Phased array Feeds and Advanced Receivers 2022

Building the Cryogenic Front-end for ALPACA

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for the ALPACA Team

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Arizona State University

Radio Astronomy Systems BYU

Green Bank Observatory

A MOMENT TO THANK THE FRIENDS WE'VE LOST ALONG THE WAY

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Focal Plane Phased Array Feeds

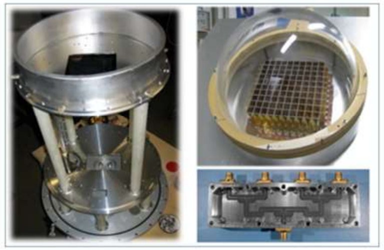
Offer the possibility to more efficiently use a large reflector antenna by:

- Providing a well sampled, larger FoV
- Higher Aperture efficiency in each beam

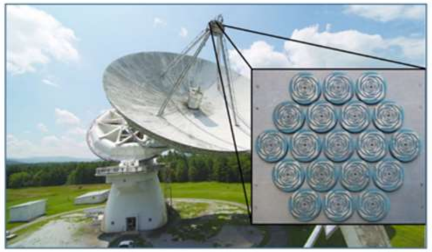
ASKAP PAF (Australia)

APERTIF (Netherlands)

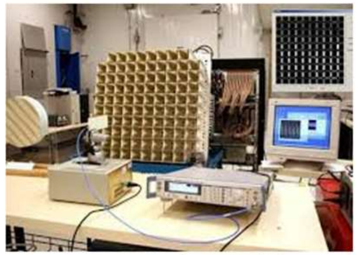
BYU/NRAO PAF (U.S.)



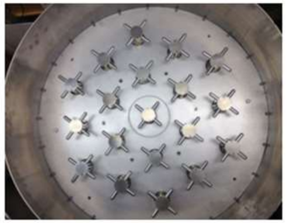
PHAROS (Netherlands)



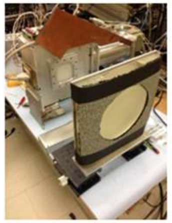
Early NRAO PAF (U.S.)



DRAO PHAD (Canada)



Cornell AO19 (U.S.) - Arecibo



UMASS/BYU PHAMAS mm-wave 70-95 GHz PAF

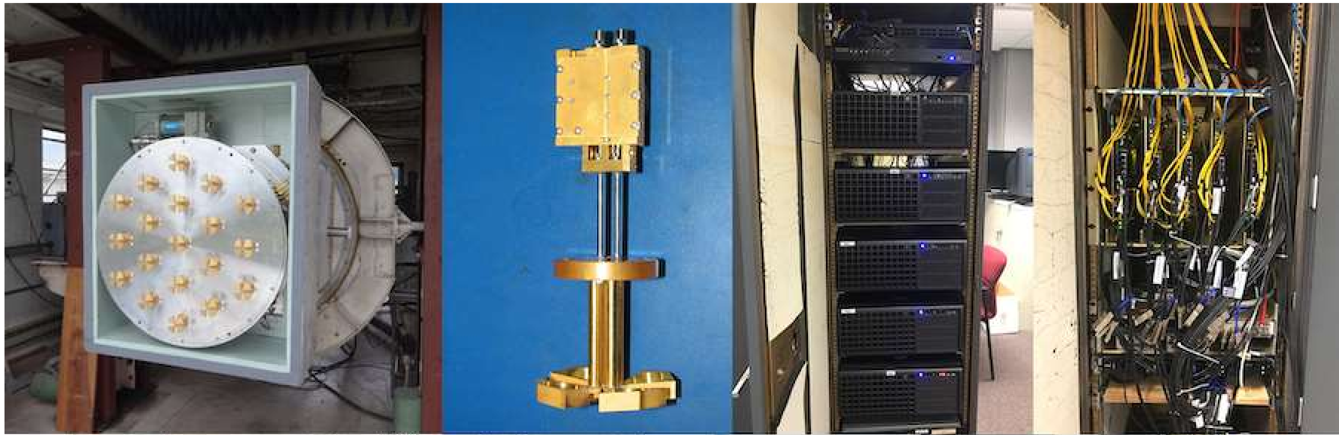
DRAO CryoPAF4

Photo credits: David V. Davidson, Cornell U., Junming Diao, casca.ca

Focal Plane Phased Array Feed

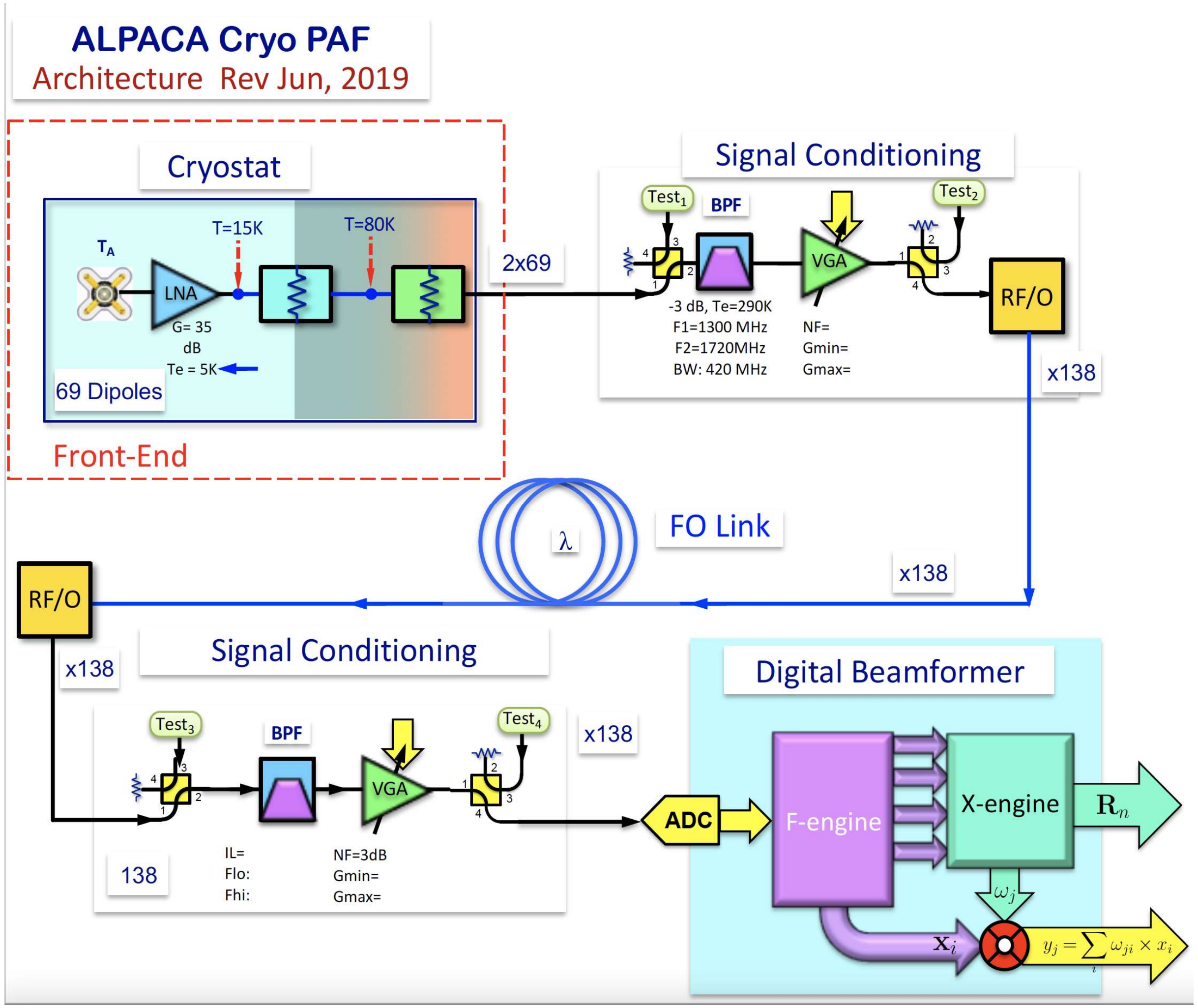
BYU and Cornell have undertaken research and development of several technologies that are at the core of ALPACA

- Mechanically Strong and RF Transparent Vacuum Window
- Manageable Thermal loading on internal Cryogenic stages
- Large instantaneous Bandwidth
- Real-time Digital Beamforming



ALPACA System Description

- **Analog front-end**: Phased array elements, Cryogenics, LNAs
- **Signal Transport**: Gain stages, Interconnects, Filters, Phase calibration & RFoF Link
- **Digital Back-end:** Coarse & Fine Filterbank, Data Distribution, Correlator, Beamformer and Storage



