SPACE HAUC

Science Program Around Communication Engineering with High Achieving Undergraduate Cadres

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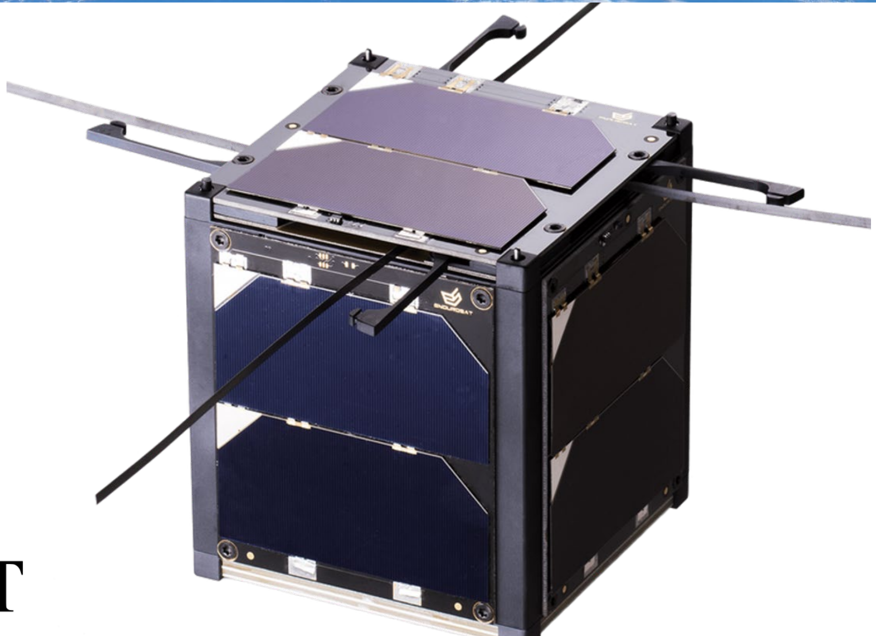
NASA

Cube Satellites

- Cube Satellites (CubeSat) are standardized small satellites
- Standard unit ‘U’ with dimensions of 11cm x 10cm x 10cm and mass of 1.3 kg
- Used for educational purpose, technology demonstration and scientific research
- Usually deployed from International Space Station (ISS)
- Mostly built using Commercial of-the-shelf (COTS) parts

Picture courtesy: Nanoracks



Picture courtesy: GomSpace Inc.

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Undergraduate Student Instrument Project (USIP)

- Educational flight opportunity
- Earth or space science payload design, competitively selected
- Payload to be deployed on sounding rocket, balloon, aircraft or commercial suborbital launch vehicles
- Promotes interest in STEM research
- Provides students with experience and career opportunities

The SPACE HAUC team describing their project to distinguished visitors. From left, undergraduate students Simthyrearch Dy, project manager, and Sanjeev Mehta, communication systems lead. The visitors include James Green, NASA chief scientist, Megan Donahue and Bob Twiggs, inventor of CubeSat.

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About SPACE HAUC

- SPACE HAUC is an undergraduate students-led Cube Satellite mission at UMass Lowell
- Funded by NASA under USIP, receiving technical assistance from various other industry partners
- 3U CubeSat: 34 x 10 x 10 cm^3 and 3 kg
- Provide undergraduate students with an opportunity to work on a satellite project
- Demonstrate practicality of a student developed high data rate (50-100 Mbps) X band communication system with beam steering capability using a phased array antenna
- Designed entirely around COTS components
- ISS Orbit: 400 km and 51.6º inclination

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About Us

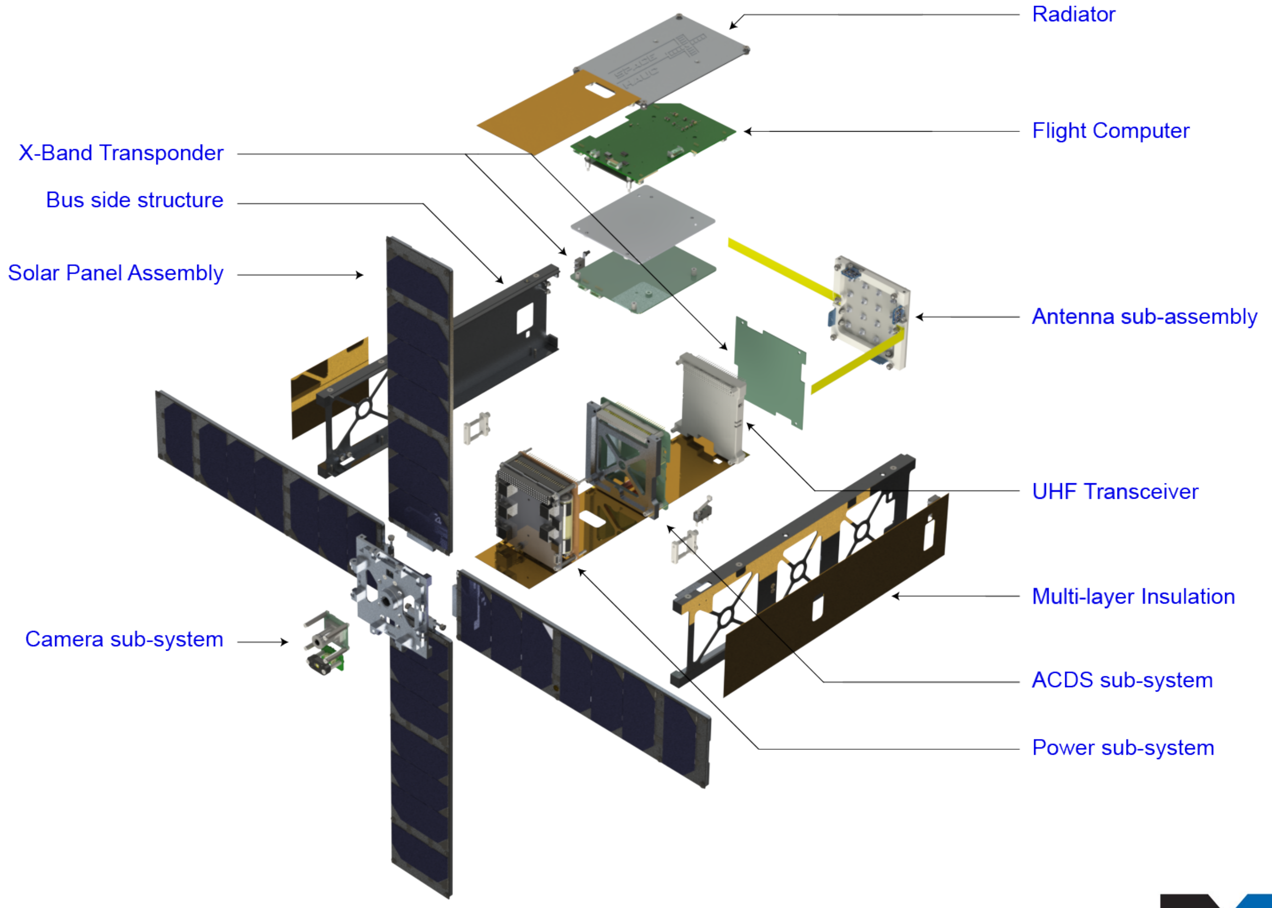
- Every aspect of the spacecraft design (except for power system) is developed in house
- Testing methodology and utilities also developed in house
- Enables students with the opportunity of learning mission and systems design in a very on-hand approach
- Provides students with experience in combining hardware and software

Applications of Phased Array Systems

- High resolution remote sensing
  - Most CubeSats without propulsion system
  - Life is 1-2 years, and then burn out in atmosphere
  - Need to transfer huge amount of data while in orbit
- Low latency and uninterrupted communication
  - Constellation of CubeSats
  - Need cross-link and downlink capability
- Increased link time with phased array
  - With beam steering capability spacecraft does not need to be overhead to complete link
  - Higher gain

