



Band 2+
67 – 95 GHz ?

Central Development Laboratory



NA Development Cycle 2

ALMA Band 2 Prototype Project

NRAO Science & Technical (SciTech) Discussion Group

K. Saini / 16 June 2017

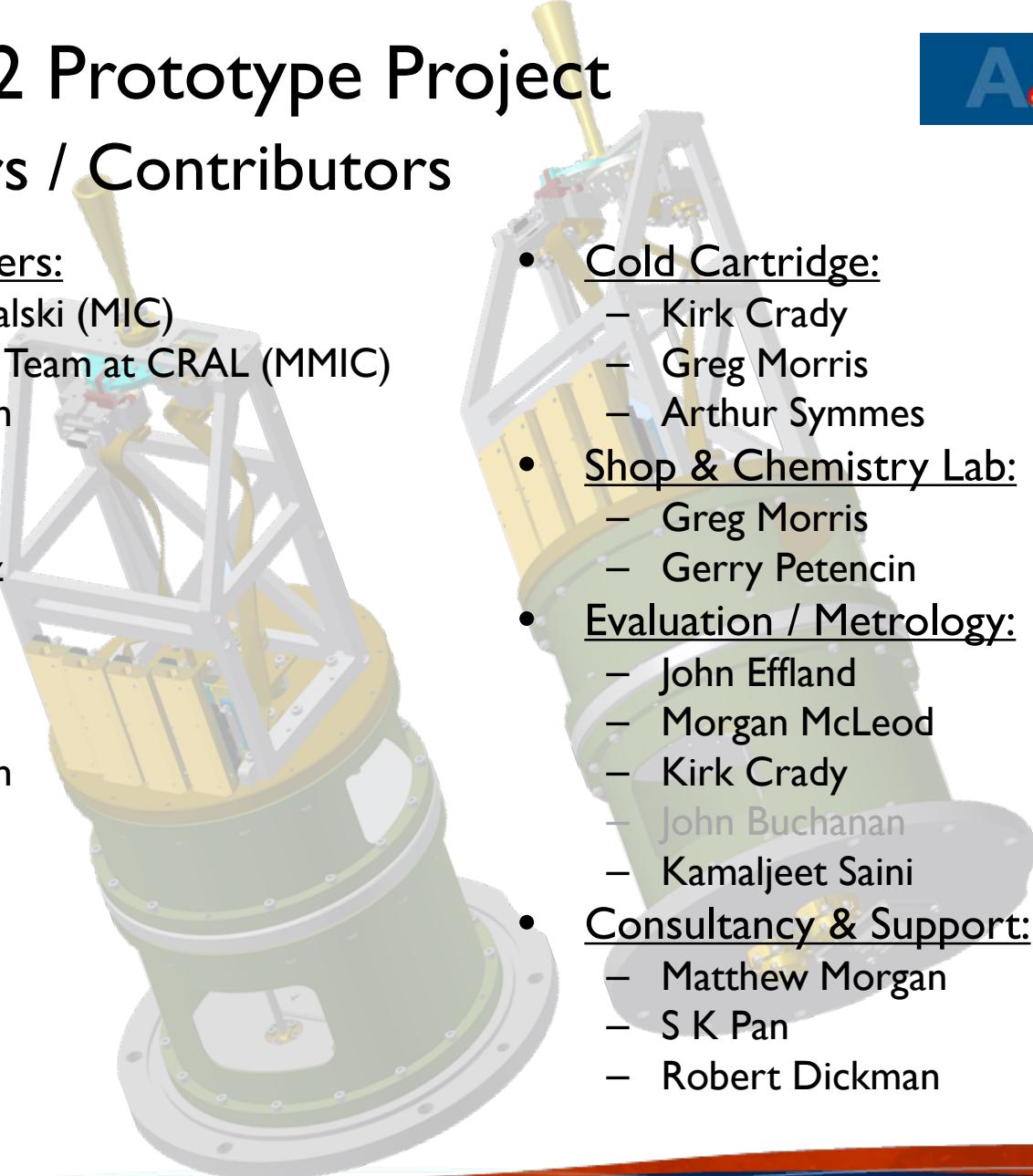


ALMA Band 2 Prototype Project

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Band 2
67-90 GHz

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



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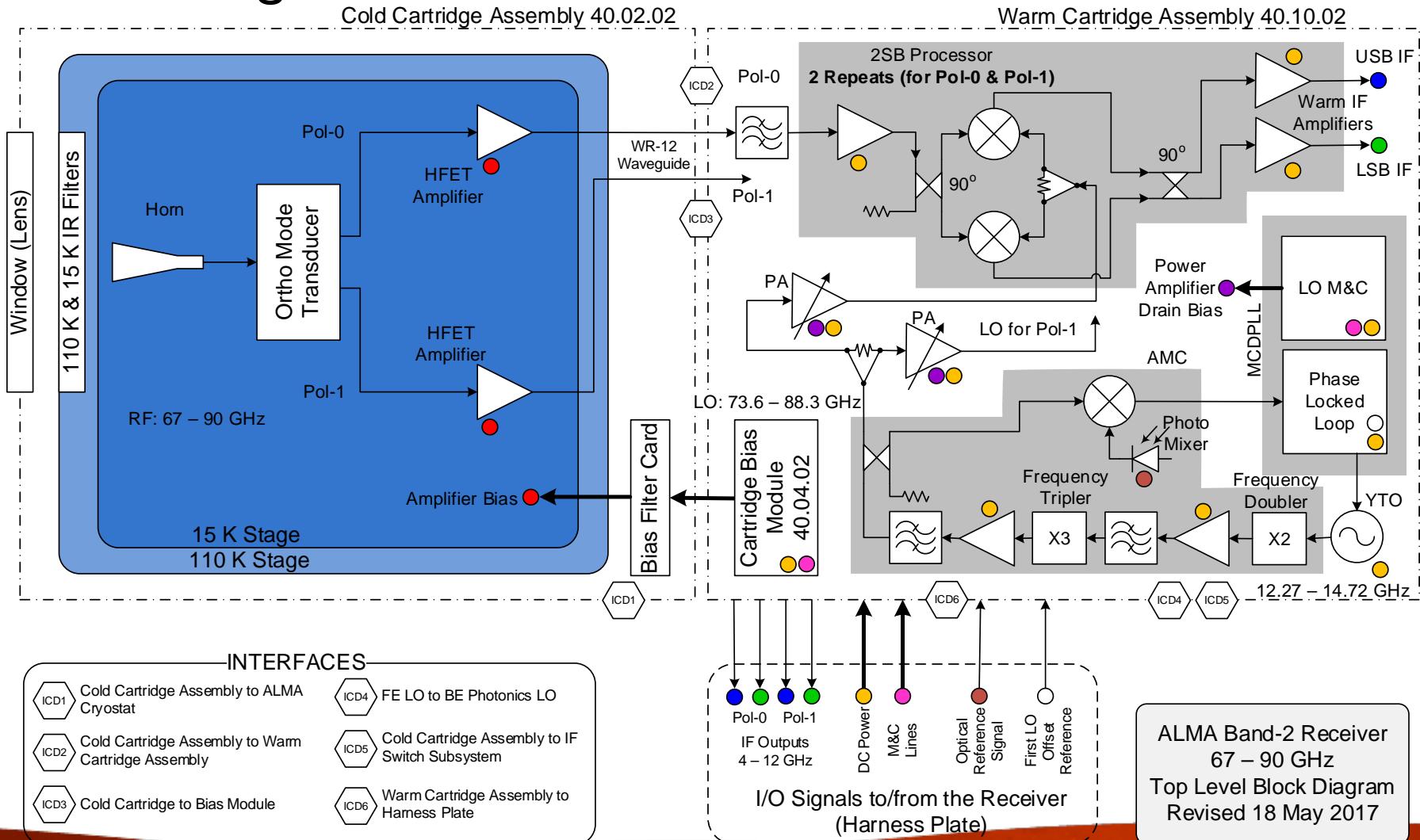
Project Summary

- 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 was upgraded with MMIC LNAs when they became available & has been remeasured.
- Will present test data from prototype evaluation.
- Preliminary Design Review was held on 30-31st of May, 2017.

ALMA Band 2 Receiver Prototype

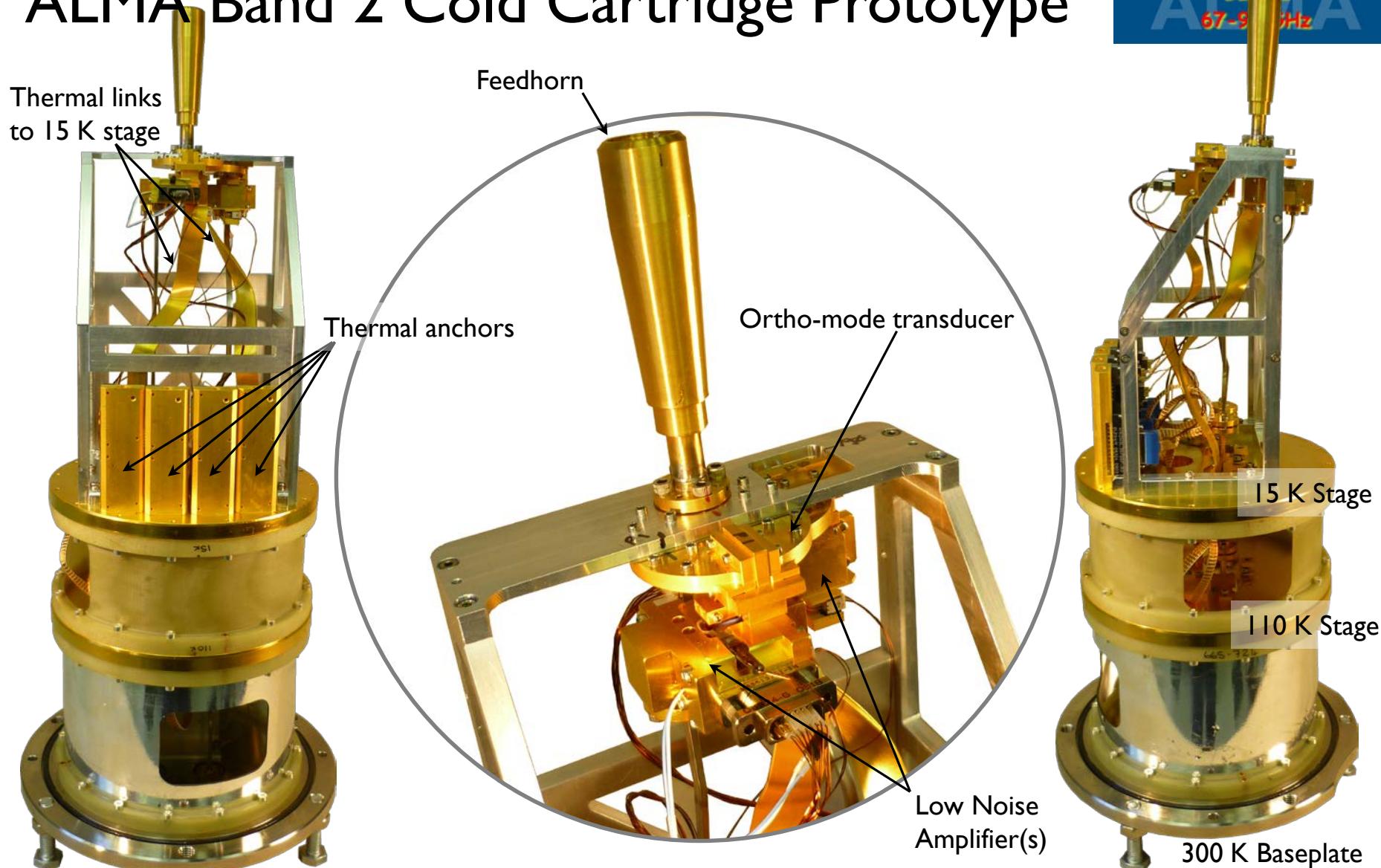
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Block Diagram



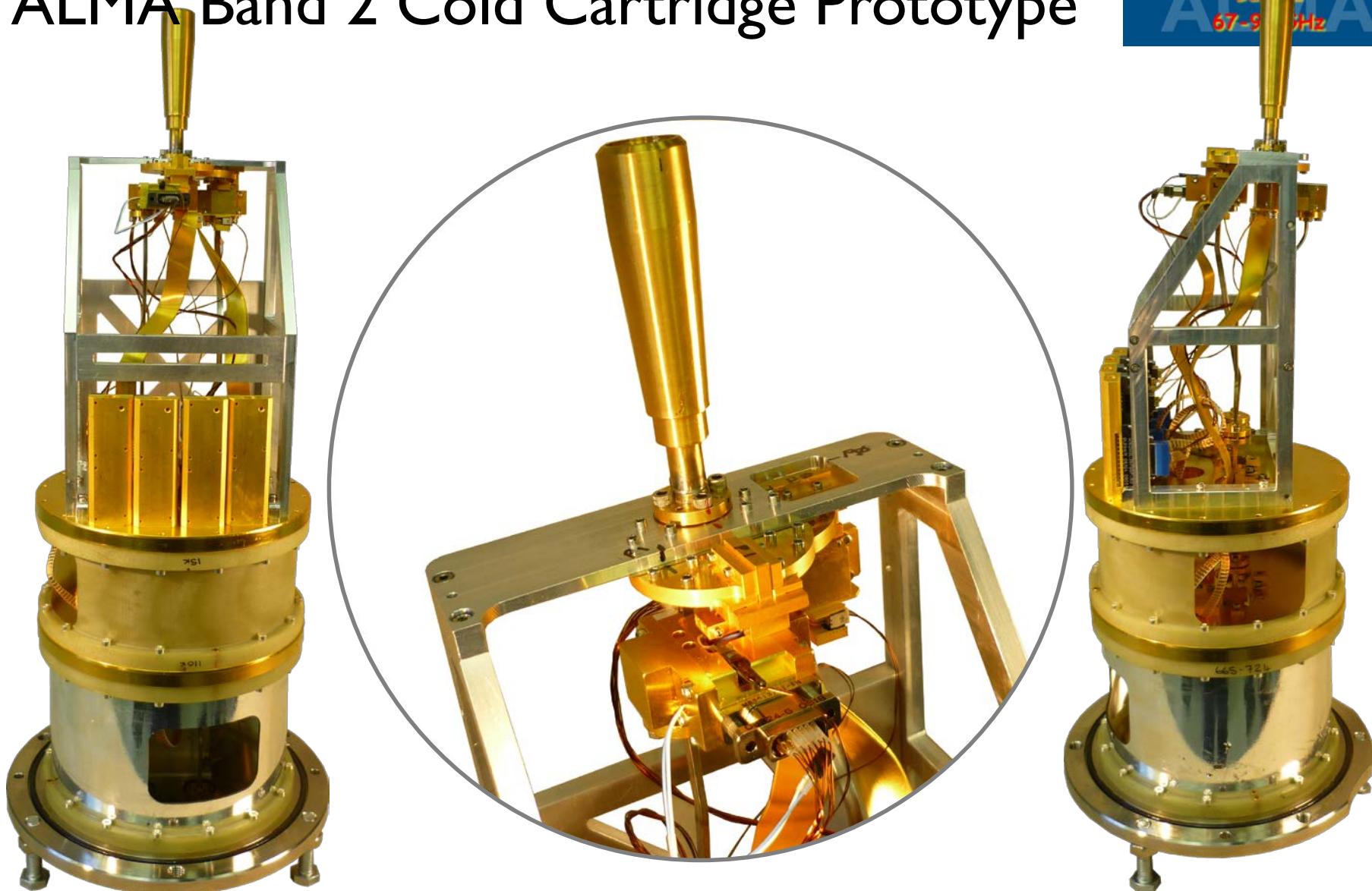
ALMA Band 2 Cold Cartridge Prototype

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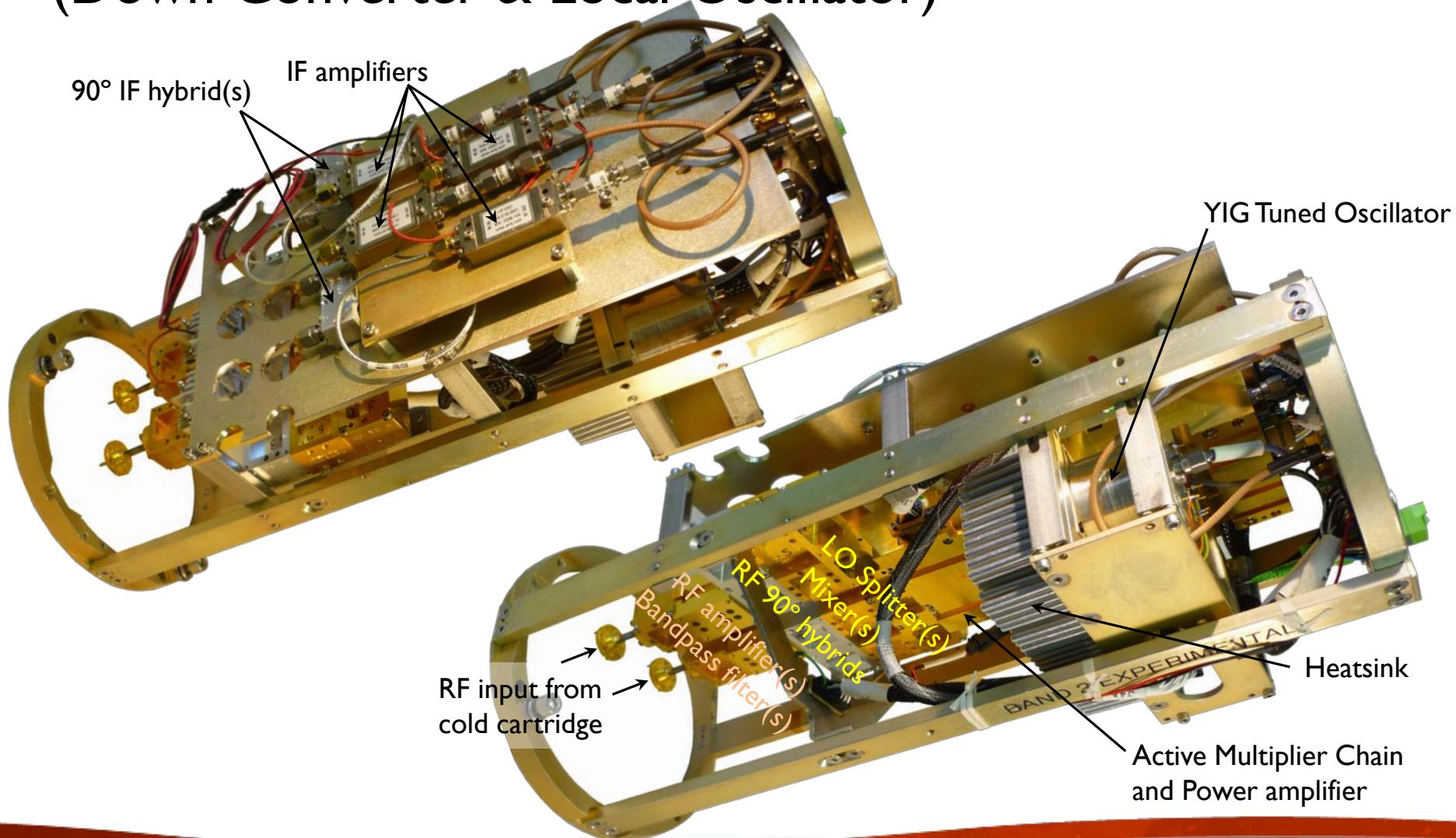
ALMA Band 2 Cold Cartridge Prototype

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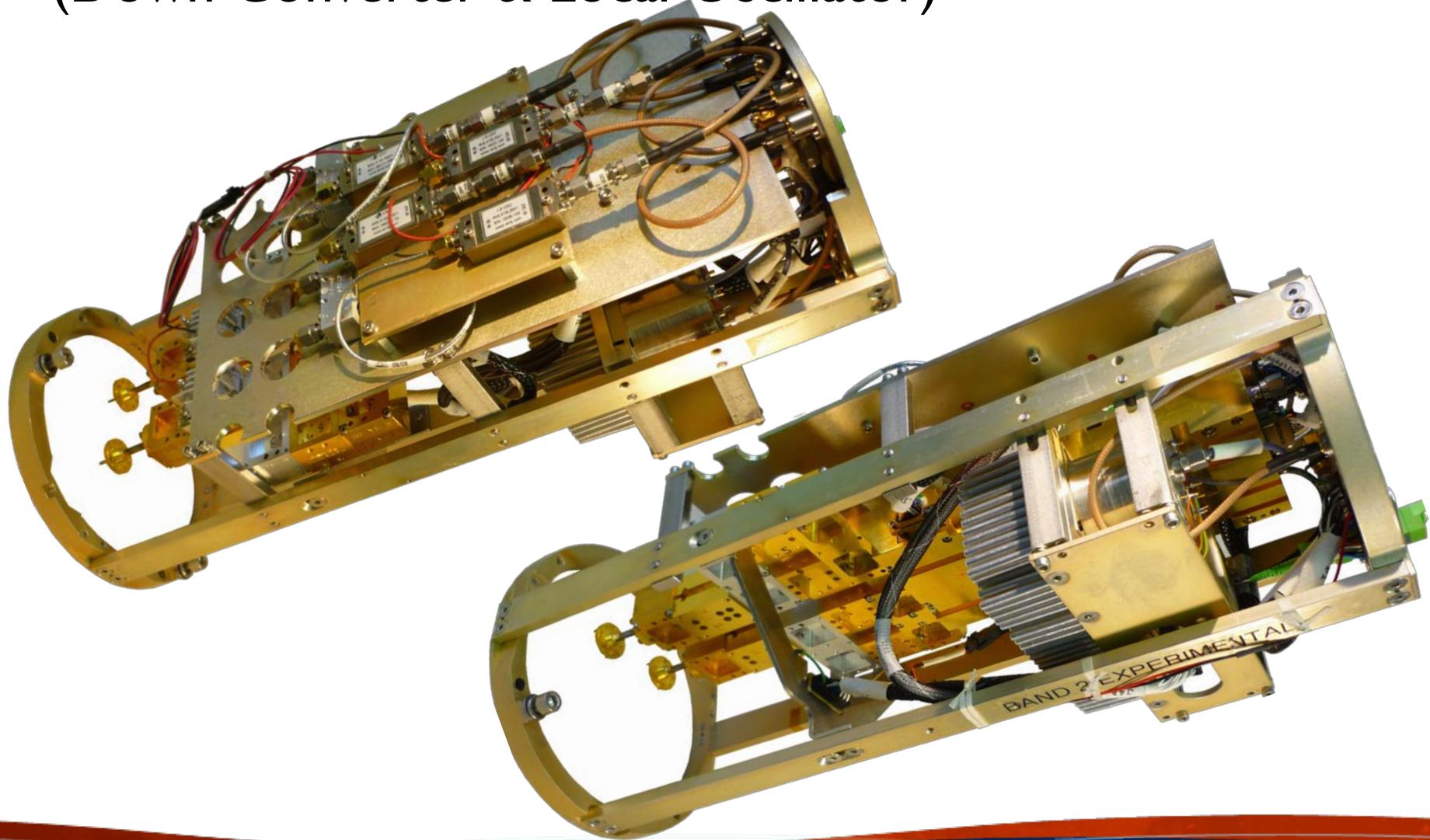
ALMA Band 2 Warm Cartridge Prototype (Down Converter & Local Oscillator)

