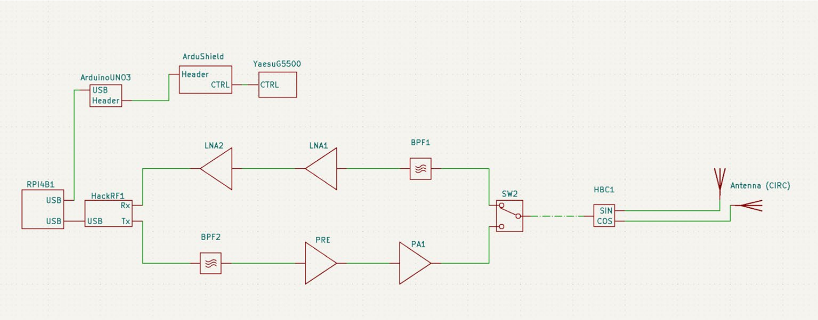
WashU Satellite - Ground Station

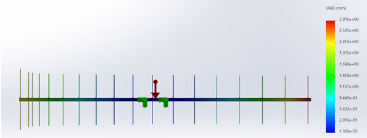
Approach, Design, and Lessons Learned

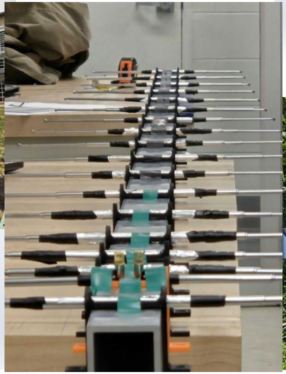
Our Ground Station, GS -1

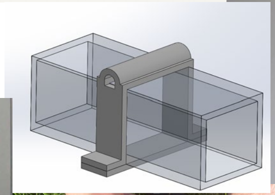
Ground Station

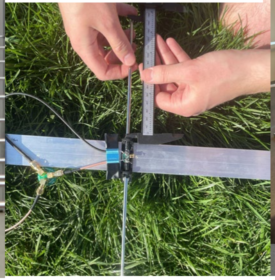


GS-1 Simplified Block Diagram





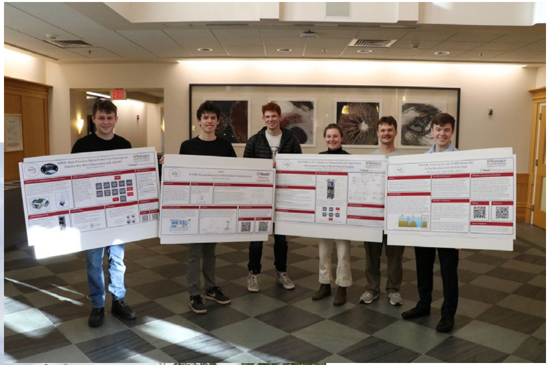




GS-1 CAD render

Who is our Team?

How Did We Get Here?



Agenda

Organizing for Success

Building a Ground Station

Our Experience and Thoughts

Agenda

Organizing for Success

Building Ground Station

Experience and Reflection

Team organization comes from values, which are tradeoffs

We Choose

- Invest in skill development of all members
- Design with a thoroughness fit for space

What do we not choose?

Team organization comes from values, which are tradeoffs

We Choose

- Invest in skill development of all members
- Design with a thoroughness fit for space

What do we not choose?

- Strict minimization of budget
- Optimized design/build speed
- Optimized flexibility

