X-Band Software-Defined Radio Payload Design for CubeSat Communications

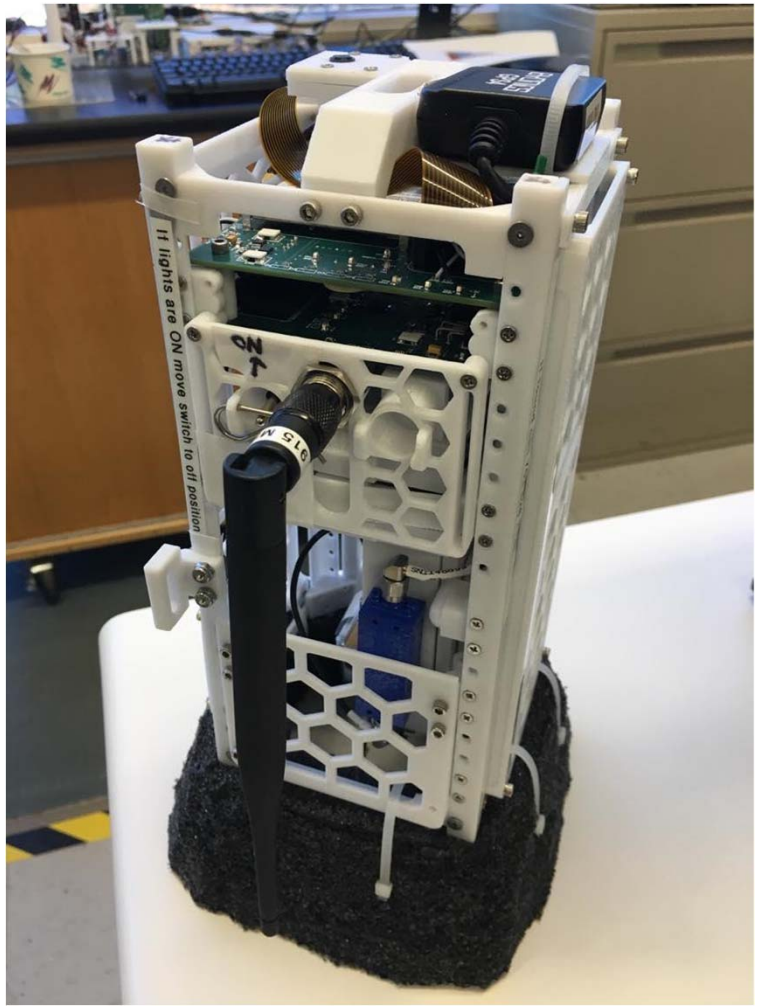
23 April 2019

LCDR Greg Bischoff, LT Bianca Lovdahl,
Dr. Giovanni Minelli, Dr. Wenschel Lan,
Dr. James Newman

NAVAL POSTGRADUATE SCHOOL

Agenda

- Mission and Requirements
- Background
- Scope
- Previous Work (C-Band)
- Hardware
- Software
- Test Progress
- Future Work



C-Band Flight Test Unit

NAVAL POSTGRADUATE SCHOOL

Mission and Requirements

Mission

- Create a low-cost CubeSat X-Band transmitter to work with Mobile CubeSat Command and Control (MC3) network and future NPS CubeSats.
- Support DoD efforts in small satellites and move from congested traditional communications frequencies to X-Band for greater bandwidth and data rates.
- Collect and transmit data to a ground station via X-band using an SDR payload.

Requirements

Threshold:

- Transmit and receive data in X-band
- Package transmitter in 1U form factor

Additional goals:

- Achieve 1 Mbps data transfer

Accomplishes

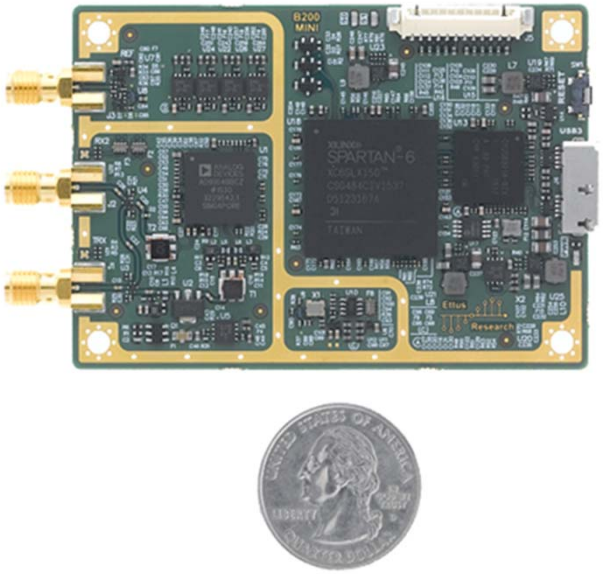
- Flight demonstration of potential baseline X-band SDR mission software
- Assessment of performance of SDR meant for CubeSat payload
- Estimate requirements to close link with payload on-orbit

NAVAL POSTGRADUATE SCHOOL

Background

SDR

- **Reduces hardware requirements** of traditional radios and **provides signal processing and tuning over a wide range of frequency bands**
- **Reprogrammable**, can offer **on-orbit configurability**, **compact size**, and affordable
- COTS SDRs exist within the **CubeSat form factor**



Ettus B205mini-i SDR without Enclosure Compared to a Coin

X-Band (8 - 12 GHz)

- Represents one of the higher radio frequency bands of interest to the DoD for space communications applications
- Higher frequency means **increased bandwidth** and capacity for **higher data-rate**

X-Band CubeSat transmitter examples

- NASA MarCO mission (6U)
- Commercial examples (higher cost: ~$25k+)

NAVAL POSTGRADUATE SCHOOL

Scope

Frequency Authorization

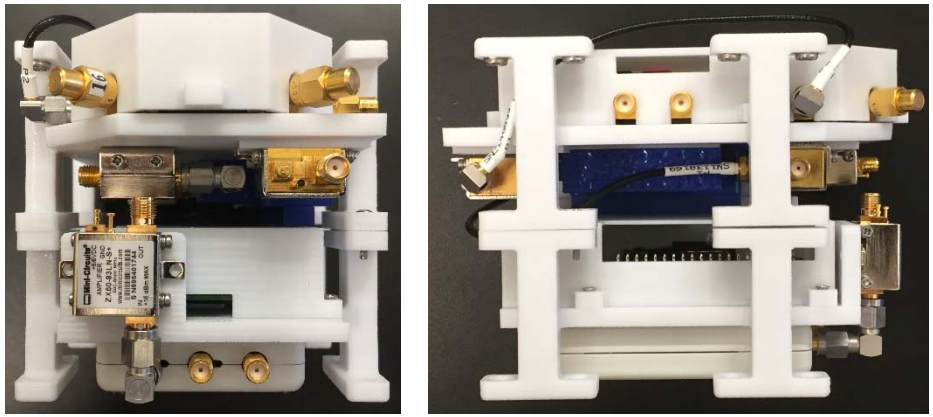
- Federal use of RF allocated by National Telecommunications and Information Administration (**NTIA**)
- Pending **X-band frequency authorization**
  - Chose **X-Band** (8025 - 8400 MHz)
  - Designated for EARTH EXPLORATION SATELLITE (space to Earth)

Weather Balloon Testing

- Small Sat Lab has used balloon flight tests as a **method to test components of payload designs intended for use on-orbit**
- **Less expensive, less complex,** and offers an **accelerated path to a flight demonstration**, compared to a CubeSat space launch
- HAB flight testing in a **near-space environment**
- Provides a **rapid deployment cycle and an opportunity to retrieve the unit after the launch**

Flight Test Unit:

- 2U structure
- Main components of payload: Ettus USRP B205mini-i and Raspberry Pi 3 with camera
- **~ $2500 (excluding antenna)**