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ALMA Band 2 Warm Cartridge Prototype (Down Converter & Local Oscillator)

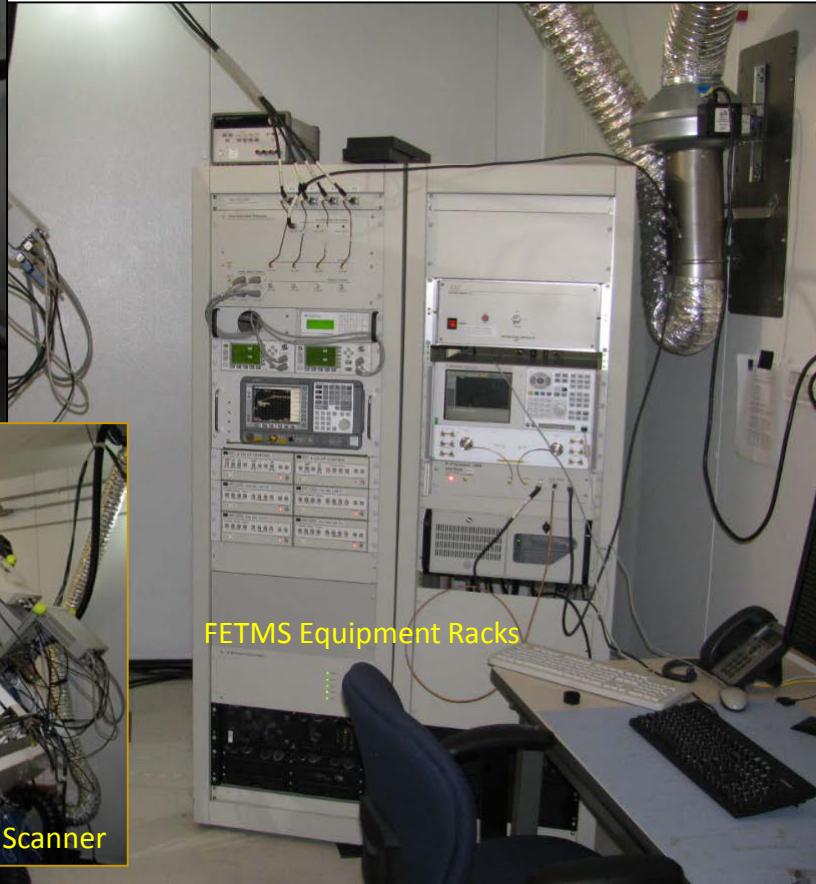
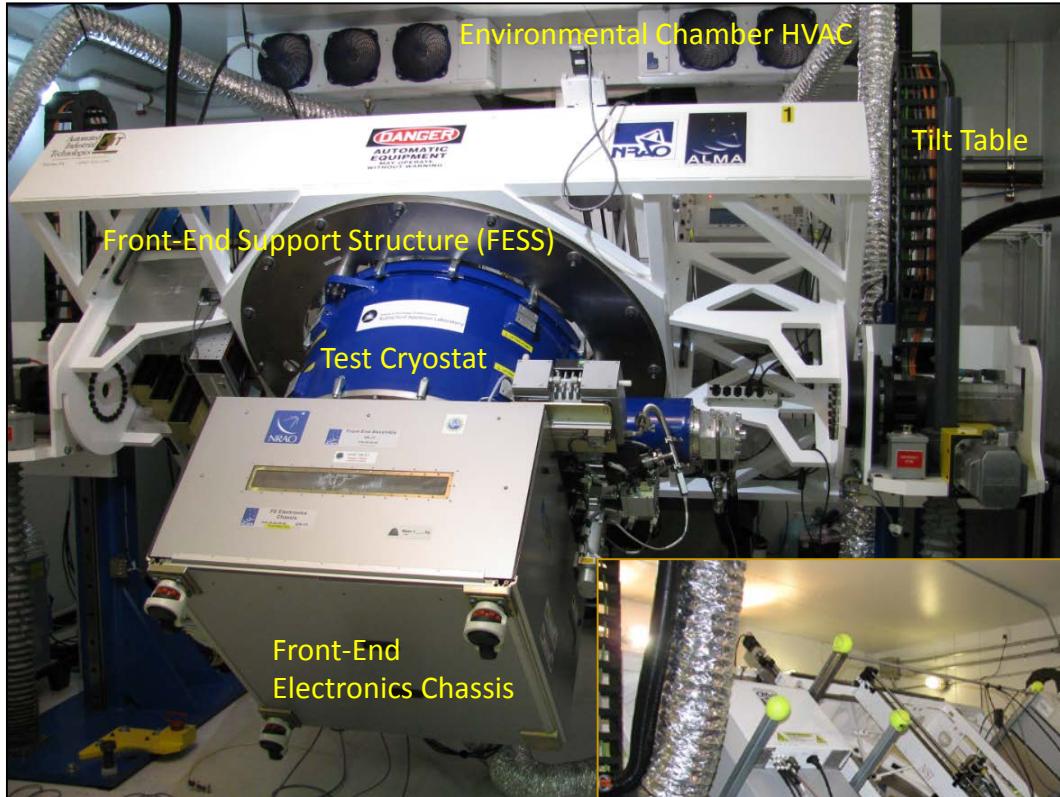
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ALMA Band 2 Receiver Prototype

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Evaluation in the ALMA Cryostat



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

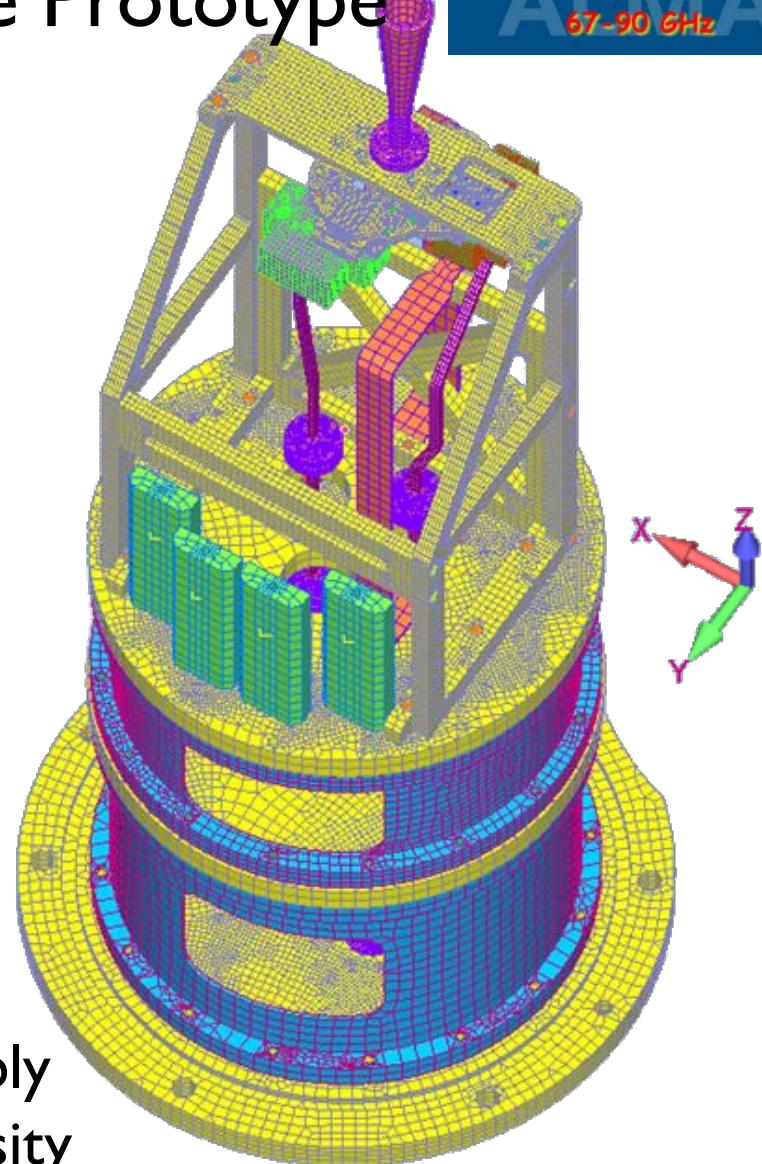
- Requirements met comfortably for 15 K stage, CLNAs dissipate 15-30 mW each (article to article variation, depends on optimization).
- No active component on the 110 K stage.

ALMA Band 2 Cold Cartridge Prototype

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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.



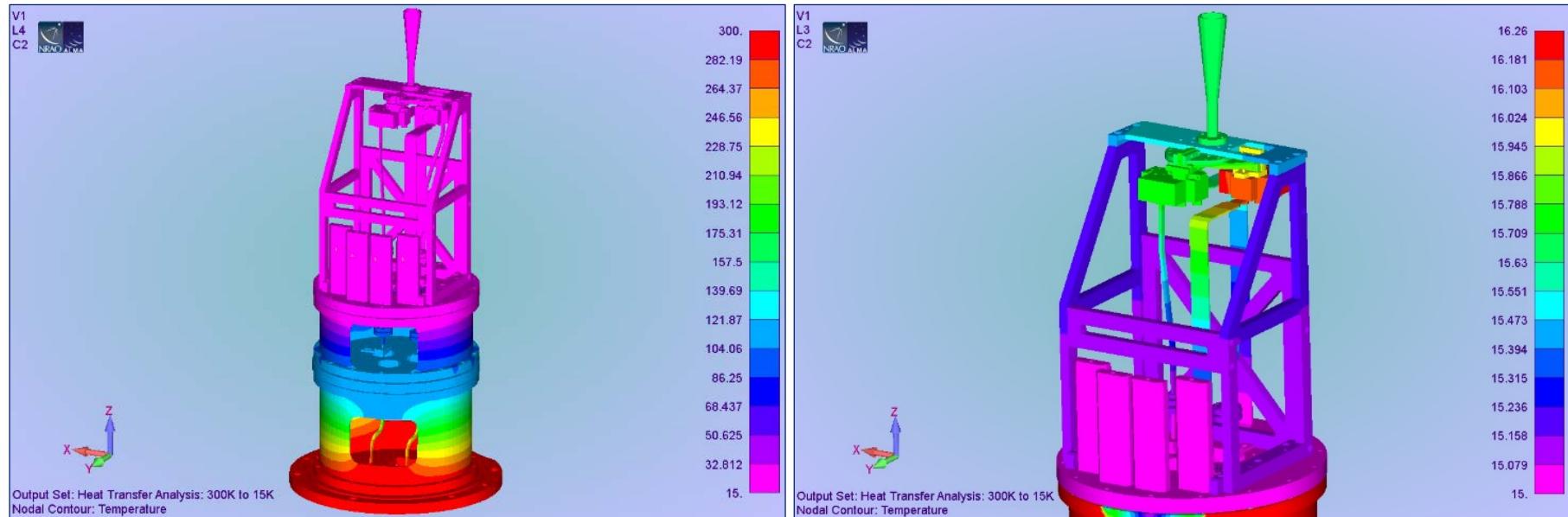
Band 2 Cold Cartridge Assembly
FEA Model showing mesh density

ALMA Band 2 Cold Cartridge Prototype

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Mechanical / Thermal Analysis

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



ALMA Band 2 Cold Cartridge Prototype

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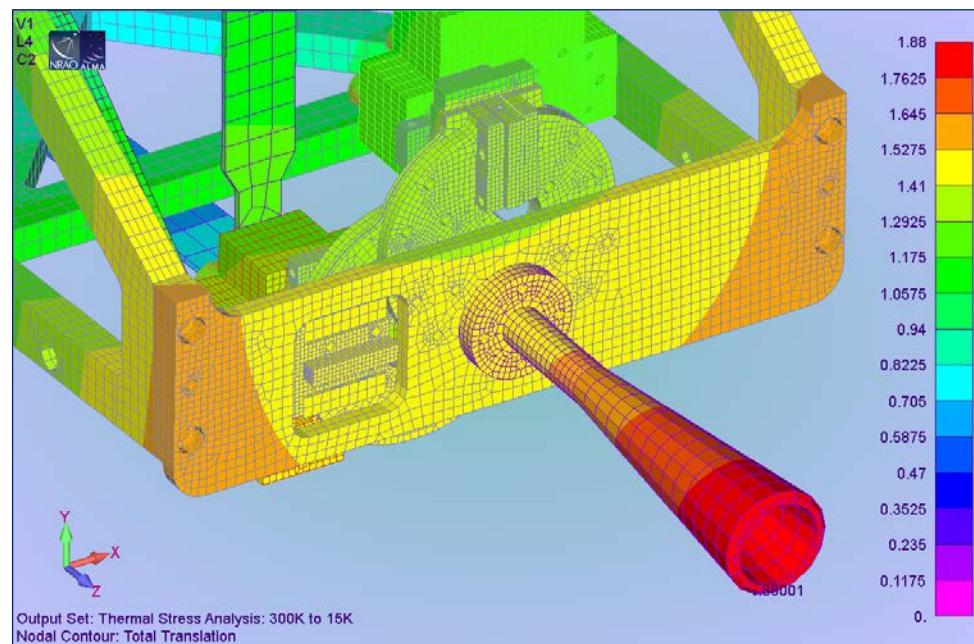
Mechanical / Thermal Analysis

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.

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

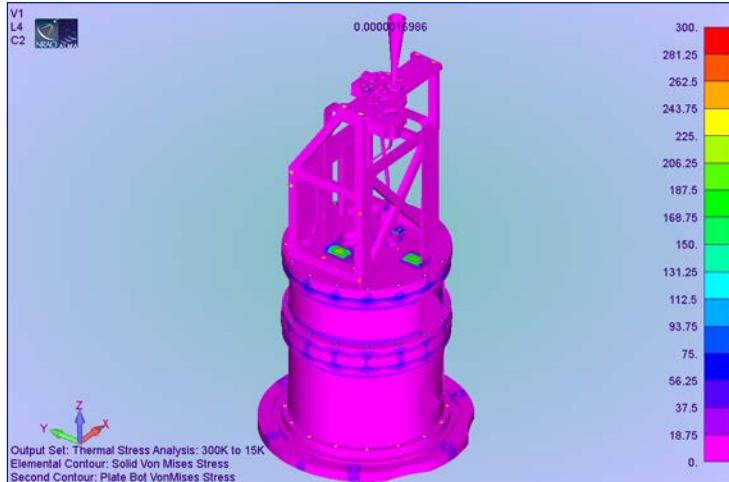
Resultant displacement (total due to x-, y- , and z- direction displacements) at and near the feed horn due to cooling.



ALMA Band 2 Cold Cartridge Prototype

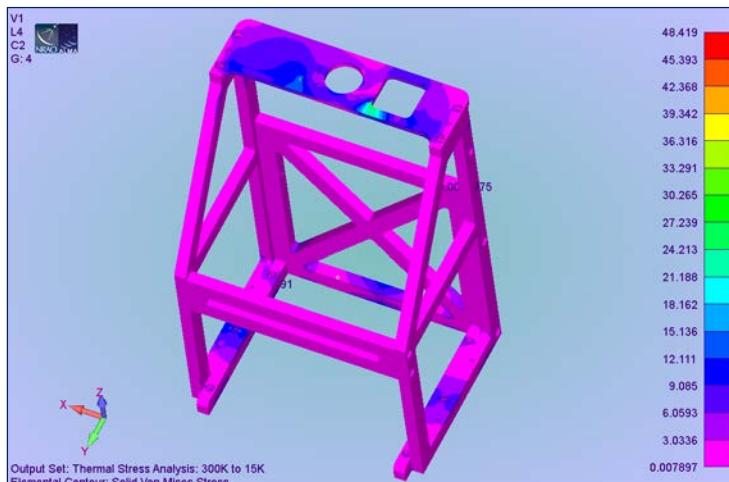


Mechanical / Thermal Analysis



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.

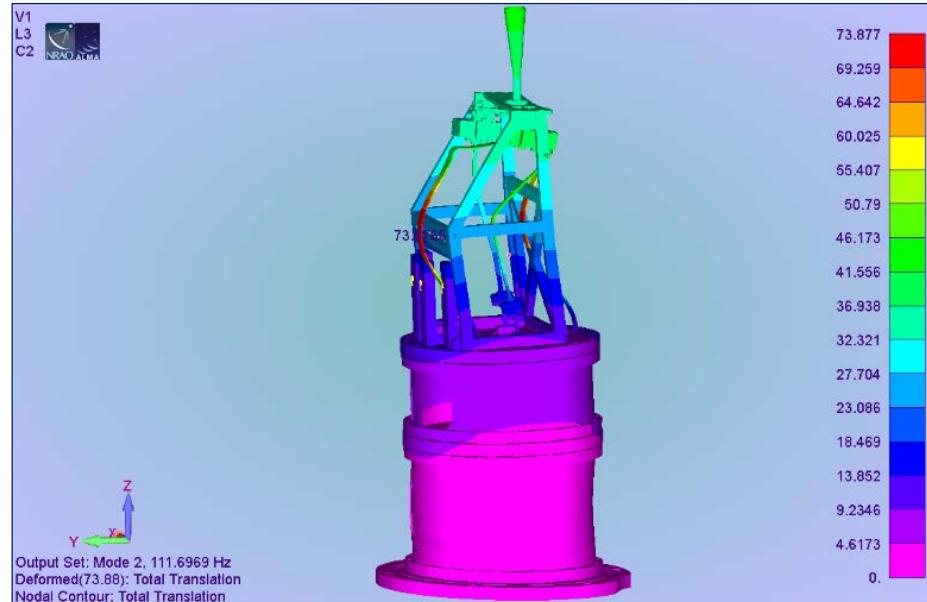
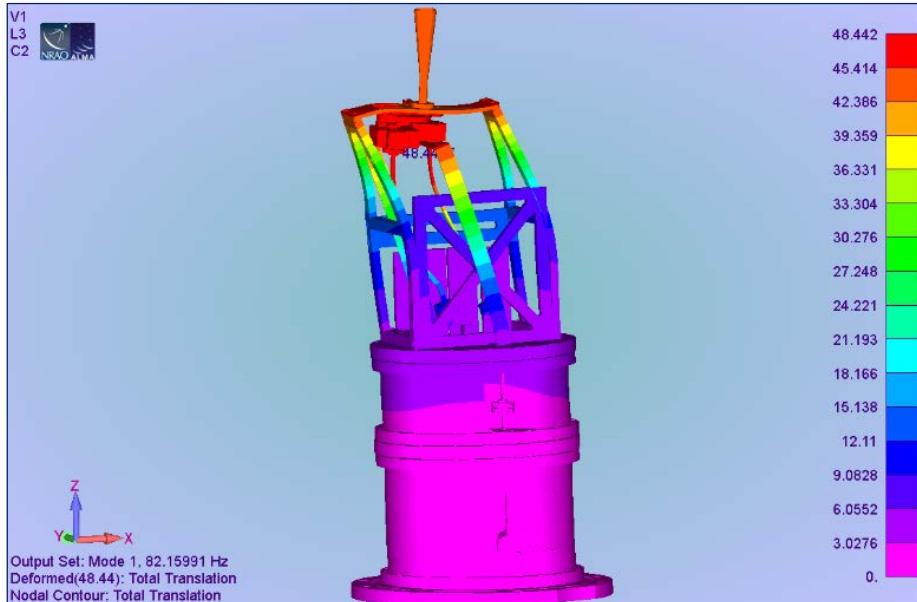


Gravity loading stresses are significantly lower than the equivalent thermal stresses; as a result we should expect that the Band 2 cold cartridge assembly should adequately handle shipping loads.

ALMA Band 2 Cold Cartridge Prototype

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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



Mechanical / Vibrational Analysis

- Problem?
- Cartridges use stainless steel (SUS304) for the 300 K base plate and OFC (confirming to BS2870-C103/C110) for the 15 K plate. These are heavier than the aluminum material specified in the original project released cartridge drawings.
- RAL confirmed that the cartridge body drawings are incorrect.
- Impacts:
 - Vibration Mode (recalculated with 15K stage material modified): 1st Mode – 96.2 Hz, 2nd Mode – 106.2, ... First ten modes calculated. 1st mode is compliant with respect to the > 70 Hz requirement.
 - Mass: Compliance was determined by weighing, so this is not impacted.
 - Thermal distributions and deflections – some impact expected – will update models and repeat analysis once RAL confirms thermal conductivity and modulus of elasticity values.

