Wideband Prototype Front-end for the ngVLA

Development Report

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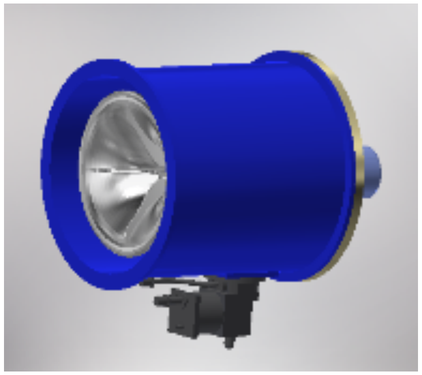
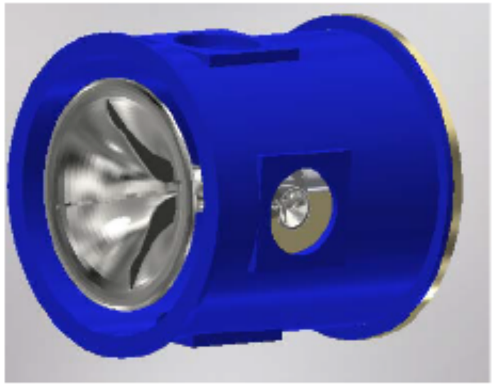
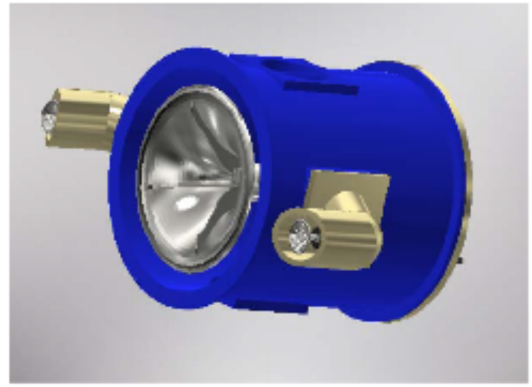
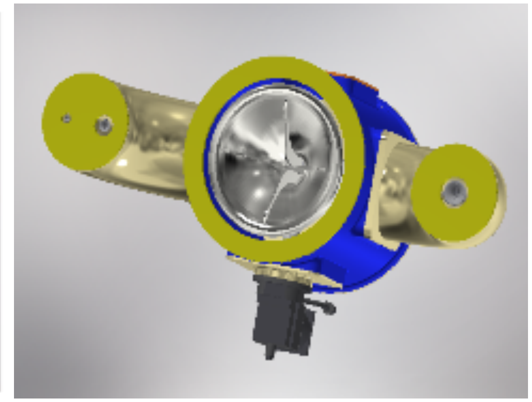
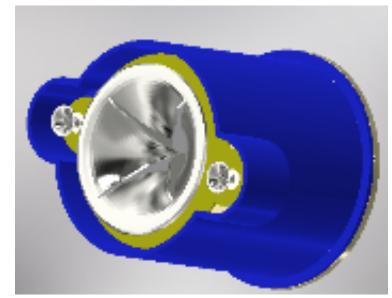
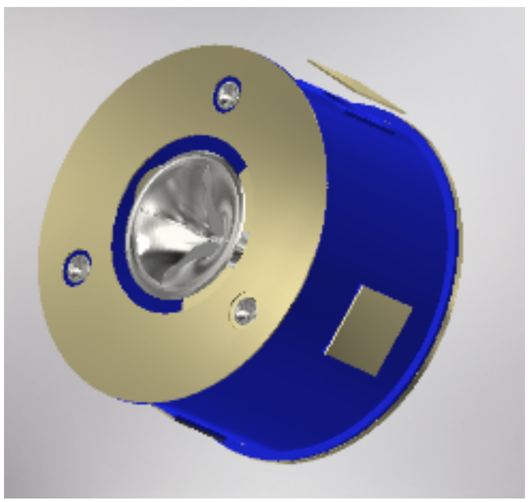
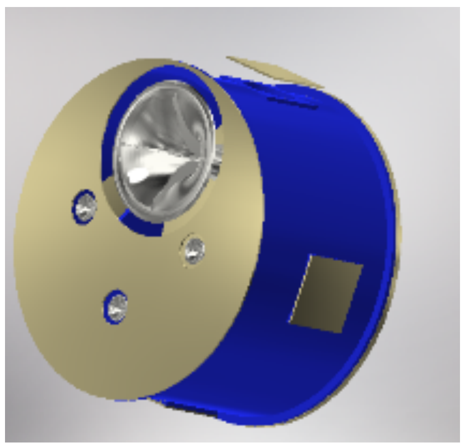
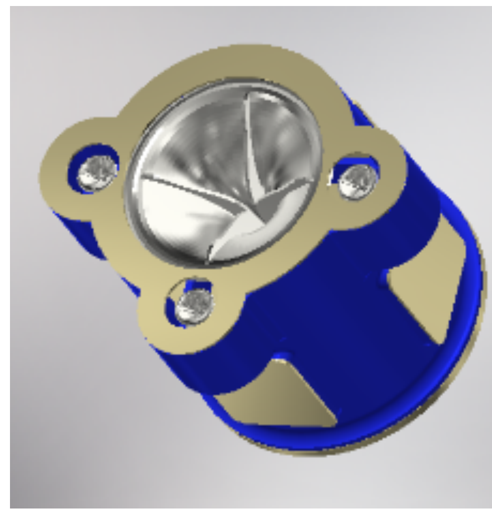
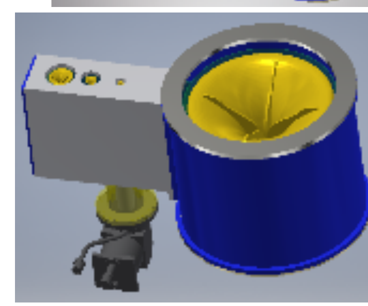
Motivation

- Develop a compact and highly integrated front-end
- Reduce the power consumption of the cryogenics
- Build a reliable large vacuum window for the low frequency feed
- Evaluate the thermal design of the cryostat
- Test different noise calibration schemes
- Reduce the cost of manufacturing the cryogenic package
- Build a package that is easy to assemble and maintain
- Evaluate wideband feeds and cryogenic LNAs to maximize the figure of merit: Efficiency / Noise

