ASEN 4028 Senior Projects - Spring 2019

Manufacturing Status Review

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Advisor: Professor Dennis Akos

Customer: Raytheon
Project Overview
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
- Portable: 46.3 kg (102 lbs), able to be carried a distance of 100 meters by two people
## Levels of Success

<table>
<thead>
<tr>
<th>Level</th>
<th>Mechanical</th>
<th>Software</th>
<th>Electronics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1</td>
<td>Transportable in back of truck</td>
<td>Take TLE data and for az/el pointing commands</td>
<td>Provide power to all sub-systems</td>
</tr>
<tr>
<td></td>
<td>Assembled &lt; 6 hours</td>
<td>Data packets demodulated using QPSK</td>
<td>System used with monitor, keyboard, and mouse</td>
</tr>
<tr>
<td></td>
<td>Track LEO satellites at 5°/sec</td>
<td>- BER ≤ 10(^{-5})</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Communicate with LEO satellite at 10(^{+})° elevation above horizon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level 2</td>
<td>Transportable by unpowered rolling vehicle</td>
<td>Able to predict LEO satellite locations to less than 2.75° deg accuracy</td>
<td>System used with personal laptop interfaced using secure shell over a Cat-5 ethernet cable</td>
</tr>
<tr>
<td></td>
<td>Assembled &lt; 2 hours</td>
<td>Reconfigurable for other frequency bands</td>
<td>Reconfigurable for other frequency bands</td>
</tr>
<tr>
<td></td>
<td>Reconfigurable for other frequency bands</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level 3</td>
<td>Two people carry 100 meters</td>
<td>BER ≤ 10(^{-9})</td>
<td></td>
</tr>
</tbody>
</table>
Baseline Design

- Modified 1.5m Dish
- Tripod Adapter Plate
- Dutch Hill Tripod 1.12m to 2.08m
- S-Band Feed
- SPX-01 Motors
- Electronics Case
- Carrying Case
## Critical Manufacturing Elements

<table>
<thead>
<tr>
<th>CME</th>
<th>Reason</th>
<th>Predicted Required Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dish Modifications</td>
<td>Precise modification required for reliable communication</td>
<td>80</td>
</tr>
<tr>
<td>Mounting System &amp; Tripod</td>
<td>Stable antenna base critical to closing link with satellite</td>
<td>15</td>
</tr>
<tr>
<td>Command Motor Controller &amp; Drive Motors</td>
<td>Several steps of software must work together to achieve accurate control</td>
<td>40</td>
</tr>
<tr>
<td>Tracking GUI &amp; Signal GUI Interfacing</td>
<td>Software must work in conjunction with all electronics and user simultaneously</td>
<td>40</td>
</tr>
</tbody>
</table>
Project Schedule
Manufacturing: Mechanical
Critical Manufacturing Area: Mechanical

- User Computer
  - GPS (GlobalSat BU-353-S4)
    - USB
  - Signal Processing Software
  - Tracking Software
  - Motor Control Software
  - LNA (ZX00-P33ULN+)
    - SMA
  - Conditioning and Processing Unit
  - Adalm Pluto SDR
  - SPX-01HR Motor Unit
  - LH-13XL Feed
  - MD-02 Motor Controller
  - Antenna Unit
  - Satellite
    - Legend: Power, Satellite Signal, Pointing Control
    - Not purchased/started, On the way/in progress, Arrived/finished, Outside project scope
  - NUC Computer
    - NUC Power Supply
    - Power Source 120 V AC
    - 3.3 V 10 W AC-DC
    - 12 V 200 W AC-DC
    - 24 V 600 W AC-DC
  - SDR
  - Motor Controller
  - NUC
# Mechanical - Components