Sub-Systems

- ***Attitude Determination and Control***: Guides and navigates the spacecraft to a detumbled state
- ***Command and Data Handling***: Responsible for all software controls and tools
- ***Communications***: Designs and builds the primary X-band and UHF communications system
- ***Ground Station***: Builds and controls the ground station to communicate with the spacecraft
- ***Power***: Generates, stores, and distributes electrical power to all components and systems
- ***Structures***: Designs the structural chassis to mount all components
- ***Thermal***: Controls and regulates the satellite's components and systems



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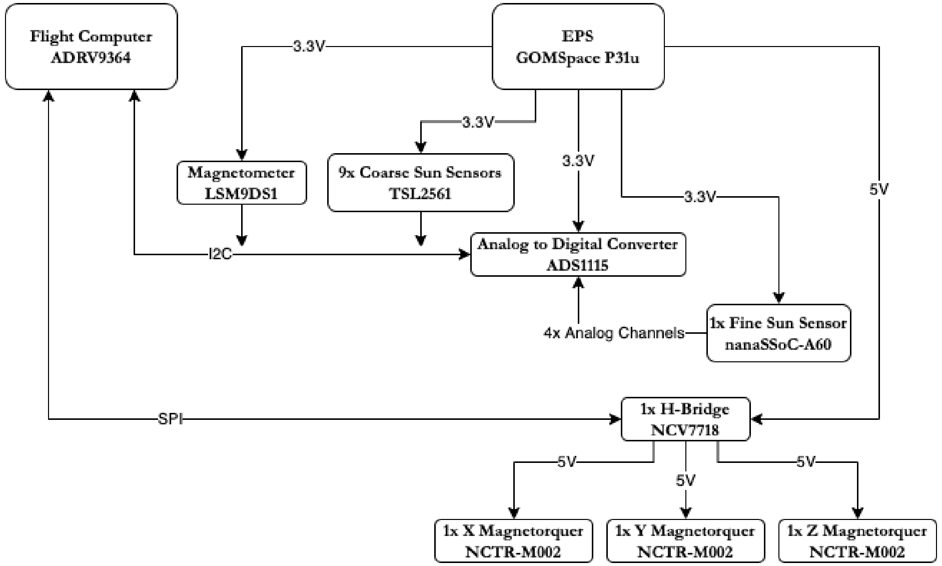
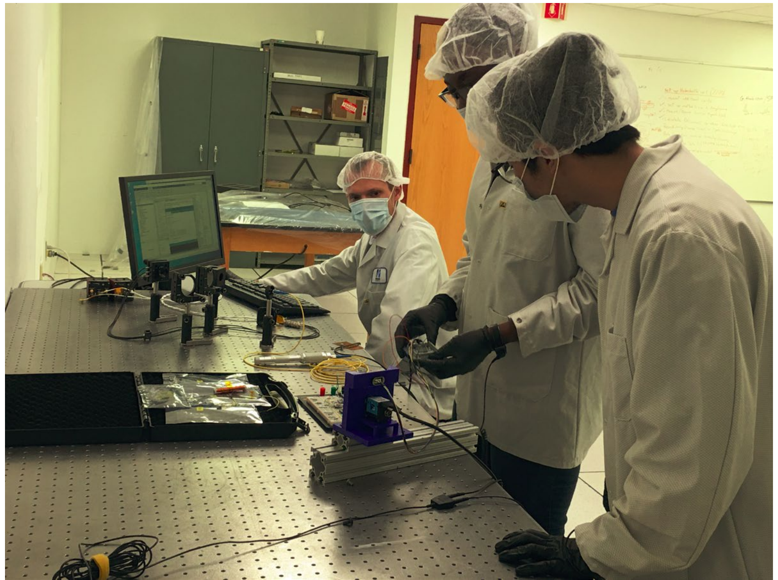
Technical Details

Attitude Determination and Control (ADC)

- Corrects initial random tumbling of the spacecraft post-launch from ISS
- Uses a magnetometer to determine angular speed and magnetic coils for attitude correction
- Can measure and correct angular speed up to 300 rpm
- Initially aligns spacecraft spin axis to the longest body frame axis within 4°, and spins up to 10 rpm (detumble mode)
- Then tracks the Sun in the sky and aligns both the spin axis and the longest body frame axis to the Sun within 4° (sun-pointing mode)
- Uses a collection of lux sensors to determine position of the sun in the sky





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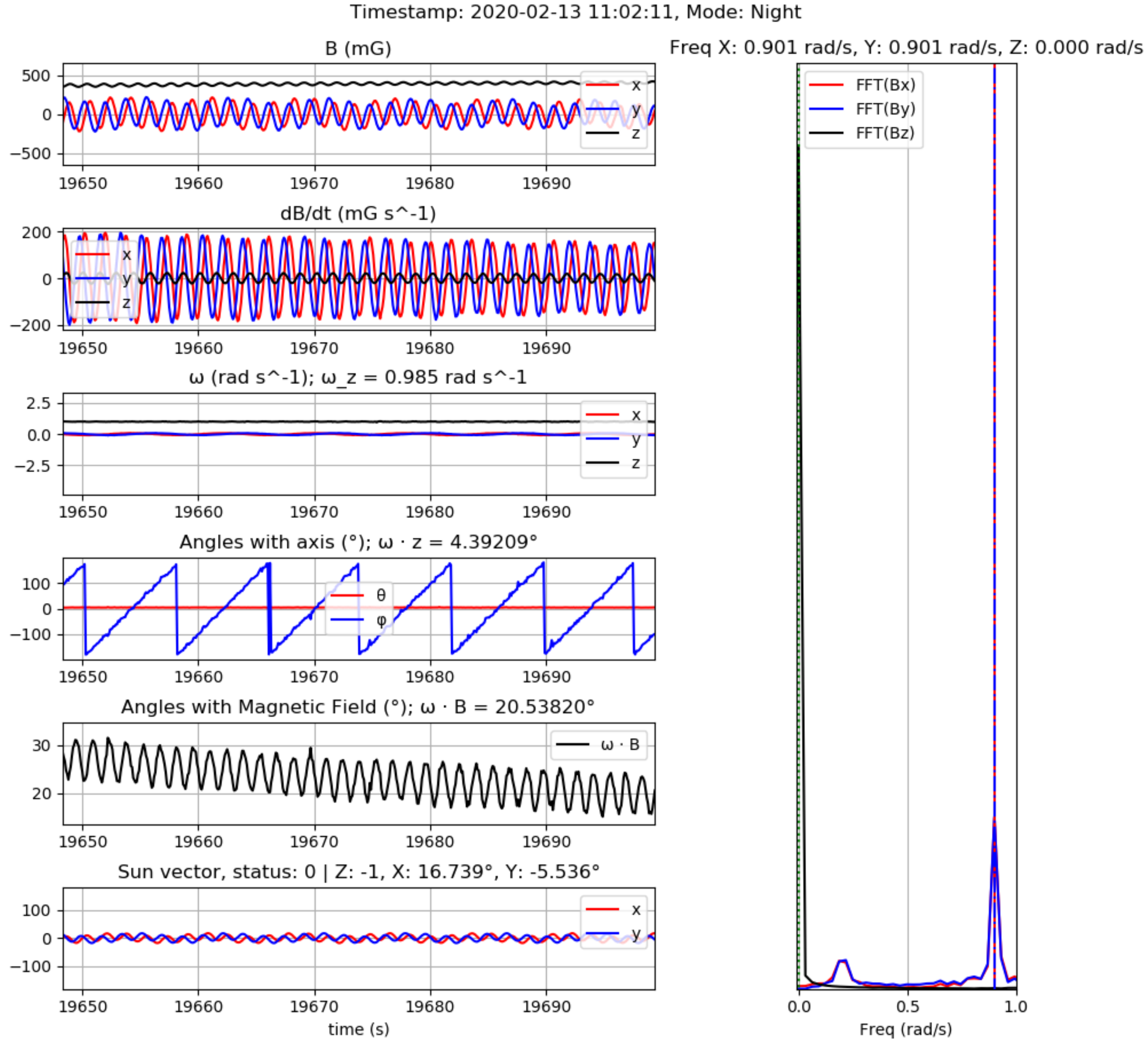
ADC Testing