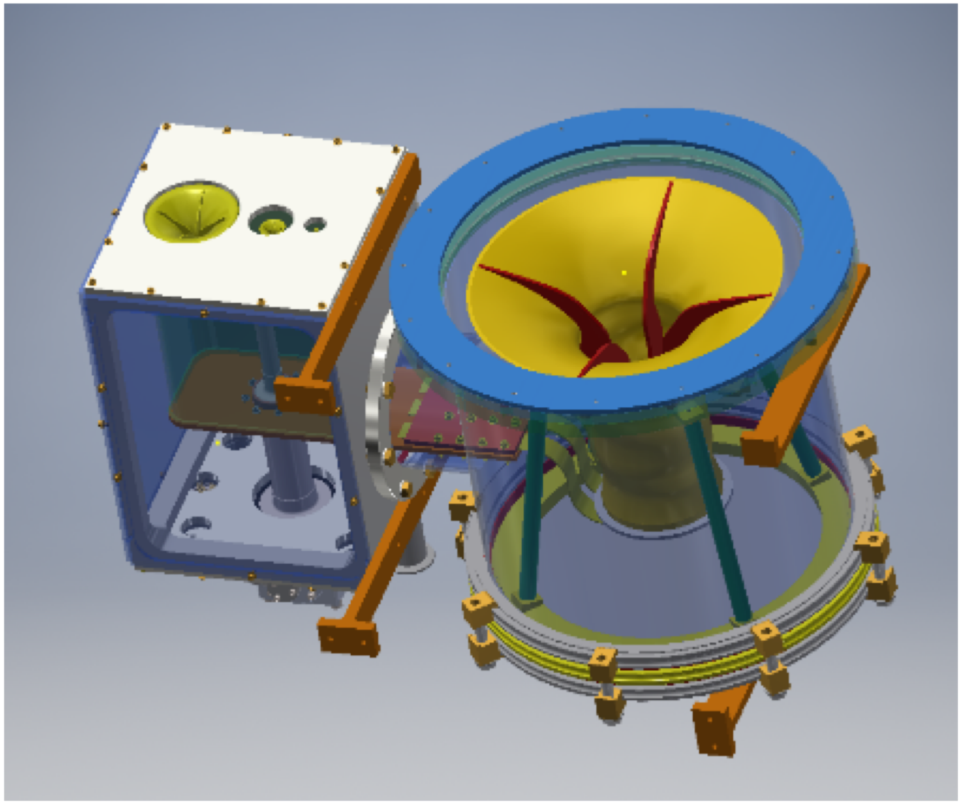





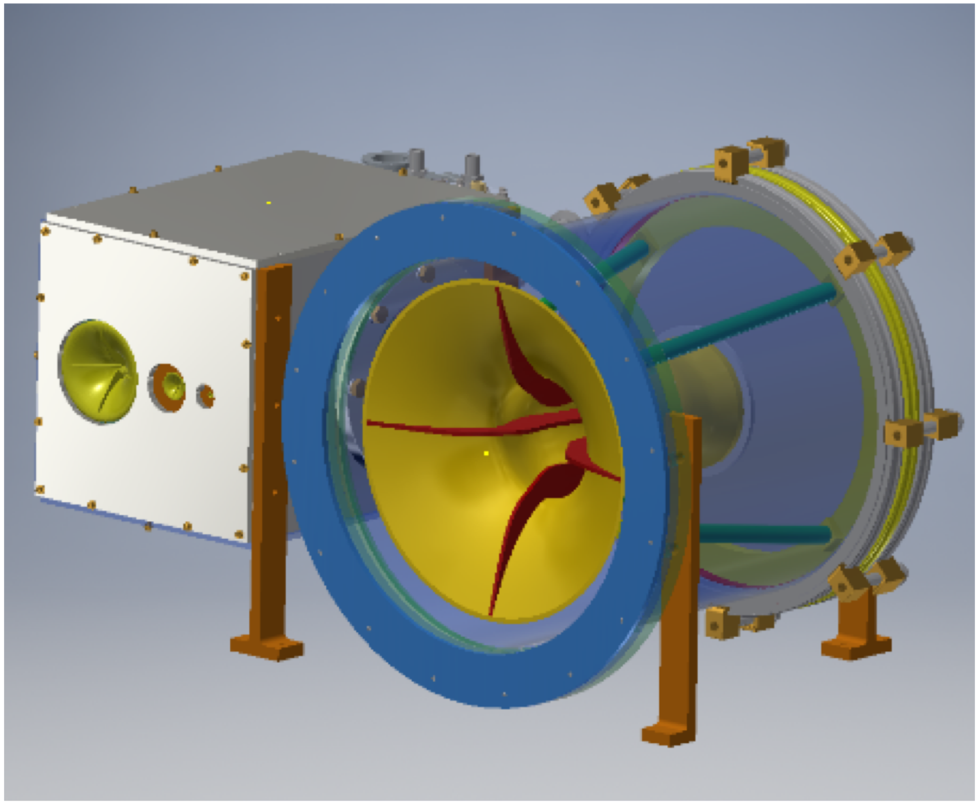
Package 4 receivers covering 1.2-116GHz in ONE Cryostat

Wideband front end Concept:

4 receivers in ONE cryostat , cooled with ONE cryocooler



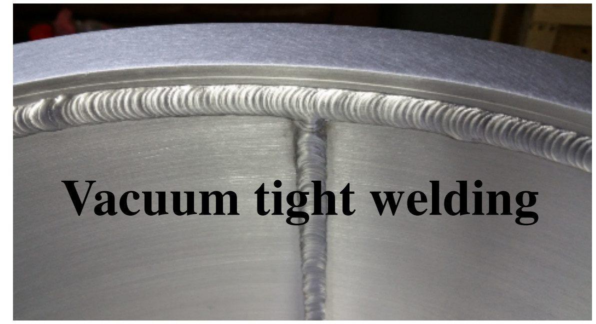


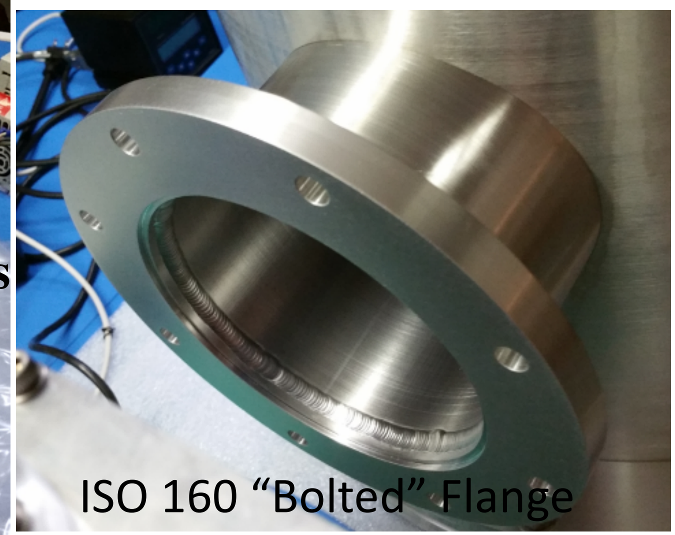
Cylinder “Tee” for the Low frequency feed

ISO 400 Cylinder
OD = 16in
Thickness: ¼ in

ISO 160Cylinder
OD = 6in
Thickness: 0.188 in

Material:
6061−T6 Aluminum

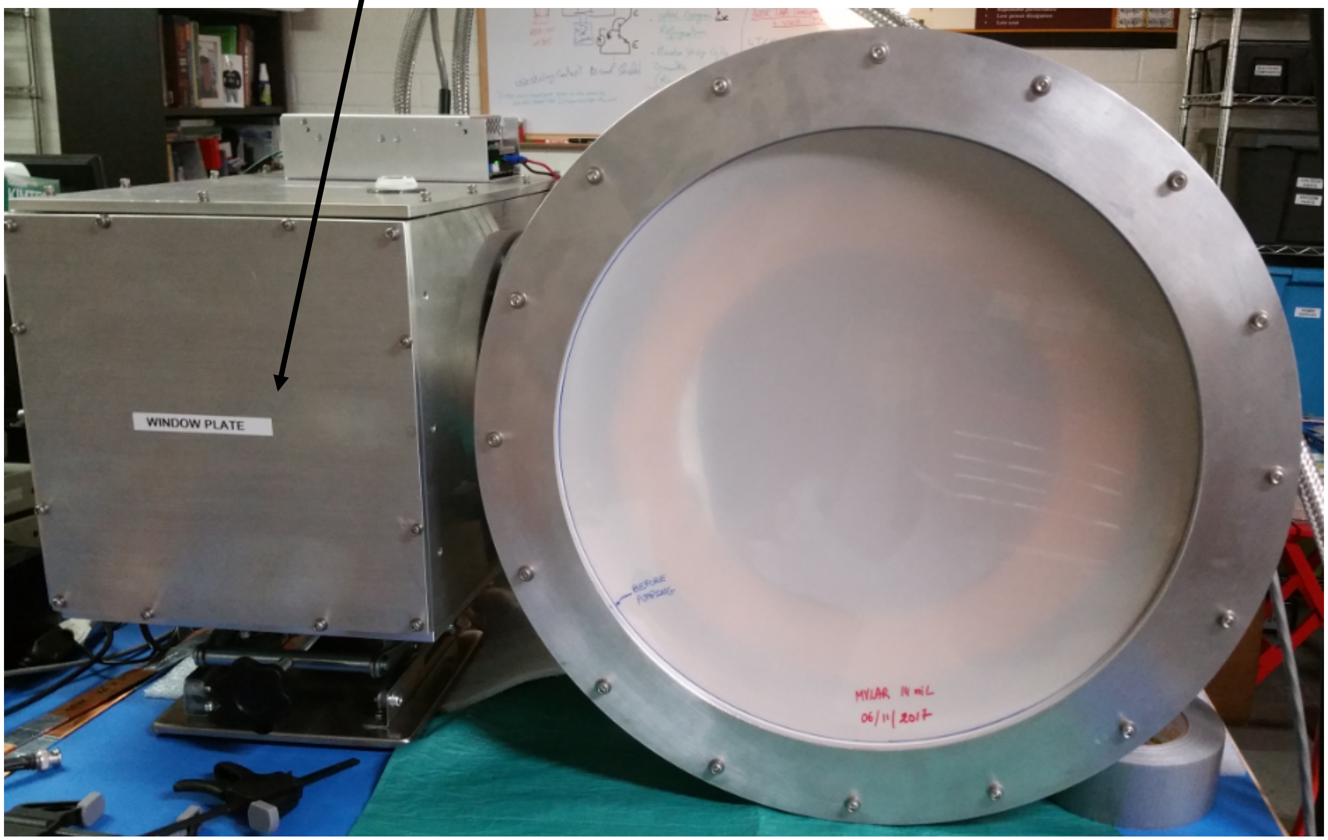




Advantages of using rolled and welded Aluminum (instead of stainless steel):

