3UCubed: Ground Station Operations

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https://imap.princeton.edu/engagement/student-collaboration

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OVERVIEW

- 3UCubed CubeSat: A Student Collaboration under NASA's IMAP Mission
- Ground Station's Role in UHF CubeSat Missions
- System Architecture
- Ground Station Testing
- Link Budget Breakdown
- Challenges and Solutions

NASA's IMAP Student Collaboration: 3UCubed

Program Goals

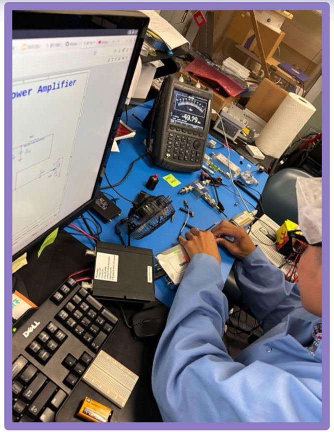
1	*We aim to complement NASA's IMAP mission science research*
2	*develop a hands-on research experience for students*
3	*develop the talent pipeline in space science and engineering.*

Project Overview

- Partnership between 3 Universities with diverse student enrollment:

  Howard University, Sonoma State University and University of New Hampshire

- Collaborate to **design, build, test and launch a 3UCubeSat**



3UCubed: 3 Universities; 3U CubeSats; Upwelling, Uplifting Undergraduates

3U3 Project: IMAP Student Collaboration

The science goal of this project is to better understand the properties and processes behind the electron precipitation and its effects on neutral atomic oxygen density in the auroral cusp regions of the thermosphere and ionosphere

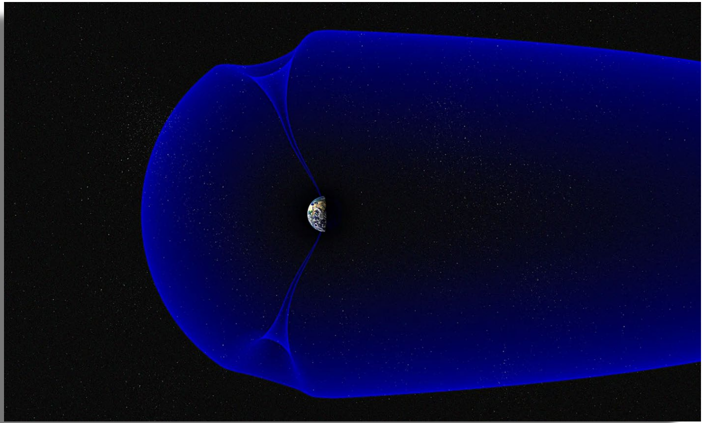
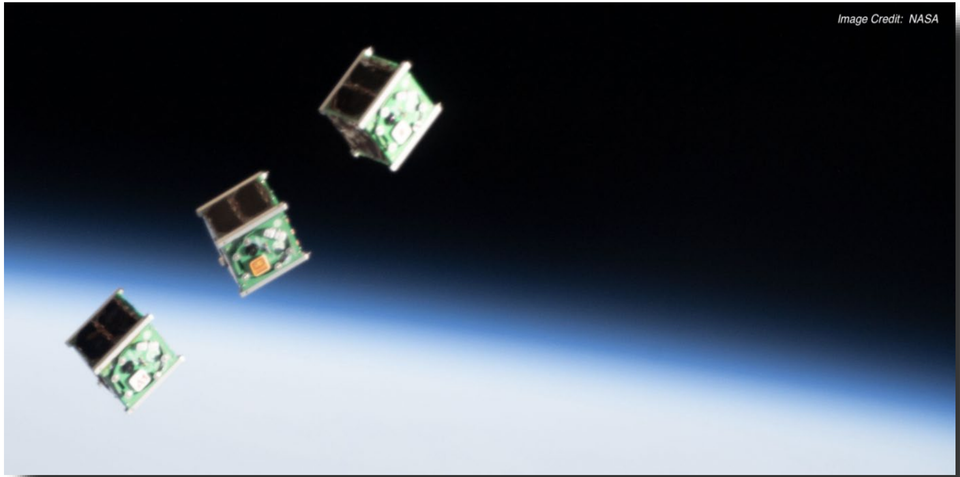


