NA Development Cycle 2

ALMA Band 2 Prototype Project

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NRAO NSF Associated Universities Inc

ALMA Band 2 Prototype Project

Team Members / Contributors

- Low Noise Amplifiers:
  - Marian Pospieszalski (MIC)
  - Kieran Cleary & Team at CRAL (MMIC)
  - Matthew Morgan
- Optics:
  - Sri Srikanth
  - Alvaro Gonzalez
- Down Converter:
  - Dustin Vaselaar
  - Jim Muehlberg
  - Matthew Morgan
  - Kamaljeet Saini
- Local Oscillator:
  - Dustin Vaselaar
  - Jim Muehlberg
  - Kamaljeet Saini
- Cold Cartridge:
  - Kirk Crady
  - Greg Morris
  - Arthur Symmes
- Shop & Chemistry Lab:
  - Greg Morris
  - Gerry Petencin
- Evaluation / Metrology:
  - John Effland
  - Morgan McLeod
  - Kirk Crady
  - John Buchanan
  - Kamaljeet Saini
- Consultancy & Support:
  - Matthew Morgan
  - S K Pan
  - Robert Dickman

ALMA Band 2 Prototype Project

Goals

Hardware Deliverable(s):

1. 35 nm InP HEMT MMIC wafer(s) with optimized Band-2 designs.
2. Four prototype single-pol. MMIC amplifier modules.
3. Four prototype single-pol. MIC amplifier modules.
4. Sufficient probe-tested MMIC chips for 150 modules.
5. Optics design (including drawings and analysis).
6. Optics components (horn, mirrors, etc.)
7. Auxiliary components (bias modules, cables, etc.) for prototype cartridge.
8. Prototype integrated cold cartridge.
9. Prototype Warm Cartridge Assembly (including down-converter and LO).
10. Band-2 cartridge test system (implemented around the ALMA cryostat).

Software Deliverable(s):

1. Cartridge M&C software, modified for Band-2.
2. Cartridge test software, modified for Band-2.

Deliverable Documentation:

1. "PDR Ready" design report.
2. Cartridge test data report.
3. Specifications and ICDs.
4. Preliminary costing for full production run.
5. Monthly "4-square" Progress, Final, and Outcome Reports.

ALMA Band 2 Prototype Project

Project Summary - I

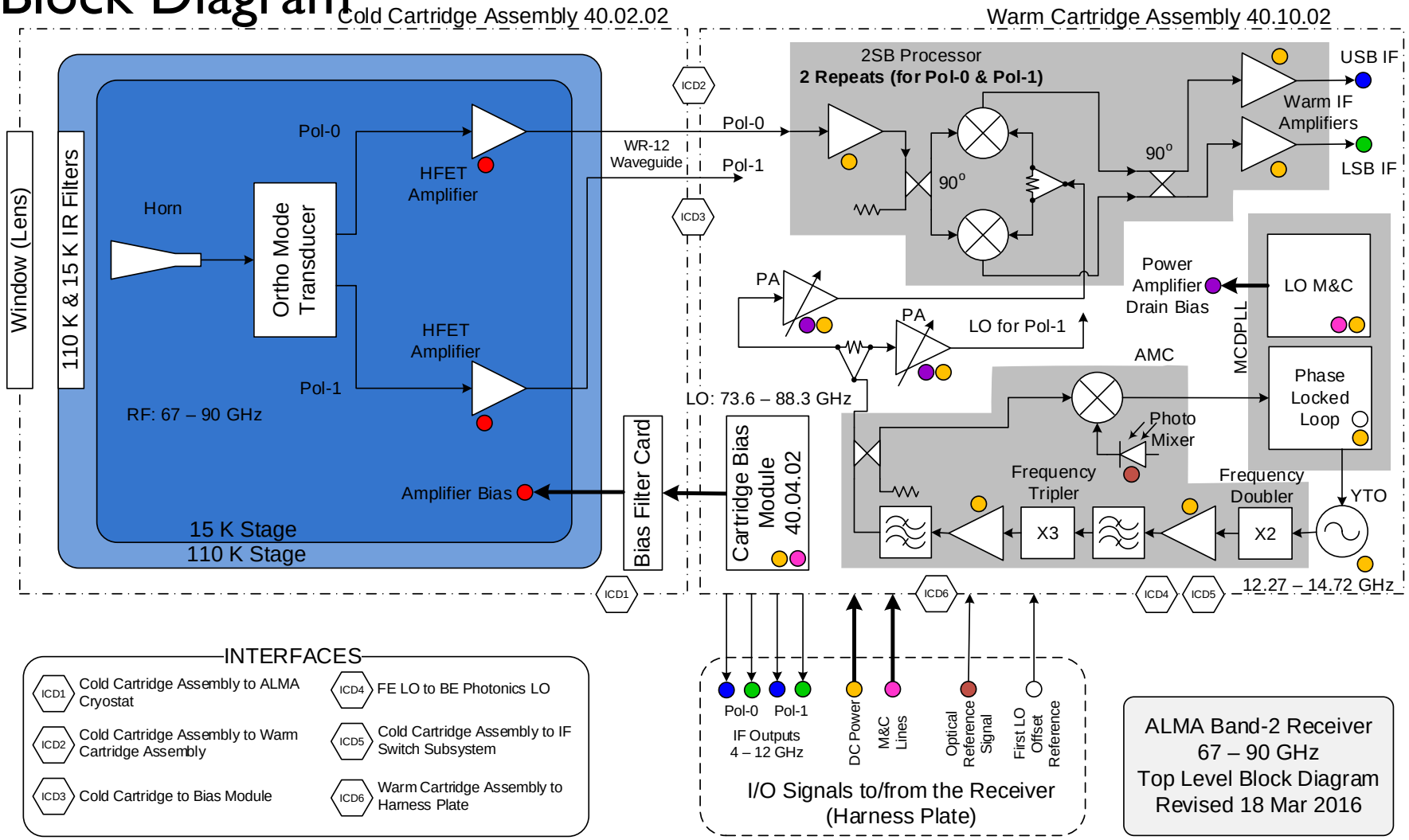
- The first ALMA Band 2 receiver (cold cartridge, local oscillator, as well as IF down converter) has been constructed.
- Even at the outset, the two year development project timeline was very tight to develop (design, fabricate and construct) MMIC based LNAs and then construct the receiver in a serial fashion.
- Consequently, we have constructed the receiver prototype around NRAO/CDL MIC (chip and wire) E-band LNAs in parallel with the CRAL MMIC effort. Receiver will be upgraded with MMIC LNAs when they are delivered.
- This presentation provides an overview of important cartridge component performances, cartridge (cold and warm) construction and alignment details, and significant receiver performance metrics (but not comprehensive compliance data, which has been taken and incorporated into the design report).

ALMA Band 2 Prototype Project

Project Summary - II

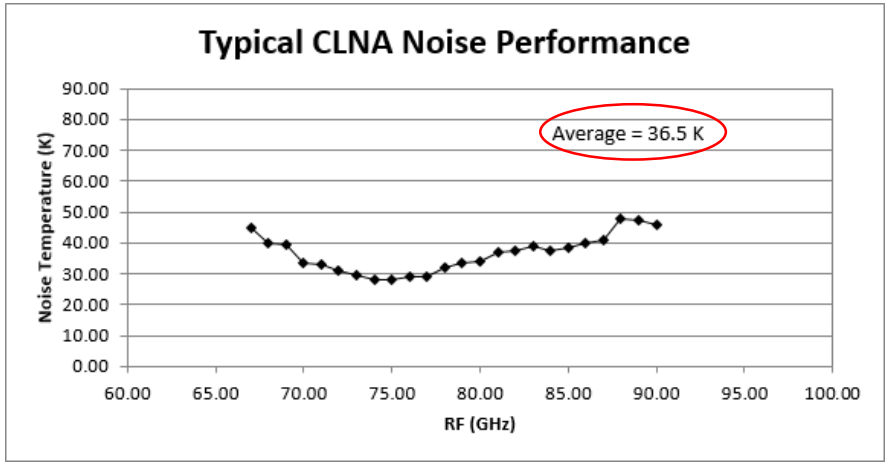
- Test results indicate that even the state-of-the-art E-band LNAs barely meet the overall ALMA Band 2 noise specification by themselves. Allowing for additional noise degradation from the optics, it will be difficult to meet the existing ALMA noise specification. Seeking a review of the ALMA Band 2 receive noise specification seems to be in order.
- The optics specifications are generally met with the exception that there are dips in polarization efficiency at specific frequencies that fall below the 99.5% specification value. These are attributed (both by measurements as well as by simulations) to an interaction of the 15 K IR filters with the horn aperture – an effect also seen on some other ALMA bands. (More on this later).

ALMA Band 2 Receiver Prototype Block Diagram



ALMA Band 2 Receiver Prototype

System Noise Temperature Estimation



Band 2 Receiver stage	Gain	Cumulative Gain to preceding stage	Noise Figure	Noise Temperature	$T_{equivalent}$
Lens/Window (room temperature)	-0.1 dB	0.0 dB	0.1 dB	8.9 K	8.9 K
IR Filters (15 K and 80 K)	-0.1 dB	-0.1 dB	0.1 dB	1.4 K	1.5 K
Feedhorn (15 K)	-0.1 dB	-0.3 dB	0.1 dB	0.3 K	0.4 K
OMT	-0.1 dB	-0.4 dB	0.1 dB	0.3 K	0.4 K
Q-Band Amplifier (15 K)	35.0 dB	-0.5 dB		36.5 K	40.6 K
Waveguides, feed-thru and BPF	-4.0 dB	34.5 dB	4.0 dB	453.6 K	0.2 K
Q-Band Amplifier (room temperature)	14.0 dB	30.5 dB	3.5 dB	371.6 K	0.3 K
2 SB Downconverter	-12.0 dB	44.5 dB	12.0 dB	4454.7 K	0.2 K
Warm IF Amplifier	30.0 dB	32.5 dB	2.0 dB	175.5 K	0.1 K
Total	**62.5 dB**				**52.4 K**

ALMA Band 2 Receiver Prototype

Thermal Budget(s)

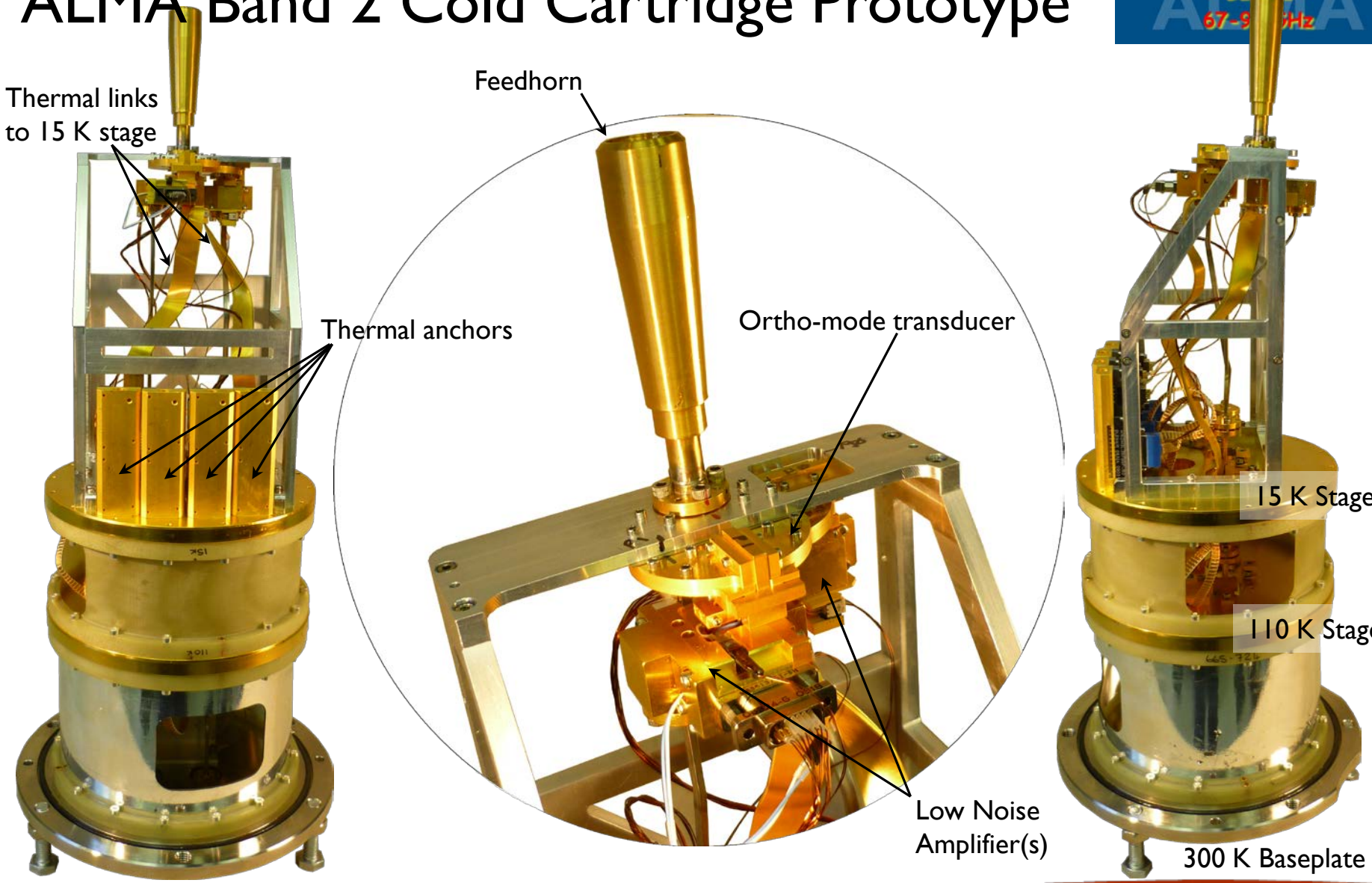
From ALMA Front End Thermal Budget, FEND-40.00.00.00-050-B-GEN:

15 K Stage	Bands 1 - 2	Band 3	Bands 4 - 5, 8 - 10	Band 6	Band 7	Sum
Passive heat load	95 mW	95 mW	95 mW	75 mW	115 mW	950 mW
Active heat load	90 mW	20 mW	67 mW	67 mW	15 mW	200 mW
Total heat load	185 mW	115 mW	162 mW	162 mW	130 mW	1150 mW

110 K Stage	Bands 1 - 2	Band 3	Bands 4 - 8	Bands 9 - 10	Sum
Passive heat load	450 mW	350 mW	700 mW	600 mW	5950 mW
Active heat load	150 mW	50 mW	150 mW	250 mW	550 mW
Total heat load	600 mW	400 mW	850 mW	850 mW	6500 mW

- Requirements met comfortably for 15 K stage, CLNAs dissipate 15-30 mW each (article to article variation, depends on optimization).
- No active component on the 110 K stage.