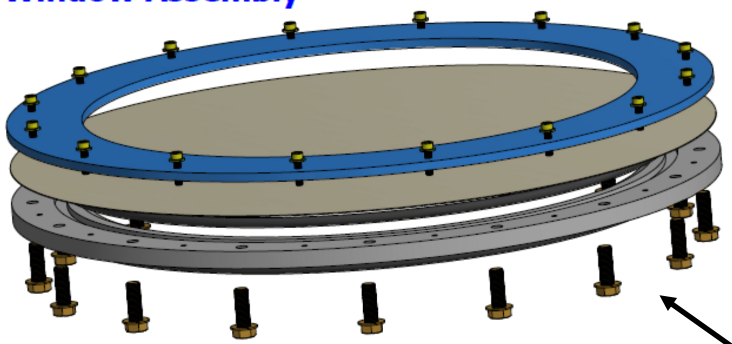
- Large cylinders can be made cheaply
- Complex shapes can be made by welding aluminum parts
- lower material cost
- lighter weight (1/3rd of stainless steel)
- faster machining (10x faster)
- low carbon and hydrogen outgassing
- Stainless steel flanges can be explosion bonded to Aluminum
- Proven technology: used extensively to build UHV chambers (no risk associated with this technology)

A square shaped side cryostat is attached to the cylinder "Tee" to host the higher frequency systems

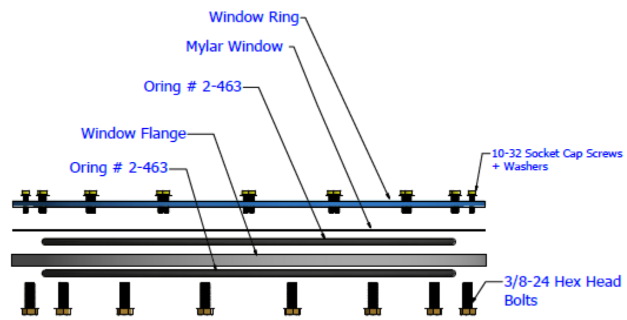


A vacuum tight but Microwave transparent window

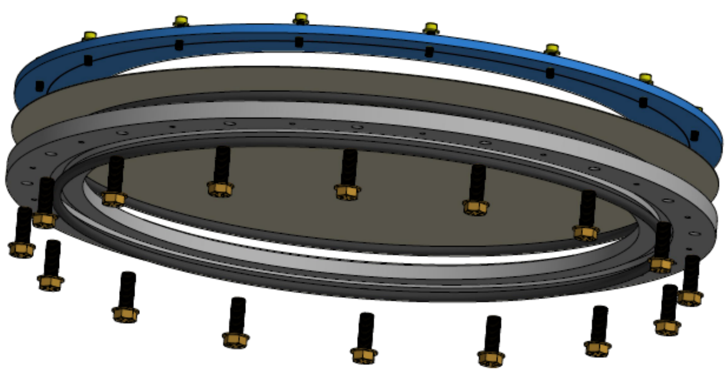
Window Assembly



Top View
SCALE 3/4



Side View
SCALE 1 / 2



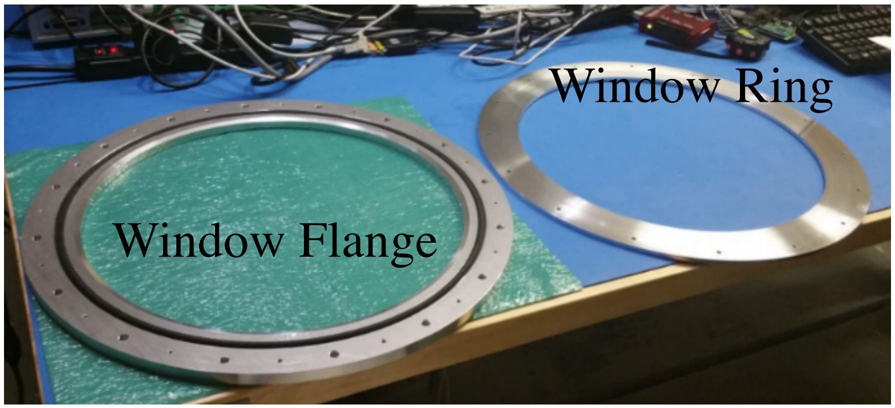
Bottom View
SCALE 3 / 4

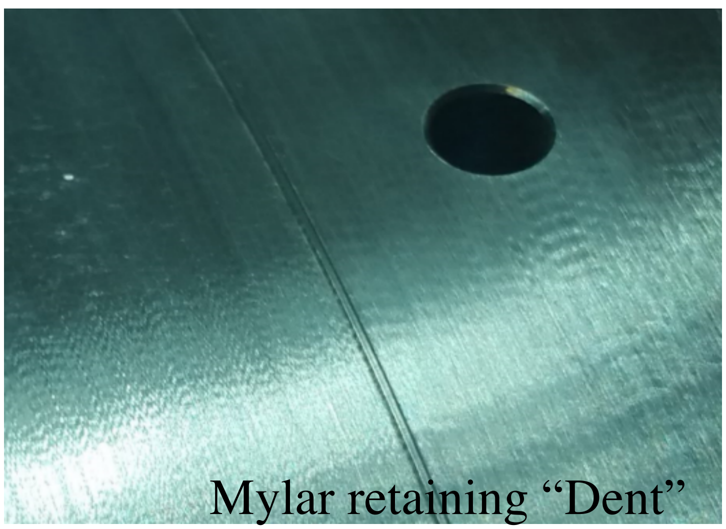
Window requirements:

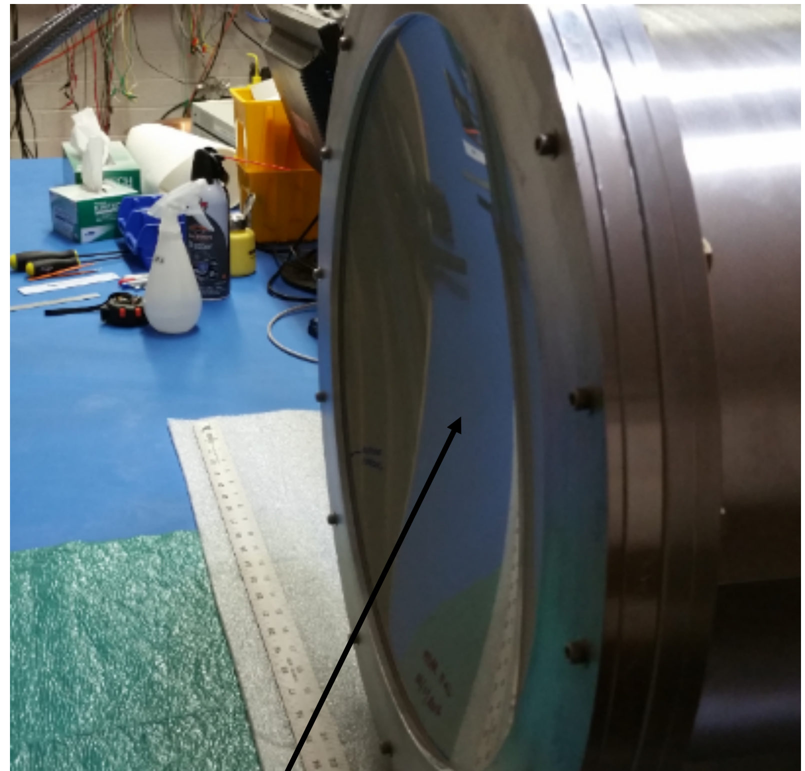
Vacuum tight
Has low insertion loss
Has low reflections
Mechanically strong
Reliable
Relatively thin