- Custom MATLAB/Simulink routine that
  - Generates spacecraft orbit using STK software
  - Calculates (and generates) magnetic field as perceived by the satellite
  - Calculates position of the Sun and the Earth as seen by the satellite and generates light that would be perceived by the lux sensors
  - Reads in satellite's reaction
  - Updates satellite attitude as necessary
- Custom hardware for magnetic field generation and update at 200 Hz rate
- Collection of LEDs and piezoelectric mirrors for Sun and Earth simulation driven by Arduino®



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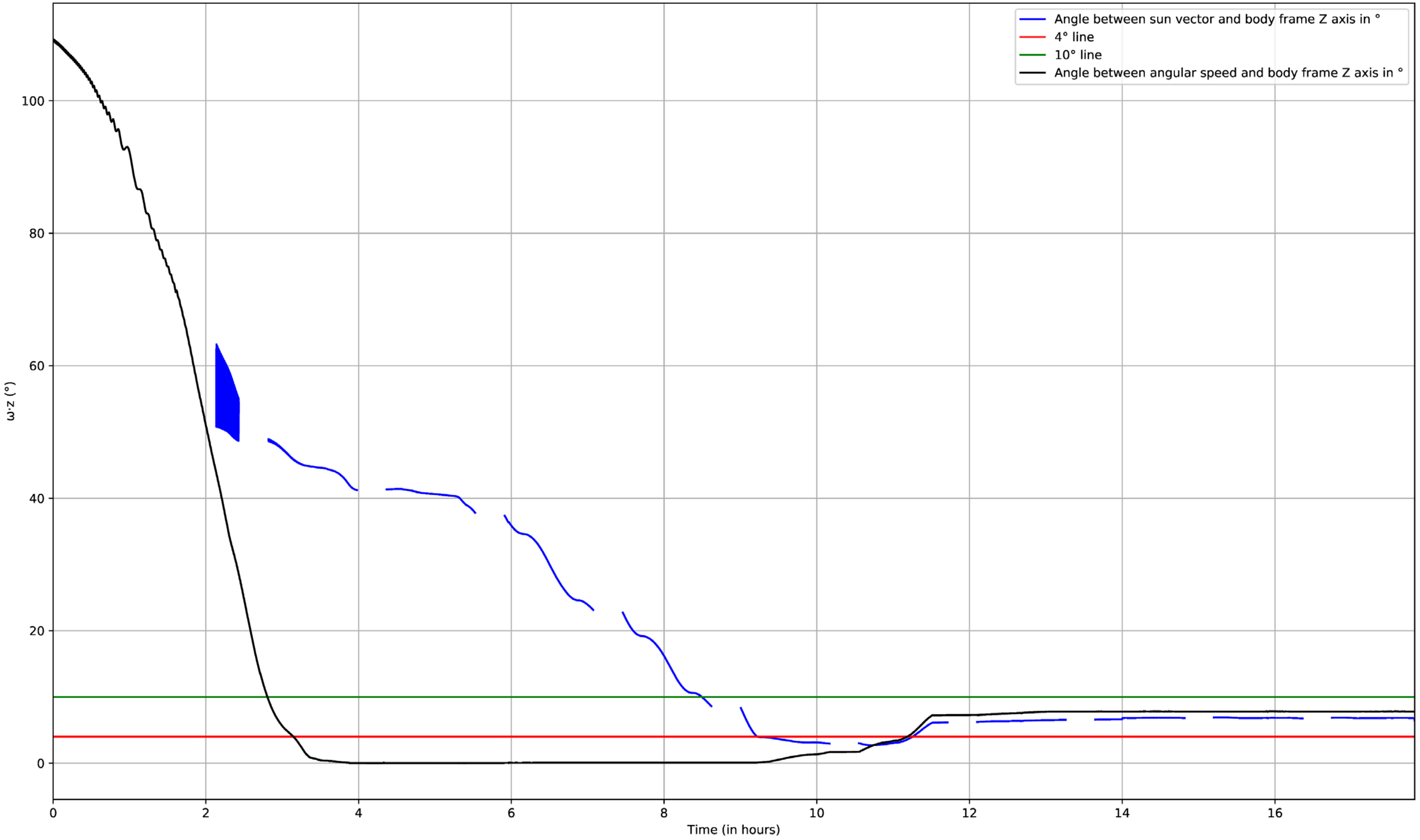
ADC system test result

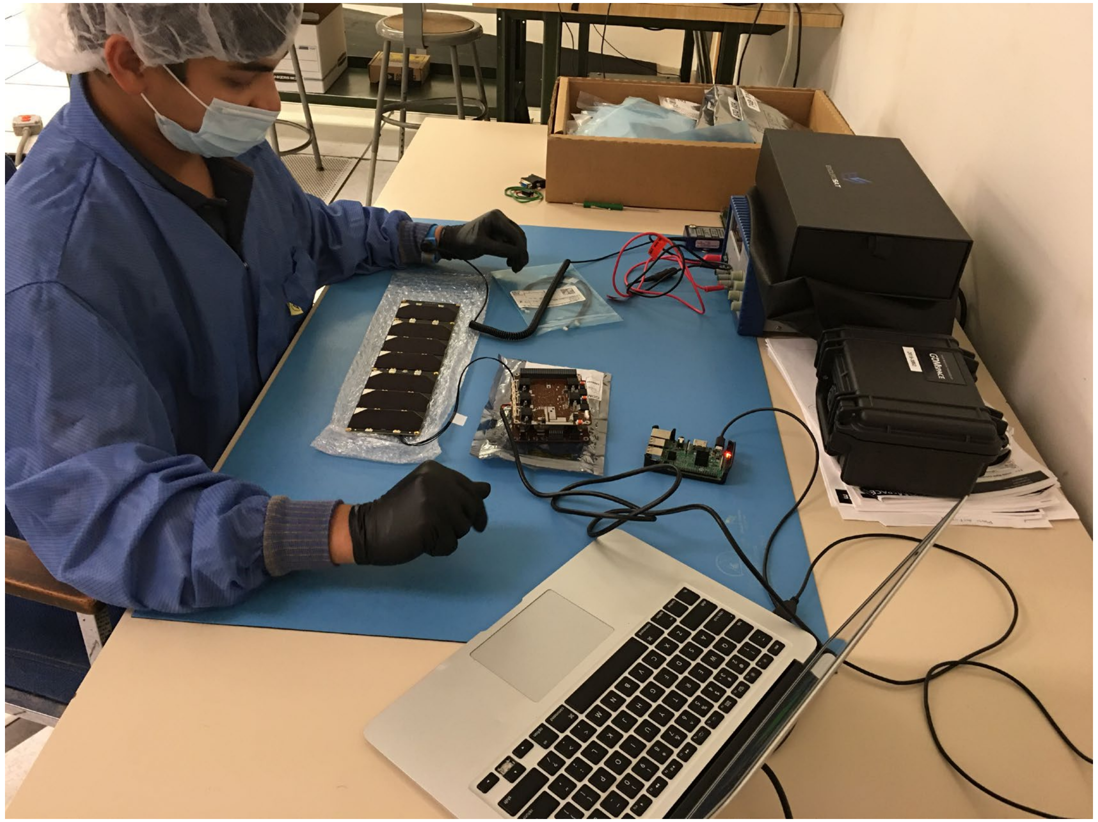


Command and Data Handling

- Controls all operations of the spacecraft
- Modules are written to handle ACS, power management, telemetry data collection, data transmission over UHF and X-Band radio systems
- Implemented in ANSI C99 and designed to execute in the Linux user-space
- Modular design where every subsystem is a POSIX thread with shared memory space for inter-process communication

Power

- On-board:
  - 4 solar panels with up to 32W charging
  - 4 lithium-ion cell battery pack with 38.5 Wh capacity
  - Electrical Power System unit for controlling power to sub systems
- Provides watchdog functionality for system reset in case of a stall