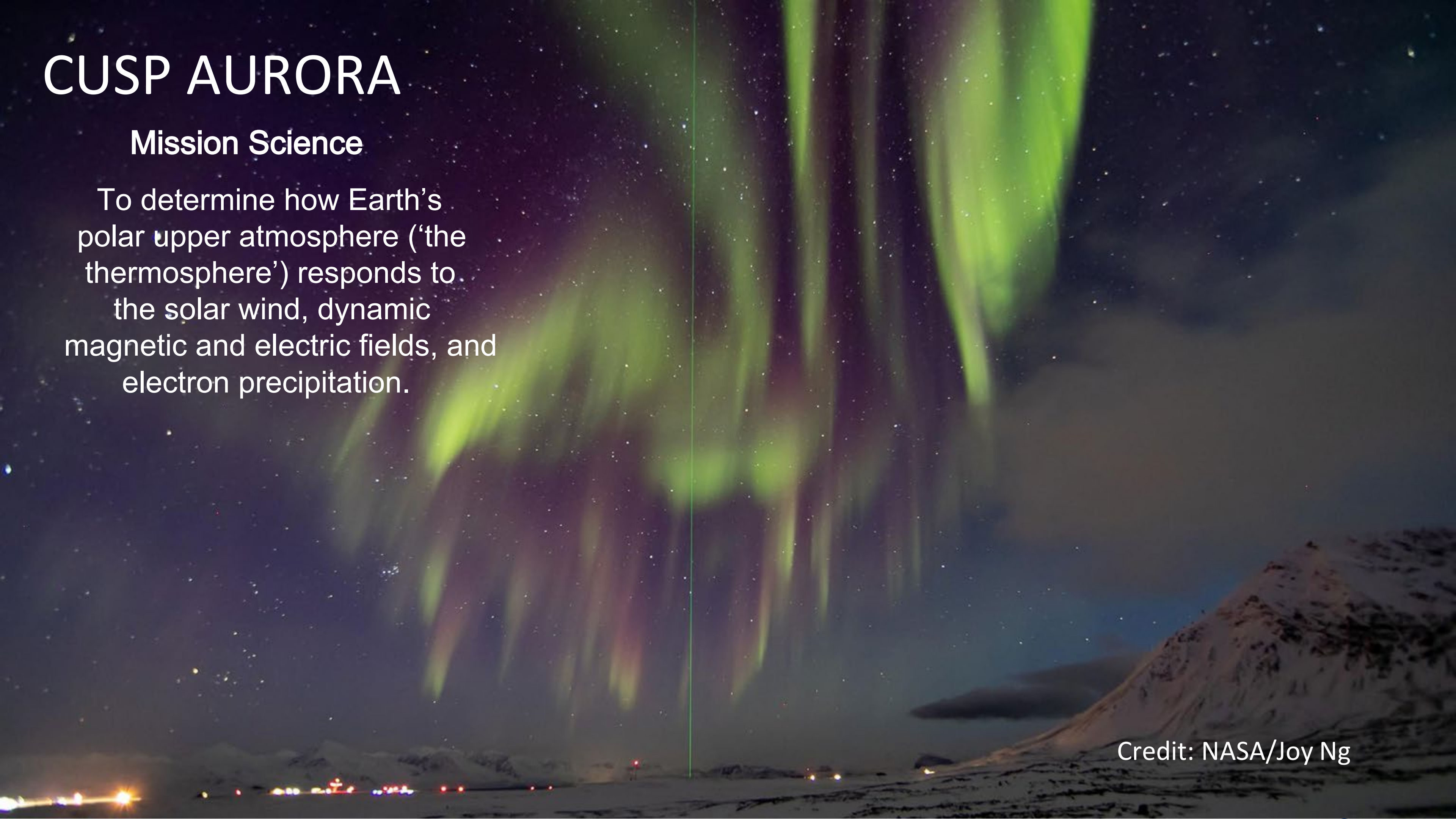
Image credit: *Andøya Space Center/Trond Abrahamsen*



CUSP AURORA

Mission Science

To determine how Earth's polar upper atmosphere ('the thermosphere') responds to the solar wind, dynamic magnetic and electric fields, and electron precipitation.



