# Heimdall

sddec24-01

Client: H.A.B.E.T.

Advisor: Matthew Nelson

# Team Members & Roles

**Brandon Beaver** - Project Manager

**Alec Sutton** - Design and Power Team Lead

**Branden Buhler** - Communications and Program Team Lead

**Cullen White** - Power Systems and Logistics Manager

**George Cleaver** - Communications and Controls Advisor

**Lex Somers** - Programming and Software Advisor

# Agenda

1. Client Info/Background
2. Project Information
3. Conceptual overview
4. Resources
5. Detailed design
6. System/Module testing
7. Project Logistics
8. Project Status
9. Looking forward
10. Individual contributions

# Client Info

## H.A.B.E.T.

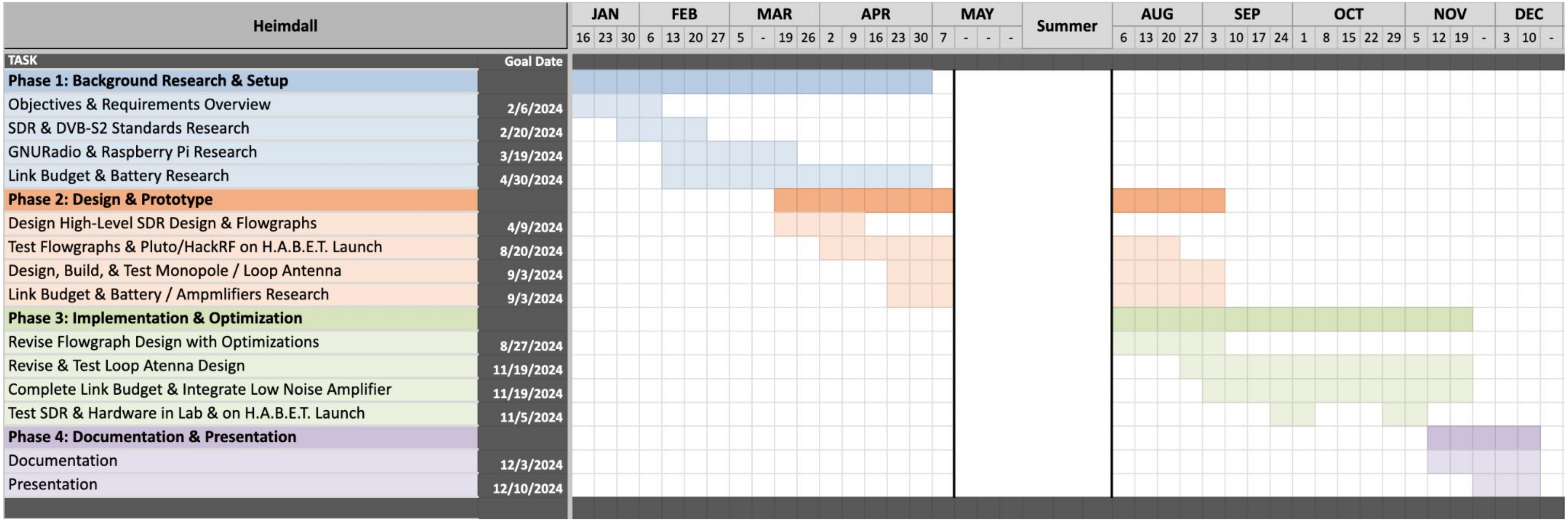
- High-Altitude Balloon Experiments in Technology
    - Established in 1993 by CITS by Ralph Wallio
    - Previously used amature radio as basis for flights
    - Absorbed by ISU in 1995
    - Funded by the ISGC, a NASA cooperative
- Iowa State student lead team through M2I
    - Client/Advisor: Director Matthew Nelson
- Perform experiments using custom spacecraft design specs based on project/client needs
- Goals: capturing atmospheric, telemetry, and visual data, stored locally and transmitted to ground.
    - Video and telemetry data transmission issues result in change needed in current methods

# Problem Statement

- Problem:
  - H.A.B.E.T. currently transmits with a 5.8 GHz signal, but often experiences data loss due to excessive noise and signal disconnection. Additionally, H.A.B.E.T. is prone to video loss due to craft recovery issues.