15.5in Diameter Mylar window
14 mil Thick Mylar
Type A Mylar / Electrical grade polyester film
20000 psi Tensile Strength
1.25 Metric Ton Force

14mil Mylar Window Assembly





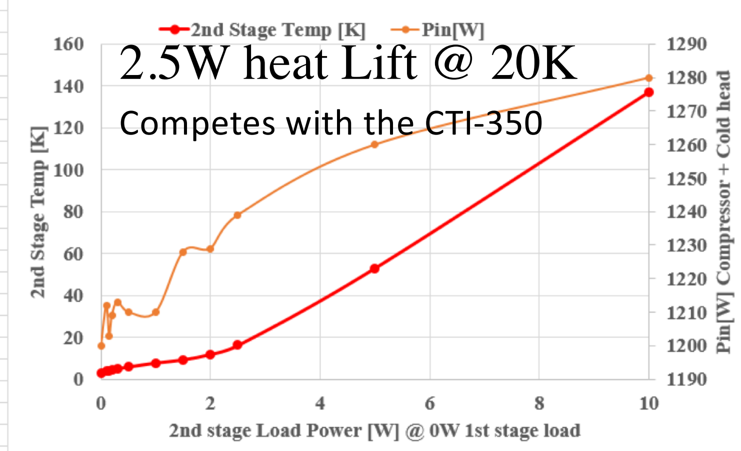


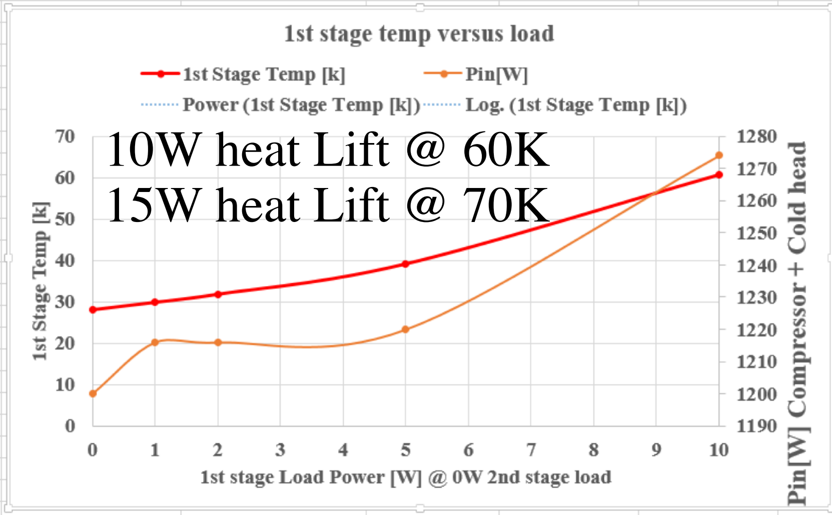
2in deflection form top surface
Of window Ring

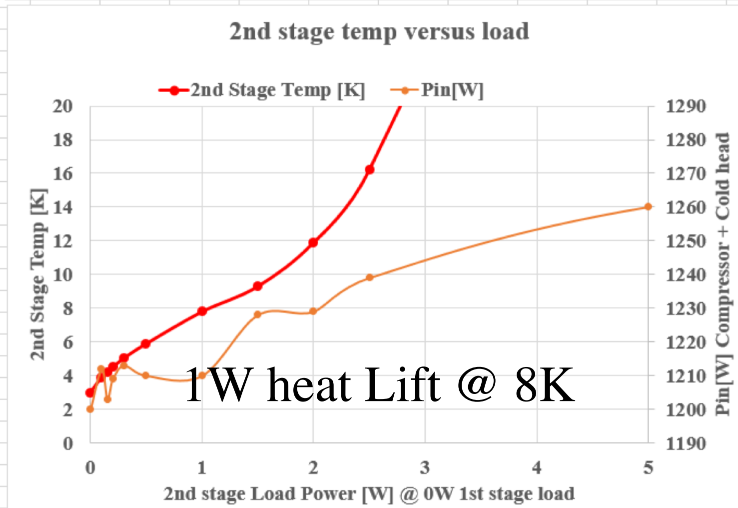
The cryocooler: Sumitomo RDK-101D with the CAN-11C compressor :

lowest power consumption GM Cryocooler in the market

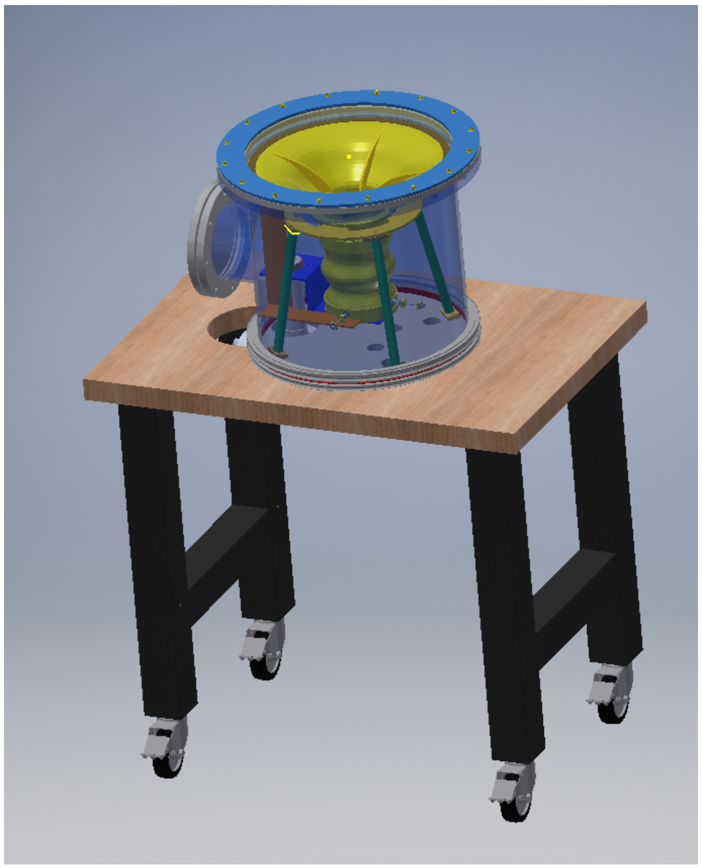
1st stage Load Power [W]	2nd stage Load Power [W]	1st Stage Temp [k]	2nd Stage Temp [K]	Pressure [Torr]	Pin[W]
0	0	28	3	1.70E-07	1200
0	0.1	28.13	3.9	1.70E-07	1212
0	0.15	28.3	4.2	1.90E-07	1203
0	0.2	28.39	4.5	2.80E-07	1209
0	0.3	28.5	5.04	1.70E-07	1213
0	0.5	29.45	5.9	1.40E-05	1210
0	1	30.6	7.8	3.30E-05	1210
0	1.5	31.4	9.3	8.80E-05	1228
0	2	32.4	11.9	7.00E-05	1229
0	2.5	32.5	16.2	9.00E-05	1239
0	5	30.2	53	9.00E-05	1260
0	10	30.25	137	9.00E-05	1280
0	0	28	3	1.70E-07	1200
1	0	29.8	3.025	4.00E-07	1216
2	0	31.75	3.1	3.50E-07	1216
5	0	39.1	3.1	4.30E-07	1220
10	0	60.68	3.4	1.20E-07	1274