Credit: NASA/Joy Ng

UHF Transceiver & On-Board Computer (OBC) Roles in CubeSat Communication

📡 UHF Transceiver – Satellite's Communication Gateway

- Enables two-way communication between the satellite and ground station
- **Ground station transmits commands** via UHF frequencies
- Satellite **receives commands** and forwards them to the OBC
- Satellite **sends telemetry data back** through the same UHF transceiver

🧠 On-Board Computer (OBC) – The Satellite's Brain

- Central processor managing all satellite operations
- **Processes incoming commands** from the ground station
- **Stores and manages telemetry data** (e.g., system health, power, sensors)
- Sends stored data back to the ground station when commanded

ENDUROSAT

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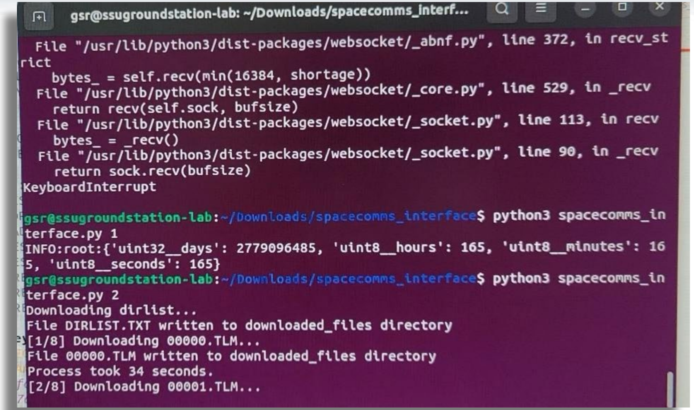
GS Role in UHF CubeSat Missions

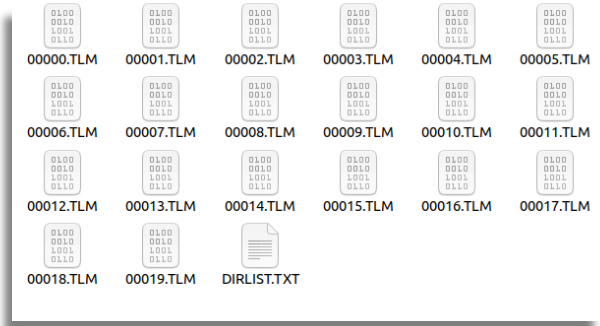
- **Command Uplink:**
  Sends critical commands, including Two-Line Element (TLE), from mission control to the CubeSat via UHF Ground Station.

- **Telemetry Downlink:**
  Receives real-time data from the CubeSat (e.g., health, position, sensor data).

- **Tracking & Communication Scheduling:**
  Uses orbital data (TLEs) to predict passes and align antennas for communication.

- **Data Logging & Analysis:**
  Stores and decodes received telemetry for mission diagnostics and scientific research.

