RFI Mitigation and Testing Employed at GGAO for NASA's Space Geodesy Project (SGP)

[1]L. M. Hilliard Lawrence.M.Hilliard@NASA.gov
[2]Ganesh Rajagopalan ganesanr@mit.edu
[1]Charles Turner charles.j.turner@nasa.gov
Thomas Stevenson thomas.r.stevenson@nasa.gov
Berhanu Bulcha berhanu.t.bulcha@nasa.gov

1NASA Goddard Space Flight Center, Greenbelt MD, USA
2 MIT Haystack Observatory, Westford MA, USA

The Space Geodesy Project

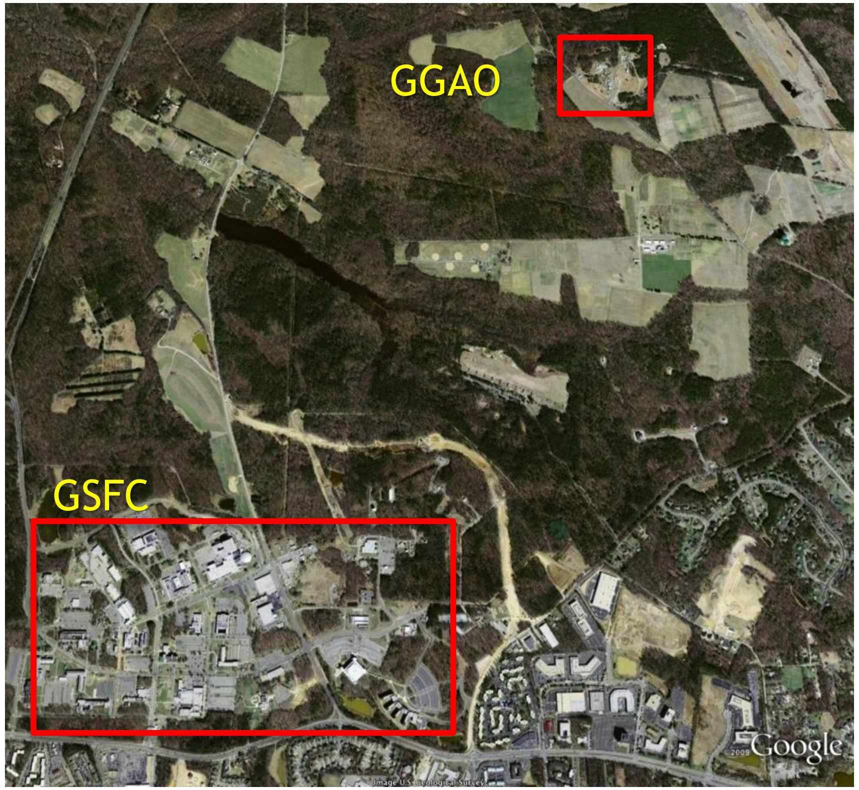
VLBI	NGSLR	GNSS	Vector Tie
			

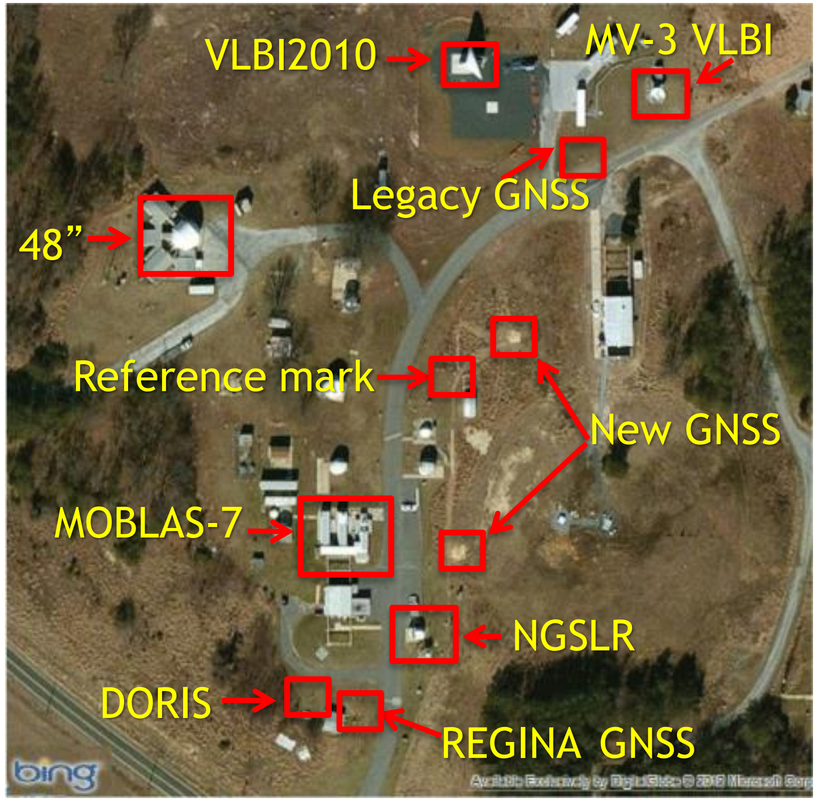
- Establish and operate a prototype next generation space geodetic station with integrated next generation SLR, VLBI, GNSS (and DORIS) systems, along with a system that provides for accurate vector ties between them.
- Develop a Project Implementation Plan for the construction, deployment and operation of a NASA network of similar next generation stations that will become the core of a larger global network of modern space geodetic stations.

NRC Recommendation: “In the near term, the United States should construct and deploy the next generation of automated high-repetition rate SLR tracking systems at the four current U.S. tracking sites: Haleakala, Hawaii; Monument Peak, California; Fort Davis, Texas; and **Greenbelt, Maryland**. It also should install the next-generation VLBI systems at the four U.S. VLBI sites: **Greenbelt, Maryland**; Fairbanks, Alaska; Kokee Park, Hawaii; and Fort Davis, Texas.”

Prototype Geodetic Station at GGAO

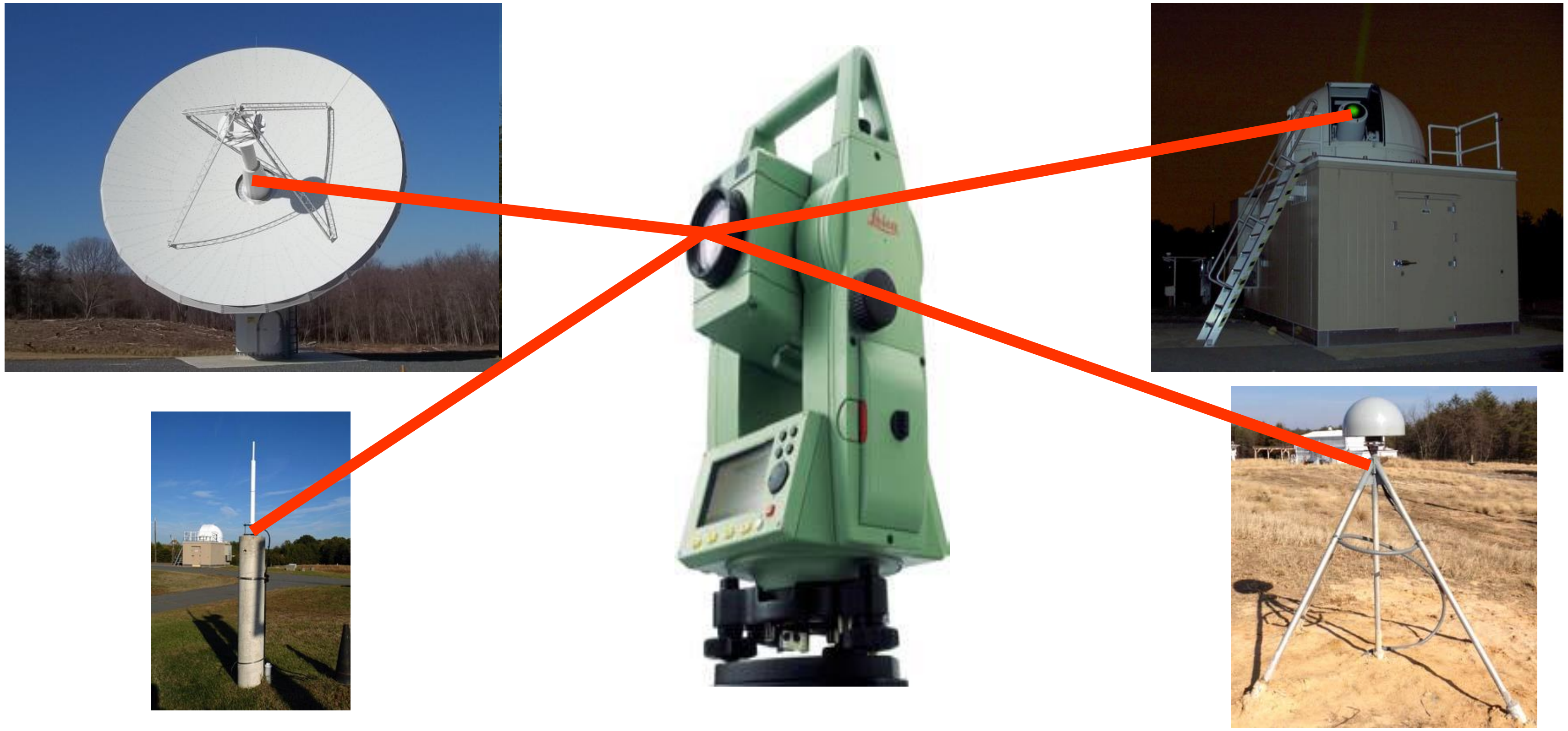
- Goddard Geophysical and Astronomical Observatory (GGAO) is located 5 km from Goddard Space Flight Center in the middle of the Beltsville Agricultural Research Center. GGAO is one of the few sites in the world to have all four geodetic techniques co-located at a single location.