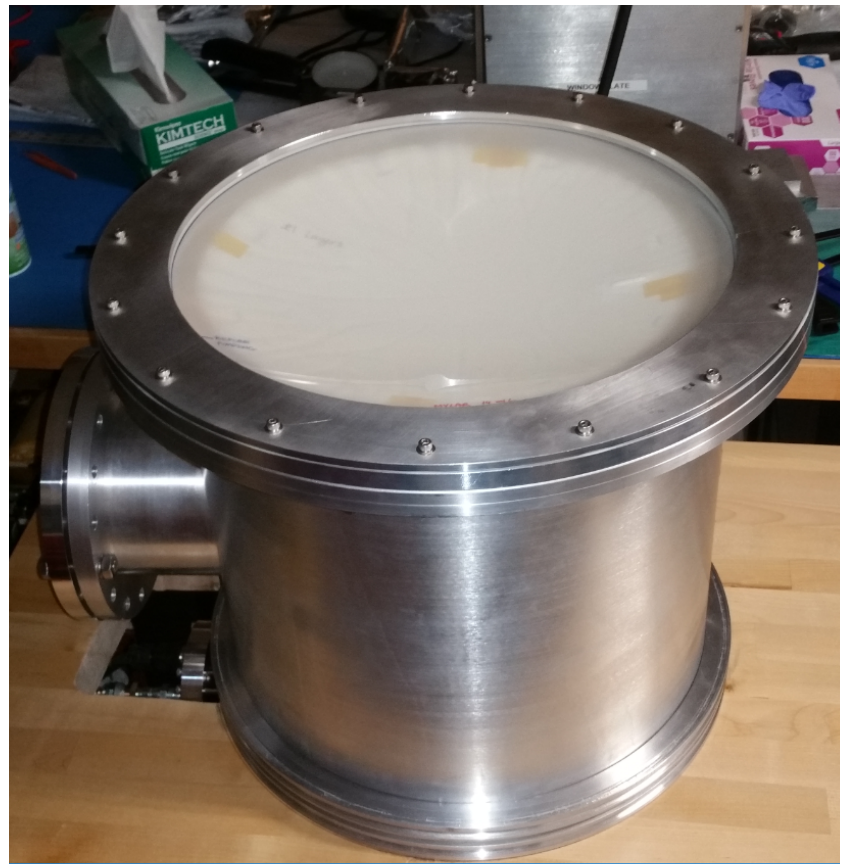


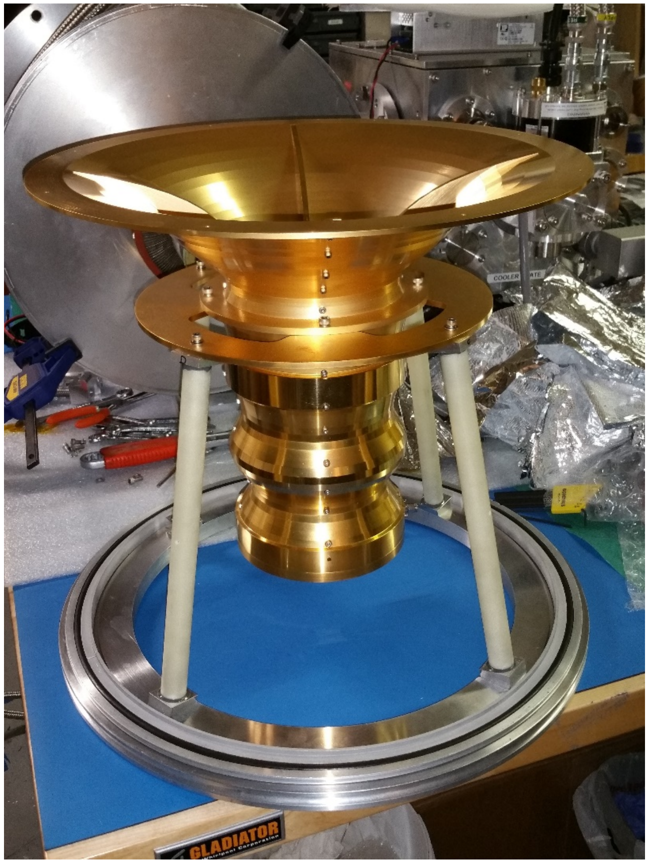




Phase 1 of the development:
Build and test the low frequency front end







The prototype QRFH feed

Developed at Caltech based on
Ahmed Akgiray's Thesis

Advantages of QRFH Feeds:

- Wide bandwidth
- Constant beam width with frequency
- Constant phase center with frequency
- Low cross pol
- Easy to manufacture (CNC machining)
- "Coolable" as it is made of thick metal

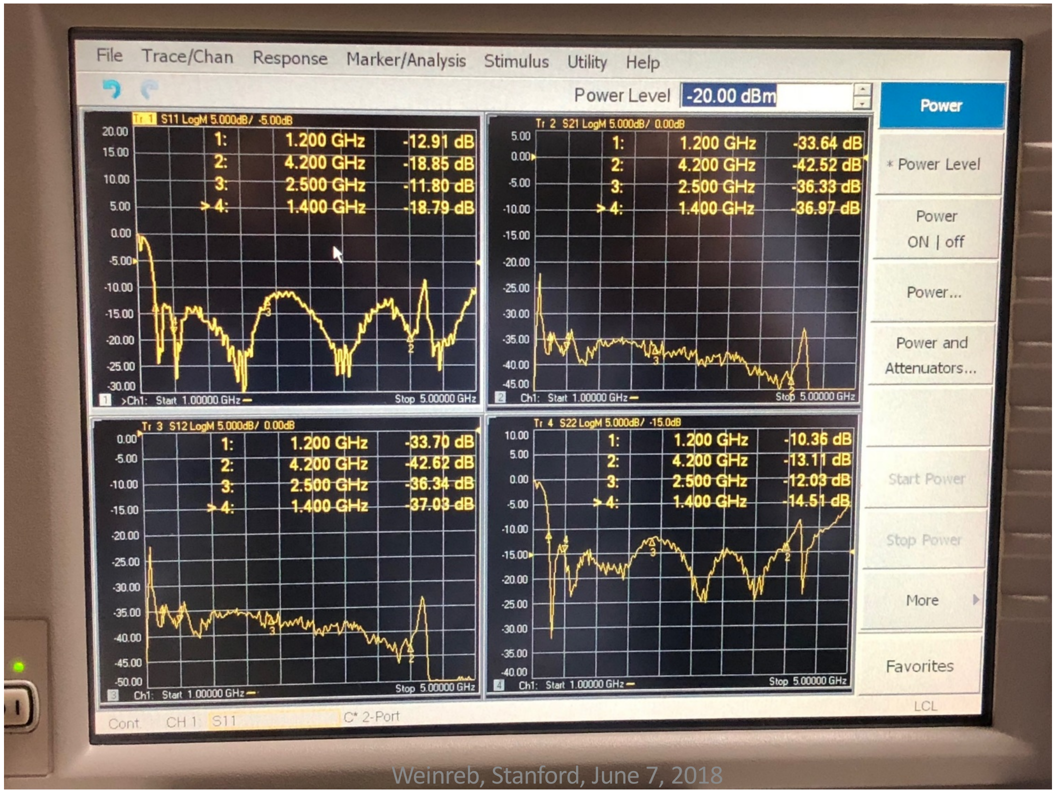
Bandwidth: 1.2-4.2 GHz
Half Angle: 58 degrees
Diameter : 15.27 in
Length: 12.25 in
Wall Thickness: 0.19 in
Total Area : 0.707 m^2
Material: 6061 Aluminum
Total Mass:
Finish: Gold plated

Support structure:
4 x G10 Tubes
Length: 10in
OD = ¾"
Wall Thickness: 1/8in

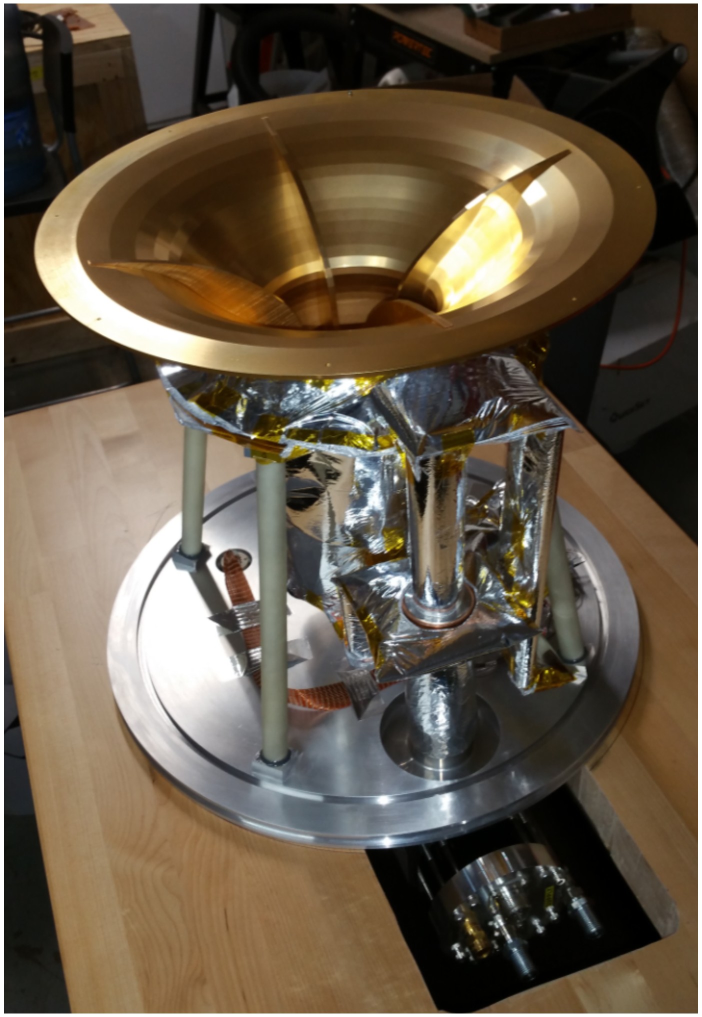
Expected conductive heat load through the 4 G10 tubes: 0.3692 W