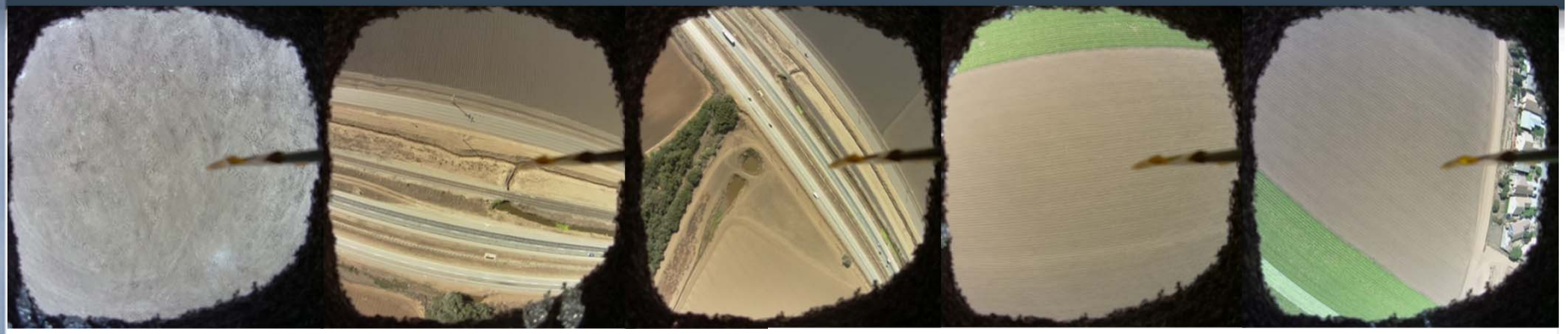
Picture X-Band Transmitter components

B205mini-i with Enclosure

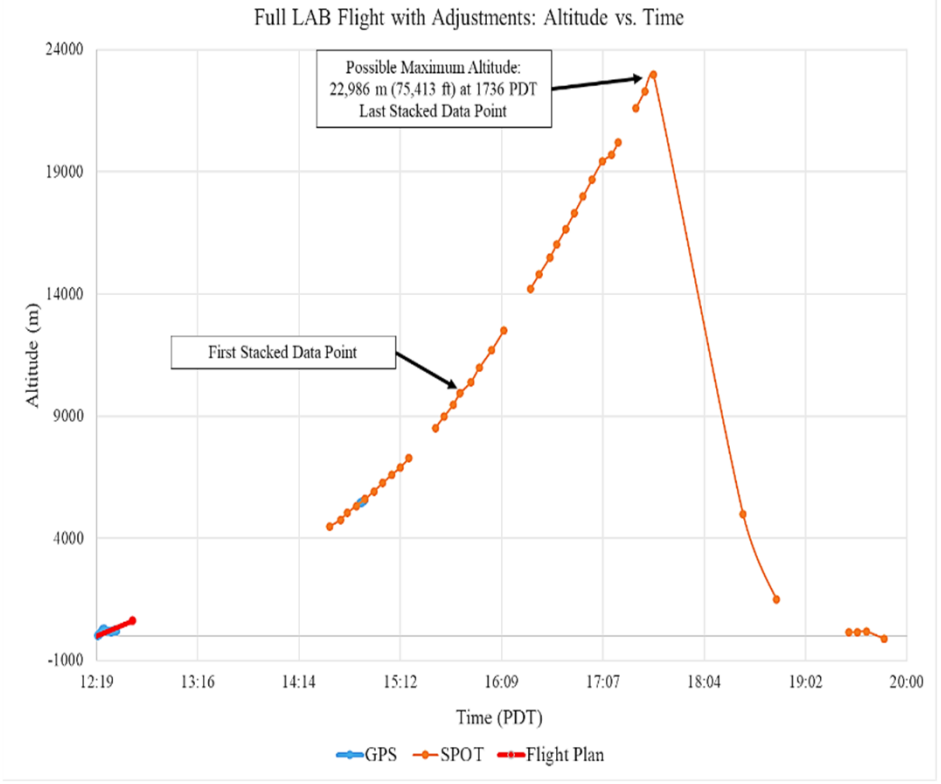
Raspberry Pi 3 Model B

NAVAL POSTGRADUATE SCHOOL

C-Band Results (History)



- Launched on 18 Oct 2018 at 1219 PDT from Chualar in Salinas Valley
- Successful test of C-band downlink
- Transmitted 5 images at max slant range of 1.1 km as proof of concept
- 480x640 images (67.5kB)
- Data Rate: 9600 baud
- Bus SW reset 11 min after launch
- Balloon release failed