Requirements reduce risk and make testing easier

Req #	Description	Requirement Type	Status
1.1.1	GS-1 resonant architecture shall be operable from 432-437.5 MHz inclusive with VSWR of less than 1.5:1	Performance	Yellow
1.1.2	GS-1 shall achieve a link budget predicting SNR of 0 at an altitude of ____ and elevation of 10 degrees	Design	Yellow
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3.2.1	GS-1 shall achieve an angular tolerance of ±5 degrees in elevation for antenna pointing.	Performance	Green
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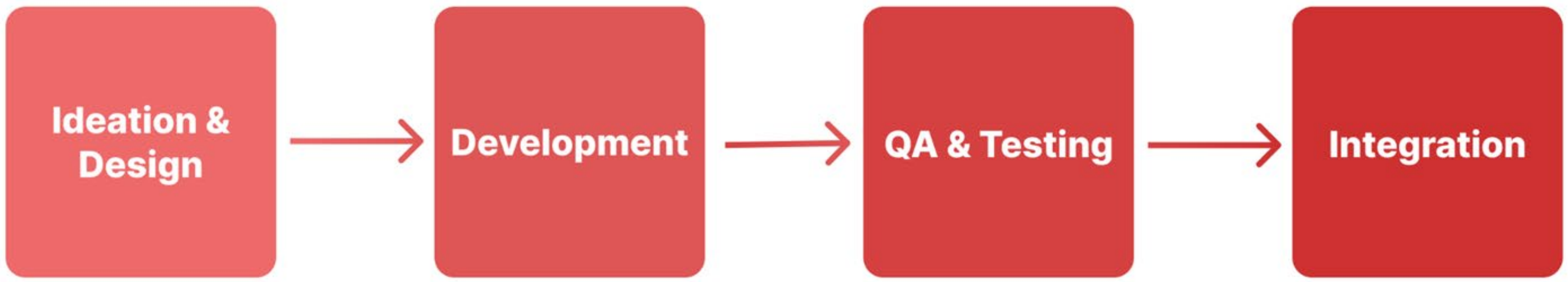
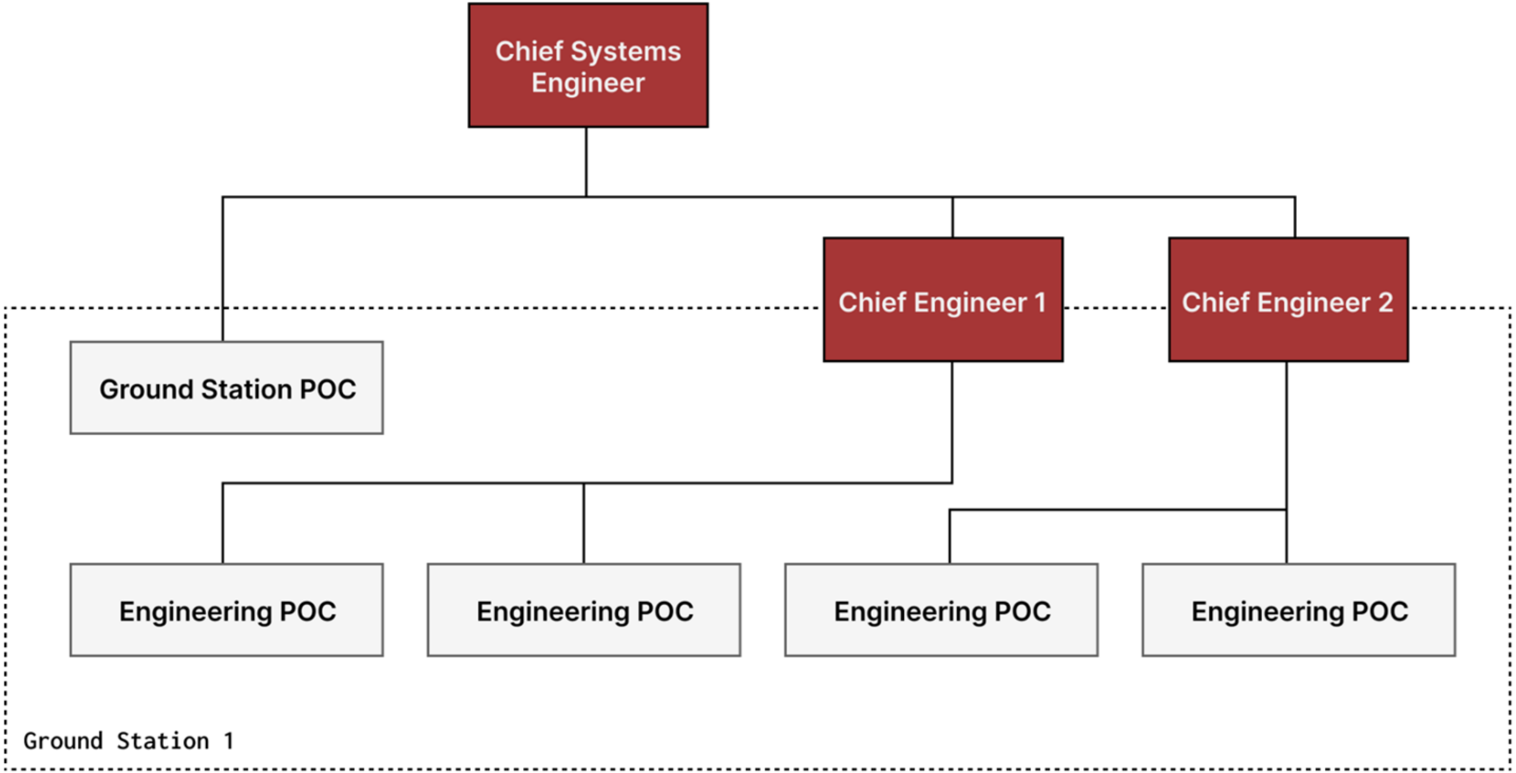
Responsible engineers own their design work



Team structure supports individual responsibility



Review cycles and documentation stop issues early

GS-1 Mechanical Final Design Review

WUSat | Mechanical- 1.0.0 | [10/11/2024]

Team: Mechanical

Chief Engineer: Jack Galloway

Responsible Engineer(s): Jack Galloway, Geoffrey Goffman,

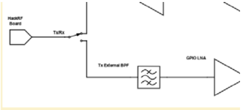


Figure 5: The architecture of the RF front-end. Rx
Tx includes an LNA preamp with

The LNAs are currently designed to operate on
testing they might be placed on a single PCB. A
The power amplifier operates with a VDD of 13

Design Considerations, Decisions, and R

This subsystem is designed to meet link budget and to supply the HackRf on Rx and the antenna subsystem on Tx with sufficient power to support communications. The main concern of this subsystem is ensuring sufficient Signal-to-Noise Ratio. If SNR is not sufficient, there will be excessive packet loss at best and total communication failure at worst. In the context of satellite communication, we view an SNR of 20dB as an appropriate target.

To this effect, the use of LNAs is essential in order to introduce as little noise as possible to the signal along its propagation chain. Additionally, strict bandpass filters are also necessary in order to remove as much extraneous noise as possible, especially before amplification.

Our link budget currently specifies an uplink Tx transmitter power of 10dBW. The 25dBW amplifier is our only option within the price range and has the added benefit of flexibility in amplifier configuration, since a maximum linear input is not necessarily required.

SDR Amplifier Configuration

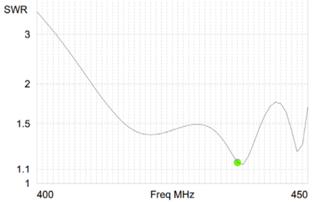
As of now, the SDR amplifier configuration is undetermined. It will probably be determined not through analysis but through trial and error, starting with low

30	17.28		1.12	437.5
20	17.39		1.12	437.5
15	17.57		1.12	437.5
10	18.71	14.11	1.12	437.5
5	18.26	13.5	1.12	437.5

Table 3: The gain and impedance matching of the antenna above real ground.

However, this is for a "perfect construction" Yagi of our design! Unfortunately, while our tolerances do not affect directionality too much, they absolutely can affect SWR and impedance matching. Through an iterative tuning process, we hope to minimize losses to SWR through reinforcement and adjustment rather than building randomly within a defined tolerance range.