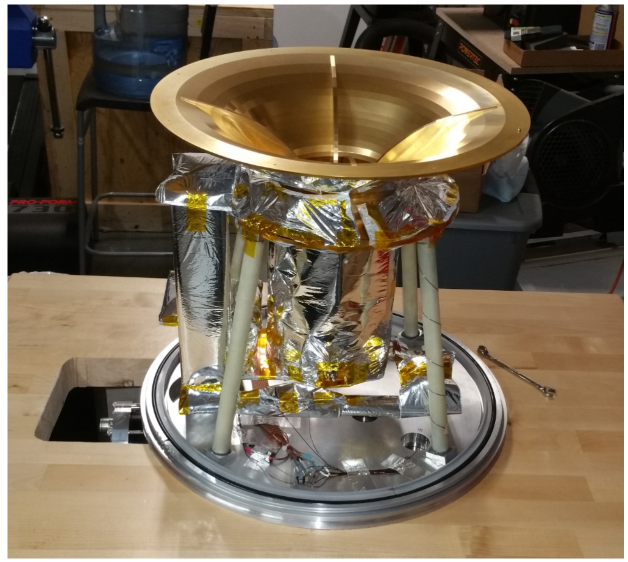
Measured S Parameters of Feed

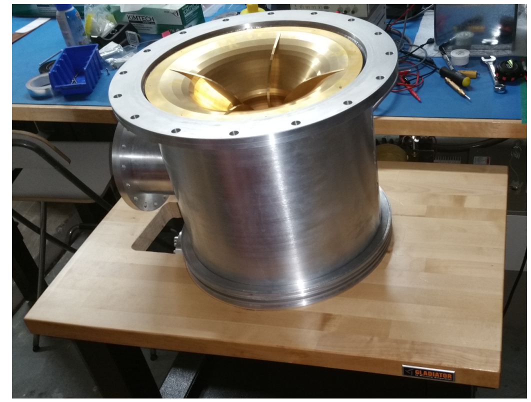
- One polarization on Port 1; other on Port 2.
- Return loss of both ports averages to 15 dB form 1.2 to 4.2 GHz. This is excellent and is what what is expected.
- Cross coupling is less than 34 dB which shows excellent symmetry of fins and low capacitance between coaxial probe.



Thermal Design and implementation



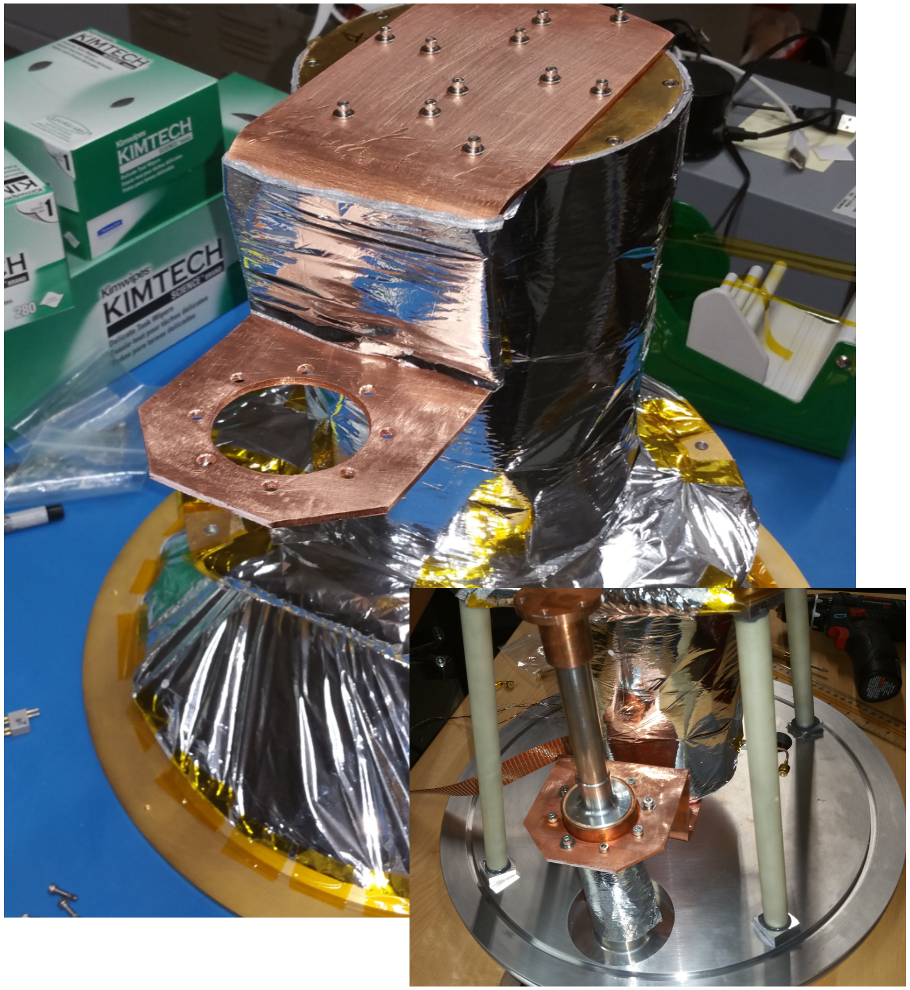




Critical factors affecting the thermal design:

- Feed to cryocooler connections: the heat straps!
- Radiative heat load coming from the large window
- Radiative heat load from the warm walls of the cryostat

Feed Connected to the 1st stage of the Cryocooler

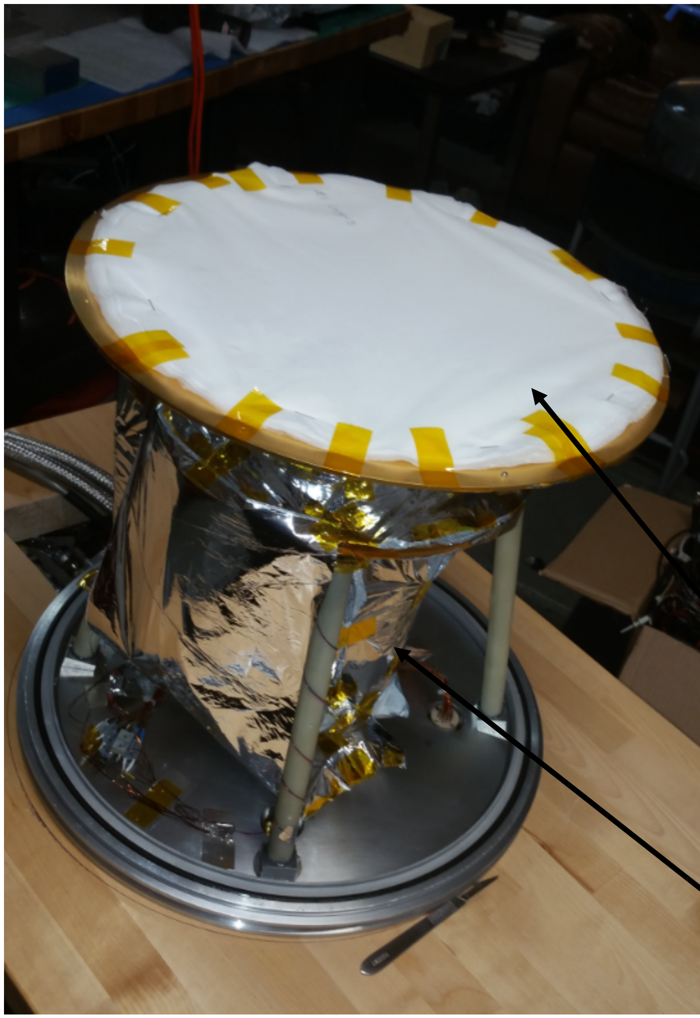


<u>Heat strap:</u>
Length:13.5”
Width:4”
Thickness: 1/8”
Material: OFHC, Copper 101
Shape: Z- bracket (to absorb contraction during cooling)
Finish: Polished and covered with 30 Layers of MLI
2mil thick Indium used as thermal gasket to reduce contact thermal resistance