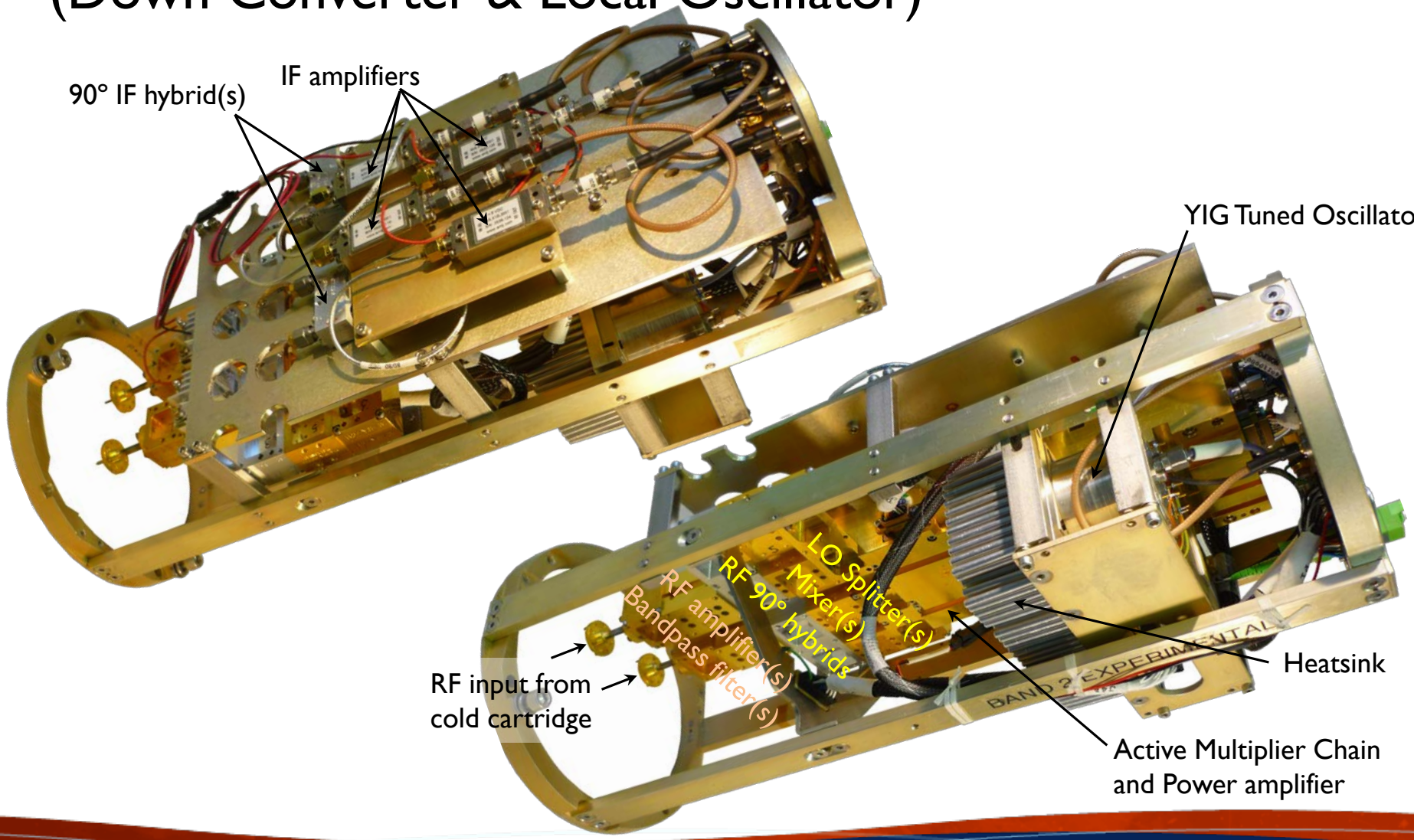
ALMA Band 2 Cold Cartridge Prototype



ALMA Band 2 Warm Cartridge Prototype

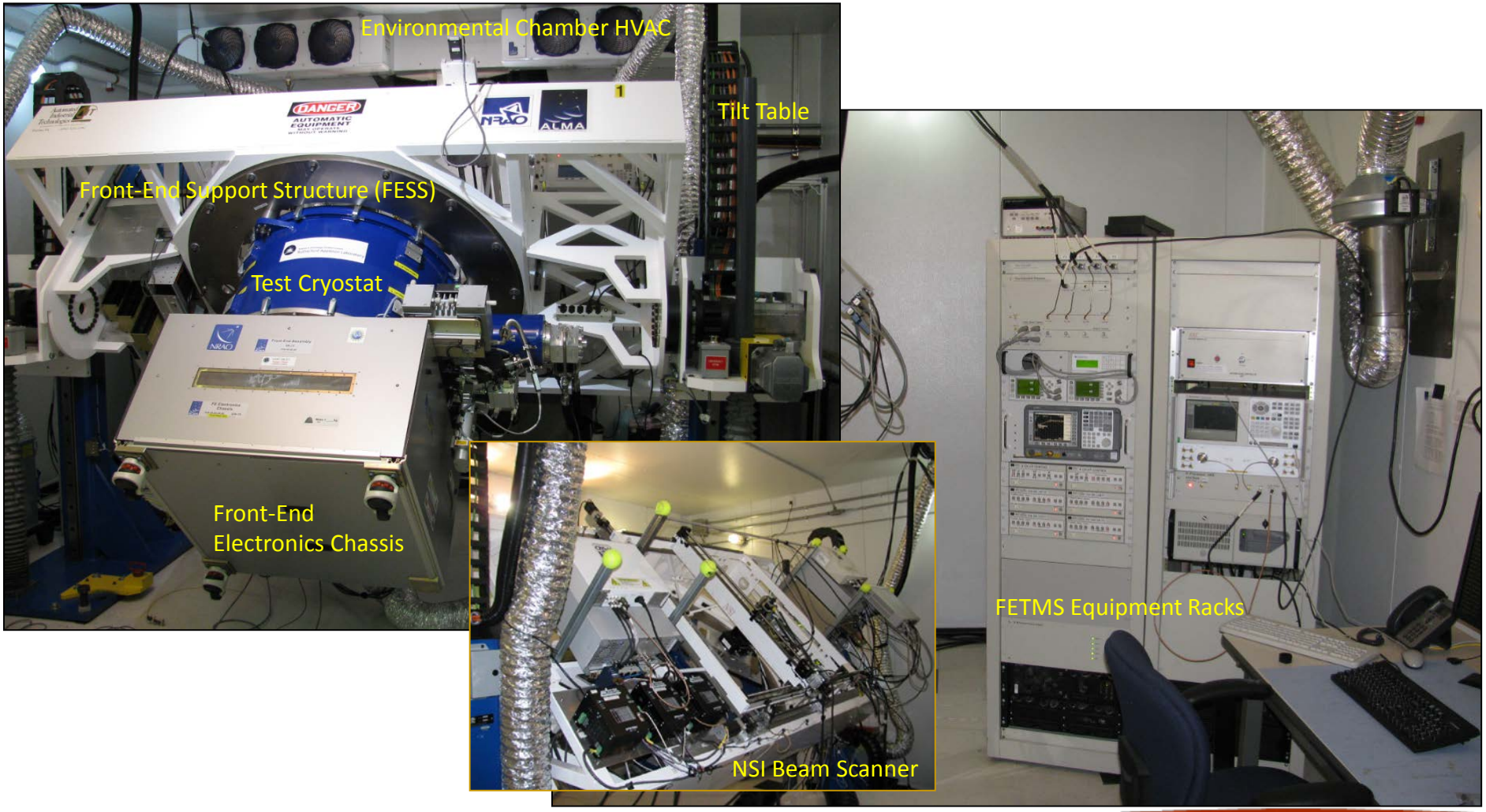
(Down Converter & Local Oscillator)

Band 2
67-90 GHz



ALMA Band 2 Receiver Prototype

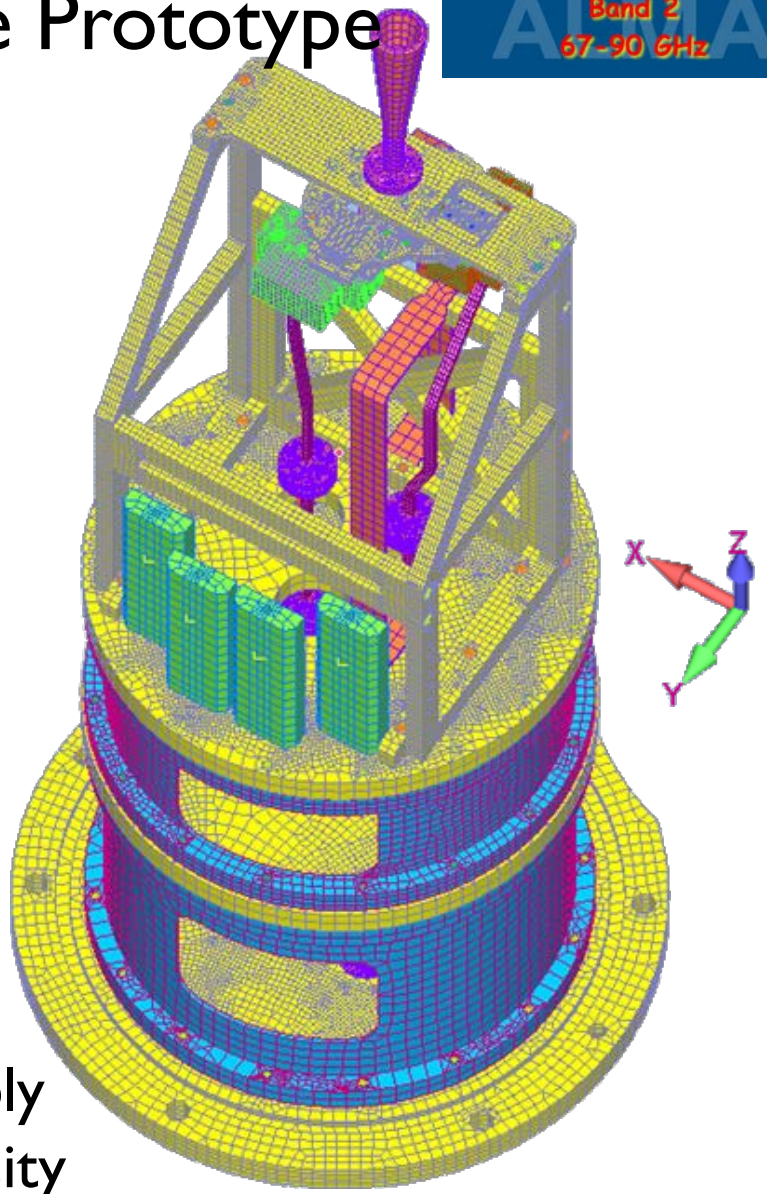
Evaluation in the ALMA Cryostat



ALMA Band 2 Cold Cartridge Prototype

Mechanical Analysis

A mechanical design analysis was performed by employing the Finite Element Analysis (FEA) technique using the NX NASTRAN version (with FEmap) provided by Siemens.



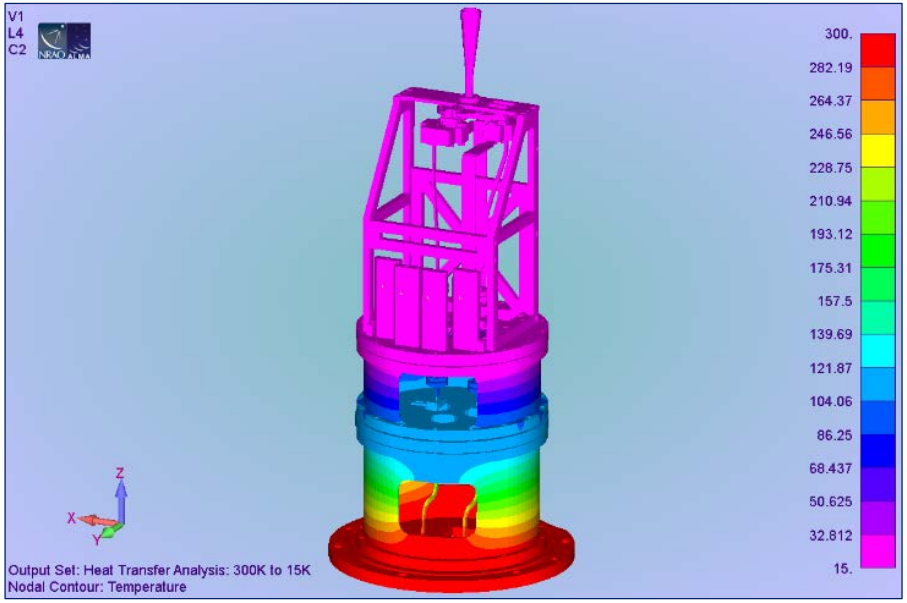
Band 2 Cold Cartridge Assembly
FEA Model showing mesh density

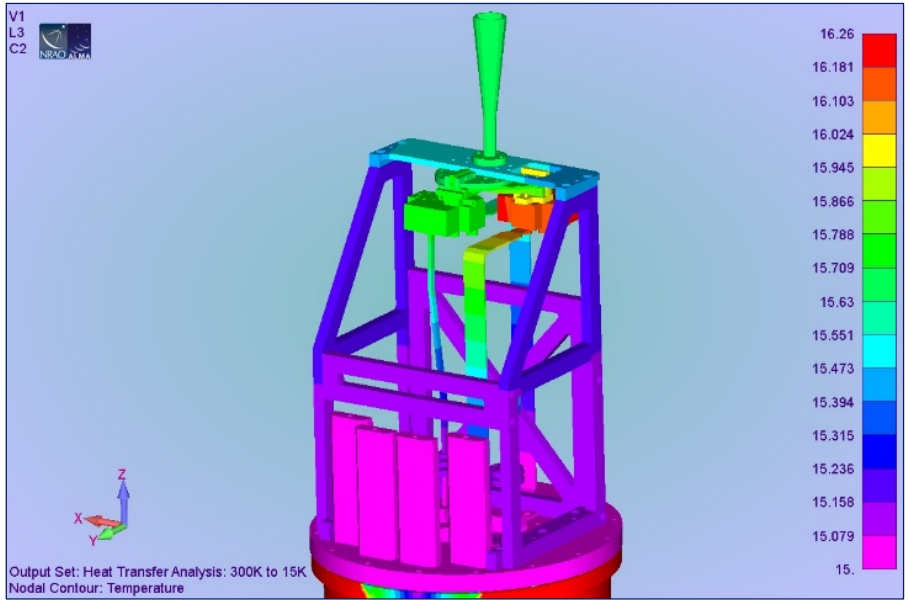
ALMA Band 2 Cold Cartridge Prototype

Band 2
67-90 GHz

Mechanical / Thermal Analysis

Temperature distributions, stresses, & deflections (both gravity and temperature induced), and vibrational modes and frequencies calculated.





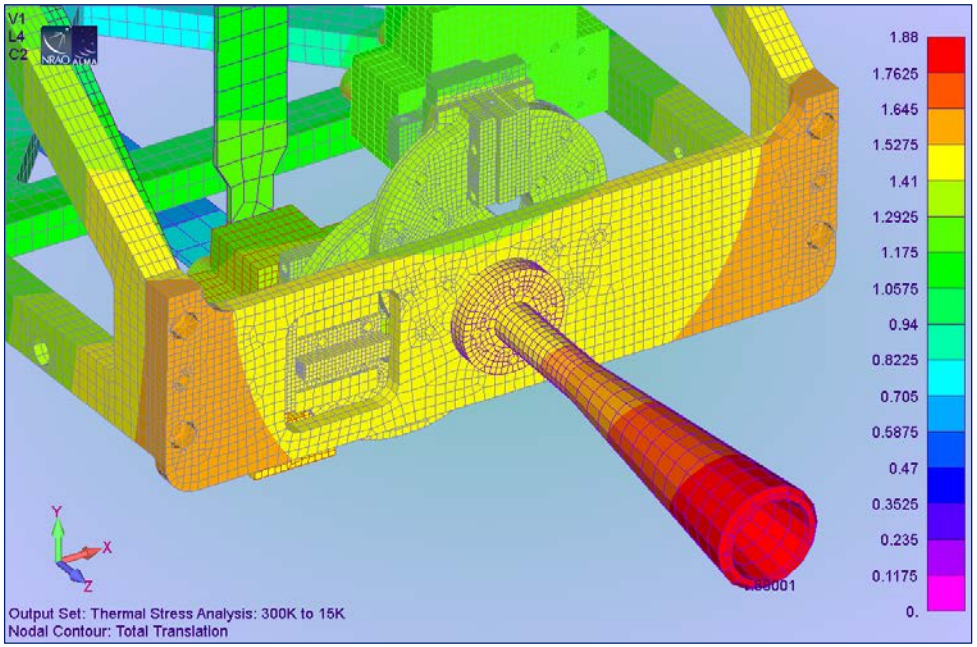
ALMA Band 2 Cold Cartridge Prototype

Mechanical / Thermal Analysis

Deformation Component	Deformation (mm)
X-Direction	-0.00036
Y-Direction	-0.081
Z-Direction	-1.857

Displacement of the feed horn aperture center point due to cooling.

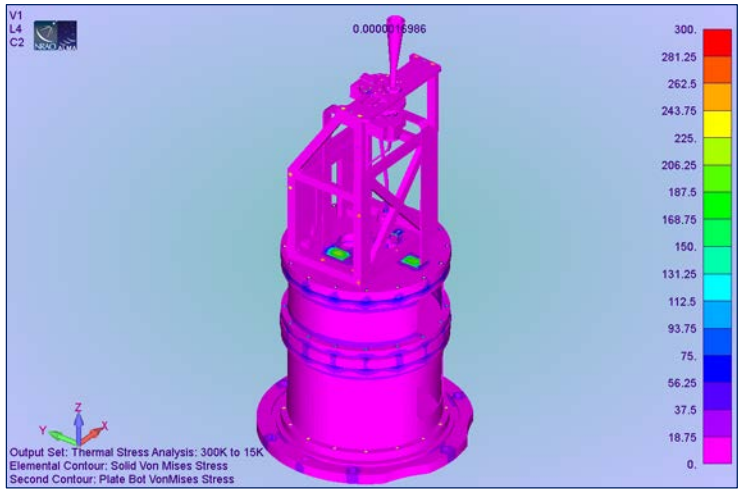
Resultant displacement (total due to x-, y- , and z- direction displacements) at and near the feed horn due to cooling.