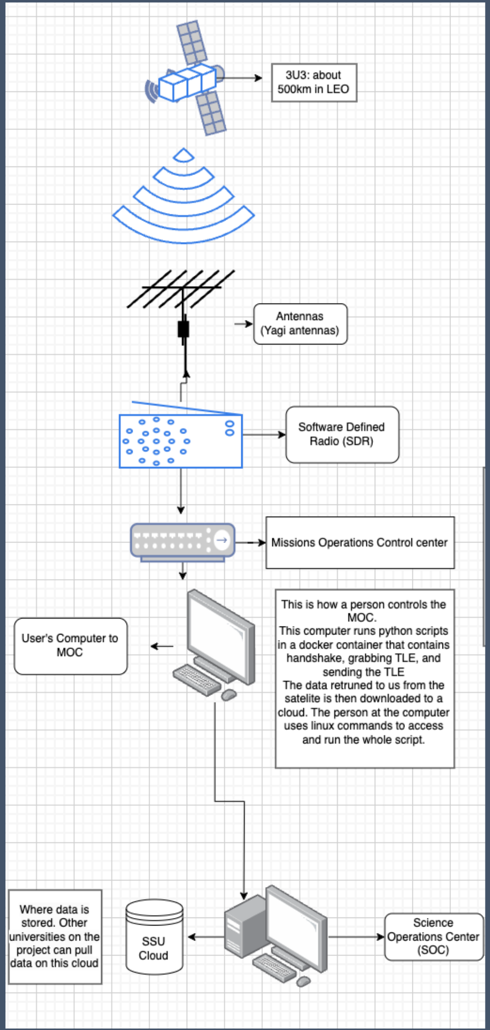




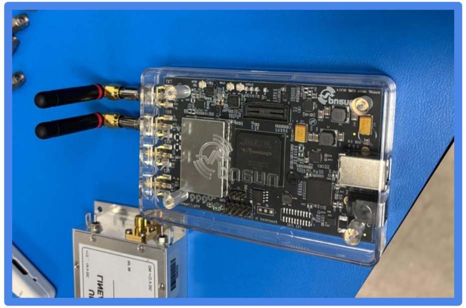
Sonoma State Ground Station

Welcome to our Yagi Antennas!

- Right antenna: Wide beam transmitting (435MHz)
- Left Antenna: Narrow beam receiving (436.5MHz)



Ground Station Continued: Inside the Box



What's inside?

Headless computer (Missions Operations Center)

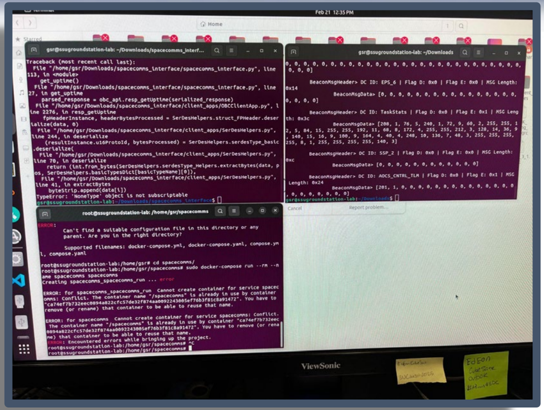
Azimuth and declination to control the antenna

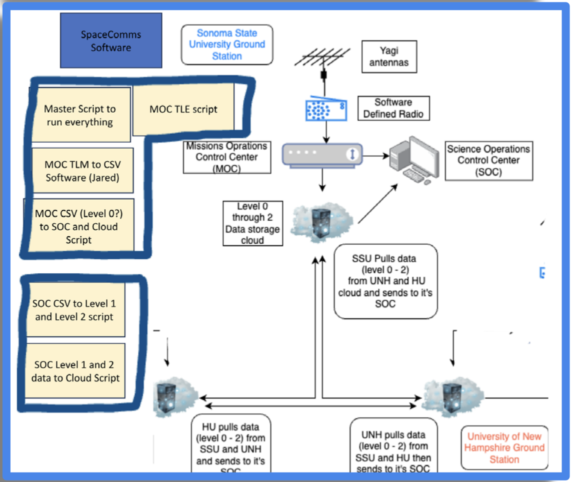
BladeRF (our Software defined radio)

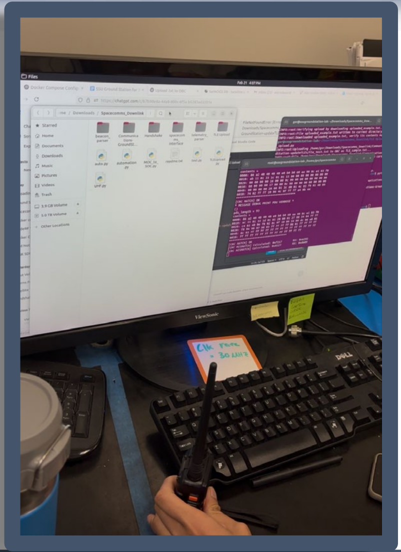
Transceiver containing tx and rx passage connected between SDR and antennas.

Power Amplifier

What is MOC? What is SOC?