Thermal resistance at 60K: 0.6K / W
(measure based on 6K temperature drop across heat strap at 10W heat load)

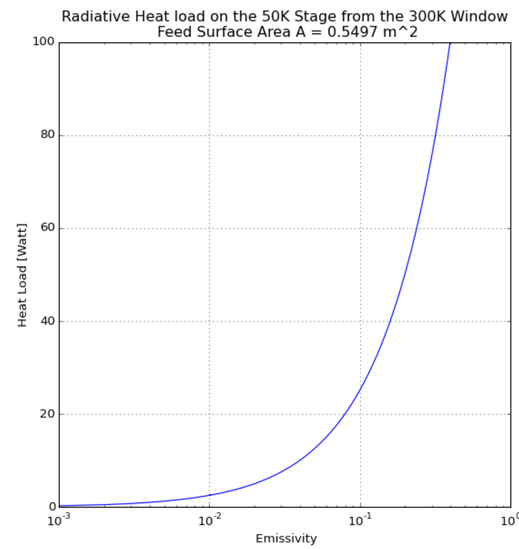
Total Area : 0.707 m^2

Radiative heat : ~ 325W (~50mW / cm^2)



21 Layers of 2 mil thick
Teflon sheets separated by
A thermal insulator (net)

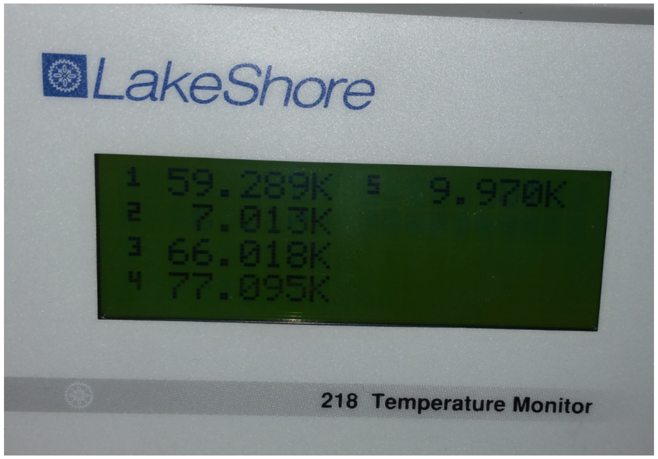
30 Layers of MLI
Covering the feed and electronics



Surface Emissivity < 0.1
Should be achievable with
Polished and plated Aluminum

Measured Performance of the cryogenic packaging and thermal Design

Measured temperature of LNA = 10K
Measured temperature of top plate of feed = 77K.

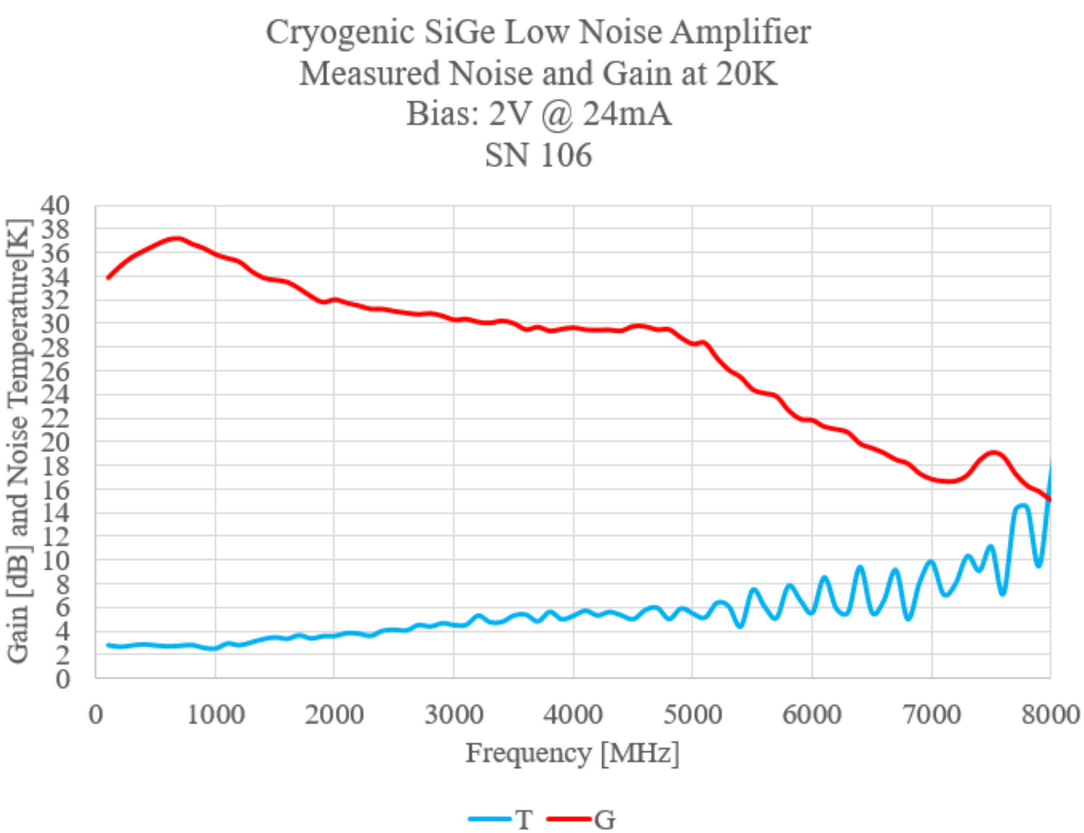


Temperature at the 1st stage of the Cryocooler: 60K → 10 W of heat load on 1st stage
Temperature at the 2nd stage of the Cryocooler: 7K → 1 W of heat load on 2nd stage

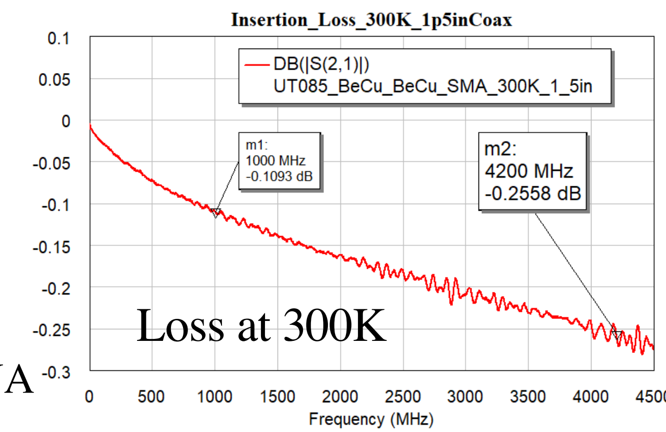
Temperature at the bottom plate of the feed: 66K → heat strap thermal resistance: 6k / 10w
Temperature at the top plate of the feed: 77K → thermal resistance of the feed:11K/ 10W

Temperature at the LNA (far end of the heat strap connecting the LNA to the 2nd stage):10K
→ Thermal resistance of heat strap: 3k/ W

