Test Readiness Review

P4LO

Positioning For Lunar Operations

Team Advisor: Dr. Jade Morton
Agenda

1. Project Overview/Objectives
2. Test Readiness
3. Test Schedule
4. Budget
Project Overview
Background
Lunar CONOPS

- Provide ground-based positioning and communication to the South Pole
- 10 km radius region
P4LO CONOPS

Top down view of field

Pseudolite 1

Handheld Mock up

Pseudolite 2

Pseudolite 3

1. Pseudolite network
2. Reception of pseudolite signal
3. Store signal data in file

Post processing

3. Time and position identified
4. Message Received

Overview → Test Readiness → Schedule → Budget
What is a Pseudolite?

- A portable ground station
  - Transmits positioning messages
  - Receives user communication messages

Pseudolite Hardware Block Diagram
Mission Statement

P4LO (Positioning For Lunar Operations) is a prototype network of software defined radios that demonstrates an architecture for the lunar communication and positioning system LunaNet.
How will positioning work?

- Known pseudolite positions
- Time of arrival (TOA) \( \rightarrow \) **range**
- System of equations with 3 unknowns \((x, y, \text{clock bias})\)
- Least-squares solution to account for noise and measurement error

\[
\begin{align*}
    d_1 &= c(t_1 - t_0) = \sqrt{x^2 + y^2} \\
    d_2 &= c(t_2 - t_0) = \sqrt{(D-x)^2 + y^2} \\
    d_3 &= c(t_3 - t_0) = \frac{1}{2} \sqrt{(D-2x)^2 + (D^2/3 - 2y)^2}
\end{align*}
\]

\(t_i: \text{TOA at reference } i; c: \text{speed of light}\)
Range Determination - Bias Estimation

- Measure synchronization bias at a known location (center)
- **Subtract out bias** on subsequent measurements
- Does not require pseudolite synchronization
- Requires **high-sample rates** and a **stable oscillator** (GPSDO)
Range Determination - Bias Estimation

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Range Determination - Bias Estimation

- **Measure synchronization bias** at a known location (center)
- **Subtract out bias** on subsequent measurements
- Does not require pseudolite synchronization
- Requires **high-sample rates** and a **stable oscillator** (GPSDO)
Mission Success

● Key Functional Requirements
  ○ Scalable Positioning System
    ▪ Sub 10 (m) positioning within specified area
    ▪ 30 ns 1-sigma transfer time
  ○ Communication Network
    ▪ Communication operating between 2.4 - 2.48 GHz
    ▪ 1 MHz Signal Bandwidth
    ▪ Framework allowing for up to 170 users communicating within region
    ▪ Data rate of at least 1 kilobit per second
## Critical Elements

### Signal Generation and Transmission
- LimeSDR - GNU Radio
- Antenna
- GPS Reference Oscillator (Bias Correction)
- Laptop and SSD

### Signal Reception
- LimeSDR - GNU Radio
- Antenna
- GPS Reference Oscillator (Used as stable oscillator)
- Laptop and SSD

### Signal Processing
- Acquisition and tracking
- Data extraction
- Positioning Solution
Test Readiness
Testing Overview

- SDR (Software Defined Radio) Communication
- Coarse Range Measurement
- Refined Range Measurement
- Clock Override
- Synchronization Bias Test
- Positioning Test
- Positioning + Communication Test
Basic SDR Communication Test

- **Purpose:**
  - LimeSDR transmission and reception of a test signal with information

- **Design:**
  - Hardware: LimeSDR, one computer, two antennas
  - Software: GNURadio FM transceiver script, sample audio file

- **Test:**
  - Transmit one FM audio file from SDR transmit port and receive it on the SDR receive port, play results

- **Status:** Done
Coarse Range Measurement (Acquisition)

- **Purpose:**
  - Transmit pure code-division multiple access (CDMA) codes to see if a receiver can determine code phase and therefore determine range.
Coarse Range Measurement (Acquisition)

● Design:
  ○ Hardware: Two LimeSDRs, two laptops, two antennas
  ○ Software: Generated CDMA codes, GNURadio modulation and transmission, GNURadio IF signal reception, IF signal correlators

● Test:
  ○ Level 1 - Lab testing
  ○ Level 2 - Field testing
  ○ Level 3 - Multiple Transmitters

● Status:
  ○ CDMA code file generated, acquisition MATLAB code developed
  ○ Just need to go and actually send and receive files
Refined Range Measurement (Tracking)

● **Purpose:**
  ○ Integrate a **control loop** (tracking) in order to better determine code delay (range) and signal frequency (carrier)
  ○ Allows **data bit decoding**
  ○ **Better range accuracy**

● **Design:**
  ○ Hardware: Two LimeSDRs, two laptops, two antennas
  ○ Software: Matlab tracking loop code (Post signal acquisition and reception)

● **Test:**
  ○ Process received signal with tracking loop and attempt to decode data bits.

● **Status:**
  ○ Matlab tracking loop ready
  ○ Must finish range measurement tests first (acquisition)
Clock Override Test

- **Purpose:**
  - Verify frequency of overridden clock in LimeSDR.
    - Should be at 10 MHz
- **Design:**
  - Hardware: Oscilloscope, GPSDO, LimeSDR
  - Software: GNU Radio
- **Test:**
  - Check oscilloscope FFT and verify peak at 10 MHz
- **Status:**
  - Currently working GPS-DO integration
  - After this is done, oscilloscope testing should only take a day or two.
Synchronization Bias Test

- **Purpose:**
  - Establish pattern of deviation for biases by computing synchronization bias for each pseudolite
  - Peak structure should repeat every 1ms

- **Design:**
  - Hardware: Positioning pseudolite configuration (triangle) + receiver in the middle
  - Software: GNUradio

- **Test:**
  - Compute relative biases and establish pattern of variation for biases.

- **Status:**
  - Still setting up pseudolites
Positioning Test

- **Purpose:**
  - Demonstrate pseudolite system *positioning capability* at testing location
Positioning Test

● Design:
  ○ Hardware: Pseudolites, User system
  ○ Software: Positioning Algorithm

● Test:
  ○ Feed range measurements into positioning algorithm. Determine the position of the user to sub 10m accuracy at testing location

● Status:
  ○ Positioning algorithm ready to go
  ○ Need previous tests to be completed first
  ○ Pseudolites need to be setup
Positioning + Communication Test

- **Purpose:**
  - Demonstrate *positioning and communication* capability
Positioning + Communication Test

- **Design:**
  - Hardware: Pseudolites, User system
  - Software: Positioning Algorithm, Communications Protocol

- **Test:**
  - Determine the position of the user to sub 10m accuracy AND send/decode data bits from receiver to pseudolites.

- **Status:**
  - Need previous tests to be completed first
  - Pseudolites need to be manufactured
Schedule
Schedule

- SDR Transmit/Receive Test
  - Completed: 2/23/21
- Tracking Research
  - Margin
- Tracking Loop Test
  - Margin
  - Completed: 3/8/21
- GPS Integration
  - Margin
  - Completed: 3/10/21
- Clock Override Test
  - Margin
  - Completed:
Budget
Cost Plan & Margin

<table>
<thead>
<tr>
<th>Group</th>
<th>Cost (USD)</th>
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<tbody>
<tr>
<td>Dual TE Connectivity Antennas (4)</td>
<td>$19.80</td>
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<tr>
<td>Lime SDR’s (4)</td>
<td>$1,399.80</td>
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<tr>
<td>Raspberry Pi (4)</td>
<td>$220.00</td>
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<td>Adapters &amp; Connectors (4 Sets)</td>
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<td>5 Feet Tripods (4)</td>
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<td>GPS Disciplined Oscillator (4)</td>
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<tr>
<td>Samsung External SSD 500Gb(4)</td>
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Budget Status

<table>
<thead>
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<th>Cost (USD)</th>
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<tbody>
<tr>
<td>Projected Purchases Total</td>
<td>$3026.12</td>
</tr>
<tr>
<td>Current Up to date Purchase Amount Total</td>
<td>$2862.19</td>
</tr>
<tr>
<td>Available Amount / Percentage</td>
<td>$1973.68 ~ 39.48%</td>
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</tbody>
</table>
## Major Item List & Status

<table>
<thead>
<tr>
<th>Item</th>
<th>Status</th>
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</thead>
<tbody>
<tr>
<td>Dual Band TE Connectivity Antenna (4)</td>
<td>In Possession (4)</td>
</tr>
<tr>
<td>Lime SDR’s (4)</td>
<td>In Possession (4)</td>
</tr>
<tr>
<td>Laptops (4)</td>
<td>In Possession (4) Team Member Laptops</td>
</tr>
<tr>
<td>GPS Disciplined Oscillator (4)</td>
<td>Shipped From China (4) Max ETA (3/1)</td>
</tr>
<tr>
<td>Samsung External SSD 500Gb(4)</td>
<td>In Possession (4)</td>
</tr>
</tbody>
</table>

Obstacles: P-card access, Shipping Logistics & Chinese New Years Celebration
Acknowledgements

- Nicholas Rainville
- Jade Morton
- Dennis Akos
- Trudy Schwartz
- Kathryn Wingate
- John Mah
- Steve Taylor
- Brian Breitsch
Questions?
Backup Slides
References

LimeSuiteGUI - GNU Radio - Gr-LimeSDR Plugin


Overall FBD

Overview

Schedule

Manufacturing

Budget

Key:
- Hardware
- Software
- Signal
- Power
Overall FBD

- **Overview**: Pseudolite
- **Solution**: Master Pseudolite, Pseudolite
- **CPE**: Signal From Pseudolite(s) (2.48 GHz)
- **DR**: Signal To Master Pseudolite (2.4 GHz)
- **Risk & M**: Analog Down Conversion, Receive
- **V&V**: Analog Up Conversion, Transmit
- **Planning**: LimeSDR