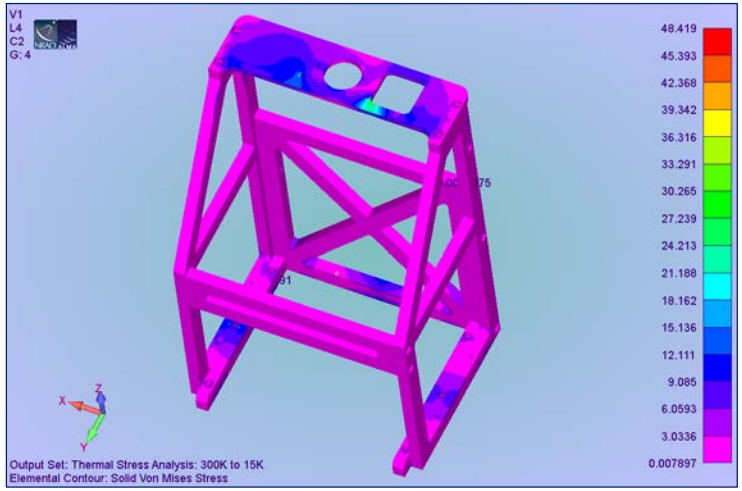


Gravity induced displacements found to be significantly lower than the thermal induced deformations.

ALMA Band 2 Cold Cartridge Prototype

Mechanical / Thermal Analysis





Band 2 Structural Component	Material	Peak Stress (MPa)	Factor of Safety (on Yield Stress)
300K Base Plate	6061 AL	48.2	5.73
300K-110K Spacer Tube	G10	100.9	2.39
110K Plate	6061 AL	127.2	2.17
110K-15K Spacer Tube	G10	154.7	1.56
15K Plate	6061 AL	169.9	1.62
OMT Support Structure	6061 AL	48.4	5.70

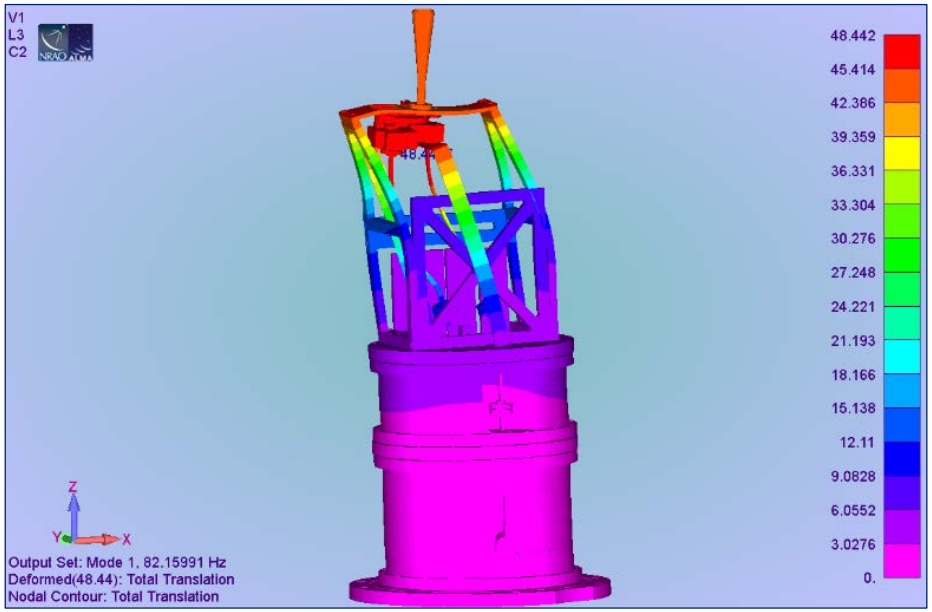
The equivalent static stresses associated with the thermal loading boundary conditions are summarized in the table above. In general, all stress conditions during cool-down are provided with sufficient material factors of safety.

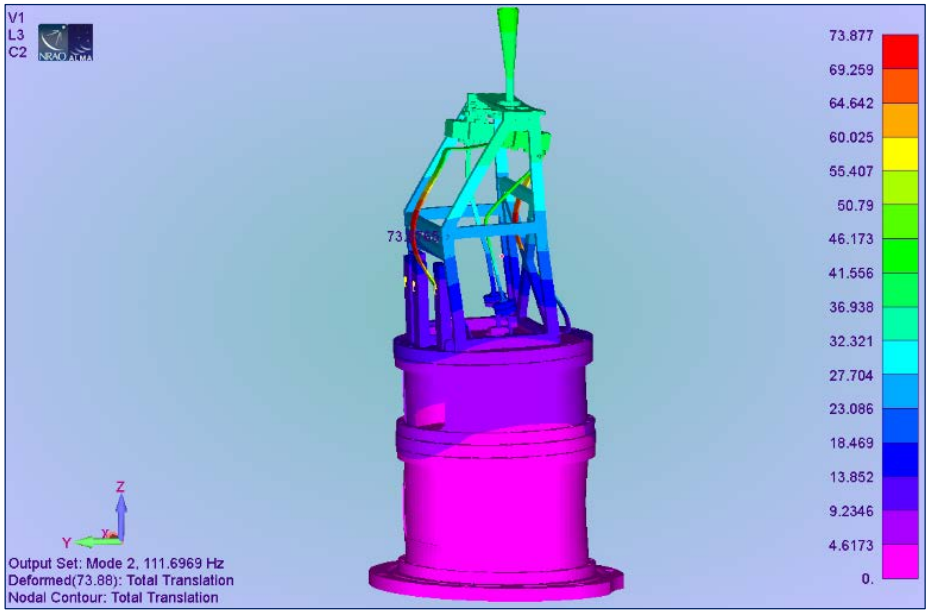
Gravity loading stresses are significantly lower than the equivalent thermal stresses; as a result we should expect that the Band 2 cold cartridge assembly should adequately handle shipping loads.

ALMA Band 2 Cold Cartridge Prototype

Band 2
67-90 GHz

Mechanical / Vibrational Analysis





- Vibration Mode Shapes: 1st Mode – 82.2 Hz, 2nd Mode – 111.7 Hz, . . . First ten modes calculated. 1st mode is compliant with respect to the > 70 Hz requirement.
- Analysis pointed to a modification that would use two extra fasteners (screws) to increase the stiffness of the OMT support structure. This would raise the resonant frequency for the first mode to 99 Hz. This change has not been implemented in the prototype cartridge but can be implemented in the pre-production/production versions of the Band 2 cold cartridge assembly.

ALMA Band 2 Cold Cartridge Prototype

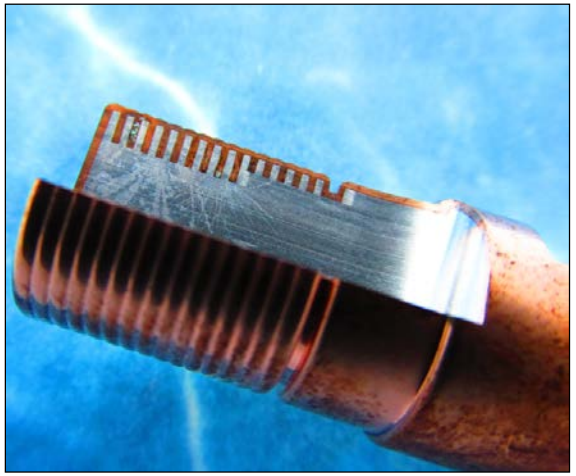
Optics Design

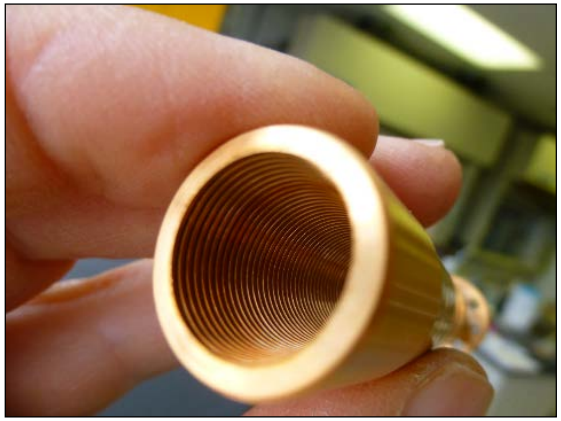
- Frequency independent illumination taper of -12 dB requires a 106 mm diameter, 785 mm long horn. Will result in beam truncation due to limited cryostat aperture. Similar truncation constraints apply to cooled lens.
- Reflective optics has to be placed outside the cartridge/cryostat (due to space constraints). Limited space outside due to calibration device, experimental design increased angle of incidence on the subreflector and yielded poorer polarization performance.
- Moderate beam waist horn with refractive optics (lens, which also serves as the vacuum window) design option was chosen.
- HDPE was selected for the lens material. Alternatives like high dielectric constant Si were studied (to save losses, since the lens would be thinner), but were not selected as the loss was found to be similar to a thicker HDPE lens. (Loss depends on electrical thickness, not the physical thickness).

ALMA Band 2 Cold Cartridge Prototype

Band 2
67-90 GHz

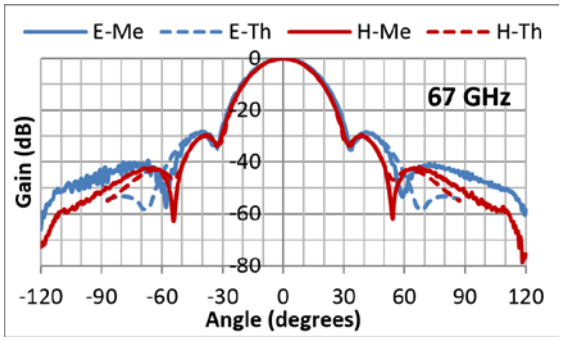
Feed Horn

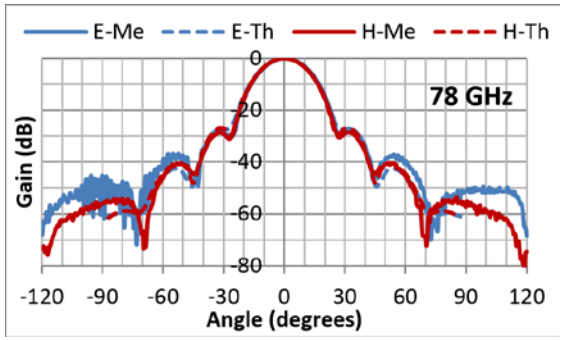


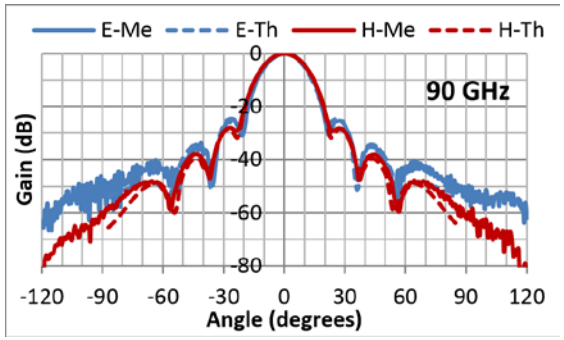


ALMA Band 2 Cold Cartridge Prototype

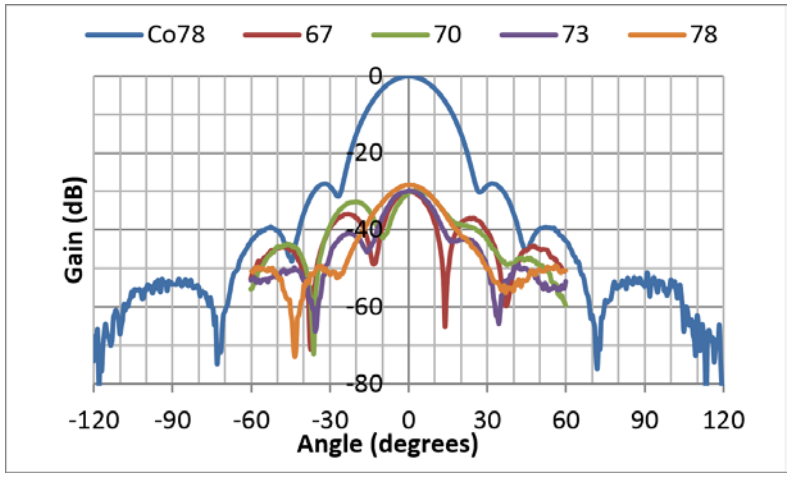
Feed Horn

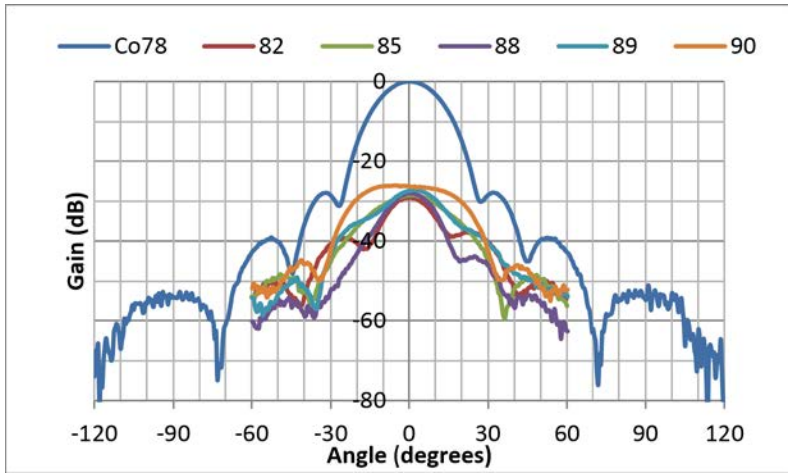






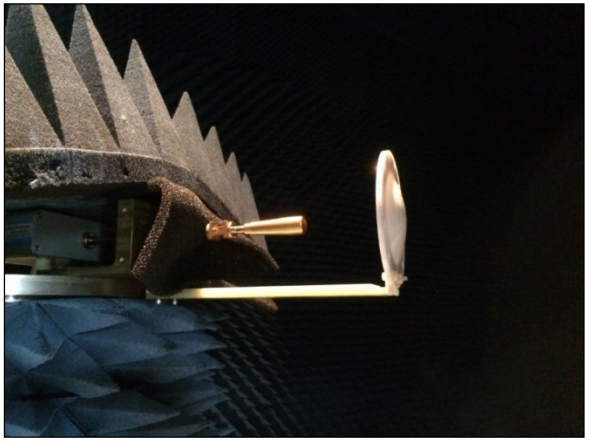
Frequency (GHz)	Taper in dB at 20° (Calculated)		Beam waist (Calculated) (mm)	Phase center (Calculated) (mm)
	E-plane	H-plane		
67	-9.07	-10.52	4.73	2.7
78	-14.40	-15.72	4.71	3.8
90	-23.44	-22.18	4.67	5.0