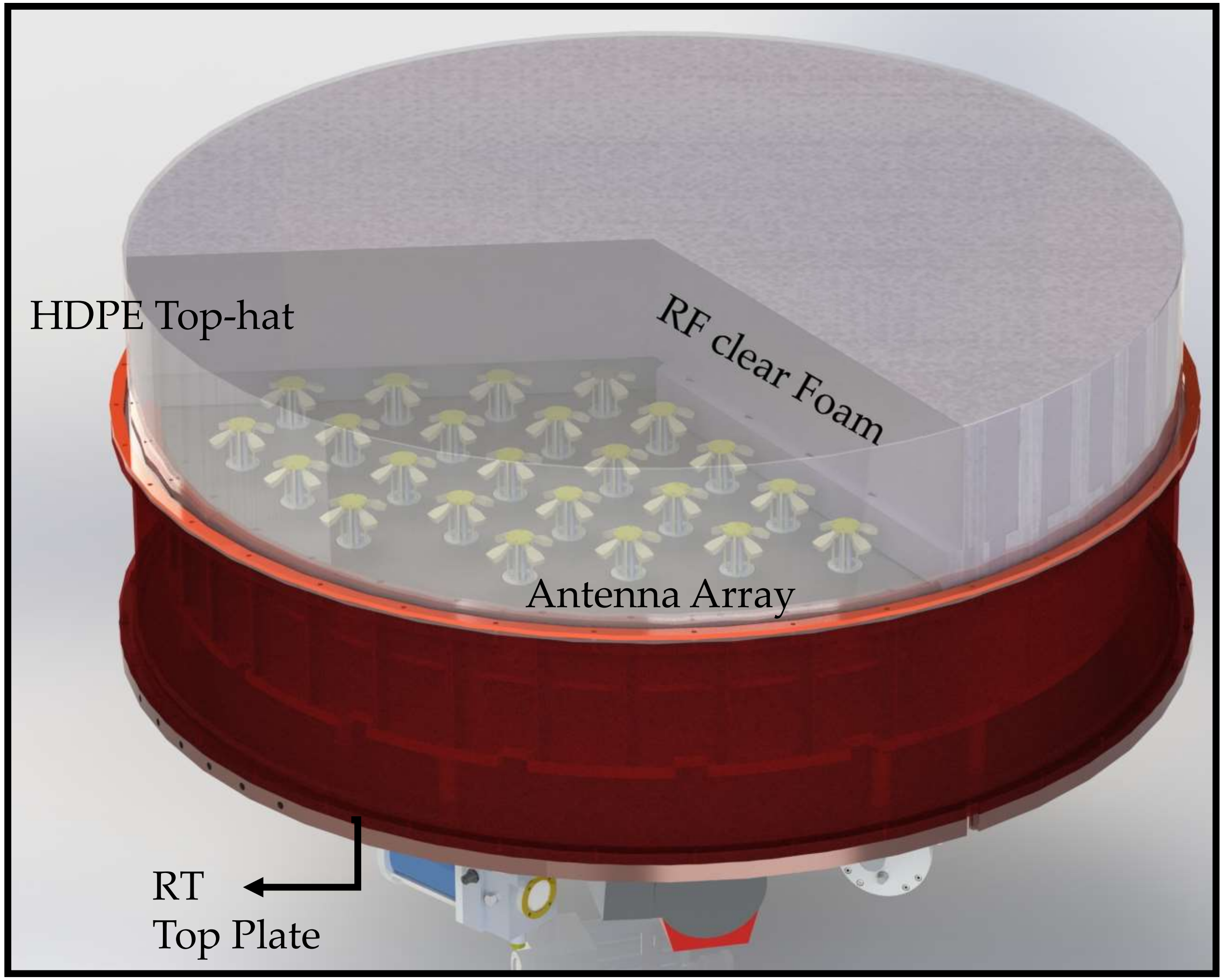
ALPACA Front-end Performance Spec

	System Characteristic	Specification
Receiver Element	Element Type	Dual-pol Dipole with Pie shaped Outer Arms
	Frequency Coverage	1300-1720 MHz, (305 MHz tunable within 420 MHz Total Bandwidth)
	Tilt (α) and Pie shape Angle (β)	20° from horizontal & 40°
	LNA Gain and Bias Power	>35 dB across band <20mW
Antenna Array	Number of Dual-pol Elements	69
	Array Geometry & Element Spacing	Hexagonal Close Packing with 135mm spacing
	RF signal routing	Semi-rigid coax (at 2nd stage) & 8-ch Flexible Stripline (to RFoF board)
	T_{sys} Spec (Goal)	35K (27K)
Cryostat	First Cryogenic Stage	Provide ~100K thermal intercept
	Second Cryogenic Stage	Provide ~20K heat sink for LNA packages
	Number & Type of Cold head	3x CTI 1020 dual-stage
	Number & Type of Compressor	1x Trillium M700
	Cryostat Rotation	using GBT Sterling Mount

Mechanical Design

Unique Aspects:

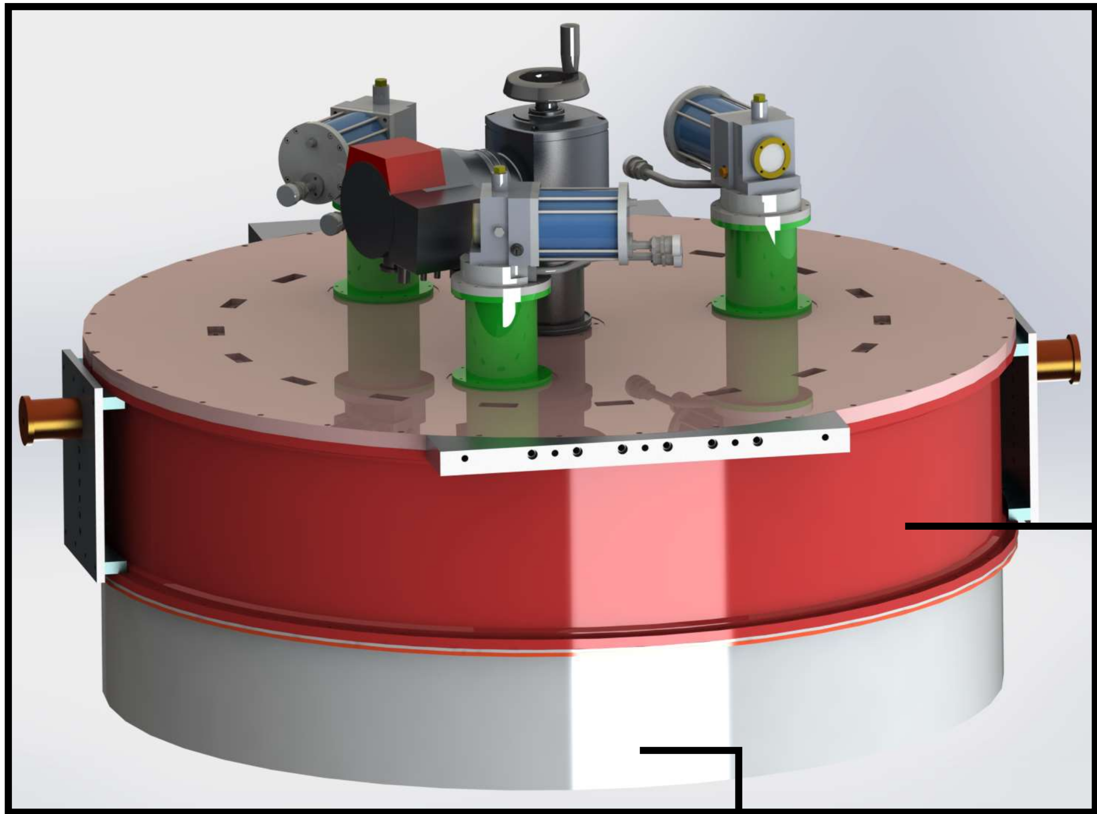
- Large RF transparent Vacuum Window
- Blind-mate Receiver Modules
- Monolithic Flexure-based compliant Thermal Links
- Thermally Insulating Blade Flexure and sliding Column Standoffs
- 3-fold Symmetry to minimize unique components
- Height is determined by internal cryogenic components ~ 56 cm



Vacuum Vessel

Solid Top Half:

- **Aluminum Top-plate and Welded Shell**
  - Top plate provides all mounting interfaces feedthroughs for vacuum, metrology and signal readout
- **RF transparent Window**