- Proposed Solution:
  - Transmit using software-defined radio (SDR) at a target frequency of 1.243 GHz to maintain a link at low-space altitude with less noise interference. Heimdall aims to maintain a video link so maximum footage is obtained.

# Project Schedule



| Heimdall | | JAN | | | FEB | | | | MAR | | | | APR | | | | | MAY | | | | Summer | AUG | | | | SEP | | | | OCT | | | | | NOV | | | | DEC | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TASK | Goal Date | 16 | 23 | 30 | 6 | 13 | 20 | 27 | 5 | - | 19 | 26 | 2 | 9 | 16 | 23 | 30 | 7 | - | - | - | | 6 | 13 | 20 | 27 | 3 | 10 | 17 | 24 | 1 | 8 | 15 | 22 | 29 | 5 | 12 | 19 | - | 3 | 10 | - |
| **Phase 1: Background Research & Setup** | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | | | | | | | | | | | | | | | | | | | | |
| Objectives & Requirements Overview | 2/6/2024 | ■ | ■ | ■ | ■ | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| SDR & DVB-S2 Standards Research | 2/20/2024 | | | ■ | ■ | ■ | ■ | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| GNURadio & Raspberry Pi Research | 3/19/2024 | | | | | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Link Budget & Battery Research | 4/30/2024 | | | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | | | | | | | | | | | | | | | | | | | | | | |
| **Phase 2: Design & Prototype** | | | | | | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | | ■ | ■ | ■ | ■ | ■ | | | | | | | | | | | | | | | |
| Design High-Level SDR Design & Flowgraphs | 4/9/2024 | | | | | | | | | | ■ | ■ | ■ | ■ | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Test Flowgraphs & Pluto/HackRF on H.A.B.E.T. Launch | 8/20/2024 | | | | | | | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | | | | | ■ | ■ | ■ | | | | | | | | | | | | | | | | | |
| Design, Build, & Test Monopole / Loop Antenna | 9/3/2024 | | | | | | | | | | | | | | | ■ | ■ | ■ | | | | | ■ | ■ | ■ | ■ | ■ | | | | | | | | | | | | | | | |
| Link Budget & Battery / Ampmlifiers Research | 9/3/2024 | | | | | | | | | | | | | | | ■ | ■ | ■ | | | | | ■ | ■ | ■ | ■ | ■ | | | | | | | | | | | | | | | |
| **Phase 3: Implementation & Optimization** | | | | | | | | | | | | | | | | | | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | |
| Revise Flowgraph Design with Optimizations | 8/27/2024 | | | | | | | | | | | | | | | | | | | | | | ■ | ■ | ■ | ■ | ■ | | | | | | | | | | | | | | | |
| Revise & Test Loop Atenna Design | 11/19/2024 | | | | | | | | | | | | | | | | | | | | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | |
| Complete Link Budget & Integrate Low Noise Amplifier | 11/19/2024 | | | | | | | | | | | | | | | | | | | | | | | | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | |
| Test SDR & Hardware in Lab & on H.A.B.E.T. Launch | 11/5/2024 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | ■ | ■ | | | | ■ | ■ | | | | | | |
| **Phase 4: Documentation & Presentation** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | ■ | ■ | ■ | ■ | ■ | |
| Documentation | 12/3/2024 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | ■ | ■ | ■ | ■ | ■ | |
| Presentation | 12/10/2024 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | ■ | ■ | ■ | |

# IEEE Standard Compliance

- IEEE 802.11 b/g/n
  - Standard for WiFi that operates on the 2.4 GHz band.
- IEEE C95.7 - 2022
  - Standard for RF safety programs for various safety applications when using radiation at RF frequencies from 0 to 300 GHz.
- IEEE 287
  - Standard for using and applying RF coaxial cable connectors and best practices for inclusion.
- IEEE 287.3-2021
  - Standard for involving recommended usages for connectors, coaxial cable types, and recommendations for best performance.