Key:
- Hardware
- Software
- Signal
- Power

- **Receive Signal Processing**: Comms Data, Position Solution
- **Transmit Processing**: Message Generation
- **GPS Disciplined Oscillator**: True Position (~1 meter Accuracy)
- **GPS Receiver**: CPU - Raspberry Pi
- **Battery**: 5V @2A
- **Display**
Overall FBD

Key:
- Hardware
- Software
- Signal
- Power

Signal From Pseudolite(s) (2.48 GHz)

Master Pseudolite

Pseudolite

Signal To Master Pseudolite (2.4 GHz)

GPS Receiver

True Position (~1 meter Accuracy)

GPS Disciplined Oscillator

LimeSDR

Analog Down Conversion

Receive

Analog Up Conversion

Transmit

Comms Data

Position Solution

Message Generation

Transmit Processing

Receive Signal Processing

CPU - Raspberry Pi

Battery 5V @2A

Display

Overall FBD Diagram
Overall FBD

Signal From Pseudolite(s) (2.48 GHz) → Analog Down Conversion → Receive → Receive Signal Processing

Signal To Master Pseudolite (2.4 GHz) → Analog Up Conversion → Transmit → LimeSDR

True Position (~1 meter Accuracy) → GPS Disciplined Oscillator → GPS Receiver

Comms Data → Position Solution

Transmit Processing → Message Generation

CPU - Raspberry Pi

Battery 5V @2A

Display
Overall FBD
Scaled Down Testing (Placeholder Title)

- Scale from 2.4 km to 0.18 km dist. between transmitters
- Assume 2D (only x and y, no height)
- Transmitting on Earth is at least as complicated as on the Moon
  - Atmospheric losses
  - RF Interference
  - Man-made structures/materials interfering
- **Not** testing environmental constraints

A scaled-down test in Boulder, CO is still able to validate the design for use on the lunar surface
Design Solution Set Up

Contents of Black Boxes

1. LimeSDR
2. Raspberry Pi
3. Cut out for antenna
4. Septentrio PolaRxS GPS receiver
5. Mlady 10000 mAh portable power pack

- Red: Positioning
- Yellow: Comms to main pseud.
- Blue: Positioning w/in 10 m

180 m
10 m
## Critical Project Elements

<table>
<thead>
<tr>
<th>Critical Project Element</th>
<th>Design Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positioning System</td>
<td>One-Way Pseudolite Ranging</td>
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<tr>
<td>Antenna</td>
<td>Dual Band TE-Connectivity Antenna</td>
</tr>
<tr>
<td>Communication</td>
<td>BPSK Modulation</td>
</tr>
<tr>
<td>Software Defined Radio</td>
<td>LimeSDR</td>
</tr>
<tr>
<td>Clock</td>
<td>Septentrio PolaRxS - GPS Receiver</td>
</tr>
<tr>
<td>CPU</td>
<td>Raspberry Pi</td>
</tr>
</tbody>
</table>
## Software Overview

### GNU Radio
- Reference oscillator integration
- Signal reception and transmission
  - Modulation
  - Multiplexing
  - Up/Down Conversion
  - Acquisition
  - Tracking

### Matlab
- Packet Creation
- Positioning algorithm
- For simulation
  - Modulation
  - Multiplexing
  - Up/Down Conversion
  - Acquisition
  - Tracking

### LimeSDR
- Overwrite clock with reference oscillator
- Integrate antenna

Team Created
Open Source Edited
Outside Leveraged
What is a Pseudolite?

- A portable ground station
  - Transmits positioning messages
  - Receives user communication messages

Pseudolite Hardware Block Diagram
Positioning Test

- **Design:**
  - Hardware: Pseudolites, User system
  - Software: Positioning Algorithm

- **Test:**
  - Feed range measurements into positioning algorithm. Determine the position of the user to sub 10m accuracy at testing location

- **Status:**
  - Positioning algorithm ready to go
  - Need previous tests to be completed first
  - Pseudolites need to be setup
Test Site Images
Manufacturing Slides
Changes since CDR

● **Signal Reception: SSD + Laptops instead of Raspberry Pi**
  ○ Due to computation restrictions, boot Linux off external SSDs connected to laptops for additional speed and memory

● **Signal Transmission: Pseudolites equipped with a reference oscillator**
  ○ GPS disciplined oscillator (GPSDO)
  ○ Parts have been selected and ordered.
Customer Value Proposition

● Develop testing scenario
  ○ Testing out a **scaled down version** of the system
  ○ What it takes to test the system
  ○ What works, what doesn’t

● Develop/Integrate hardware & software
  ○ LimeSDR (Radio)
    ■ Performance metrics
    ■ External clock integration
  ○ GNU Radio v3.8 (Software)
    ■ Performance
    ■ Interfacing with LimeSDR
Manufacturing Overview

**Purchase**
- LimeSDR
- Reference Oscillator
- Antenna
- SSD
- Tripod

**Integrate**
- Pseudolite electronics
  - Antenna
  - GNU Radio
  - Laptop
- Pseudolite clock
  - Override internal clock
- Calibrate system

**Develop / Manufacture**
- GNU Radio script
- Communications Protocol
- Positioning Algorithm
- Pseudolite Housing
Manufacturing Overview

**Purchase**
- LimeSDR
- Reference Oscillator
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**Integrate**
- Pseudolite electronics
  - Antenna
  - GNU Radio
  - Laptop
- **Pseudolite clock**
  - Override internal clock
- **Calibrate system**

**Develop / Manufacture**
- GNU Radio script
- **Communications Protocol**
- Positioning Algorithm
- Pseudolite Housing
Integrate: Pseudolite Electronics

**Task:** Send and receive test signals using pseudolite electronics

- GNU Radio 3.8 (Software)
- Ubuntu Linux booted on a Samsung T7 500 GB External SSD
  - Running GNURadio
  - 1 GBps read/write
- Dual Band TE Connectivity Patch Antennas
- LimeSDR USB 3.0
- ASUS Zenbook (Core i5 @ 3.5 GHz)
- Write samples to file

**Status:** Done
Integrate: Pseudolite Clock

**Task:** Override internal LimeSDR clock in each pseudolite
- **Synchronize** all pseudolites in order to get **accurate** range measurements.
- Provide a more **stable** oscillator for higher quality transmitting and receiving.
- Using a GPS-disciplined oscillator (GPSDO)

**Status:** **Shipping** (ETA: 2/5/21)
Integrate: Calibrate System

**Task:** Measure and calibrate for total system bias (Pseudolite + GPSDO) when transmitting

**Status:** Waiting for overall system integration
Develop: Positioning Algorithm

**Task:** Develop code to process received samples and then compute position.

**Status:**
- Signal processing script *in progress*
- Positioning script *done*
Develop: Communications Protocol

Task: Format communication data into packets
Status: Done
CDR Status Update

- GNU Radio system setup
- Signal detection between two transmitters
- Measured signal interference at testing location
- Preliminary CAD Housing Model Done
- Selected Referenced Oscillator
Hardware
Pseudolite Electronic Configuration

- Electronic/Hardware functional block diagram.
  - DR 2.1.3: The system will operate using the LimeSDR electronics device
- The LimeSDR combined with the GNU Radio software package.
  - FR1: The system must operate under a scalable LPS model
- How is this scalable?
  
  DR 2.1.3: LimeSDR is in use
Mechanical Hardware Integration - CAD

- CAD model of case for holding the limeSDR, GPS, power supply, and Raspberry Pi
- Holes for cable, antenna, and ventilation.
- To do: get a tripod so that the model can be made to attach
SDR - Requirements

- **FR1:** The system must operate under a scalable LPS model
  - DR 2.1.3: The system will operate using the LimeSDR electronics device
- **FR2:** Demonstrate SMS-like communication
  - DR 2.2.1: Device must demonstrate wireless transmission and reception of data
- **FR 4:** System will transmit and receive data between (2.4 - 2.48 GHz)
  - DR 2.4.1: Demonstrate uplink transmission at 2.4-2.48 GHz
  - DR 2.5.1: Demonstrate downlink transmission at 2.4-2.48 GHz
LimeSDR (SDR - “Software Defined Radio”)  

- **LimeSDR (Hardware)**  
  - Customer requirement  
  - Reception and Transmission of signal  
  - Ability to work with modulator/demodulator software packages  
  - Functions at 2.4-2.48 GHz  

- **GNU Radio (Software)**  
  - Suggested by customer  
  - Able to implement all communication schemes and all frequency ranges  
  - Able to do simulation and testing
LimeSDR Output Power

![LimeSDR output power graph](image-url)
Antenna - Requirements

**FR4:** The system will transmit data on the S-Band frequency.

- DR 2.4.1: Demonstrate uplink transmission at a frequency range between 2.4-2.48 GHz

**FR5:** The system will receive data on the S-Band frequency.

- DR 2.5.1: Demonstrate downlink reception at a frequency range between 2.4-2.48 GHz
Dual Band-TE Connectivity Antenna

Dual Band-TE Connectivity

- Peak Gain 2dBi
- Embedded Antenna Style
- Freq Range: 2.4-3.8GHz
- Low Weight (<3.3gram)
- Low Cost (5 USD)
- Voltage Standing Wave Ratio (VSWR) - MAX 3:1
Antenna - Selection Analysis

Customer Requirement: S-Band (due to radio silent far side of the moon)

<table>
<thead>
<tr>
<th>Frequency Range</th>
<th>PROS</th>
<th>CONS</th>
</tr>
</thead>
</table>
| S- Band: (2-4 GHz) | ● Previous communication satellites (NASA)  
● Unlicensed bandwidth (2.4-2.483 GHz) good for testing  
● Low Cost system | ● Large amount of interference (Many devices at this bandwidth)  
● Mainly used for large antennas (transmission) |
Antenna - Evidence of Feasibility