An interesting note here is that the ARRL design and the simulator appear at a first glance to disagree on the resonating frequency of, or the correct measurements for, the antenna, as measured by SWR/load impedance frequency sweep and frequency of maximum gain, which are correlated. Looking at the SWR plots, it became apparent that the ARRL design places its center frequency at the center of the 1.5:1 bandwidth, while we place our center frequency at the actual resonating frequency, which is not quite in the center. See Figure TMTband_SWR



round station shall be operated on a flat roof
shall be capable of operating outdoors in all seasons

	Requirements for GS-1
	hall be capable of pointing a yagi antenna with 180 degree elevation and 360 azimuthal control with an angular tolerance of +/- 5 degrees
	esign shall minimize bending of antenna and any support components
	hall have a base fitting within a 2m x 2m square area
	hall have a non-penetrating roof mount
	hall have an enclosure for all sensitive electronics
7.2	GS-1 shall be capable of operating in winds up to 40mph
7.3	GS-1 shall be capable of withstanding winds up to 90mph
7.4	GS-1 shall be capable of withstanding 12in of snow

Req #	Level 3 Requirements for GS-1
3.1.1	GS-1 shall use a COTS rotator capable of the angular requirements specified in 3.1
3.1.2	GS-1 shall have a support arm capable of connecting the yagi antenna to the rotator unit
3.2.1	GS-1 shall have a support arm with a maximum deflection of ____ under normal operating conditions
3.2.2	GS-1 shall have an antenna with a maximum deflection of 50mm under normal operating conditions
4.1.1	GS-1 shall have a frame and any additional elements that fit inside the specified area
4.2.1	GS-1 shall not have any elements that may damage the roof for securement of the frame
7.1.1	GS-1 shall have a water-proof enclosure for electronics
7.1.2	GS-1 shall have an enclosure with a heating element to maintain internal temperatures of above ___ degrees

Different Values for Different Domains

Electronics (“do it custom and learn”)

Structure (“analyze thoroughly to absolutely minimize failure risks”)

Software (“leverage and contribute to open-source”)