<table>
<thead>
<tr>
<th>Manufacture</th>
<th>Purchase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demo Dish</td>
<td>Dish Kits ✓</td>
</tr>
<tr>
<td>Dish Modification</td>
<td>Modification Materials ✓</td>
</tr>
<tr>
<td>LNA Shield</td>
<td>Motor System ✓</td>
</tr>
<tr>
<td>Tripod Feet</td>
<td>Tripod ✓</td>
</tr>
<tr>
<td>Case Modification</td>
<td>Hardware Case</td>
</tr>
<tr>
<td>Motor System Mount</td>
<td>Electronics Case</td>
</tr>
</tbody>
</table>

- Critical Element

![Diagram](image-url)
Mechanical - Demonstration Dish

- Demonstration Dish Purpose
  - To learn basic assembly process for modified version
  - To learn how to make modifications

- Lessons Learned:
  - Large flat surfaces forced into curves are not ideal
    - Smaller sections will be easier: less binding/folding
  - Lots of slop in center hub -- may modify
  - Assembly required 3 people
  - Rivets and mesh are very strong
  - Modified dish will be much easier to assemble

Status: Completed ✓ || Hours: 18 of 18 || Deadline: 2/4/2019
Mechanical - Modified Dish

- Slow shipping of dish kit caused later start time
  - Work on off-days and weekends to offset slow start
- All additional components and tools purchased and prepared
- Challenges:
  - Splitting up outer ring for panels
  - Buckling of the mesh

Status: On Track || Hours: 3 of 83 || Deadline: 2/28/2019
Mechanical - Modified Dish

- Still need to machine aluminum tabs
  - Can be done in stacks in CNC machine
  - Files are prepared
  - Doing test print
- Modification to center hub

Status: On Track  ||  Hours: 3 of 83  ||  Deadline: 2/28/2019
Mechanical - Tripod and Motor System Mount

- Changed selected tripod from CDR to accommodate uneven ground
- Need to create adapter plate to connect tripod to motors
  - Tripod and motor have not arrived
- Current plan:
  - Surveying tripod
  - Create adapter plate

Status: Delayed  ||  Hours: 0 of 15  ||  Deadline: 2/25/2019
# Mechanical - Progress Report

<table>
<thead>
<tr>
<th>Dish Modification</th>
<th>Task</th>
<th>Hours Completed/Total Working Hours</th>
<th>Expected Deadline Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demo Dish</td>
<td>Assemble dish</td>
<td>18/18</td>
<td>Completed</td>
</tr>
<tr>
<td></td>
<td>Cut tabbed aluminum sheets</td>
<td>2/12</td>
<td>2/8/19</td>
</tr>
<tr>
<td></td>
<td>Cut mesh panels</td>
<td>1/4</td>
<td>2/6/19</td>
</tr>
<tr>
<td></td>
<td>Assemble panels</td>
<td>0/20</td>
<td>2/11/19</td>
</tr>
<tr>
<td></td>
<td>Drill connecting holes in ribs</td>
<td>0/12</td>
<td>2/11/19</td>
</tr>
<tr>
<td></td>
<td>Assemble full dish</td>
<td>0/20</td>
<td>2/28/19</td>
</tr>
<tr>
<td></td>
<td>Motor/Tripod interface plate</td>
<td>0/15</td>
<td>2/25/19</td>
</tr>
</tbody>
</table>
Manufacturing: Software
Critical Manufacturing Area: Software
Software - Overview

- Overview:
  - Tracks and displays future passes and current location of specified satellite
  - Control antenna pointing position
  - Receive signal, display, and save bit stream to file

- Inputs:
  - Lat/Lon/Alt from GPS or QTH file
  - TLE text file
  - Signal Frequency & Bandwidth
  - Adalm Pluto Signal

- Outputs:
  - Binary text file of demodulated signal
  - Tracking GUI & Signal Processing GUI
Software - Status

Status: On Track

2/10/2019
Hours: 10/12
Receive Latitude, Longitude, and Elevation from GPS

User Interface/Control through GUI

Track Predicted Azimuth and Elevation over a Pass

Control Motors to Point Dish at Satellite

2/10/2019
Hours: 10/20

Code tested on hardware

2/10/2019
Hours: 40/50
Receive Signal from Satellite using SDR and Display to User