- FCC - Part 97 §97.113 “Prohibited transmissions”
  - Restrictions for amateur radio station transmissions
- FAA - Section 6 “Unmanned Free Balloons” §9-6-1 “Application”
  - Weight requirements for HAB Balloons

## Functional Requirements

- Receive video data transmission.
- Transmit at carrier frequency on the 1.2 GHz frequency band to remain at amatuer radio frequency.
- Maintain connection at rated balloon altitude (30km).

## Non-Functional Requirements

- Heimdall components must fit within H.A.B.E.T. payload dimension and weight requirements.
- High quality documentation to ensure ease of use for H.A.B.E.T. in the future.
- Provide a free/open-source SDR product that H.A.B.E.T. can use going forward.

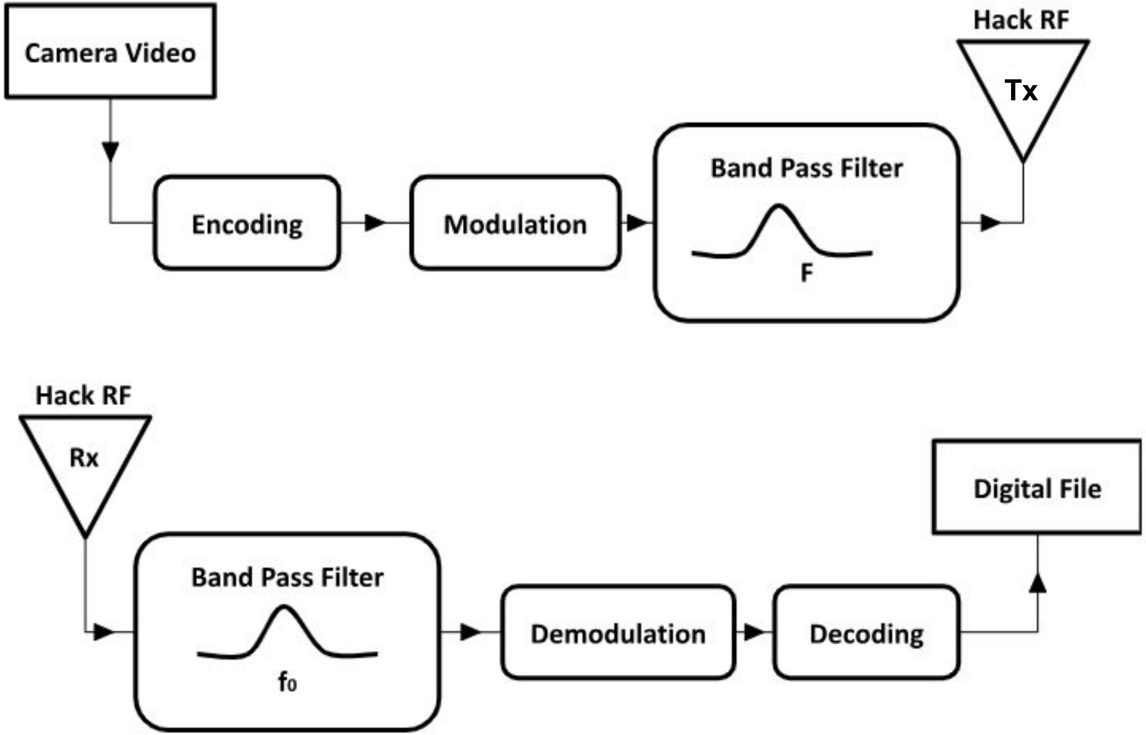
# Deliverables/Milestones:

- Determine ideal modulation and encoding scheme to be tested in H.A.B.E.T.'s eclipse launch
- Develop preliminary transmission design, including:
  - Hardware:
    - Controller
    - Camera
    - Software-Defined Radio (SDR) Device [PlutoSDR, HackRF, etc.]
    - Sourced/Built antenna specified to the selected carrier frequency
    - Low Noise Amplifier
  - Software:
    - Graphical programming model for modulation and encoding
      - GNURadio
    - Controller programming
      - Proper operating system (Raspberry Pi OS)
      - Linux OS