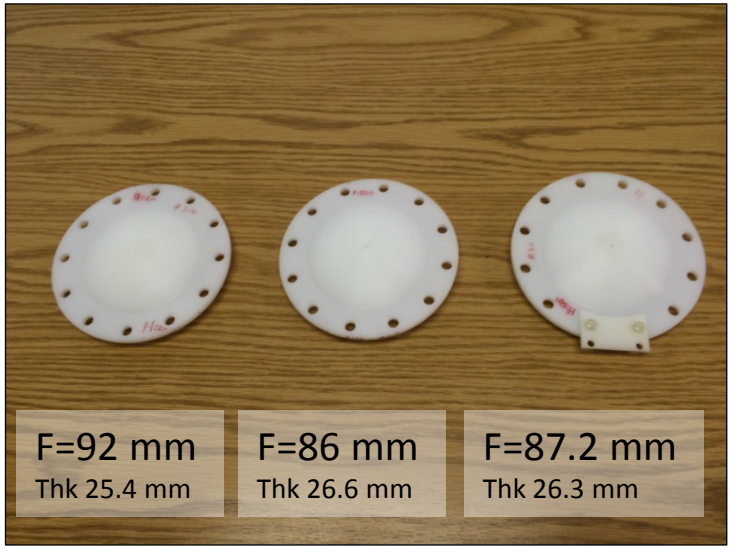


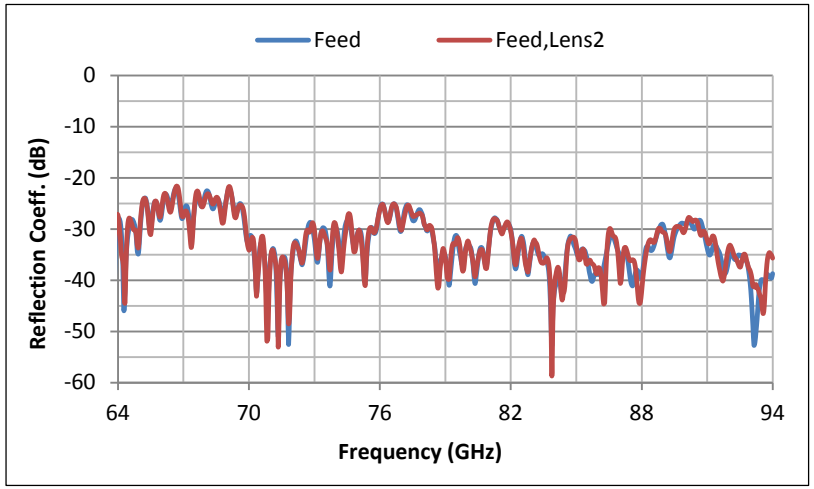


ALMA Band 2 Cold Cartridge Prototype

Horn & Lens



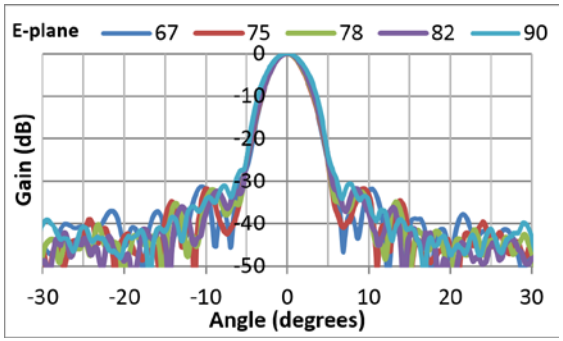


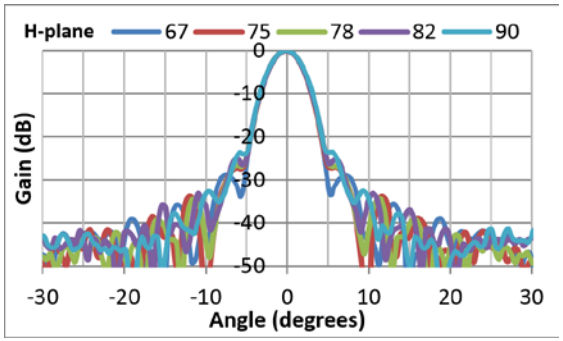


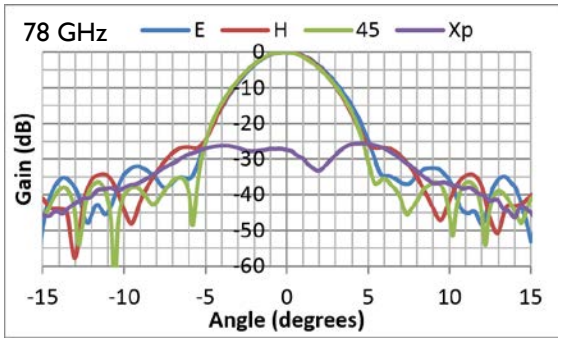
ALMA Band 2 Cold Cartridge Prototype

Horn & Lens

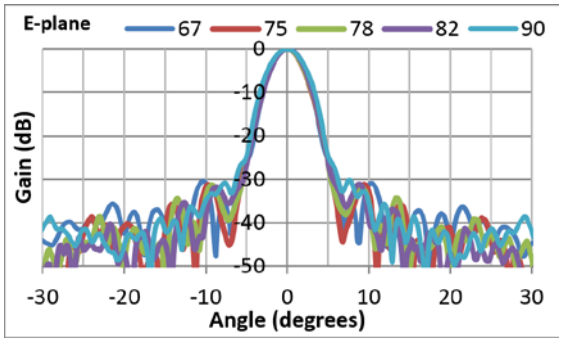
Lens #2

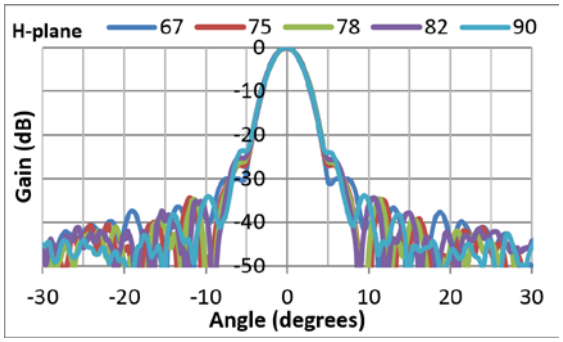


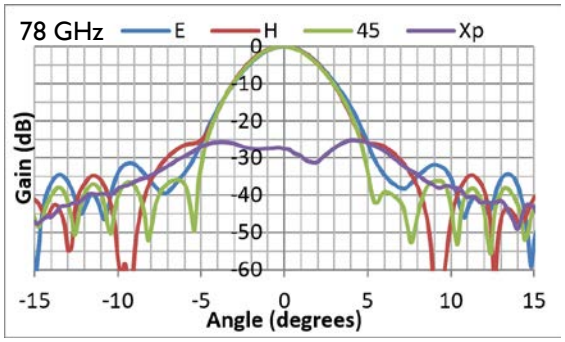




Lens #3



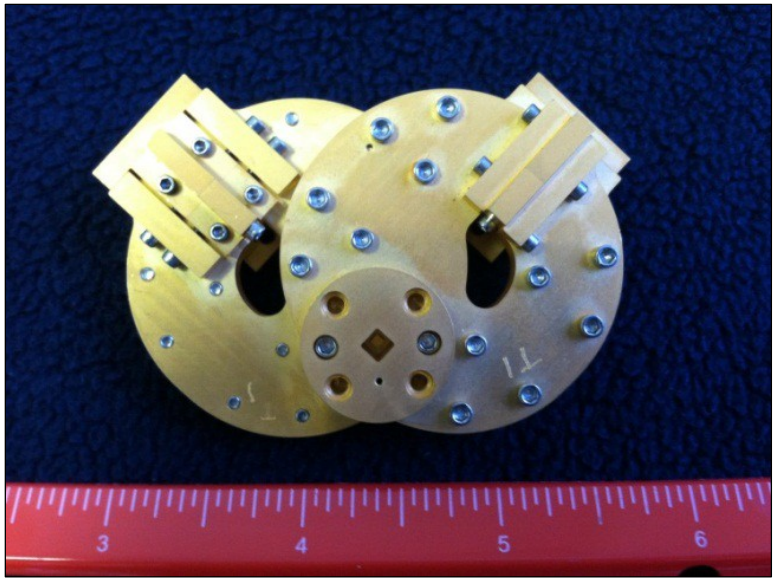


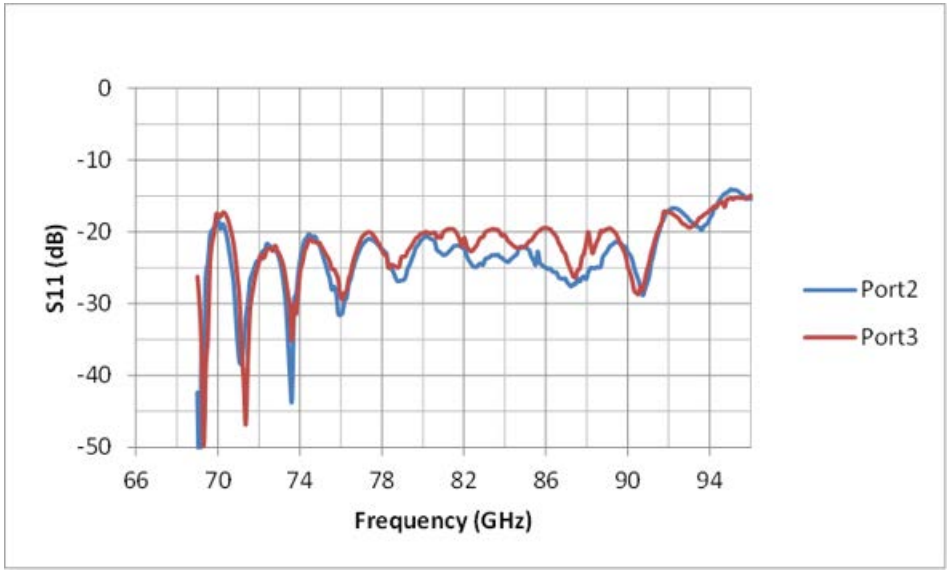


Lens #	Illumination taper at 3.6° (dB)		
	67 GHz	78 GHz	90 GHz
2	-13.44	-12.80	-11.33
3	-14.37	-14.03	-12.60
4 (Fresnel, 1-zone)	-10.88	-11.56	-11.36

ALMA Band 2 Cold Cartridge Prototype

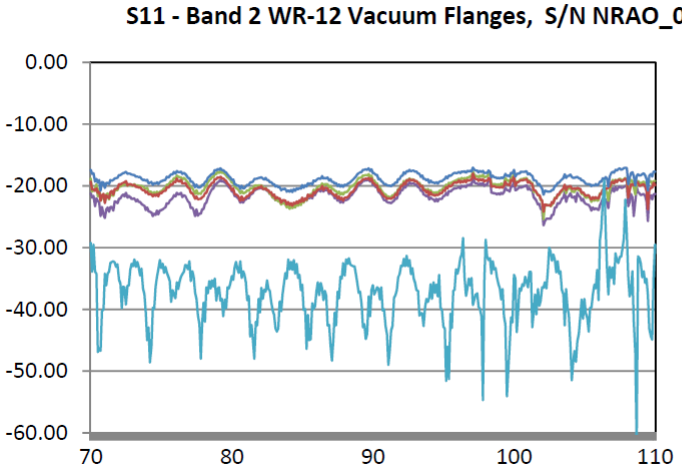
Orthomode Transducer

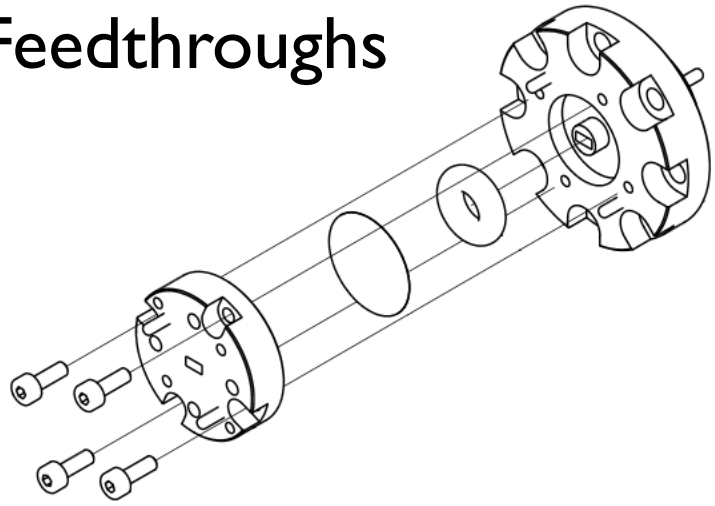


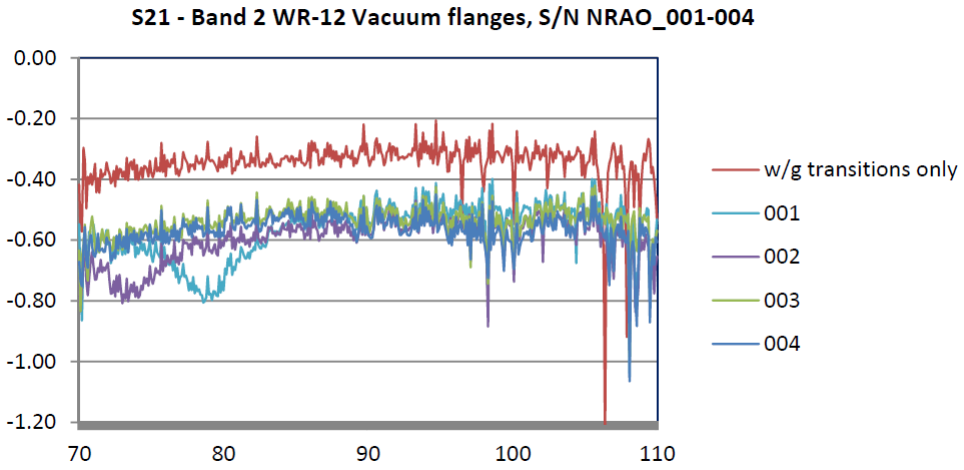


ALMA Band 2 Cold Cartridge Prototype

WR-12 (E-Band) Vacuum RF Feedthroughs





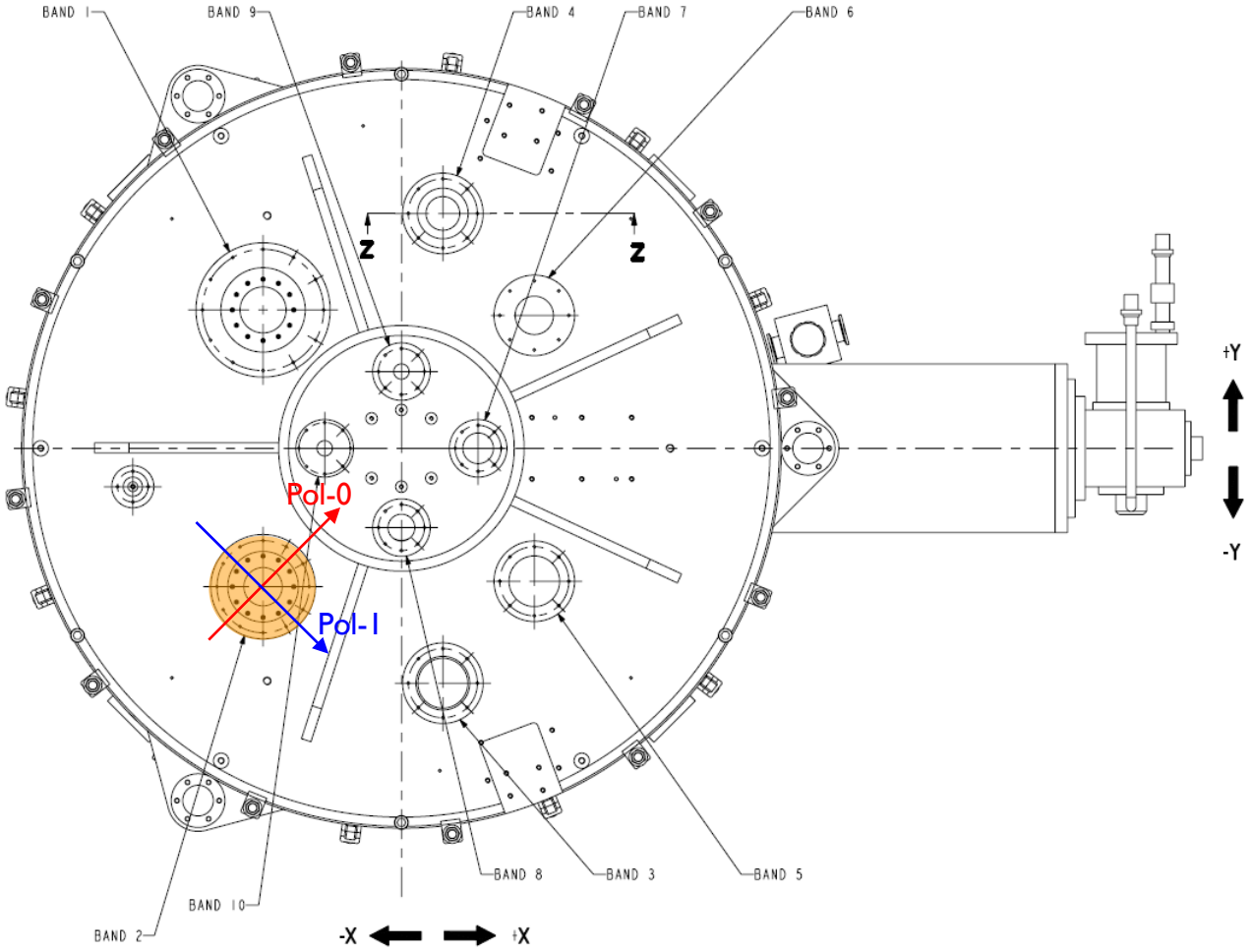


This design is adopted from the NAOJ Band 8 LO waveguide feedthrough design. The vacuum barrier is a 18 μm thick mica disk. One such assembly is used for each of the two polarization channels.