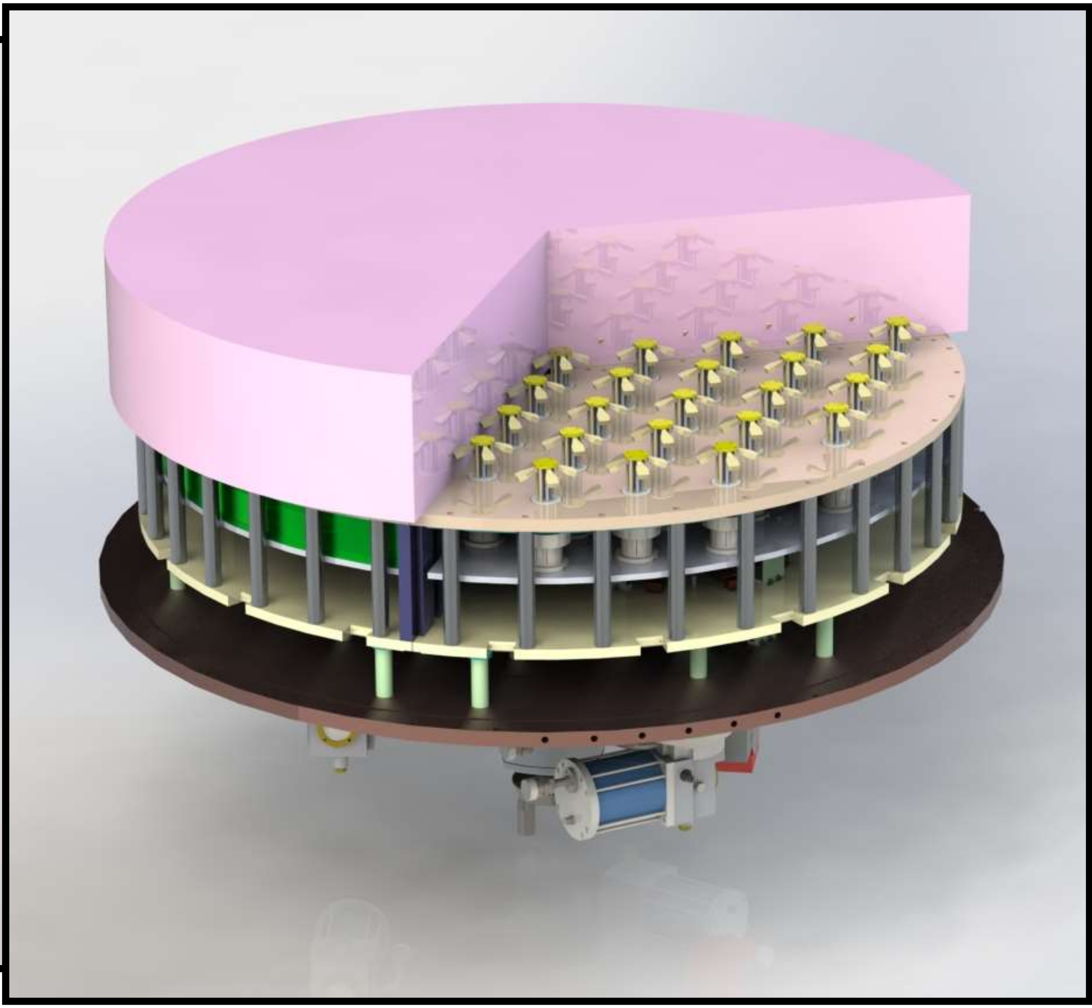
Solid Top Half

RF Transparent Window

Vacuum Vessel

Main Parts:

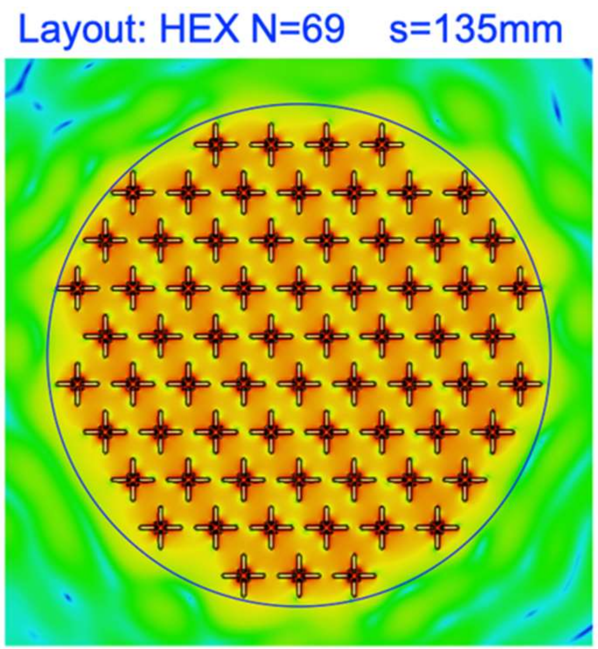
- **Solid Top Half**
- **RF Transparent Window:**
  - **Vacuum Tight**: Durable structure is achieved by a welded HDPE top-hat.
  - **Structurally Sound**: Rohacell HF71 provides adequate compressive strength
  - **Manageable Heat Load**: Rohacell HF-71 foam is RF transparent but opaque in infrared

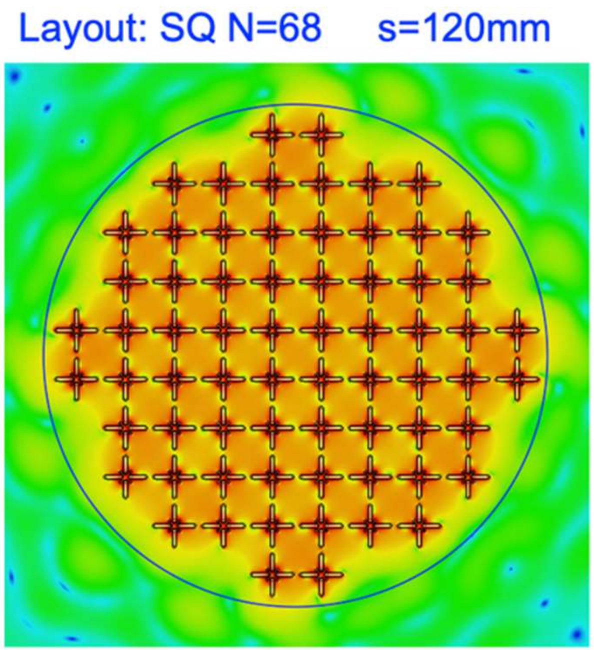


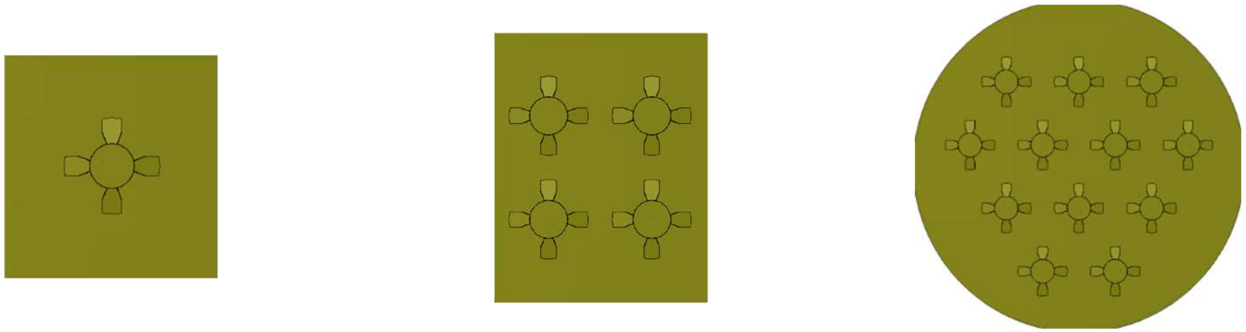
Antenna Array

Detailed EM simulations exploring:

- Array Spacing
- Array Geometry



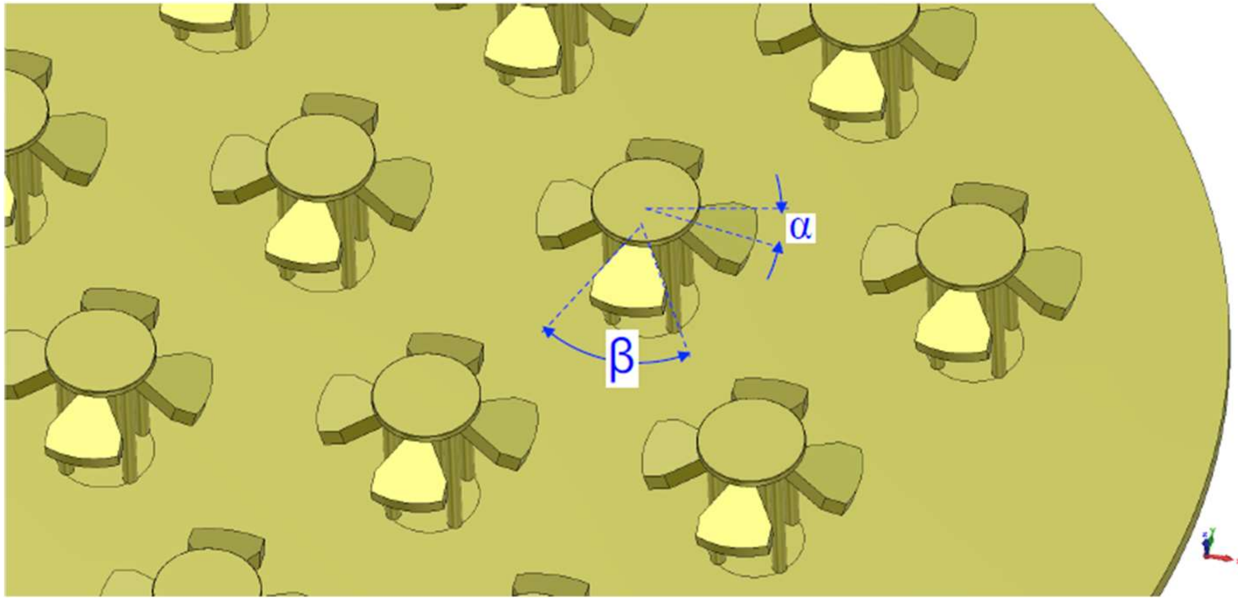


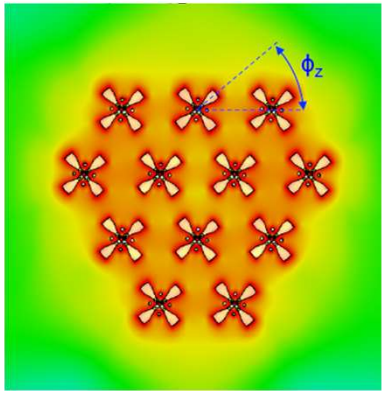


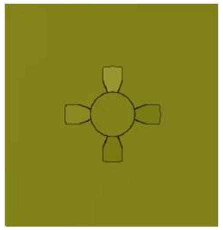
Antenna Array

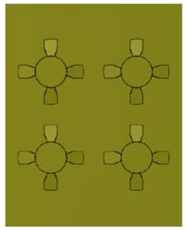
Detailed EM simulations exploring:

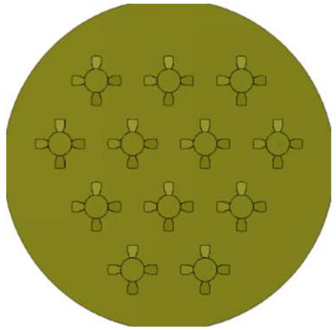
- Dipole Rotation Angle
- Wedge Pie Angle
- Wedge Tilt Angle
- Dipole Height







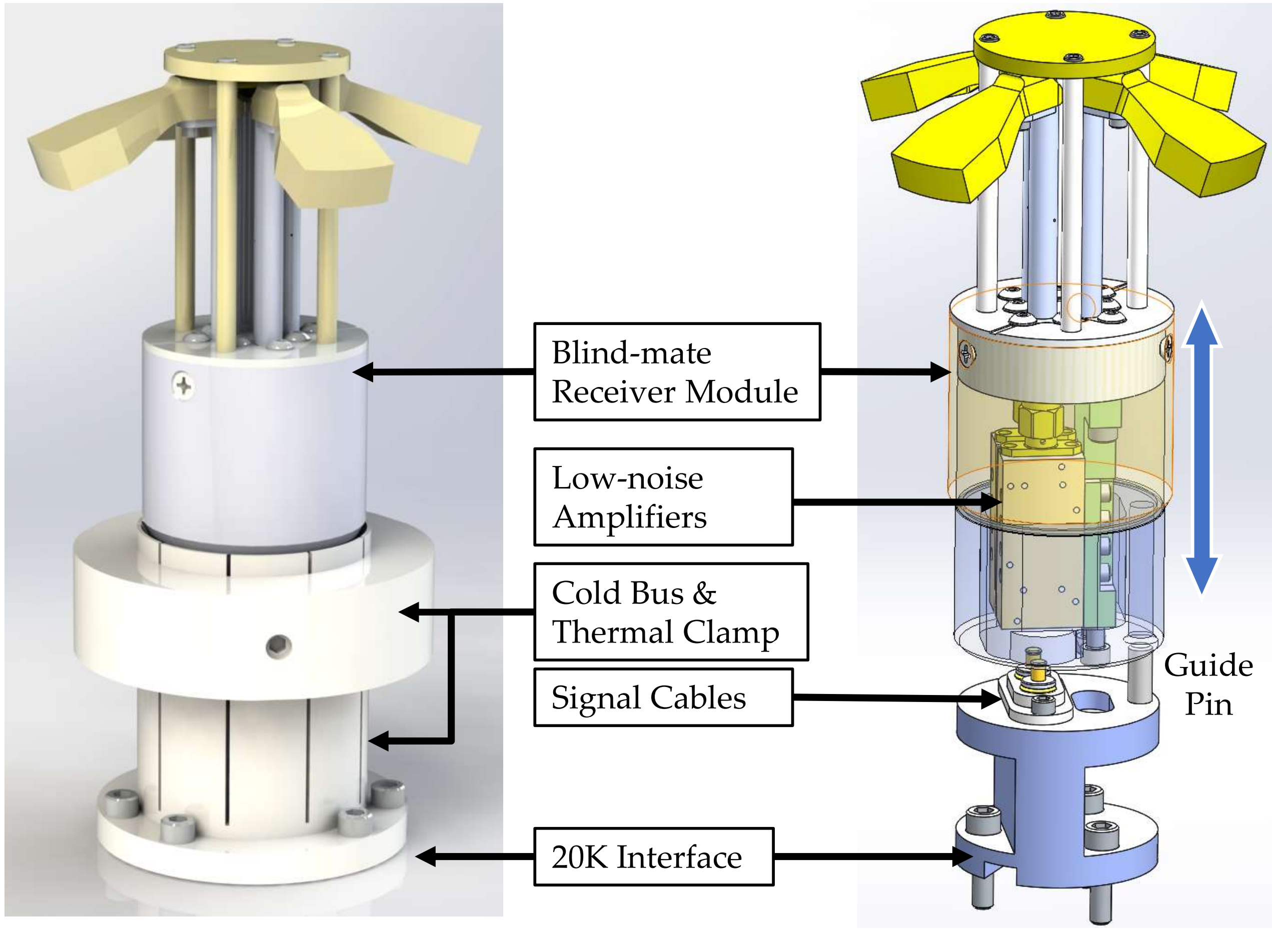




Antenna Modules

Design driven by:

- EM simulations
  - Critical dimensions for machining and assembly
- Mechanical packaging for easy replacement of the cryogenic LNAs
- Robust thermal connection to cold sink



Antenna Modules

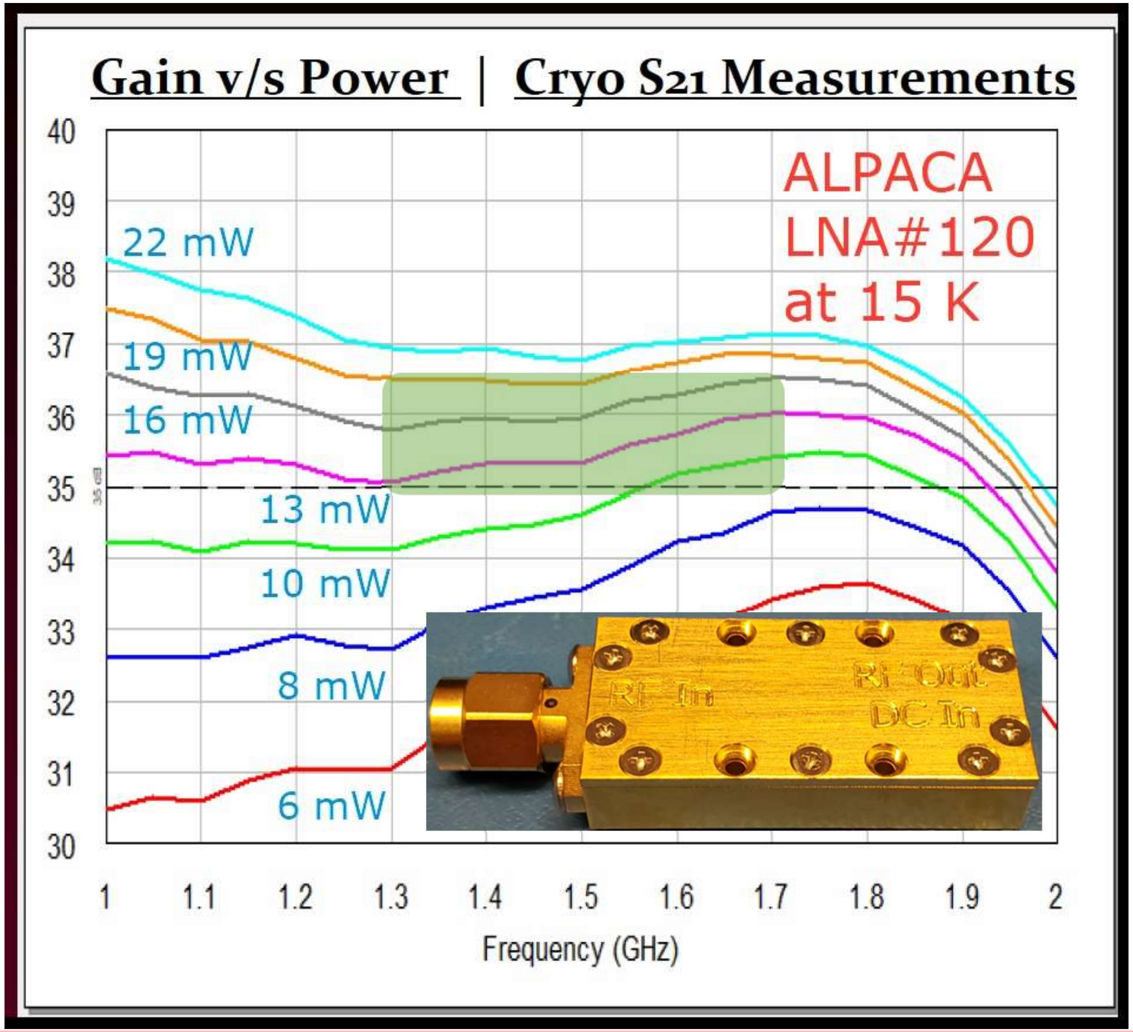
All the parts for the dipole assemblies have been machined and top half assembled.

Installing Amplifiers now.

