EVLA Front-End CDR

EVLA
Ka-Band (26-40 GHz)
Receiver

EVLA Ka-Band Receiver Overview

1) **General Description**
2) **Block Diagram**
3) **Noise & Headroom Model**
4) **Feed & Thermal Gap**
5) **RF Tree** - ***Phase-Shifter***
   - ***OMT***
   - ***LNA's***
6) **Prototype Component Tests** - ***W/G Dewar Penetration***
   - ***Calibration Path***
7) **Block Converter MMIC Module**
8) **Project Status**

General Description

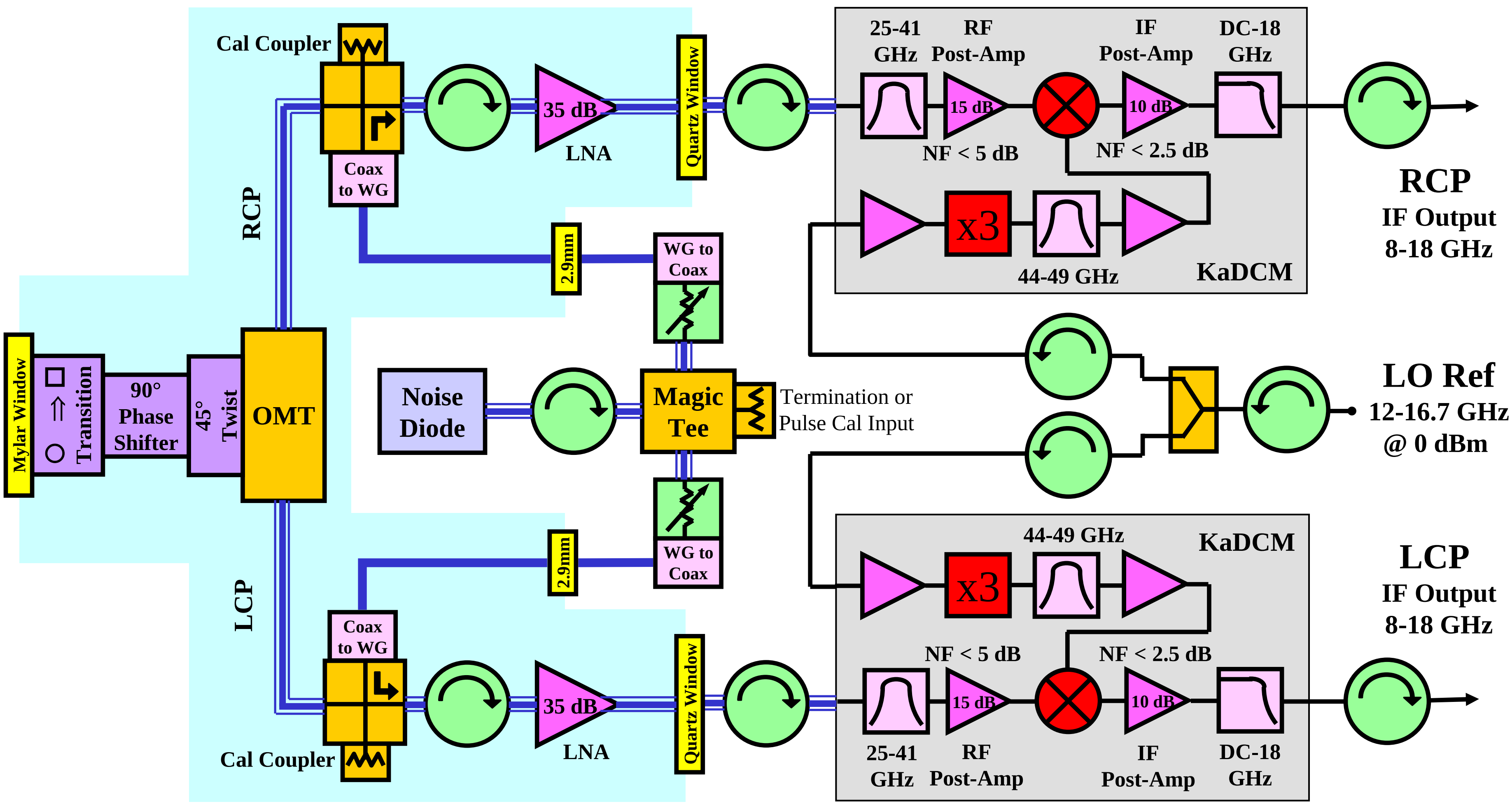
- The Ka-Band (26.5-40 GHz) receiver provides a brand new frequency band for the VLA
- Relatively straightforward "hybrid" of existing K & Q-Band receiver designs
    - **Scaled K-Band Polarizer largely verified in the GBT 1cm receiver**
    - **Waveguide output similar to Q-Band**
- Dewar will be largely be based on the C-Band receiver design
- Utilizes novel MMIC-based Block Converter
- Potential future installation on the VLBA for tracking and navigation of deep space probes for NASA

