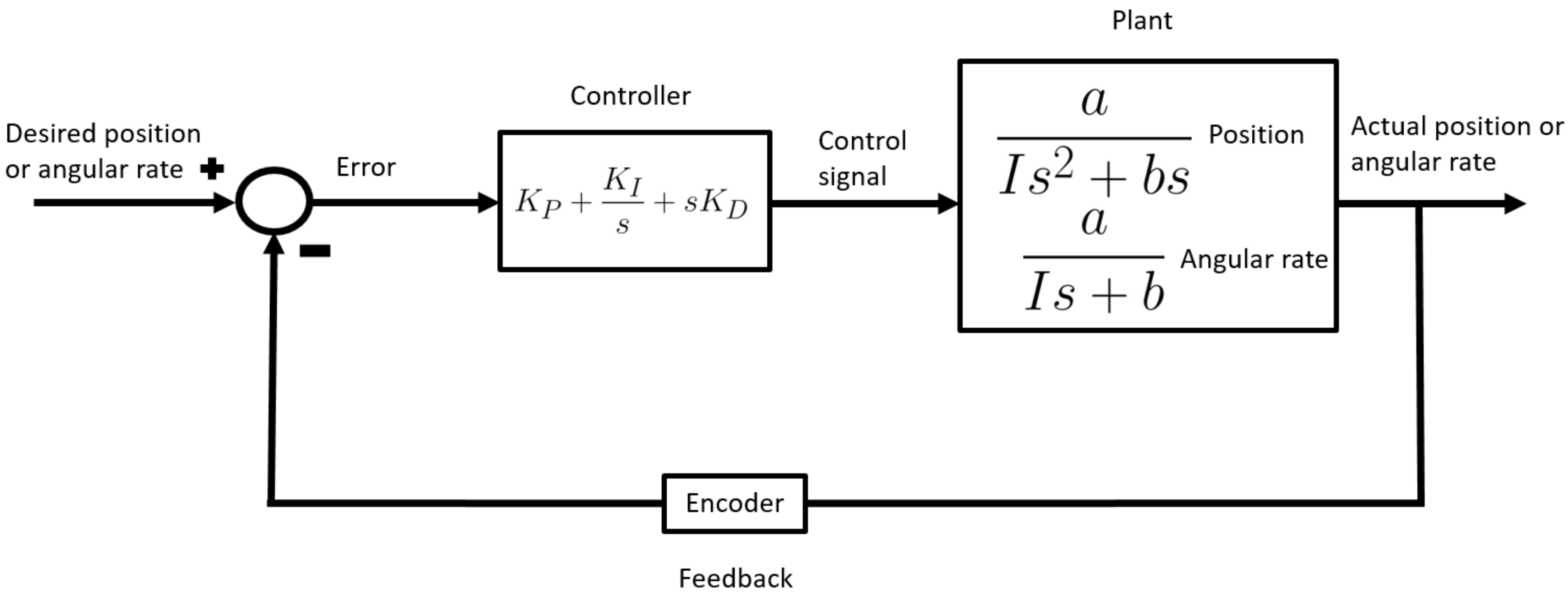
- Commanding angular rate:

$$\frac{\dot{\theta}(s)}{C(s)} = \frac{a}{Is + b}$$

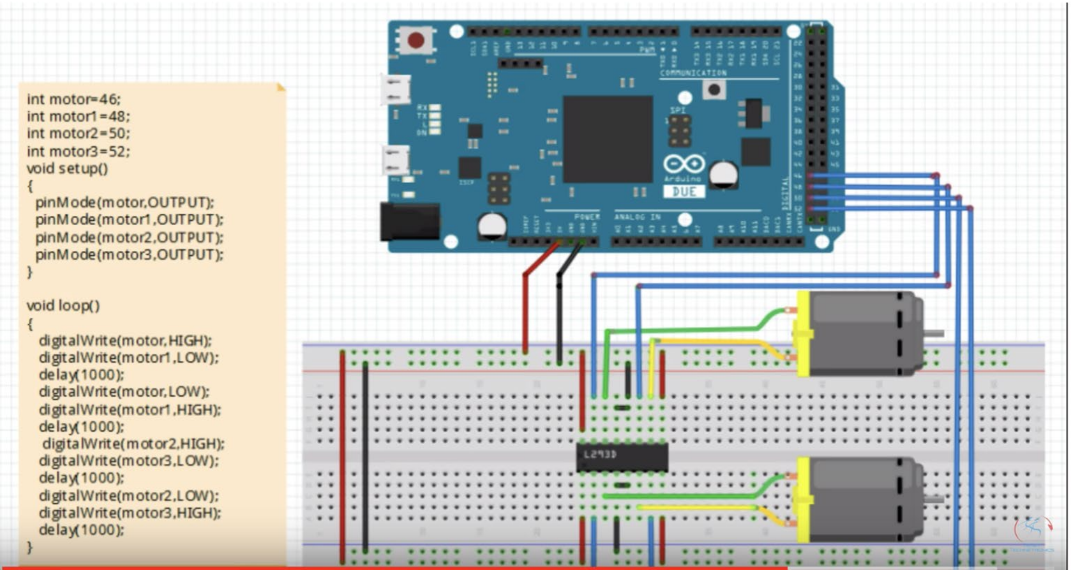
PID control

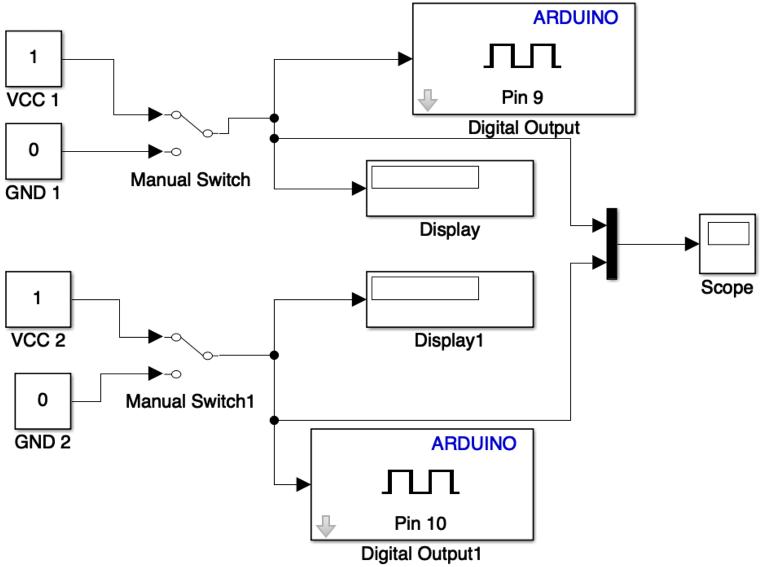
$$\frac{\dot{\theta}(s)}{\dot{\theta}_d(s)} = \frac{a(K_D s^2 + K_P s + K_I)}{(I + aK_D)s^2 + (aK_P + b)s + aK_I}$$

PID Block Diagram



Simulink and Arduino Controls





Signal Reception

ARGUS

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

Calculation Assumptions:

- TX Antenna Gain: 6.0 dBi
- TX Pointing Error: ± 6° (-12 dB loss)
- TX Power: 5 Watts
- RX Diameter: 1.5 m
- RX Antenna Efficiency: 50%
- RX Beamwidth: 9°
- RX Pointing Accuracy: 0.5°
- Range: 400 km
- Frequency: 2.3 GHz

Control Interface

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

Example Linux command: "rotctld -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