BAND 2 COLD CARTRIDGE MODAL FREQUENCIES			
	ORIGINAL CONFIGURATION	REVISED 110K & 15K PLATE MATERIAL PROPERTIES	CHANGE
Mode 1	99.0	96.2	-2.80%
Mode 2	111.2	106.2	-4.52%
Mode 3	139.2	139.2	-0.04%
Mode 4	143.0	142.2	-0.53%
Mode 5	175.6	166.5	-5.19%
Mode 6	198.5	176.3	-11.17%
Mode 7	223.2	216.5	-3.00%
Mode 8	269.7	239.1	-11.36%
Mode 9	295.0	290.6	-1.50%
Mode 10	323.9	321.8	-0.66%

ALMA Band 2 Cold Cartridge Prototype



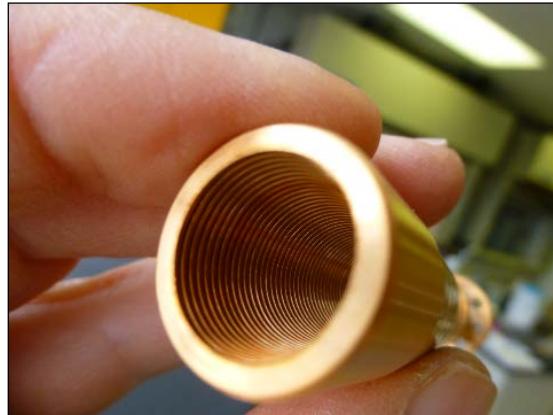
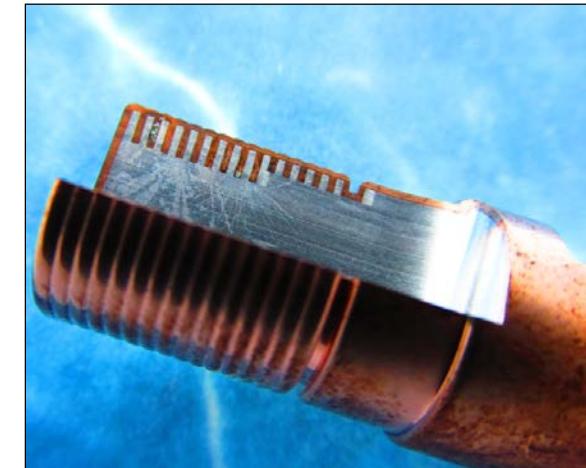
Optics Design

- 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). However, investigation continues on this front and might lead to (slightly) reduced receiver noise temperature.

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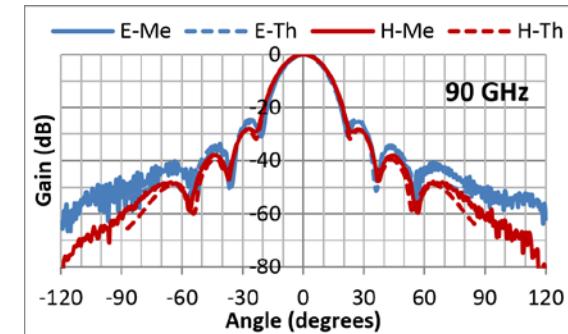
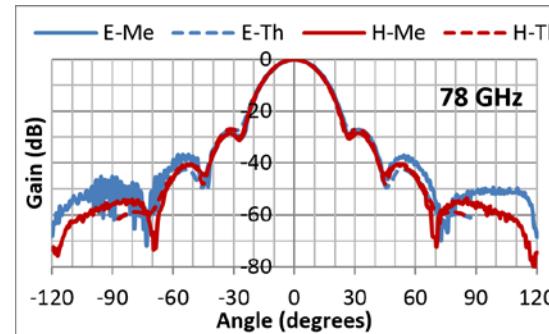
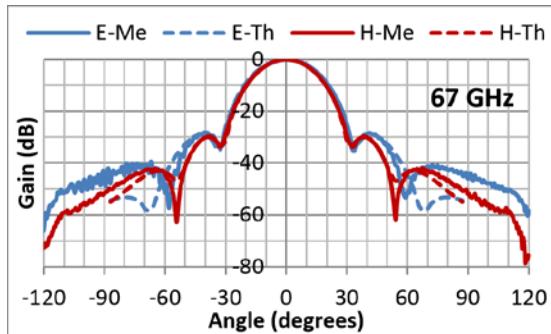
Feed Horn



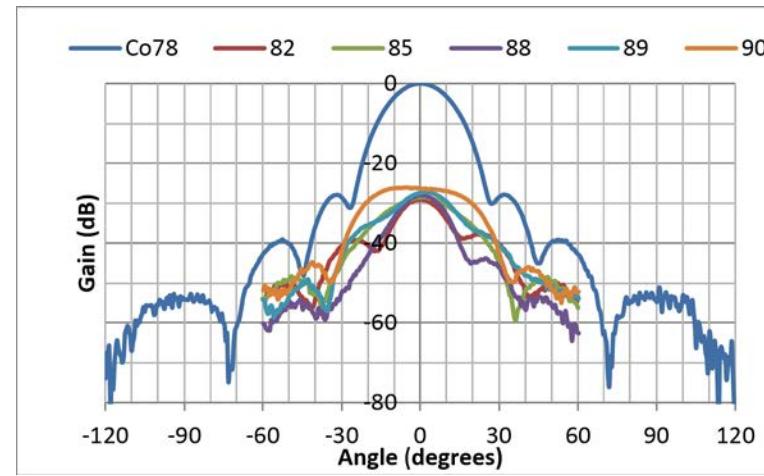
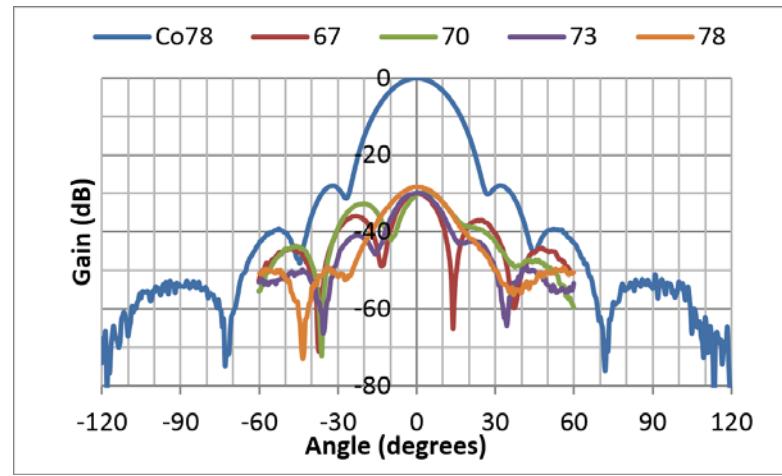
ALMA Band 2 Cold Cartridge Prototype



Feed Horn



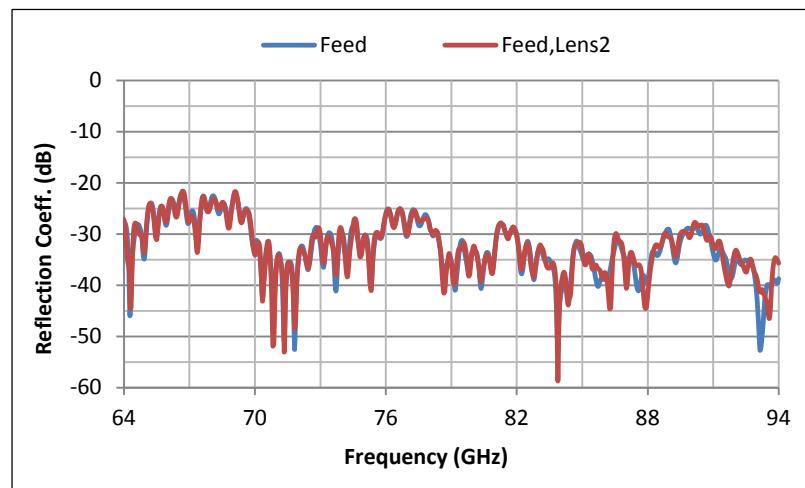
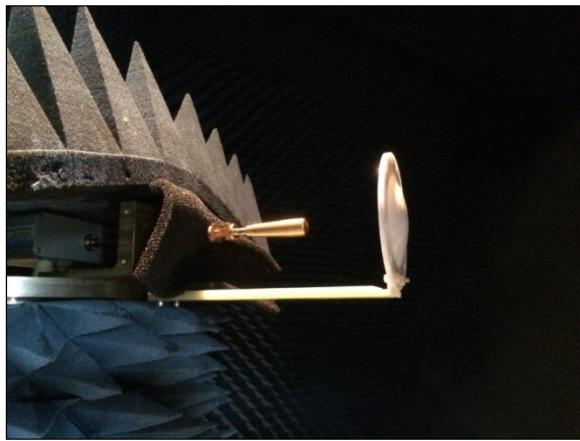
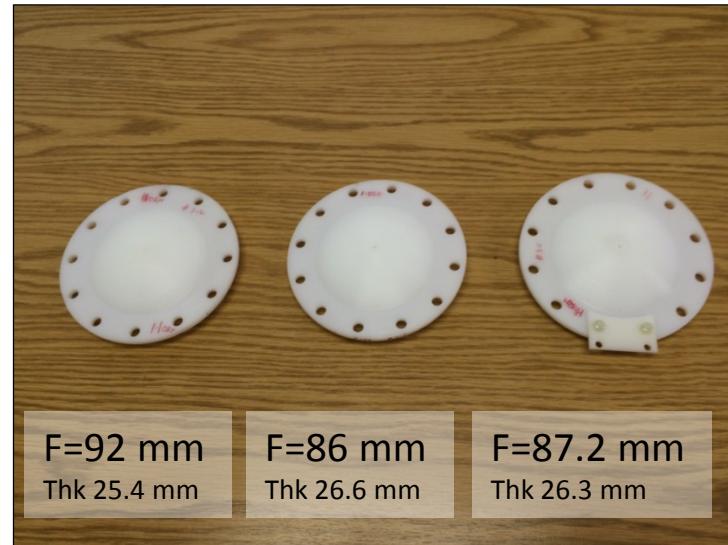
Frequency (GHz)	Taper in dB at 20° (Calculated)		Beam waist (Calculated) (mm)	Phase center (Calculated) (mm)
	E-plane	H-plane		
67	-9.07	-10.52	4.73	2.7
78	-14.40	-15.72	4.71	3.8
90	-23.44	-22.18	4.67	5.0



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Horn & Lens

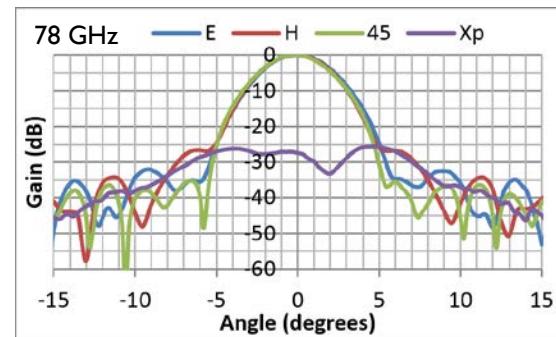
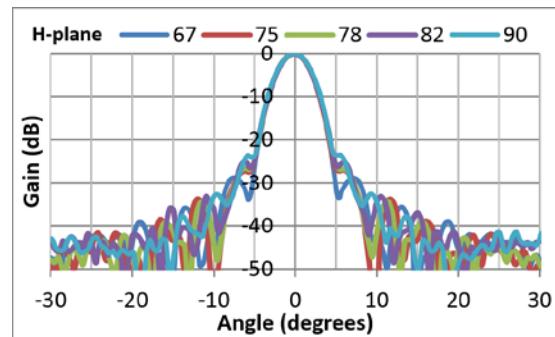
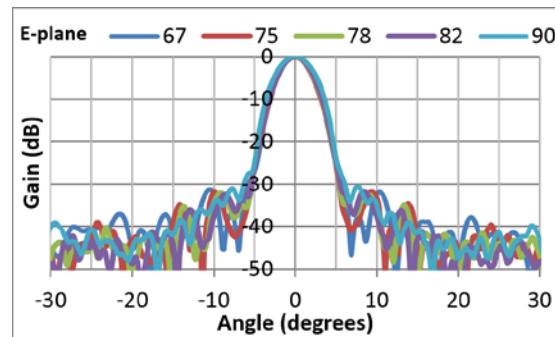


ALMA Band 2 Cold Cartridge Prototype

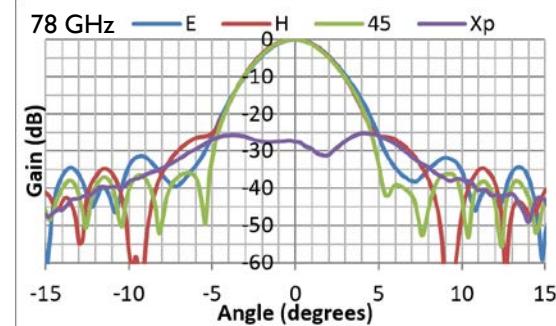
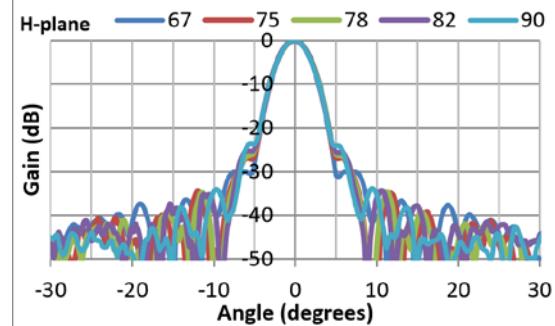
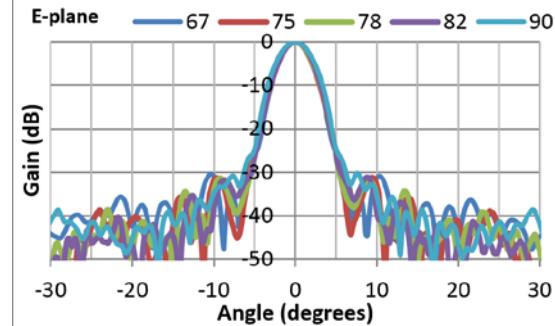


Horn & Lens

Lens #2



Lens #3

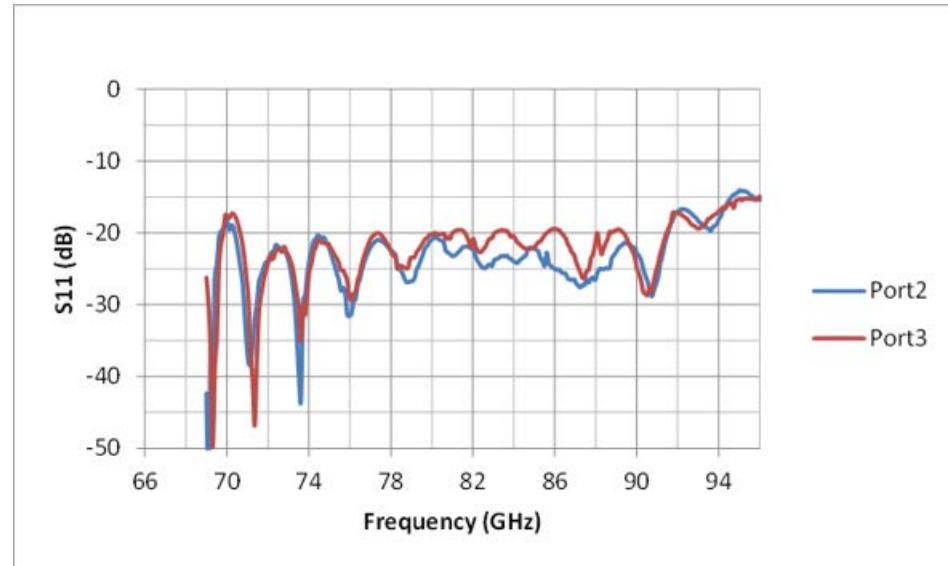
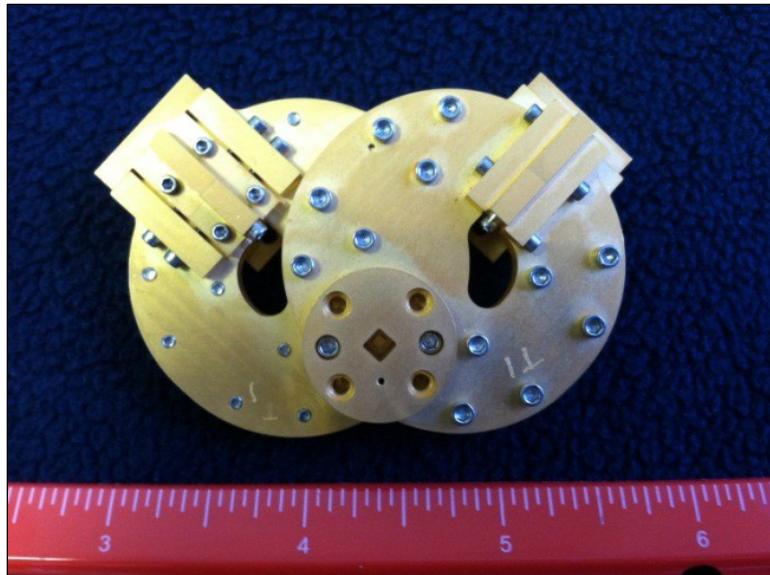


Lens #	Illumination taper at 3.6° (dB)		
	67 GHz	78 GHz	90 GHz
2	-13.44	-12.80	-11.33
3	-14.37	-14.03	-12.60
4 (Fresnel, 1-zone)	-10.88	-11.56	-11.36

ALMA Band 2 Cold Cartridge Prototype

Orthomode Transducer

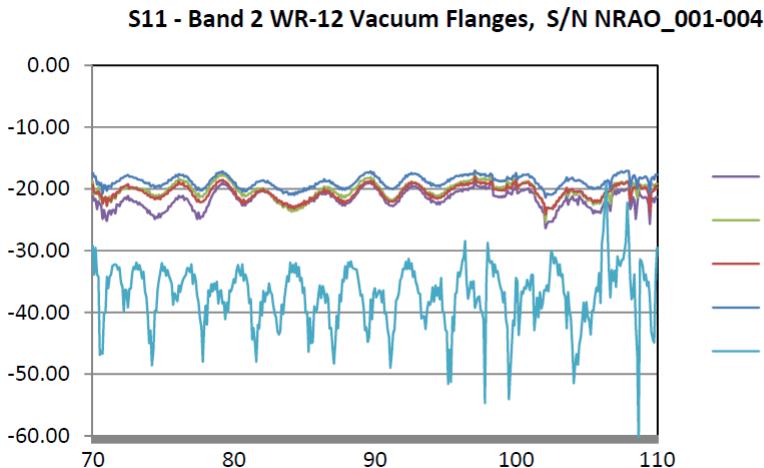
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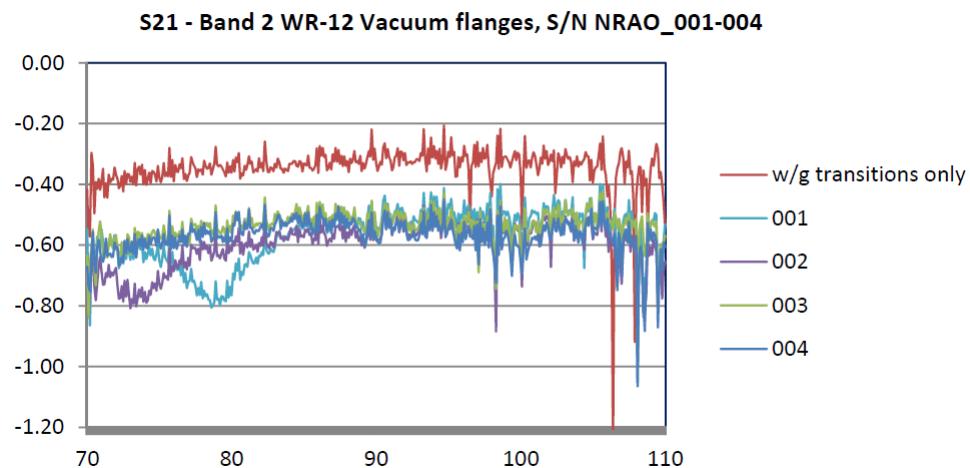
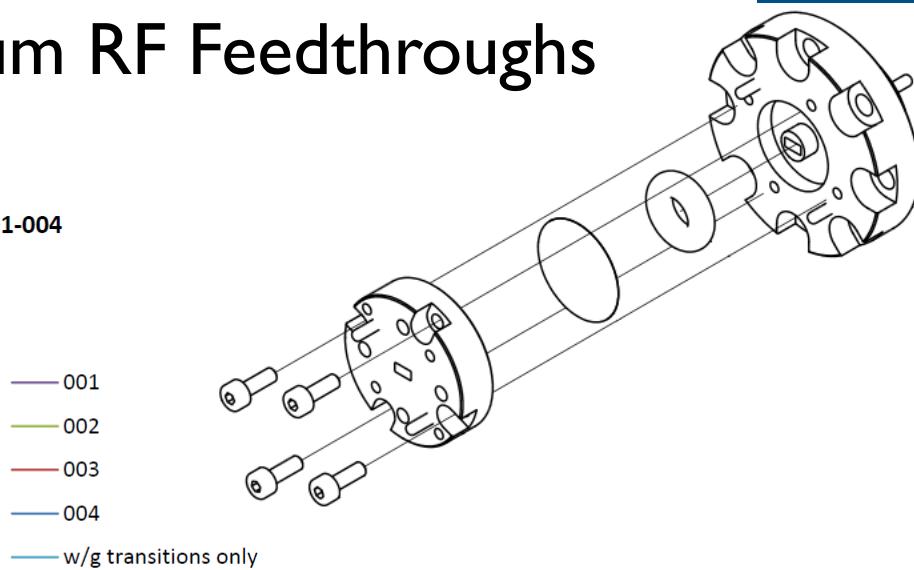
ALMA Band 2 Cold Cartridge Prototype

WR-12 (E-Band) Vacuum RF Feedthroughs

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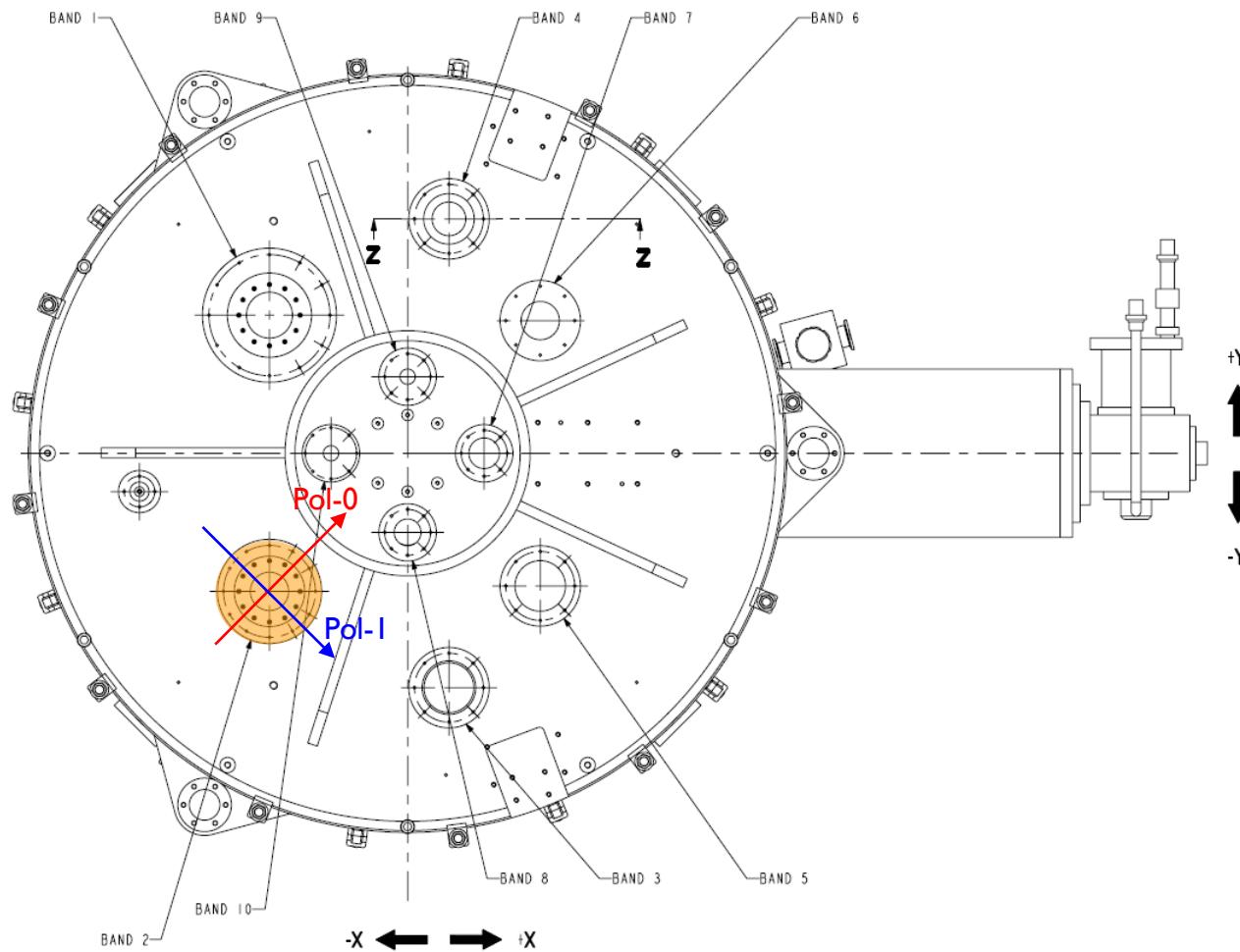
This design is adopted from the NAOJ Band 8 LO waveguide feedthrough design. The vacuum barrier is a 18 μm thick mica disk. One such assembly is used for each of the two polarization channels.