EVLA Ka-Band Receiver Block Diagram

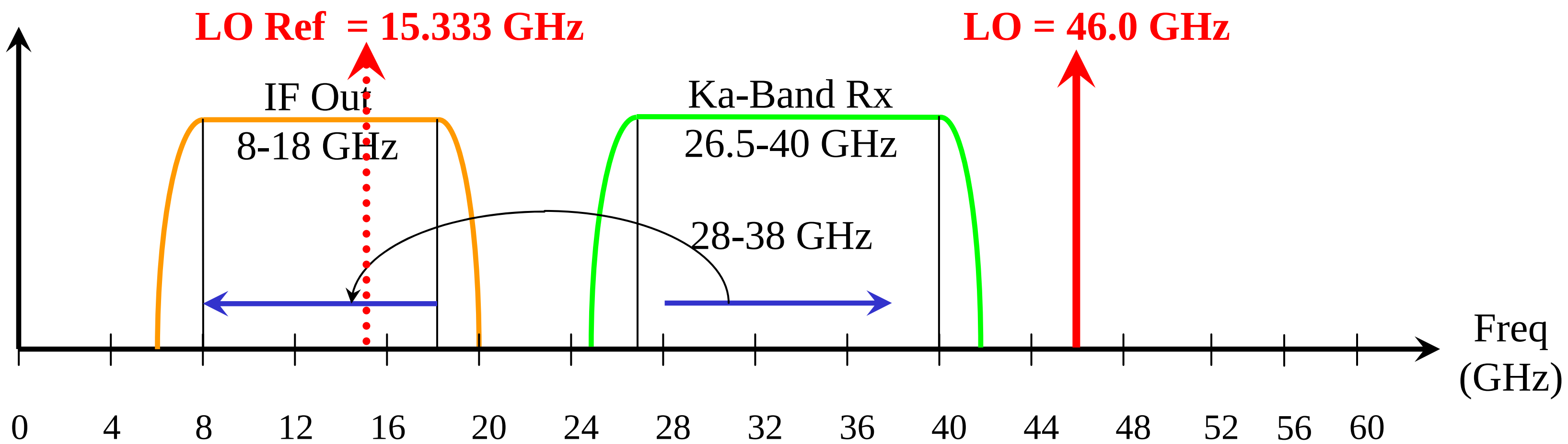
Key:

- Cryogenic Dewar
- Vacuum Window
- MMIC Module
- WR-28 Waveguide
- Coaxial Cable, 2.9mm
- Coaxial Cable, SMA

Expanded Very Large Array



Ka-Band Block Conversion Frequency Diagram



- Translation of 28-38 GHz down to 8-18 GHz
- LO Ref 15.333 GHz x 3 = 46 GHz
  - **Closest L301 Lock Point is actually 15.232 GHz**