# Fundamental Composition

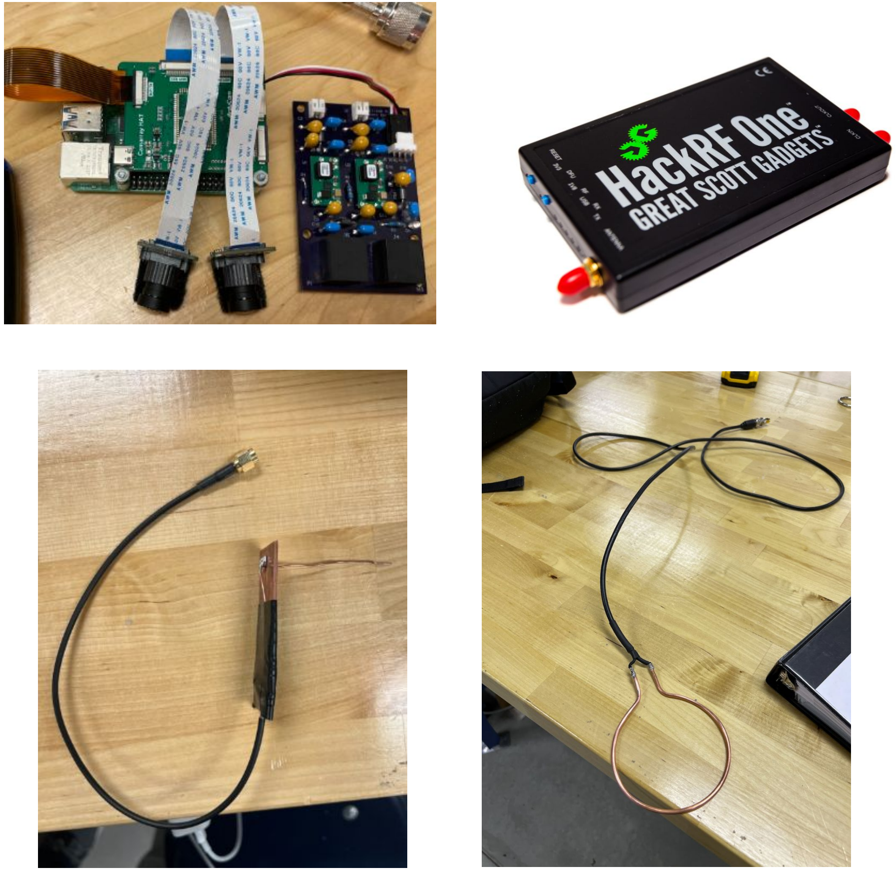
- Computational Module
- SDR Module
- Software Signal Processing GUI
- Camera
- Power source
- Transmission Antenna
- Low Noise Amplifier

# Conceptual Sketch



# Hardware Used

- HackRF Board
- Raspberry Pi 4
- Raspberry Pi Camera
- Antenna
- LaNA WB Amplifier



# Software Used

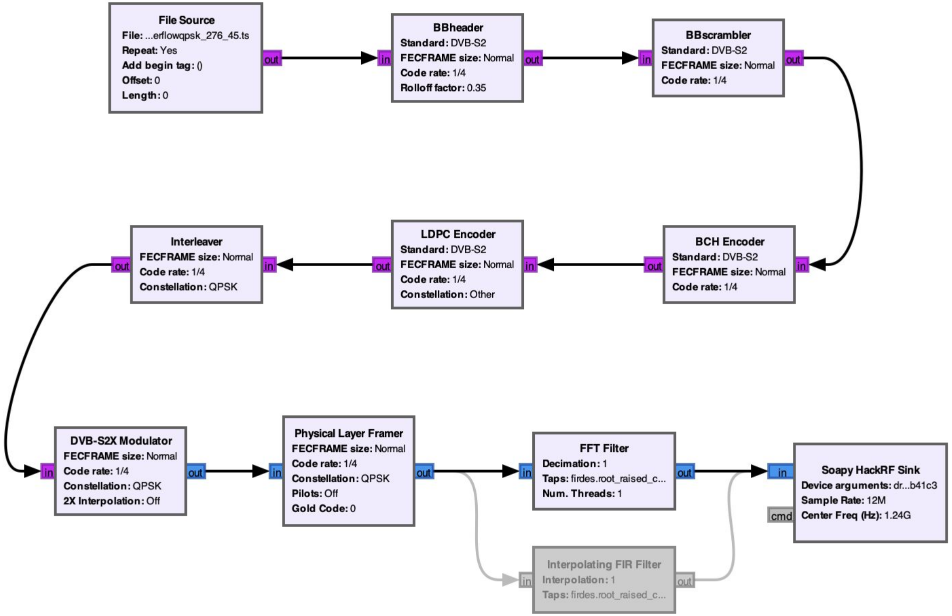
- GNU Radio
  - Out of tree modules:
    - gr-dvbs2rx
    - Gr-ldpc