DR 2.4.1, 2.5.1
FEASIBLE
Antenna - Evidence of Feasibility

![Diagram showing Azimuth and Elevation plots for different frequencies (2460 MHz, 3600 MHz, 5350 MHz)]

Legend:
- 2460 MHz
- 3600 MHz
- 5350 MHz

- 0 dB
- 5 dB

Test Orientation in Free Space

- Azimuth plane
- Elevation plane
Antenna Design Requirements

**FR4**: The system will transmit data on the S-Band frequency.
- DR 2.4.1: Demonstrate uplink transmission at a frequency range between 2.4-2.48 GHz

**FR5**: The system will receive data on the S-Band frequency.
- DR 2.5.1: Demonstrate downlink reception at a frequency range between 2.4-2.48 GHz
Antenna

Externally Mounted Antenna

Pros: Antenna is not supported by handheld device
Cons: External cable, cannot move antenna

(10-30m) Connecting Cable

at device selected

INTERNALLY EMBEDDED ANTENNA
VSWR Equations

\[ VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|} = \frac{V_{\text{max}}}{V_{\text{min}}} \]

|\Gamma| = \text{Absolute Reflection Coefficient}
## Table 1. Antenna Options with performance characteristics

<table>
<thead>
<tr>
<th>Antenna Model</th>
<th>Antenna Type</th>
<th>Antenna Design Configuration</th>
<th>Gain (dBI)</th>
<th>Bandwidth (GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TE Connectivity Antenna</td>
<td>Omnidirectional-DualBand</td>
<td>Embedded</td>
<td>2</td>
<td>2.4-3.8 GHz, 5.150-5.870 GHz</td>
</tr>
<tr>
<td>Laird-MAF94051</td>
<td>External Dual-Band Omnidirectional</td>
<td>Attached</td>
<td>2</td>
<td>2.4-2.5</td>
</tr>
<tr>
<td>Laird OC24006H</td>
<td>Omnidirectional/horizontally polarized</td>
<td>External</td>
<td>6</td>
<td>2.4-2.5</td>
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<tr>
<td>Argain-N2420M</td>
<td>Single Band embedded</td>
<td>Embedded</td>
<td>2.81</td>
<td>2.4-2.49</td>
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</table>
# Antenna Tradestudy BU-Slides (Table 2)

<table>
<thead>
<tr>
<th>Antenna Model</th>
<th>Weight (grams)</th>
<th>Unit-Cost (USD Currency)</th>
<th>Connector Type</th>
<th>Effective Area (Ae) or Effective Antenna Aperture (m^2)</th>
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</thead>
<tbody>
<tr>
<td>TE Connectivity</td>
<td>3.3</td>
<td>4.79</td>
<td>Cable-Side Entry</td>
<td>0.001828</td>
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<tr>
<td>Laird-MAF94051</td>
<td>113.4</td>
<td>7.64</td>
<td>RP SMA Connector with 90 degree elbow</td>
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<tr>
<td>Laird OC24006H</td>
<td>260</td>
<td>50.20</td>
<td>N-Female</td>
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<td>Argain-N2420M</td>
<td>0.5</td>
<td>1.80</td>
<td>IPEX/MHF/UFL</td>
<td>0.002186</td>
</tr>
</tbody>
</table>
Antenna Tradestudy BU (Effective Area Equations)

Eq#1 is assuming Linear Gain and Eq#2 Assuming dB Gain

\[ A_e = \frac{\lambda^2}{4\pi} G = \frac{c^2}{f^2} \times \frac{G}{4\pi} \]

\[ A_e = \frac{c^2}{f^2} \times \frac{10^{G (dB)/10}}{4\pi} \]
<table>
<thead>
<tr>
<th>Metric</th>
<th>High Score (3)</th>
<th>Medium Score(2)</th>
<th>Low Score(1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost Effectiveness</td>
<td>low cost for a high performance and capabilities (price&lt;5)</td>
<td>The antenna has an average cost for its capabilities(5-30)</td>
<td>The antenna has a high cost for its capabilities (Over 30)</td>
</tr>
<tr>
<td>Weight</td>
<td>The antenna is very light (Under 50 grams)</td>
<td>The antenna has a medium weight (from 50-200grams)</td>
<td>The antennas has a high weight value (over 200 grams)</td>
</tr>
<tr>
<td>Compatibility</td>
<td>The antenna can easily connect to the SDR, The user has no issues when using the antenna</td>
<td>The antenna is compatible with the sdr without any extra hardware but needs intervention for it to start working</td>
<td>The antenna is not compatible with the sdr without any extra hardware and needs intervention for it to start functioning</td>
</tr>
<tr>
<td>Performance/Specs</td>
<td>Omnidirectional, Operates in designated frequency, high bandwidth, good materials, Large Effective Area,etc.</td>
<td>The antenna has all the required specs but does not have good materials or other hardware constraints</td>
<td>The antenna doesn't satisfy all the needed requirements</td>
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</table>
### Antenna Trade Study BU-Slides (Table 4)

<table>
<thead>
<tr>
<th>Metric</th>
<th>Weighting</th>
<th>Antenna #1</th>
<th>Antenna #2</th>
<th>Antenna #3</th>
<th>Antenna #4</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>TE</td>
<td>Laird-1</td>
<td>Laird-2</td>
<td>Argain</td>
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<tr>
<td>Cost</td>
<td>0.15</td>
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<td>1</td>
<td>3</td>
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<td>Weight</td>
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<td>1</td>
<td>3</td>
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<tr>
<td>Compatibility</td>
<td>0.15</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>3</td>
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<tr>
<td>Performance/Specs</td>
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<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Total Score</td>
<td>100%</td>
<td>100%</td>
<td>80%</td>
<td>65%</td>
<td>90%</td>
</tr>
</tbody>
</table>
## Power Budget

<table>
<thead>
<tr>
<th>Component</th>
<th>Max Operating Power (Transmit)</th>
<th>Max Operating Power (Receive)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LimeSDR</td>
<td>4.5W (More like 2mW)</td>
<td>NA</td>
</tr>
<tr>
<td>Antenna</td>
<td>NA</td>
<td>3.0W</td>
</tr>
<tr>
<td>Raspberry Pi</td>
<td>NA</td>
<td>3.5W</td>
</tr>
<tr>
<td>Total</td>
<td>4.5W</td>
<td>6.5W</td>
</tr>
</tbody>
</table>

or approx 2mW

Battery Pack: Miady
- 5V 2A spread evenly from two outputs
Power Pack (Selected Battery)

Miady 10000mAh Dual USB Portable Charger
Scaling and Power

● Scaling
  ○ In the real-life application of this project we will use 2.4km side-lengths for the pseudolite geometry
    ■ Calculated using the horizon of the Moon.
    ■ Would also need to take into account any terrain on the Moon.
  ○ Scaled down geometry was created for practical reasons.

● Power
  ○ Current testing power is 2 mW which is more than enough (even for a pseudolite configuration with 2.4km side-lengths)
  ○ As part of our testing we will vary transmit power and plot ranging accuracy vs. SNR in order to determine the optimal transmit power.
Pseudolite Clocks

**FR3**: All clocks must be within **30 ns** of each other for the duration of a test (2 hr)

- **On-board Clock (TCXO)**: Drifts on average 0.05ns every second
- **Pseudolite Clocks**: **GPS Disciplined**
  - Using clock bias to keep pseudolite clock synced
  - Reduces jitter
  - Septentrio PolaRxS
- **Expected Accuracy**: **0.5 ns**
Navigation
Positioning System Requirements

**FR3:** The system will be able to provide an architecture for a navigation solution with a 10 meter position accuracy and a 30 nanosecond 1-σ transfer time

- **DR 2.3.2:** Provide LPS coverage to the Moon’s South Pole

**Solution:** Pseudolite geometry composed of a 0.18km equilateral triangle + GPS-disciplined clocks
One way ranging

- Requires accurate clocks on both ends to determine the distance based on time differences.
- Lots of research/documentation available supporting the algorithms and systems.
- Only satellite transmits.
- The energy and time required is low due to only one transmission of data.
Two way ranging

- Requires clocks on both ends but does need them to be synced up with each other.
- Receiver must transmit data BACK to the transmitter - multiple times.
- **Both the satellite and the receiver know the location of the satellite.**
- The energy and processing requirements are high due to the fast data transmission requirements.
One way vs Two way ranging

<table>
<thead>
<tr>
<th></th>
<th>One way</th>
<th>Two way</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power required</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Position information</td>
<td>Only receiver</td>
<td>Both receive info</td>
</tr>
<tr>
<td>Clock synchronization</td>
<td>Required</td>
<td>Not required</td>
</tr>
</tbody>
</table>
Positioning Algorithm: Least-Squares Solution

- Reason for using least-squares method
- Position Guess and corrections

\[
\begin{bmatrix}
\frac{x^{(1)} - x_0}{R_0^{(1)}} & \frac{y^{(1)} - y_0}{R_0^{(1)}} & \frac{z^{(1)} - z_0}{R_0^{(1)}} \\
\frac{x^{(2)} - x_0}{R_0^{(2)}} & \frac{y^{(2)} - y_0}{R_0^{(2)}} & \frac{z^{(2)} - z_0}{R_0^{(2)}} \\
\frac{x^{(3)} - x_0}{R_0^{(3)}} & \frac{y^{(3)} - y_0}{R_0^{(3)}} & \frac{z^{(3)} - z_0}{R_0^{(3)}} \\
\vdots & \vdots & \vdots \\
\frac{x^{(m)} - x_0}{R_0^{(m)}} & \frac{y^{(m)} - y_0}{R_0^{(m)}} & \frac{z^{(m)} - z_0}{R_0^{(m)}}
\end{bmatrix}
\]

\[
\begin{bmatrix}
\delta \hat{x} \\
\delta \hat{b}
\end{bmatrix} = \left( G^T G \right)^{-1} G^T \delta \rho
\]

\[
\delta \rho = G \begin{bmatrix}
\delta x \\
\delta b
\end{bmatrix}
\]
Positioning System - HDOP