Estimated EVLA Ka-Band

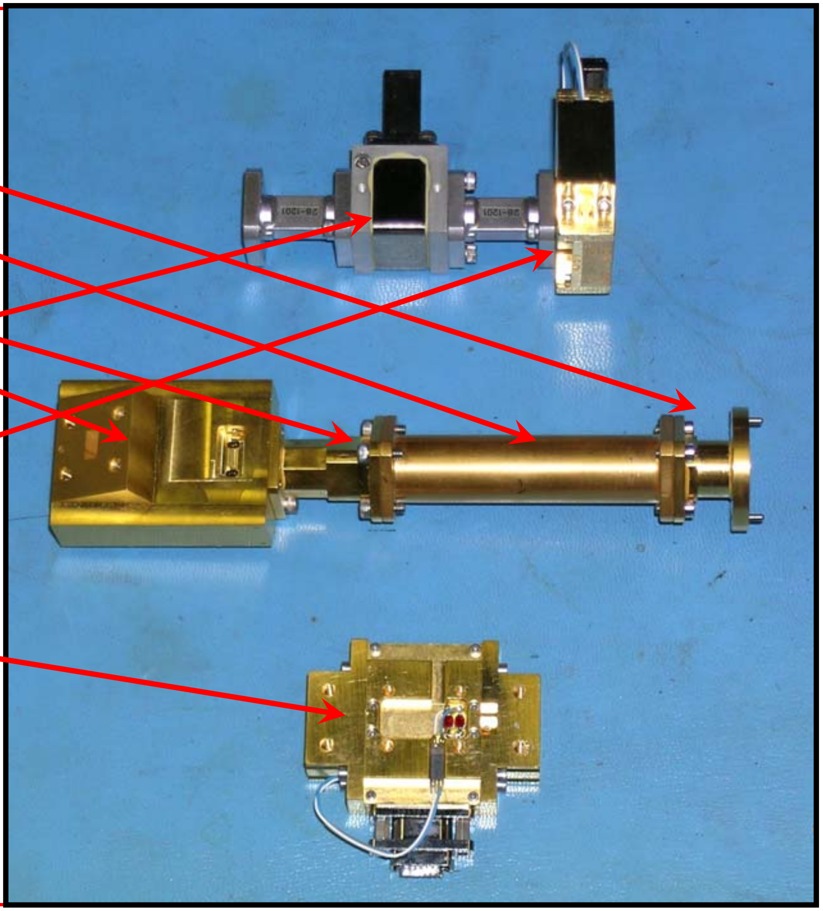
T_{Rx}, Output Power & Headroom

EVLA Ka-Band Rx (RHH : 28 March 2006)	P (1dB) (dBm)	P (1%) (dBm)	Temp (K)	NF/C (dB)	Loss/Gain (dB)	Loss/Gain (linear)	Delta T (K)	Trx (K)	BW (MHz)	Pnoise (dBm)	Pnoise dBm/GHz	Headroom (dB)
										for Tsky of		
										13.0		
										(K)		
									18000	-84.9	-97.5	
Weather Window			300		-0.05	0.9886	3.474			-83.9		
Feed Horn			300		-0.05	0.9886	3.514			-83.1		
Vacuum Window			300		-0.01	0.9977	0.708			-83.0		
Phase Shifter			15		-0.1	0.9772	0.358			-83.0		
OMT			15		-0.2	0.9550	0.742			-83.1		
Waveguide			15		-0.1	0.9772	0.384			-83.1		
Cal Coupler (IL)			15		-0.2	0.9550	0.795			-83.1		
Cal Coupler (Branch)			300	-30	0	1.0000	0.300			-83.1		
Isolator			15		-0.5	0.8913	2.155			-83.2		
LNA	-10	-22	20		35	3162.2777	26.426			-45.1		23.1
Stainless Steel W/G			157.5		-2	0.6310	0.038	38.89		-47.1		
Vacuum Window			300		-0.2	0.9550	0.009			-47.3		
Waveguide			300		-1	0.7943	0.054			-48.3		
Isolator			300		-0.5	0.8913	0.032			-48.8		
RF Post-Amp	15	3	637.9	5	13	19.9526	0.625			-35.7		38.7
RF Filter (25-41 GHz)			300		-1	0.7943	0.004		14000	-37.8	-49.3	
Attenuator			300		-5	0.3162	0.040			-29.8		
RF Post-Amp	15	3	637.9	5	13	19.9526	0.125			-29.8		32.8
Mixer (Level 10 + 5dB)	3	-9	300		-14	0.0398	0.071			-43.8		20.8
IF Filter (DC-18 GHz)			300		-1	0.7943	0.019		14000	-44.8	-56.3	
Post-Amp	18	6	229.6	2.5	13	19.9526	0.071			-31.8		37.8
Attenuator			300		-3	0.5012	0.005			-34.8		
Isolator			300		0.5	1.1220	-0.001	39.95		-34.3		