- Linux OS (Debian)
  - rpicam command line application

- SDRAngel

# Detailed Design - Transmitting End

- File Source
  - Input data from Pi camera
- BB header
  - Adds header to initiate signal
- BB scrambler
  - Scramble for accurate timing recovery
- BCH Encoder
  - Convert data to Hierarchical Temporal Memory (HTM) format
- LDPC Encoder
  - Low density parity check - Encode binary data for transmission



**File Source**
**File:** ...erflowqpsk_276_45.ts
**Repeat:** Yes
**Add begin tag:** ()
**Offset:** 0
**Length:** 0

**BBheader**
**Standard:** DVB-S2
**FECFRAME size:** Normal
**Code rate:** 1/4
**Rolloff factor:** 0.35

**BBscrambler**
**Standard:** DVB-S2
**FECFRAME size:** Normal
**Code rate:** 1/4

**BCH Encoder**
**Standard:** DVB-S2
**FECFRAME size:** Normal
**Code rate:** 1/4

**LDPC Encoder**
**Standard:** DVB-S2
**FECFRAME size:** Normal
**Code rate:** 1/4
**Constellation:** Other

**Interleaver**
**FECFRAME size:** Normal
**Code rate:** 1/4
**Constellation:** QPSK

**DVB-S2X Modulator**
**FECFRAME size:** Normal
**Code rate:** 1/4
**Constellation:** QPSK
**2X Interpolation:** Off

**Physical Layer Framer**
**FECFRAME size:** Normal
**Code rate:** 1/4
**Constellation:** QPSK
**Pilots:** Off
**Gold Code:** 0

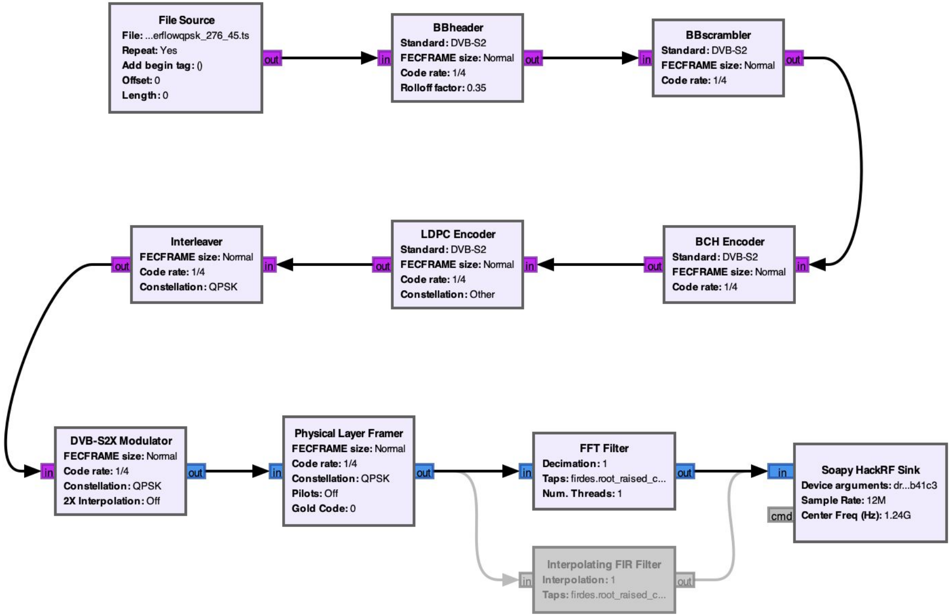
**FFT Filter**
**Decimation:** 1
**Taps:** firdes.root_raised_c...
**Num. Threads:** 1