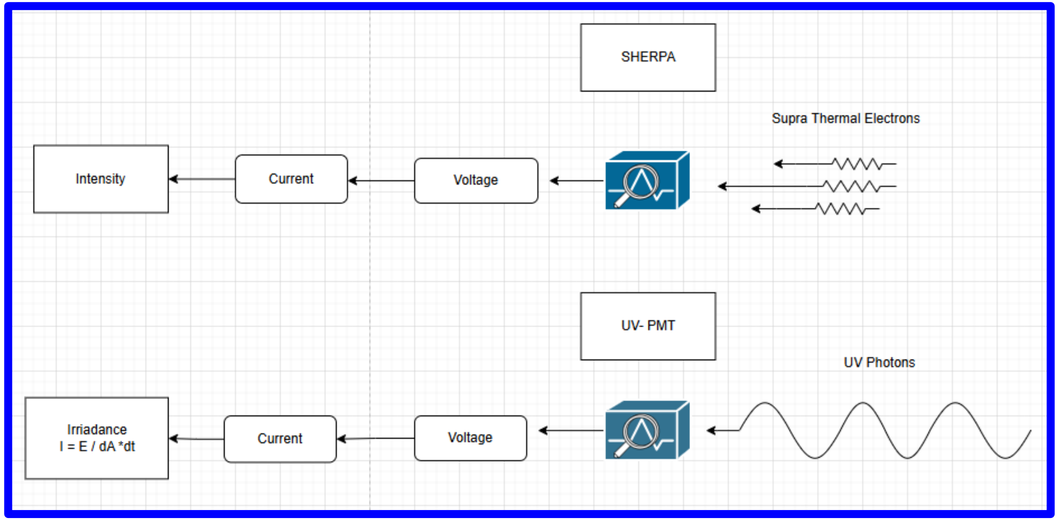
Mission Operation Center:

- Commands the Cubesat
- Monitors the Cubesat (Is it functioning properly?)
- Requests and retrieves data through telemetry

Science Operation Center:

- Collects the .csv files from the MOC (Cubesat data)
- Spreads and analyzes the science data products
- Converts data from level 0 to level 2

Level 0 through 2 conversions



Level 0 (Voltage vs time): Receiving and converting the integer values to voltage from the two detectors (UV-PMT and SHERPA).

Level 1 (Current vs. Time): Voltage converted back to current.

Level 2 (Irradiance vs. Time): Converting current to the flux per unit area using cross calibration with photodiode (UNH) (This is for the UV-PMT)

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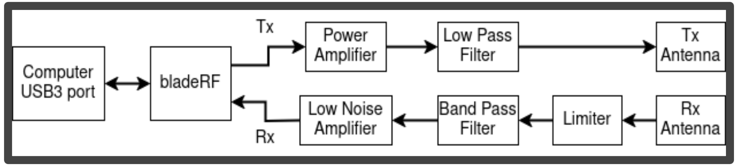
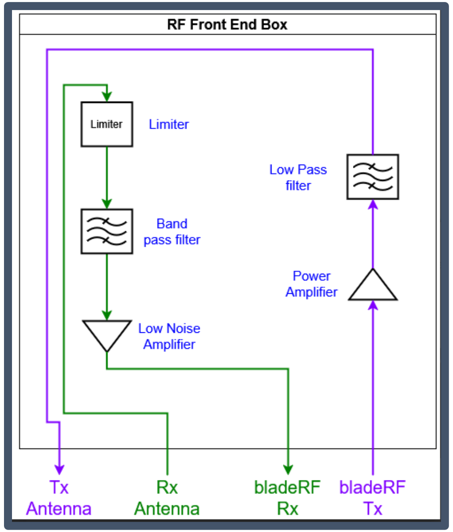
Ground Station Testing



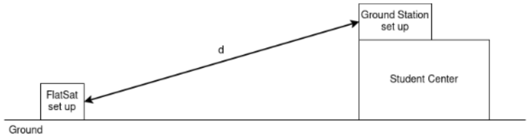
- **Component Verification –** To verify the RF Front End components used for the ground station system.

- **Hardware System Bench Testing –** To determine how much effect the free space path loss (FSPL) has on the packet error rate (PER) and how much the PER is improved when adding the external hardware to the bench ground station.

- **Ground Station Field Testing –** To verify that the ground station can upload and download files to and from the flatsat with a packet error rate of 3% or better. This test will be done using the narrow and wide beam antennas, making a connection to the flatsat that is out in the field adjacent to where the ground station is located.