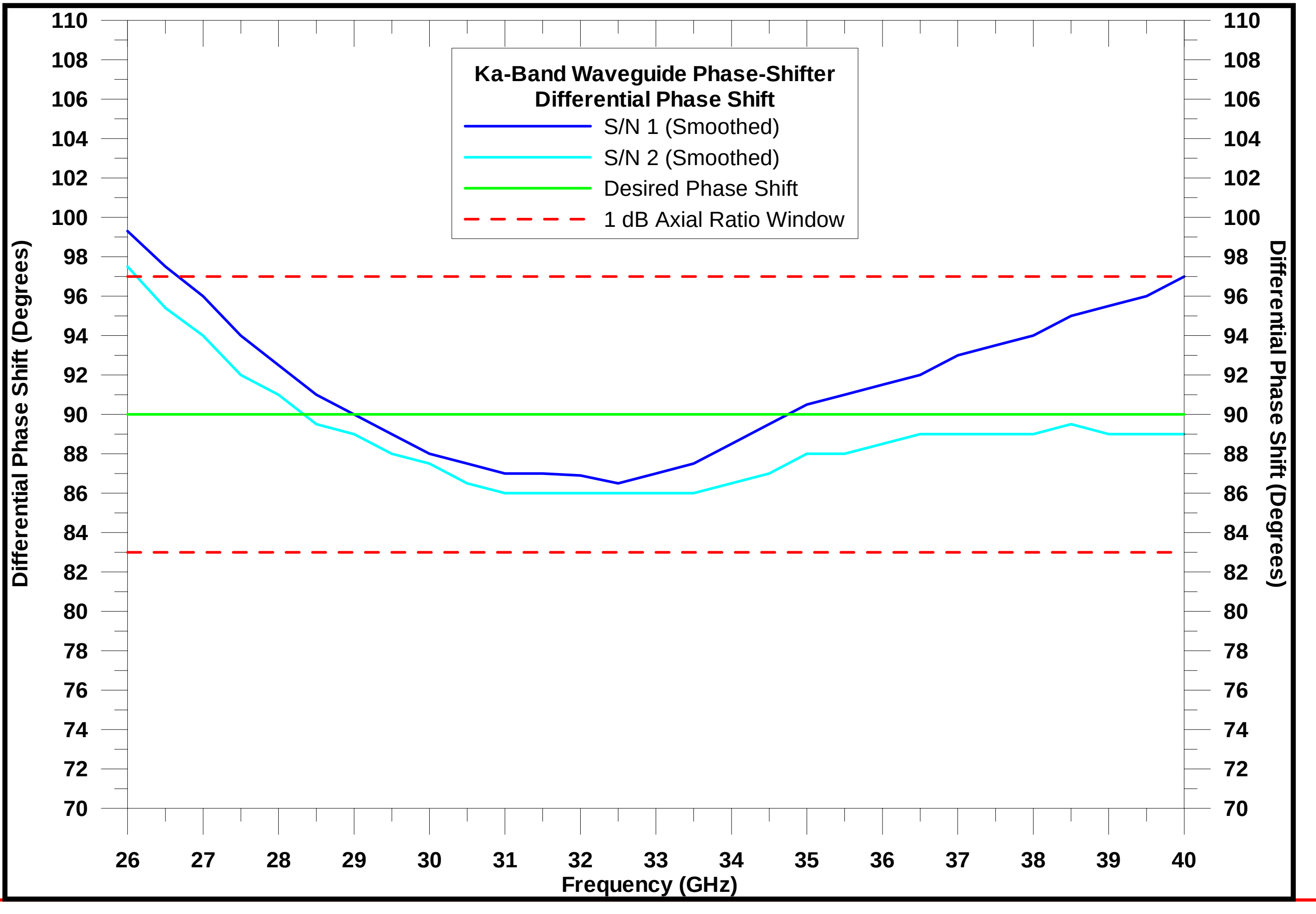
Ka-Band Feed

Ka-Band RF Tree

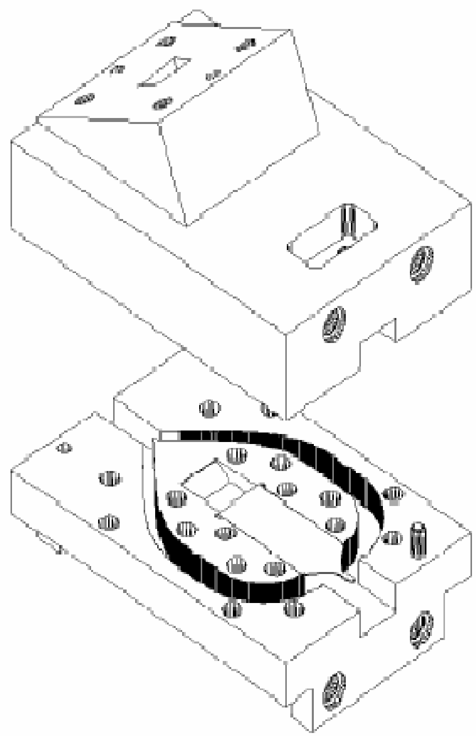
- "Srikanth" designed Ka-Band versions of
  - **Circular-to-Square Transition**
  - **W/G Corrugated Phase-Shifter**
  - **45 Degree Twist Section**
- "Wollack" Ortho-Mode Transducer
- NRAO Cal Coupler (not shown)
- Cryogenic Isolator
  - **Pamtech or Dorado**
- CDL MAP-style LNA
- Output WR-28 waveguide path will need complicated bends & twists for alignment and thermal stress relief
  - **Prototype Rx will use flexguide**