**Horizontal Dilution Of Precision**

Definition: “Used to specify error propagation as a mathematical effect of navigation pseudolite geometry on positional measurement precision”.

\[
\text{RMS horizontal error} = \sqrt{\sigma_x^2 + \sigma_y^2} = \sigma \cdot \text{HDOP}
\]

\[
\text{RMS vertical error} = \sigma_u = \sigma \cdot \text{VDOP}
\]

\[
\text{RMS 3-D error} = \sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_z^2} = \sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_z^2} = \sigma \cdot \text{PDOP}
\]
Positioning System - HDOP

The DOPs provide a simple characterization of the user-satellite geometry. The more favorable the geometry, the lower the DOP. The lower the DOP and $\sigma$, the better the quality of the position estimate, in general. If a receiver is limited in the number of satellites it can track simultaneously, the user pays a price with larger rms position error due to higher DOP values.

\[
\text{RMS horizontal error} = \sqrt{\sigma_E^2 + \sigma_N^2} = \sigma \cdot \text{HDOP}
\]

(6.27a)

\[
\text{RMS vertical error} = \sigma_U = \sigma \cdot \text{VDOP}
\]

(6.27b)

\[
\text{RMS 3-D error} = \sqrt{\sigma_E^2 + \sigma_N^2 + \sigma_U^2} = \sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_z^2} = \sigma \cdot \text{PDOP}
\]

(6.27c)
Pseudolite Geometry

Side length: 0.18 km
Avg. HDOP = 1.3
STD = 0.18
Polygon Coverage: 0.013/0.014 km² (89%)

HDOP Distribution

[Graph showing HDOP distribution with bars and a color scale indicating HDOP values]
Near-Far Problem

- Side length: 0.18 km
  - Avg. HDOP = 1.3
  - STD = 0.18
- Polygon Coverage: 0.013/0.014 km² (89%)
Positioning System - Evidence of Feasibility

DR 2.3.3

FEASIBLE
Time of Arrival (TOA)

\[
\begin{align*}
    d_1 &= c(t_1 - t_0) = \sqrt{x^2 + y^2} \\
    d_2 &= c(t_2 - t_0) = \sqrt{(D - x)^2 + y^2} \\
    d_3 &= c(t_3 - t_0) = \frac{1}{2}\sqrt{(D - 2x)^2 + (D\sqrt{3} - 2y)^2}
\end{align*}
\]

\( t_i \): TOA at reference \( i \); \( c \): speed of light
Time of Arrival (TOA)

\[ d_i = c(t_i - t_0), \]

\[ d_1^2 = x^2 + y^2, \]
\[ d_2^2 = (x_2 - x)^2 + (y_2 - y)^2 = (D - x)^2 + y^2, \]
\[ d_3^2 = (x_3 - x)^2 + (y_3 - y)^2 = \frac{1}{2} (D - 2x)^2 + (D\sqrt{3} - 2y)^2. \]
Time of Arrival (TOA)

\[ R_i^2 = (X - x_i)^2 + (Y - y_i)^2 + (Z - z_i)^2, \quad i = 1, 2, 3. \]
Angle of Arrival (AOA)

\[ x = d_i \cos(\phi_i) + x_i, \]
\[ y = d_i \sin(\phi_i) + y_i, \quad i = 1, 2, 3. \]
Time Difference of Arrival (TDOA)
Time Difference of Arrival (TDOA)

\[ d_{ij} = d_i - d_j = c(t_i - t_o) - c(t_j - t_o) = c(t_i - t_j), \quad i = 1, 2, 3, \quad j = 1, 2, 3, \quad i \neq j. \]

\[ d_i = d_{ij} + d_j; \]

\[ d_1^2 = x^2 + y^2. \]

\[ d_2^2 = (d_{21} + d_1)^2 = (x_2 - x)^2 + (y_2 - y)^2 = x_2^2 - 2x_2x + x^2 + y_2^2 - 2y_2y + y^2 = x_2^2 - 2x_2x + y_2^2 - 2y_2y + d_1^2, \]

\[ (d_{21}^2 - x_2^2 - y_2^2) + 2d_{21}d_1 = -2x_2x - 2y_2y, \]

\[ (d_{31}^2 - x_3^2 - y_3^2) + 2d_{31}d_1 = -2x_3x - 2y_3y. \]
Lunar Pseudolite Geometry
Positioning Solution

Tentative Trade/Analysis Aspects

- Will we need accurate clocks
- How complicated the positioning algorithm will be / is it feasible for us to implement
- Antenna requirements
- Near Far problem
-
P4LO’s Bootleg Positioning System
GNSS: Error sources

- Error sources can be divided into two categories:
  - Ranging error: signal quality, errors in transmitter location, environmental effects, receiver design, etc....
  - Geometry: Geometric Dilution of Precision (GDOP). Measures the quality of the geometric distribution of the satellites visible to the receiver.

GNSS: Architecture

- **3 segments:**
  - **Ground control segment**
    - Provides satellites with ephemeris data and almanac
    - Provides clock-correction factors and data on atmospheric effects
    - Keeps satellites “in check”
  - **Space segment**
    - Satellites which send out coded ranging signals, ephemerides, correction parameters and almanac.
  - **User segment**
    - Receiver (which in the case of this project, can also transmit SMS messages)
    - Acquires and track satellite signals.
    - Computes position solution.
    - For this project, THIS is the segment we’ll be working with. All other segments will be assumed as working.
Communications - Requirements

FR 2: The prototype will provide two-way SMS-like messaging
  ● DR 2.1: Device must have wireless transmission and reception of data
  ● DR 2.2: Communication data rate must be at least 200 bits/s
FR 3: The prototype will provide path to navigation solution with 10 meter positioning accuracy and 30 nanosecond 1-sigma transfer time
  ● DR 3.1: Receiver Signal to Noise Ratio must be at least 20 dB
FR 4/5: The communication link must operate at 2.4-2.48 GHz
FR 6: The architecture must be extendable to 170 simultaneous users
FR 7: The communication link must have 3 dB channel bandwidth of 1 MHz
Receive FBD
Transmit FBD

Data

Data Rate: 1 Kbps

Modulator

Chipping Rate: 1.023 Mbps

PRN Spreading Code

CPU - Raspberry Pi

DAC

Analog Up Conversion

Power Amplifier

LimeSDR

GPS Disciplined Oscillator

GPS Receiver

Antenna Transmits

Signal Transmitted to Pseudolite 2.4 GHz

Key:

Hardware

Software

Signal
Link Design: Modulation

- **Design Choice:** Binary Phase Shift Keying (BPSK)
- **Reasoning:**
  - Low bit error rate (BER)
  - Low complexity
  - Able to use carrier phase to get even more precise signal time of arrival
  - Currently used in GPS implementations
Link Design: Multiplexing

- **Design:** Code Division Multiple Access
- **Reasoning:**
  - Able to use phase of spreading code to calculate time of arrival (TOA)
  - Single Frequency
  - Asynchronous CDMA
  - Low cross-interference
- **Specification (Design Solution):**
  - 1023 bit Gold Code PRN chipping code
  - 1.023 MHz chipping rate
  - 1 ms code period (same as data rate)
Communications - Link Budget

Link Budget (Single User):
- Data Rate: **1 kbps**
- Frequency: **2.4 GHz**
- Modulation: **BPSK**
- Distance: **10 km**
- Transmit Power: **2 mW**
- Minimum Receive SNR: **-12 dB**
  - BER: **$10^{-8}$**, **$E_b/N_0$: 12 dB**
- Link Margin: **9 dB**

DR 2.1, 2.2, FR4, FR 5

FEASIBLE
Minimum Ranging SNR

- FR 3: System will provide path to a position to 10 m accuracy (30 ns transfer time)
  - DR 3.1: Received SNR (Signal-to-Noise Ratio) must be at least 20 dB from following formula

$$\delta R = \frac{c_0}{2B\sqrt{2SNR}}$$

- FR 7: Link must operate at 1 MHz bandwidth
- Link Budget operates on a 48 dB-Hz minimum C/N₀

DR 3.1, FR7
FEASIBLE
Modulation: Phase Shift Keying

- Modulation Scheme must be compatible with SDR
  - Compatible with LimeSDR
  - Compatible with GNU Radio
- Low Bit Error Rate
- Single Frequency
- Use carrier phase for additional position accuracy
- GPS uses Phase Shift Keying

DR 2.1, 2.2, 3.1, FR4, 5, 7
SDR Compatibility

FEASIBLE
Multiplexing: CDMA

- CDMA used in GPS
- CDMA code rate relates to first level of position accuracy
- CDMA can operate on single frequency
- Receiver can receive multiple signals simultaneously
- CDMA with 1023 bit chip code:
  - One way ranging: more end users overall, more precise timing requirements
  - Two way ranging: each user contributes to multiple access interference

![CDMA Diagram]

**Project Overview**

**Baseline Design**

**Feasibility**

**Summary**

- Feasible
  - DR 2.1, 3.1, FR 4, 5, 7
- More Analysis
  - One Way Ranging: FR 6
  - Two Way Ranging: FR 6

- DR 2.1, 3.1, FR 4, 5, 7
- More Analysis
Signal Generation

D(t) data

PRN(t) spreading sequence

PN Code Generator

BPSK Modulator

Sin(2\pi f_c t)

f_{ch} = PN sequence chipping rate
f_c = RF carrier/center frequency

Courtesy Logan Scott
Downlink Packet Breakdown

- **Preamble**
  - Unique 24 bit code sequence to allow for signal correlation

- **Navigation Message**
  - Element of set bit length providing timing for positioning algorithm

- **User ID**
  - 8 bit element containing a unique user identification sequence for each user to identify intended recipient
  - Designed to accommodate 30 user requirement

- **Communications Message**
  - 5000 bit text communication element broken into 8 bit characters
  - Message will be appended with ‘ ‘ (space) buffers to maintain constant size
Uplink Breakdown

● Preamble
  ○ Unique 24 bit code sequence to allow for signal correlation

● User Identification
  ○ 8 bit element containing a unique user identification sequence for each user to identify transmitting user
  ○ Designed to accommodate 30 user requirement

● Communications Message
  ○ 5000 bit text communication element broken into 8 bit characters
  ○ Message will be appended with ‘ ‘(space) buffers to maintain constant size
Bit Error Rates of Modulation Schemes

Bharati et. al.