2/17/19
Hours: 2/4
Connect to NUC using Laptop Computer

2/10/2019
Hours: 2/4
Code development

2/20/2019
Hours: 10/12
Code tested on laptop

2/17/19
Hours: 50/50
Not started
Software - Integration

1. Receive Latitude, Longitude, and Elevation from GPS
   - Hours: 4/4

2. User Interface/Control through GUI
   - Hours: 4/4

3. Track Predicted Azimuth and Elevation over a Pass
   - Hours: 0/2
   - 2/20/2019

4. Control Motors to Point Dish at Satellite
   - Hours: 4/4

5. Connect to NUC using Laptop Computer

6. Receive Signal from Satellite using SDR and Display to User

Status: On Track

Integration not started
Integration in progress
Integration complete
Integration unnecessary - separate components
Manufacturing: Electrical
Critical Manufacturing Area: Electrical
Electrical - Components

Manufacturing

- Wiring Assembly
- Radio Frequency Path Design
- Power Supply

Critical Element

Purchased

- Cables ✓
- LNA ✓
- Motor Controller ✓
- NUC ✓
- GPS ✓
- SDR ✓
- Power Converters
- Feeds
<table>
<thead>
<tr>
<th>Electrical Status Report</th>
<th>Task</th>
<th>Hours Completed/Total Man Hours</th>
<th>Expected Deadline Date</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wiring Assembly</strong></td>
<td>Feed to SDR</td>
<td>0/0.5</td>
<td>2/15/19</td>
</tr>
<tr>
<td></td>
<td>NUC Connections</td>
<td>0/0.5</td>
<td>2/15/19</td>
</tr>
<tr>
<td></td>
<td>Motor Connections</td>
<td>0/1</td>
<td>2/30/19</td>
</tr>
<tr>
<td><strong>Radio Frequency Path Design</strong></td>
<td>Component Assembly</td>
<td>0/0.5</td>
<td>2/08/19</td>
</tr>
<tr>
<td></td>
<td>Loss Testing</td>
<td>2/3</td>
<td>2/08/19</td>
</tr>
<tr>
<td></td>
<td>Demo Dish Gain Testing</td>
<td>0/10</td>
<td>2/16/19</td>
</tr>
<tr>
<td></td>
<td>Modified Dish Gain Testing</td>
<td>0/10</td>
<td>3/08/19</td>
</tr>
<tr>
<td><strong>Power Supply</strong></td>
<td>LNA Power Interface</td>
<td>0/2</td>
<td>2/08/19</td>
</tr>
<tr>
<td></td>
<td>Motor Interface</td>
<td>0/3</td>
<td>2/20/19</td>
</tr>
<tr>
<td></td>
<td>NUC interface</td>
<td>1/1</td>
<td>Completed</td>
</tr>
</tbody>
</table>
Electrical - RF Path Design

- Component Loss Testing: 2/3 hours, 2/08/19
- Assembly: 0/0.5 hours, 2/08/19
- Demo Dish Gain Testing: 0/10 hours, 2/16/19
- Modified Dish Gain Testing: 0/10 hours, 3/08/19

- Gain test depends on dish construction (Estimated modified dish completion 2/28/19)
System Integration
System Integration Plan
ARGUS

Mechanical 284 hours
Electronics 189 hours
Software 140 hours
Management 130 hours

Software
140 hours

Compile Software User Guide  Verify Calibration Method and Program  User/GUI Interfacing and Data Transfer over Cat5e  RF Circuit Processing and Final Integration  Satellite Pass Power Verification  Send Serial Comms to Motor Controller

Management
130 hours

Full System Integration Coordination  Compile Full System User Guide  Formatting (MSR, TSR, AIAA, SFR)  Test Protocols Compilation  Component and Interface Documentation
Overall Project Status: **On Track**