ALMA Band 2 Cold Cartridge Prototype

Band 2
67-90 GHz

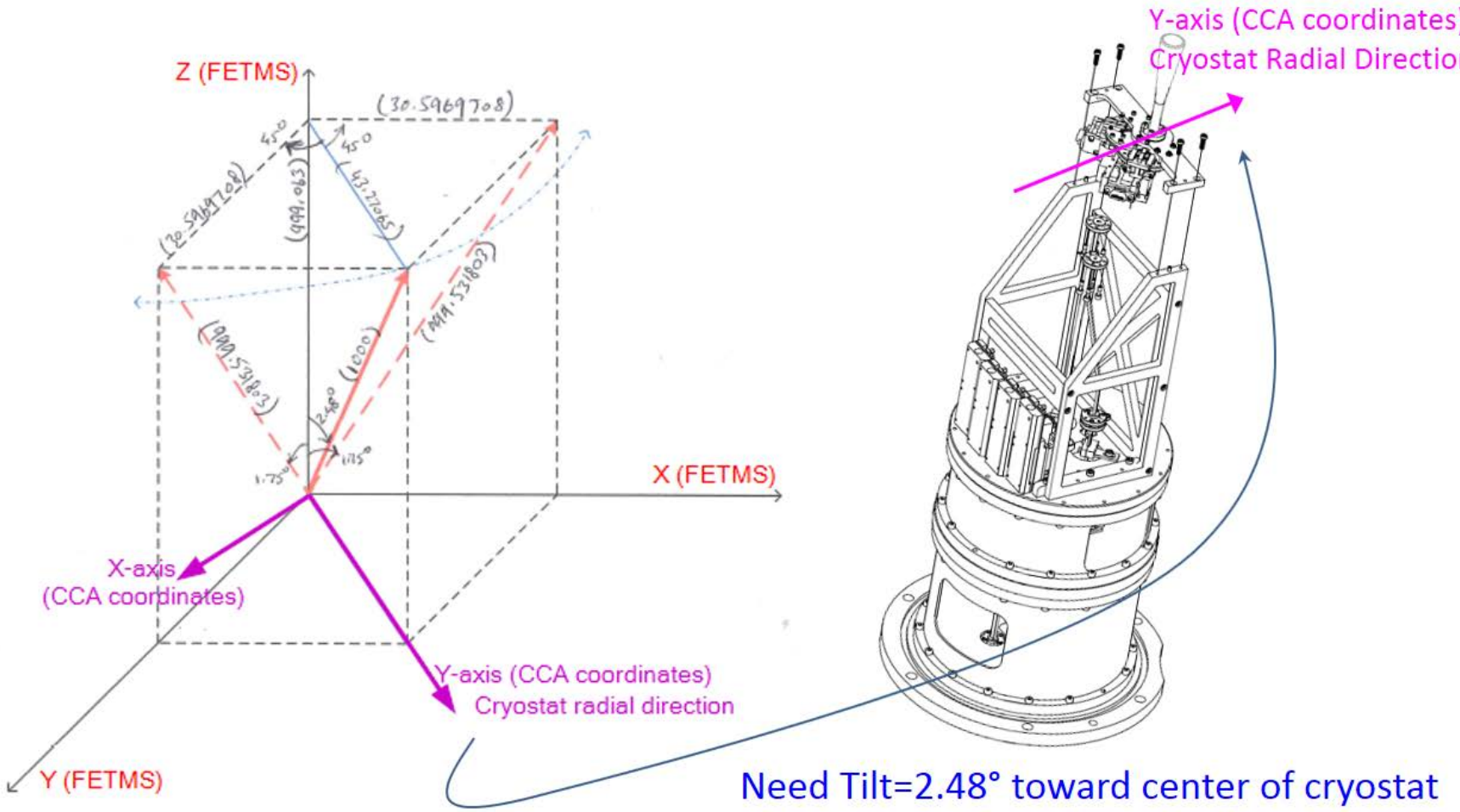
Location of the Band 2 window on the ALMA cryostat



ALMA Band 2 Cold Cartridge Prototype

Band 2
67-90 GHz

Feed-Horn Alignment



ALMA Band 2 Cold Cartridge Prototype

Optics Assembly Tolerance Analysis

Band 2 Optics Error Budget			system misalignment	weighting coefficient	top-level spec	2nd level spec	spec units	responsibility	notes
Static misalignment									
(A0-A1)	Telescope axis to FESS								
		FESS linear	0.00 mrad	1.00	0.00		mm	ALMA	
		FESS angular	0.63 mrad	1.00	0.634		mrad	ALMA	NRAO: "FESS analysis7.pdf"
(A1-A2)	FESS to cryostat								
		Cryostat linear	0.00 mrad	1.00	0.00		mm	FEND	
		Cryostat angular	0.28 mrad	1.00	0.279		mrad	FEND	NRAO: "FESS analysis7.pdf"
(A2-A3)	Cryostat to 300K plate								
		300K plate linear	1.40 mrad	4.67	0.300				total static linear error in cryostat
			300K plate linear (mfg tol.)			0.200	mm	RAL	RAL: "Tolerance Budget.doc"
			300K plate linear (evacuation)			0.100	mm	RAL	RAL: "Tolerance Budget.doc"
		300K plate angular	0.77 mrad	1.00	0.770		mrad	RAL	total static angular error in cryostat
			300K plate angular (parallelism)			0.170	mrad	RAL	RAL: "Tolerance Budget.doc"
			300K plate angular (evacuation)			0.600	mrad	RAL	RAL: FEND-40.03.01.00-001-A-REP
(A3-A4)	300K plate to 15K plate								
		15K plate linear	1.71 mrad	4.67	0.366		mm	RAL	total static linear error in cartridge body
			15K plate linear (mfg tol.)			0.300	mm	RAL	RAL: "Tolerance Budget.doc"
			15K plate linear (cooling)			0.066	mm	RAL	RAL: "Tolerance Budget.doc"
		15K plate angular	0.90 mrad	1.00	0.900		mrad		total static angular error in cartridge body
			15K plate angular (parallelism)			0.400	mrad	RAL	RAL: "Tolerance Budget.doc"
			15K plate anguar (cooling)			0.500	mrad	RAL	RAL: "Tolerance Budget.doc"
(A4-A5)	15K plate to horn aperture								
		Horn linear	0.47 mrad	4.67	0.100		mm	NRAO	ass'y tolerances of RF components
		Horn angular	3.00 mrad	1.00	3.000		mrad	NRAO	total angular error in RF components
			Horn angular (parallelism)			3.000	mrad	NRAO	ass'y tolerances of RF components
(A2-A6)	Cryostat to lens mount								
		lens mount linear (mfg tol.)	0.93 mrad	4.67	0.200		mm	RAL	RAL: KG0772-050-D
		lens mount angular (parallelism)	0.40 mrad	1.00	0.400		mrad	RAL	RAL: KG0772-050-D
		Total (RSS)	**4.12 mrad**					equal to	0.24 °
		Total (Sum)	**10.49 mrad**					equal to	0.60 °
		Specification is	**5.50 mrad**					equal to	0.32 °

= Unknown contribution
= Guess - to be confirmed
= To be confirmed
= preliminary value, could be wrong

ALMA Band 2 Cold Cartridge Prototype

Feed Horn Alignment

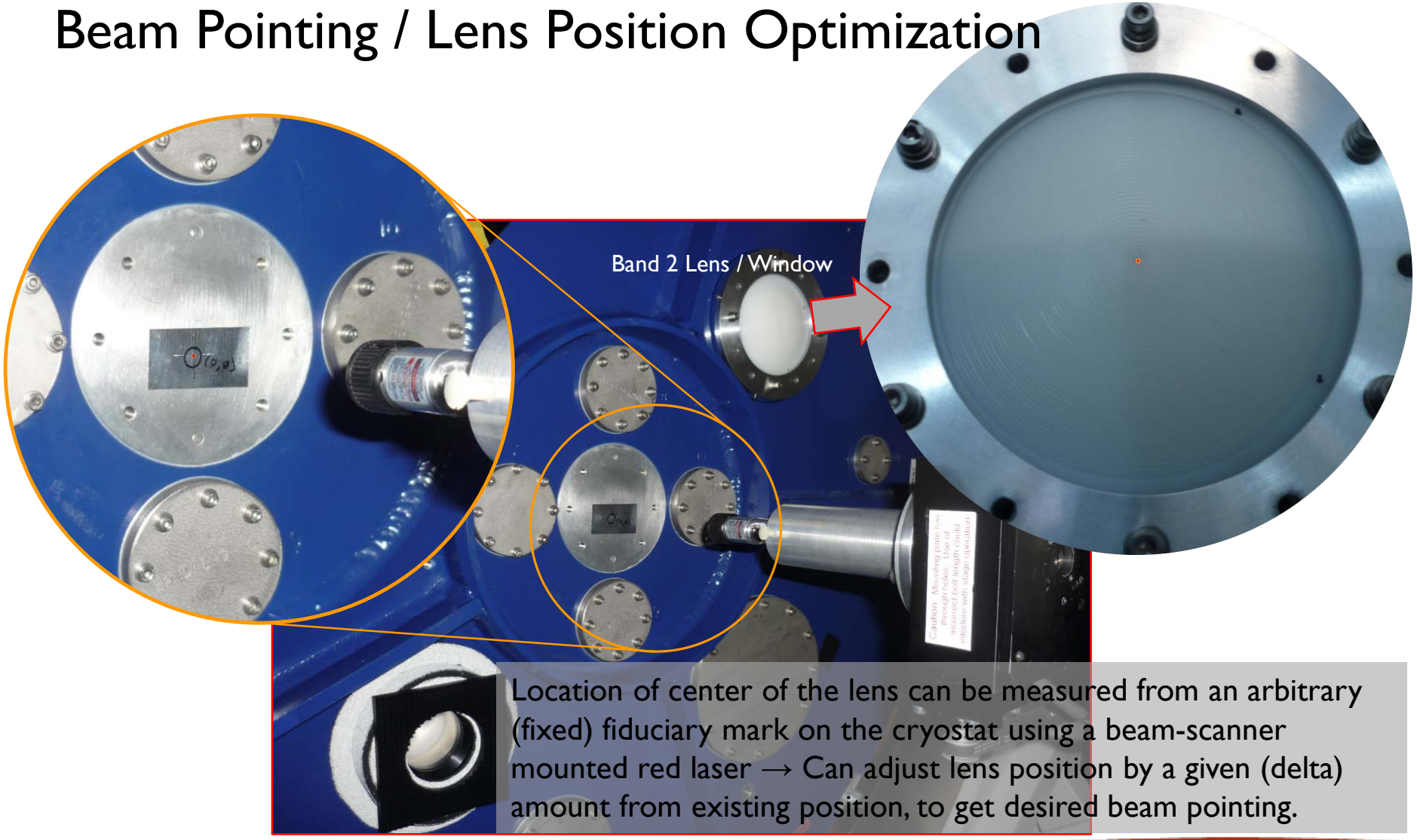
	Winchester Machine and Tool Metrology Results, Band 2 CCA					
	6/29/2015					
	* Note: measurements include 4mm spacer (Lens 3 configuration)					
	Model	Run 1	vs Model	Run 2	vs Model	Repeatability of Runs
feedhorn aperture center, x	0.0000	0.0114	0.0114	0.0115	0.0115	0.0001
feedhorn aperture center, y	1.4322	1.4699	0.0377	1.4713	0.0391	0.0014
feedhorn aperture center, z	19.2517	19.2654	0.0137	19.2136	-0.0381	-0.0518
feedhorn aperture angle to base	2.4800	2.8671	0.3871	2.8864	0.4064	0.0193
omt bracket angle to base						
omt waveguide center, x						
omt waveguide center, y						
omt waveguide center, z						

Measured residuals (both offsets and pointing) can be corrected by lens position optimization . . .

. . . but, to be conservative, horn was shimmed to physically correct the horn tilt, and this also removed most of the y-offset residual.

ALMA Band 2 Receiver Prototype

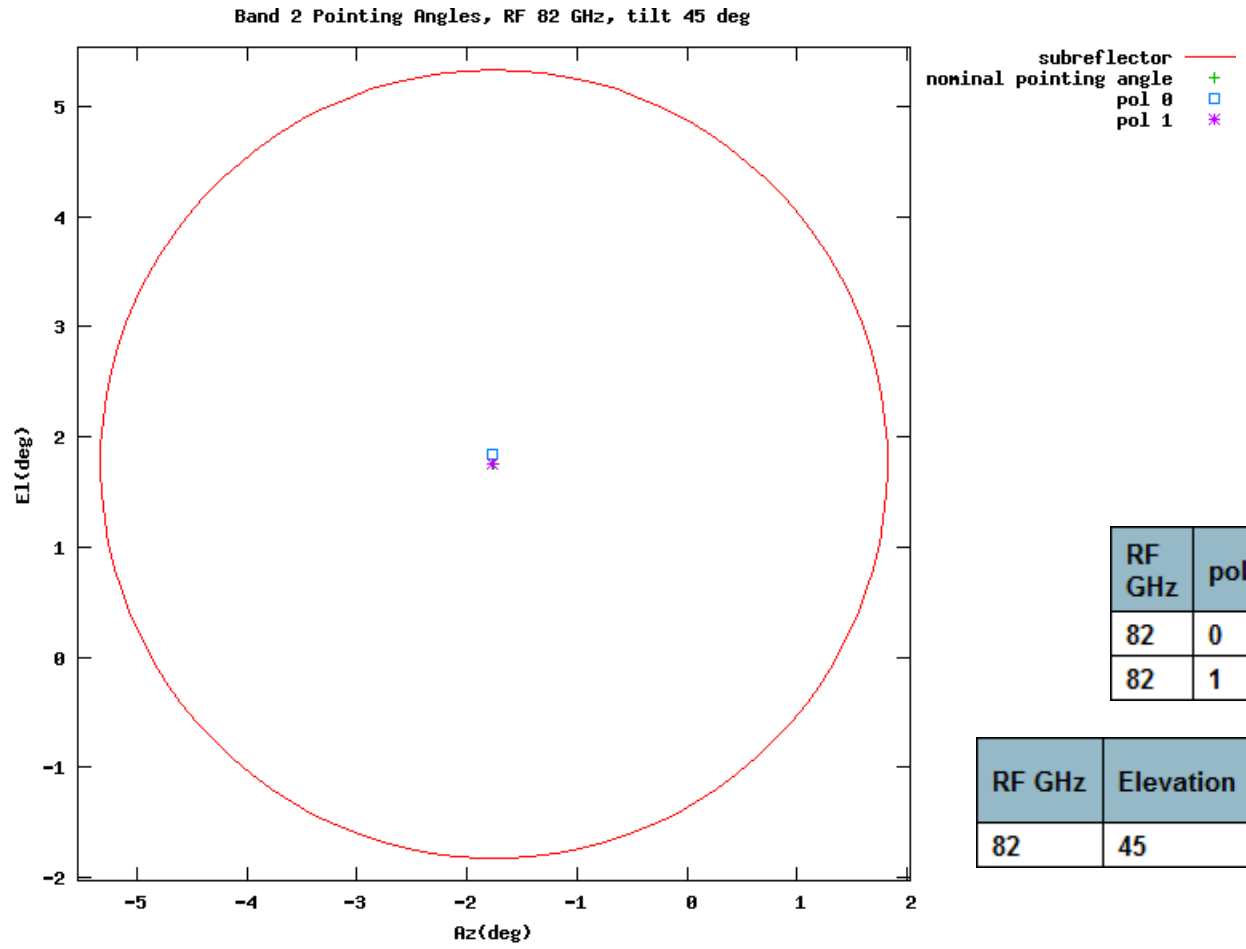
Beam Pointing / Lens Position Optimization



Location of center of the lens can be measured from an arbitrary (fixed) fiduciary mark on the cryostat using a beam-scanner mounted red laser → Can adjust lens position by a given (delta) amount from existing position, to get desired beam pointing.

ALMA Band 2 Receiver Prototype

Optics Performance / Beam Pointing

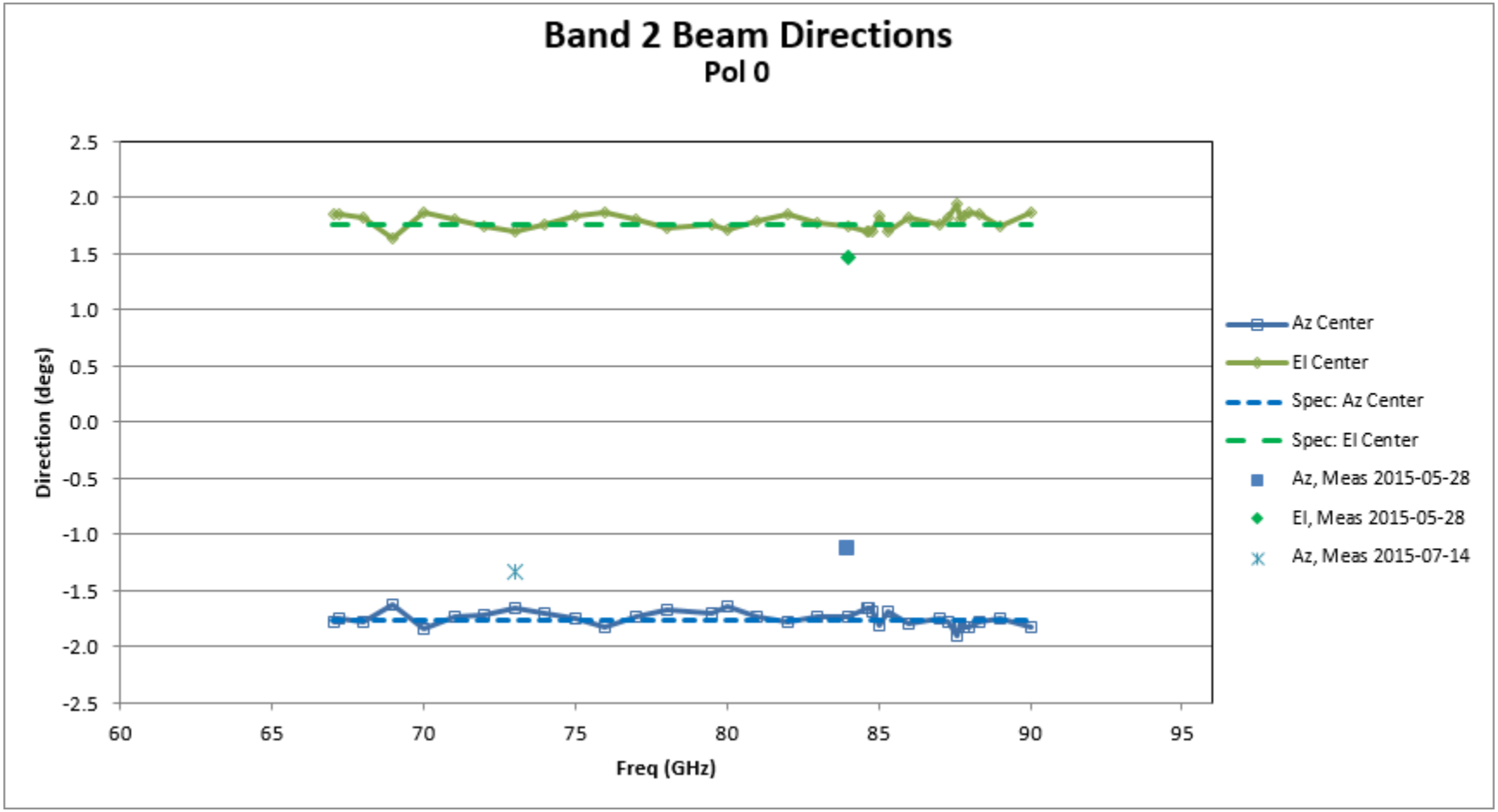


RF GHz	pol	Elevation	AZ Center	EL Center
82	0	45	-1.7718	1.8484
82	1	45	-1.7624	1.7619