Ka-Band
Srikanth Phase-Shifter



Ka-Band
Wollack-style OMT



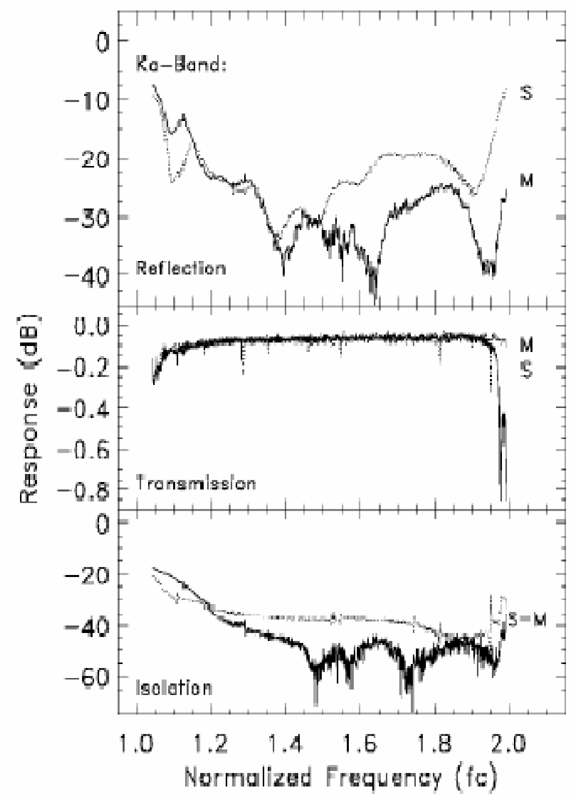
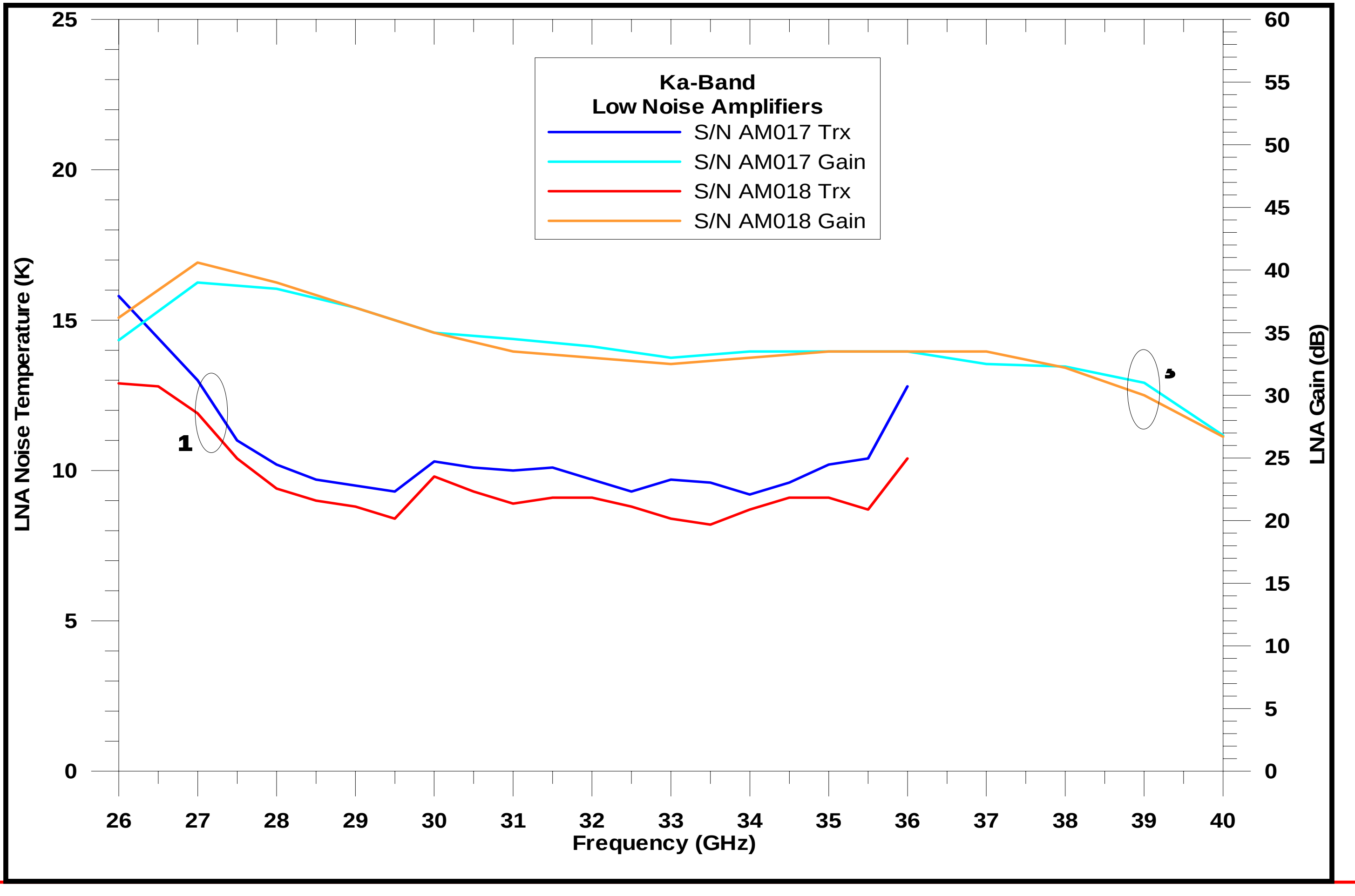


Figure 8: WR28.0 BøifotJunction OMT (fc=21.08GHz). The solid and dashed lines are respectively the side- and main-arm responses for refection and transmission. The solid isolation line is with a load on the common-arm; the dashed line is with a short on the common-port