NAVAL POSTGRADUATE SCHOOL

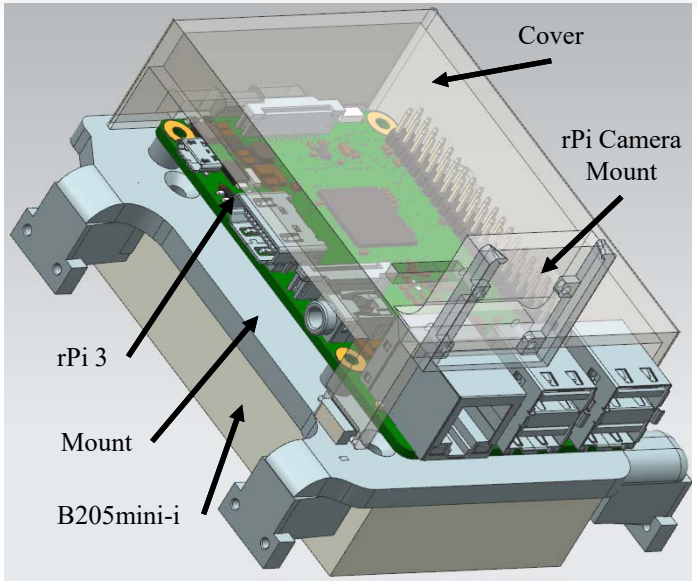
C-Band Hardware (History)

Payload

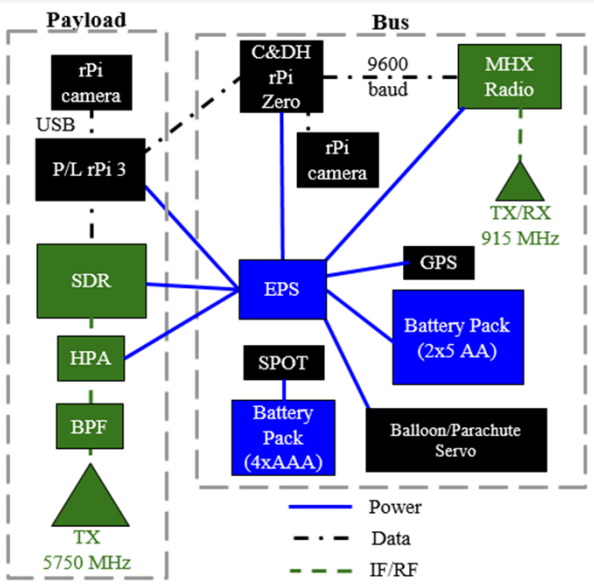
- SDR: B205mini-i
- Raspberry Pi 3 Model B with Camera
- Dipole Antenna
- Band Pass Filters
- Low Noise Amplifiers

Bus

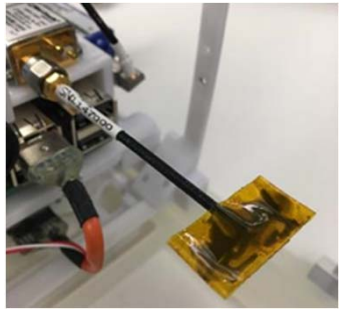
- EPS and Power
- C&DH
- GPS Receiver and SPOT Trace
- Balloon and Parachutes