RF GHz	Elevation	Squint (%FPBW)	squint (arc seconds)
82	45	1.37	0.99

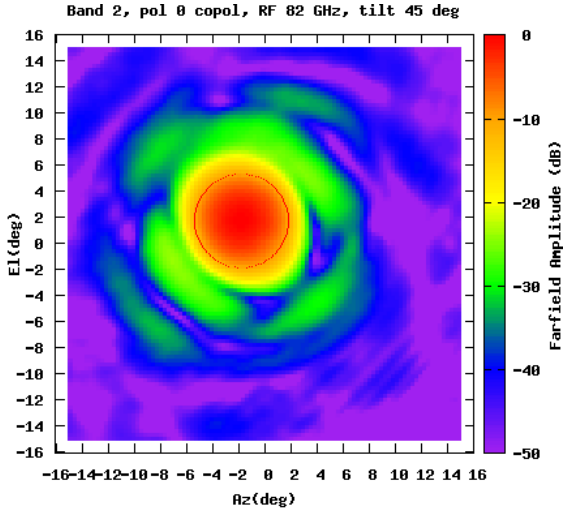
ALMA Band 2 Receiver Prototype

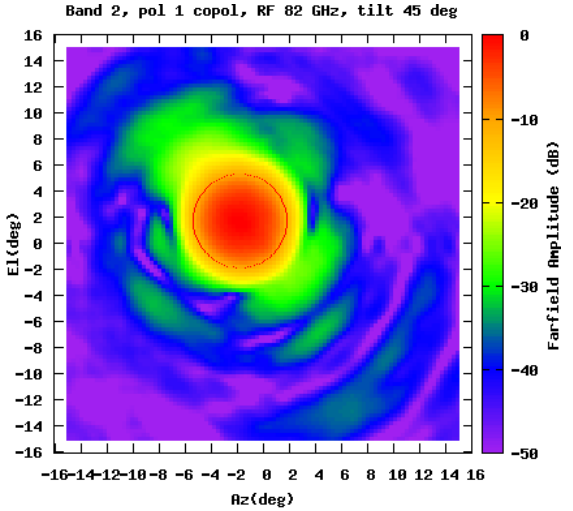
Optics Performance / Beam Pointing

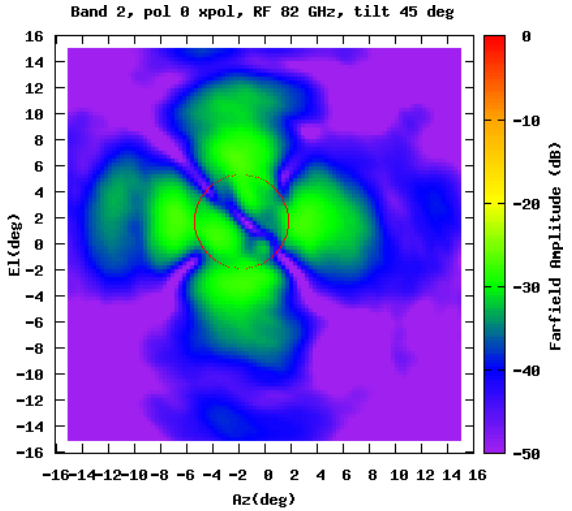


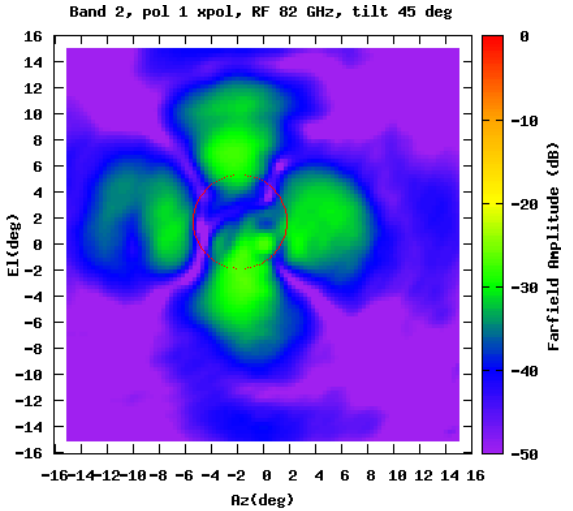
ALMA Band 2 Receiver Prototype

Optics Performance / Beam Patterns



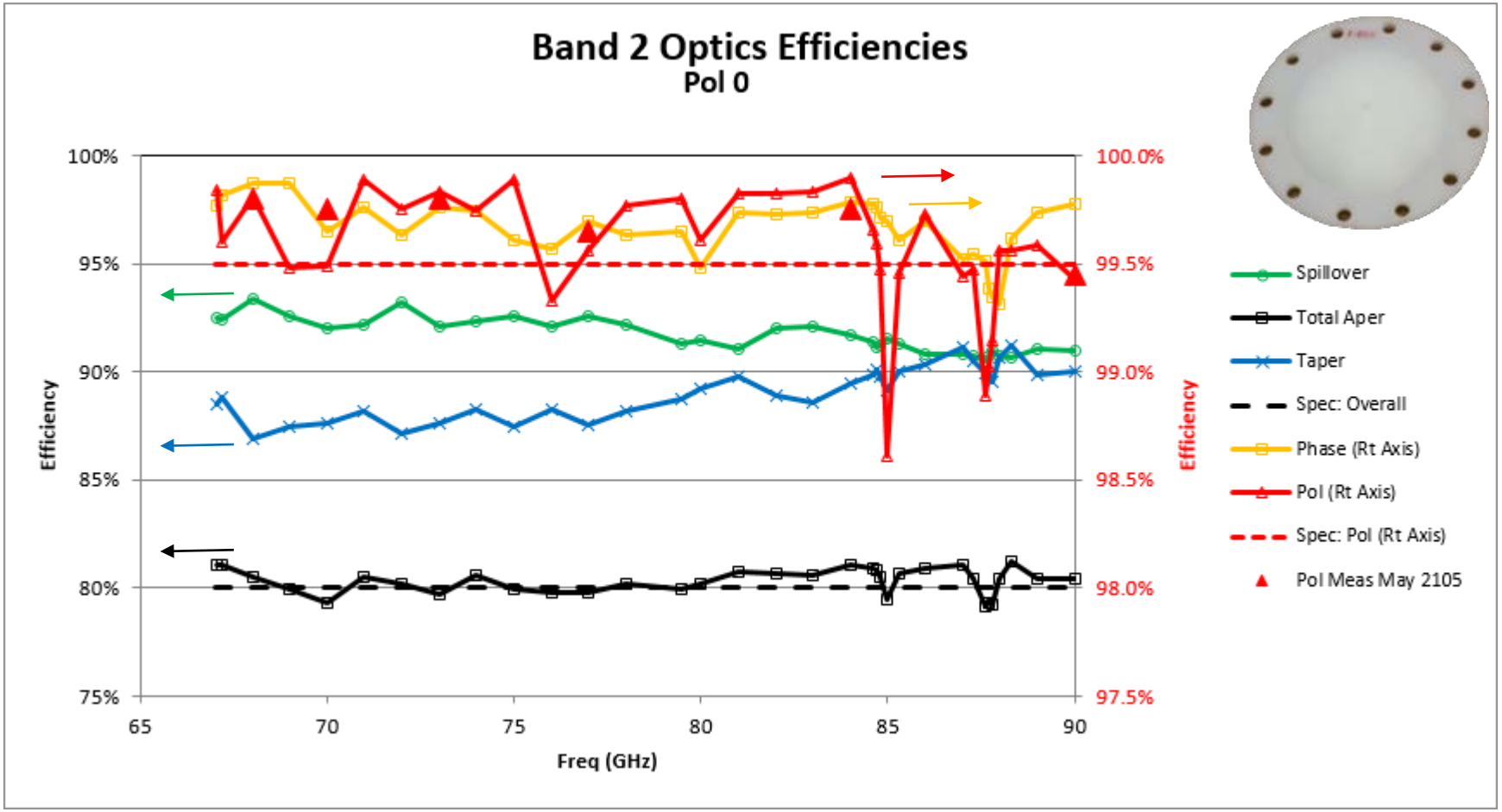






ALMA Band 2 Receiver Prototype

Optics Performance / Beam Efficiencies



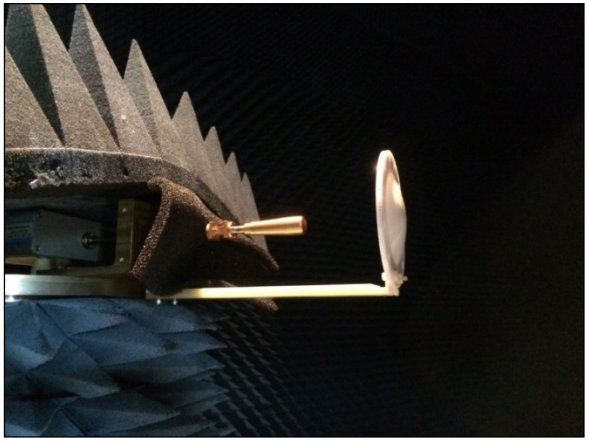
ALMA Band 2 Receiver Prototype

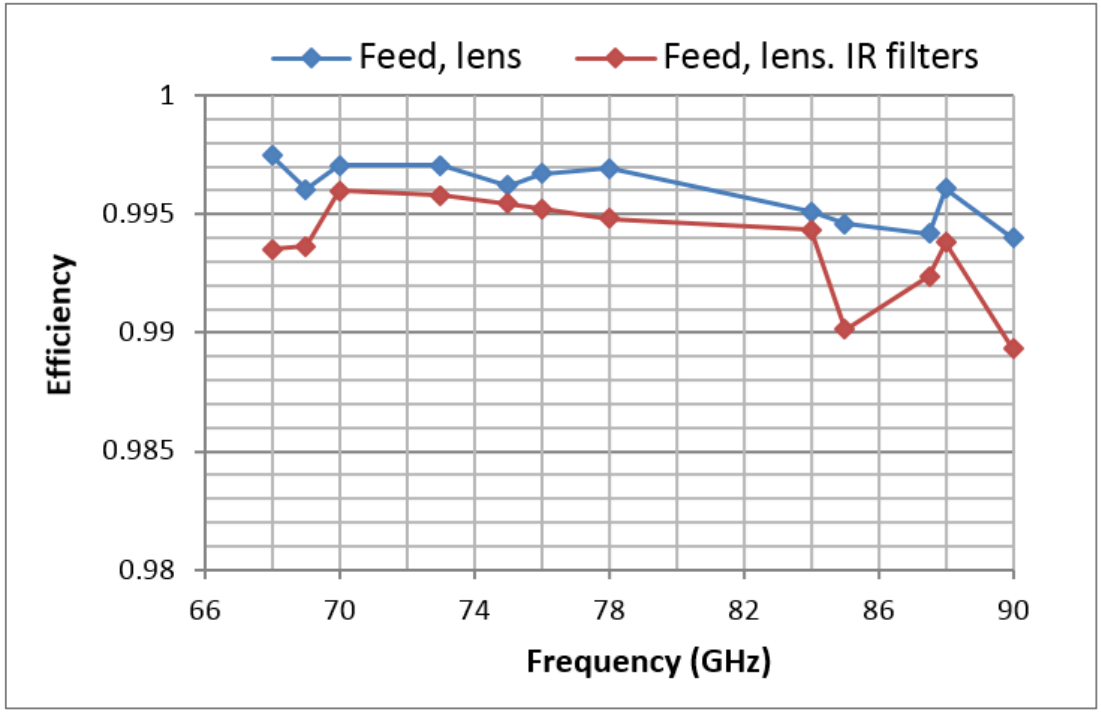
Optics Performance / Beam Efficiencies

w/ Fresnel Lens

ALMA Band 2 Receiver Prototype

Optics Performance / Beam Efficiencies

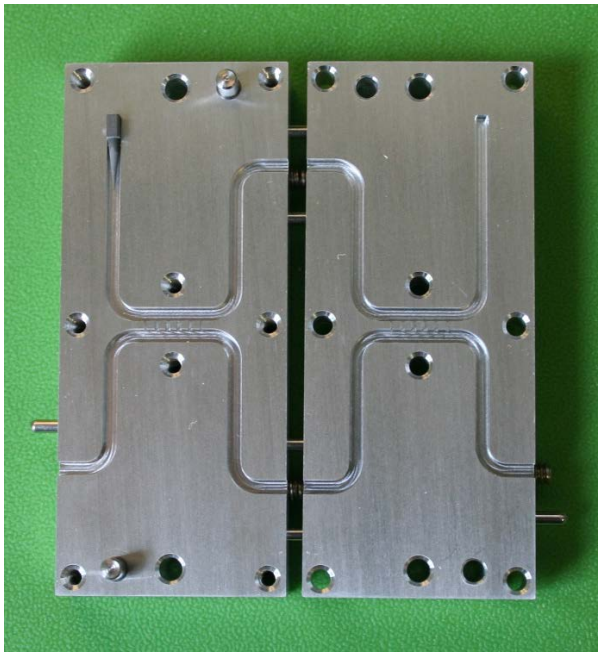


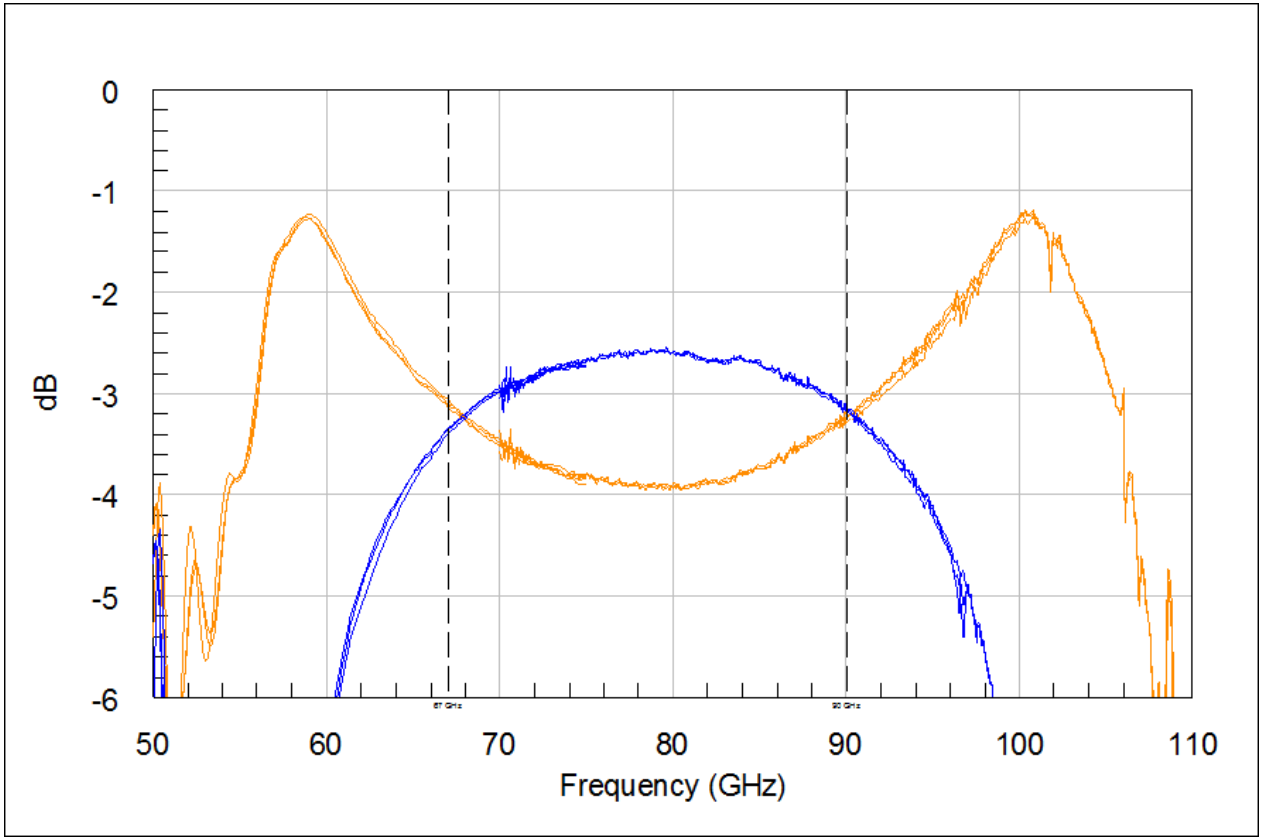


Measured polarization efficiency of feed horn & lens with and without the 15 K IR filter (anechoic chamber measurements).