Carey et. al.
### Pseudolite Link Budget 1

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>UPLINK (Receiver to Satellite)</th>
<th>DOWLINK (Satellite to Receiver)</th>
<th>UNITS</th>
<th>Symbol</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed of Light</td>
<td>3.085×10^8</td>
<td>3.085×10^8</td>
<td>m/s</td>
<td>C</td>
<td>constant</td>
</tr>
<tr>
<td>Frequency</td>
<td>2.4</td>
<td>2.4</td>
<td>GHz</td>
<td>f</td>
<td>Impact system choice, X-band/11.25GHz set</td>
</tr>
<tr>
<td>Wavelength</td>
<td>0.125</td>
<td>0.125</td>
<td>m</td>
<td>l</td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>10</td>
<td>10</td>
<td>km</td>
<td>R</td>
<td>Impact Geostationary Satellite (km)</td>
</tr>
<tr>
<td>Boltzmann’s Constant</td>
<td>1.3806×10^-23</td>
<td>1.3806×10^-23</td>
<td>W/(K-H)</td>
<td>k</td>
<td>constant</td>
</tr>
</tbody>
</table>

#### Data Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Uplink</th>
<th>Downlink</th>
<th>Units</th>
<th>Symbol</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bit Error Rate / Probability of Bit Error</td>
<td>10^-8</td>
<td>10^-8</td>
<td>[b]</td>
<td>BE</td>
<td>Design requirement</td>
</tr>
<tr>
<td>Data Coding Scheme</td>
<td>QPSK</td>
<td>QPSK</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Required Bit Energy to Noise Ratio</td>
<td>12</td>
<td>12</td>
<td>dB</td>
<td>Eb/No</td>
<td>Impact chosen modulation (SMAD Tab. 13-10)</td>
</tr>
<tr>
<td>Data Rate</td>
<td>1000</td>
<td>1000</td>
<td>bps (Hz)</td>
<td>R</td>
<td>Impact based on mission / objective</td>
</tr>
<tr>
<td>Carrier to Noise Ratio Density</td>
<td>42.00</td>
<td>42.00</td>
<td>dB-Hz</td>
<td>C/N</td>
<td>PN/No</td>
</tr>
<tr>
<td>Required Design Margin</td>
<td>0.00</td>
<td>0.00</td>
<td>dB</td>
<td></td>
<td>Design rule (Hofmann chart, 9.4.4)</td>
</tr>
<tr>
<td>Minimum PN/No</td>
<td>40.00</td>
<td>40.00</td>
<td>dB-Hz</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Noise (applies to receiving elements)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Uplink</th>
<th>Downlink</th>
<th>Units</th>
<th>Symbol</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Receiving Antenna Noise Temperature</td>
<td>400</td>
<td>400</td>
<td>K</td>
<td>T</td>
<td>Lecture Pt. 2, Slide 13</td>
</tr>
<tr>
<td>Receiver Cable Loss</td>
<td>0.9</td>
<td>0.9</td>
<td>dB</td>
<td>L</td>
<td>Smad Table 13-10</td>
</tr>
<tr>
<td>Receiver Noise Figure (based on receiver)</td>
<td>3.0</td>
<td>3.0</td>
<td>dB</td>
<td>NF</td>
<td>Smad Table 15-10</td>
</tr>
<tr>
<td>Receiver Noise Factor</td>
<td>2.9</td>
<td>2.9</td>
<td>[1]</td>
<td>F</td>
<td>Lecture Pt. 2, Slide 10</td>
</tr>
<tr>
<td>Receiver Noise Temperature</td>
<td>288.6</td>
<td>288.6</td>
<td>K</td>
<td>Tr</td>
<td>Lecture Pt. 2, Slide 10</td>
</tr>
<tr>
<td>Temperature</td>
<td>290</td>
<td>290</td>
<td>K</td>
<td>T</td>
<td>Smad Eqn 13-24</td>
</tr>
<tr>
<td>Receiver System Noise Temperature</td>
<td>580.32</td>
<td>580.32</td>
<td>K</td>
<td>T</td>
<td>Lecture Pt. 2, Slide 13</td>
</tr>
<tr>
<td>Receiver System Noise Power</td>
<td>-290.36</td>
<td>-290.36</td>
<td>dBW-Hz</td>
<td>L</td>
<td>Lecture Pt. 2, Slide 9</td>
</tr>
</tbody>
</table>

#### Receiver Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Uplink</th>
<th>Downlink</th>
<th>Units</th>
<th>Symbol</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Receive Antenna Diameter</td>
<td>NA</td>
<td>NA</td>
<td>m</td>
<td>D</td>
<td>Impact given geometry from spacecraft</td>
</tr>
<tr>
<td>Receive Antenna Area</td>
<td>NA</td>
<td>NA</td>
<td>m^2</td>
<td>A</td>
<td>Geometry</td>
</tr>
<tr>
<td>Receive Antenna Efficiency</td>
<td>NA</td>
<td>NA</td>
<td>[f]</td>
<td>h</td>
<td>Impact typical value</td>
</tr>
<tr>
<td>Receive Antenna Effective Area</td>
<td>NA</td>
<td>NA</td>
<td>m^2</td>
<td>Ae</td>
<td>Efficiency * area</td>
</tr>
<tr>
<td>Receive Antenna Gain</td>
<td>2.00</td>
<td>2.00</td>
<td>[over Gain]</td>
<td>G</td>
<td>Lecture Pt. 1, Slide 14</td>
</tr>
<tr>
<td>Receive Antenna Steamworth</td>
<td>100.0</td>
<td>100.0</td>
<td>Degrees</td>
<td>gr</td>
<td>Lecture Pt. 1, Slide 10</td>
</tr>
<tr>
<td>Receive Antenna Pointing Accuracy</td>
<td>0.00</td>
<td>0.00</td>
<td>[degrees]</td>
<td>er</td>
<td>Impact pointing error for chosen system</td>
</tr>
<tr>
<td>Receive Antenna Pointing Loss</td>
<td>0.00</td>
<td>0.00</td>
<td>dB</td>
<td>L</td>
<td>Smad 13-21</td>
</tr>
<tr>
<td>Receiver Cable Loss (see notes)</td>
<td>-0.5</td>
<td>-0.5</td>
<td>dB</td>
<td>L</td>
<td>Impact typical value</td>
</tr>
<tr>
<td>Receiver Figure of Merit</td>
<td>0.00</td>
<td>0.00</td>
<td>dB</td>
<td>F</td>
<td>FOM</td>
</tr>
</tbody>
</table>

#### Propagation Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Uplink</th>
<th>Downlink</th>
<th>Units</th>
<th>Symbol</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space Loss</td>
<td>-120.05</td>
<td>-120.05</td>
<td>dB</td>
<td>L</td>
<td>Lecture Pt. 2, Slide 3</td>
</tr>
<tr>
<td>Atmospheric Attenuation (clear air)</td>
<td>0</td>
<td>0</td>
<td>dB</td>
<td>L</td>
<td>Lecture Pt. 2, Slide 7</td>
</tr>
<tr>
<td>Polarization Loss</td>
<td>0</td>
<td>0</td>
<td>dB</td>
<td>L</td>
<td>Impact typical value</td>
</tr>
</tbody>
</table>
# Satellite Link Budget 1

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>UPLINK</th>
<th>DOWNLINK</th>
<th>UNITS</th>
<th>SYMBOL</th>
<th>REFERENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed of Light</td>
<td>3.0E+08</td>
<td>3.0E+08</td>
<td>m/s</td>
<td>C=1+f</td>
<td>constant</td>
</tr>
<tr>
<td>Frequency</td>
<td>2.5</td>
<td>2.5</td>
<td>GHz</td>
<td>f</td>
<td>Input: system choice, X-band mil.com sat.</td>
</tr>
<tr>
<td>Wavelength</td>
<td>0.120</td>
<td>0.120</td>
<td>m</td>
<td>l</td>
<td>Input:</td>
</tr>
<tr>
<td>Range</td>
<td>10000</td>
<td>10000</td>
<td>km</td>
<td>R</td>
<td>Input: Geostationary/Satellite [km]</td>
</tr>
<tr>
<td>Boltzmann's Constant</td>
<td>1.3806E-23</td>
<td>1.3806E-23</td>
<td>[W/K-m]</td>
<td>k</td>
<td>constant</td>
</tr>
</tbody>
</table>