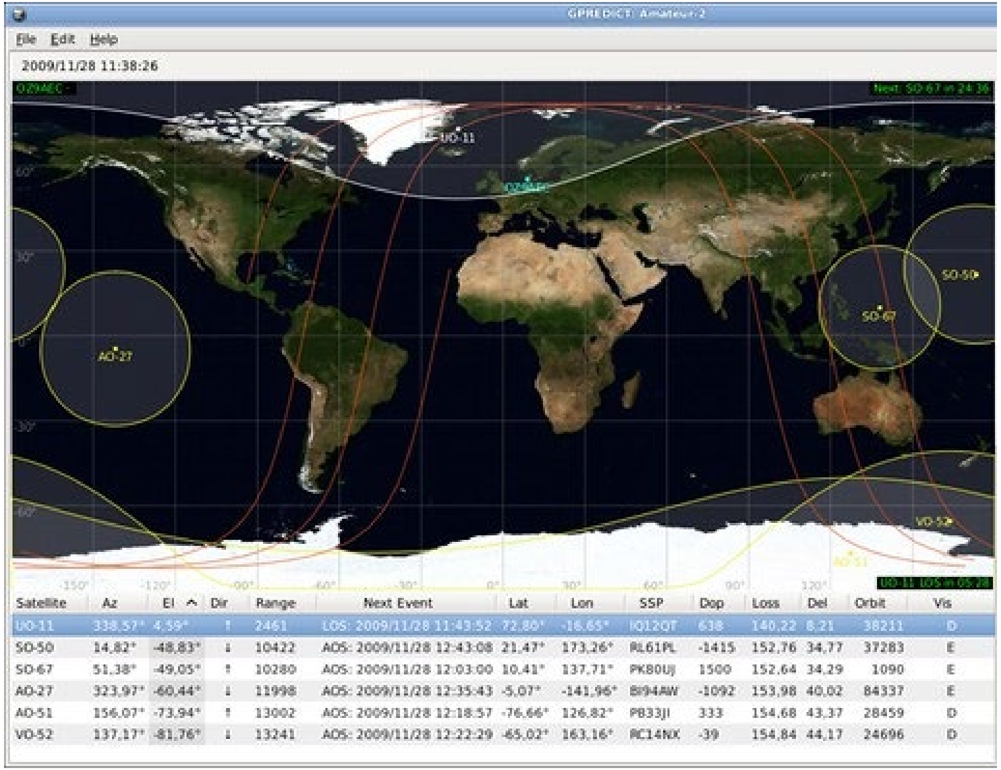
Agenda

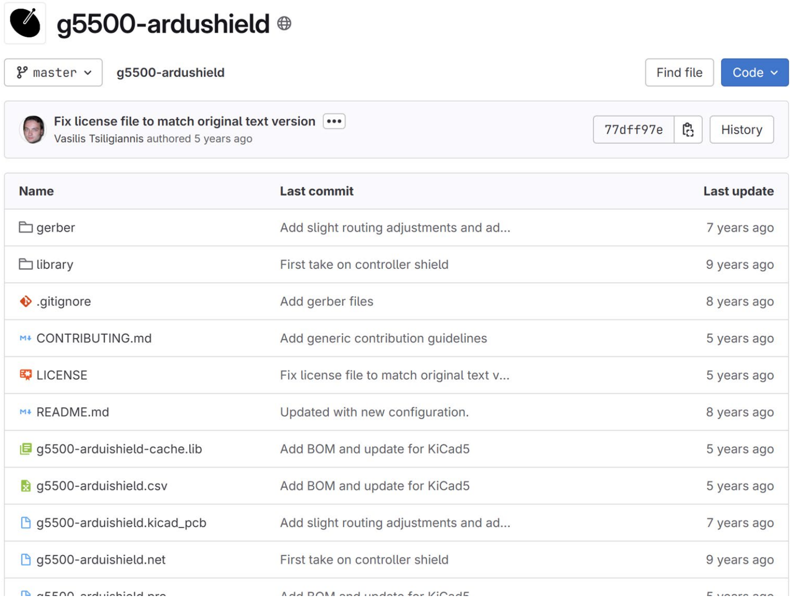
Organizing for Success

Building a Ground Station

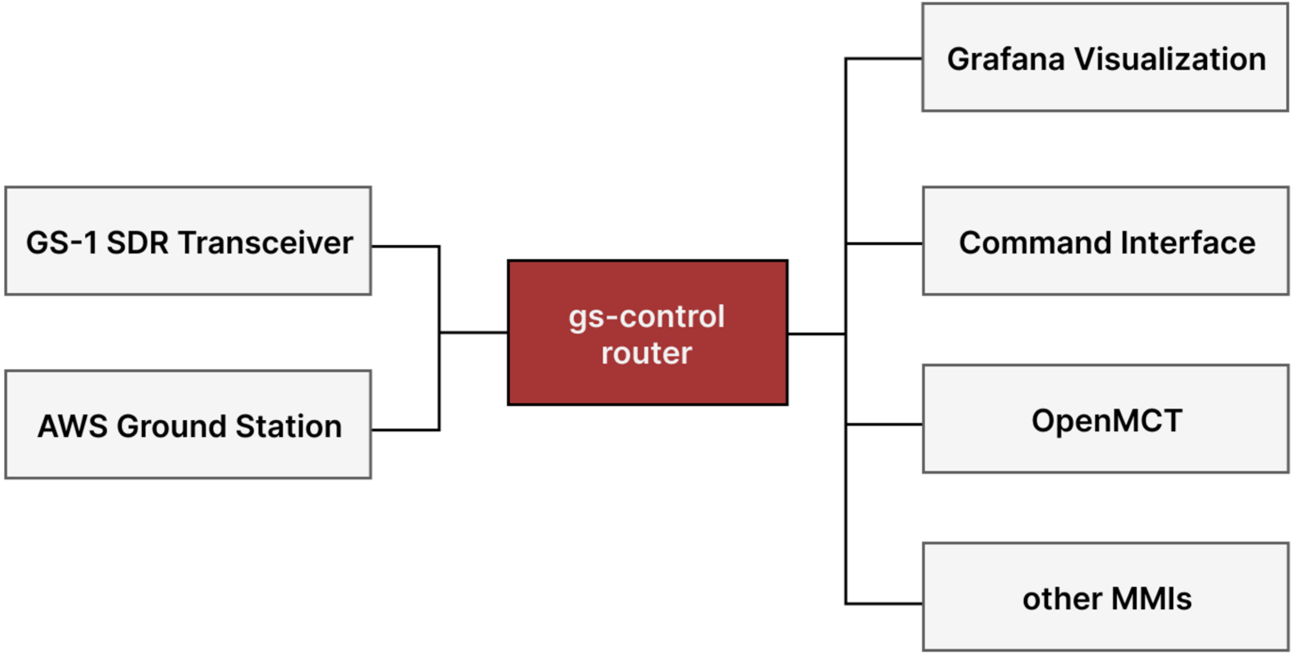
Our Experience and Thoughts

Open - source tracking infrastructure reduces developmental complexity

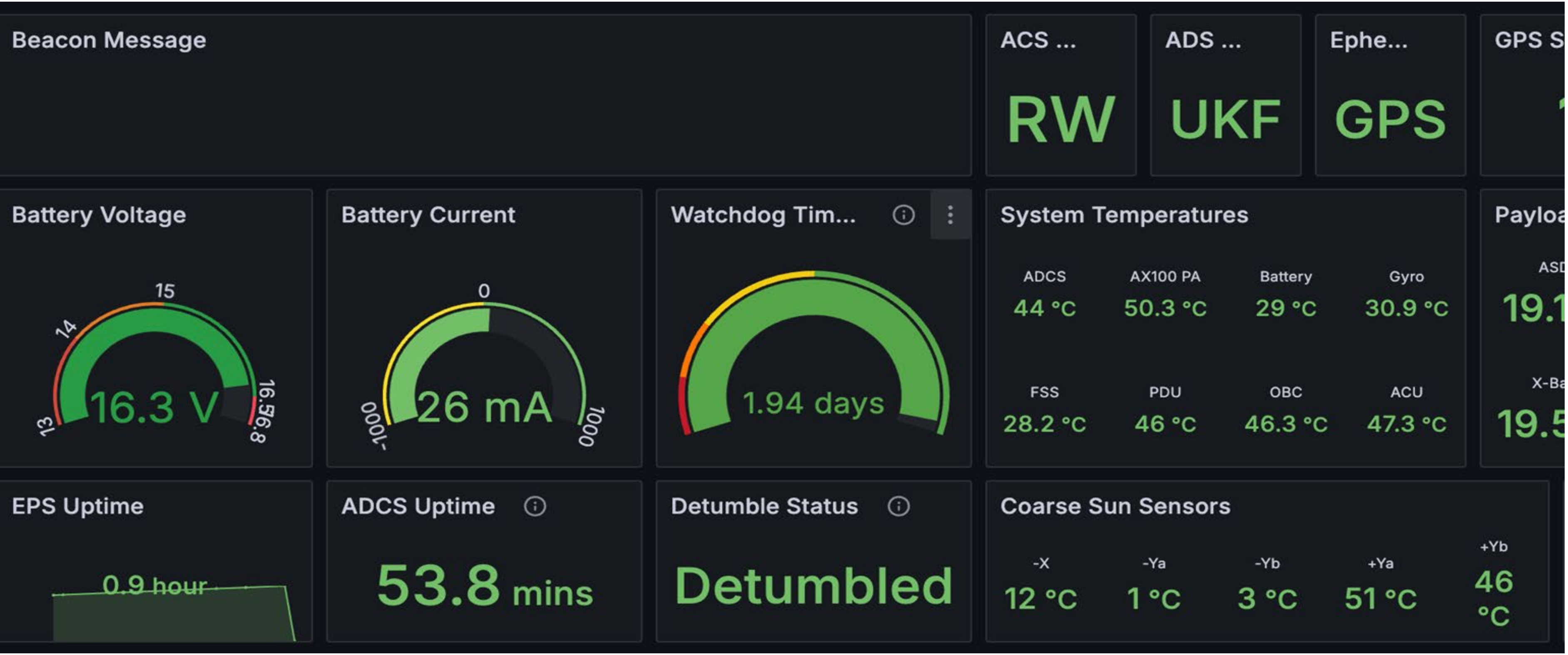




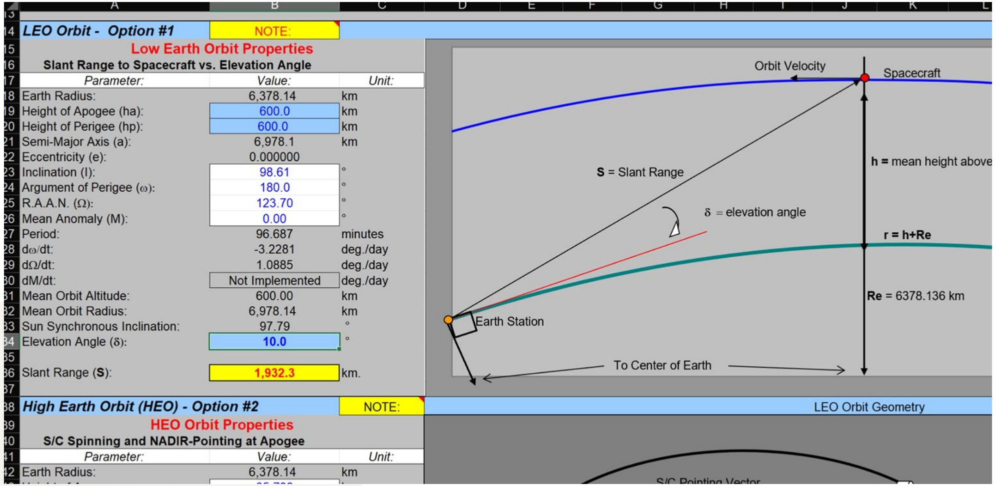
Communication frontend supports adaptive mission management