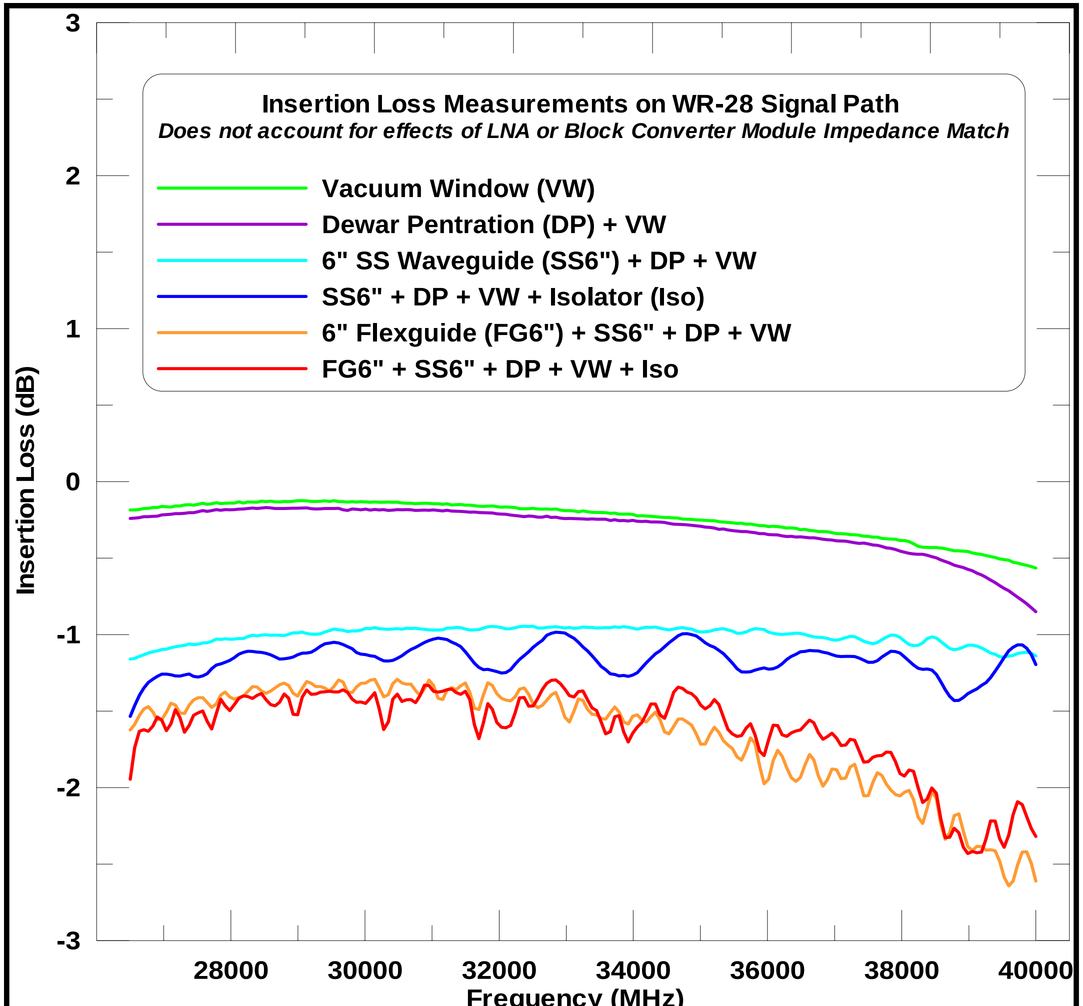
CDL Ka-Band Low Noise Amplifiers



WR-28 Dewar Output Penetration Fixtures

- Rather than fabricate new WR-28 waveguide windows, we will reuse the commercial vacuum windows & custom-made dewar penetration fixtures preserved from the old A-Rack receiver package.
  - The long-ago decommissioned VLA C-Band parametric amplifiers was once fed by a 32 GHz pump.
- We have managed to find about 116 units and 135 windows.
  - More than enough for 30 EVLA and 11 VLBA receivers
- The supposedly narrowband units were found to have a surprisingly flat and low-loss broadband response.
  - Less than 1 dB across 26.5-40 GHz