**Interpolating FIR Filter**
**Interpolation:** 1
**Taps:** firdes.root_raised_c...

**Soapy HackRF Sink**
**Device arguments:** dr...b41c3
**Sample Rate:** 12M
**Center Freq (Hz):** 1.24G

# Detailed Design - Transmitting End

- Interleaver
  - Grouped bit error for Forward Error Correction (FEC)
- DVB-S2X Modulator
  - Modulate data to target frequency
- Physical Layer Framer
  - Tags data for later reconstruction
- FFT Filter
  - Band pass filter
- HackRF Sink
  - Interface to change SDR config
- Antenna
  - Transmit signal



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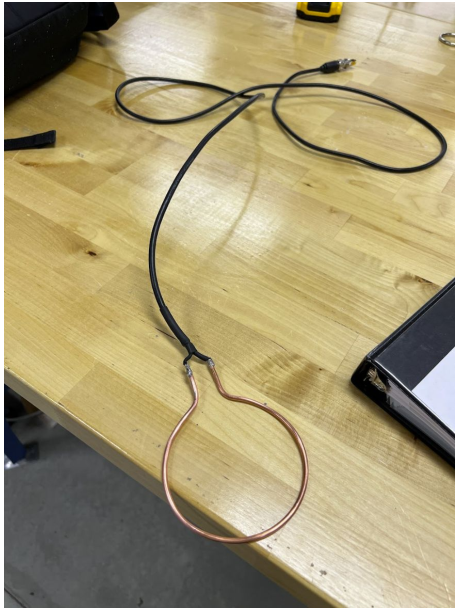
**Soapy HackRF Sink**
**Device arguments:** dr...b41c3
**Sample Rate:** 12M
**Center Freq (Hz):** 1.24G

# Detailed Antenna Design & Testing V1

- Half wavelength dipole vs quarter wavelength monopole
  - Quarter wavelength monopole has similar gain for our application and is more easily constructed.
- Copper plate used for PEC due to its high conductivity.
  - Drilled a hole at the top for feeding port.
  - Frequency is 1.2 GHz
  - ~2.46 inch monopole
- Identified there was a short on the PEC.

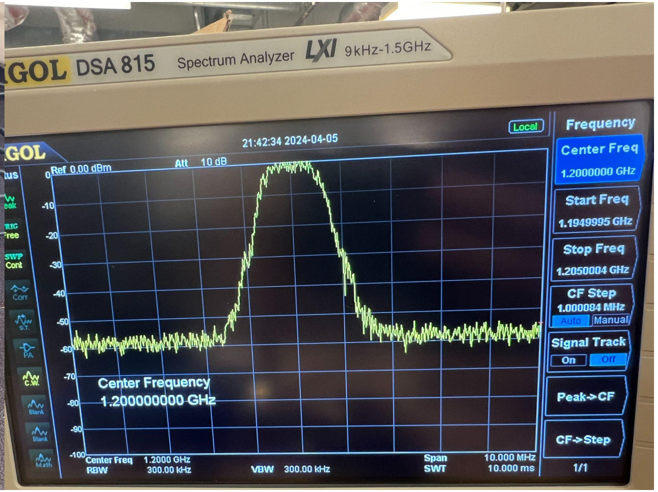
# Detailed Antenna Design & Testing V2

- Initially assumed to have a 6 dB gain at 1.243 GHz.
- Simulations and measurements ran in MATLAB antenna toolbox.
- Designed with 8 AWG wire and RG-58 cable.
- Upon creation it was identified that there was a mistake.
  - The plot that was thought to be 6 dB of gain was actually the source match and was incorrect and was verified to be incorrect upon testing.