## Data Parameters

<table>
<thead>
<tr>
<th></th>
<th>Upstream</th>
<th>Downstream</th>
<th>SYMBOL</th>
<th>REFERENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bit Error Rate / Probability of Bit Error</td>
<td>10-6</td>
<td>10-6</td>
<td>[1]</td>
<td>BER Input: design requirement</td>
</tr>
<tr>
<td>Data Coding Scheme</td>
<td>QPSK</td>
<td>QPSK</td>
<td></td>
<td>Input: chosen modulation (SMAD Tab. 13-10)</td>
</tr>
<tr>
<td>Required Bit Energy to Noise Ratio</td>
<td>11</td>
<td>12</td>
<td>dB</td>
<td>Eb/No</td>
</tr>
<tr>
<td>Data Rate</td>
<td>1000</td>
<td>1000</td>
<td>bps/Hz</td>
<td>R</td>
</tr>
<tr>
<td>Carrier to Noise Ratio Density</td>
<td>41.00</td>
<td>42.00</td>
<td>dB</td>
<td>Pr/No</td>
</tr>
<tr>
<td>Required Signal Margin</td>
<td>3.00</td>
<td>6.00</td>
<td>dB</td>
<td>Ls</td>
</tr>
<tr>
<td>Minimum Pr/No</td>
<td>44.00</td>
<td>48.00</td>
<td>dB</td>
<td>Pr/No</td>
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</table>

## Noise (applies to receiving elements)

<table>
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<th>Downstream</th>
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<th>REFERENCE</th>
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<tbody>
<tr>
<td>Receiver Antenna Noise Temperature</td>
<td>400</td>
<td>25</td>
<td>K</td>
<td>Ta</td>
</tr>
<tr>
<td>Receiver Cable Loss</td>
<td>0.9</td>
<td>0.9</td>
<td>dB</td>
<td>Lc</td>
</tr>
<tr>
<td>Receiver Noise Figure (based on receiver)</td>
<td>2.0</td>
<td>1.0</td>
<td>dB</td>
<td>NF</td>
</tr>
<tr>
<td>Receiver Noise Factor</td>
<td>2.0</td>
<td>1.3</td>
<td>Ls</td>
<td>F</td>
</tr>
<tr>
<td>Receiver Noise Temperature</td>
<td>288.5</td>
<td>75.1</td>
<td>K</td>
<td>Tr</td>
</tr>
<tr>
<td>Reference Temperature</td>
<td>290</td>
<td>290</td>
<td>K</td>
<td>To</td>
</tr>
<tr>
<td>Receiver System Noise Temperature</td>
<td>599.32</td>
<td>31.75</td>
<td>K</td>
<td>Ta</td>
</tr>
<tr>
<td>Receiver System Noise Power</td>
<td>-209.96</td>
<td>-219.58</td>
<td>dBm/Hz</td>
<td>No</td>
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</table>

## Receiver Parameters

<table>
<thead>
<tr>
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<th>Upstream</th>
<th>Downstream</th>
<th>SYMBOL</th>
<th>REFERENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Receive Antenna Diameter</td>
<td>NA</td>
<td>NA</td>
<td>m</td>
<td>D</td>
</tr>
<tr>
<td>Receive Antenna Area</td>
<td>NA</td>
<td>NA</td>
<td>m²</td>
<td>A</td>
</tr>
<tr>
<td>Receive Antenna Efficiency</td>
<td>NA</td>
<td>NA</td>
<td>h</td>
<td>h</td>
</tr>
<tr>
<td>Receive Antenna Effective Area</td>
<td>NA</td>
<td>0.002</td>
<td>m²</td>
<td>Ae</td>
</tr>
<tr>
<td>Receive Antenna Gain</td>
<td>29.00</td>
<td>2.38</td>
<td>[watts</td>
<td>Gr</td>
</tr>
<tr>
<td>Receive Antenna Emissivity</td>
<td>25.0</td>
<td>190.0</td>
<td>[degrees</td>
<td>G</td>
</tr>
<tr>
<td>Receive Antenna Pointing Accuracy</td>
<td>0.2</td>
<td>0</td>
<td>degrees</td>
<td>r</td>
</tr>
<tr>
<td>Receive Antenna Pointing Loss</td>
<td>0.00</td>
<td>0.03</td>
<td>dB</td>
<td>Lpr</td>
</tr>
<tr>
<td>Receive Cable Loss (no noise)</td>
<td>0.50</td>
<td>0.50</td>
<td>dB</td>
<td>Lc</td>
</tr>
<tr>
<td>Receiver Figure ofMerit</td>
<td>9.03</td>
<td>0.08</td>
<td>dB</td>
<td>FOM</td>
</tr>
</tbody>
</table>

## Propagation Parameters

<table>
<thead>
<tr>
<th></th>
<th>Upstream</th>
<th>Downstream</th>
<th>SYMBOL</th>
<th>REFERENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmospheric Attenuation (clear air)</td>
<td>0</td>
<td>0</td>
<td>dB</td>
<td>La</td>
</tr>
<tr>
<td>Polarization Loss</td>
<td>0</td>
<td>0</td>
<td>dB</td>
<td>Lp</td>
</tr>
</tbody>
</table>
# Pseudolite Link Budget 2

## Transmitter Parameters:

<table>
<thead>
<tr>
<th></th>
<th>Uplink</th>
<th>Downlink</th>
<th>Units</th>
<th>Symbol</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmit Antenna Diameter</td>
<td>NA</td>
<td>NA</td>
<td>m</td>
<td>D</td>
<td>Switch Receive</td>
</tr>
<tr>
<td>Transmit Antenna Area</td>
<td>NA</td>
<td>NA</td>
<td>m²</td>
<td>A</td>
<td>Switch Receive</td>
</tr>
<tr>
<td>Transmit Antenna Efficiency</td>
<td>NA</td>
<td>NA</td>
<td>[-]</td>
<td>h</td>
<td>Switch Receive</td>
</tr>
<tr>
<td>Transmit Antenna Effective Area</td>
<td>NA</td>
<td>NA</td>
<td>m²</td>
<td>Aₑ</td>
<td>Switch Receive</td>
</tr>
<tr>
<td>Transmit Antenna Gain</td>
<td>2.00</td>
<td>2.00</td>
<td>dB</td>
<td>Gₜ</td>
<td>Switch Receive</td>
</tr>
<tr>
<td>Transmit Antenna Beamwidth</td>
<td>180.00</td>
<td>180.00</td>
<td>degrees</td>
<td>qₜ</td>
<td>Switch Receive</td>
</tr>
<tr>
<td>Transmit Antenna Pointing Accuracy</td>
<td>0.00</td>
<td>0.15</td>
<td>degrees</td>
<td>eₜ</td>
<td>Switch Receive</td>
</tr>
<tr>
<td>Transmit Antenna Pointing Loss</td>
<td>0.00</td>
<td>0.00</td>
<td>dB</td>
<td>Lₚt</td>
<td>Switch Receive</td>
</tr>
<tr>
<td><strong>Transmit Line Loss</strong></td>
<td>-0.5</td>
<td>-0.5</td>
<td>dB</td>
<td>Lᵢ</td>
<td>Input: based on chosen cable/geometry</td>
</tr>
<tr>
<td><strong>Transmit Power</strong></td>
<td>-27.0</td>
<td>-27.0</td>
<td>dBW</td>
<td>Pᵣ</td>
<td>10*log₁₀(Transmit power)</td>
</tr>
<tr>
<td><strong>Transmit Power, Linear</strong></td>
<td>0.002</td>
<td>0.002</td>
<td>W</td>
<td>Pᵣ</td>
<td>Input: chosen transmitter</td>
</tr>
<tr>
<td><strong>Effective Isotropic Radiated Power</strong></td>
<td>-25.49</td>
<td>-25.49</td>
<td>dBW</td>
<td>EIRP</td>
<td>Sum of Power, Gain, and Losses in dB</td>
</tr>
</tbody>
</table>

## Link Budget:

<table>
<thead>
<tr>
<th></th>
<th>Uplink</th>
<th>Downlink</th>
<th>Units</th>
<th>Symbol</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective Isotropic Radiated Power</td>
<td>-25.49</td>
<td>-25.49</td>
<td>dBW</td>
<td>EIRP</td>
<td>From Above</td>
</tr>
<tr>
<td>Propagation Losses</td>
<td>-120.05</td>
<td>-120.05</td>
<td>dB</td>
<td>L</td>
<td>Sum of Losses</td>
</tr>
<tr>
<td>Receive System Gain</td>
<td>1.50</td>
<td>1.50</td>
<td>dB</td>
<td>Gᵣ</td>
<td>Sum of antenna gain and system losses</td>
</tr>
<tr>
<td>Received Power</td>
<td>-144.04</td>
<td>-144.04</td>
<td>dBW</td>
<td>Pᵣ</td>
<td>Sum of Power sent out minus losses</td>
</tr>
<tr>
<td>System Noise Power</td>
<td>-200.96</td>
<td>-200.96</td>
<td>dBW-Hz</td>
<td>Nᵣ</td>
<td></td>
</tr>
<tr>
<td>Carrier to Noise Ratio Density</td>
<td>56.93</td>
<td>56.93</td>
<td>dB-Hz</td>
<td>Pᵣ/Nᵣ</td>
<td></td>
</tr>
<tr>
<td>Minimum Pr/No</td>
<td>48.00</td>
<td>48.00</td>
<td>dB-Hz</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Link Margin

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Link Margin</strong></td>
<td>8.93</td>
<td>8.93</td>
<td>dB</td>
</tr>
</tbody>
</table>
# Satellite Link Budget 2