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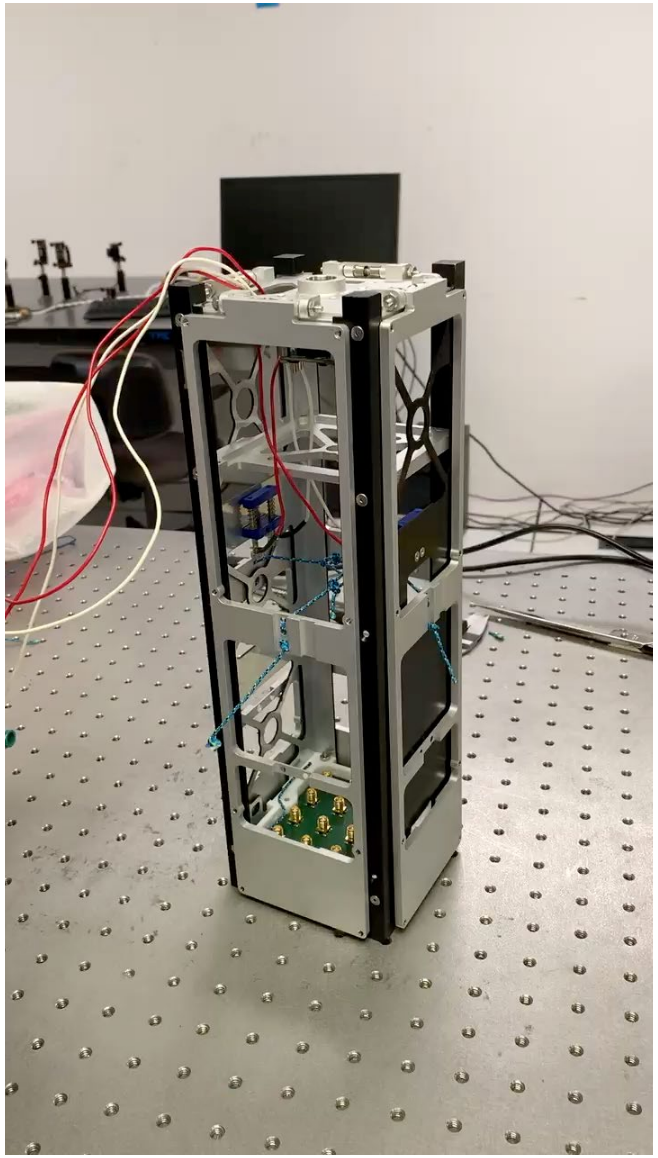
Structures

- Custom designed 3U chassis
- Designed and built by students for this mission
- A custom deployment system is designed to deploy solar panels upon launch from ISS



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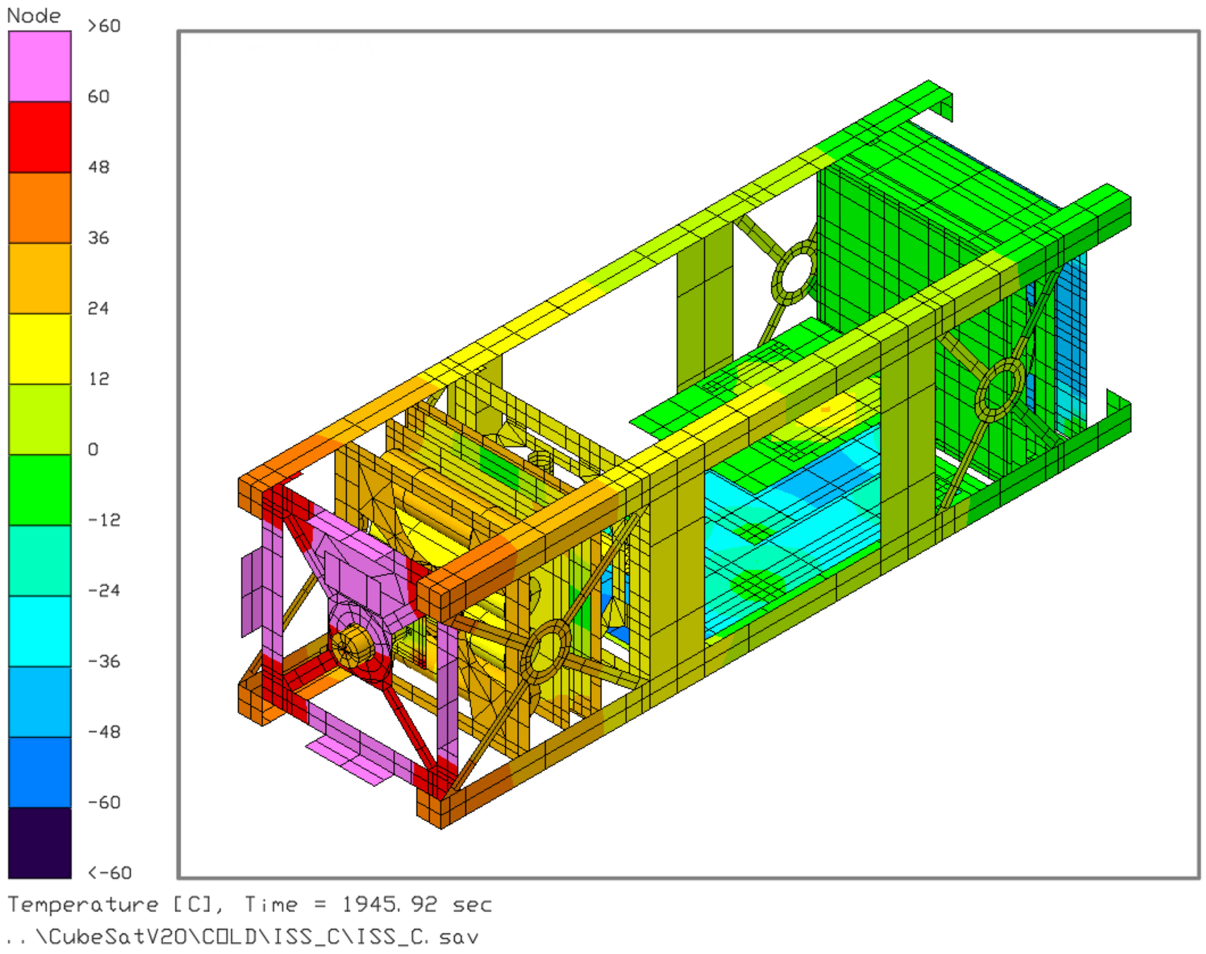
Thermal

- Thermal model is under development for verification via thermal-vacuum testing
- Using copper straps to extract heat from electronic components
- Chassis of the spacecraft acts as a radiator



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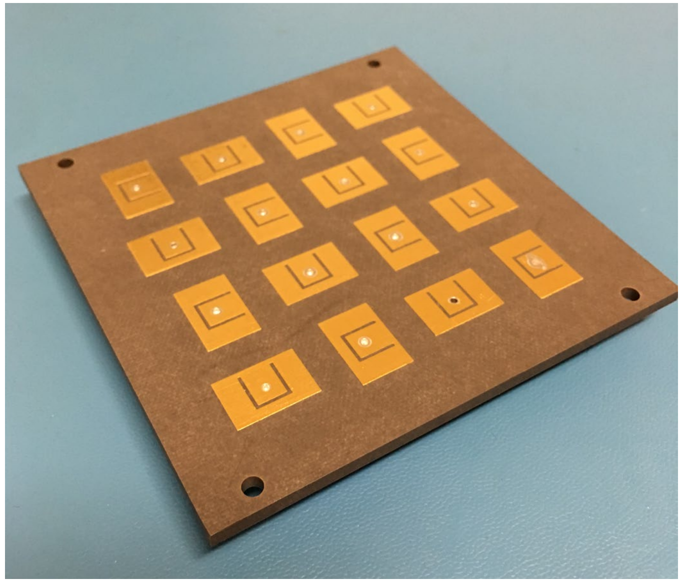
X-Band Communication System

Uplink	Downlink
• UMass Lowell Ground Station	• MIT Haystack Ground Station
• 1.7 m dish	• 18 m dish
• Frequency: 7.2 GHz	• Frequency: 8.35 GHz
• Bandwidth: 2 MHz	• Bandwidth: 40 MHz
• Modulation: OQPSK	• Modulation: OQPSK