Cryogenic LNA

Requirement: >35dB Gain at <20mW power

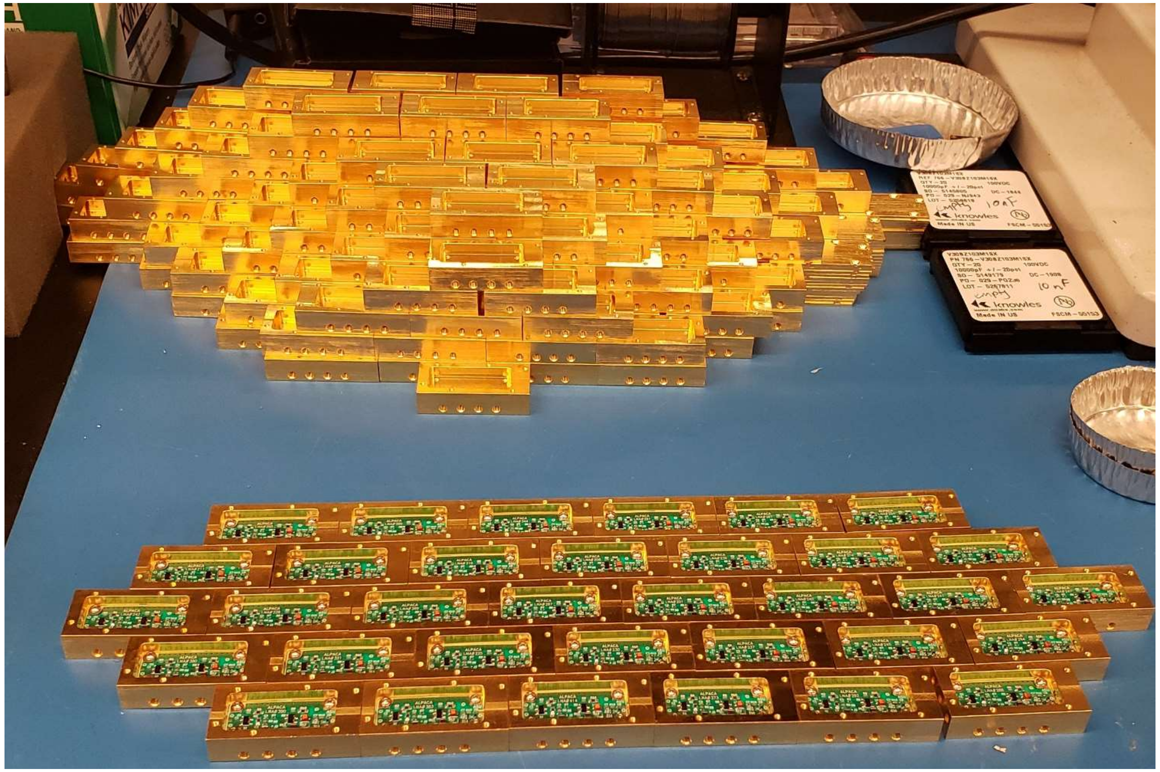
- **180 production amplifiers built, cryogenically cycled and fully tested**.
- Design of **DC bias boards** for the amplifiers (8 channel on standard 3U cards) underway, included health monitoring.



Cryogenic LNA

Additional Feature:

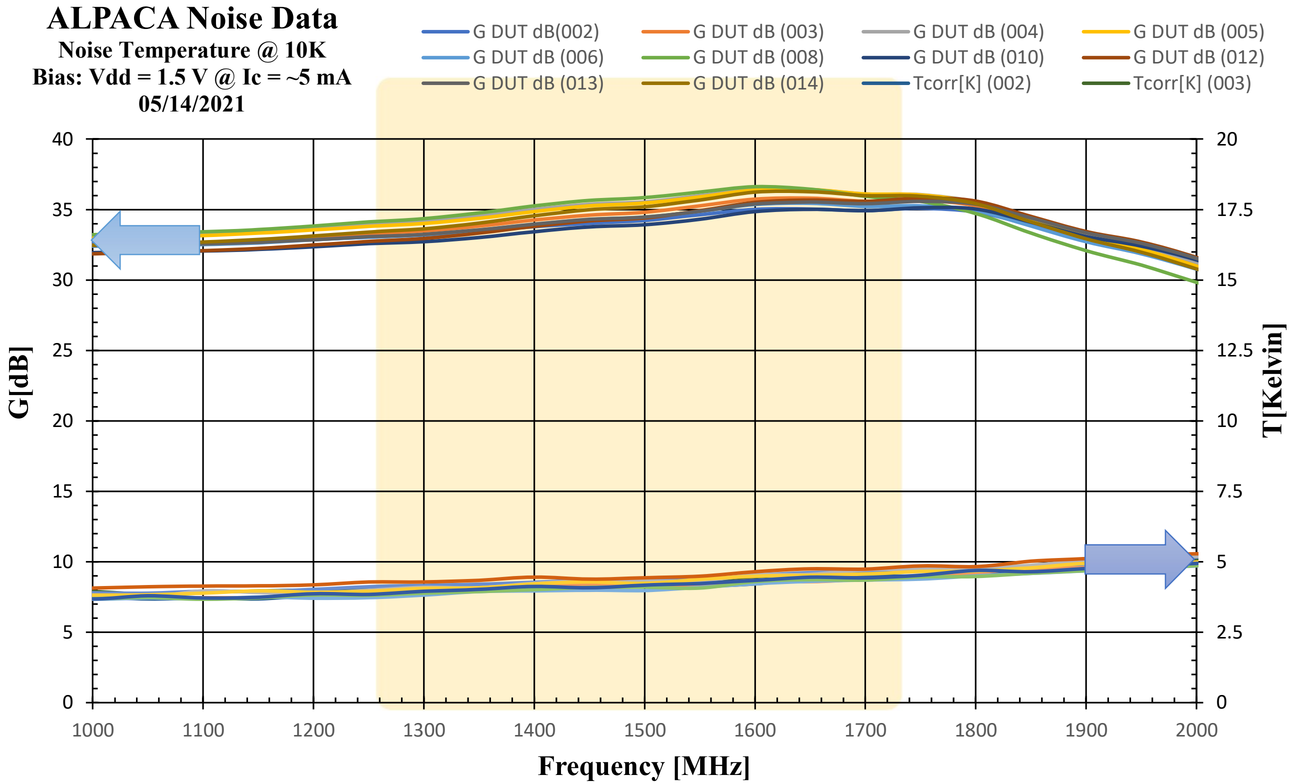
- **Integrated Bias-tee** to carry amplifier bias and RF signal on the same coax line
- **No cryogenic wiring** for biasing
    - Save 4(wires) x 2 (temp stages) x 138 LNAs



Ensuring Reliability of LNAs

Rigorous Testing for all Production LNAs:

1. Cryogenically **cycled** from room temperature **to 15K six times** in a non-operational configuration.
2. Tested for **S-parameters at room temperature**. Performance will be **compared to** the lot of 10 **prototype amplifiers**.
3. Any amplifiers that fail step 2 will have their boards replaced. Repeat steps 1 and 2 until all amplifiers pass.
4. Randomly select **20% of the amplifiers** and **perform full cryogenic testing** (cold S-Parameters and noise measurements) on those 36 amplifiers.
5. Only encountered soldering issues and some infant mortality.