<table>
<thead>
<tr>
<th><strong>Transmitter Parameters:</strong></th>
<th><strong>Uplink</strong></th>
<th><strong>Downlink</strong></th>
<th><strong>Units</strong></th>
<th><strong>Symbol</strong></th>
<th><strong>Reference</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmit Antenna Diameter</td>
<td>NA</td>
<td>NA</td>
<td>m</td>
<td>D</td>
<td>Switch Receive</td>
</tr>
<tr>
<td>Transmit Antenna Area</td>
<td>NA</td>
<td>NA</td>
<td>m²</td>
<td>A</td>
<td>Switch Receive</td>
</tr>
<tr>
<td>Transmit Antenna Efficiency</td>
<td>NA</td>
<td>NA</td>
<td>[-]</td>
<td>h</td>
<td>Switch Receive</td>
</tr>
<tr>
<td>Transmit Antenna Effective Area</td>
<td>0.002</td>
<td>NA</td>
<td>m²</td>
<td>Ae</td>
<td>Switch Receive</td>
</tr>
<tr>
<td>Transmit Antenna Gain</td>
<td>2.38</td>
<td>20.00</td>
<td>dB</td>
<td>Gt</td>
<td>Switch Receive</td>
</tr>
<tr>
<td>Transmit Antenna Beamwidth</td>
<td>180.00</td>
<td>20.00</td>
<td>degrees</td>
<td>qt</td>
<td>Switch Receive</td>
</tr>
<tr>
<td>Transmit Antenna Pointing Accuracy</td>
<td>0.00</td>
<td>0.15</td>
<td>degrees</td>
<td>et</td>
<td>Switch Receive</td>
</tr>
<tr>
<td>Transmit Antenna Pointing Loss</td>
<td>0.00</td>
<td>0.00</td>
<td>dB</td>
<td>Lpt</td>
<td>Switch Receive</td>
</tr>
<tr>
<td><strong>Transmit Line Loss</strong></td>
<td>-0.5</td>
<td>-0.5</td>
<td>dB</td>
<td>Lt</td>
<td>Input based on chosen cable/geometry</td>
</tr>
<tr>
<td>Transmit Power</td>
<td>3.0</td>
<td>14.1</td>
<td>dBW</td>
<td>Pt</td>
<td>10^LOG10(Transmit power)</td>
</tr>
<tr>
<td><strong>Transmit Power, Linear</strong></td>
<td>2</td>
<td>25.6</td>
<td>W</td>
<td></td>
<td>Input chosen transmitter</td>
</tr>
<tr>
<td>Effective Isotropic Radiated Power</td>
<td>4.89</td>
<td>33.58</td>
<td>dBW</td>
<td>EIRP</td>
<td>Sum of Power, Gain, and Losses in dB</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Link Budget:</strong></th>
<th><strong>Uplink</strong></th>
<th><strong>Downlink</strong></th>
<th><strong>Units</strong></th>
<th><strong>Symbol</strong></th>
<th><strong>Reference</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective Isotropic Radiated Power</td>
<td>4.89</td>
<td>33.58</td>
<td>dBW</td>
<td>EIRP</td>
<td>From Above</td>
</tr>
<tr>
<td>Propagation Losses</td>
<td>-180.37</td>
<td>-180.37</td>
<td>dB</td>
<td>L</td>
<td>Sum of Losses</td>
</tr>
<tr>
<td>Receive System Gain</td>
<td>19.50</td>
<td>1.88</td>
<td>dB</td>
<td>Gr</td>
<td>Sum of antenna gain and system losses</td>
</tr>
<tr>
<td>Received Power</td>
<td>-155.97</td>
<td>-144.90</td>
<td>dBW</td>
<td>Pr</td>
<td>Sum of Power sent out minus losses</td>
</tr>
<tr>
<td>System Noise Power</td>
<td>-200.96</td>
<td>-213.58</td>
<td>dBW-Hz</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Carrier to Noise Ratio Density</td>
<td>44.99</td>
<td>68.68</td>
<td>dB-Hz</td>
<td>Pr/No</td>
<td></td>
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<tr>
<td>Minimum Pr/No</td>
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<td>43.00</td>
<td>dB-Hz</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Link Margin</strong></td>
<td>0.99</td>
<td>20.68</td>
<td>dB</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
CDMA Signal Acquisition

Cross Correlation between Data and Code, No Noise

Cross Correlation between Data and Code, 10 Extra Users
Simple Tracking Loop (Costas Loop)
Multiple Access Interference
LimeSDR Hardware/Software Validation
Signal Interference (Simple Tranceiver)

- Preliminary interference and verification test resulted in positive results.
- Single tone SNR:
  - At 1 foot separation 40dB
  - At 590 feet (180 Meters) -15dB (Extrapolation)
Downlink Packet Breakdown

- **Preamble**
  - Unique 24 bit code sequence to allow for signal correlation

- **Navigation Message**
  - Element of set bit length providing timing for positioning algorithm

- **User ID**
  - 8 bit element containing a unique user identification sequence for each user to identify intended recipient
  - Designed to accommodate 30 user requirement

- **Communications Message**
  - 5000 bit text communication element broken into 8 bit characters
  - Message will be appended with ‘ ‘ (space) buffers to maintain constant size
Uplink Breakdown

● **Preamble**
  ○ Unique 24 bit code sequence to allow for signal correlation

● **User Identification**
  ○ 8 bit element containing a unique user identification sequence for each user to identify transmitting user
  ○ Designed to accommodate 30 user requirement

● **Communications Message**
  ○ 5000 bit text communication element broken into 8 bit characters
  ○ Message will be appended with ‘ ‘ (space) buffers to maintain constant size
Gr-LimeSDR Installation Process

The goal is to create a universal installation script, which a person could run on a Linux terminal and have access to a LimeSDR Development Environment.
Gr-LimeSDR Installation Process

Integrating gr-limesdr plugin package.

Example script:

[3.1] - Installing Dependencies:
-> `sudo apt-get install libboost-all-dev swig`
Just in case:
-> `sudo apt-get install gnuradio-dev`
[3.2] - Building gr-limesdr from source: (Only for GNU Radio 3.8!)
-> `git clone https://github.com/myriadrf/gr-limesdr`
-> `cd gr-limesdr`
-> `git checkout gr-3.8`
-> `mkdir build`
-> `cd build`
-> `cmake ..`
-> `make`
-> `sudo make install`
-> `sudo ldconfig`
We have a head start in the environment setup!

We can also verify that the GNU Radio communicates with the Gr-LimeSDR plugin.

We can already verify the LimeSDR communicates with the given software via the LimeSuiteGUI.
The goal is to create a universal installation script, which a person could run on a Linux terminal and have access to a LimeSDR Development Environment.

**Example script:**

1. **LimeSuiteGUI Installation**: (PPA Installation)
   - `sudo add-apt-repository -y ppa:myriadrf/drivers`
   - `sudo apt-get update`
   - `sudo apt-get install limesuite liblimesuite-dev limesuite-udev limesuite-images`
   - `sudo apt-get install soapysdr-tools soapysdr-module-lms7`
   To open the LimeSuiteGUI simply type the command:
   - `LimeSuiteGUI`
   To close, simply close the window.
   If you have access to the LimeSDR, you can verify the GUI can talk to it by typing the command:
   - `SoapySDRUtil --find="driver=lime"`

2. **GNU Radio Installation**: (PPA Installation)
   Note: The Release version must be 3.8.2.0
   - `sudo add-apt-repository ppa:gnuradio/gnuradio-releases`
   - `sudo apt-get update`
   - `sudo apt install gnuradio`
   To optimize GNU Radio kernel usage type:
   - `volk_profile`
   To Open GNU Radio GUI:
   - `gnuradio-companion`
   To close, simply close window.
Integration: LimeSDR + GNU Radio

- gr-limesdr plugin for GNURadio
  - Provides LimeSDR Transmit and Receive blocks
    - Can specify Rx/Tx channels for multiple antennas
- Automatically finds the LimeSDR
- Configurable via .ini file
- These blocks feed samples into the well documented GNURadio sample stream
Project Risks and Mitigation
## Risk Identification

<table>
<thead>
<tr>
<th>Risk ID</th>
<th>Description</th>
<th>Likelihood</th>
<th>Consequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>COM-3</td>
<td>Near-Far problem: Difficulty to hear weak-far signals from strong-close signal sources</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>ELE-1</td>
<td>Time synchronization between pseudolite and GPS receiver</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>SOF-1</td>
<td>Team inexperience handling new software. For example, GNU radio</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>COM-2</td>
<td>Signal Interference in testing environment</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>SOF-2</td>
<td>Lime-SDR, Raspberry Pi, and other hardware components not communicating correctly</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>COM-1</td>
<td>Multiple User Communicating</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>LOG-1</td>
<td>Hardware/Electronics don’t arrive on time which sets back schedule of overall project</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>
Risk Matrix

### Legend

- **LOW RISK**
  - Acceptable
- **LOW-MED RISK**
  - Low Risk
- **MEDIUM RISK**
  - Requires Monitoring
- **MED-HIGH RISK**
  - Moderate Mitigation
- **HIGH RISK**
  - Immediate Mitigation
- **CRITICAL RISK**
  - Unacceptable Risk

### Risk ID | Description
---|---
COM-3 | Near-Far problem: Difficulty to hear weak-far signals from strong-close signal sources
ELE-1 | Time synchronization between pseudolite and GPS receiver
SOF-1 | Team inexperience handling new software. For example, GNU radio
COM-2 | Signal Interference in testing environment
SOF-2 | Lime-SDR, Raspberry Pi, and other hardware components not communicating correctly
COM-1 | Multiple User Communicating
LOG-1 | Hardware/Electronics don’t arrive on time which sets back schedule of overall project