Vector Tie System (VTS)

- Accurate measurement of inter-station vectors is an essential aspect of an integrated space geodesy site.
- Measurements provide closure between terrestrial reference frames derived from different space geodesy techniques.
- Tests of technologies and currently available systems underway at GGAO.

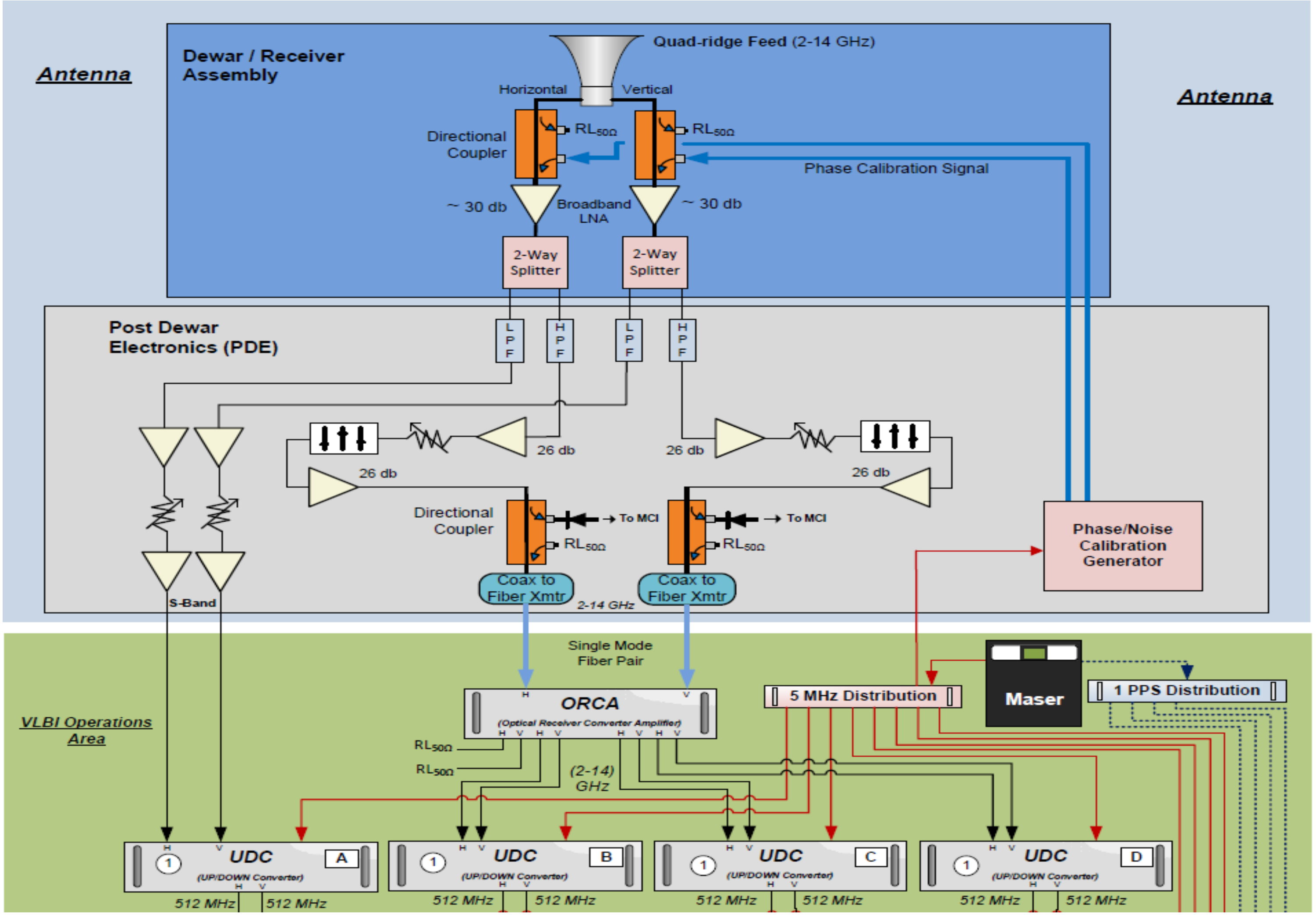


Space Geodesy Project (SGP) and RFI

- Modeling the GGAO environment and VLBI2010 susceptibility before & after the trees came down
- Measuring the DORIS Beacon, and the NGSLR radars in South , radar masks & DORIS path loss provide mitigation
- Measuring 12m side lobes with a standard gain horn simulator ≥100m away
- Mitigate RFI with masks, filtering, and shielding
- Measure the effectiveness of an all-weather blocker to reduce the RFI of a DORIS Test Transmitter placed 136 meters away
- Measure the multi-path effects of the blocker on DORIS
  - Different distances and heights of blocker
  - Different angles of blocker

S-Band Filtering

- S- Band (2-5 GHz) is transferred separately to avoid saturation from RFI in the fiber optic link



RF Compatibility Methodology

Measurement of Transmitter Radiation Properties in 2010-2011

MOBLAS 7 Summary

Location	Expected Power (+/- 2 dB)	Measured Power			
		No Obstruction	Radome	Railings	Radome-Railings
Loc #2	-4.1 dBm	-4.9 dBm	-7.0		-0.7
GODE W	-1.0 dBm	-0.8 dBm	-5.9	8.1	2.4

NGSLR Summary

Location	Expected Power (+/- 2 dB)	Measured Power	
		No Obstruction	Radome
Loc #2	-3.0 dBm	-3.6 dBm	-0.7