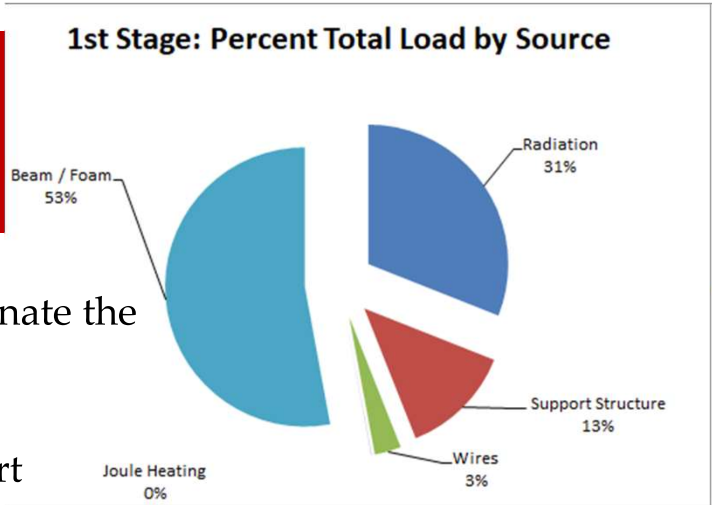


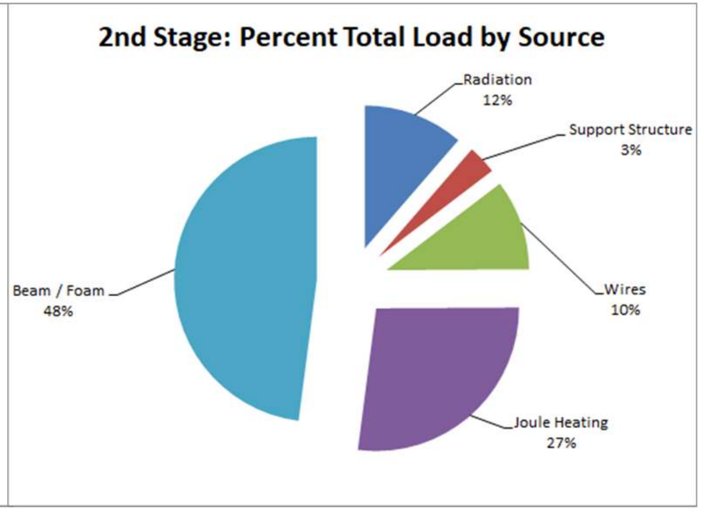
Thermal Model

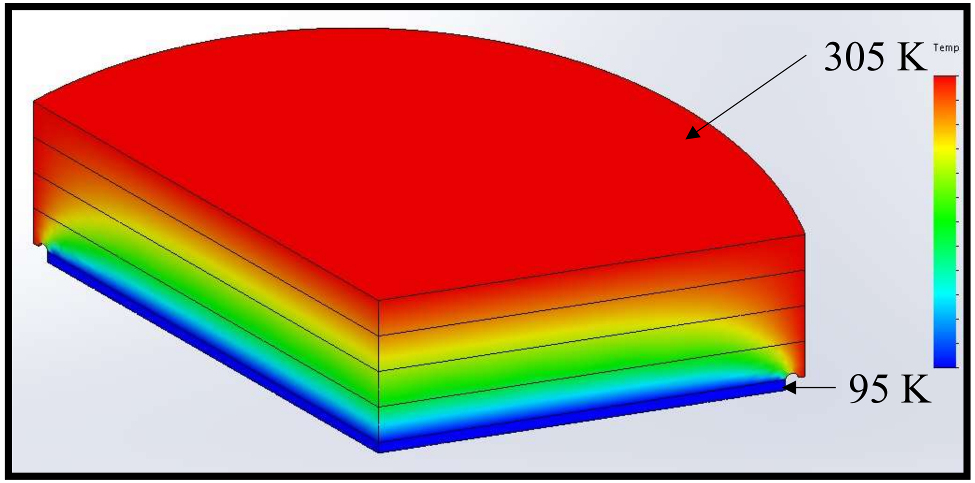
- "Dry Dewar" : Closed-cycle Cryogenic System
- Be able to keep the receiver array and LNAs at ~20K physical temperature throughout GBT environmental operating conditions
- Heat loads:
  - Conduction (wiring and structure)
  - Radiative loads
  - Joule heating (LNAs)
  - Assuming 305K ambient (32C, 90F)
- Supplemented with thermal FEA for complex items
- Help guide material choices for components

Thermal Model

- Foam conduction and radiation dominate the heat load on each temperature stage
- Use high conductivity Al-6063 support structures at the 1st cold stage connecting the base plate to the ground plane
- Use Al-1100 for 2nd stage base plate that provides cooling for the cryogenic LNAs
- Using Flexible striplines reduces 2nd stage heat load as compared to individual SS coax cables
    - Greatly simplifies internal wiring too!

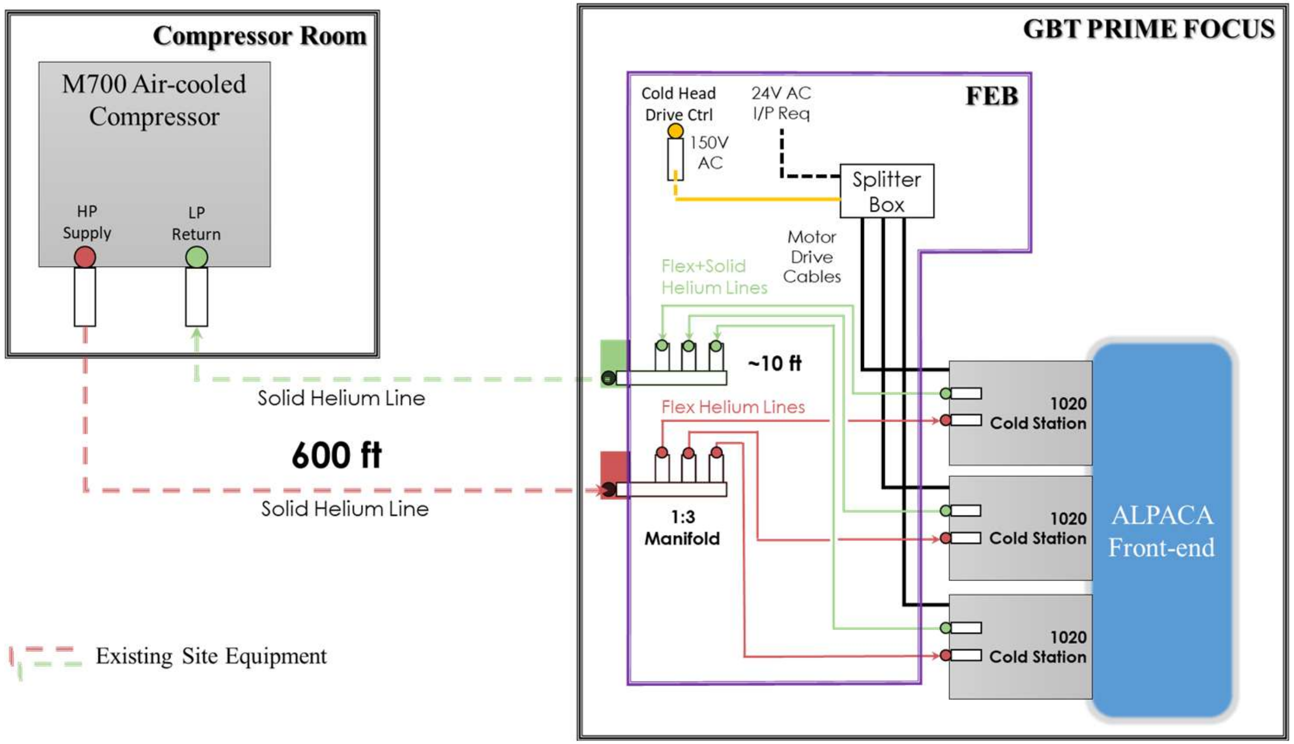






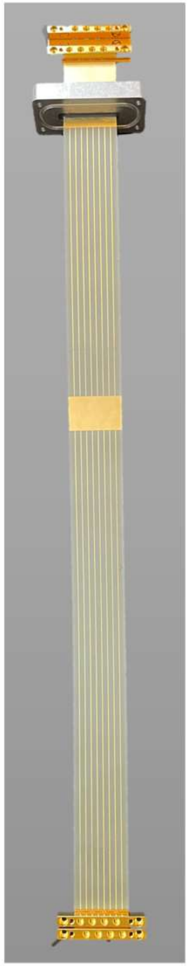
Cooling System

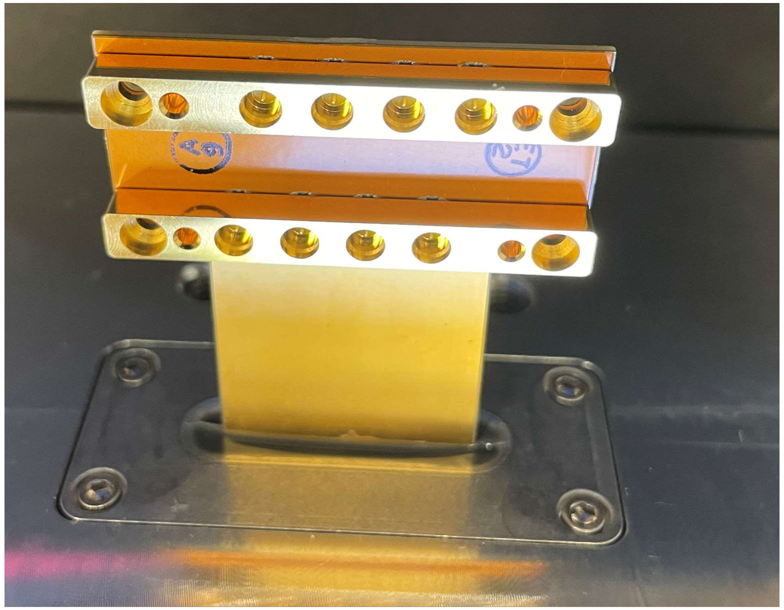
- Length of Helium lines at GBT could impact the cooling capacity
- Pre-cool the instrument in lab and maintain steady state at telescope
- Cold head Motor Power supply to be provided at FEB



Cryogenic RF Stripline

- Four Receiver modules connect to a single 8-ch stripline at the 2nd cold stage (from GUSTO heritage)
  - **Improved Reliability**: Custom-designed ganged SMP connectors reduce mechanical stress at demate
- The stripline carries the input LNA Bias and carries the received RF signal out of the cryostat
- Thermally sunk at the intercept stage, keeping 2/3 of the length of the stripline cooler than 100K.