ALMA Band 2 Cold Cartridge Prototype

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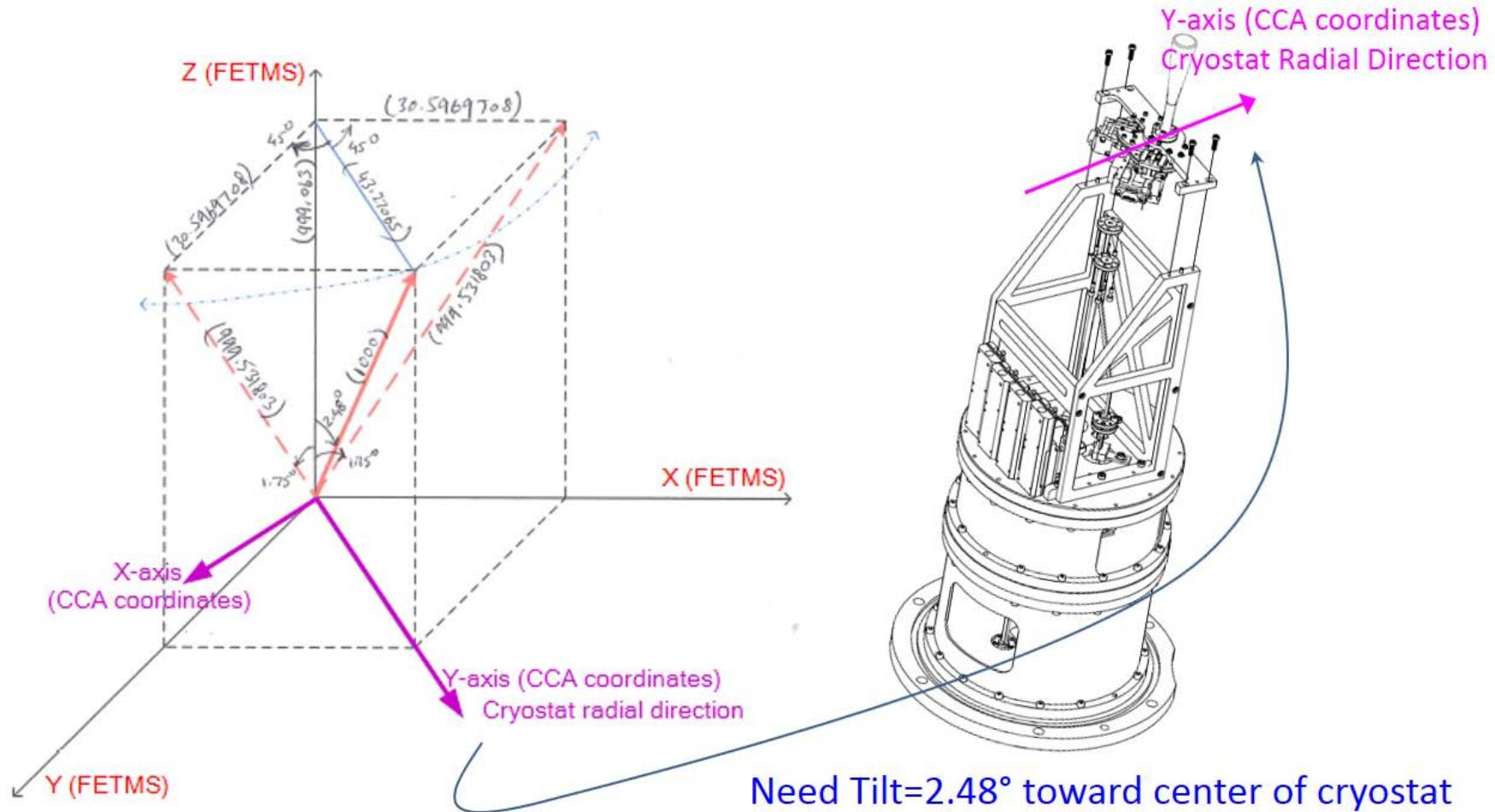
Location of the Band 2 window on the ALMA cryostat



ALMA Band 2 Cold Cartridge Prototype

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Feed-Horn Alignment



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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	RAL	total static angular error in cartridge body								
	15K plate angular (parallelism)				0.400	mrad	RAL	RAL: "Tolerance Budget.doc"								
	15K plate angular (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 °								
<table border="1"> <tr> <td>█</td> <td>= Unknown contribution</td> </tr> <tr> <td>█</td> <td>= Guess - to be confirmed</td> </tr> <tr> <td>█</td> <td>= To be confirmed</td> </tr> <tr> <td>█</td> <td>= preliminary value, could be wrong</td> </tr> </table>									█	= Unknown contribution	█	= Guess - to be confirmed	█	= To be confirmed	█	= preliminary value, could be wrong
█	= Unknown contribution															
█	= Guess - to be confirmed															
█	= To be confirmed															
█	= preliminary value, could be wrong															

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Feed Horn Alignment

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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						

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

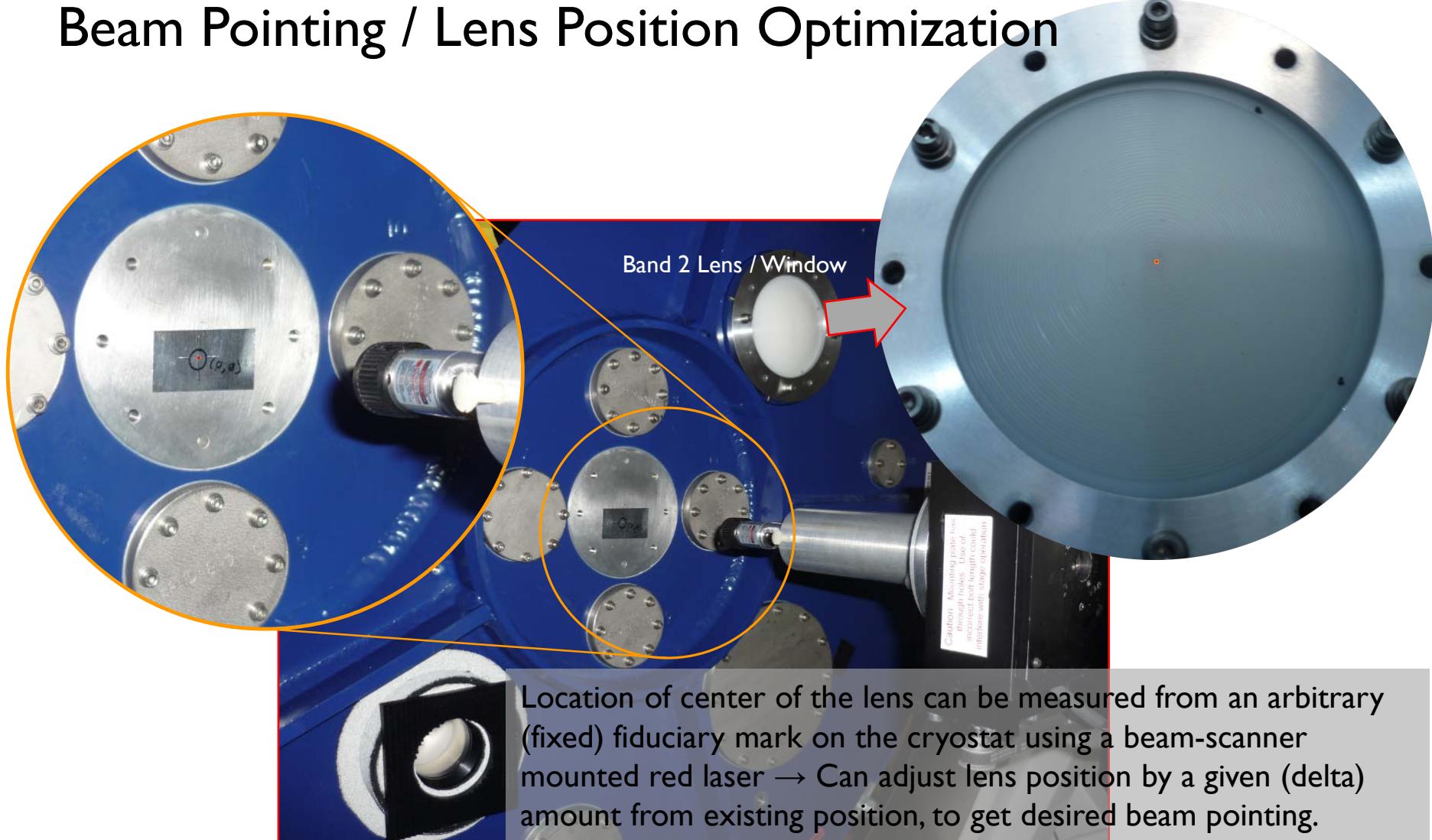


Measured residuals (both offsets and pointing) can be corrected by lens position optimization ...

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Beam Pointing / Lens Position Optimization

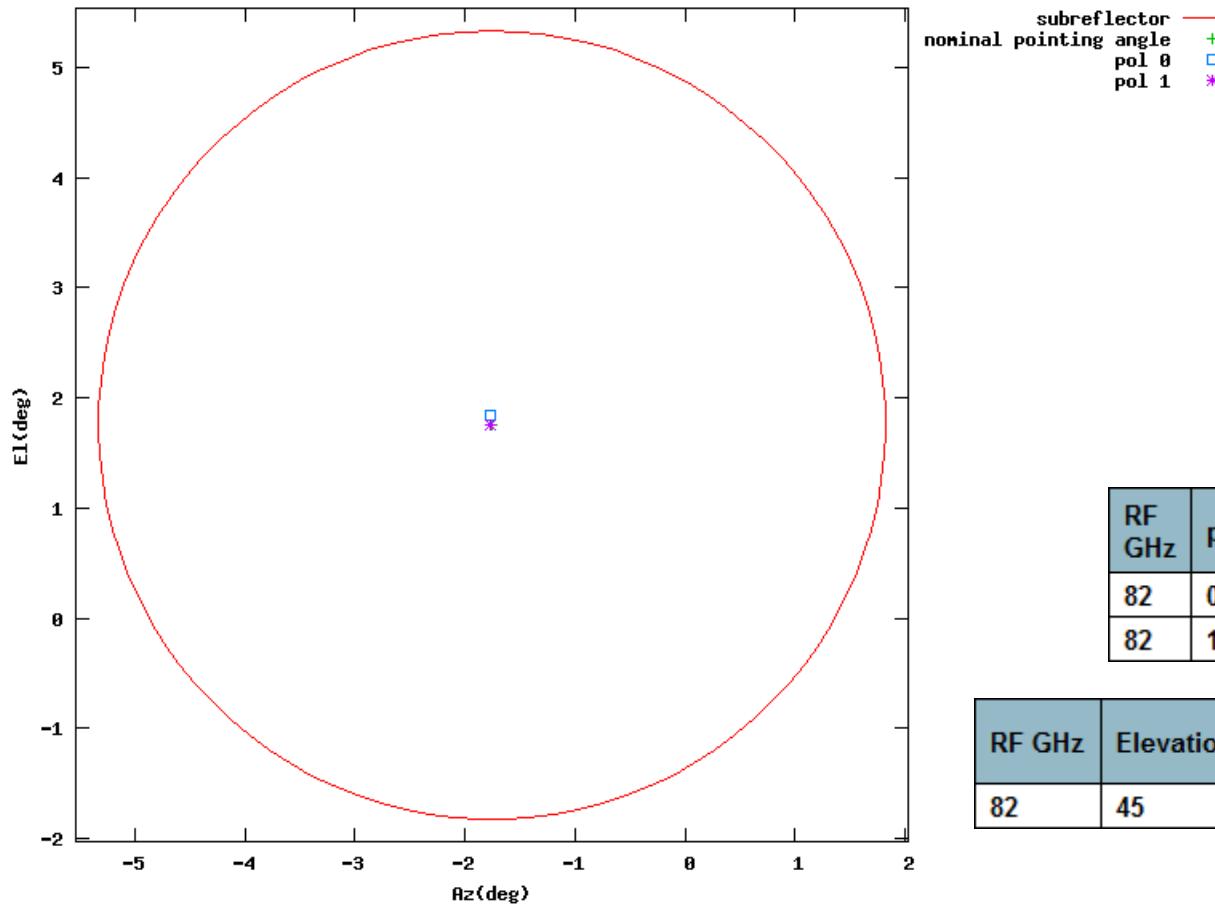


ALMA Band 2 Receiver Prototype



Optics Performance / Beam Pointing

Band 2 Pointing Angles, RF 82 GHz, tilt 45 deg



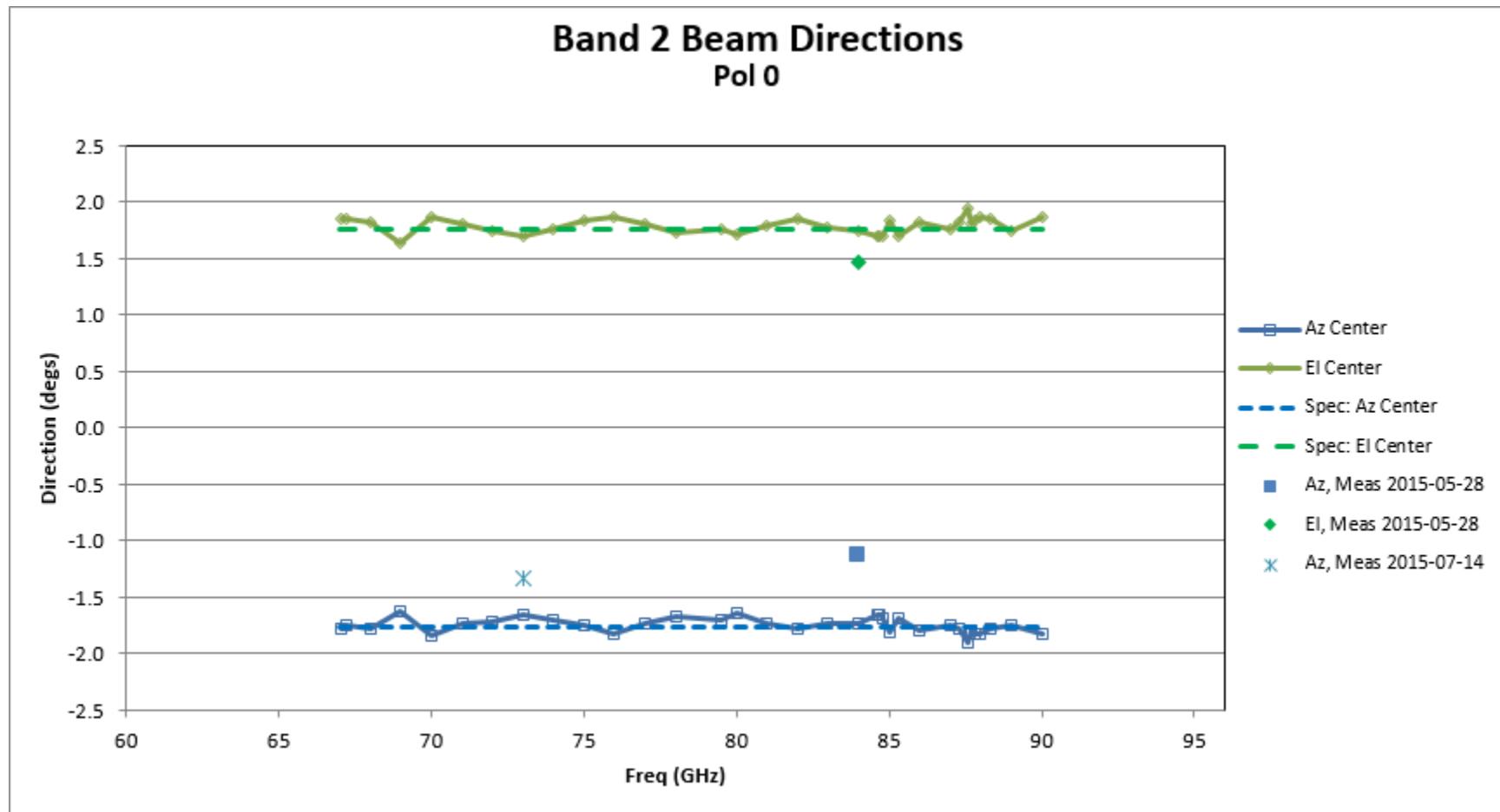
RF GHz	pol	Elevation	AZ Center	EL Center
82	0	45	-1.7718	1.8484
82	1	45	-1.7624	1.7619

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

ALMA Band 2 Receiver Prototype



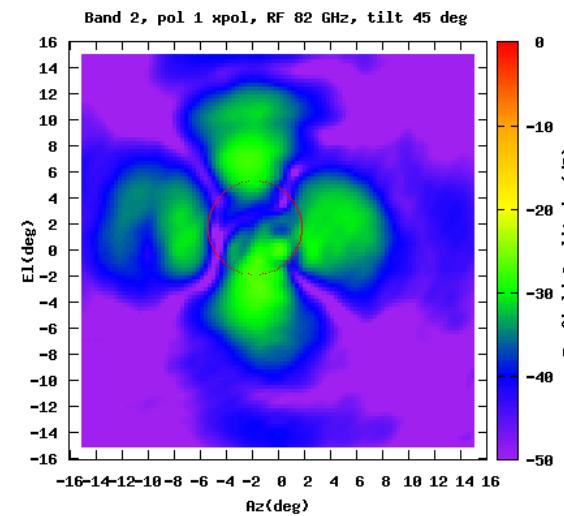
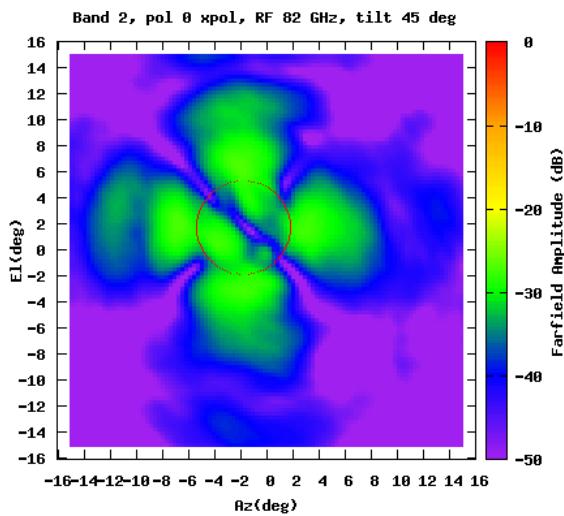
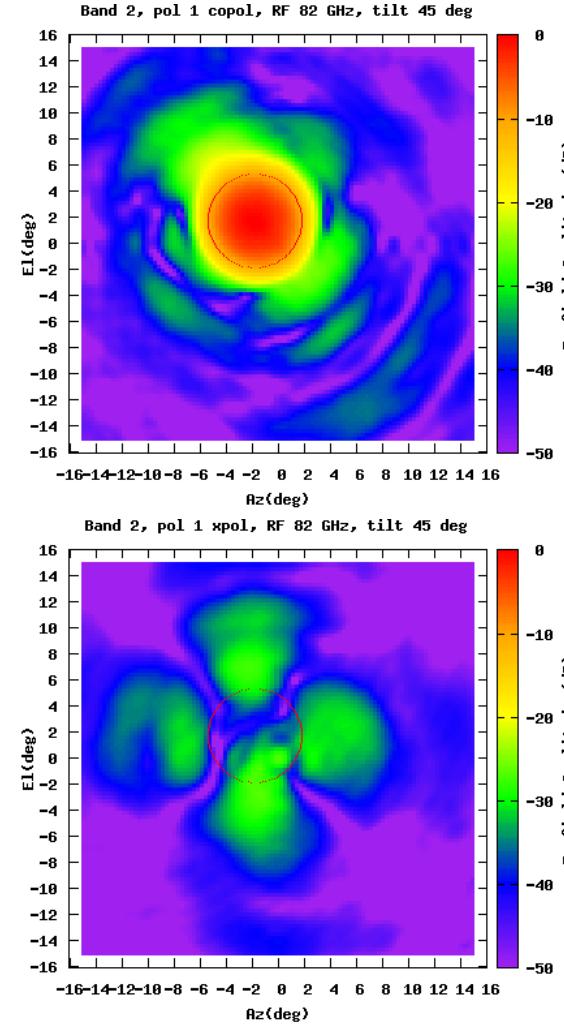
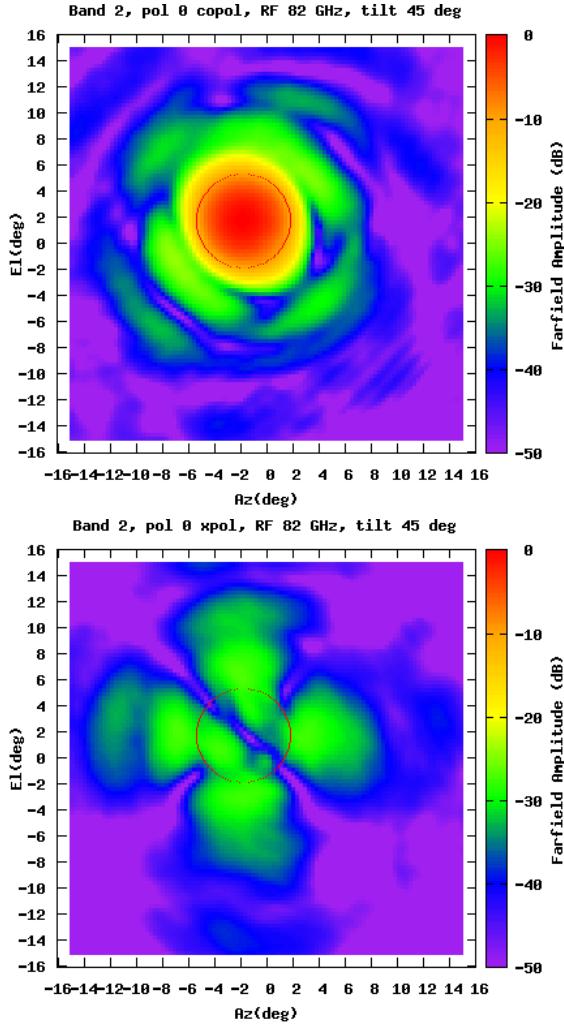
Optics Performance / Beam Pointing