Under budget with 38% left
Currently 33% total labor accomplished

Critical Elements:
- Modification of Dish
- System Integration
- Program Demonstration

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Hours Completed/Total Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical</td>
<td>10/189</td>
</tr>
<tr>
<td>Software</td>
<td>100/140</td>
</tr>
<tr>
<td>Mechanical</td>
<td>120/284</td>
</tr>
<tr>
<td>Management</td>
<td>20/130</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>250/743 (≈33%)</strong></td>
</tr>
</tbody>
</table>
Budget
### Cost Plan

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical</td>
<td>$308.26</td>
</tr>
<tr>
<td>Software</td>
<td>$1,099.16</td>
</tr>
<tr>
<td>Mechanical</td>
<td>$3,139.15</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>$127.41</td>
</tr>
</tbody>
</table>

**Money Spent** $4,673.98

**EEF Grant** +$2,500

**Remaining Budget** $2,826.02

**Total** $7,500

\[ \approx 38\% \text{ Margin} \]
**Procurement Status - Remaining Items**

<table>
<thead>
<tr>
<th>Item</th>
<th>Status</th>
<th>Estimated Delivery Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor</td>
<td>Ordered</td>
<td>February 20th</td>
</tr>
<tr>
<td>S-Band Feeds</td>
<td>Ordered</td>
<td>February 20th</td>
</tr>
<tr>
<td>Tripod</td>
<td>Ordered</td>
<td>February 8th</td>
</tr>
<tr>
<td>Travel Cases</td>
<td>Not Ordered</td>
<td>Needed by March 1st</td>
</tr>
<tr>
<td>Motor System Power Converters</td>
<td>Ordered</td>
<td>February 5th</td>
</tr>
<tr>
<td>Sheet Metal</td>
<td>Not Ordered</td>
<td>Needed by March 1st</td>
</tr>
</tbody>
</table>

Uncertainties: Delivery time from the Netherlands
Questions?
Backup Slides
# Software - Progress Report

<table>
<thead>
<tr>
<th>Task</th>
<th>Hours Completed / Total Hours</th>
<th>Expected Deadline Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satellite Tracking</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Predict Az/El over satellite pass</td>
<td>50 / 50</td>
<td>Completed</td>
</tr>
<tr>
<td>Software Interfacing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laptop/NUC Interfacing</td>
<td>2 / 4</td>
<td>2/17/19</td>
</tr>
<tr>
<td>Motor Interfacing</td>
<td>10 / 20</td>
<td>2/20/19</td>
</tr>
<tr>
<td>User Interface</td>
<td>50 / 50</td>
<td>Completed</td>
</tr>
<tr>
<td>Data Reception</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SDR data reception</td>
<td>40 / 50</td>
<td>2/10/19</td>
</tr>
<tr>
<td>GPS data reception</td>
<td>10 / 10</td>
<td>Completed</td>
</tr>
</tbody>
</table>
Task Breakdown Structure

**Mechanical Labor: 39.84%**
- Build Unmodified Dish
  - Jan 29 Labor: 1.05%
- Complete CAD Model for All Integrated Components
  - Feb 15 Labor: 1.97%
- Construct Motor & Tripod Interfacing Plate
  - Feb 22 Labor: 2.62%
- Prog. Motor Operation With Dish Installed
  - Mar 1 Labor: 10.48%
- Modified Dish Completion
  - Mar 11 Labor: 2.62%
- Case Installation Completion
  - Mar 11 Labor: 10.48%
- Full Mechanical Operation Testing Completion
  - April 12 Labor: 13.11%
- Compile Mechanical User Guide
  - April 20 Labor: 5.24%