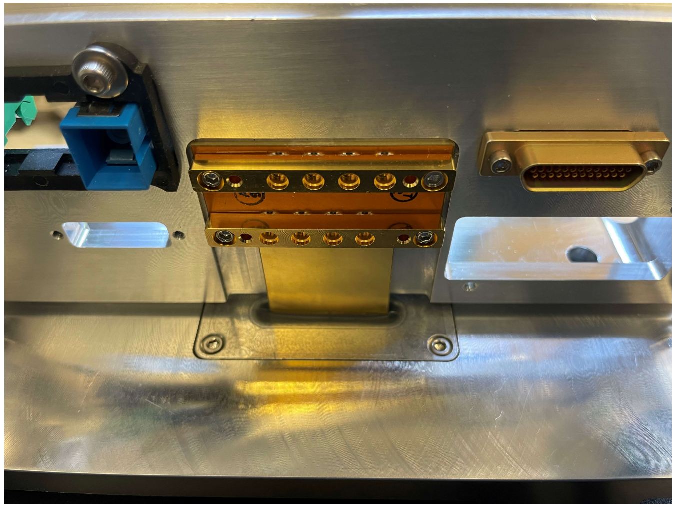


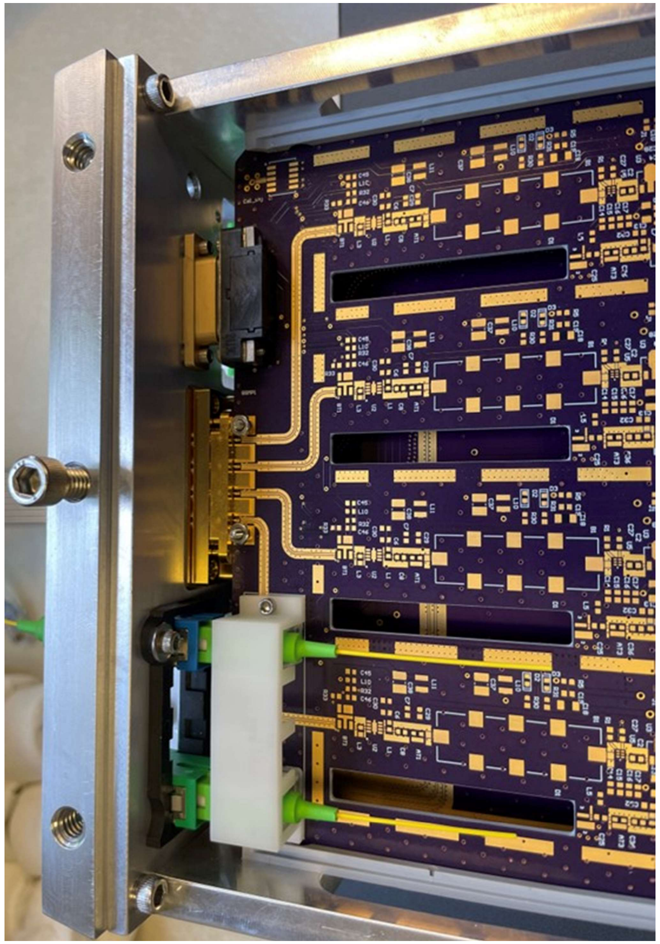


- Potted in a flange that installs on the RT Plate
- Fully covered ground plane external to cryostat is necessary to avoid pickup

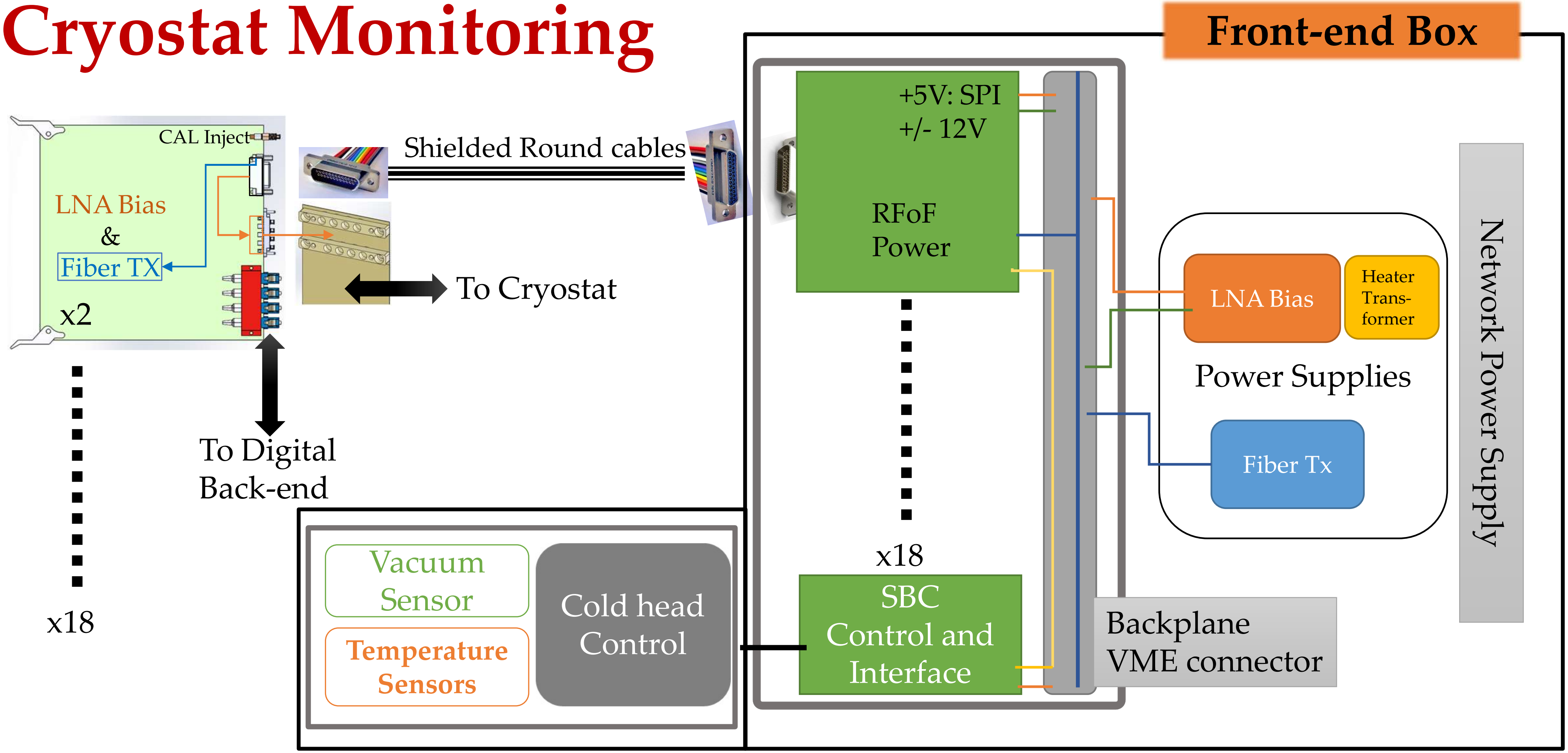
RFoF Signal Transport

- Two RFoF transmitter cards plug into a single stripline
- Mirrored connections: All cards are manufactured identical.



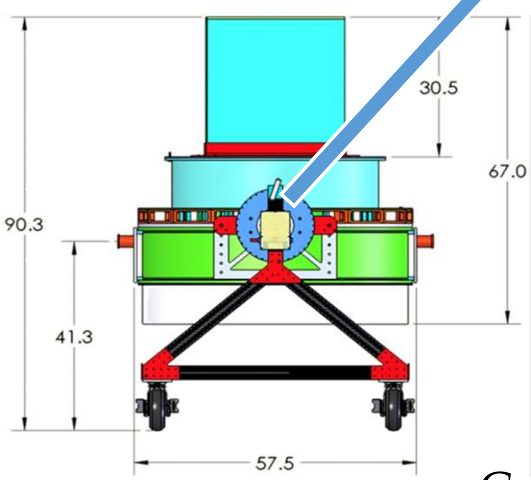


Cryostat Monitoring



Mechanical Interfaces - Transport

- Cart provides a safe and reliable way to move the cryostat
- Blank weight of cryostat ~900 lbs.
- Additional equipment:
  - Interface assemblies
  - Power supplies
  - Front-end Box
  - Cable assemblies
- Careful mass estimates for all modelled components (+ some additional known equipment)
  - 1350 lbs of equipment