On-board Phased Array System:

- Data rate: up to 61.44 Mbps
- Transmitter power: 1.8 W
- Receiver sensitivity: -100 dBm
- $\leq 5^{o}$ beam steering error
- CubeSat standard 3.3V and 5V
- Tx Electrical Power: 28 Watts
- Rx Electrical Power: 12 Watts

Antenna

- 4 x 4 Elements
- Polarization: Right Hand Circular
- Antenna Gain: 16.6 dBi
- Beamwidth: 25^{o} (FWHM)
- Steering capability: $\pm 45^{o}$
- VSWR 2:1 match band: 7 to 8.5 GHz

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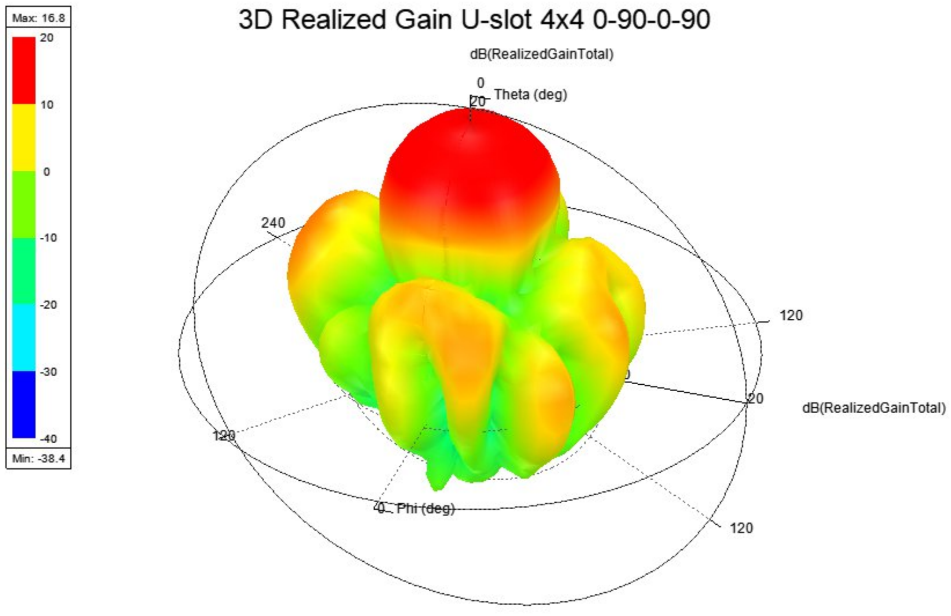
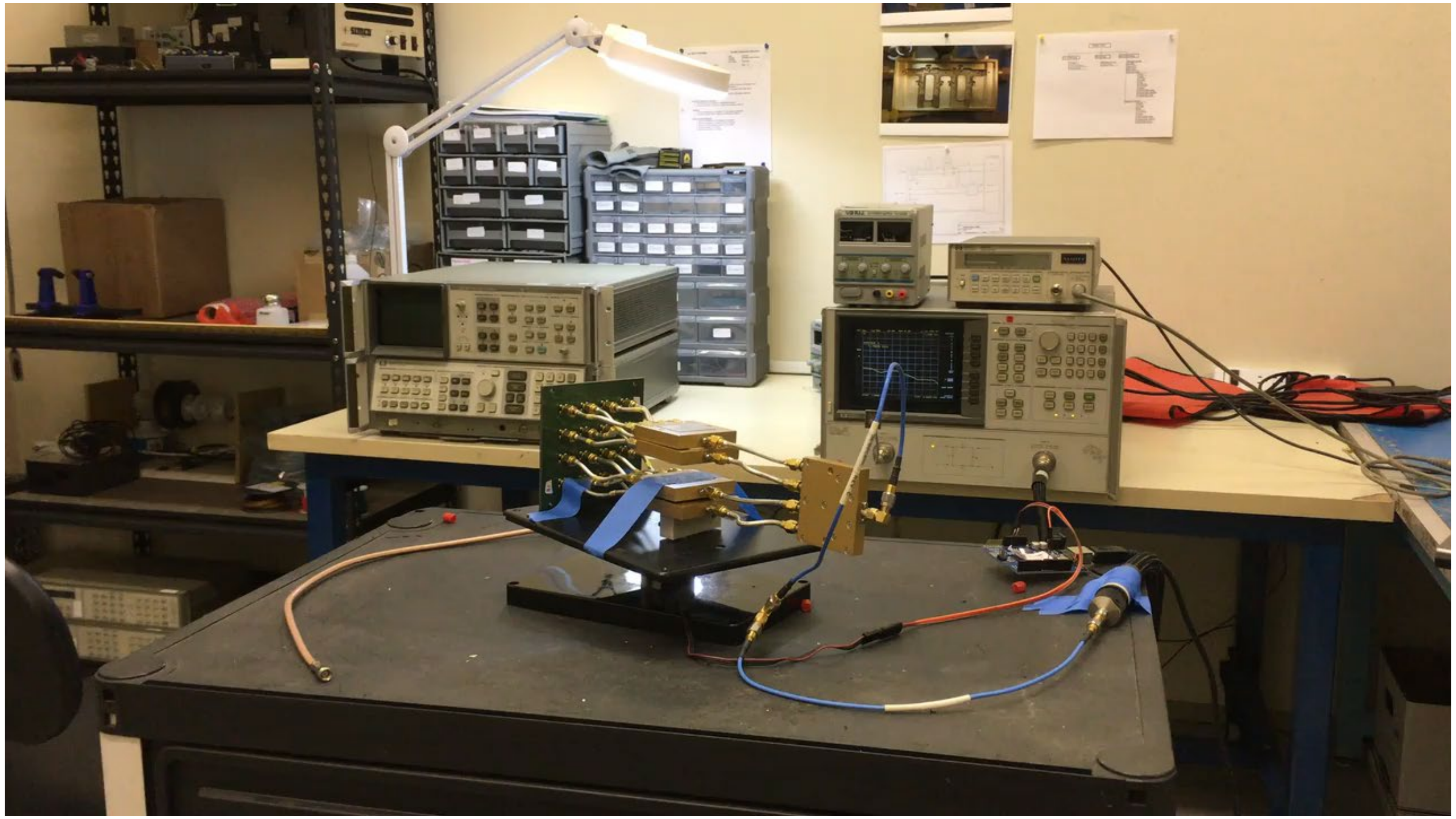
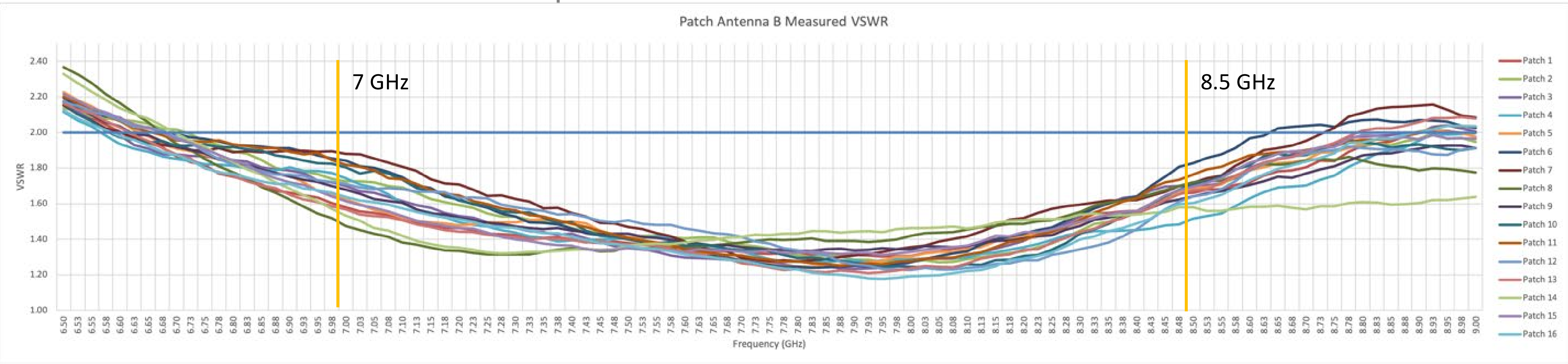