Full System Set Up:



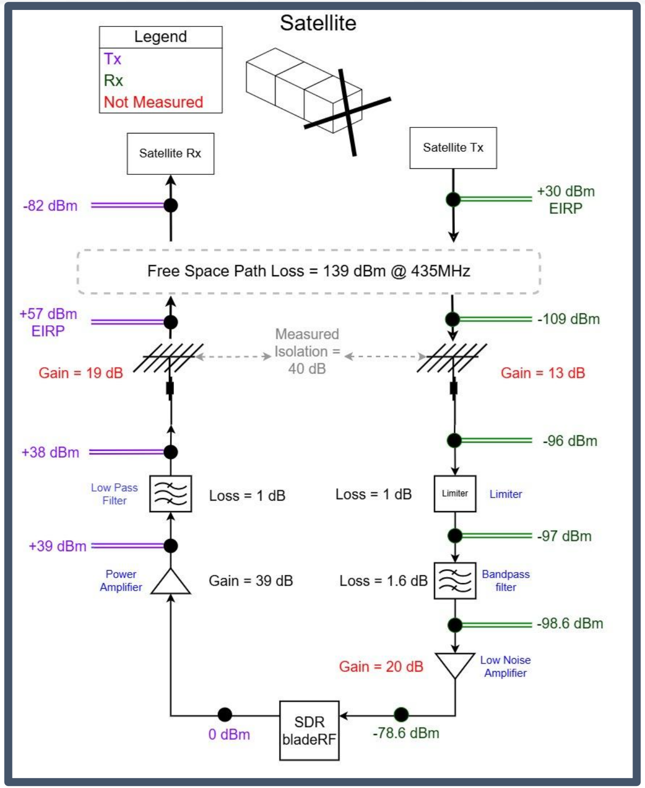
Link Budget

Uplink Path: Ground Station → Satellite

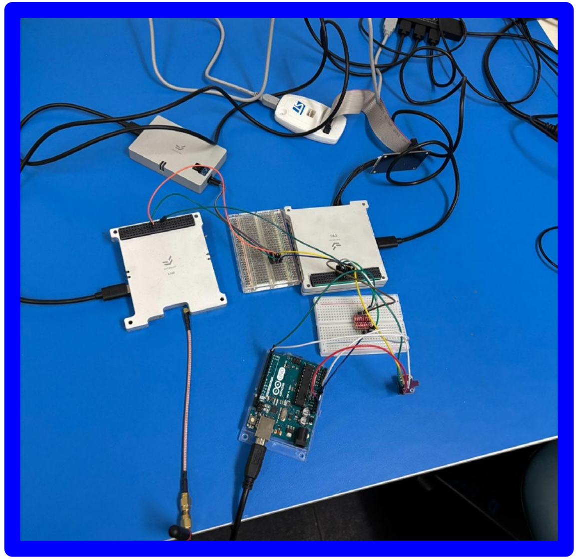
1. **SDR bladeRF (Tx)**: Starts at **0 dBm**
2. **Power Amplifier**: Adds **+39 dB gain**, total: **+39 dBm**
3. **Low Pass Filter**: Causes **1 dB loss**, total: **+38 dBm**
4. **Antenna Gain**: Adds **+19 dB**, resulting in **+57 dBm EIRP**
5. **Free Space Path Loss**: **−139 dB** (at 435 MHz over long distances)
6. **Satellite Receive Power**: **−82 dBm**, which is acceptable for CubeSat receiver sensitivity

Downlink Path: Satellite → Ground Station

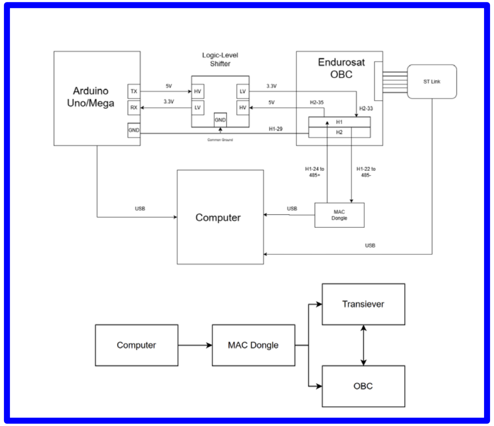
1. **Satellite Transmitter EIRP**: **+30 dBm**
2. **Free Space Path Loss**: **−139 dB**
3. **Signal Received at Ground Antenna**: **−109 dBm**
4. **Antenna Gain**: Adds **+13 dB**, resulting in **−96 dBm**
5. **Limiter**: Protects sensitive components, slight loss
6. **Bandpass Filter**: Small **1.6 dB loss**
7. **Low Noise Amplifier (LNA)**: Adds **+20 dB gain**
8. **Final Signal into SDR bladeRF (Rx)**: **−78.6 dBm**, which is strong enough to decode telemetry (.TLM files)