NX Screen Capture of Com-Cube Payload

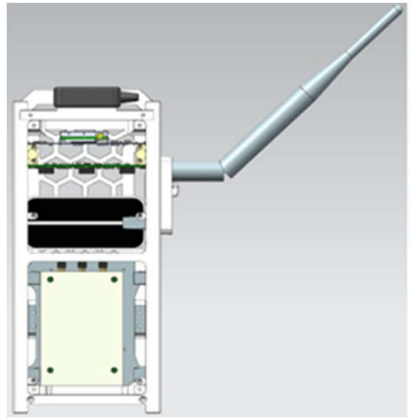


Com-Cube Interface Diagram



C-Band Dipole Antenna

C&DH and EPS PCBs



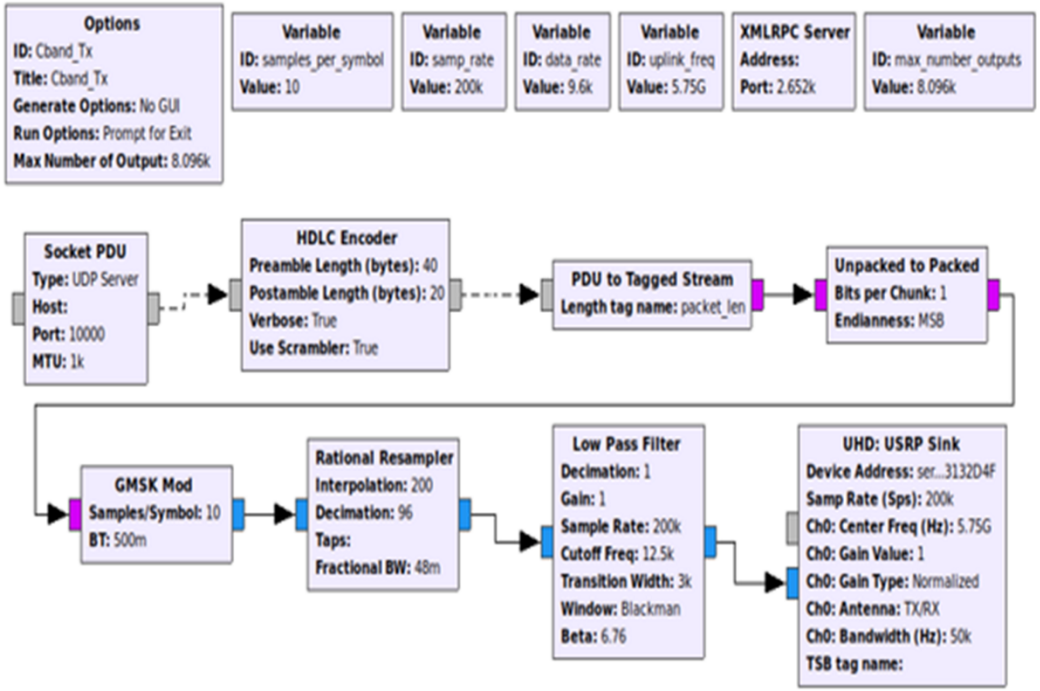
NX Screen Capture of Full Model

NAVAL POSTGRADUATE SCHOOL

C-Band Software (History)

C-Band GNU Radio Software Development Issues

- Desired:
  - Transmit imagery data near-real time with QPSK digital modulation scheme
- Challenges:
  - Deprecated flow graph blocks
  - Limited official documentation
  - Lacked knowledge to hard-code blocks
  - Ran out of time to develop new software
- Solution
  - Utilize software that already works: repurposed flow graphs and code used for communication with 3 on-orbit PropCube CubeSats from NPS MC3 ground station
  - GMSK digital modulation scheme
  - 9600 baud data rate (slower than desired)