DORIS Summary

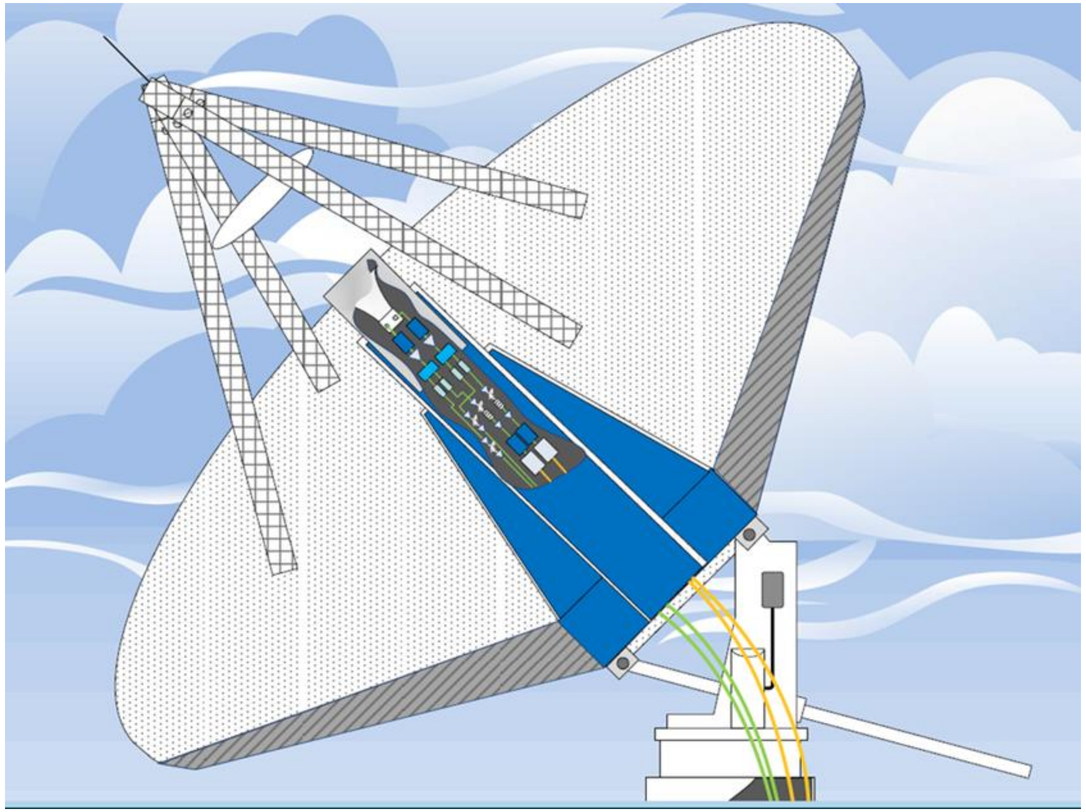
Location	Expected Power	Measured Power
DORIS Pad	-1.3 dBm	-1 dBm
Observatory Pad	-29.5 dBm	-27.6 dBm

- DORIS and SLR radar power levels were measured using S and X-band standard gain horn antennas
- SLR Radar Power Level Measurement Memo:

http://www.haystack.mit.edu/geo/vlbi_td/BBDev/037.pdf

VGOS: Broadband Flexibility /Susceptability

•Background: The VGOS version of VLBI has recently been modernized to collect a 2-14 GHz broadband spectrum in accordance with VLBI2010: Current and Future Requirements for Geodetic VLBI Systems . One of the objectives of that 2005 report was to "Reduce Susceptibility to External Interfaces" and "continuous frequency coverage … to 14 GHz, but the channels and frequencies actually used would be selected as those that are most free from RFI at all sites".



Geodesy Techniques at GGAO – Therefore RFI Mitigation Techniques

- Radio Frequency Interference (RFI) Mitigation at Goddard Geophysical and Astronomical Observatory (GGAO) has been addressed in three different ways by NASA's Space Geodesy Project (SGP); masks, blockers, and filters. All of these techniques will be employed at the GGAO, to mitigate the RFI consequences to the Very Long Baseline Interferometer.
- The SGP combines the four geodetic techniques of Global Navigation Satellite System (GNSS), DORIS (Doppler Orbitography and Radiopositioning Integrated from Space), Space Geodesy Satellite Laser Ranging (SGSLR), and the VLBI Global Observing System (VGOS).

GGAO, and SGP generally, Problem Statement: Competing Requirements

- The problem at GGAO, and at the 4-technique geodetic stations of the future being deployed by SGP, is that both DORIS and SGSLR require emissions that are found in the VGOS broadband. For DORIS, path loss and blockage on the GGAO campus reduce the effect of RFI to that of raising the noise floor to a tolerable level. For SGSLR, we have had to introduce low-elevation restrictions or "masks" to both the Laser Hazard Reduction System (LHRS) radars and the VLBI antenna. The VLBI can be damaged by the 4kW peak power output LHRS radar, so the main lobe (-57.1 dBW at VLBI phase center) must be avoided which will destroy the receiver, and the 1st sidelobe saturates the optical link in the receiver chain in effect blinding VLBI from high band (5-14 GHz). In VLBI, low band (2-5 GHz) does not use the same optical link because the low band RFI (e.g. DORIS, wifi, …) would saturate as well, but can be carried back via coaxial cable.

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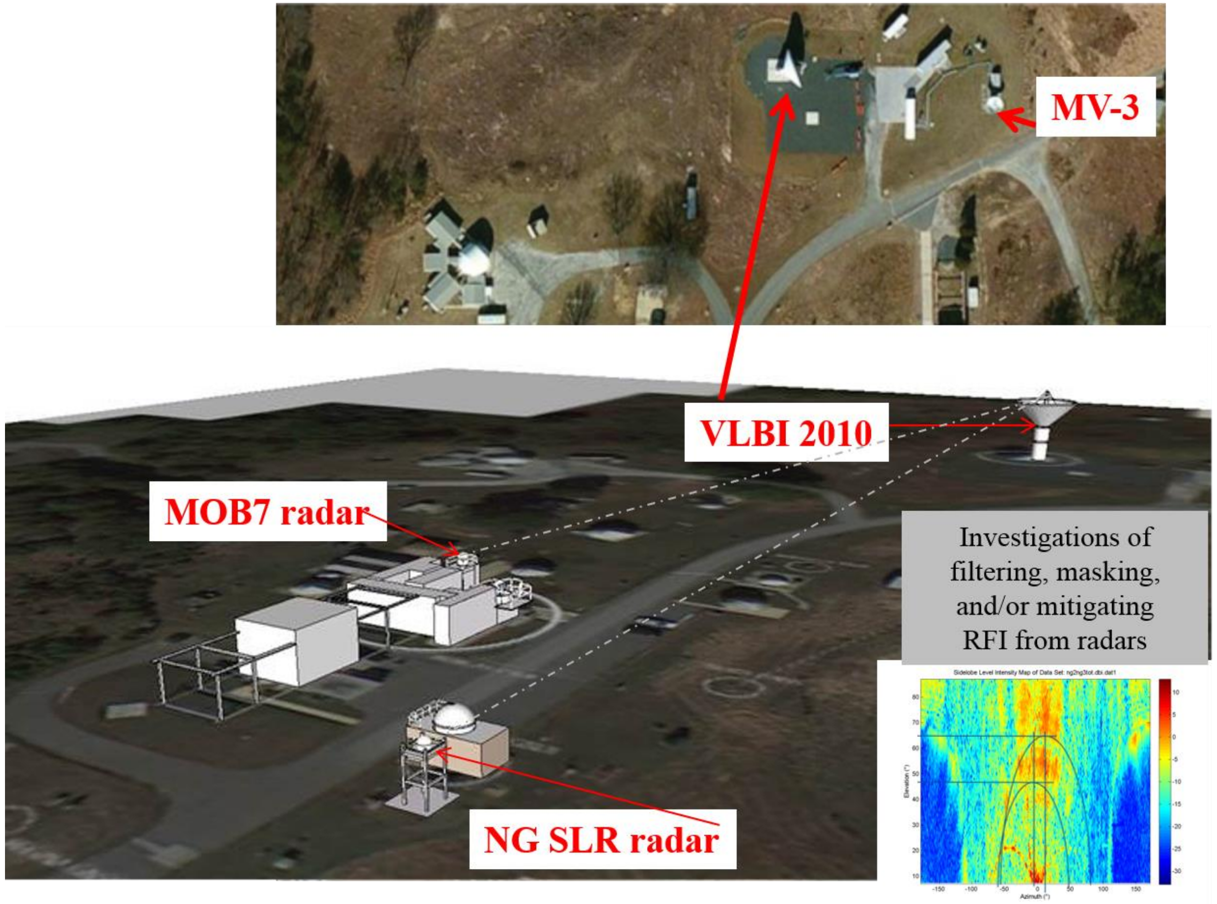
Masks, Loss of Sky Coverage, Characterizing the 12m Sidelobes

- In October 2012, at GGAO we conducted two different VLBI tests defining the reduced sky coverage impact of using masks to restrict the viewing angle of both the SGSLR and the VLBI on the GGAO campus. We also ran tests earlier in 2012, characterizing the VLBI antenna beam pattern with 9.41 GHz (sidelobe surrogate(ss)) beacons transmitting from locations near the directional antenna locations used by LHRS. With these tests we recognized hot spots associated with the VLBI subreflector looking right at the LHRS ss beacon.