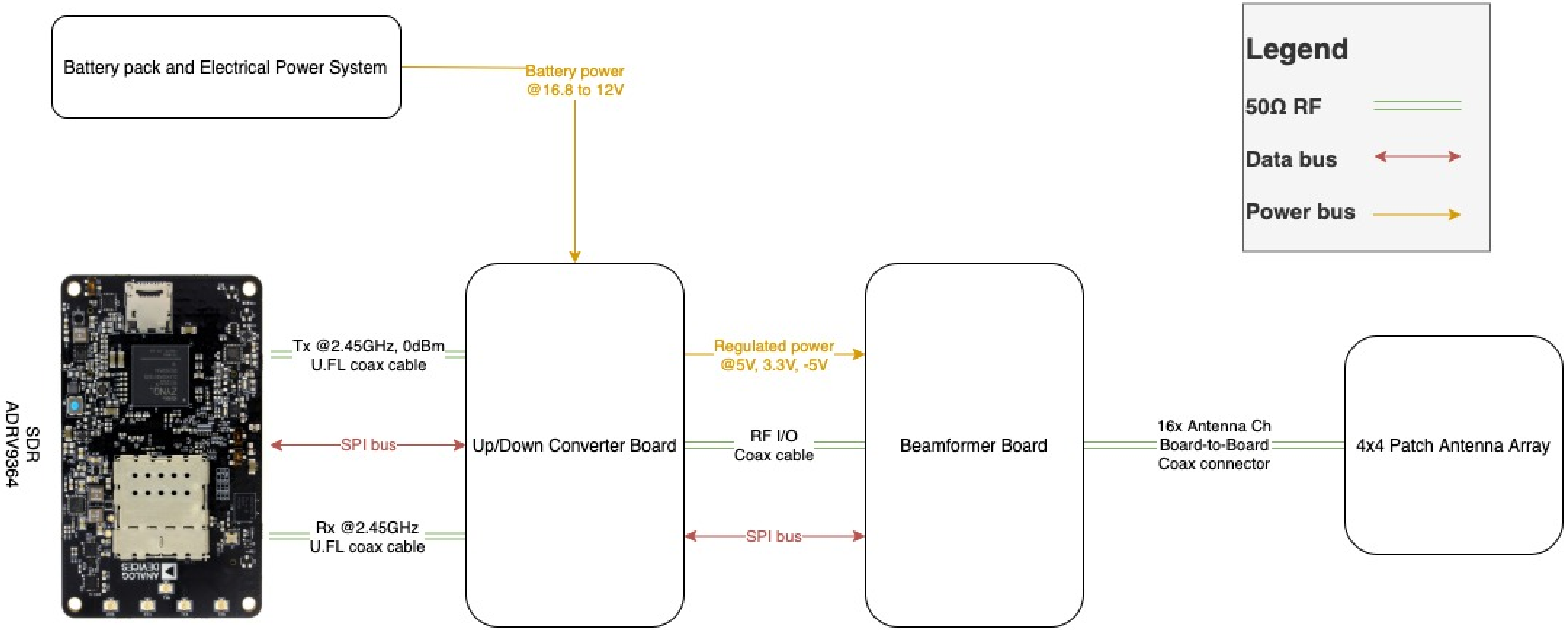
Max: 16.8
20
10
0
-10
-20
-30
-40
Min: -38.4
3D Realized Gain U-slot 4x4 0-90-0-90
dB(RealizedGainTotal)
0
Theta (deg)
20
240
120
120
20
dB(RealizedGainTotal)
120
0 Phi (deg)
120





Patch Antenna B Measured VSWR
7 GHz
8.5 GHz
VSWR
2.40
2.20
2.00
1.80
1.60
1.40
1.20
1.00
Frequency (GHz)
Patch 1
Patch 2
Patch 3
Patch 4
Patch 5
Patch 6
Patch 7
Patch 8
Patch 9
Patch 10
Patch 11
Patch 12
Patch 13
Patch 14
Patch 15
Patch 16

X-Band System Design



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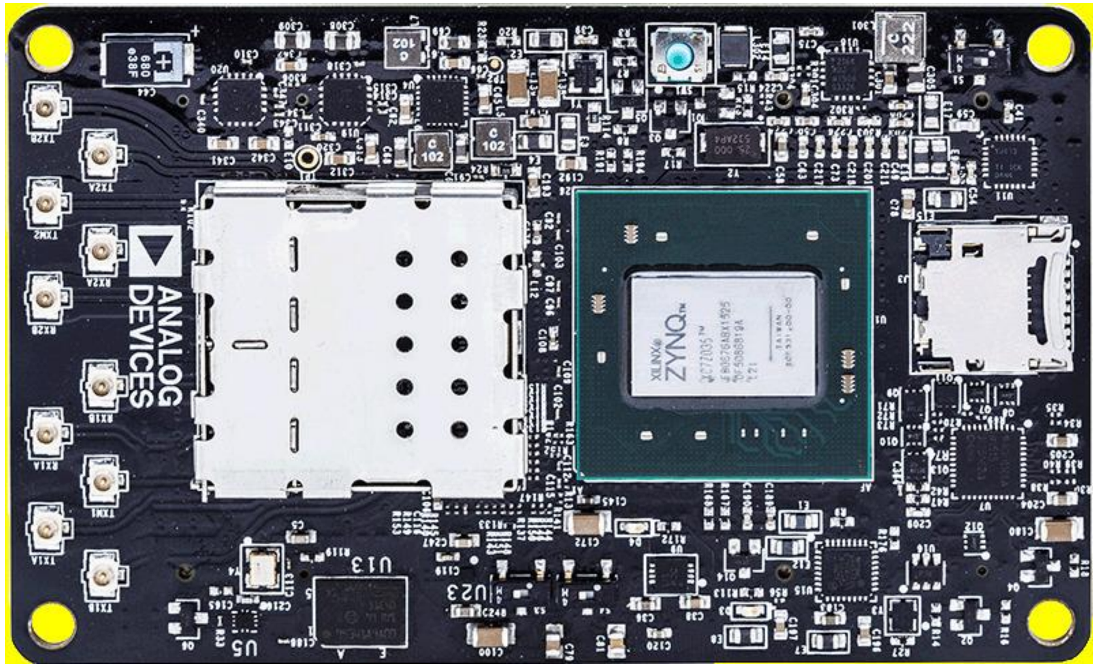
X-Band Back End

- AD9361 baseband transceiver
- Tunable bandwidth from 20 kHz to 56 MHz
- Programmable 128-tap Finite Impulse Response Filter
- Software defined radio, baseband modulation and demodulation performed using onboard FPGA
- On board ARM processor which is used as flight computer



Picture courtesy: Arrow

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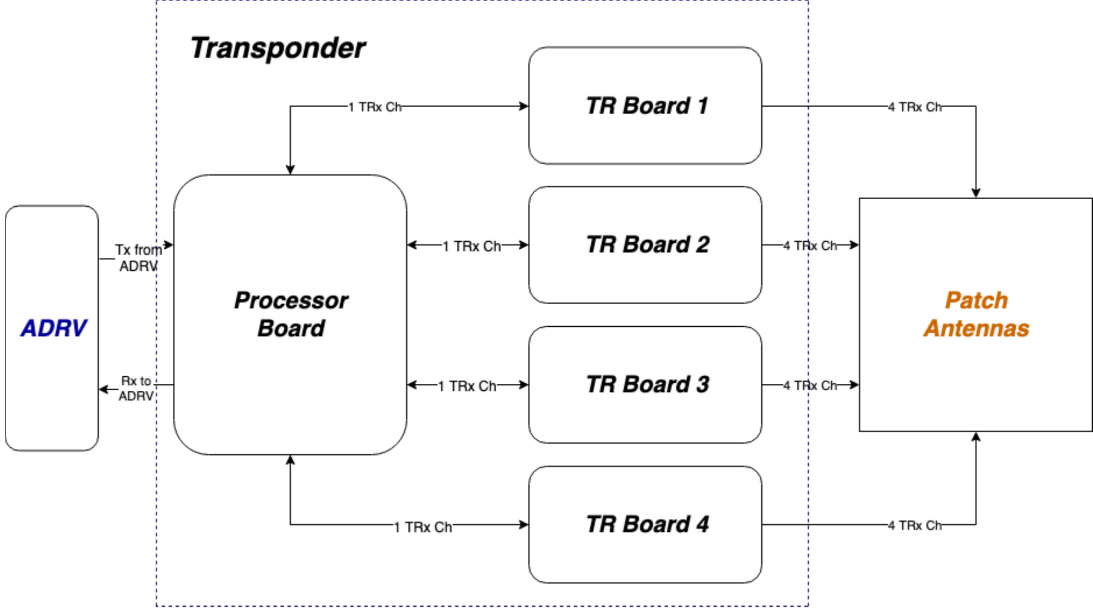
X-Band Front End v1.0