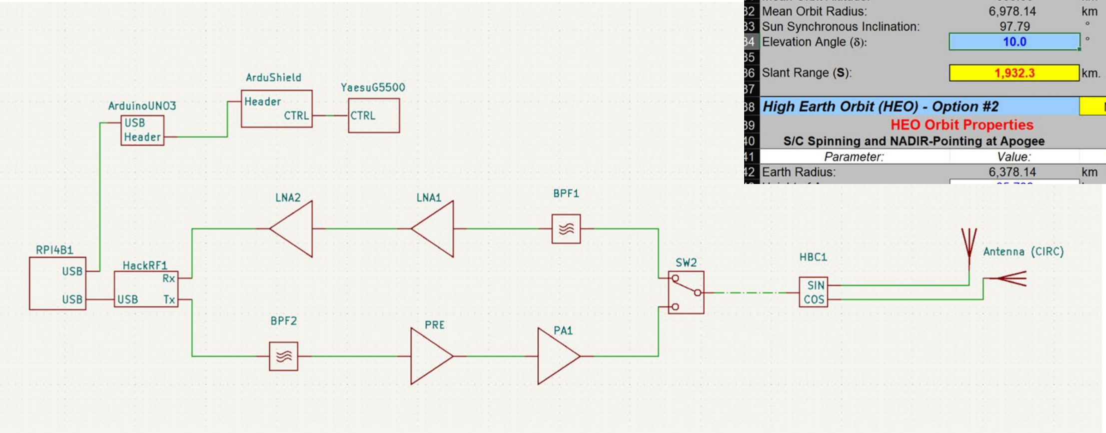


Grafana enables comprehensive integration without unnecessary graphical development



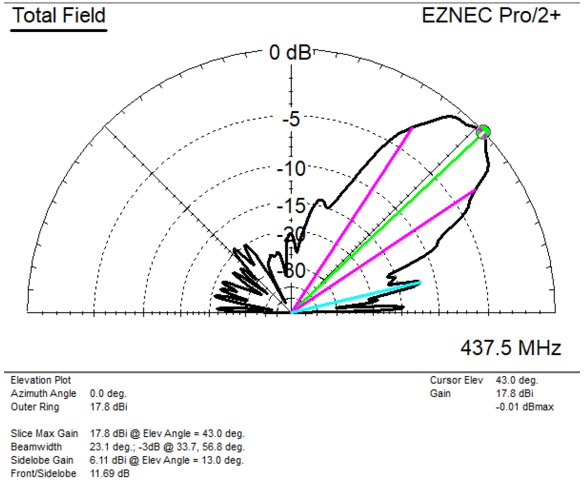
A modest RF front end with established link budget tools ensures connection





Antenna design *can* be easy…

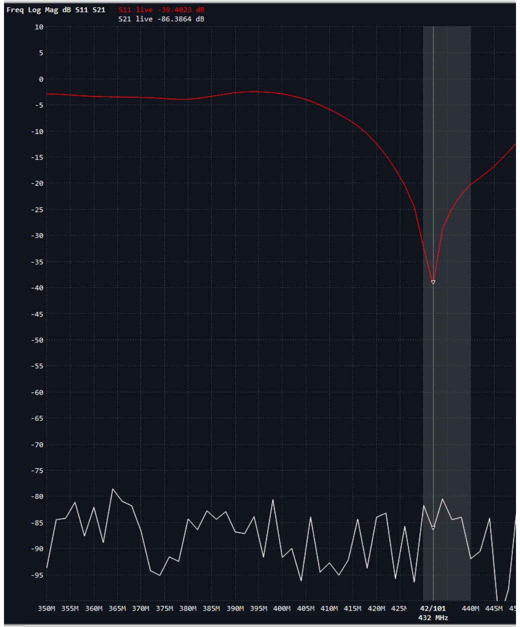
- Use Simulation and Scripting when a parameter- or possibility-space is large…




```
# This script generates EZNEC-formatted descriptions of imperfect Yagi-Uda
# antennae based on a pre-defined design (positions and lengths of elements).

# ----------------------------------------------------------------------------

# PARAMETERS - DESIGN CHOICES, ENVIRONMENT NOTE
# these are "whole-antenna" parameters, not individual element parameters

# Whether to simulate realistic construction instead of a perfect build
realistic_antenna = False
# Whether to simulate artificial circular polarization in far field by two
# nearby, perpendicular, 90-degrees separated linearly polarized antennas
# instead of constructing one antenna with two axes
artificial_circ = False
# Measure all distances relative to the driven element instead of to x=0
measure_relative_to_driven = False
# The number of elements in the antenna, incl DE/RFL (in each polarization axis)
num_elements = 19
# The x-axis offset between the horizontal and vertical sets of elements
offset_mm = 75
# The drop in the back due to bending (from CAD simulation, FEA)
drop_back_mm = 20
# The drop in the front due to bending (from CAD simulation, FEA)
drop_front_mm = 30
# The height of the antenna above ground
antenna_height_mm = 2500
# The elevation angle of antenna
antenna_elevation_angle = math.radians(45)
# The twist-direction orientation of the antenna
twist_orientation = "+" # binary choice between "+" and "x"
# The maximum deflection of the antenna on the back end
back_deflection_mm = 0 # not actual measure of deflection! guess, and check wires
# The maximum deflection of the antenna on the front end
front_deflection_mm = 0 # not actual measure of deflection! guess, and check wires
# The driven element type
driven_element_type = "straight" # binary choice between "straight" and "folded"
```