VLBI @ (area 200 at Goddard aka GGAO)



Comparison to ANSI sidelobe envelope

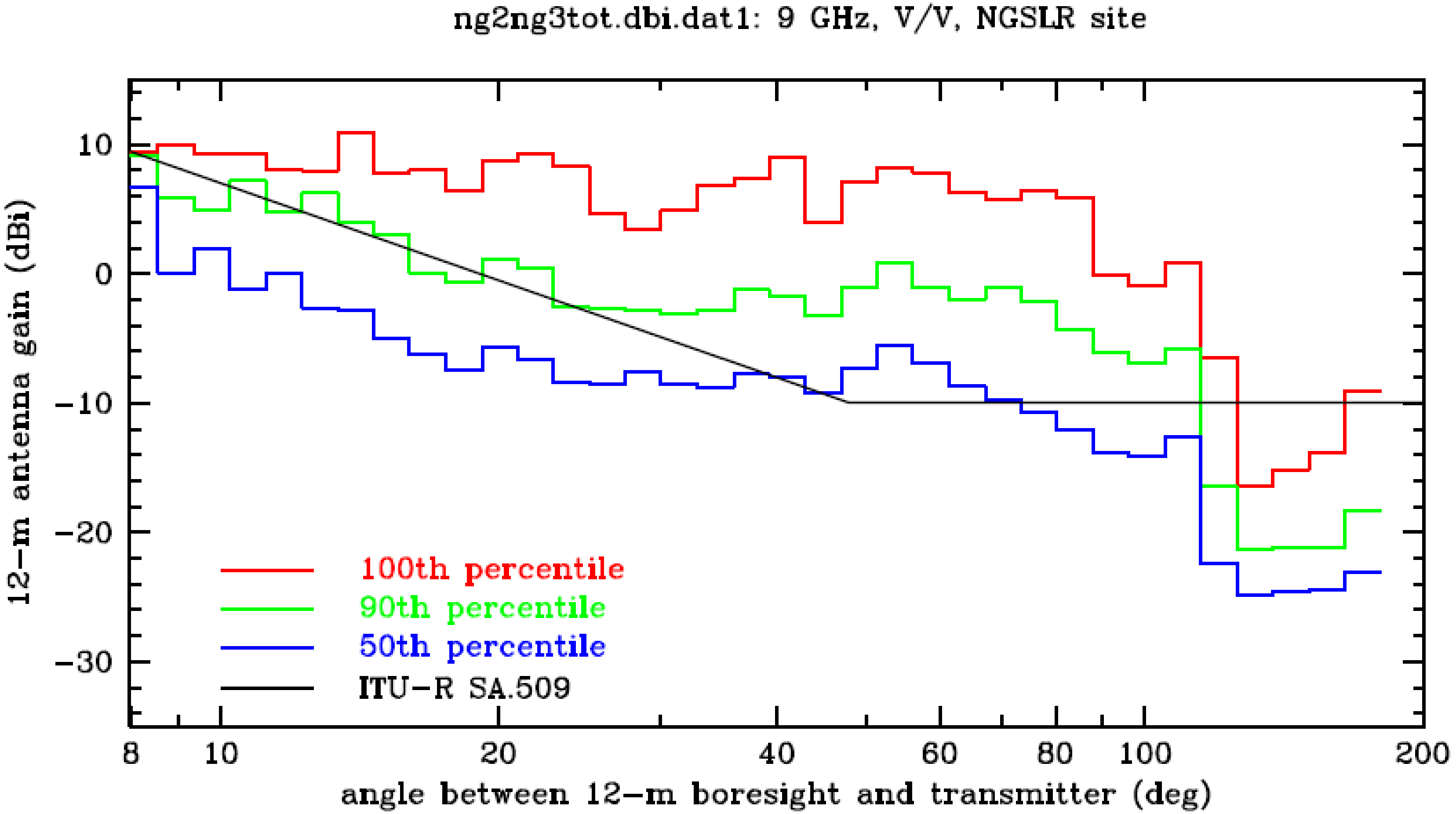
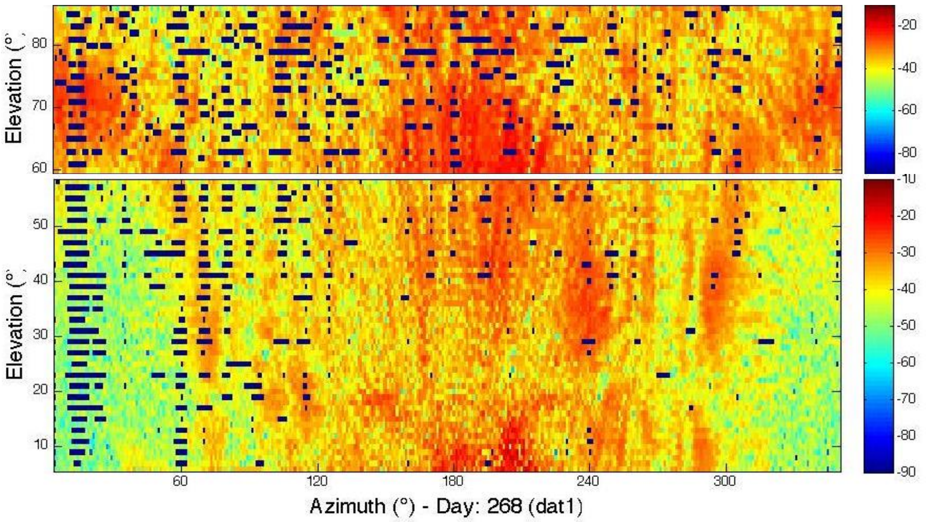


Figure 1: ITU-5009 antenna sidelobe envelope model incorporated in numerical RFI-compatibility studies.

VLBI Sidelobe Tests reveal higher noise floor with radar on/ blanking may be tried to clean up data

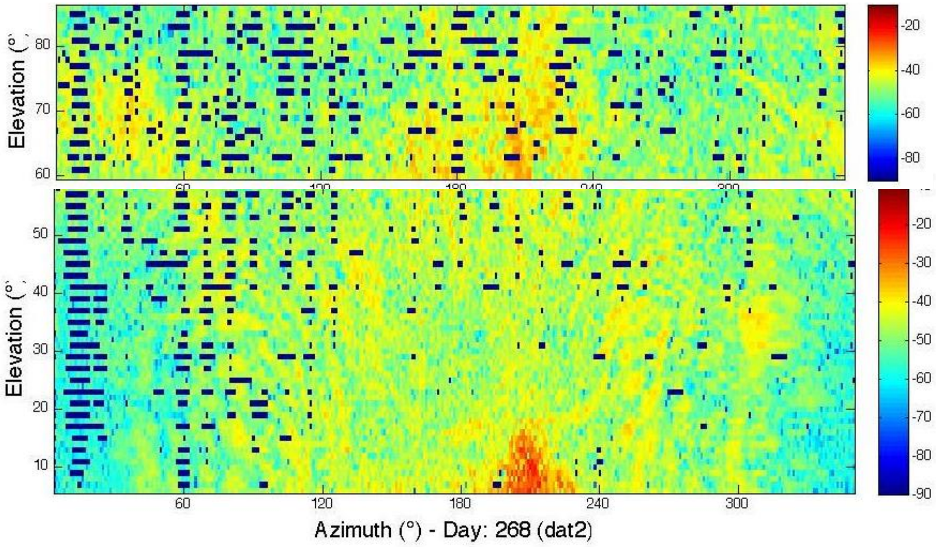


- Tests above 60 degrees elevation were conducted on October 8th
- Tests on September 25th (day 268) were conducted without radars operating