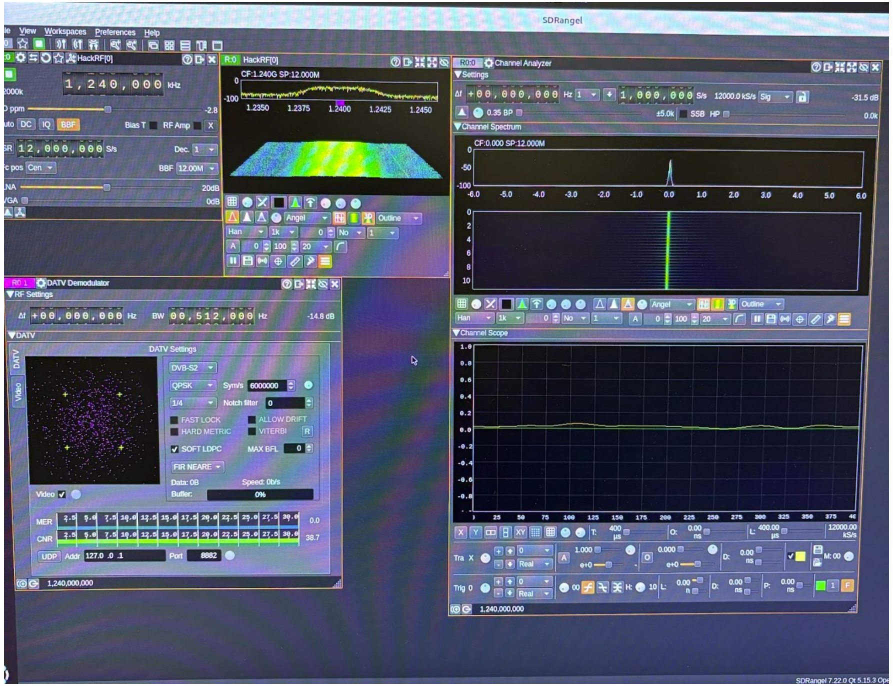
# Testing - PLUTO

- Unit testing
  - Hardware and GNU Radio activation
- Interface and integration testing
  - Export video to GNU Radio
  - Activate PlutoSDR modules with GNU Radio
- System testing
  - Transmit a test file using PlutoSDR
- Acceptance criteria testing
  - Worked toward an “Over-the-air” video transmission
  - Integrating project into H.A.B.E.T. payload



# Testing - HackRF

- Unit testing
  - Hardware and GNURadio activation
- Interface and integration testing
  - Export video to GNU Radio
  - Activate HackRF modules with GNU Radio
- System testing
  - Transmit a test file using HackRF
- Regression testing
  - Integrating HackRF SDR module with GNU Radio flowgraphs
- Acceptance criteria testing
  - Working toward an “Over-the-air” video transmission
  - Integrating project into H.A.B.E.T. payload



# Prototype Implementation

- System integrated into H.A.B.E.T. payload for April 8, 2024 flight. (Solar Eclipse)
    - Due to miscommunication during launch preparation, the Heimdall system was active and tested during the flight.
- Weak signal showed more improvements needed before integration step.

# Potential Risks and Mitigation

| **Task/Component** | **Risk** | **Mitigation** |
|---|---|---|
| **Phase 1:** | | |
| Research hardware & software documentation | Inadequate understanding & underestimation of requirements | Allocate sufficient time for research and perform thorough testing for all components |
| **Phase 2:** | | |
| Determine necessary components signal must pass through | Miss critical components for signal modulation encoding, etc | Perform multiple over the line tests, starting simple & small files building up to videos. Consult GNURadio documentation. |
| Design transmission antenna | Antenna design flaws affecting signal transmission or reception | Analyze antenna output with spectrum analyzer, consider deployment conditions, etc |
| Equip H.A.B.E.T. test launches with Heimdall System | Hardware damage or malfunction during transportation or launch | Ensure at least one Heimdall member is on site for each launch and securely package Heimdall's system in payload |