**Electronics Labor: 24.77%**
- Proof of Concept SDR w/ WiFi
  - Feb 1 Labor: 0.52%
- RF Component Gains & Losses Testing
  - Feb 1 Labor: 1.31%
- SDR to RF System Reception Testing
  - Feb 15 Labor: 2.62%
- Electronic Box Design
  - Feb 22 Labor: 2.62%
- Electronics Thermal Model
  - Feb 23 Labor: 1.97%
- Thermal "Day in the Life" Testing
  - Mar 4 Labor: 2.62%
- Modified Dish Gain vs. Standard Dish Gain
  - Mar 31 Labor: 2.62%
- Final Electronics Integration & Simultaneous Operation
  - April 20 Labor: 10.48%

**Software Labor: 18.35%**
- User/GUI Interfacing and Data Transfer over Cat 5e
  - Feb 17 Labor: 2.62%
- Send Serial Comms to Motor Controller
  - Feb 24 Labor: 1.97%
- Verify Calibration Method and Program
  - Mar 15 Labor: 3.28%
- RF Circuit and Processing Final Integration
  - March 8 Labor: 2.62%
- Satellite Pass Power Verification
  - April 20 Labor: 2.62%
- Compile Software User Guide
  - April 20 Labor: 5.24%

**Management Labor: 17.04%**
- Formatting (MSR, TSR, AIAA, SFR)
  - Labor: 2.62%
- Component and Interface Documentation Labor: 1.31%
- Test Protocols Compilation Labor: 2.62%
- Full System Integration Coordination Labor: 5.24%
- Compile Full System User Guide Labor: 5.24%
ARGUS

Spring Semester

Mechanical
- Assemble Demo Dish
- Convert SolidWorks to SolidCam for...
- MSR
- Finalize Tab Design
- Order Bolts
- Order Tripod
- Order Materials for Motor Adapter Plate
- CNC Mill the tabs
- Drill Holes in Ribs and in Tabs
- Cut Mesh into 12 sections
- Rivet Tabs to Mesh
- Attach Bolts to Ribs
- Test Fit
- TRR
- Assemble Final Design
- Compare Demo and Modified
- Test Final Assembly Time
ARGUS

Spring Semester

Mechanical

Software

MSR
Signal Processing: Demodulation
Signal Processing: BER
Interface NUC w/ User Laptop
Test GPS
Interface ARGUS GUI with Motor Cont...
Test SDR
Test Pointing Accuracy
Test Motor Response to ARGUS GUI
TRR
Test Calibration
ARGUS

Spring Semester

Mechanical

Software

Electrical
- Obtain Motor Controller Power Converter
- MSR
- Test RF Components
- Test Power Converter
- Solder LNA Power Connection
- Device Cable Management Scheme
- Finalize Electronics Box Layout
- Test Motor Functionality
- Create Electronics Box Power Ports
- Create Electronics Box Connections
- Test All Connections
- Test Connection Assembly
- TRR
- Test Full Antenna Gain
Tracking Overview

12 V DC
200 W

Az/El command
Rot2Prog protocol
via USB

24 V DC
600 W

SPX-01/HR

Motor system

Controller: MD-02

Az motor

El motor

Sensor

Sensor
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

**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**
- \( I_1 = 2 \, m, 0.7 \, \frac{dB}{m} \rightarrow L_A = 1.4 \, dB \)
- \( L_2 = L_3 = 0.45 \, dB \)

**Adalm-Pluto SDR**
- \( T_{SDR} = 288.6 \, K \)

\[ L_{tl} = L_1 + L_2 + L_3 \]

\[ T_S = aT_a + (1 - a)T_0 + T_{LNA} + \frac{l_0}{l_{lin}} \]

\[ \Rightarrow T_S = 140K \]

**Requirement:** \( \frac{G}{T_S} = 3 \, dB/K \)

\[ G_{required} = 26.2 \, dBi \]
Estimated Efficiency

\[ \eta = \eta_{\text{feed}} \eta_{\text{bl}} \]

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

<table>
<thead>
<tr>
<th>Gain at 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 gain</td>
<td>26.2 dBi</td>
</tr>
</tbody>
</table>

✔️ 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. |
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