- Up-down conversion mixes baseband signal and local oscillator frequency
- Beam forming using individual phase shifters and amplifiers
- Beam forming requires 1 PCB for every 4channels, high area consumption
- Schematic of design done in house, layout and fabrication done through external vendor
- Extreme loss of signal on traces because of digital-like layout



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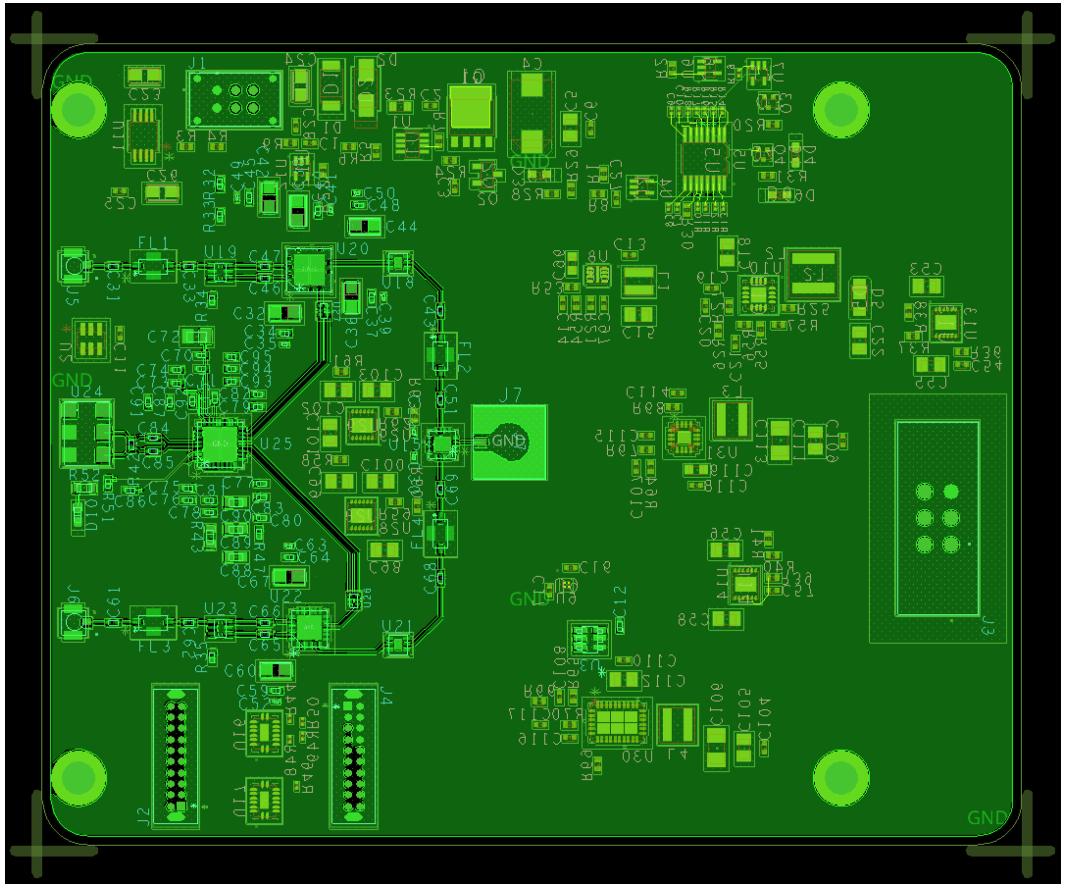
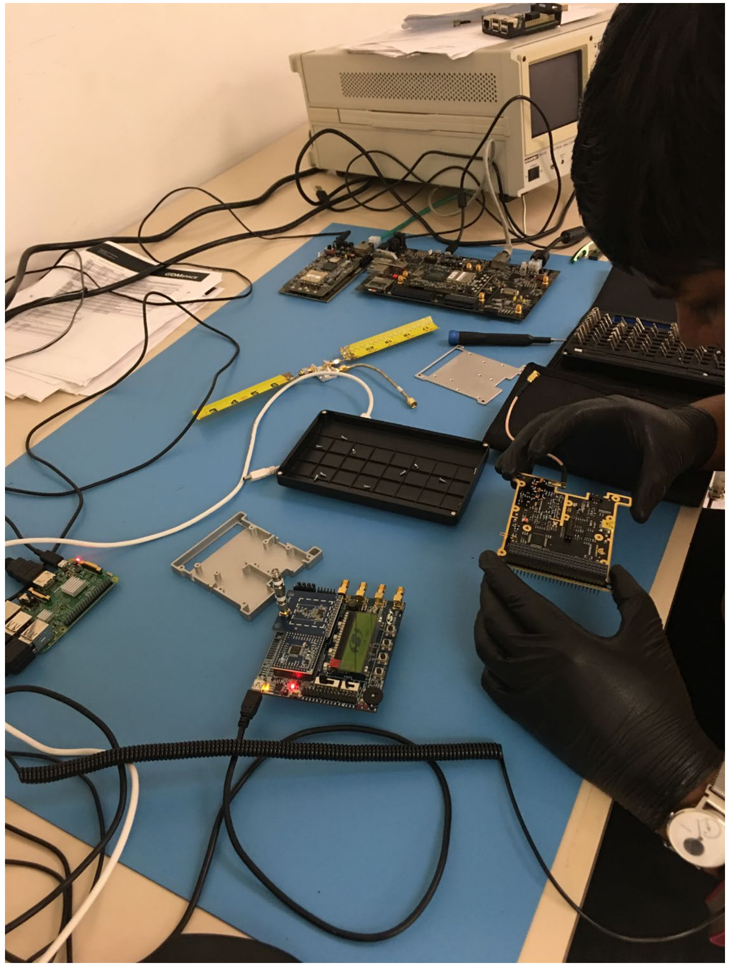
X-Band Front End v2.0

- Up-down conversion mixes baseband signal and local oscillator frequency
- Beam forming using single ADAR1000 that can drive 4 channels at once, one board can fit complete beamforming system for 16 channels
- Schematic of design is done, layout in progress in house



UHF Communication System



- Included as an always-on communication system after stabilization
- Can transmit telemetry data upon request from ground
- Can receive system commands and software updates (planned)
- Using Si446x based transceivers
- Software implemented for half-duplex communication, planned upgrade to full-duplex.