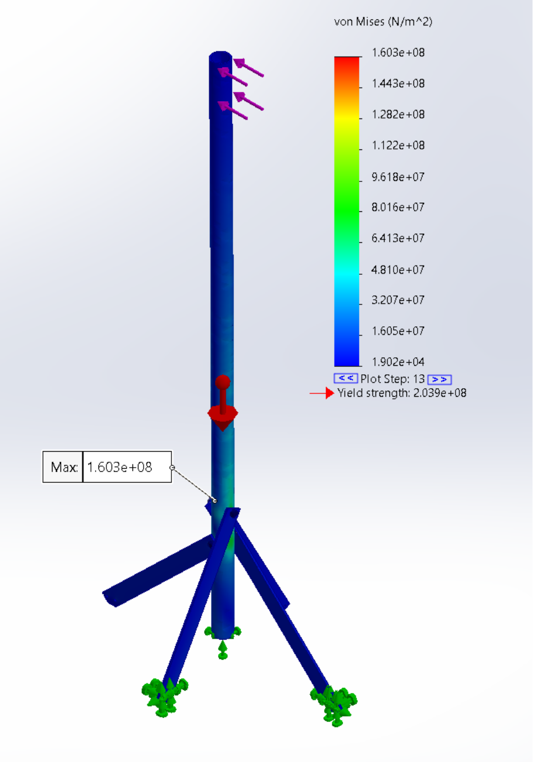
Analysis loops can be broken by physical testing

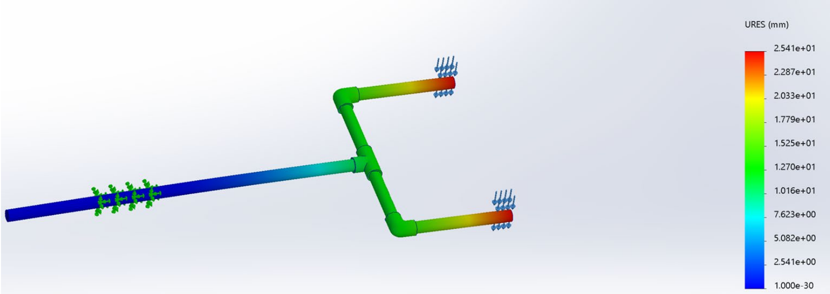
Invest in flexible test equipment

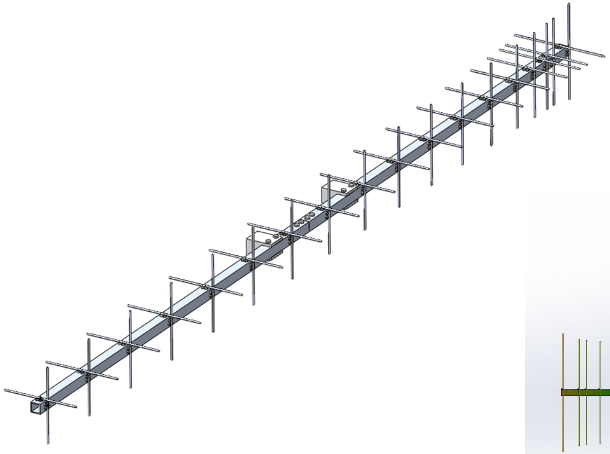


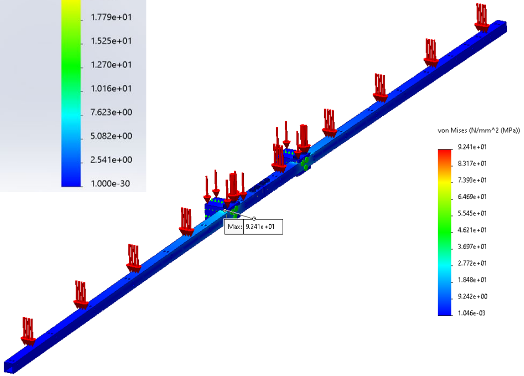
Grey band: 430 - 440 MHz,
1.5-VSWR bandwidth: 25 MHz,
@437.5 MHz, VSWR=1.16

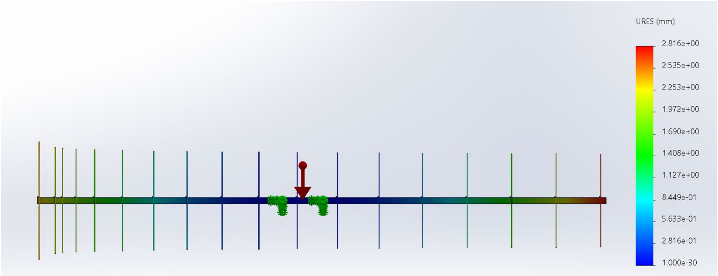
FEA's support safety and function (even when material constraints are imposed)