Validating Ground Station Performance with FlatSat Testing



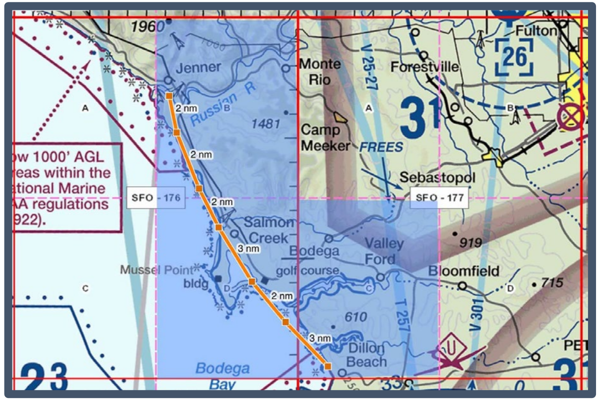
The flatsat is what we use to test our ground station. To make sure the .tlm files are being received with very little packet error rates and to also make sure our mission operations scripts will be successful and guarantee communication.



How we test:

- Open docker container
- Run the handshake
- Run space comms interface
- Parse the .tlm files
- Upload the TLE to the flatsat
- Response that TLE was successfully received

What's Next?



Flight Testing the FlatSat – To validate and demonstrate our CubeSat ground station ability to successfully:

- **Track, receive, and decode telemetry** from a real airborne platform **Transmit commands** using UHF frequencies and confirm end-to-end communication
- **Simulate realistic pass conditions** (Doppler shift, signal attenuation, timing windows)
- **Test interoperability** between the EnduroSat Onboard Computer and the ground station's SDR setup
- **Evaluate antenna performance** (including gain, polarization, and pointing accuracy) in real-world flight conditions
- **Altitude: 4,000–5,000 feet AGL (Above Ground Level)**
- **Distance: 20–30 nautical miles from Sonoma State University**

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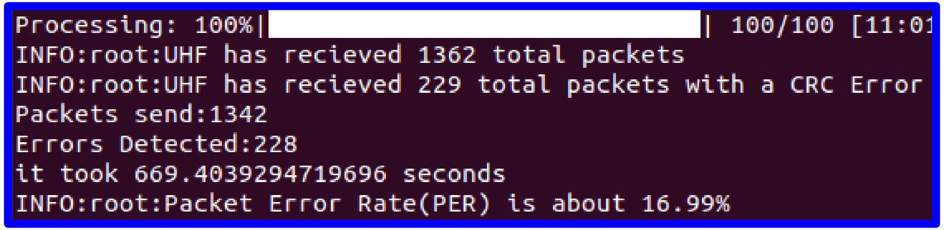
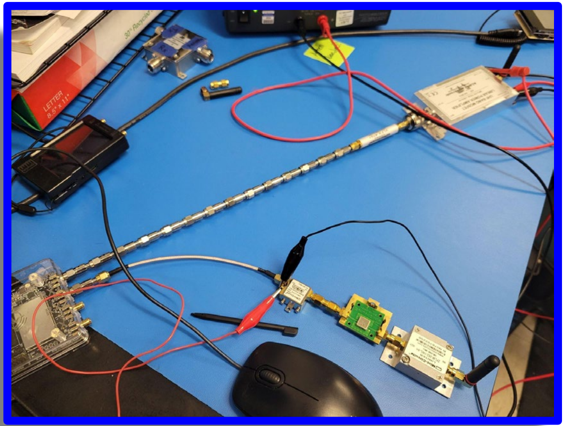
Challenges and Solutions

- Broken Power Amplifier that results to Fluctuation of Transmission Gain and High PER Rate
- Hardware & Software Issues with the BladeRF SDR
- Wide beam antenna does not have a high enough gain (Miscalculation of transmission power).



```
Processing: 100%|████████████████████████████| 100/100 [11:01
INFO:root:UHF has recieved 1362 total packets
INFO:root:UHF has recieved 229 total packets with a CRC Error
Packets send:1342
Errors Detected:228
it took 669.4039294719696 seconds
INFO:root:Packet Error Rate(PER) is about 16.99%
```



THANK YOU!

Questions?

Come find us if you have more questions.