# Potential Risks and Mitigation

| Task/Component | Risk | Mitigation |
|---|---|---|
| **Phase 3:** | | |
| Revise and optimize design based on tests in lab and from H.A.B.E.T. launches | Insufficient time or resources for optimization efforts and frequency of H.A.B.E.T. test launches | Consistent team meetings to ensure continuous progress, and consulting with advisor about test results, and good communication with H.A.B.E.T. |
| Determine fine-tuned values for modulation, transmitting, etc | Suboptimal system performance due to improper parameter selection | Conduct testing and tuning, use mathematical models and spectrum analyzer for testing |
| Determine fine-tuned values for power consumption & analog components | Inaccurate power consumption estimates leading to weak or failed transmission | Conduct power measurements, consider worst-case scenarios, incorporate safety margins in power budgeting |

# Market Alternatives

| **Complete Hardware Implementation (vs. SDR hybrid)** | **Arduino Uno or BeagleBone Black (vs. Raspberry Pi)** | **MATLAB Simulink (vs. GNURadio)** |
|---|---|---|
| ● Less flexible for potential changes to modulation scheme, frequency, etc.<br>● Less scalable and can't be adjusted for different use cases. | ● Arduino is cheaper, but lacks necessary processing power.<br>● BeagleBone Black is a similar cost as the Pi, more powerful and versatile, but lacks documentation and is more complex | ● Potentially better performance depending on implementation.<br>● More expensive than GNURadio which is open source.<br>● Inconsistent access to necessary libraries due to frequent licensing changes. |
| | | |

# Resource/Cost Estimation

- Great Scott Gadgets’ HackRF (2x@ ~$350/each)
- Materials for helical antenna
  - Copper wire ~ $15
  - 3D Printable structure PLA ~$6.30
- Power Supply
  - Currently sourced: 8000mAh @ ~$10
- Raspberry Pi 4B ~ $45\
- Nooelec LaNA WB ~ $60
  - Low noise amp for testing and preamp

Total Cost Estimation: ~$836.30

# Current Project Status

- SDR module transmits at target frequency.
- Loop antenna is not optimized, will be re-simulated and constructed for next semester.
- GNURadio transmission end, SDRAngel receiving end, using HackRF.
- A low noise pre-amp has arrived and power amplifier will be implemented

# Looking Forward

- Integrate low-noise amplifier for stronger Rx signal
- Integrate power amplifier for Tx signal
- Optimize antenna for stronger transmission
- Re-testing modules with over-line testing
- Implement design and test during flight

# Team Contributions

- **Brandon Beaver:**
  - Logistics & material sourcing of devices
  - Design & test GNURadio transmission & receive flowgraphs
  - Collaborative work with H.A.B.E.T.
    - Flight operations on Heimdall's Behalf
    - inter-group communications
  - Aiding in Antenna design & testing
  - Preliminary HackRF testing & SDRangel use
- **Branden Buhler:**
  - Design & implement monopole antenna
  - Simulated and constructed loop antenna.
  - Designed GNURadio flowgraph for transmission/reception.
  - Received signal on SDRangel.
- **George Cleaver:**
  - Design & build monopole antenna
  - Design transmitter & receiver flowgraph in GNU Radio
  - Set up HackRF on Raspberry Pi
  - Carried out unit & system testing
    - Pluto tests
    - HackRF tests
- **Alec Sutton:**
  - Assisted in design & testing of flowgraph
  - Set up Raspberry Pi for camera use & GNU Radio
  - Researched and acquired testing amplifier
  - Performed link budget research and calculations
  - Began research for power sources.
- **Cullen White:**
  - Set up Raspberry Pi for camera use & GNU Radio
  - Created team website
  - Took team members pictures for website
- **Lex Somers:**
  - Designed & tested RX / TX GNURadio flowgraphs
  - Installed & helped setup SDRAngel receiving end
  - Research & tested out of tree GNURadio modules
    - Leandvb, gr-ldpc encoder & decoder, gr-dvbs2rx demodulator
  - Integrated Pi cameras & GNURadio with rpicam application.
  - Setup PlutoSDR & HackRF drivers on Raspberry Pis
  - Setup & maintained team website

# Thank You

Questions?