  Includes Azimuth angles that are usually masked out below 40 degrees including DORIS test beacon line of sight

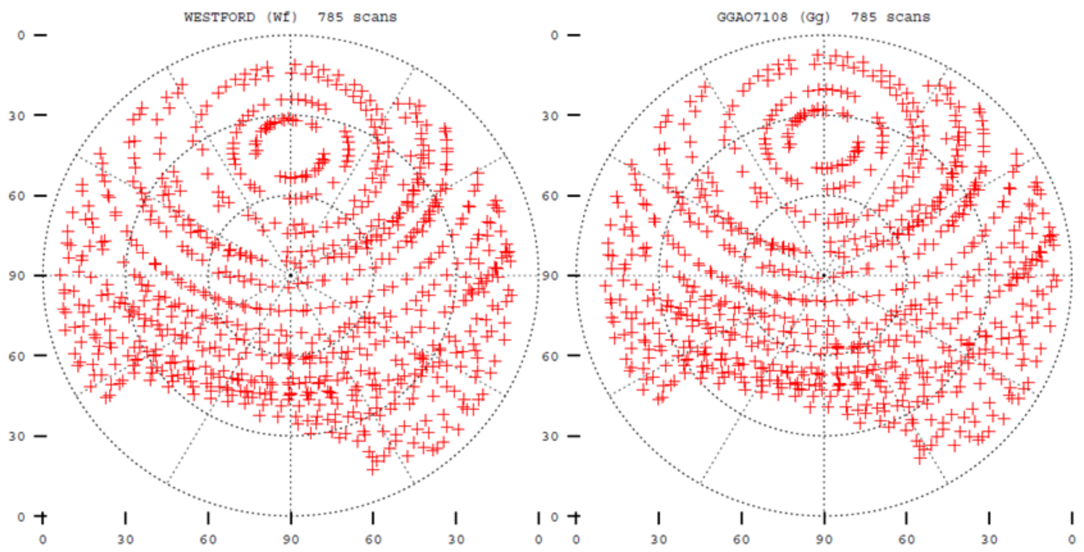
Data Dropouts are due to the spectrum analyzer re-calibrating

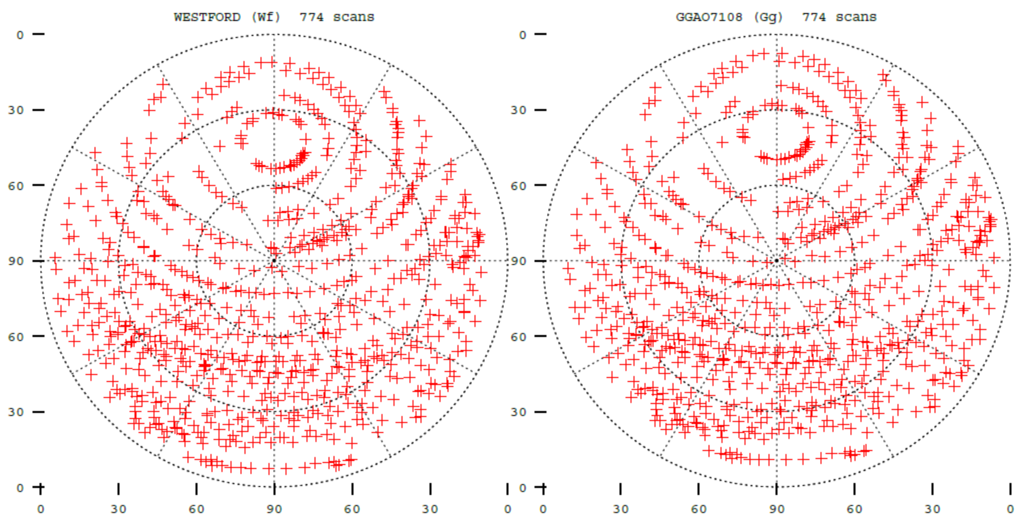
October 8th tests were conducted with the mask up and the SLR radars likely raise the noise floor



Loss of the Southern sky must be planned around due to radar masks at GGAO

- Oct 4th →
- These observing plans were specially prepared with knowledge of VLBI mask avoidance





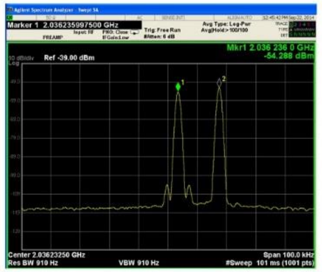
- Oct 5th
- ← These observing plans were opened up to the full sky through coordination with NG SLR and MOB7

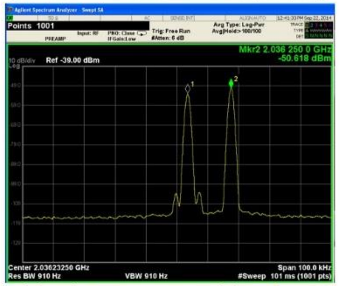
Reflective Blocker: Allowed VLBI to operate/15 dB of attenuation/Wind issues

•Reflective Blockers were investigated as well using solid cloth, and stainless steel mesh materials in 2012 and had the effect of 20 dB attenuation when located in the far field between SGSLR and VLBI. In 2014, a test DORIS was loaned to SGP by CNES to conduct similar tests on the blocking effectiveness realized from an unobstructed DORIS (direct line of sight) with less path loss and tuned to a slightly different frequency discernable by DORIS receivers in orbit above GGAO.

DORIS test as measured at VLBI antenna.

September 5th: With blocker (-49.2 dBm) and without (-35.7 dBm), blocker measured at IOA with Standard Gain Horn . At – 40 dBm is where the VLBI LNAs would saturate.





September 22nd : With blocker measured by the 12 meter(Marker 1:Test DORIS=-54.3 dBm, Marker 2: Operational DORIS=-50.6 dBm)

RFI Monitor used at GGAO, Texas, Tahiti, Hawaii

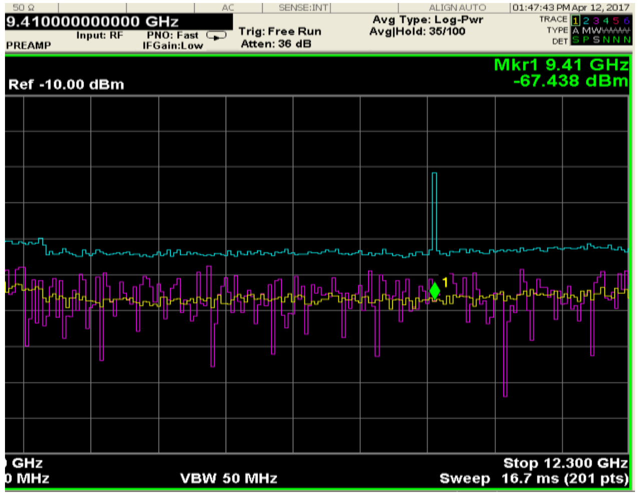
EQUIPMENT AND TEST SETUP

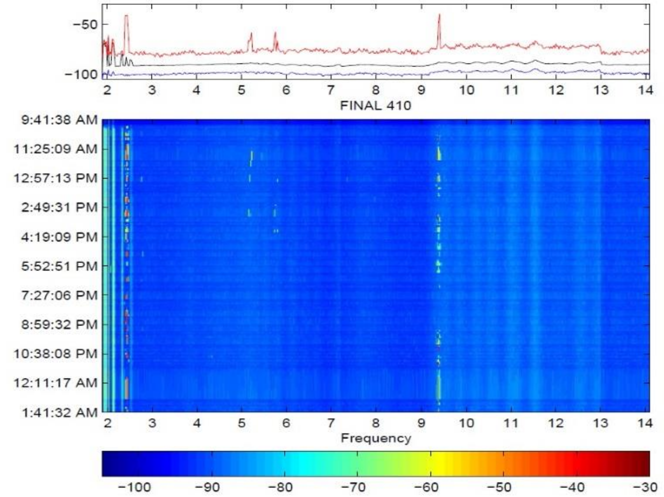
The main equipment consisted of an Anritsu MS2720T Spectrum Analyzer, a 1 to 18 GHz A. H. Systems Biconical Omnidirectional Antenna Model SAS-547, and a data acquisition computer running LabView. A directional (hemispheric) ETS-Lindgren antenna, Model 3164-05 was also used to acquire H/V polarization data at selected locations. A 2-person tent was used to keep the electronic equipment dry during periods of rain (it rained almost every day we acquired data). A picture of the equipment and setup is shown in Figure 2. Input impedance in all cases was 50Ω.