ALMA Band 2 Receiver Prototype



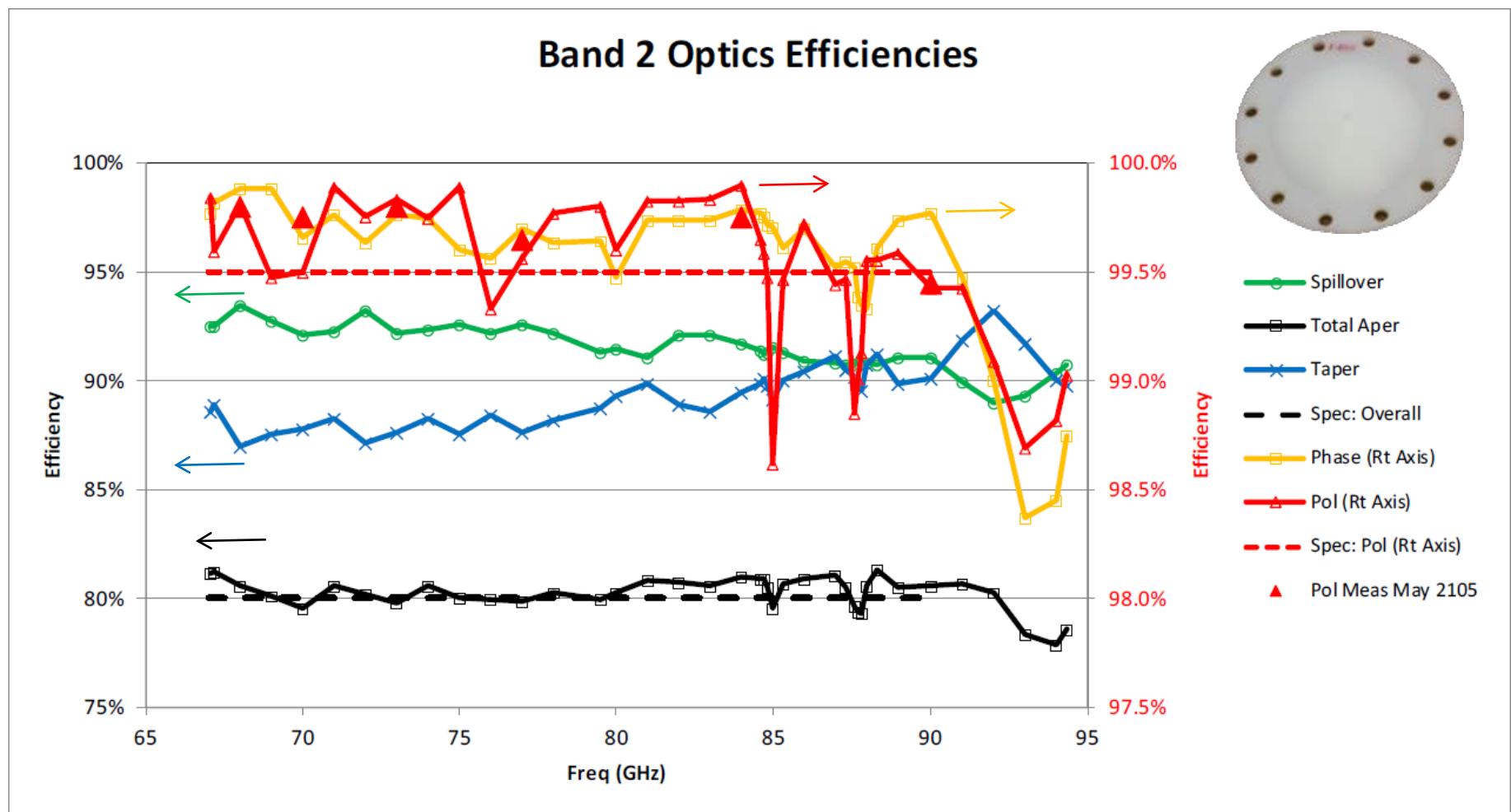
Optics Performance / Beam Patterns



ALMA Band 2 Receiver Prototype

Optics Performance / Beam Efficiencies

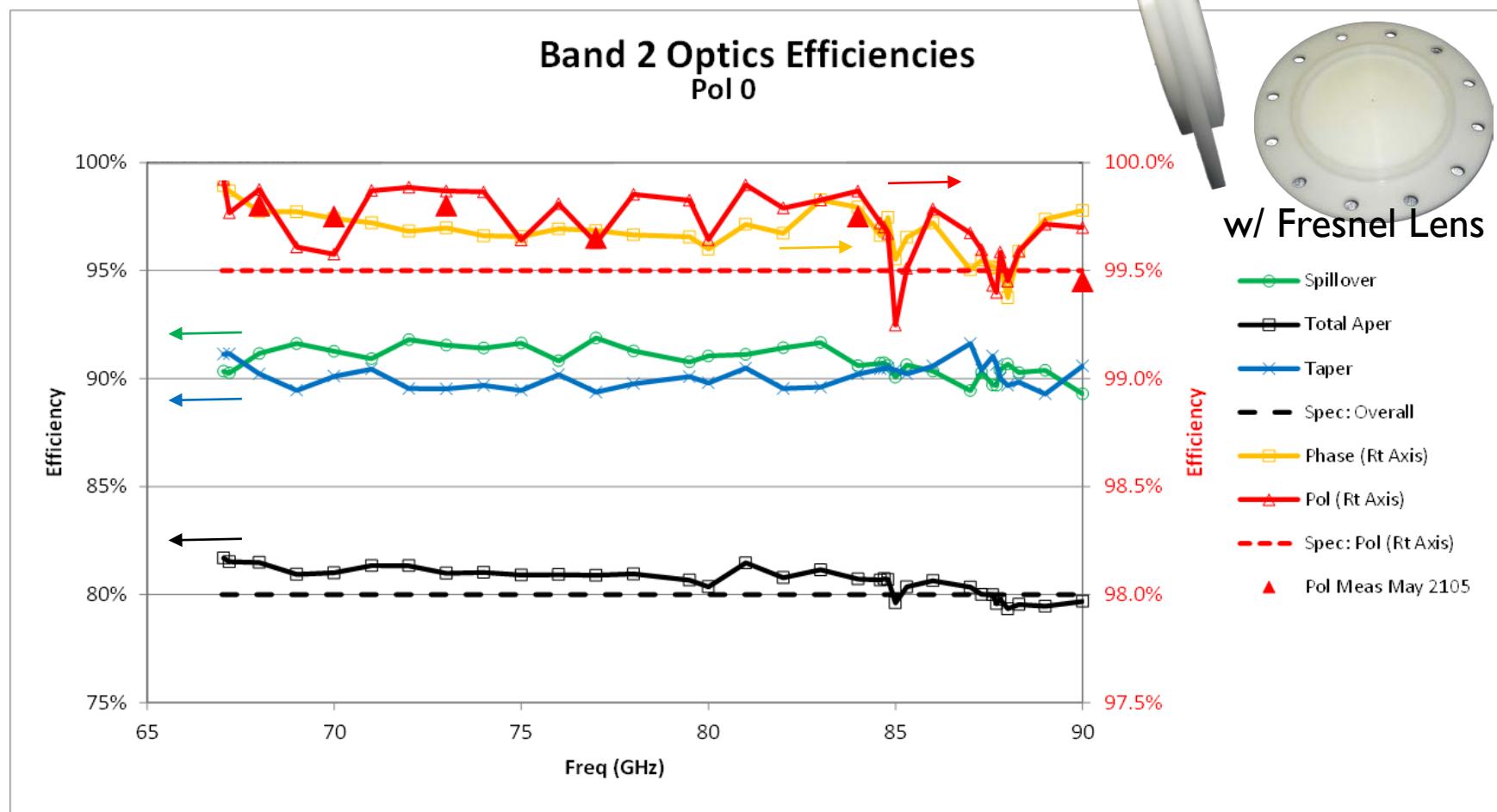
ALMA
Band 2
67-90 GHz



ALMA Band 2 Receiver Prototype

Optics Performance / Beam Efficiencies

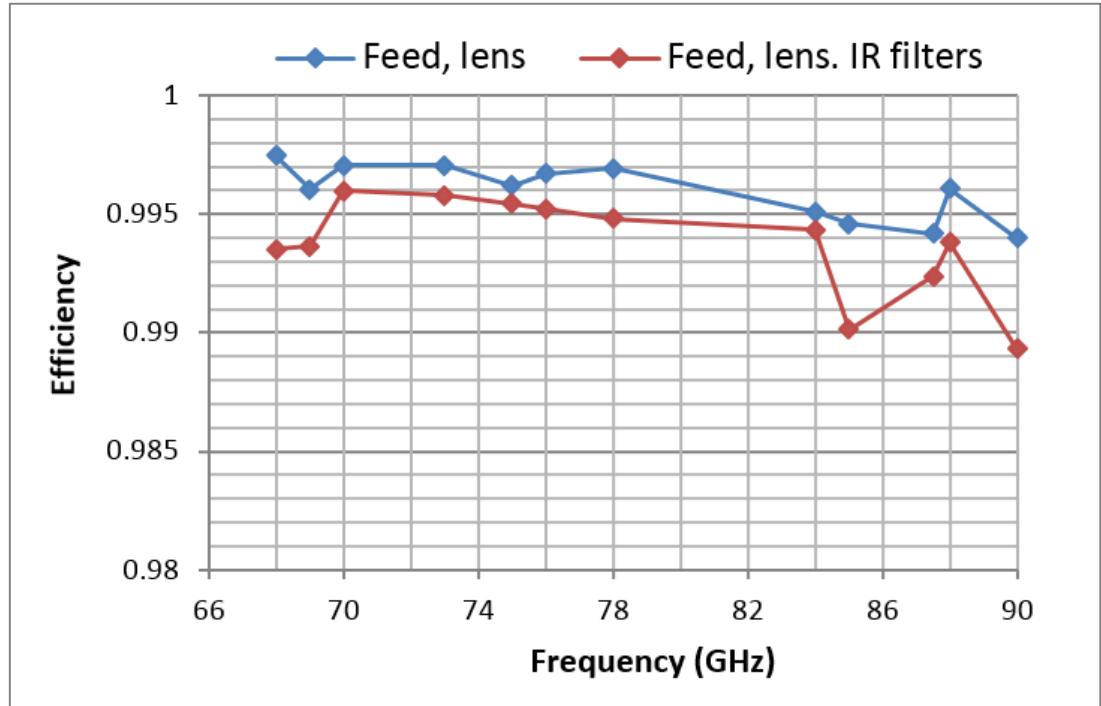
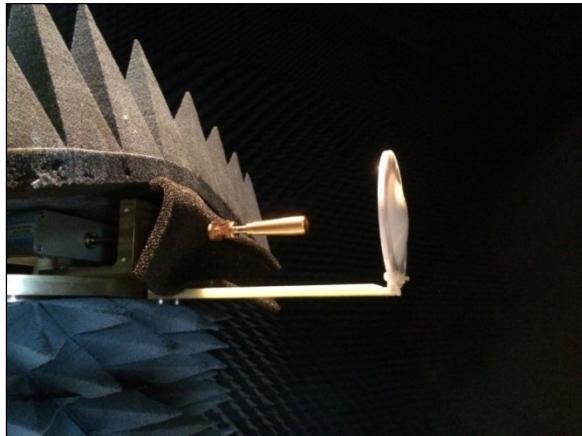
ALMA
Band 2
67-90 GHz



ALMA Band 2 Receiver Prototype



Optics Performance / Beam Efficiencies

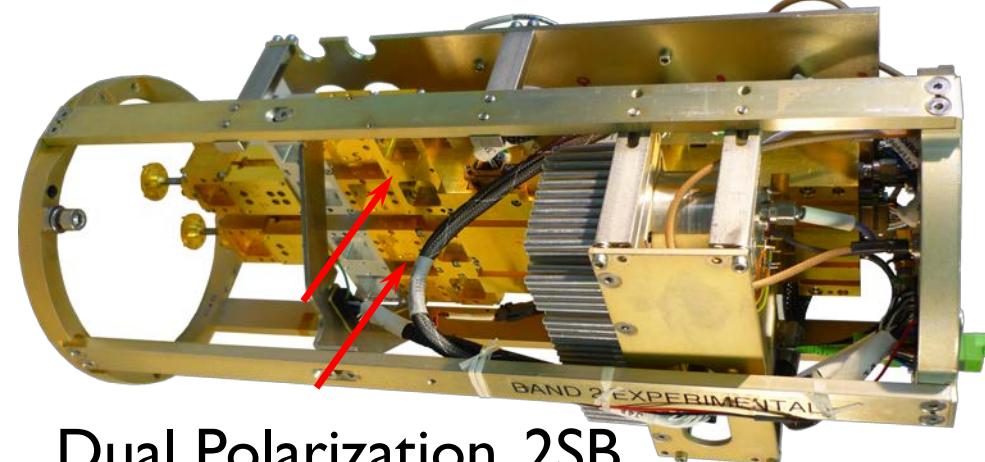
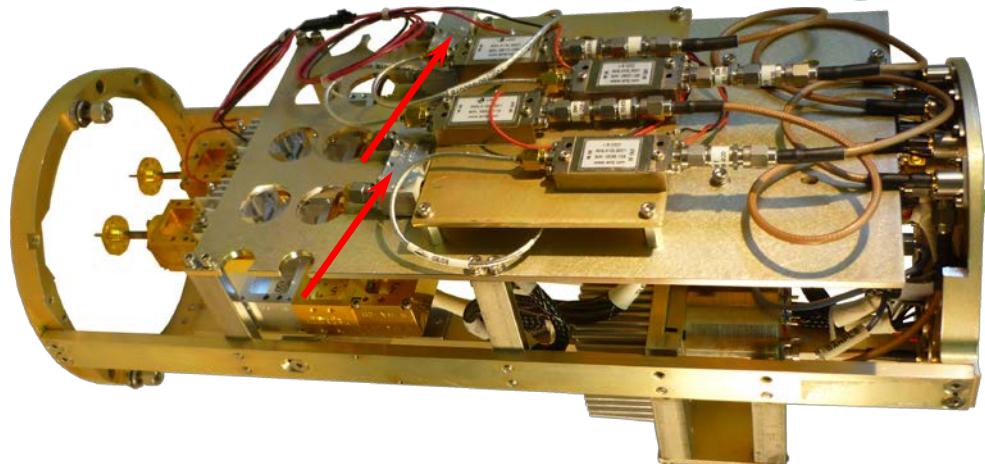


Measured polarization efficiency of feed horn & lens with and without the 15 K IR filter (anechoic chamber measurements).

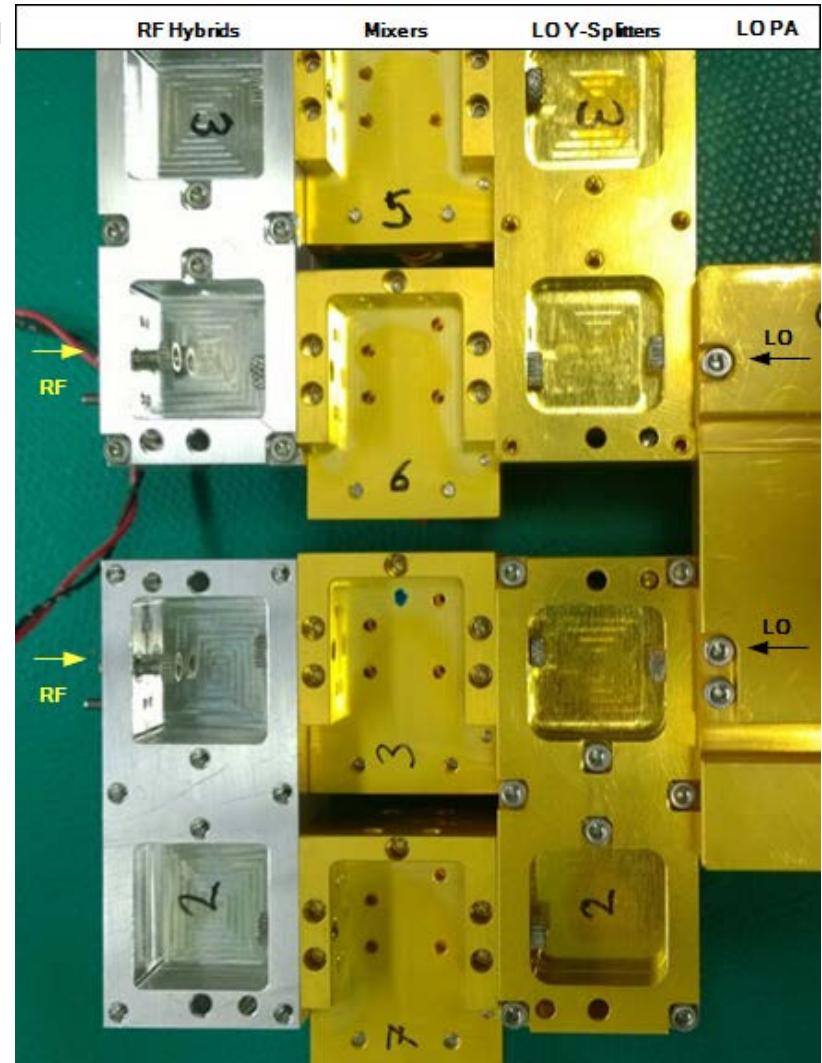
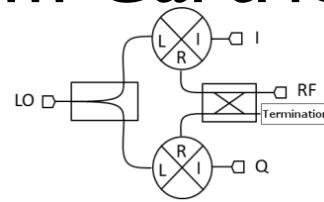
ALMA Band 2 Warm Cartridge Prototype

Band 2
67-90 GHz
ALMA

2SB Downconverter



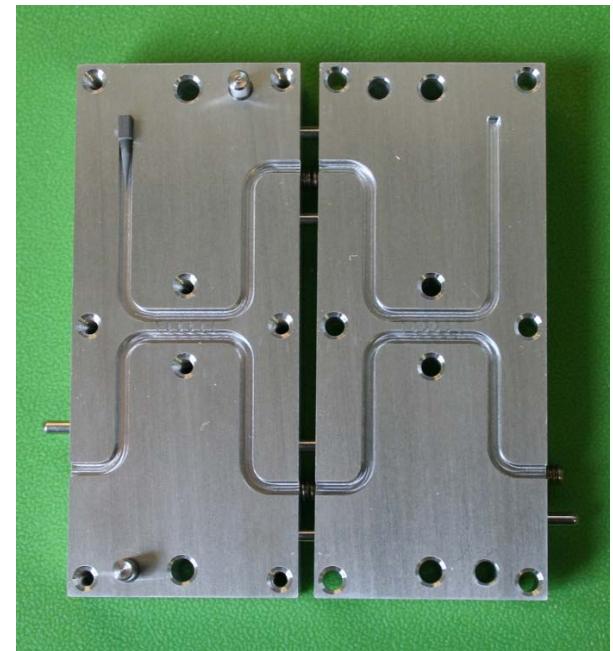
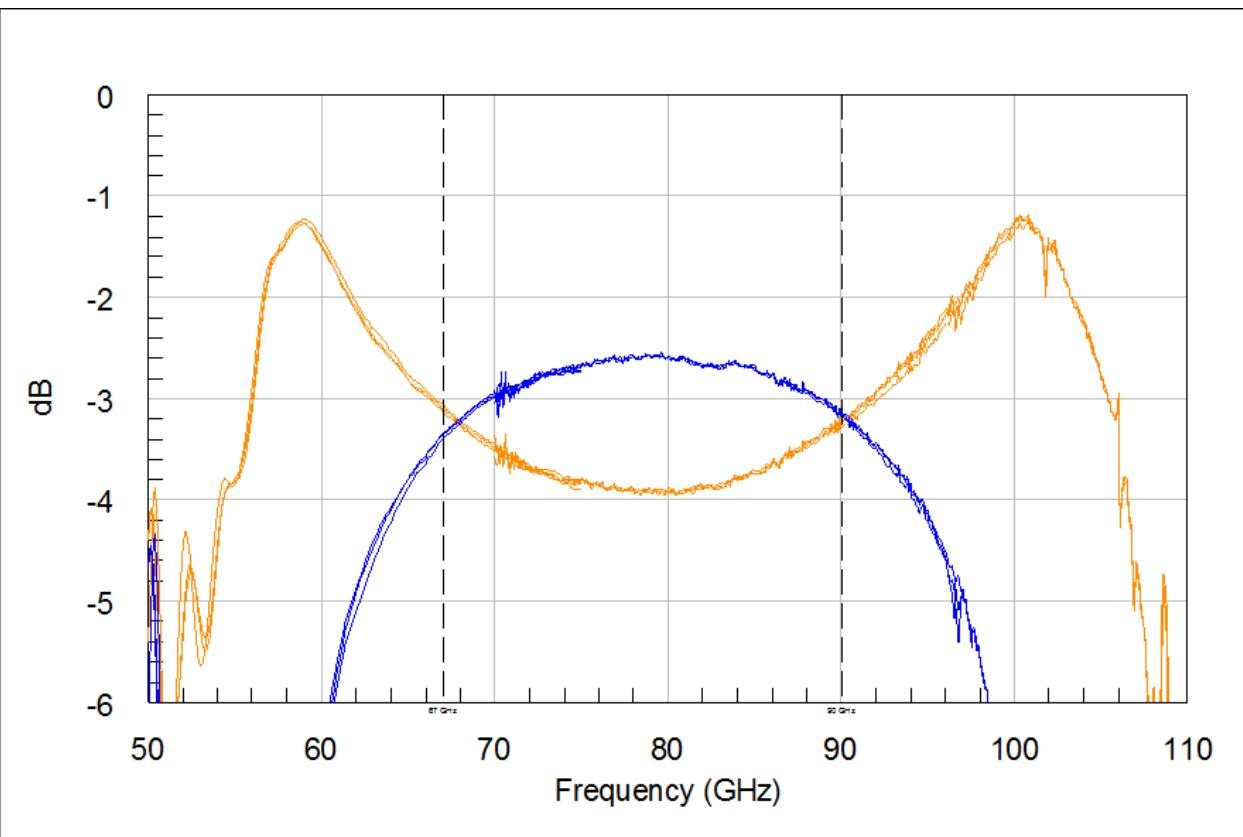
Dual Polarization, 2SB