ALMA Band 2 Warm Cartridge Prototype

RF 90° Hybrids

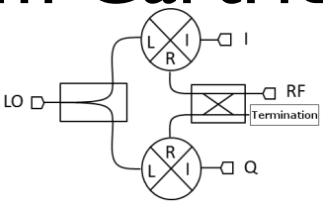


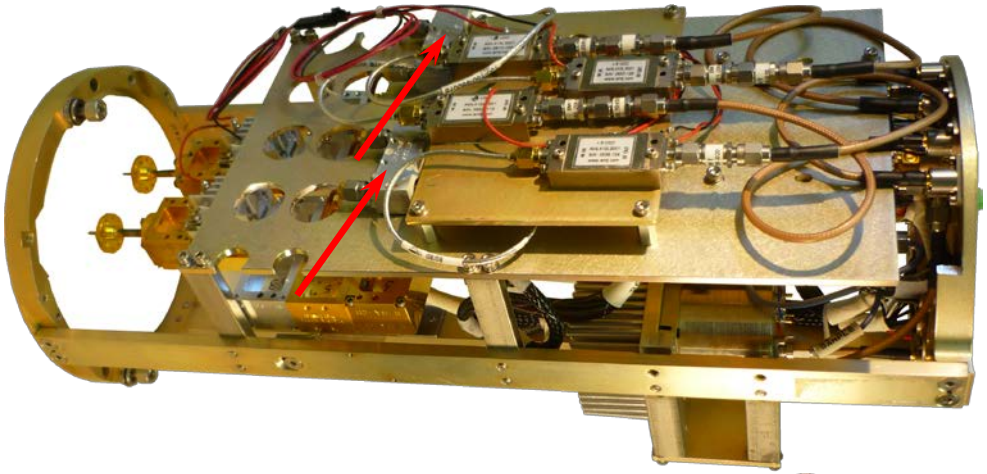


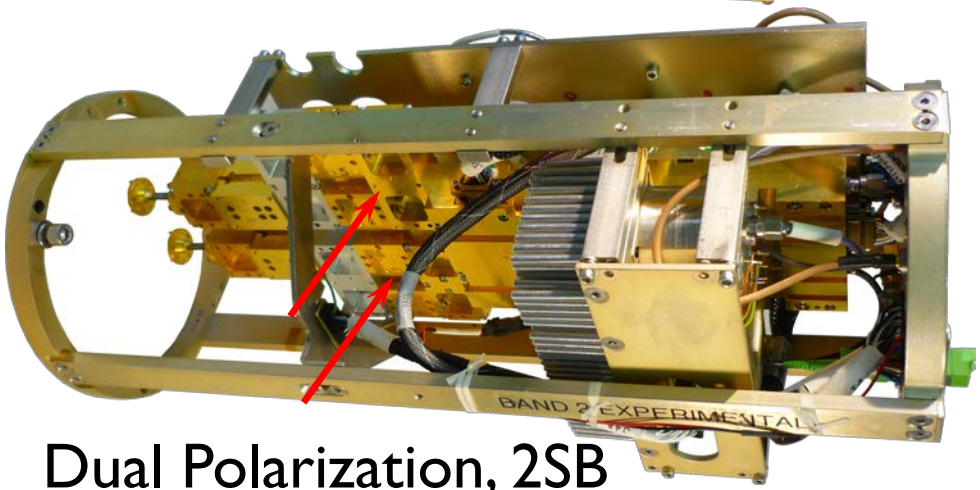
ALMA Band 2 Warm Cartridge Prototype

Band 2
67-90 GHz

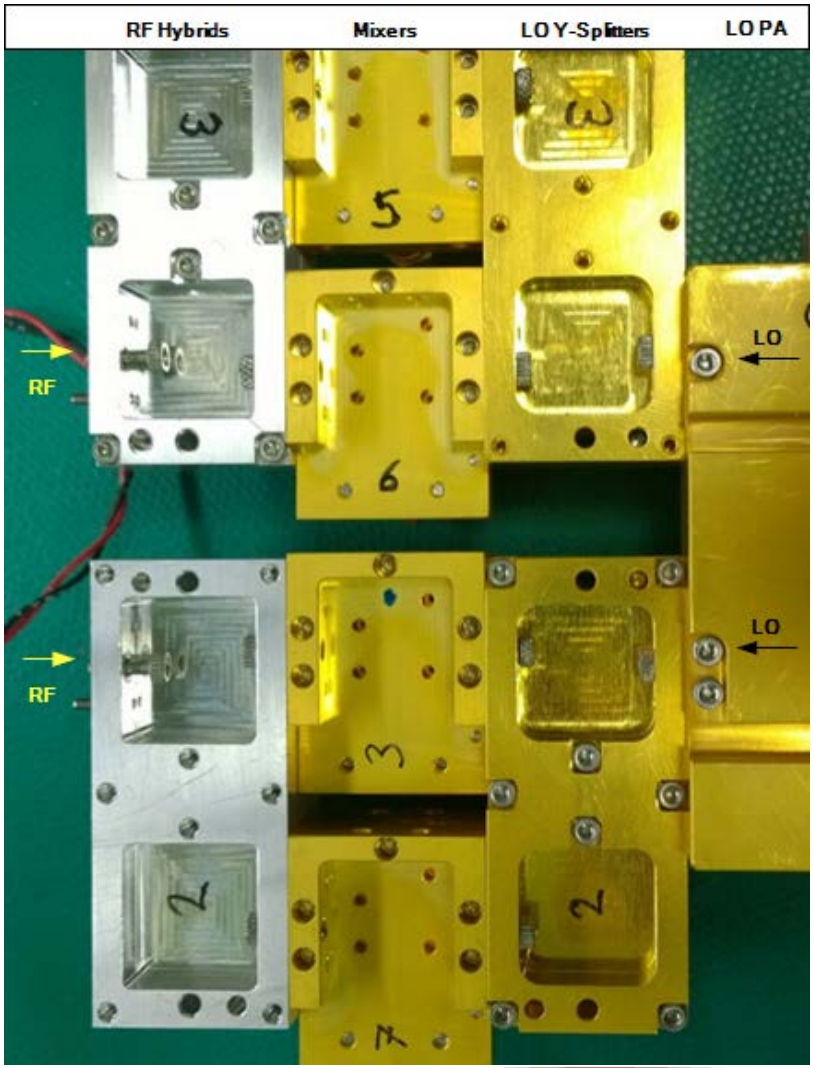
2SB Downconverter







Dual Polarization, 2SB



ALMA Band 2 Warm Cartridge Prototype

2SB Downconverter / Image Rejection

Band 2
67-90 GHz

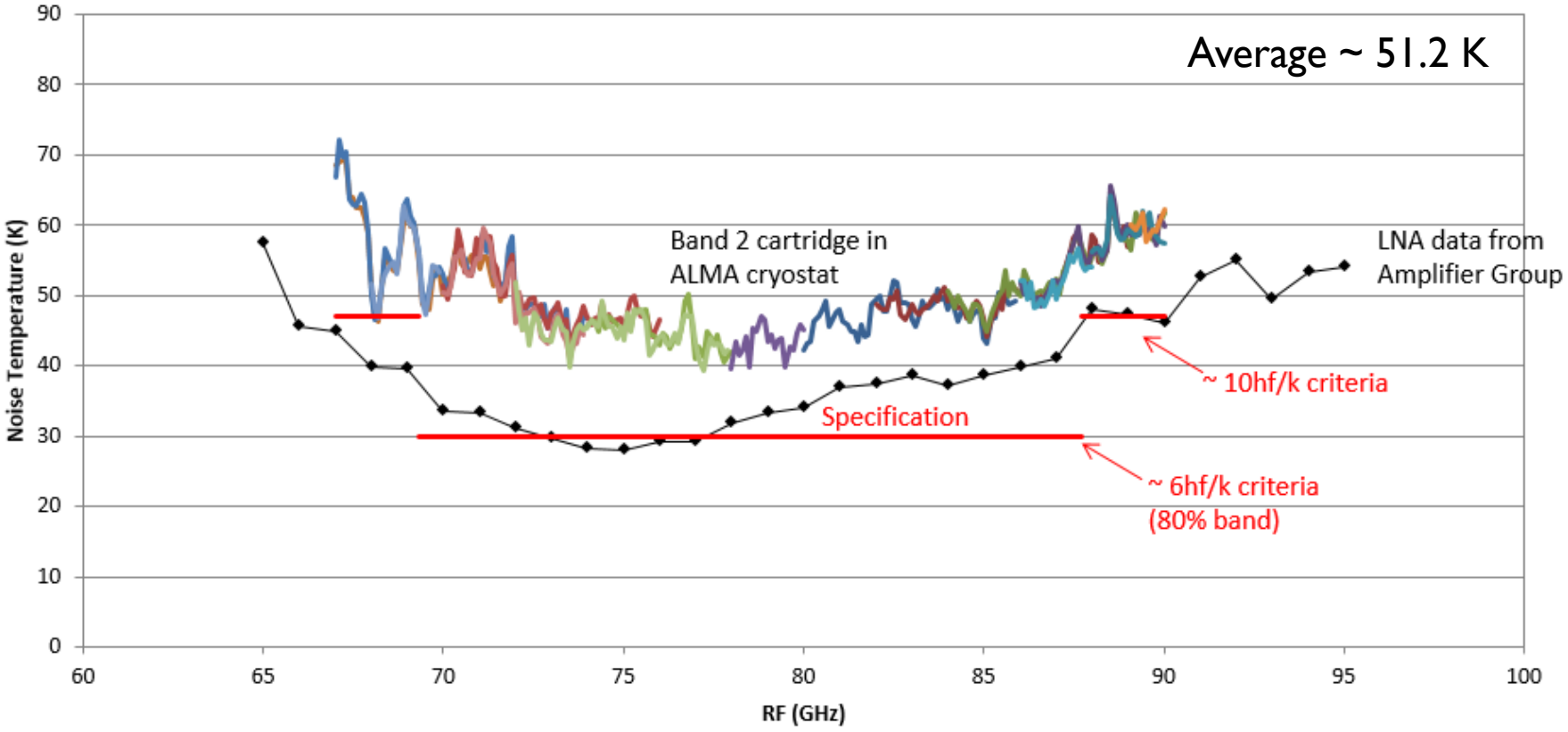
Polarization-0 Image Rejection Data

LO	(LSB)	RF IR	RF IR	RF IR	RF IR	RF IR	RF IR	RF IR	RF IR	RF IR	IR RF	IR RF	IR RF	IR RF	IR RF	IR RF	IR RF	IR RF	IR RF	(USB)
											14.5 dB	No meas								
72 GHz									67 GHz	68 GHz	76 GHz	77 GHz	78 GHz	79 GHz	80 GHz	81 GHz	82 GHz	83 GHz	84 GHz	
									No meas	28.1 dB										
											14.2 dB	17.5 dB	20.4 dB	No meas						
74 GHz						67 GHz	68 GHz	69 GHz	70 GHz		78 GHz	79 GHz	80 GHz	81 GHz	82 GHz	83 GHz	84 GHz	85 GHz	86 GHz	
						No meas	36.3 dB	16.6 dB	27.8 dB											
											10.6 dB	15.2 dB	19.5 dB	15.1 dB	19.7 dB	No meas				
76 GHz					67 GHz	68 GHz	69 GHz	70 GHz	71 GHz	72 GHz	80 GHz	81 GHz	82 GHz	83 GHz	84 GHz	85 GHz	86 GHz	87 GHz	88 GHz	
					No meas	19.8 dB	19.0 dB	22.1 dB	16.5 dB	29.0 dB										
											7.6 dB	10.0 dB	10.9 dB	11.4 dB	11.4 dB	17.0 dB	13.1 dB	No meas		
78 GHz			67 GHz	68 GHz	69 GHz	70 GHz	71 GHz	72 GHz	73 GHz	74 GHz	82 GHz	83 GHz	84 GHz	85 GHz	86 GHz	87 GHz	88 GHz	89 GHz	90 GHz	
			No meas	20.0 dB	20.8 dB	14.8 dB	19.6 dB	16.0 dB	14.2 dB	19.6 dB										
											11.4 dB	13.9 dB	23.4 dB	13.9 dB	15.1 dB	20.2 dB	24.1 dB	19.2 dB	20.6 dB	
80 GHz		68 GHz	69 GHz	70 GHz	71 GHz	72 GHz	73 GHz	74 GHz	75 GHz	76 GHz	84 GHz	85 GHz	86 GHz	87 GHz	88 GHz	89 GHz	90 GHz	91 GHz	92 GHz	
		23.1 dB	26.2 dB	28.4 dB	33.6 dB	23.2 dB	35.5 dB	24.0 dB	26.2 dB	34.0 dB										
											11.5 dB	12.7 dB	14.4 dB	12.5 dB	20.7 dB	15.3 dB	23.4 dB	No meas		
82 GHz		70 GHz	71 GHz	72 GHz	73 GHz	74 GHz	75 GHz	76 GHz	77 GHz	78 GHz	86 GHz	87 GHz	88 GHz	89 GHz	90 GHz	91 GHz	92 GHz	93 GHz	94 GHz	
			No meas	27.2 dB	36.0 dB	24.6 dB	33.7 dB	24.1 dB	18.8 dB	30.1 dB										
											10.0 dB	16.1 dB	16.0 dB	14.0 dB	19.2 dB	No meas				
84 GHz		72 GHz	73 GHz	74 GHz	75 GHz	76 GHz	77 GHz	78 GHz	79 GHz	80 GHz	88 GHz	89 GHz	90 GHz	91 GHz	92 GHz	93 GHz	94 GHz			
					No meas	23.6 dB	28.9 dB	23.9 dB	18.1 dB	35.9 dB										
											11.7 dB	17.1 dB	17.0 dB	No meas						
86 GHz		74 GHz	75 GHz	76 GHz	77 GHz	78 GHz	79 GHz	80 GHz	81 GHz	82 GHz	90 GHz	91 GHz	92 GHz	93 GHz	94 GHz					
							No meas	25.9 dB	20.5 dB	24.4 dB										
		12 GHz	11 GHz	10 GHz	9 GHz	8 GHz	7 GHz	6 GHz	5 GHz	4 GHz	4 GHz	5 GHz	6 GHz	7 GHz	8 GHz	9 GHz	10 GHz	11 GHz	12 GHz	
		IF (LSB)									IF (USB)									

Number in green and blue font represent image rejection values corresponding to lower and upper sidebands respectively. Specification is better than 10 dB IR over 80% of the IF range, and better than 7 dB IR over the full range.
Intermediate frequencies outside of the contiguous diamond shaped area correspond to RFs that are "in-band" but have out-of-band image falling on it. "Out-of-band" RFs that are of interest are shown grayed out.