Cryogenic LNA and its connection to the feed

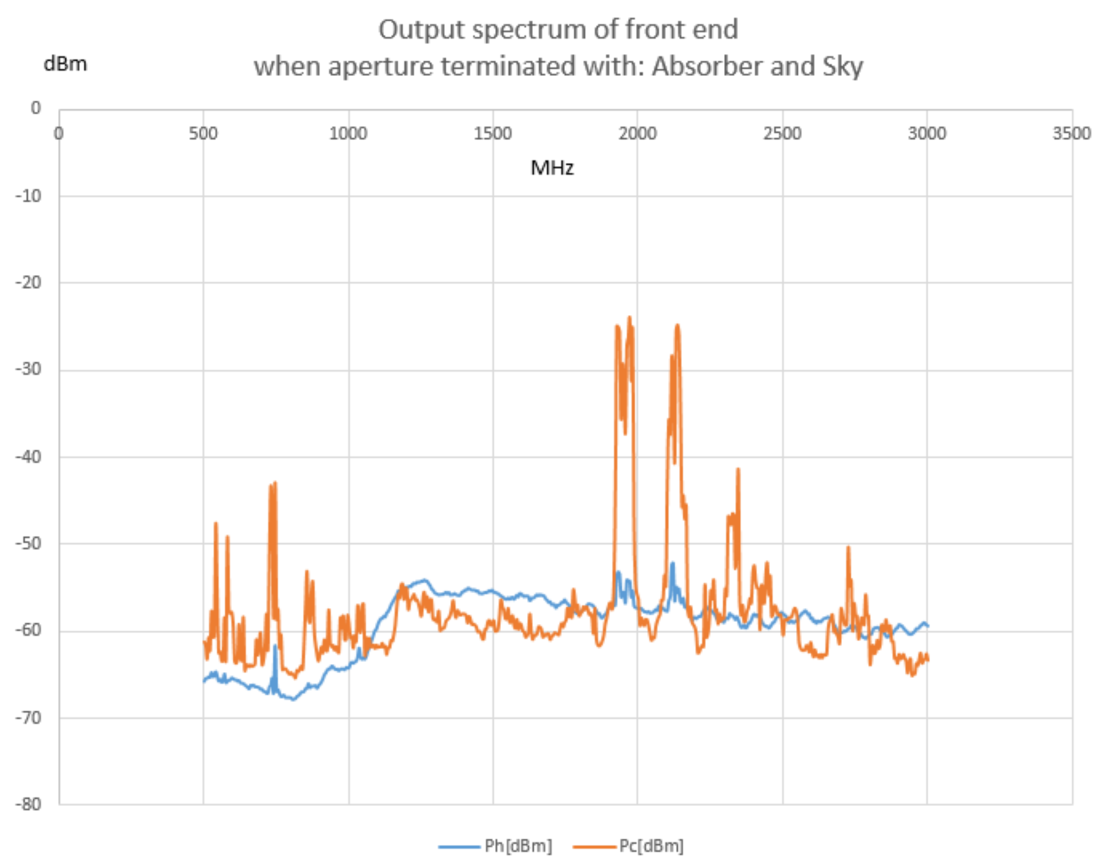


1.5in Long BeCu/BeCu Semirigid coax



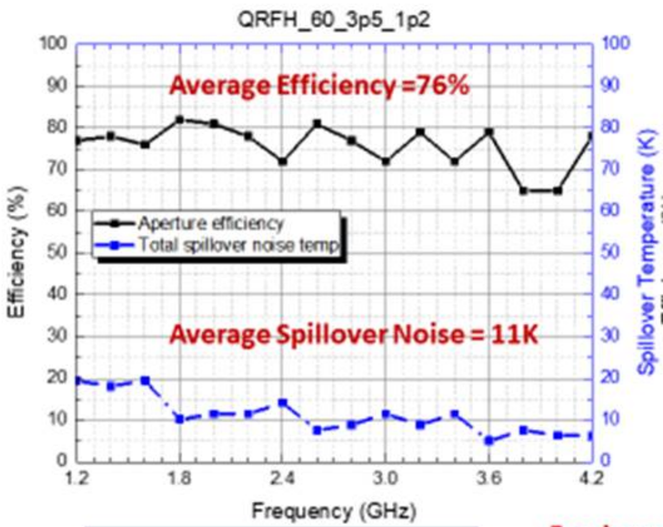
0.25dB Loss in the cable at 40K, will contribute 2.7K to the noise of the LNA

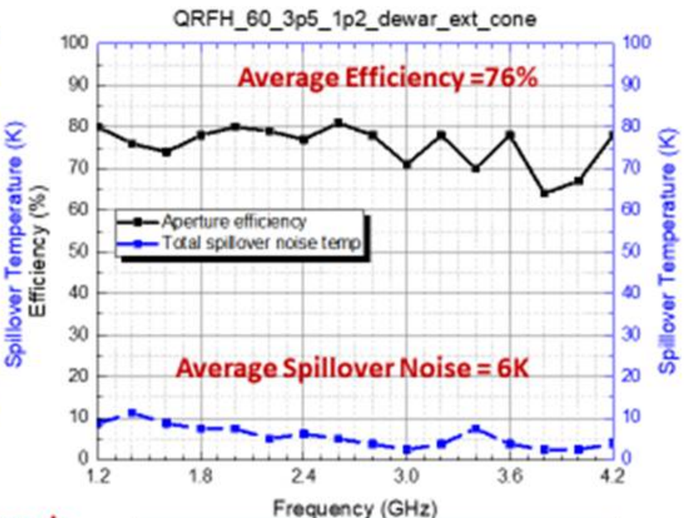
Output spectrum of the front end recorded in Phoenix:

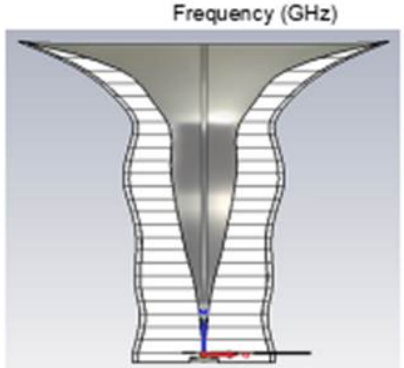


Total Feed Aperture Efficiency and Spillover Temperature

Current ngVLA demonstration design for 1.2 to 4.2 GHz with 58^{O} Half Angle

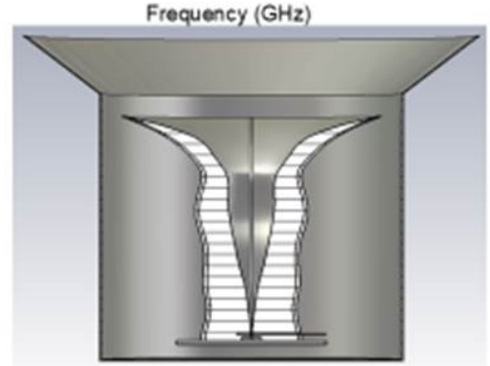






Feed cone is external to Dewar. Its main effect is on the back lobe

Spillover Noise is with conservative assumption that ½ the total spillover is at 250K



Summary of what has been achieved

- A prototype wideband receiver for the ngVLA low frequency band has been designed, built and is being tested: We have a concept on the bench!

- The mechanical and thermal design worked well: The feed cooled to <80K and a cryogenic LNA was cooled to 10K using one single low power cryocooler

- A large vacuum tight window has been built and successfully tested for 1.5 years

- The cryostat package is: light weight, low cost, easy to assemble and to maintain and is suitable to mass production

Areas of improvements and next steps

- Perform better Y-factor measurement of the current system in a radio quite zone
- Find out the noise contributions of every component of the system: Loss of window, thermal filter, coaxial line, Feed, noise coupler…
- Try to reduce the 10W heat load on the 1st stage: better shielding and lower surface emissivity
- Use a better LNA: lower noise and power dissipation, state of the art LNAs at Caltech achieve 2K over The band at < 20mW power dissipation
- Install a cone around the window of the cryostat to reduce back lobe.
- Explore variable speed compressors and cryocoolers to further reduce power consumption
- Development of cryogenic LNAs operating at 60-80K ambient temperature with 2-3K noise temp This is doable with current HEMT transistor technology and careful design of input matching network This LNA will allow direct connection to the feed and "freeing" the 2nd stage of the cooler entirely to Cool the high frequency systems
- The big dream: A room temperature feed + Room temperature electronics operating over a wide Bandwidth (1-4GHz) with good sensitivity (<20K Tsys), saving a lot of cost and complexity.