RF 90° Hybrid

Band 2
67-90 GHz

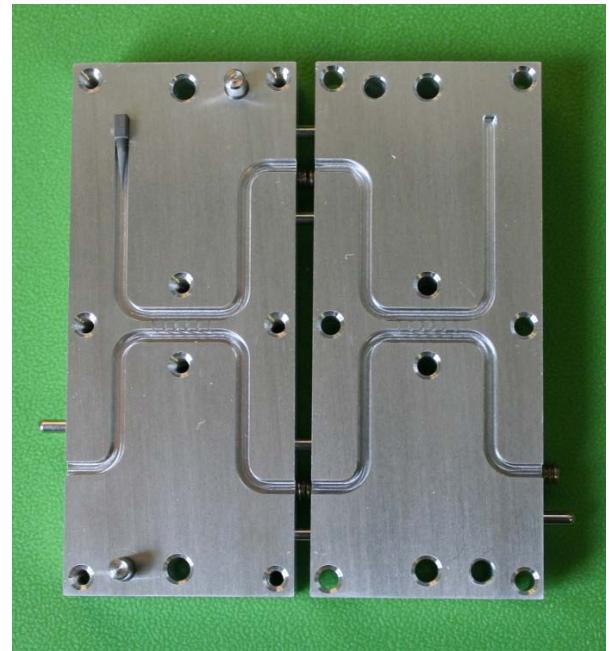
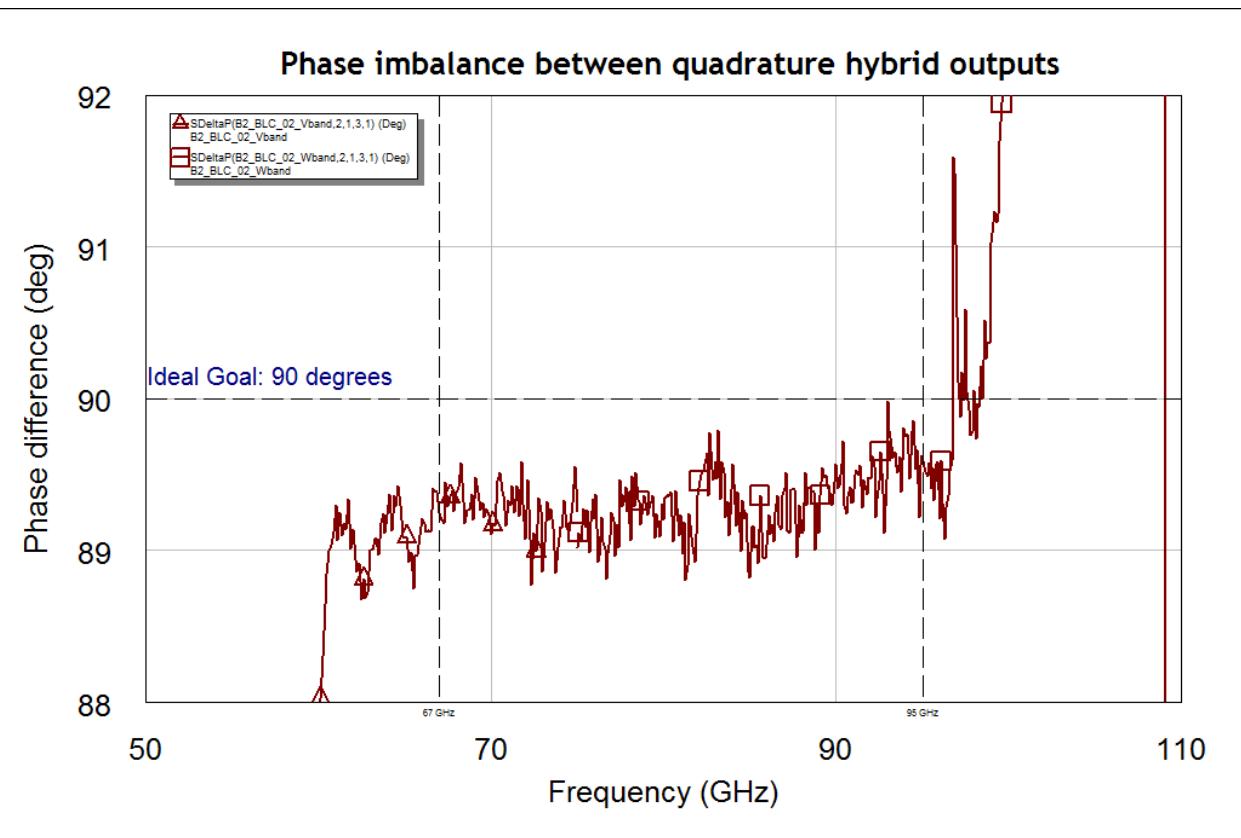
Measured Amplitude Imbalance



RF 90° Hybrid

Band 2
67-90 GHz

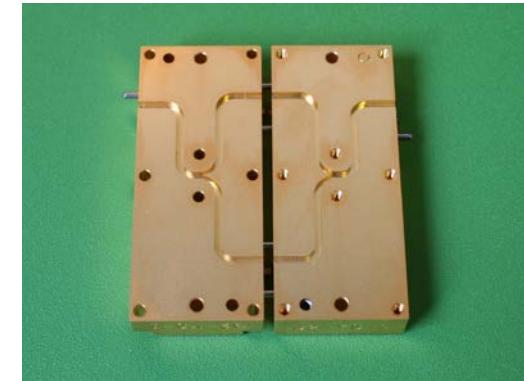
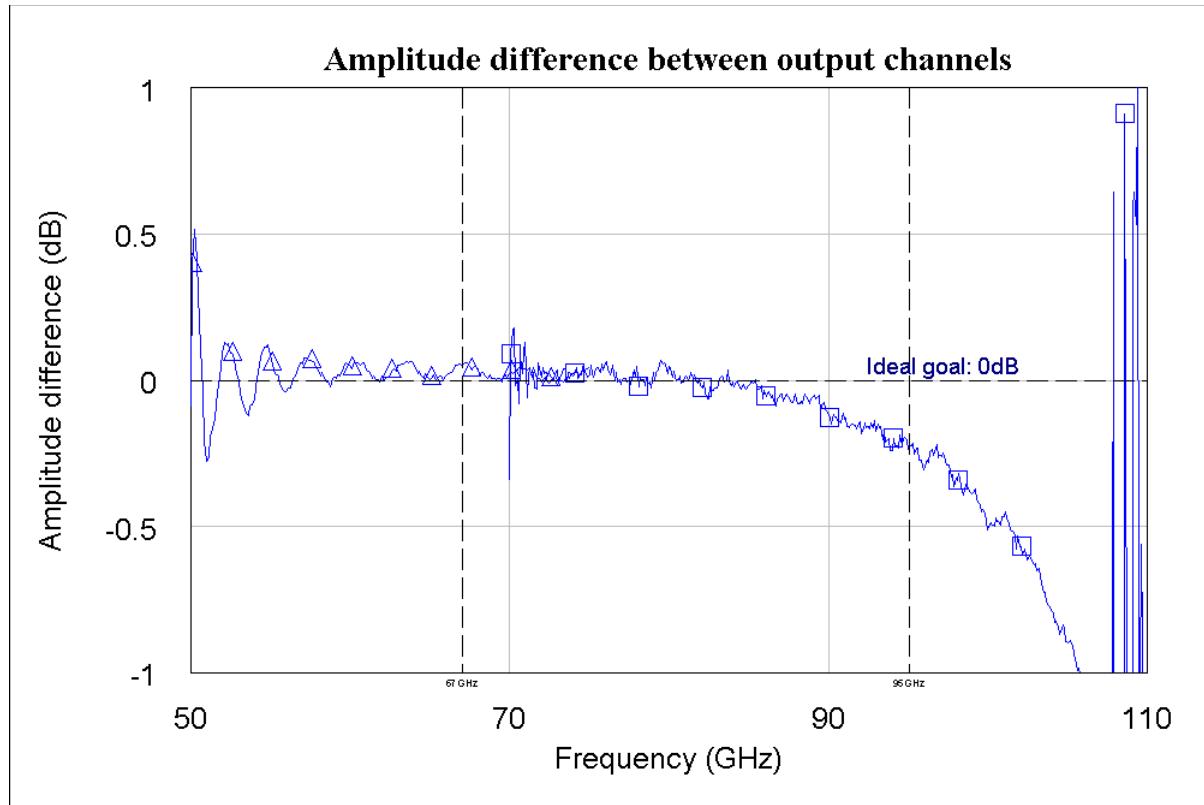
Measured Phase Imbalance



LO Y-splitter

ALMA
Band 2
67-90 GHz

Measured Amplitude Imbalance

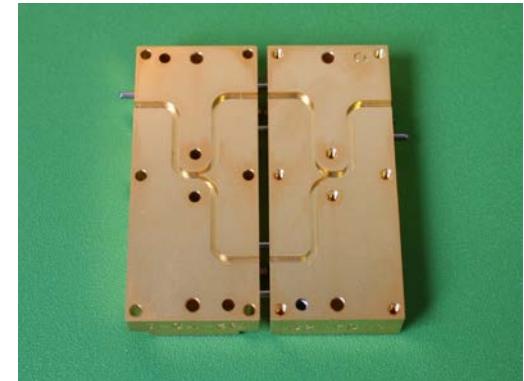
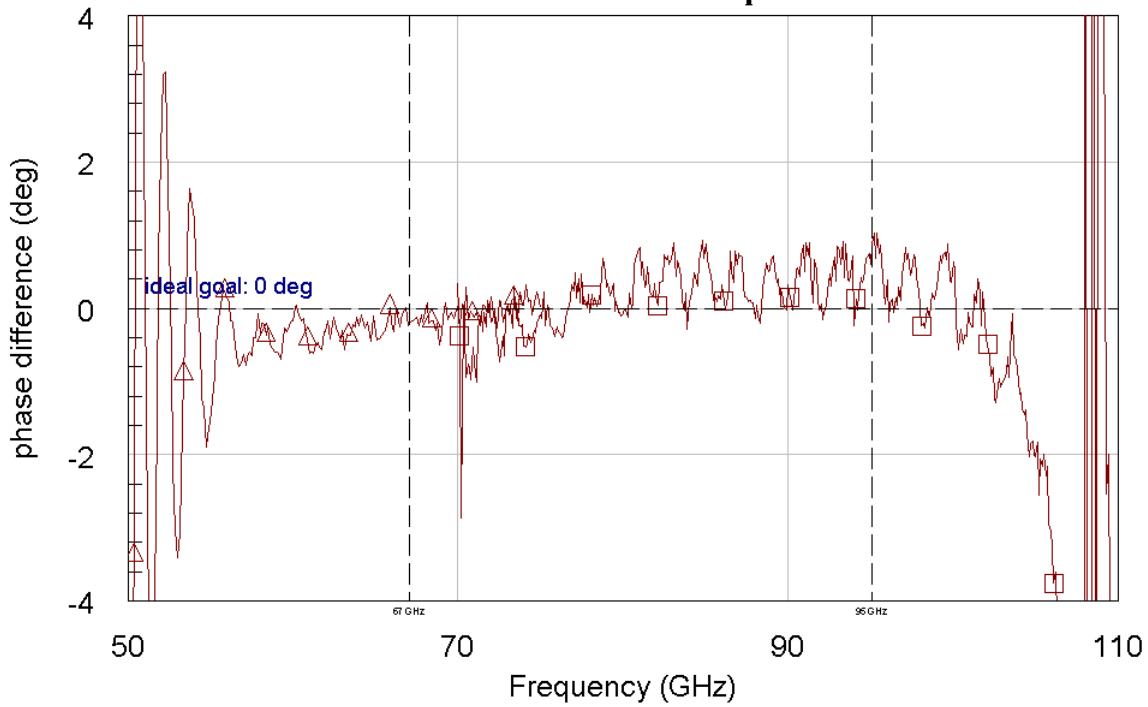


LO Y-splitter

ALMA
Band 2
67-90 GHz

Measured Phase Imbalance

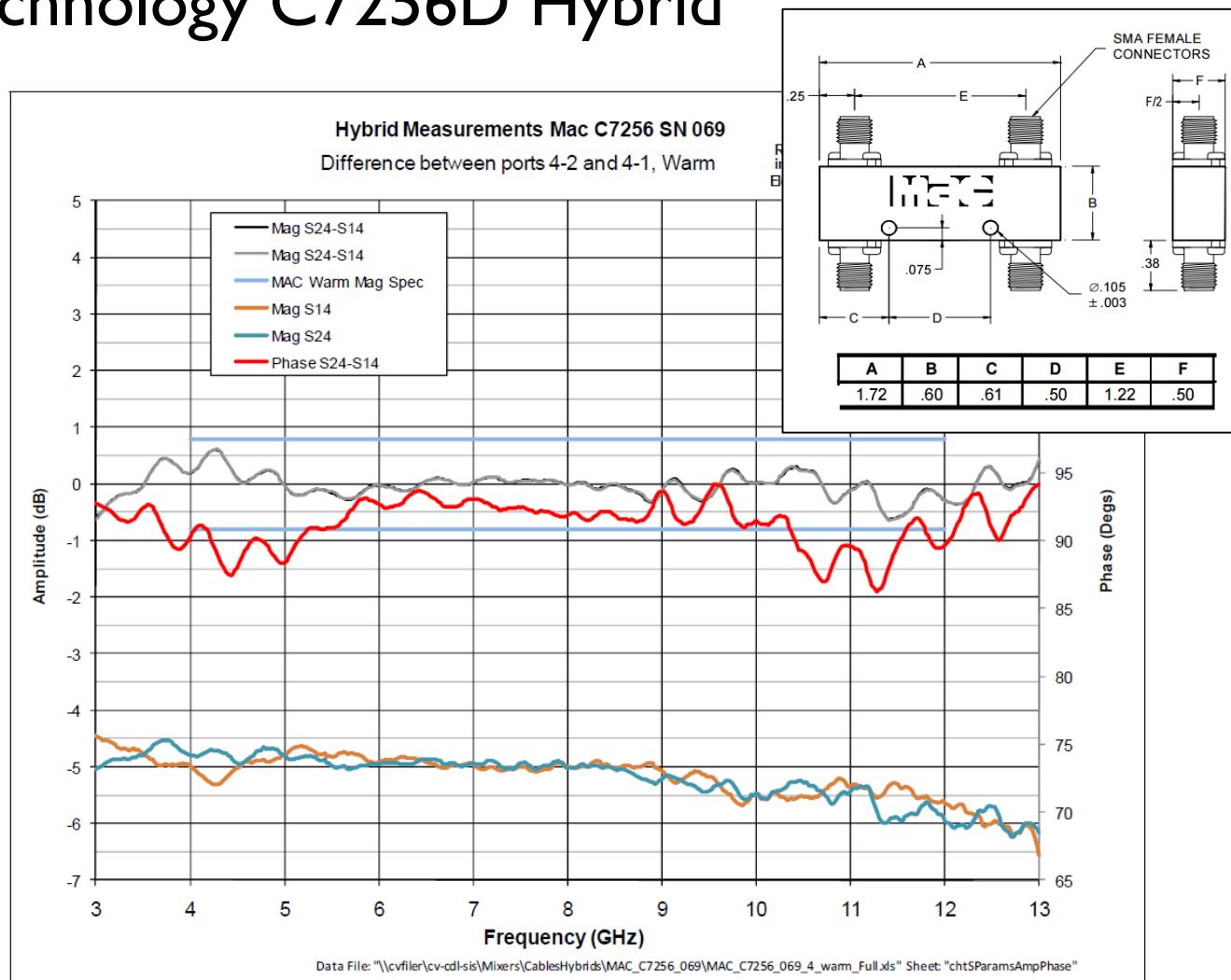
Phase difference between output channels



IF Hybrid

MAC Technology C7256D Hybrid

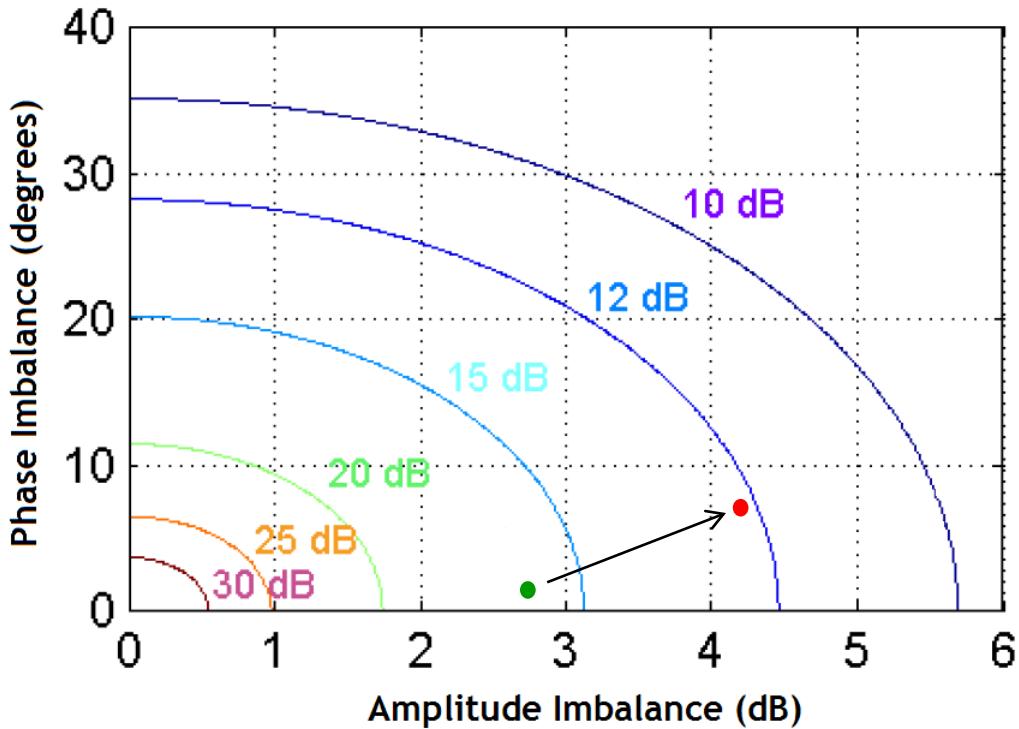
ALMA
Band 2
67-90 GHz



2SB Down converter

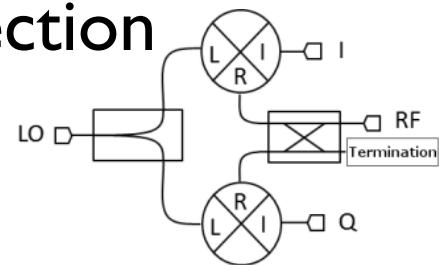
Band 2
67-90 GHz

Amplitude and Phase Imbalance / Image Rejection



- Root sum square case
- Algebraic sum case

$$R = -10 \cdot \log \left[\frac{1 - 2\sqrt{G} \cos(\theta) + G}{1 + 2\sqrt{G} \cos(\theta) + G} \right]$$



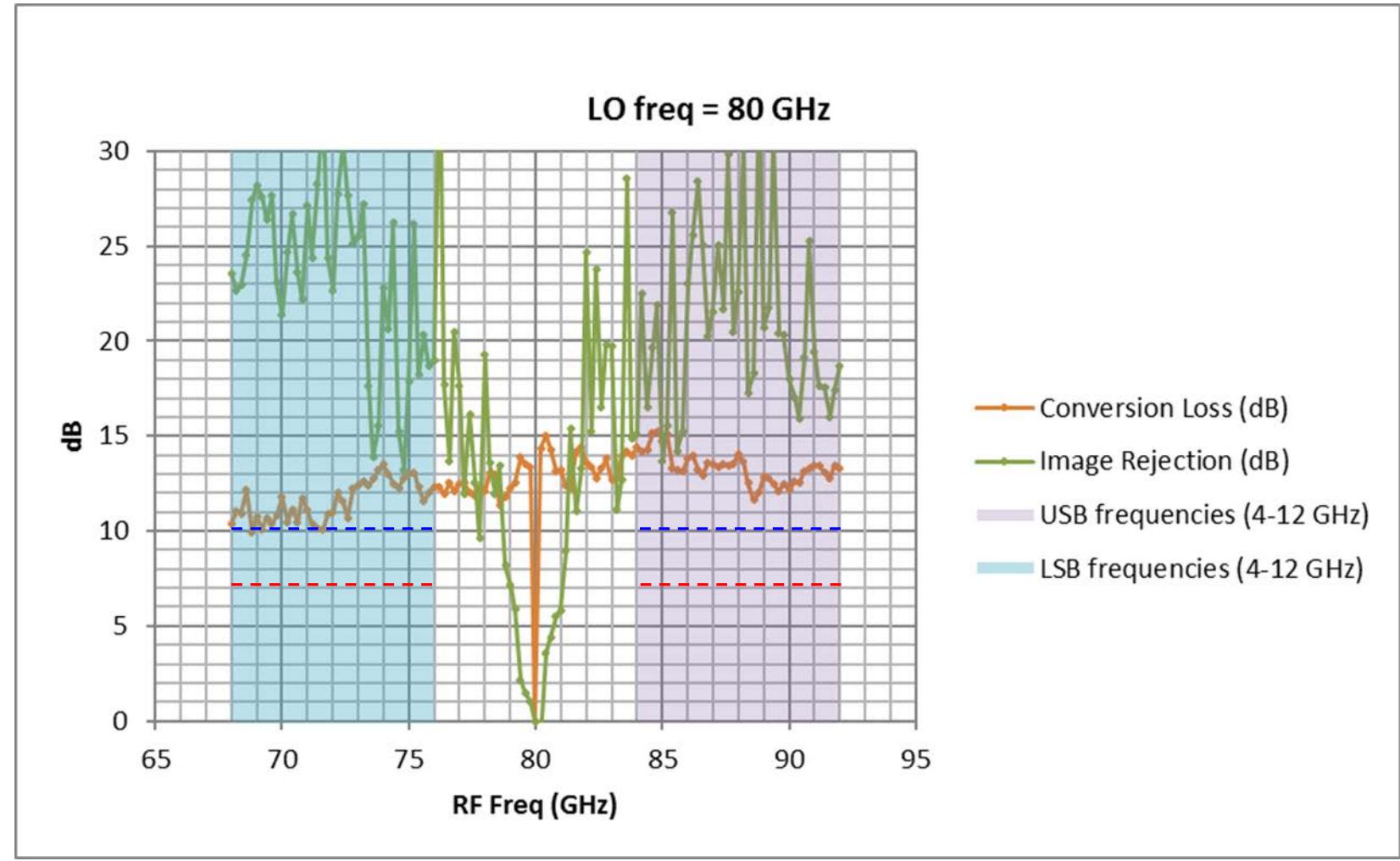
Component	Amplitude	Phase
RF Hybrid	1.30 dB	1.0 deg
Mixers	1.75 dB	TBC
LO splitter	0.25 dB	1.0 deg
IF Hybrid	0.75 dB	5.0 deg
Phase matched IF cable	0.00 dB	4.0 deg
Algebraic Sum	4.05 dB	11.0 deg
Root sum squared	2.32 dB	6.6 deg

Note: Phase matched cables are specified in terms of delay difference.
Phase imbalance calculated at 12 GHz.