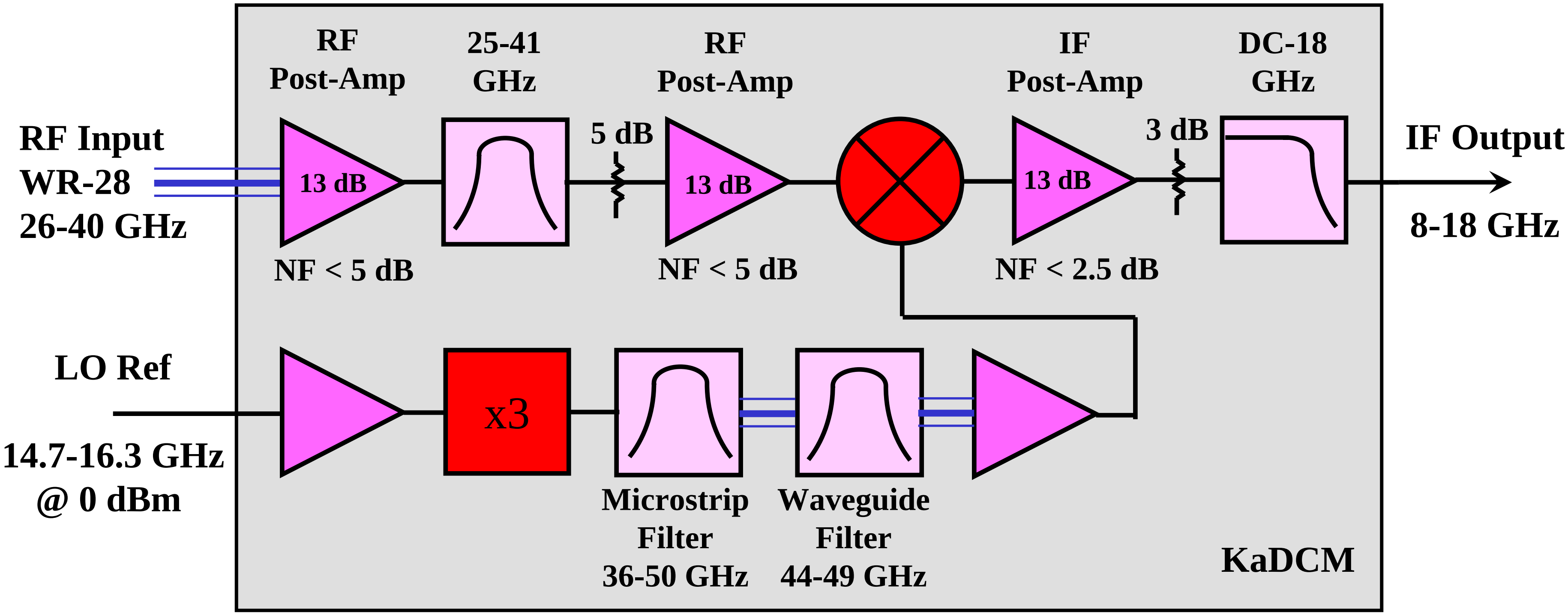
Dewar Penetration Insertion Loss Tests



Ka-band Down-Converter Module *(KaDCM)*

- Ka-Band Downconverter Specifications:
  - RF Frequency Range = 26 - 40 GHz
  - LO Frequency Range = 14.7 - 16.3 GHz
  - IF Frequency Range = 8 - 18 GHz
  - RF to IF Gain = 14 +/- 2 dB
  - Noise Figure < 6.5 dB
  - Input P_{1dB} = -16 dBm
  - LO Reference to IF leakage > -60 dB

KaDCM Block Diagram

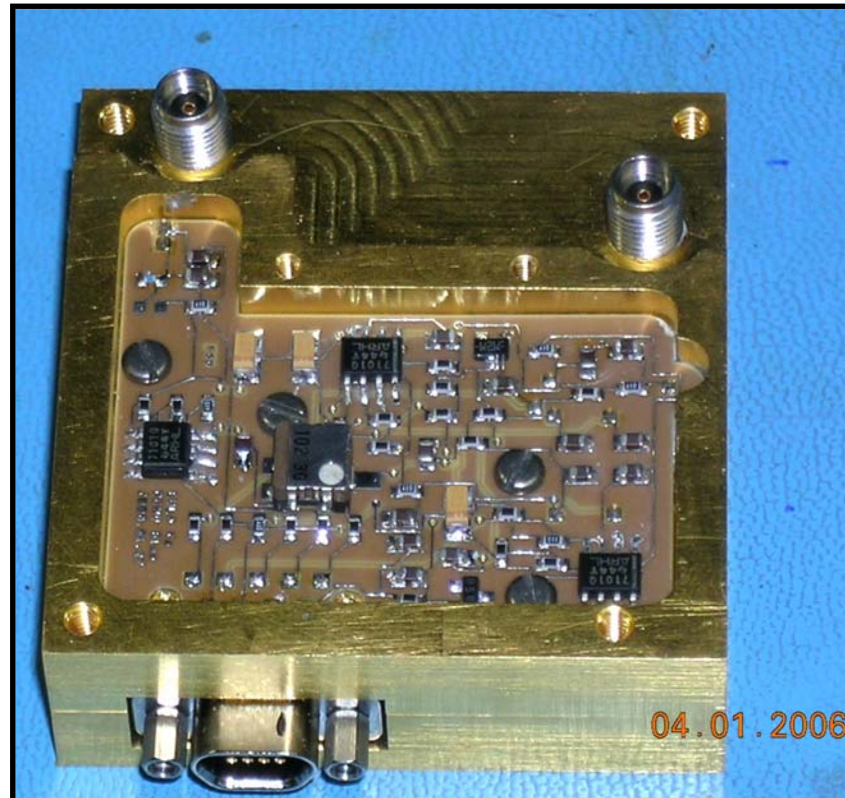


In theory, this design optimizes the RF-to-IF signal path to achieve maximum headroom while minimizing its noise contribution.