GNU Radio Flowgraph for C-Band Transmitter

NAVAL POSTGRADUATE SCHOOL

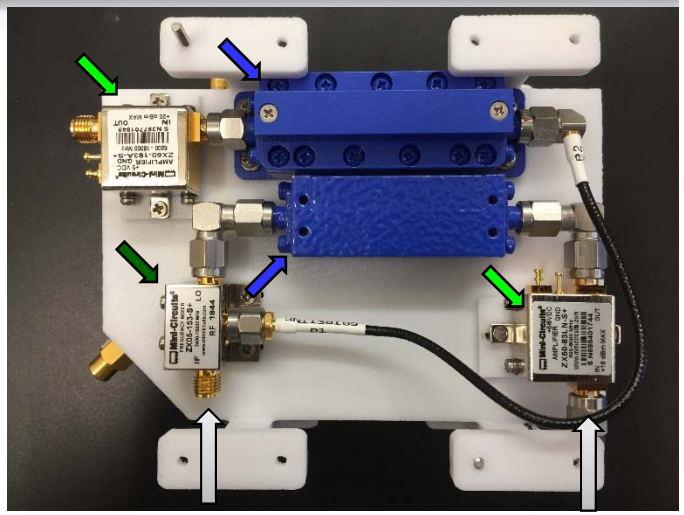
X-Band Hardware

From C-Band Project

- C&DH and EPS PCB
- Raspberry Pi 3B
- B205i mini
- ZX-60 series LNA

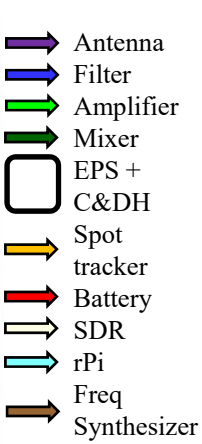
New Hardware

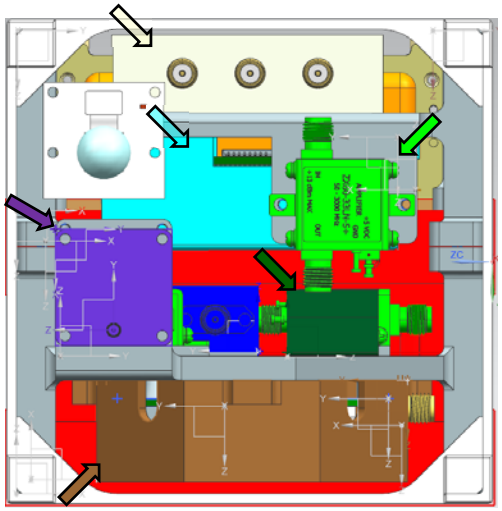
- Frequency Synthesizer (ADF-4365)
- Filters (ZVBP-8250)
- Mixer (ZX05-153-S+)
- Additional Amplifiers (ZX-60-83LN & ZX60-183A)
- X-Band Patch Antenna (Endurosat)



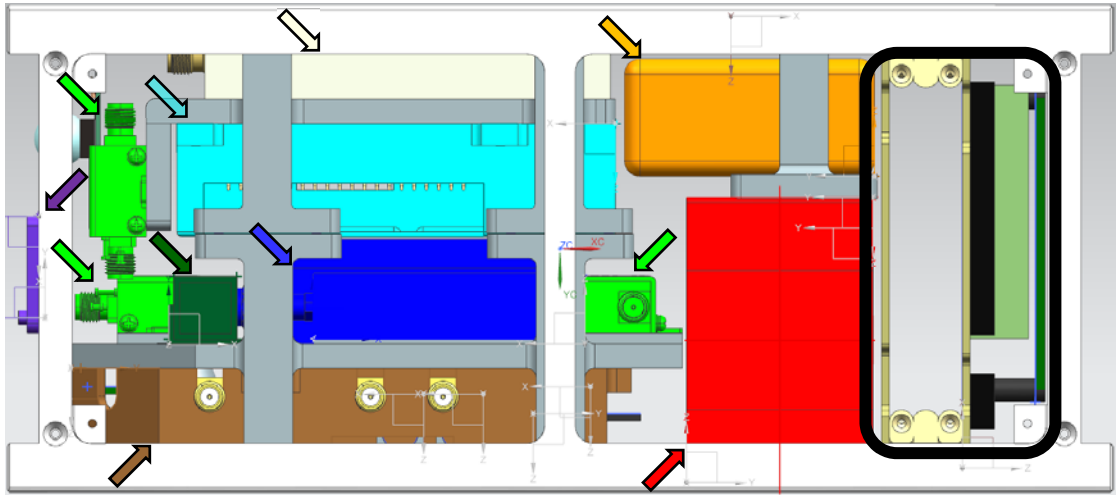
From SDR Amp From LO

Picture of frequency upconvertion components





NX Diagram of X-Band Payload (Bottom)



NX Diagram of X-Band Payload (side)