### Risk Matrix Grid

- **Consequence**
  - 1: LOW RISK
  - 2: LOW-MED RISK
  - 3: MEDIUM RISK
  - 4: MED-HIGH RISK
  - 5: HIGH RISK

- **Likelihood**
  - 1: Acceptable
  - 2: Low Risk
  - 3: Requires Monitoring
  - 4: Moderate Mitigation
  - 5: Immediate Mitigation

- **Legend Colors**
  - COM-1
  - COM-3
  - COM-2
  - SOF-1
  - ELE-1
  - LOG-1
  - SOF-2
## Risk Mitigation Table

<table>
<thead>
<tr>
<th>Risk ID</th>
<th>Description</th>
<th>Mitigation Approach</th>
</tr>
</thead>
</table>
| COM-3   | Near-Far problem: Difficulty to hear weak-far signals from strong-close signal sources | ● Test within pseudolite geometry boundaries  
● Automatic gain control                                                                                                                                  |
| ELE-1   | Time synchronization between pseudolite and GPS receiver                    | Conduct initial test to verify limeSDR clock override with Septentrio PolaRxS GPS receiver.                                                                 |
| SOF-1   | Team inexperience handling new software. For example, GNU radio              | ● Fall semester early development  
● Online tutorials, device users manual  
● External Resources: Dr Akos, Dr Rainville, Steve Taylor, Sam Holt                                                                                 |
| COM-2   | Signal Interference in testing environment                                   | Change testing area to back up location (Platteville), change testing time to reduce interference (overnight)                                         |
| SOF-2   | Lime-SDR, Raspberry Pi, and other hardware components not communicating correctly | ● Fall semester early development.  
● Refer to overall block diagram,  
● Dive into specific functional block diagrams and debug issues (divide and conquer).                                                              |
| COM-1   | Multiple User Communicating                                                  | Design an optimal CDMA code for each user                                                                                                               |
| LOG-1   | Hardware/Electronics don’t arrive on time which sets back schedule of overall project | Change provider of electronics to avoid schedule variance (Amazon, SparkFun, BestBuy, etc)                                                              |
Mitigation Effects

<table>
<thead>
<tr>
<th>Risk ID</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>COM-3</td>
<td>Near-Far problem: Difficulty to hear weak-far signals from strong-close signal sources</td>
</tr>
<tr>
<td>ELE-1</td>
<td>Time synchronization between pseudolite and GPS receiver</td>
</tr>
<tr>
<td>SOF-1</td>
<td>Team inexperience handling new software. For example, GNU radio</td>
</tr>
<tr>
<td>COM-2</td>
<td>Signal Interference in testing environment</td>
</tr>
<tr>
<td>SOF-2</td>
<td>Lime-SDR, Raspberry Pi, and other hardware components not communicating correctly</td>
</tr>
<tr>
<td>COM-1</td>
<td>Multiple User Communicating</td>
</tr>
<tr>
<td>LOG-1</td>
<td>Hardware/Electronics don’t arrive on time which sets back schedule of overall project</td>
</tr>
</tbody>
</table>
Verification and Validation
Signal Reception

LimeSDR demonstrates reception signal through wired connection

- Laptop running GNU radio creates signal and sends to LimeSDR
  - Create 100 bit .txt file to use as transmission signal
  - Send bits to LimeSDR using USB connection
- Verify receipt of signal to the LimeSDR
  - Create .txt file from bits and compare sent and received signal
USB Connection sends .txt as bits to LimeSDR

Wired from TX to RX sending bits

Bits converted to .txt and compared to initial file
Antenna test

Demonstrate that the antennas used can supply the proper gain for the design

- Measure loss between a two radio/antenna setup running multiple trials at various distances
- Use least squares calculate the gain of the antennas (they are the same)

\[ PL = G_1 + G_2 + 20 \log \left( \frac{\lambda}{4\pi R} \right) \]
Transmitter/Receiver Set up

Each transmitter and receiver will feature a casing for the electronics that will hold the LimeSDR, Raspberry Pi, a battery pack, and space for wiring and a connection to the antenna. The electronics casing will be thread-mounted to a camera tripod.

1. LimeSDR
2. Raspberry Pi
3. Cut out for antenna
4. Septentrio PolaRxS GPS receiver
5. Mlady 10000 mAh portable power pack
Modulation Scheme

LimeSDR receiver positioned 100m away from LimeSDR transmitter

- Transmitter modulates 100 bit .txt file to 2.48 GHz carrier frequency using GNU Radio PSK modulator
- LimeSDR receiver receives signal and demodulates it using GNU radio PSK demodulator
- Signal is re-output as .txt file and compared to initial file
Using Laptop and GNURadio send .txt file to LimeSDR

GNURadio modbox modulates bits using BPSK modulation scheme

LimeSDR receives the modulated signal and demodulates using GNURadio demodbox

Bits are converted to .txt file and compared to original .txt
Multiplexing and Wireless Transmission

Receiver can distinguish CDMA codes and process the desired signal

- 3 transmitters generate and transmit signals of different 100 bit .txt files
  - For each file, send preamble and .txt file using GNU radio PSK modulator
- LimeSDR receiver positioned 100m away receives the signals and listens for specific preamble
  - Based on desired preamble, receiver demodulates and converts desired signal to .txt
- Received .txt file is compared to original 3 to verify proper signal was processed
HDOP and Positioning Accuracy

LimeSDR demonstrate positioning accuracy within 10 m

- Have 3 transmitting set ups spaced out in an equilateral triangle
  - GNU radio with a LimeSDR and an antenna on a tripod
- Have a receiver set up in sensitive areas inside the triangle of transmitters: center of triangle, close to corner (near far problem)
- Receive signals from the transmitter stations to calculate position of receiver
- Verify that receiver position calculated from transmitters is within 10 m of expected position (from GPS)
Multiplexing & HDOP Test Setup

Contents of Black Boxes
1. LimeSDR
2. Raspberry Pi
3. Cut out for antenna
4. Septentrio PolaRxS GPS receiver
5. Midy 10000 mAh portable power pack

Positioning
Comms to main pseud.
Positioning w/in 10 m

180 m
10 m
Test Checklist

1. Walk transmitters to their positions
2. Sync transmitters and receiver with GPS
   a. Sync up clocks to GPS (as well as to each other)
   b. Record “true” position of each transmitter and receiver
3. Verify all stations ready
4. Run communications/positioning test
Testing site: Foothills Park
Back-Up Testing Area
Project Planning
Work Plan

Overview
Solution
CPE
DR
Risk & M
V&V
Planning

First day of spring semester
January 14th

Finalize Matlab Simulation

Work on MSR

Manufacturing Status Review
February 2nd

Testing

Work on TRR Slides
March 3rd

Test Readiness Review

LimeSDR Signal Reception

March 9th

Signal Reception Testing

Modulation and Multiplexing Test

March 16th

Modulation and Multiplexing Testing

Work on HDOP Testing
March 23rd

HDOP Testing Deadline

Work on Spring Final Review Slides
April 20th

Spring Final Review
Final Deliverables
AIAA Conf. Paper Due
Senior Design Symposium
Project Final Report
## Test Plan

<table>
<thead>
<tr>
<th>Testing Procedure</th>
<th>Date Scheduled</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal Reception Test</td>
<td>March 9th</td>
<td>Foothills Park</td>
</tr>
<tr>
<td>Modulation and Multiplexing Test</td>
<td>March 15th</td>
<td>Foothills Park</td>
</tr>
<tr>
<td>HDOP Test</td>
<td>March 23rd</td>
<td>Foothills Park</td>
</tr>
<tr>
<td>Full Scale Test</td>
<td>March 25th</td>
<td>Foothills Park</td>
</tr>
</tbody>
</table>
Budget
Tripods (4): 68 $ (USD) - 1.4%
Power Pack (4): 80 $ (USD) - 1.6%
Adaptors (4): 40 $ (USD) - 0.8%
Raspberry Pi (4): 220 $ (USD) - 4.5%
Lime SDR (4): 1400 $ (USD) - 28.8%
Antenna (4): 19.8 $ (USD) - 0.4%

Open Budget: 3026 $ (USD) - 62.3%
# Expense Budget & Margin

## Team P4LO Budget

| Allowable Budget | $5,000.00 |

## Communications Hardware

<table>
<thead>
<tr>
<th>Item</th>
<th>Individual Cost</th>
<th># of Items</th>
<th>Subtotal Per Set</th>
<th>Supplier</th>
<th>Item Link</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenna</td>
<td>$4.95</td>
<td>4</td>
<td>$19.80</td>
<td>SparkFun</td>
<td><a href="https://www.sparkfun.com/products/11320">https://www.sparkfun.com/products/11320</a></td>
</tr>
<tr>
<td>Lime SDR</td>
<td>$349.95</td>
<td>4</td>
<td>$1,399.80</td>
<td>SparkFun</td>
<td><a href="https://www.sparkfun.com/products/15027">https://www.sparkfun.com/products/15027</a></td>
</tr>
<tr>
<td>Raspberry Pi</td>
<td>$55.00</td>
<td>4</td>
<td>$220.00</td>
<td>SparkFun</td>
<td><a href="https://www.sparkfun.com/products/15447">https://www.sparkfun.com/products/15447</a></td>
</tr>
<tr>
<td>Power Pack</td>
<td>$19.99</td>
<td>4</td>
<td>$79.96</td>
<td>Amazon</td>
<td><a href="https://www.amazon.com/Miady-10000mAh-Portabl">https://www.amazon.com/Miady-10000mAh-Portabl</a></td>
</tr>
</tbody>
</table>

## Budget Balance

| Sub-total Balance       | $1,827.32       |
| Sales Tax Total         | $146.19         |
| Total Cost              | $1,973.51       |
| Budget Balance          | $3,026.49       |
References

LimeSuiteGUI - GNU Radio - Gr-LimeSDR Plugin