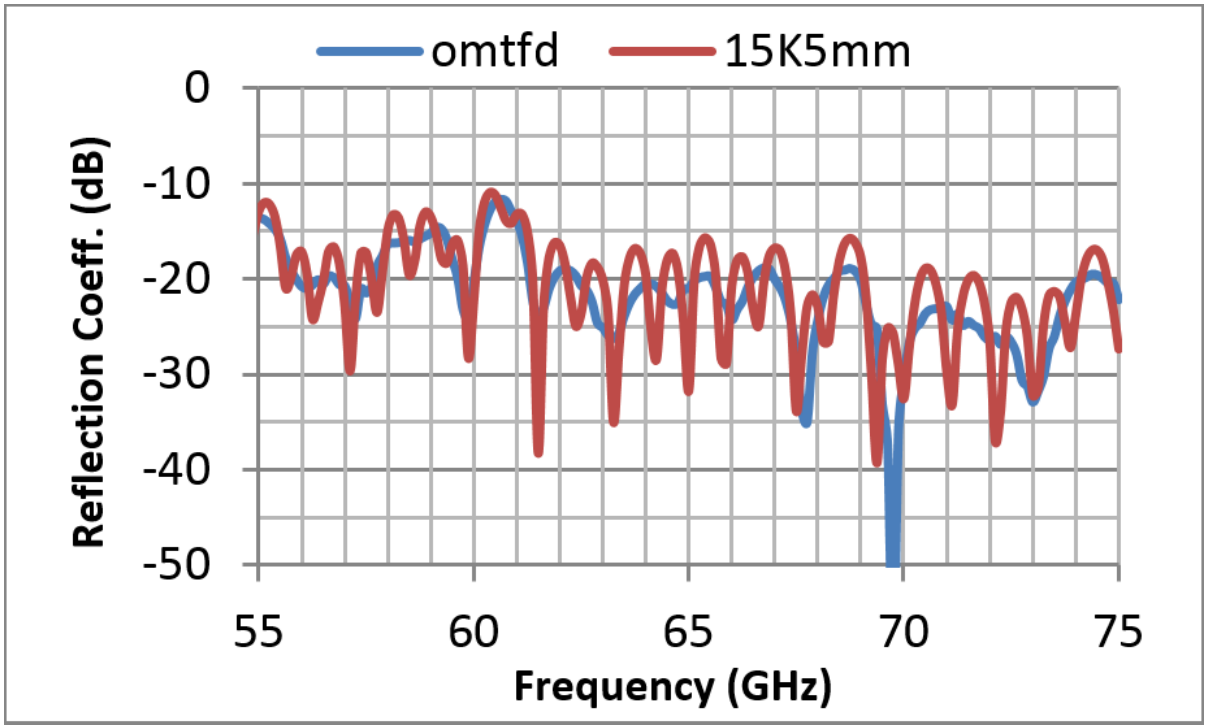
ALMA Band 2 Receiver Prototype

Noise Temperature (Polarization-0)



ALMA Band 2 Receiver Prototype

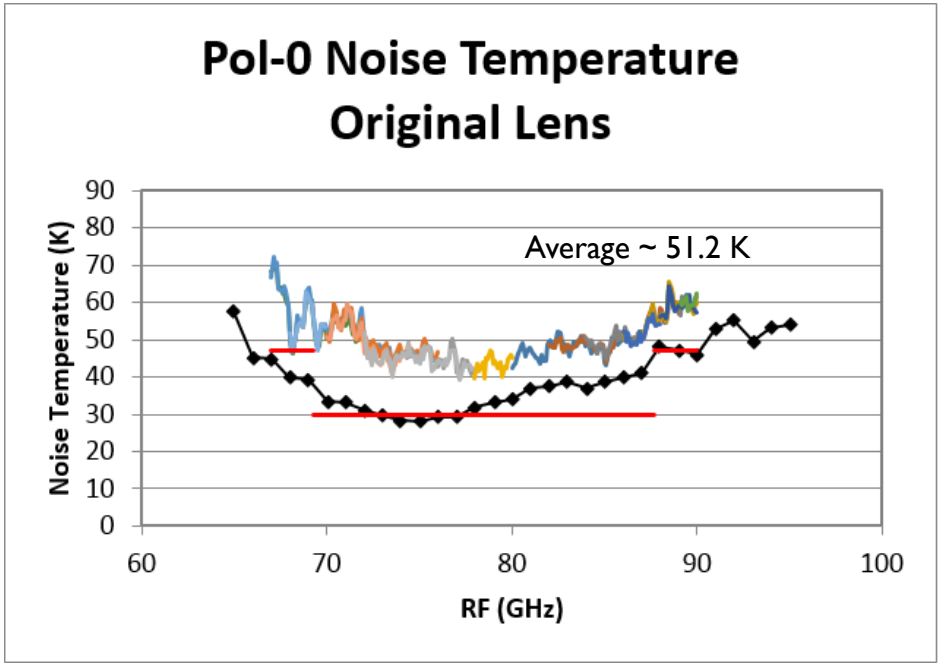
Interaction between 15 K IR filters and CLNA input

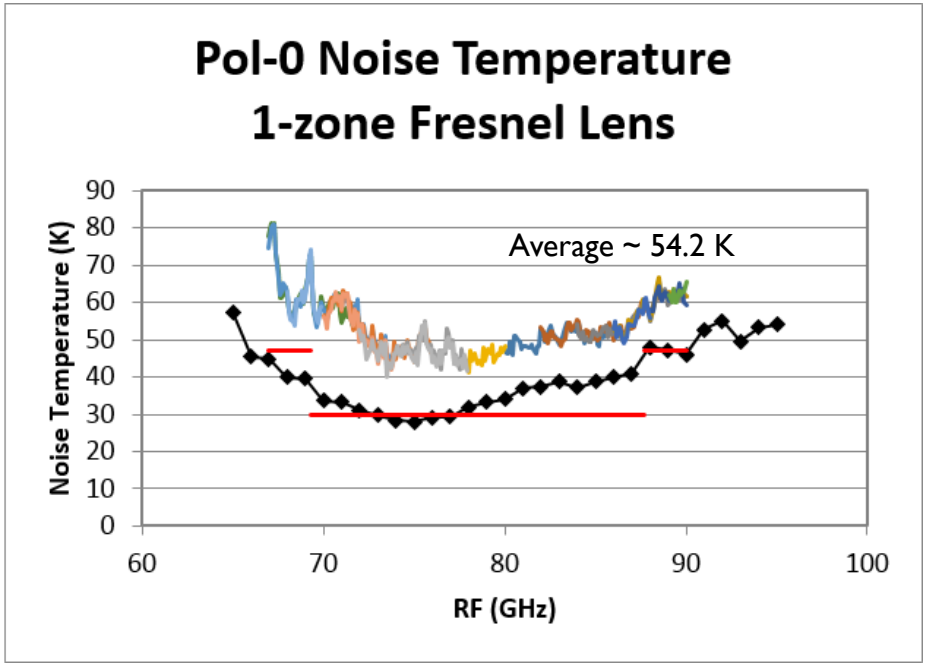


Measured reflection coefficient of the OMT plus feed horn without IR filter (trace labeled "omtfd") and that of the OMT plus feed horn with the 15 K IR filter placed 5 mm from the feed horn aperture (trace labeled "15K5mm")

ALMA Band 2 Receiver Prototype

Noise Temperature (Polarization-0)





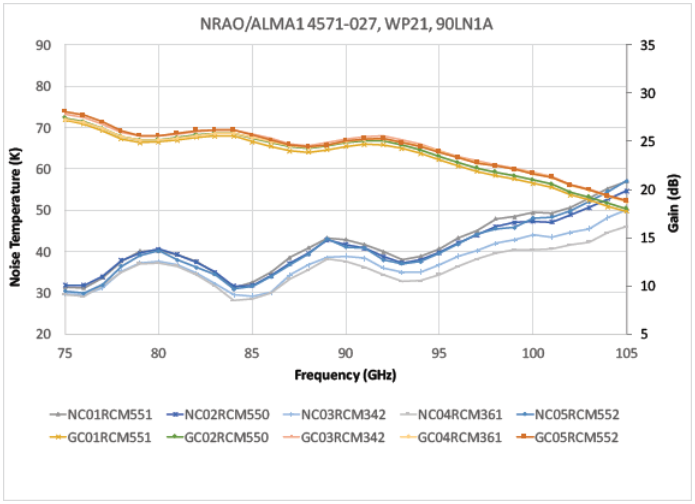
ALMA Band 2 Prototype Project

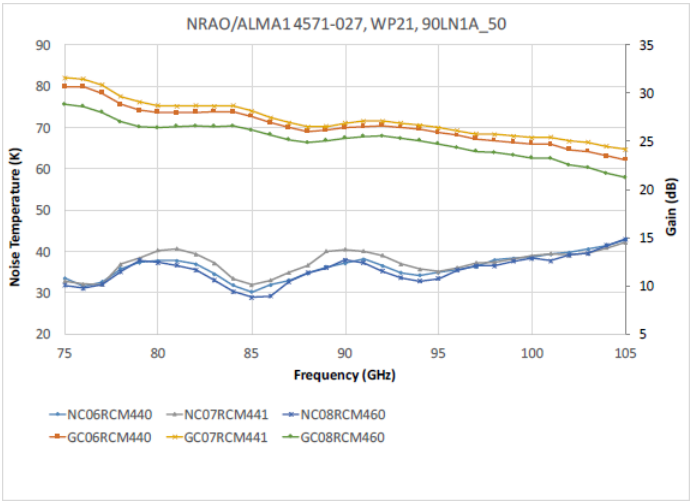
Status of the CRAL MMIC effort

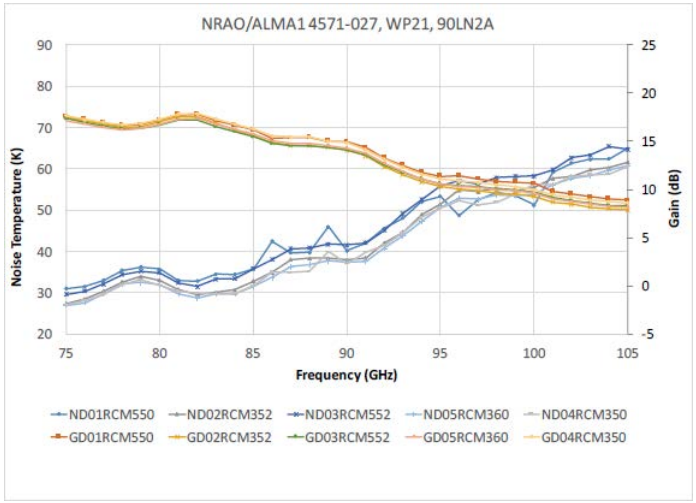
- First wafer run (NGC) with multiple Band 2 LNA MMIC design variants completed in December 2015.
- All four wafers were successful, with good yields (room temperature testing completed on all wafers).
- Cryogenic probing of two wafers at CRAL indicates that there are several promising design variants for Band 2 application.
- Next step is to package them into test blocks to qualify their performance, to identify designs that can be used for Band 2 multi-stage amplifier for integration into the prototype cartridge.
- Once the performance is confirmed, proceed to pick the corresponding chips from the NGC wafers and store for the full construction phase.

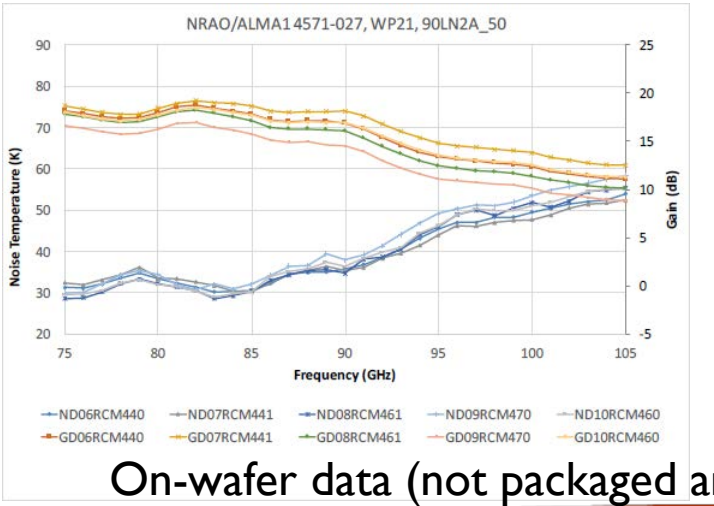
ALMA Band 2 Prototype Project

Some Cryo-probe results from NGC ISHR3 wafer









On-wafer data (not packaged amplifiers)

ALMA Band 2 Prototype Project

Some Cryo-probe results from NGC ISHR3 wafer

Performance statistics at mid-band frequency (78 GHz)

WP	Design	# Probed	Functional		Noise Temperature			Gain		
			#	%	Mean	Median	Std. Dev.	Mean	Median	Std. Dev.
22	90LN1A	10	9	90	34.3	34.8	1.3	25.8	25.9	0.6
	90LN1A_50	10	5	50	34.2	34.2	1.5	27.3	26.7	1.6
	90LN2A	10	8	80	34.0	34.9	1.9	16.5	16.5	0.7
	90LN2A_50	10	7	70	32.5	32.2	1.7	16.5	16.4	0.7
	EBLNA81BC	15	13	87	42.7	41.2	4.9	23.3	23.5	0.8
24	90LN1A	13	11	85	35.6	35.5	1.1	27.7	27.8	0.6
	90LN1A_50	15	13	87	36.1	36.6	3.2	29.7	29.6	0.9
	90LN2A	12	9	75	45.8	44.6	3.3	17.4	17.4	0.3
	90LN2A_50	15	9	60	41.5	39.7	6.2	18.2	18.3	0.7
	EBLNA81BC	15	11	73	40.2	40.2	3.1	27.4	27.4	0.6

Chip Counts

Design	Total/wafer	Functional Yield, wafer 027 (75% In)		Functional Yield, wafer 030 (100% In)	
		%	#/wafer	%	#/wafer
90LN1A	69	90	62	85	58
90LN1A_50	26	50	13	87	22
90LN2A	68	80	54	75	51
90LN2A_50	26	70	18	60	15
EBLNA81BC	345	87	300	73	251

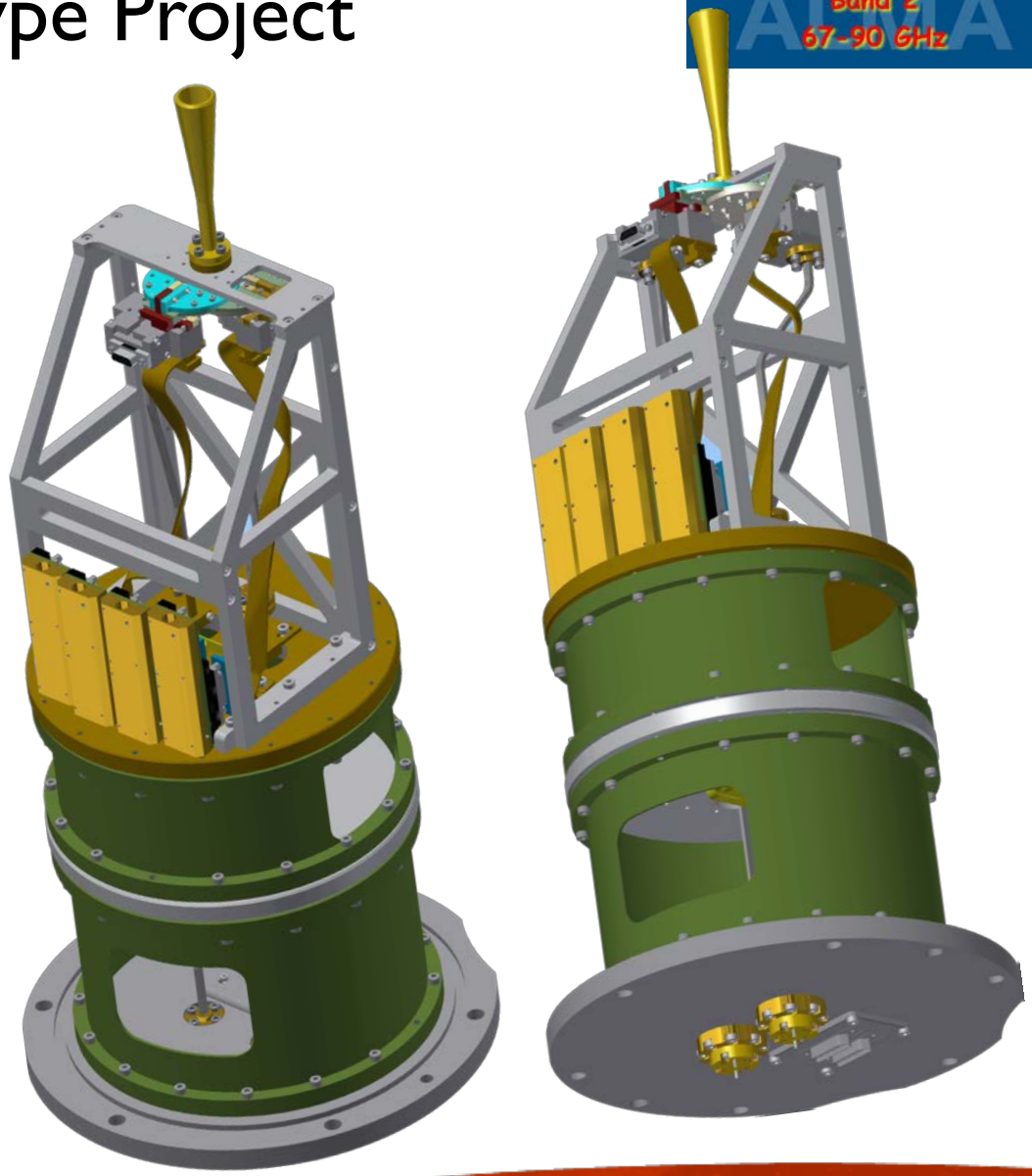
Next wafer run planned for in ~ December 2016.

On-wafer data (not packaged amplifiers)

ALMA Band 2 Prototype Project

Next Steps …

- Finish evaluation with CRAL MMIC based amplifiers and update relevant project documentation as well as test reports.
- Review Band 2 Noise Specifications.
- Preliminary Design Review.
- Propose a build-out for Band 2 under the upcoming NA Development Project Call in October 2016.



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