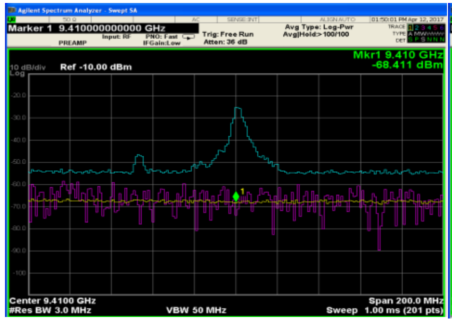
Figure 2: RFI Measurement System

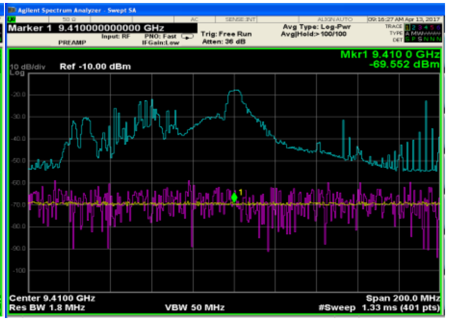
Radar Measurements with 12m and RFI monitor system

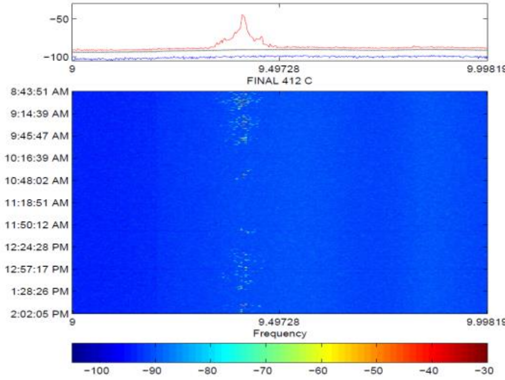
- These are measurements of the radar through the 12m antenna at GGAO(black screens), and through the RFI monitor system that takes cumulative data with an omni antenna (blue plots). These plots were taken in max hold so a large radar pulse detection would register for 100 sweeps and then the file closes and a new max is found.