2SB Down converter

ALMA
Band 2
67-90 GHz

Measured Performance – Example of detailed plot



2SB Down converter



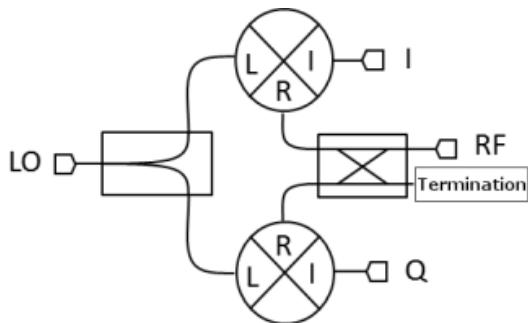
Measured Performance – Full Summary

LO	Polarization-1 Image Rejection Data																								
	RF		RF		RF		RF		RF		RF		RF		RF		RF		RF		RF		(USB)		
	(LSB)	IR	IR	IR	IR	IR	IR	IR	IR	IR	IR	IR	IR	IR	IR	IR	IR	IR	IR	IR	IR	IR	IR	IR	
72 GHz															67 GHz	68 GHz	76 GHz	77 GHz	78 GHz	79 GHz	80 GHz	81 GHz	82 GHz	83 GHz	84 GHz
74 GHz															67 GHz	68 GHz	69 GHz	70 GHz	78 GHz	79 GHz	80 GHz	81 GHz	82 GHz	83 GHz	84 GHz
76 GHz															67 GHz	68 GHz	69 GHz	70 GHz	71 GHz	72 GHz	80 GHz	81 GHz	82 GHz	83 GHz	84 GHz
78 GHz															67 GHz	68 GHz	69 GHz	70 GHz	71 GHz	72 GHz	82 GHz	83 GHz	84 GHz	85 GHz	86 GHz
80 GHz															68 GHz	69 GHz	70 GHz	71 GHz	72 GHz	73 GHz	84 GHz	85 GHz	86 GHz	87 GHz	88 GHz
82 GHz															70 GHz	71 GHz	72 GHz	73 GHz	74 GHz	75 GHz	86 GHz	87 GHz	88 GHz	89 GHz	90 GHz
84 GHz															72 GHz	73 GHz	74 GHz	75 GHz	76 GHz	77 GHz	88 GHz	89 GHz	90 GHz	91 GHz	92 GHz
86 GHz															74 GHz	75 GHz	76 GHz	77 GHz	78 GHz	79 GHz	91 GHz	92 GHz	93 GHz	94 GHz	95 GHz
	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.																									

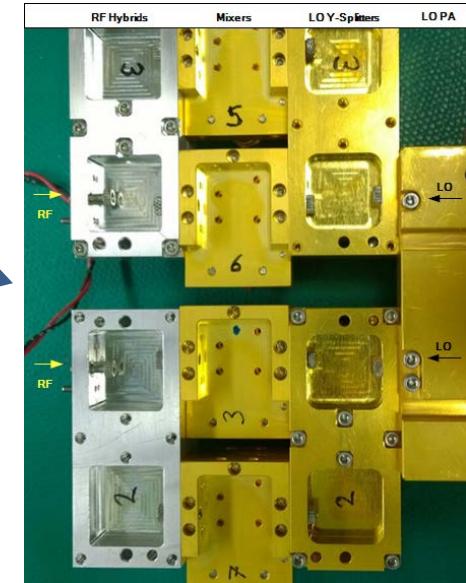
2SB Down converter

“Integrated” version

- Combines RF hybrid, LO splitter and mixers into one I/Q block.
- IF hybrid will still be separate.
- Will enable specification in terms of image rejection when produced commercially.
- Currently evaluating several design variants . . .



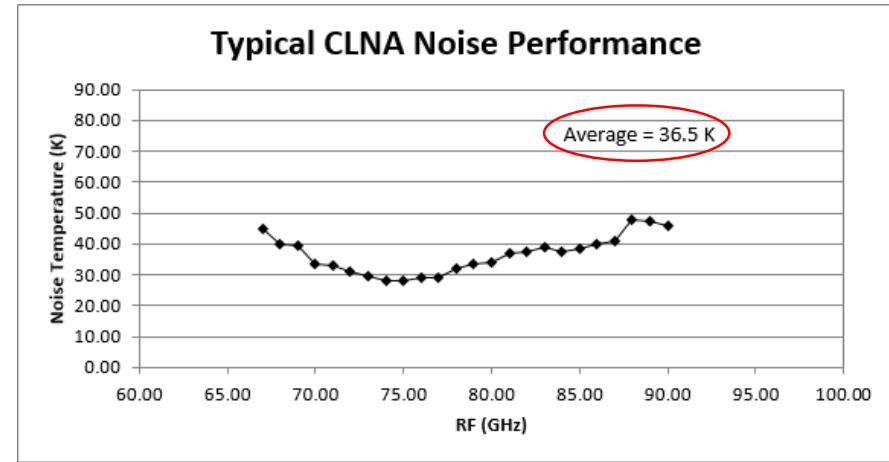
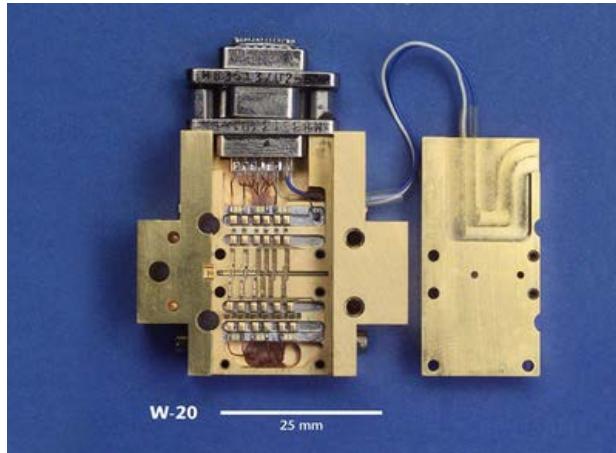
Replace all of these
...with these



ALMA Band 2 Receiver Prototype

ALMA
Band 2
67-90 GHz

System Noise Temperature Estimation (MIC CLNAs)

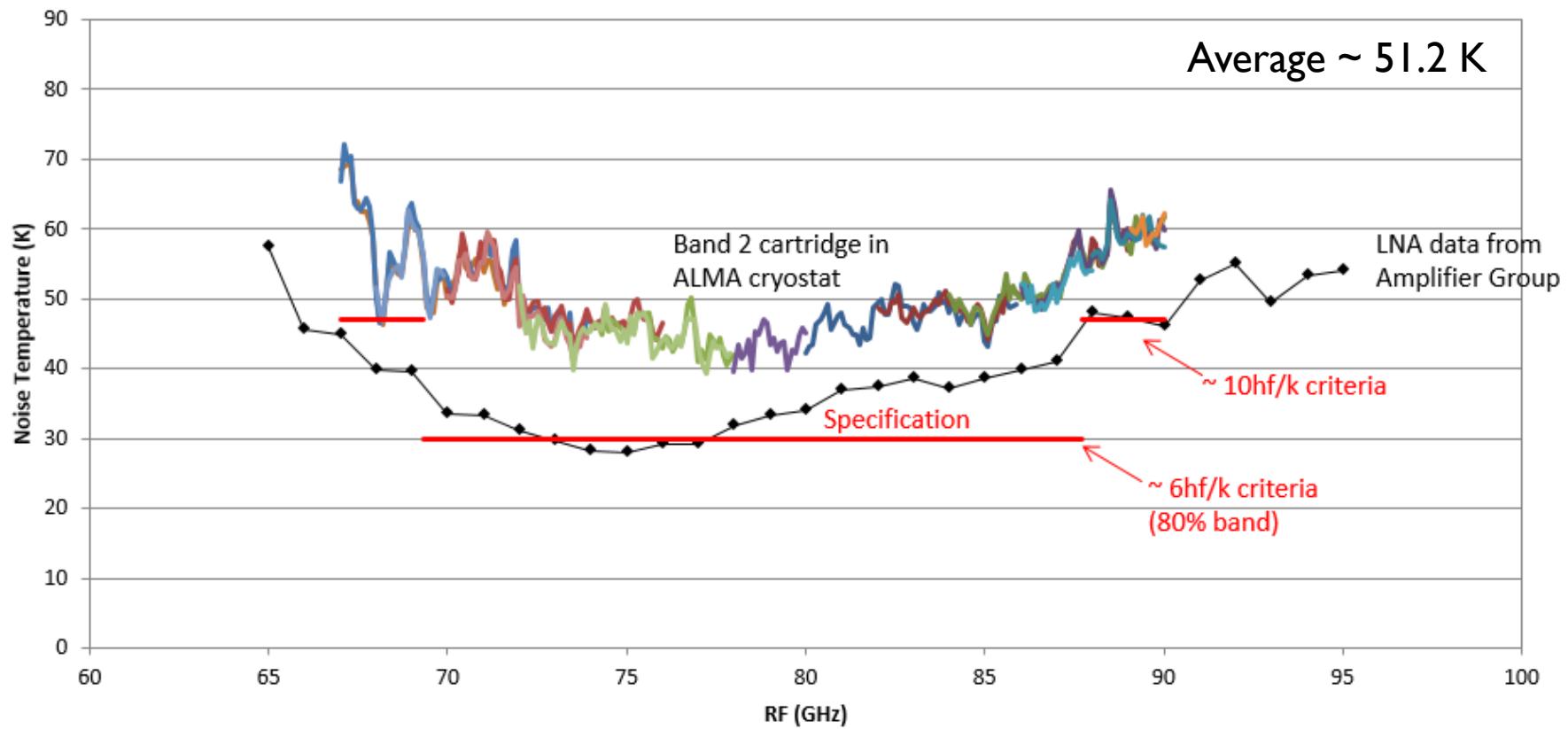


Band 2 Receiver stage	Gain	Cumulative Gain to preceding stage	Noise Figure	Noise Temperature	$T_{\text{equivalent}}$
Lens/Window (room temperature)	-0.1 dB	0.0 dB	0.1 dB	8.9 K	8.9 K
IR Filters (15 K and 80 K)	-0.1 dB	-0.1 dB	0.1 dB	1.4 K	1.5 K
Feedhorn (15 K)	-0.1 dB	-0.3 dB	0.1 dB	0.3 K	0.4 K
OMT	-0.1 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



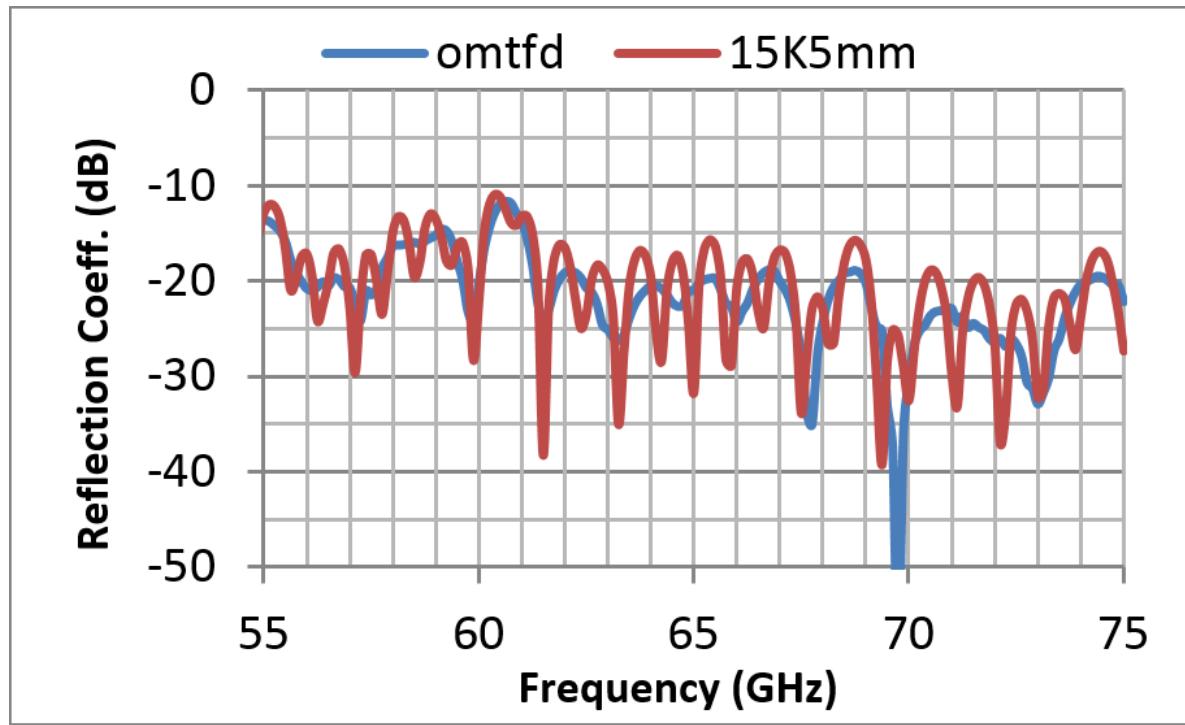
Noise Temperature (Polarization-0)



ALMA Band 2 Receiver Prototype



Interaction between 15 K IR filters and CLNA input



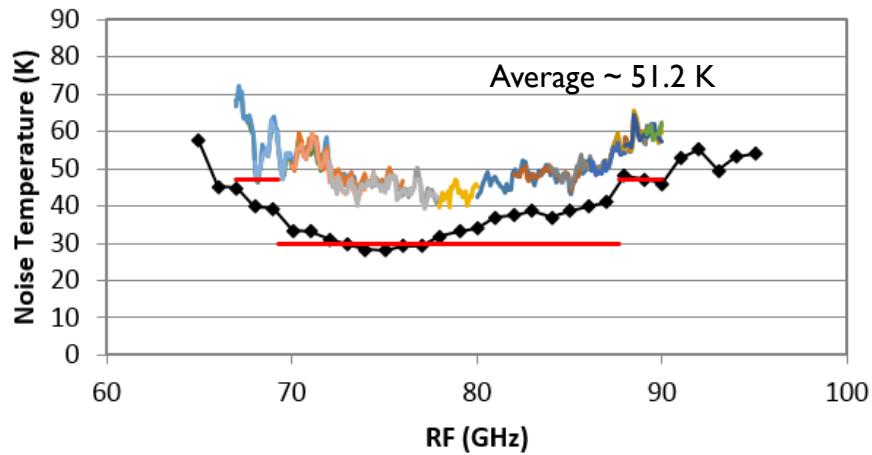
Measured reflection coefficient of the OMT plus feed horn without IR filter (trace labeled “omtfd”) and that of the OMT plus feed horn with the 15 K IR filter placed 5 mm from the feed horn aperture (trace labeled “15K5mm”)

ALMA Band 2 Receiver Prototype

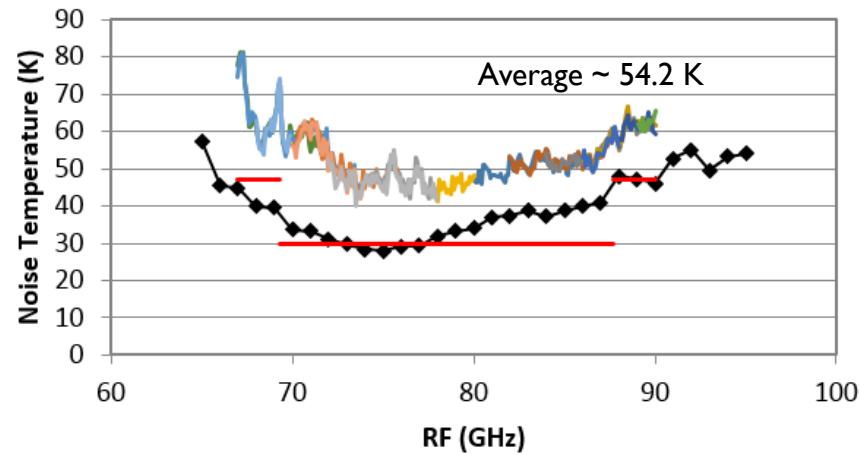


Noise Temperature (Polarization-0)

Pol-0 Noise Temperature
Original Lens



Pol-0 Noise Temperature
1-zone Fresnel Lens

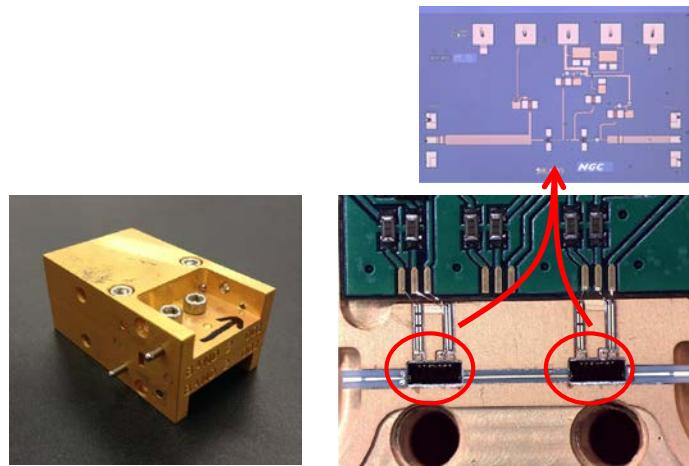


Effect of larger spill-over?