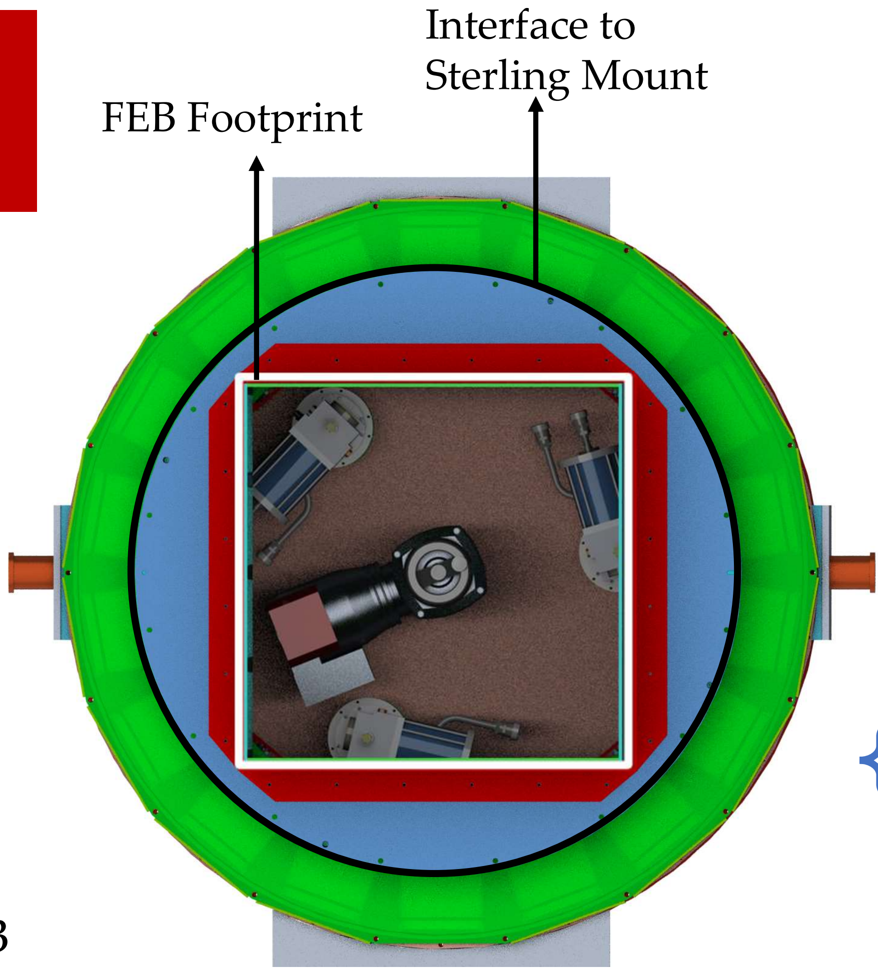


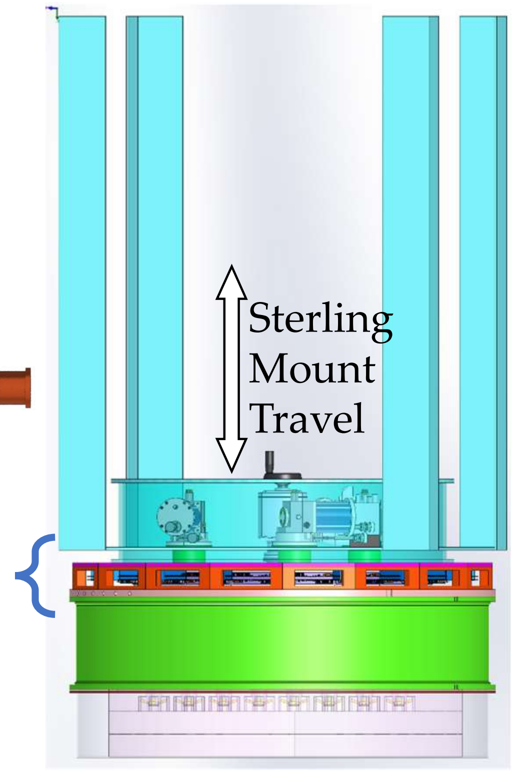
Crank-driven to rotate the cryostat in place

Footprint: 60 x 72 x 90 in
GBT Elevator: 79.25 x 78 x 120 in

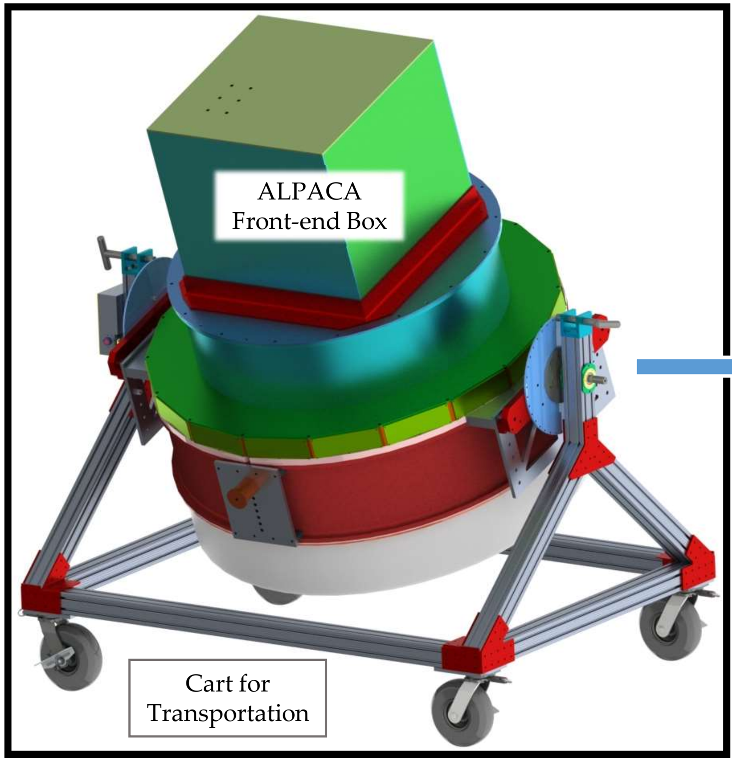
Critical Interface – GBT Prime Focus

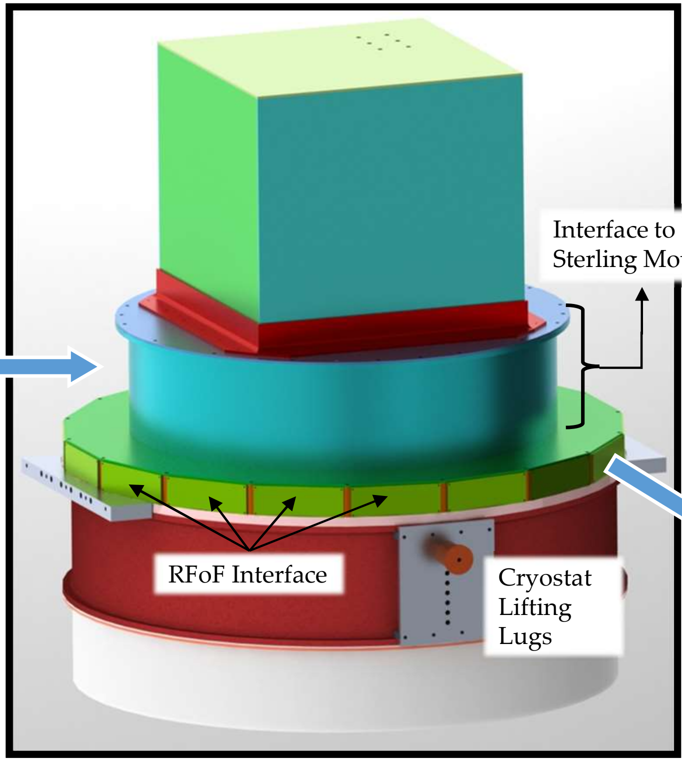
- 2nd stage Amplifiers and Fiber Transmitters installed at the output of the RF Striplines
  - Transport RF output from the antenna array to backend by converting it to optical signal
- Only ~5” clearance available behind the cryostat top-plate
- Lie-flat configuration, blind-mate cards to stripline
- Draw all cables through the FEB

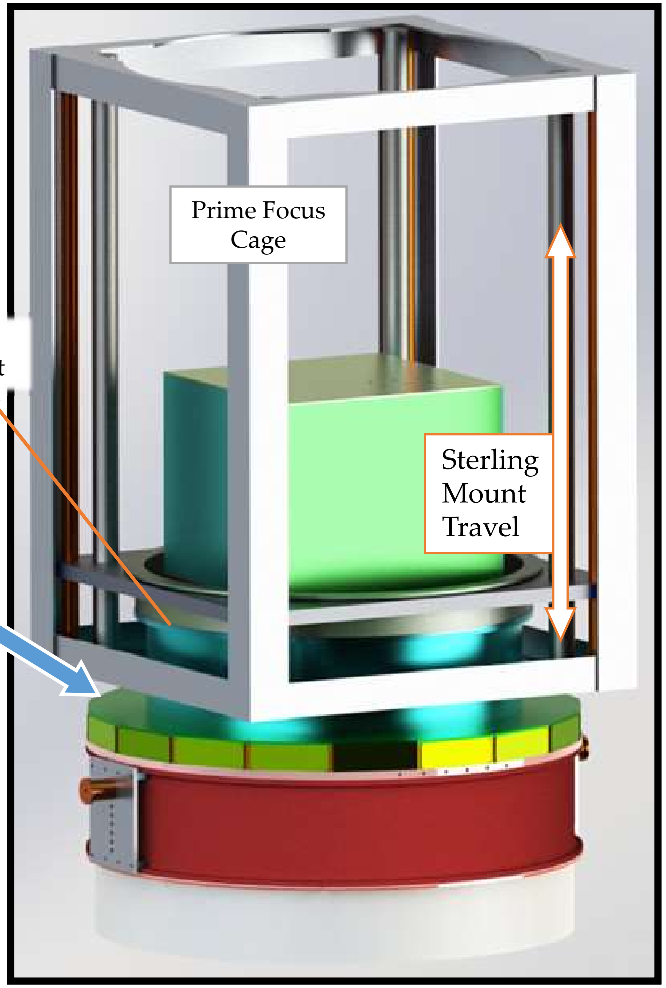




Critical Interface – GBT Prime Focus







Conclusion

- ALPACA will be a transformative instrument for large-area surveys at L-band
- Green Bank Telescope provides all-sky access, and the ALPACA on GBT will provide a large instantaneous FoV of ~0.5 deg^2
- Instrument construction is well underway and will be ready for commissioning next Fall.

Thank you!

Questions?

NSF

Cornell University Founded A.D. 1865

ASU Arizona State University

Green Bank Observatory

Radio Astronomy Systems BYU

BYU Electrical & Computer Engineering
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