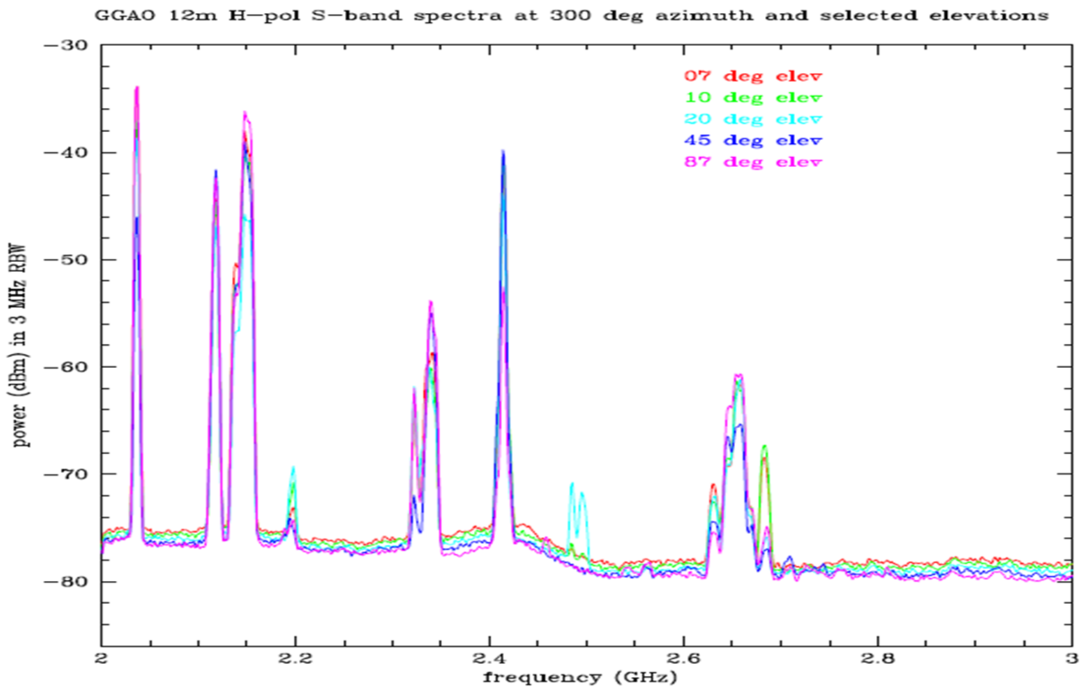




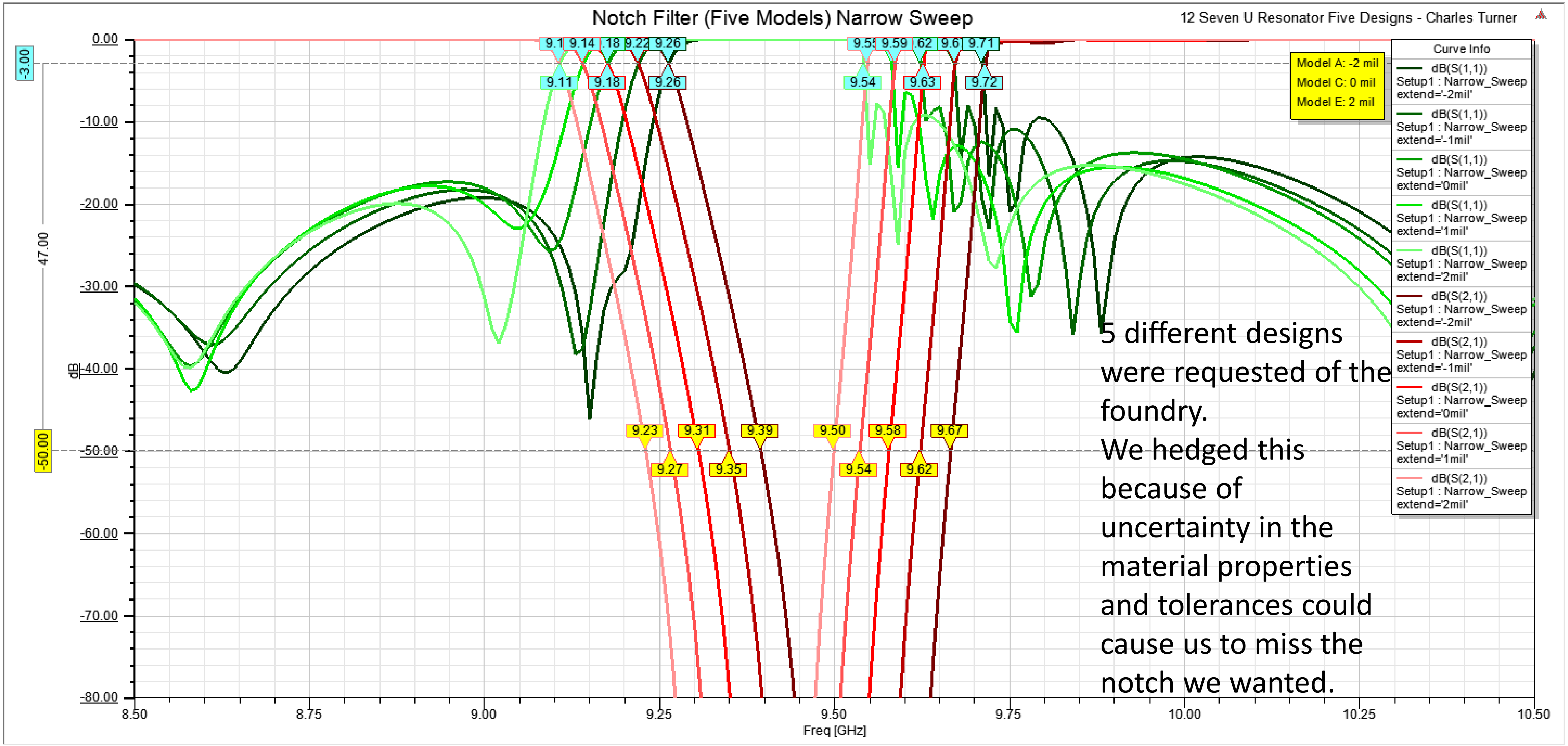


Filters designed to notch out the radar

- FILTERING:In 2017, a high pass filter with cutoff between 2.2-2.3 GHz has been tested at Westford Massachusetts VLBI station signal chain after the 1st stage amplifier. This will be tried at GGAO in the near future to mitigate low band RFI.
- There is also an HFSS designed model of a high temperature superconductor notch filter that can address the LHRS radar sidelobes and restrict our masks (and their attendant restrictions on sky coverage) to only the radar main lobe. S-parameters from the notch filter model are presented.



Notch Filter S-Parameters 5 slightly different designs w/o Connectors

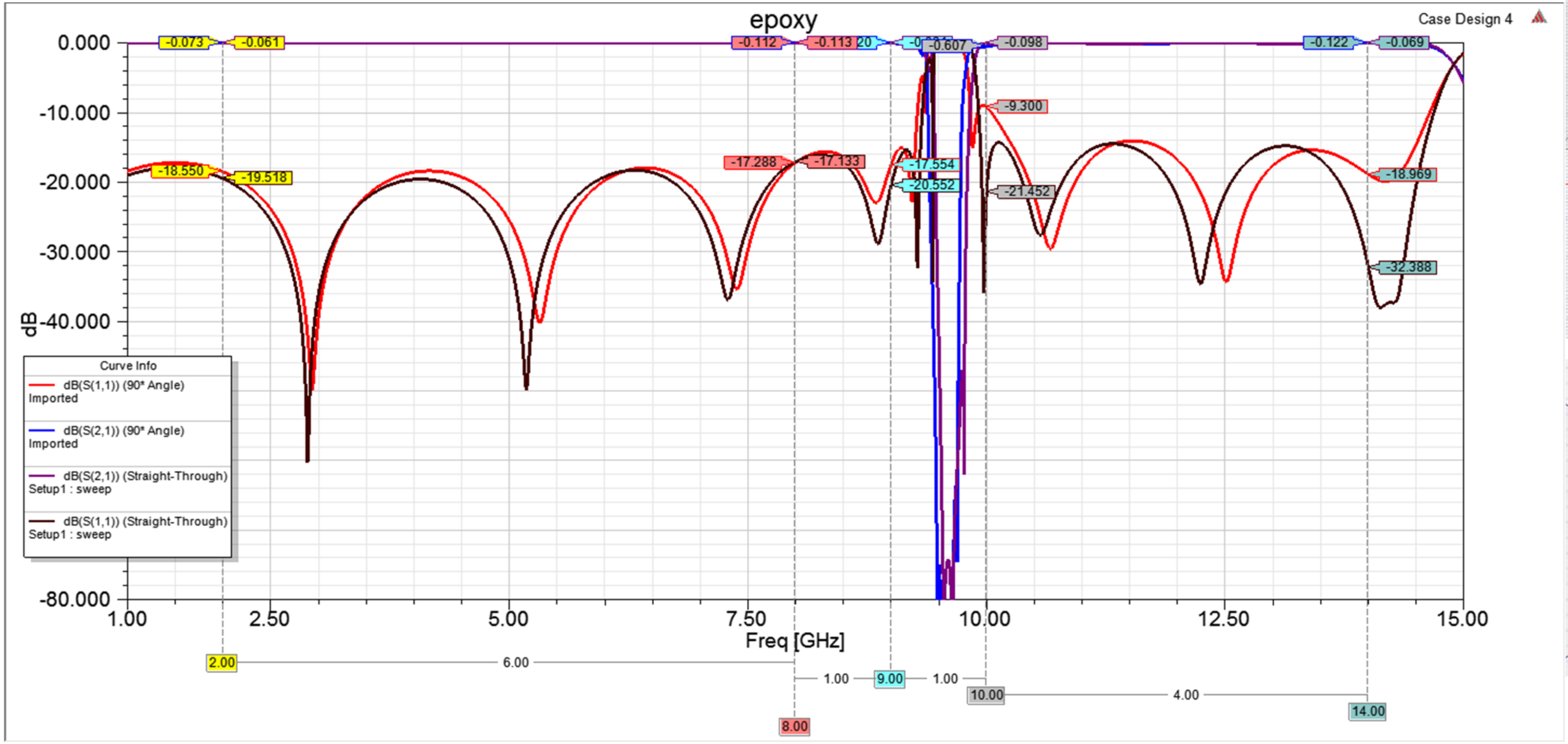


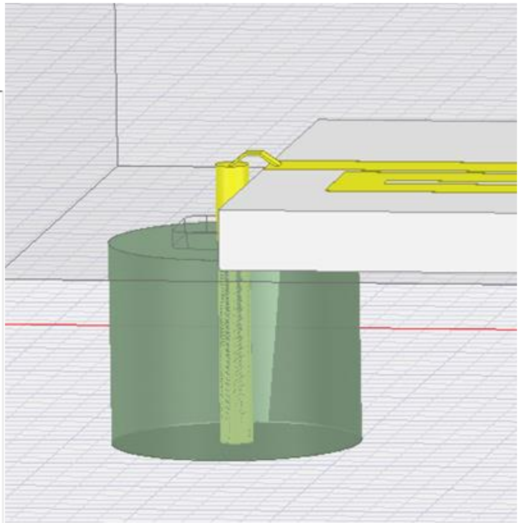
5 different designs were requested of the foundry.

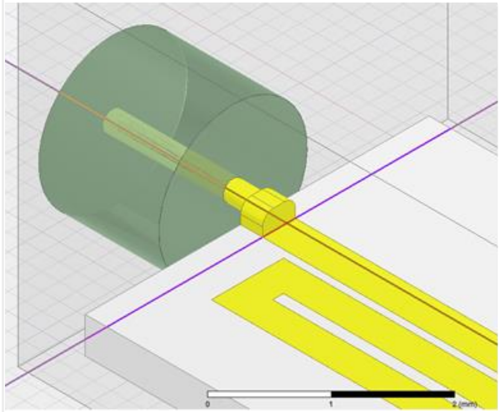
We hedged this because of uncertainty in the material properties and tolerances could cause us to miss the notch we wanted.