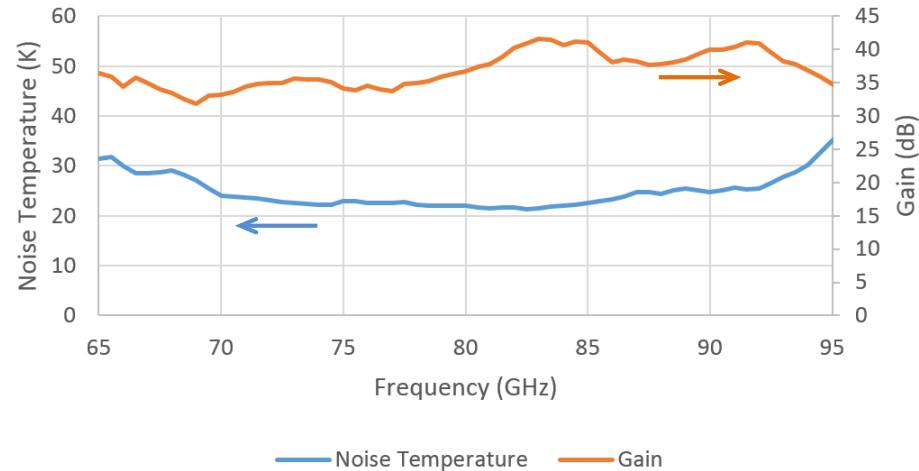
ALMA Band 2 Cold Cartridge Prototype

ALMA
Band 2
67-90 GHz

Cascade Noise Analysis (MMIC CLNAs)



Caltech/JPL 2-MMIC



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
E-Band MMIC Amplifier (15 K)	35.0 dB	-0.5 dB		26.3 K	29.2 K
Waveguides, feed-thru and BPF	-4.0 dB	34.5 dB	4.0 dB	453.6 K	0.2 K
W-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			41.1 K	

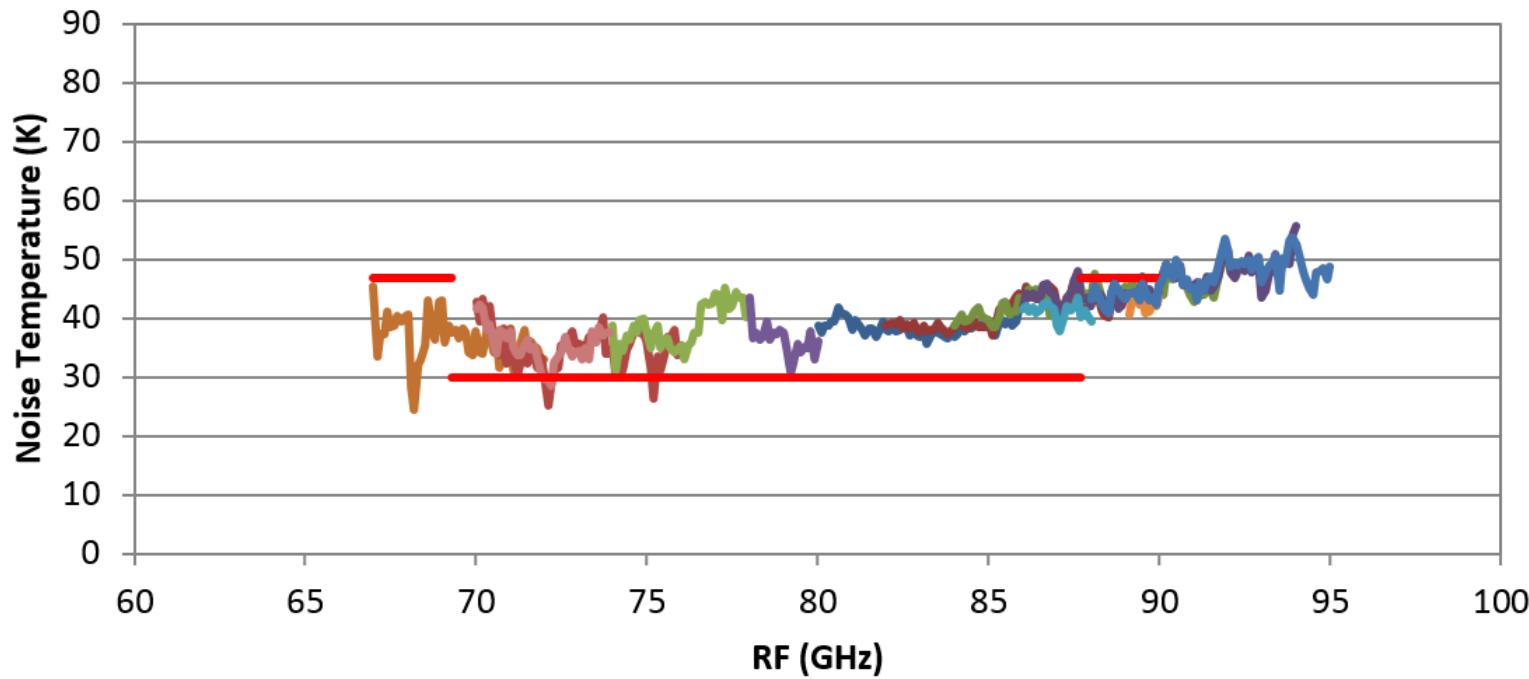
ALMA Band 2 Receiver Prototype



Noise Performance (MMIC based)

Freq Range	67-90 GHz	67-95 GHz
Average TRx	37.7 K	40.0 K

Band 2 Receiver Noise Temperature with MMIC CLNA



ALMA Band 2 Receiver Prototype



Output Power and Headroom Analysis

273 K source, 30 dB gain IF amplifier

Amplifier stage in CCA/WCA	Cumulative Gain	Eff. Bandwidth	Output Power	Headroom
Cryogenic Amplifier (15 K)	34.5 dB	28 GHz	-31.7 dBm	33.7 dB
RF Amplifier (room temperature)	44.5 dB	28 GHz	-21.7 dBm	23.7 dB
IF Amplifier	62.5 dB	8 GHz	-9.1 dBm	19.1 dB

373 K source, 15 dB gain IF amplifier

Amplifier stage in CCA/WCA	Cumulative Gain	Eff. Bandwidth	Output Power	Headroom
Cryogenic Amplifier (15 K)	34.5 dB	28 GHz	-31.1 dBm	33.1 dB
RF Amplifier (room temperature)	44.5 dB	28 GHz	-21.1 dBm	23.1 dB
IF Amplifier	47.5 dB	8 GHz	-23.5 dBm	33.5 dB

800 K source, 15 dB gain IF amplifier

Amplifier stage in CCA/WCA	Cumulative Gain	Eff. Bandwidth	Output Power	Headroom
Cryogenic Amplifier (15 K)	34.5 dB	28 GHz	-29.0 dBm	31.0 dB
RF Amplifier (room temperature)	44.5 dB	28 GHz	-19.0 dBm	21.0 dB
IF Amplifier	47.5 dB	8 GHz	-21.5 dBm	31.5 dB

ALMA Band 2 Receiver Prototype

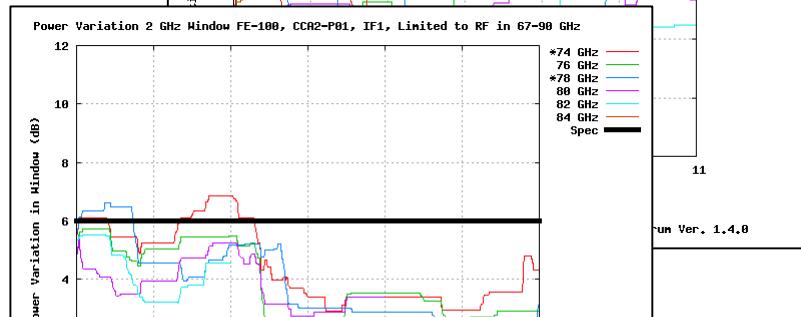
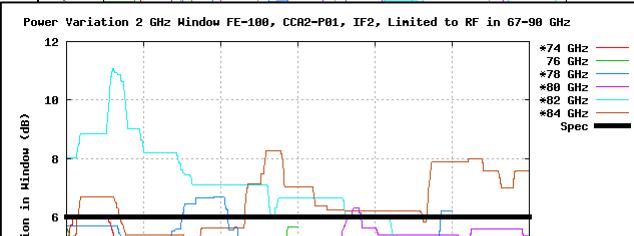
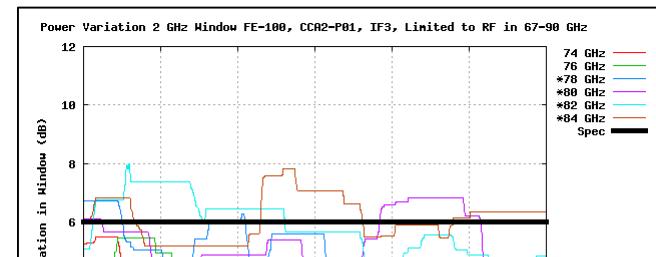
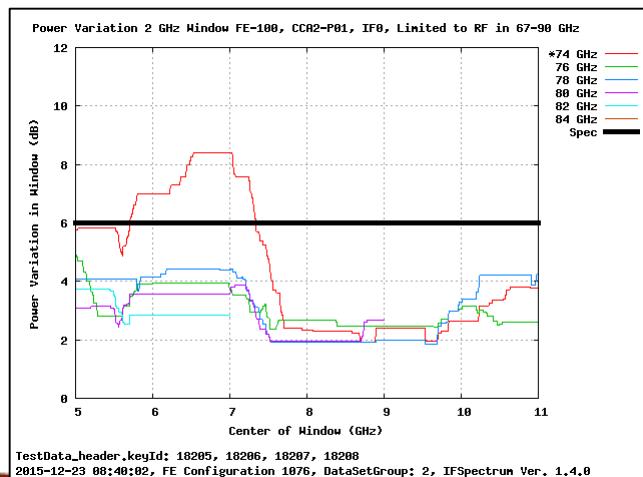
Band 2
67-90 GHz

2 GHz Ripple estimation

Band 2+ Cartridge Ripple (in any 2 GHz frequency span) Budget/Calculations

Receiver Stage	Device Ripple	Input RL	Output RL	Mismatch Ripple
IR Filters			-20.0 dB	0.2 dB
Feedhorn		-21.0 dB	-21.0 dB	0.2 dB
OMT		-20.0 dB	-20.0 dB	1.0 dB
Cryogenic LNA	1.0 dB	-5.0 dB	-3.0 dB	0.9 dB
Waveguide and BPF	0.5 dB	-23.0 dB	-15.0 dB	1.0 dB
RF Amplifier	1.0 dB	-10.0 dB	-10.0 dB	0.5 dB
Downconverter / IF hybrid	2.0 dB	-20.0 dB	-10.0 dB	1.6 dB
IF Amplifier	1.4 dB	-10.9 dB	-17.0 dB	

Algebraic summation	5.9 dB	5.3 dB
Root square summation	2.9 dB	2.3 dB



4.1.6 IF power variations

[FEND-40.00.00.00-00150-00 / A, T]

This follows from requirements number 272 and 275 of [AD13].

Within the IF band, variations in IF power over the whole IF band, specified in section 3.3.3, shall be less than:

- 1.35 dB (TBC) peak-to-peak in any 31 MHz portion of the IF band specified in section 3.3.3
- 6 dB (7 dB for Band 7 and Band 9 only) peak-to-peak in any 2 GHz portion of the IF band specified in section 3.3.3 . For Band 6, 6 dB peak-to-peak is allowed over 6 – 10 GHz range (in any 2 GHz window) and 7 dB variation is allowed in the 5 – 6 GHz IF range.
- 10 dB (11 dB for Band 7 and Band 9, 11 dB for Band 6 in the 5 – 10 GHz IF) peak-to-peak across the complete IF band specified in section 3.3.3

Copy of FE Specifications

ALMA Band 2 Prototype Project



List of tasks for the NA Development Cycle 2 Project

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.

✓ Complete

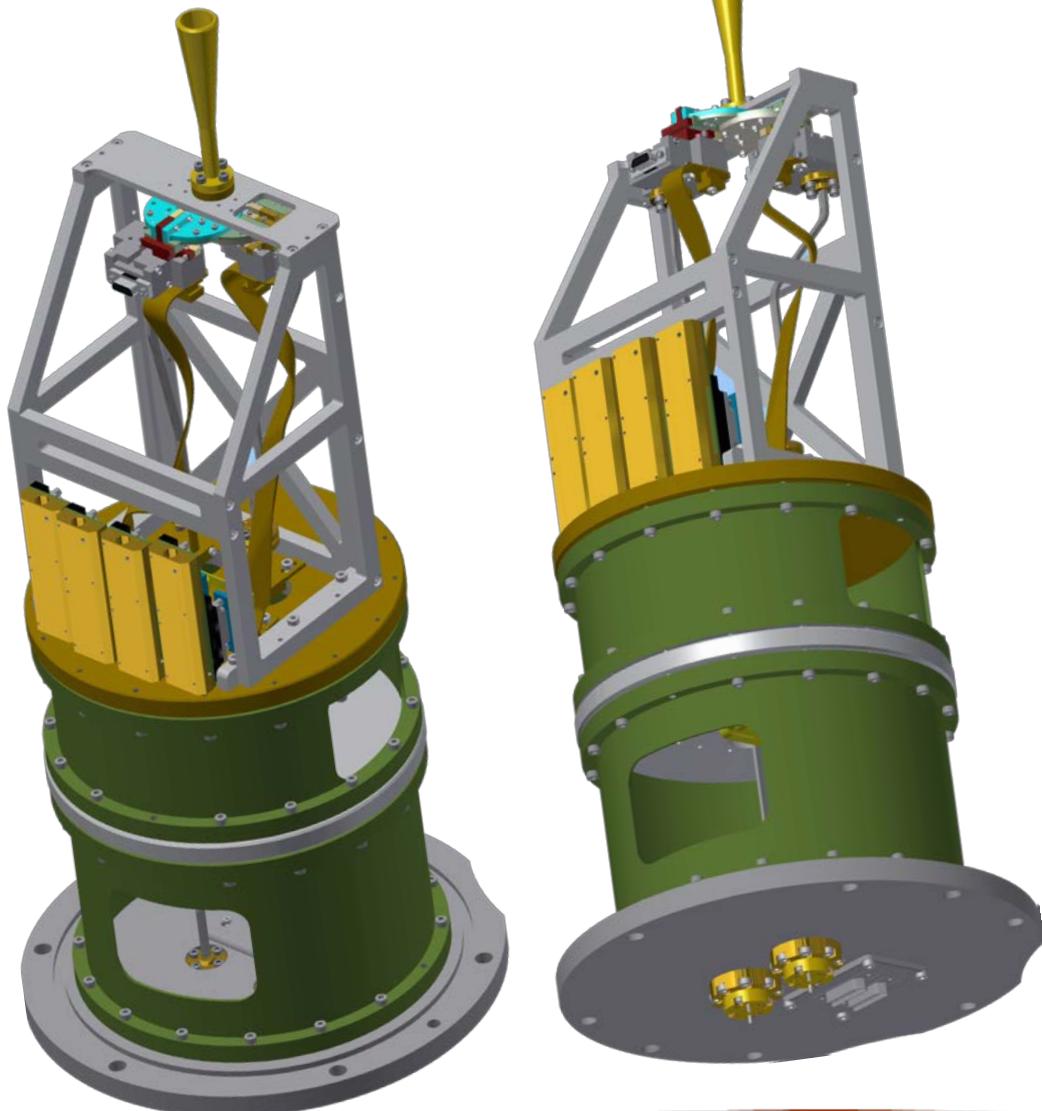
✓ In-progress

ALMA Band 2 Prototype Project

ALMA
Band 2
67-90 GHz

Next Steps ...

- Preliminary Design Review Complete.
- Secure supply of tested MMIC chips for the production phase.
- Finish evaluating the revised optics for the extended frequency range.
- Continue to address issues identified at the PDR while waiting for the construction project proposal outcome.
- Initiate the detailed design phase, build pre-production cartridges, and prepare for the Critical Design Review.



ALMA Band 2 Prototype Project



Secure MMIC chips for production phase

Chip	Cryo-Probe Yield	Comments
EBLNA81BC (75%In)	300	Fallback first-stage, Preferred second-stage
EBLNA81BC(100% In)	251	Fallback second-stage
90LN2A (75%In)	54	Preferred first-stage
90LN2A (100% In)	51	Preferred first-stage

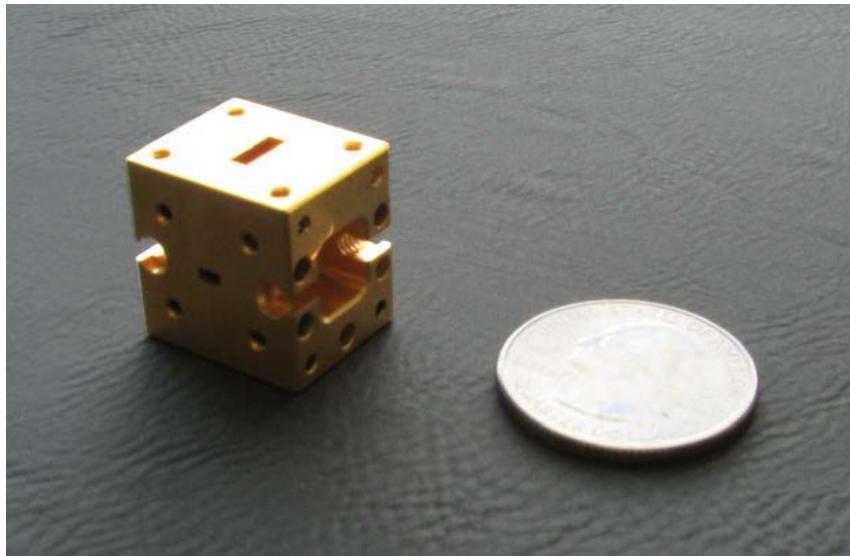
Second wafer run (already paid for as part of CRAL subcontract) will have:

- the preferred first-stage (90LN2A) in production quantity
- existing alternate second-stage designs (116LN1B) in production quantity
- newly modified second-stage EBLNA81 with improved slope characteristics

ALMA Band 2 Prototype Project

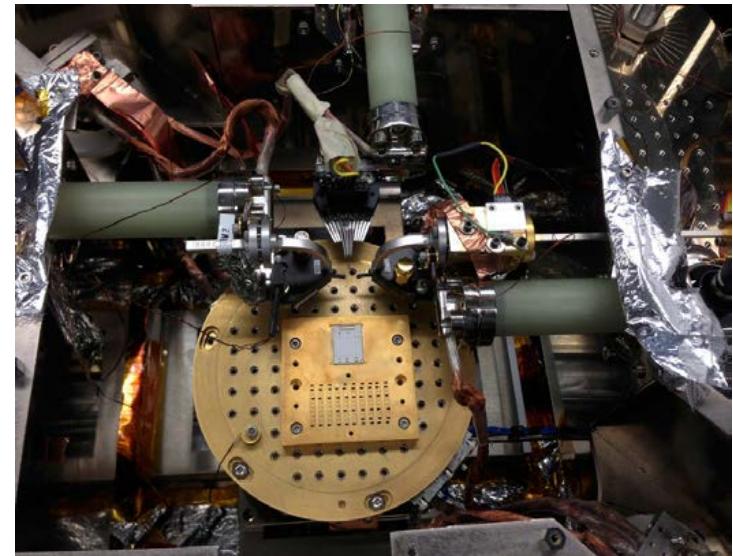
ALMA
Band 2
67-90 GHz

Secure MMIC chips for production phase



Single-chip packages:

- Most accurate way to characterize the chip design
- Gain, noise temperature, linearity, bias optimization



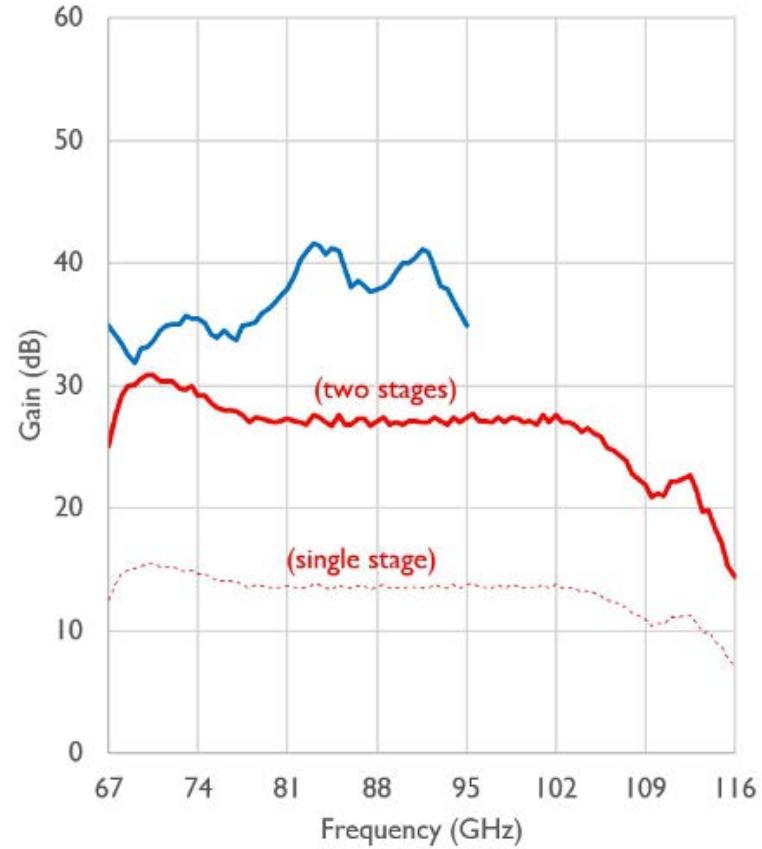
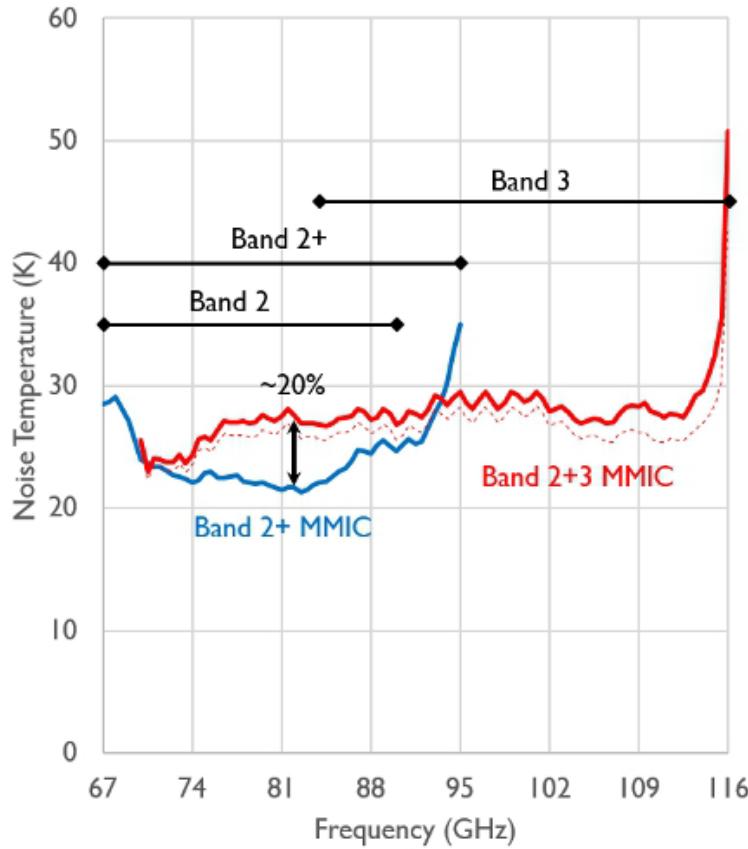
Cryogenic probing:

- Cools up to 100 chips at once
- non-destructive way of selecting the best performers from the wafer

ALMA Band 2 Prototype Project



The cost of bandwidth (Band 2 / 2+ / 2+3)



Band 2+3 data taken from: D. Calle, D. George, G. Fuller, K. Cleary, L. Samoska, P. Kangaslahti, J. Kooi, M. Soria, M. Varonen, R. Lai, and X. Mei, "Broadband MMIC LNAs for ALMA band 2+3 with noise temperature below 28 K," *IEEE Trans. Microw. Theory Techn.*, vol. 65, no. 5, May 2017.



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