NAVAL POSTGRADUATE SCHOOL

X-Band Software

GNU Radio

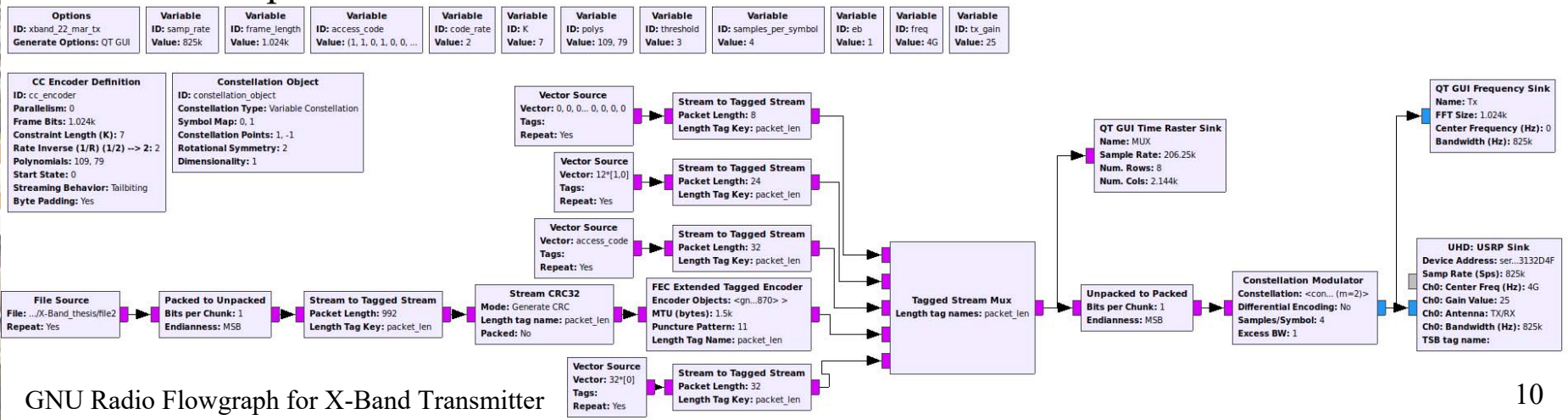
- Provides signal processing blocks to implement SDRs
- Program based in and generates Python/C++ code

Software Development

- Desired:
  - QPSK digital modulation scheme
  - FEC
  - 1 Mbps data rate
- Challenges:
  - Limited official documentation
  - Lacked knowledge to hard-code blocks

Solution

- Fixed frame length
- BPSK digital modulation scheme
- FEC
- Currently 100-200 kbps (limited by rPi)



GNU Radio Flowgraph for X-Band Transmitter

NAVAL POSTGRADUATE SCHOOL

X-Band Testing

SW Testing

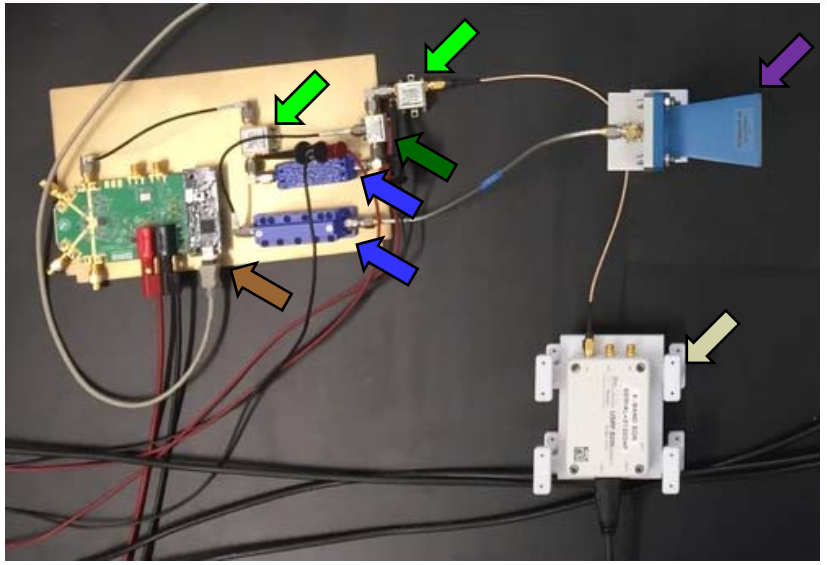
- GNU Radio simulations (without HW)
- Introduced HW
  - Over coax cables
  - Over air with horn antennas