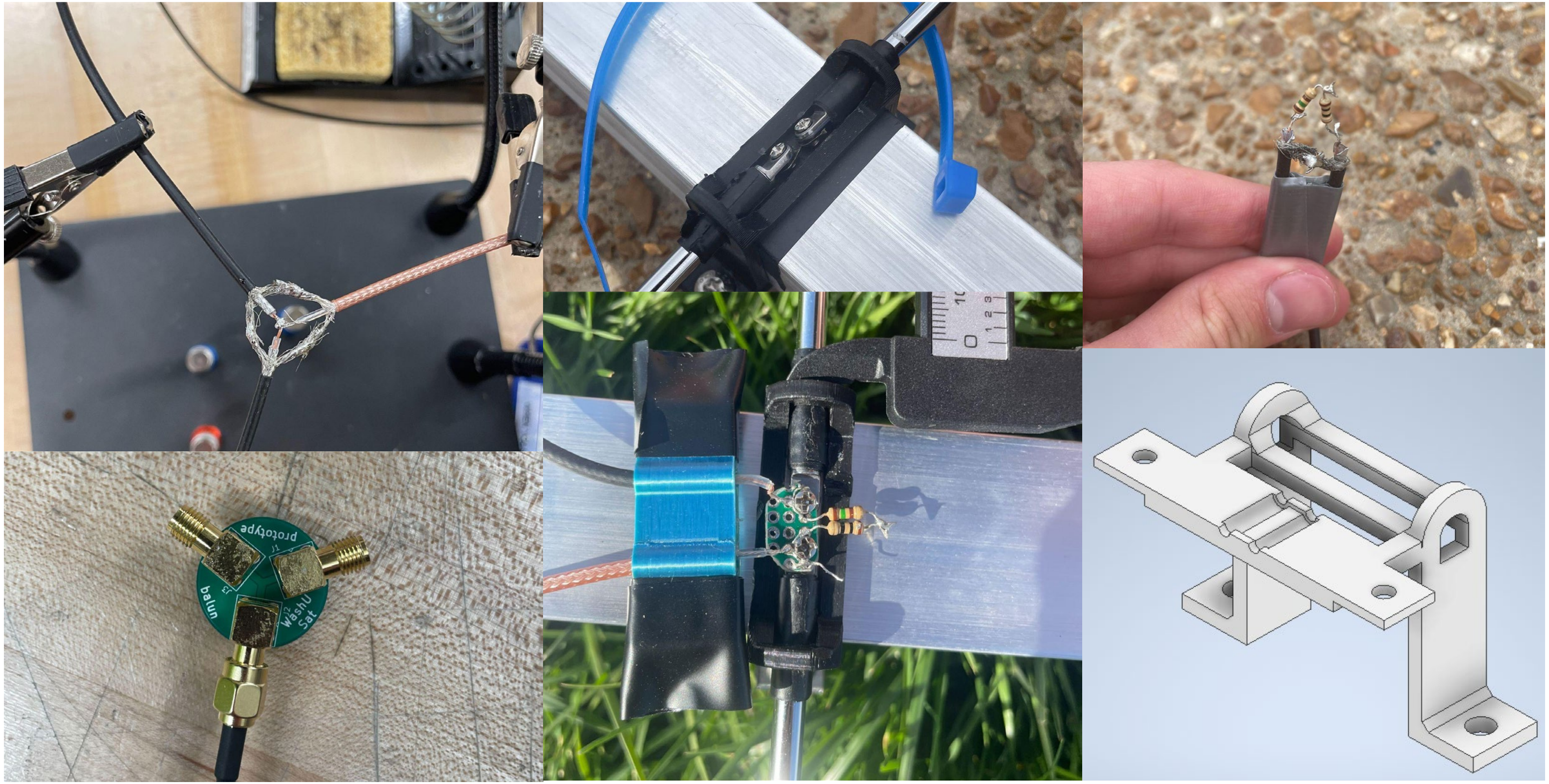






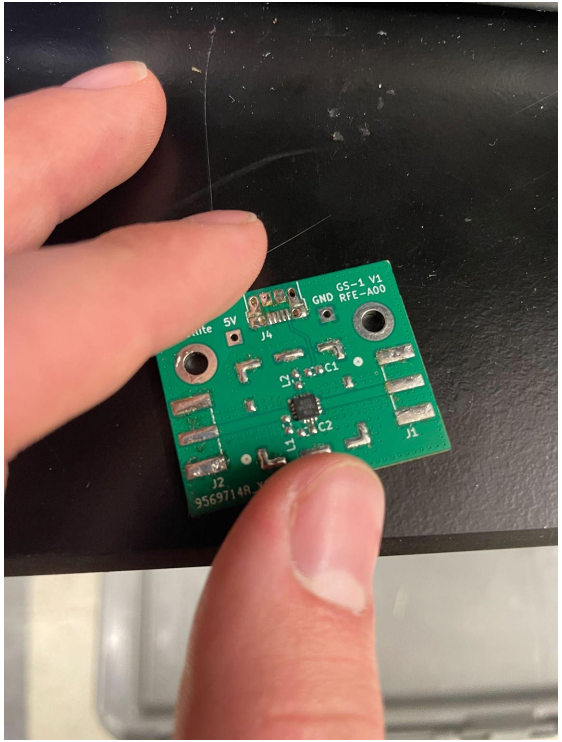
Agenda

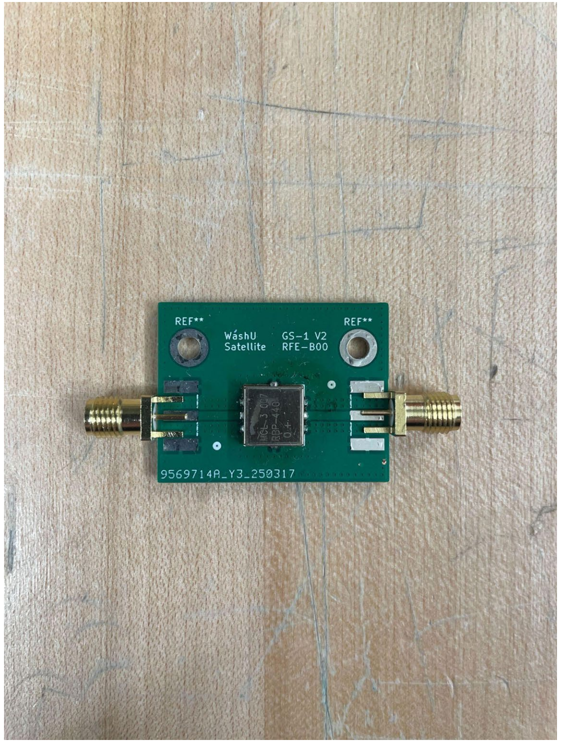
Investing in *Robust* Test Equipment is *Always* Worth it

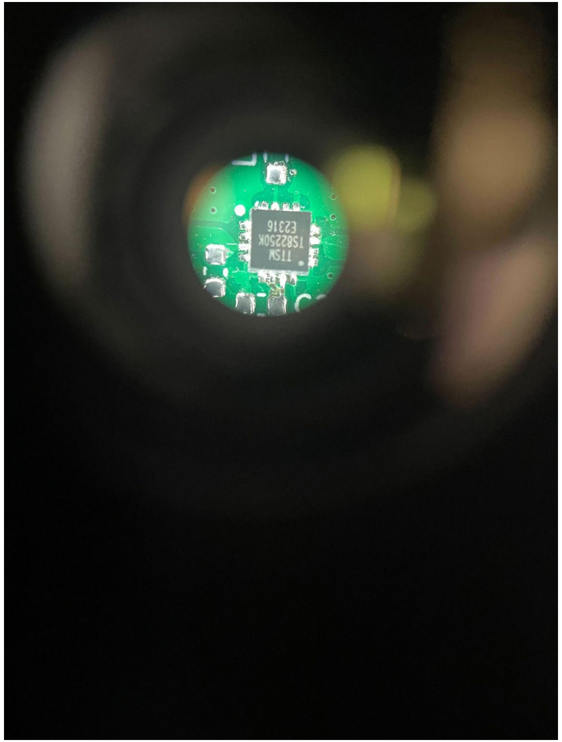


Talk to your local Hams!