Notch Filter S-Parameters –design 4 with Connectors

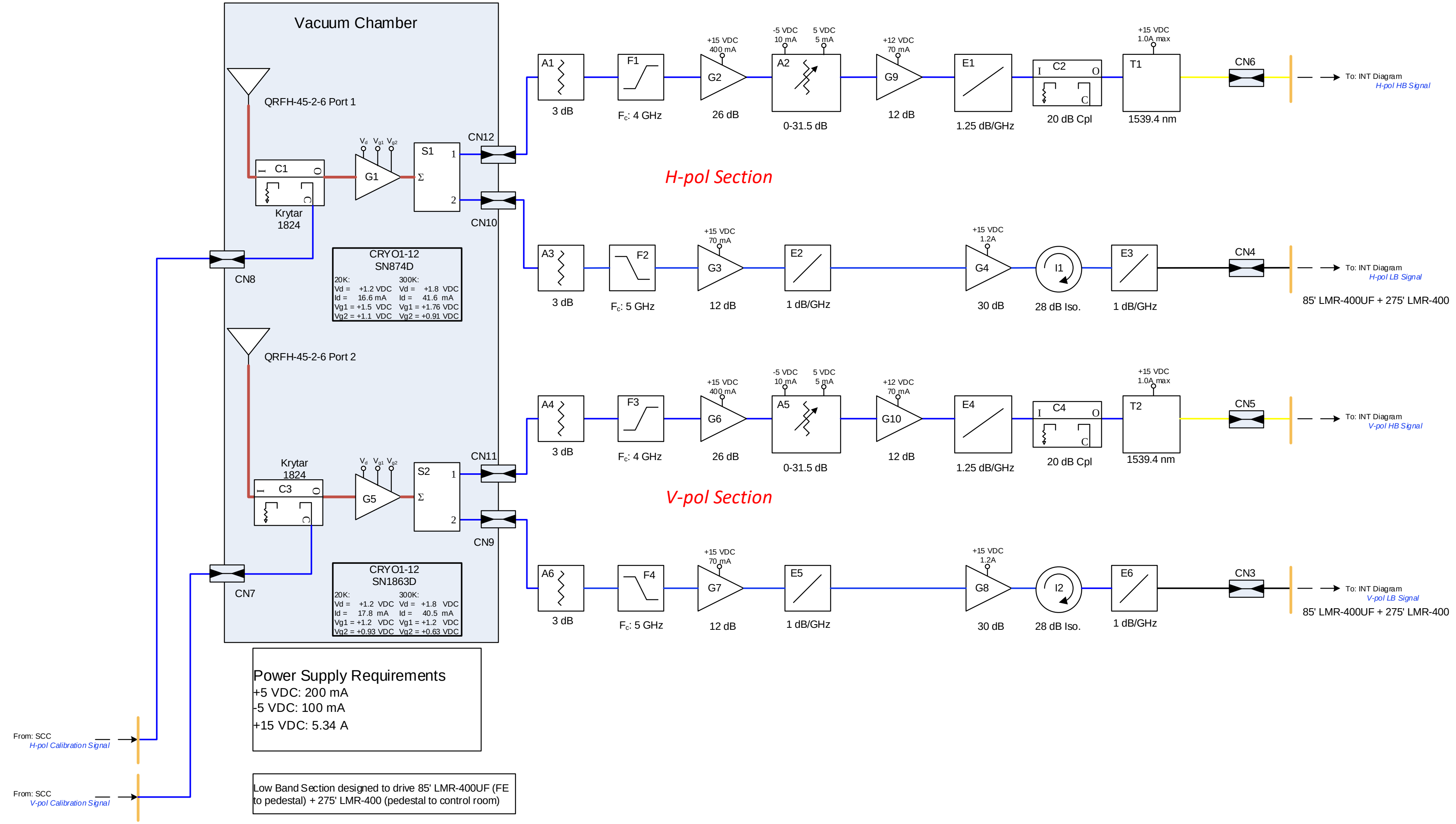
- The model was given further detail after the foundry run was started to see the effect of connectors
- The simulation shows that reflection is less if we use a straight connector versus a 90 degree bend



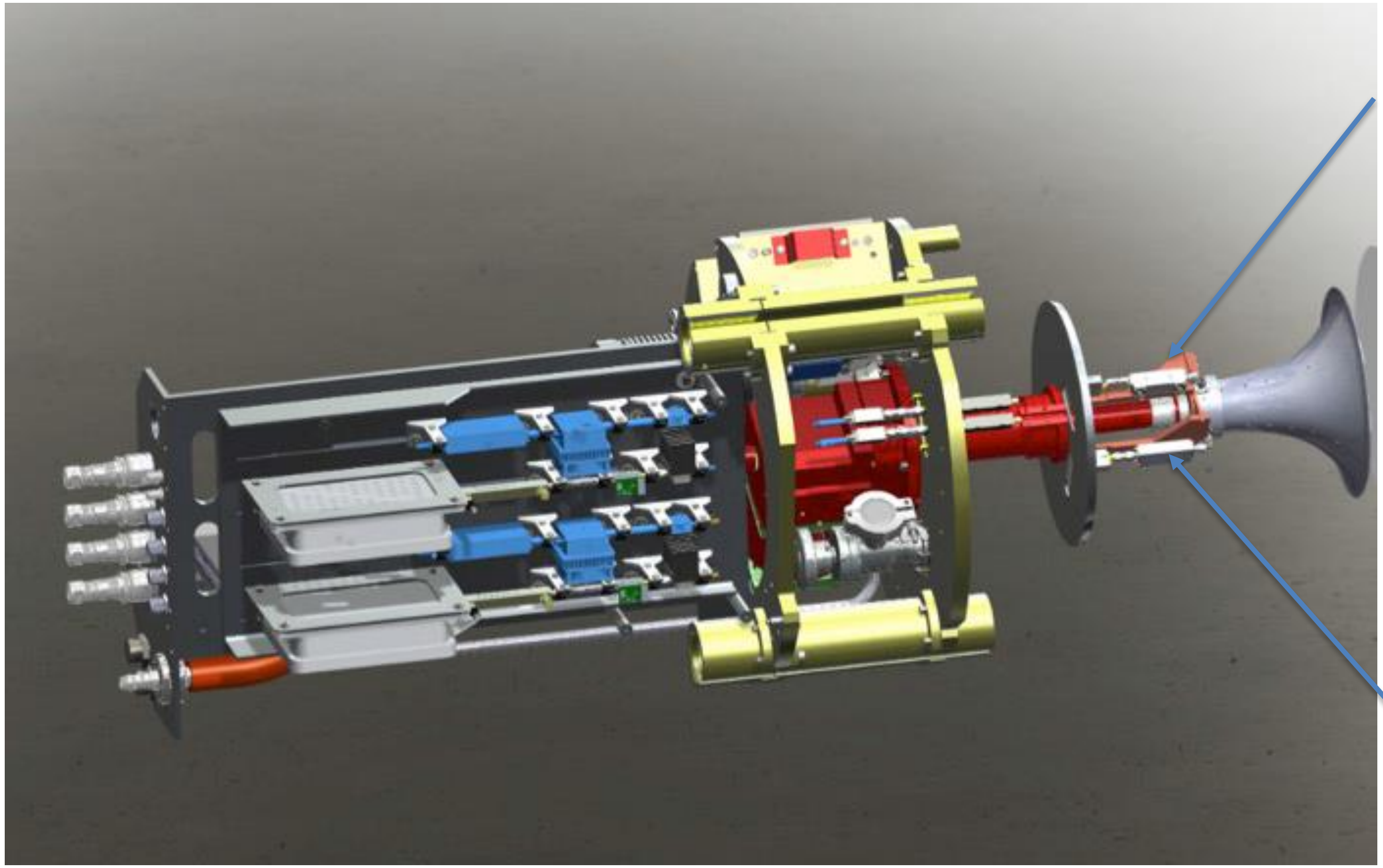




FE RF Design - Schematic



Location of couplers (and filters)



For more information on geodetic VLBI please go to:
https://space-geodesy.nasa.gov/
https://ivscc.gsfc.nasa.gov/
Upcoming Technology Proposal

- NOI Title : **Broadband self-calibrating cryogenic radiometer with integrated RFI mitigating frontend and "Digitize-at-RF" demonstrator for Space Geodesy**
- **Ganesh** Rajagopalan of Haystack Observatory is PI
- Stephen Merkowitz is co-PI from Goddard

RFI mitigation tests conducted at GGAO.

Lawrence M. Hilliard (NASA, USA)

Lawrence.M.Hilliard@NASA.gov