Frequency band: 430 – 440 MHz
Bandwidth: 14.4 kHz
Modulation: 2-GFSK

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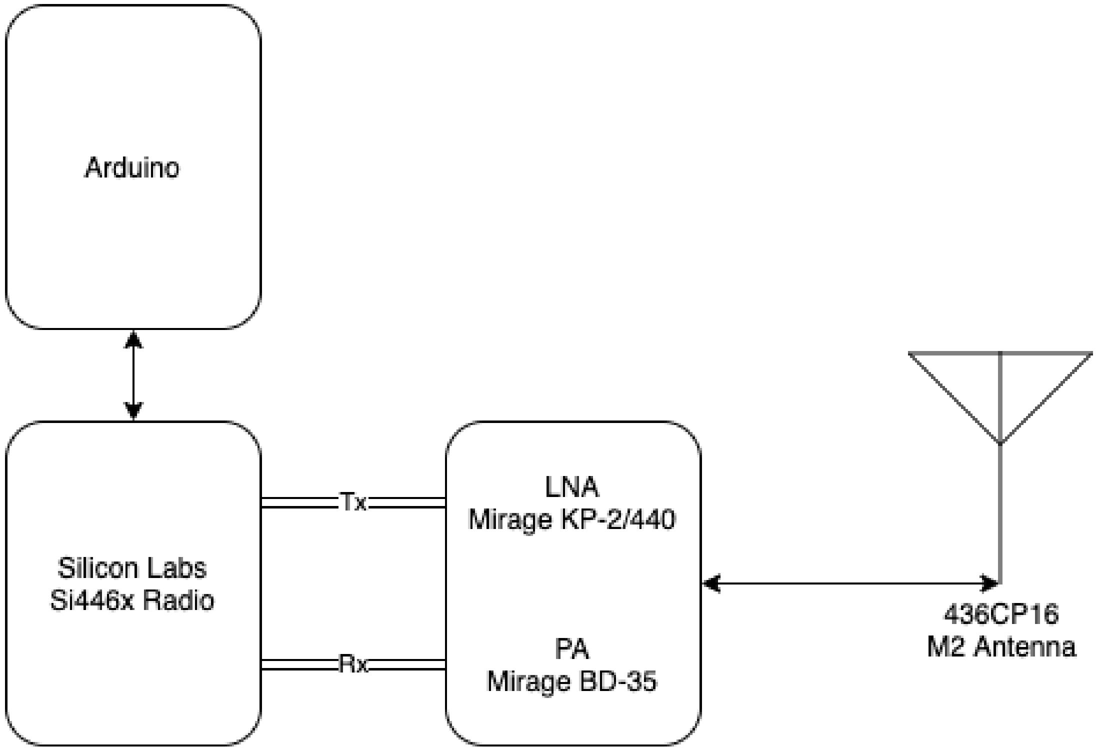
UHF Communication System

On-board System:

- Data rate: 9600 bps
- Transmitter power: 1 W
- Receiver sensitivity: -100 dBm
- Tape measure dipole antenna
- Polarization: Linear

Ground Station:

- On-campus UMass Lowell
- Yagi Antenna–M2 Antenna, 436CP16
- Polarization: RH Circular



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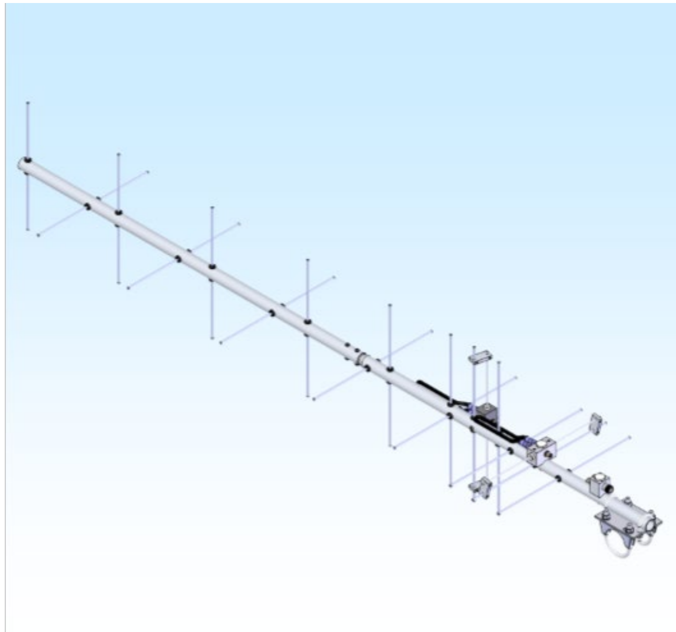
Ground Station

X-band uplink G.S at UMass Lowell

X-band downlink G.S at Haystack

UHF G.S. at UMass Lowell



Picture from M2 Antenna website

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Community Involvement

- Review of our experiment plan
- Verification of radio operating plan
- Ensuring no interference with amateur radio activity in the area
- Possibility of using SPACE HAUC as a repeater post science mission success

NVARC
Nashoba Valley Amateur Radio Club

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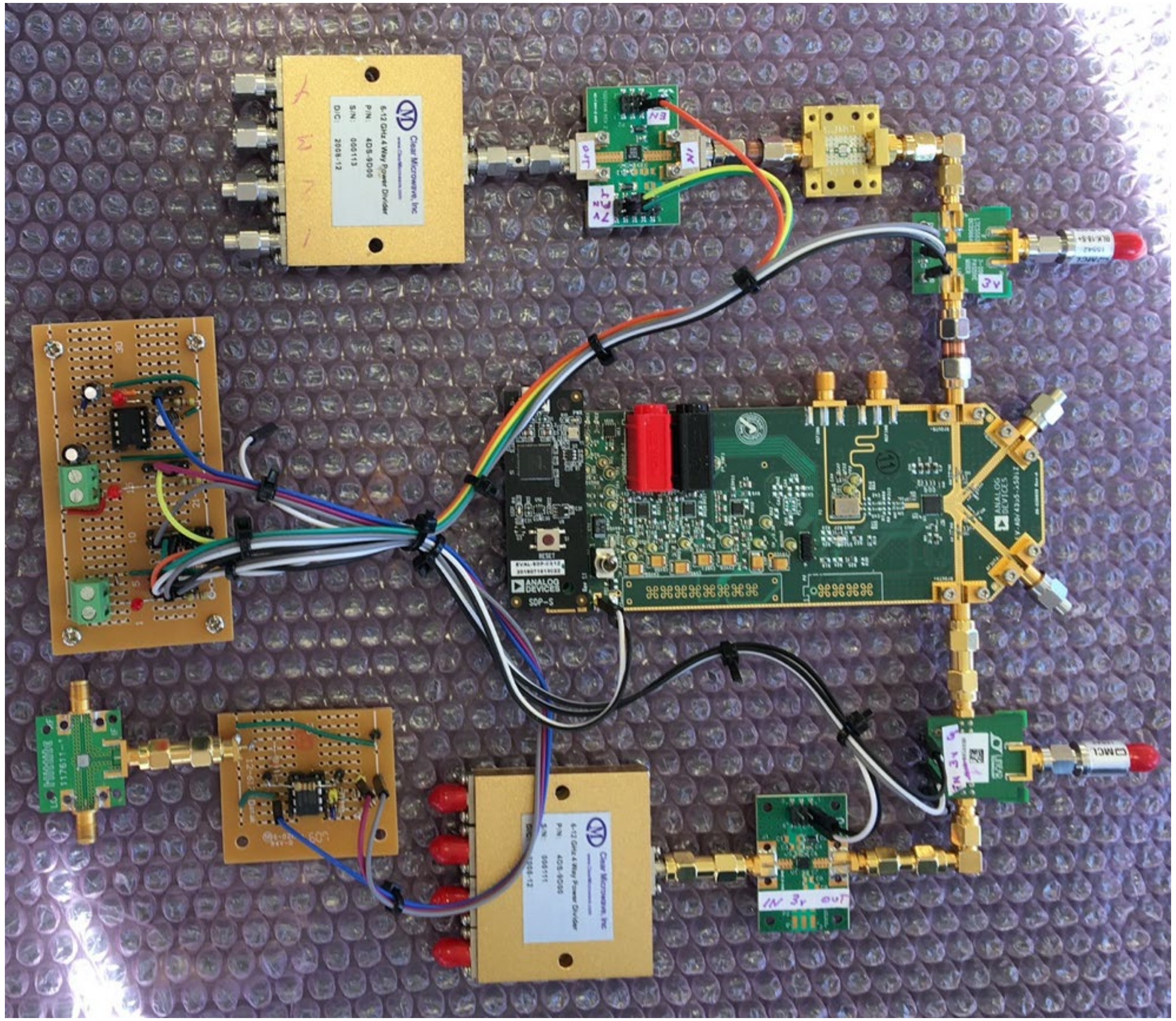
Thank you!
Questions?

-Ad Astra

Backup Slides

UDC chain test



v1.0 beamformer single channel