Component-Level Testing

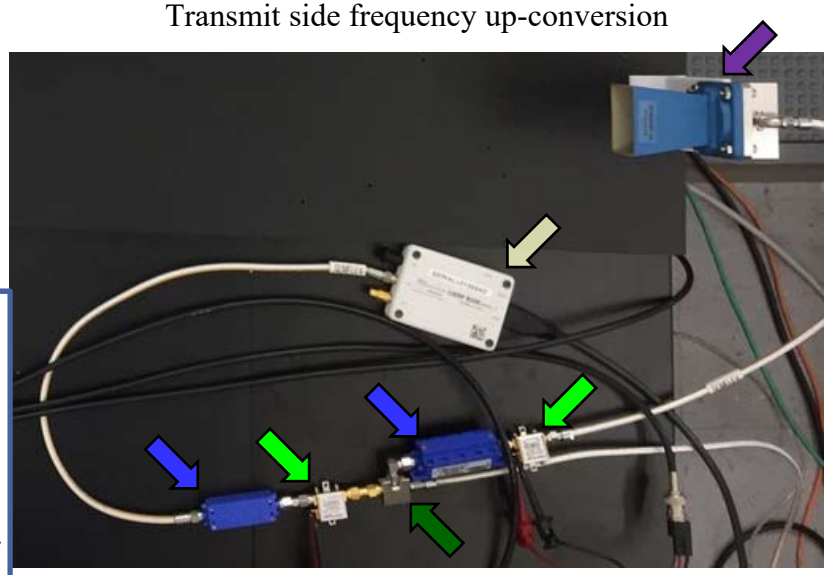
Integration Testing

Future Testing

- System Level testing
- Environmental Testing (Thermal-Vacuum and Vibration)



Transmit side frequency up-conversion

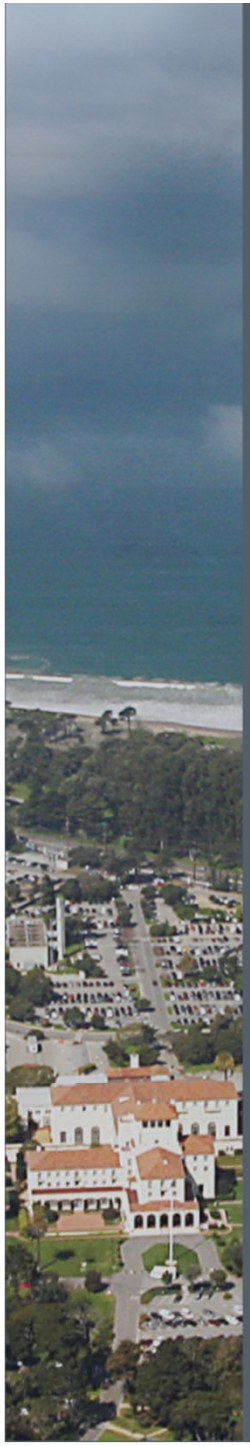


Transmit side frequency down-conversion

NAVAL POSTGRADUATE SCHOOL

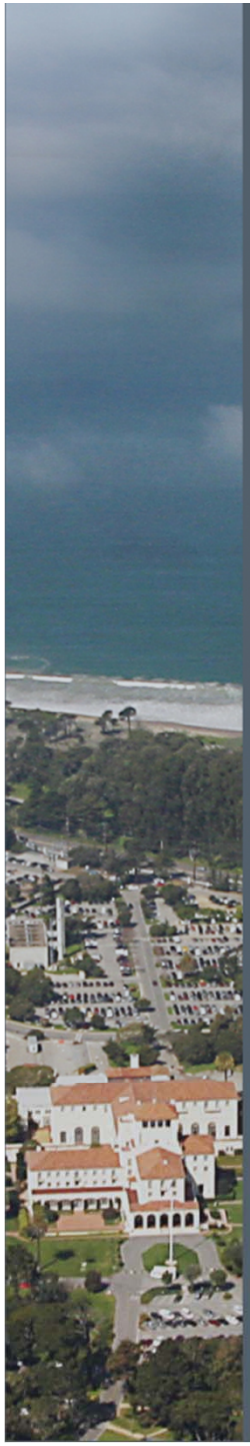
Future Work

- Improve software (GNU Radio code) or utilize a higher performance processor to enable 1 Mbps data rate
- Integrate frequency up-conversion components (LO, filters, mixers, amplifiers) onto a single custom PCB (smaller form factor, less power)
- Design and create a space flight-suitable metal housing to hold rPi, SDR, and custom PCB



NAVAL
POSTGRADUATE
SCHOOL

Acknowledgements



NAVAL
POSTGRADUATE
SCHOOL

Questions?