![Graph showing angular rates over time](image)
Worst Case Pointing Error

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

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

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

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

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

\[ \theta_{\text{HP}} = 6.5^\circ \]
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: 0.2°
  - Mass: 17.8 kg

<table>
<thead>
<tr>
<th>DR 2.3</th>
<th>The antenna motor shall be able to move the antenna at a slew rate of 5.0 °/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>DR 2.4</td>
<td>The antenna motor shall have a pointing accuracy greater than 0.72°</td>
</tr>
<tr>
<td>✔</td>
<td></td>
</tr>
</tbody>
</table>
Tracking Overview

Az/El angular command

Controller: Rot2Prog

22 V DC

Motor system

Az motor

El motor

Sensor

Sensor

SPX-01/HR
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

Antenna Pointing:
- Manual Mode
- Program Track

Input Azimuth:

Input Elevation:

Quit Calibrate

ARGUS Tracking GUI

Current Azimuth: 223.63, Current Elevation: 61.07
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°
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.
Az/El Plot Frame
The pointing control accuracy must be within $3.25^\circ$ to maintain downlink capabilities throughout the entire pass.
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 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 $\text{SNR} \geq 10.4 \text{dB}$ to achieve $\text{BER} \approx 10^{-5}$
- Current system $\text{SNR} \approx 17.2 \text{ dB}$
  - $\text{BER} \approx 8.9 \times 10^{-9}$
  - Determined using ASEN 3300 link budget and typical transmit values

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
## 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>5 kg</td>
</tr>
<tr>
<td>Dish + connecting tabs</td>
<td>7 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>5 kg</td>
<td>Case</td>
<td>8.4 kg</td>
</tr>
<tr>
<td>NUC</td>
<td>1.2 kg</td>
<td>AC-DC converters</td>
<td>2.3 kg</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>45.0 kg &lt; 46.3 kg</strong></td>
<td>✔️ Meets Mass Requirement (FR4.0)</td>
<td></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

Equipment Needed | Procurement
---|---
Laptop | Owned
GNURadio | Open Source

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

Data Needed | Compared To | Expected
-------------|-------------|-----------
BER          | Matlab estimation | 8.9E-9
QPSK Signal | Matlab generated signal | Matlab generated signal
Antenna Gain/Beamwidth Test

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

2. Transmit signal with known gain pattern and power output
   - $d > 30 \text{ m}$

3. Measure power received, compute gain
   - $P_R = \frac{P_T G_T G_R \lambda^2}{(4\pi d)^2}$
   - $G_R = \frac{P_R (4\pi d)^2}{P_T G_T \lambda^2}$
   - Waveform Analyzer

4. Rotate dish, monitor power level to verify beamwidth

<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>

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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

<table>
<thead>
<tr>
<th>Equipment Needed</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

<table>
<thead>
<tr>
<th>Data Needed</th>
<th>Resolution</th>
<th>Expected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotation Rate</td>
<td>0.2°/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

1. All ARGUS components packed in carrying case

2. Weigh disassembled system

3. Carry 100m

4. Assemble ARGUS

<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>
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

<table>
<thead>
<tr>
<th>Data Needed</th>
<th>Requirement</th>
<th>Expected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>46.3 kg</td>
<td>45.4 kg</td>
</tr>
<tr>
<td>Assembly Time</td>
<td>60 min</td>
<td>35 min</td>
</tr>
</tbody>
</table>
### Full System Test

**Objective**
- Test ARGUS portability
- Receive signal from satellite

**Location**
Business Field

**FR Verified**
All FR

---

1. Components packed in cases
2. Assemble ARGUS
3. Calibrate with Sun Az/El
4. Engage satellite tracking
5. Demodulate Signal
6. Write Bitstream
Looking Forward

- Critical items to be worked on:
  - Modified Antenna
    - Parabolic Dish
  - Signal Processing
  - Interface ARGUS GUI on Motor Controller

- Tests
  - SDR
  - GPS
  - RF Components
  - Motor Functionality
  - Connections