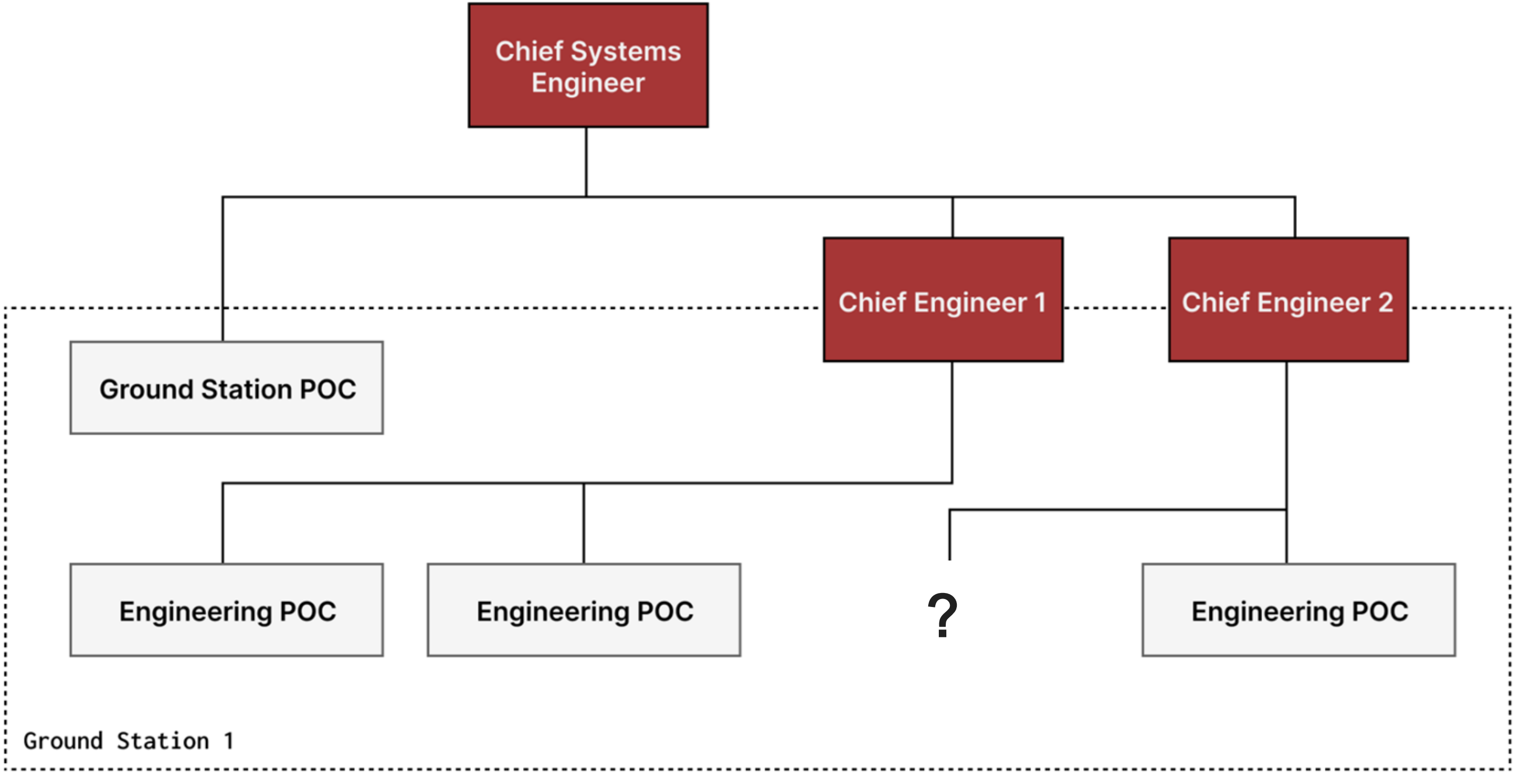
Custom RF PCBs: good for skills, *can* be bad for timeline







Individual ownership: balance this with team flexibility



Use requirements or other means to document assumptions

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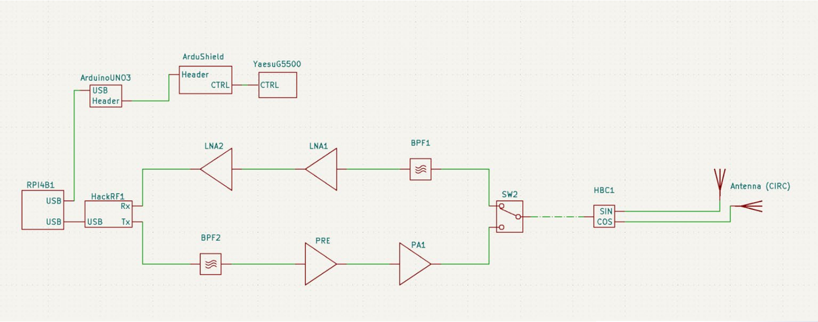
Ground Stations: very fun!



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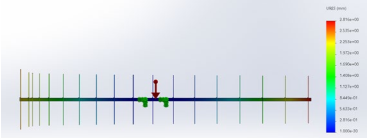

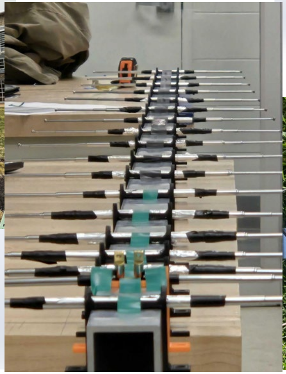

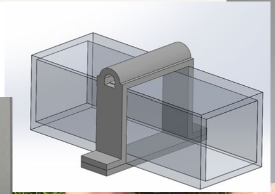

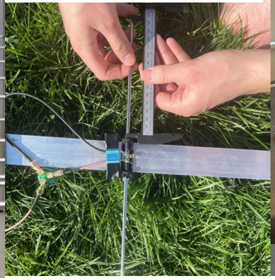

GS-1 CAD render

Thank You!

Questions?

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