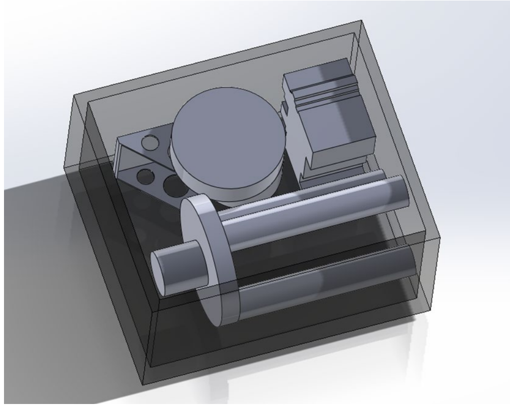
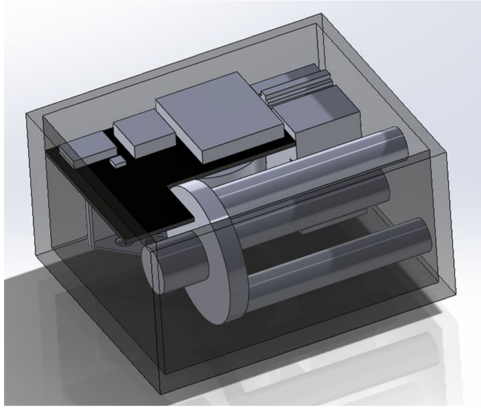
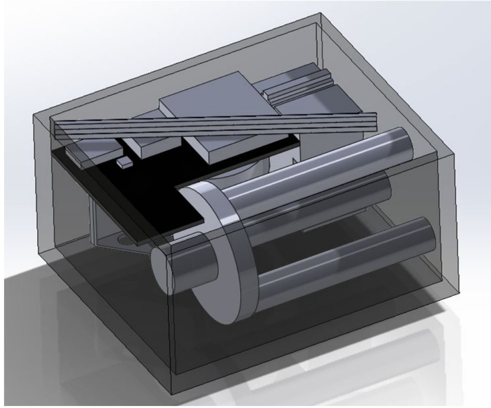
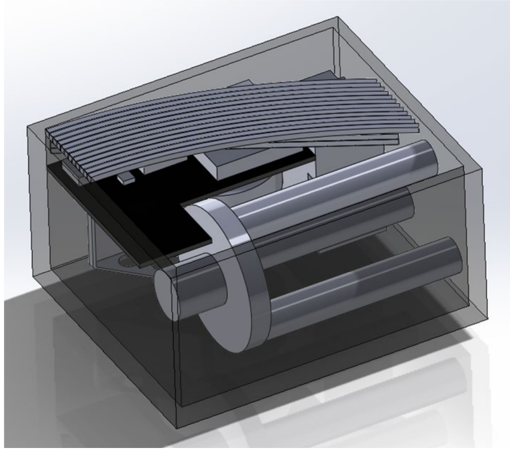
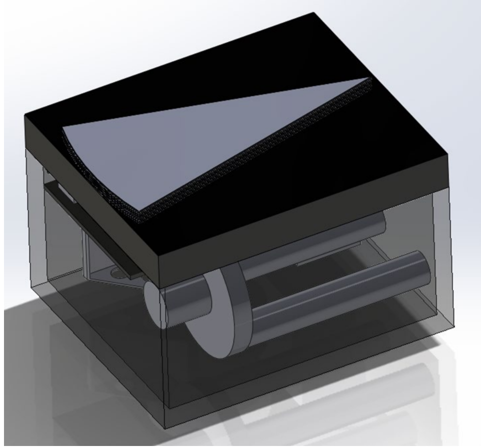
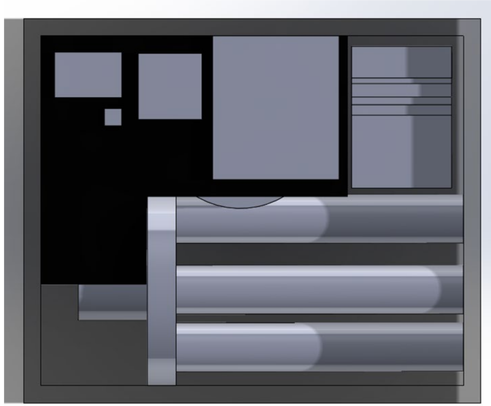
ARGUS

Requirement		Satisfaction
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.**	• 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

Requirement		Satisfaction
3.0	The ground station shall be reconfigurable to be used for different RF bands.	• Components can be swapped out; dish needs no adjustment
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

Disassembled and Packaged System