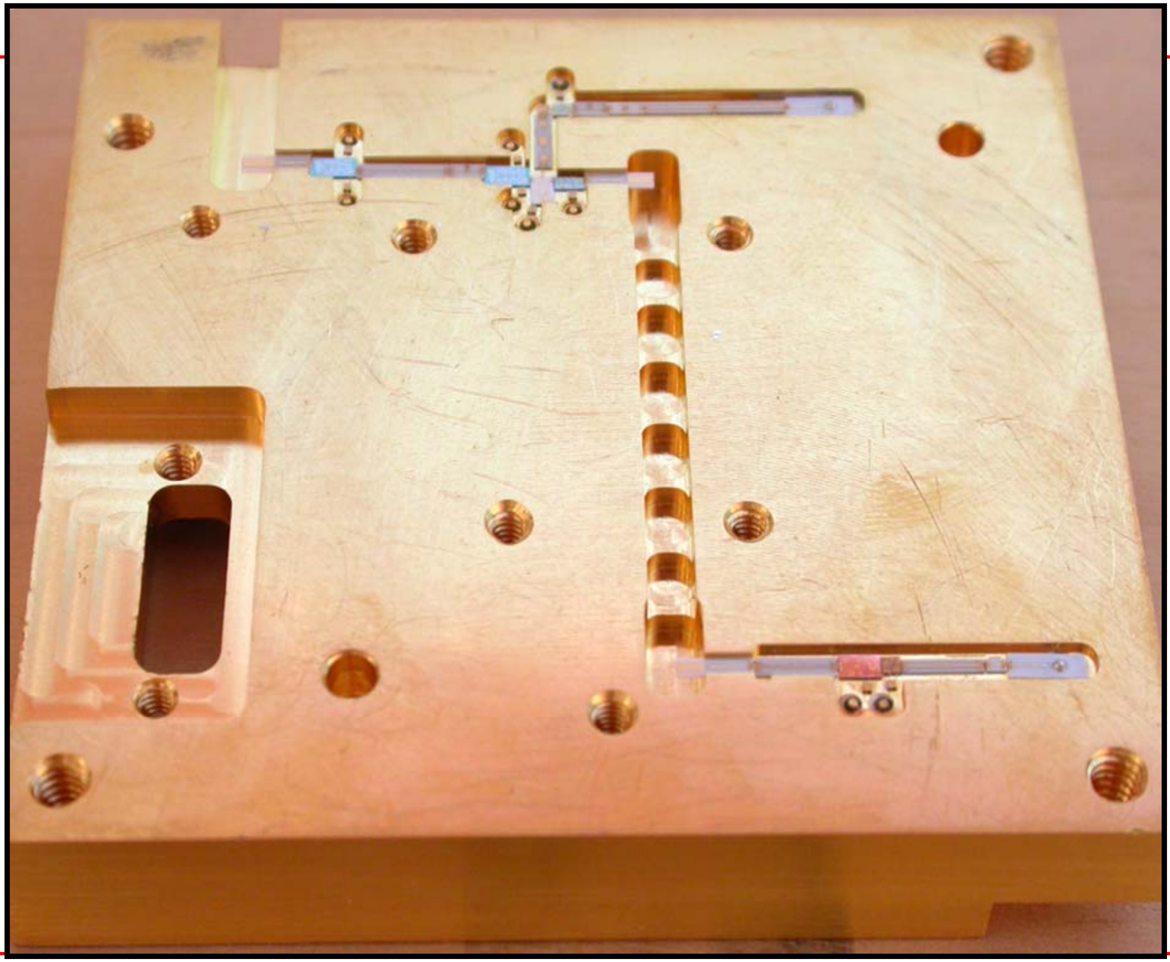
KaDCM Design

- The design of the Ka-band Down-Converter Module (KaDCM) was contracted out to the Microwave Group of Caltech's Electrical Engineering Department (i.e., Sandy Weinreb).
- The KaDCM design uses custom mixer and tripler MMIC's, designed by M. Morgan (now at CDL), which were fabricated on a United Monolithic Semiconductors (UMS) wafer.
- Caltech delivered a functioning first article KaDCM in Q3 2005, as well as a 2nd assembled but untested unit, for use in the Ka-Band prototype receiver.
- Once the performance of the KaDCM has been verified, NRAO will fabricate the 66 units required for the EVLA receivers (and the 22 VLBA units, if needed) in-house.

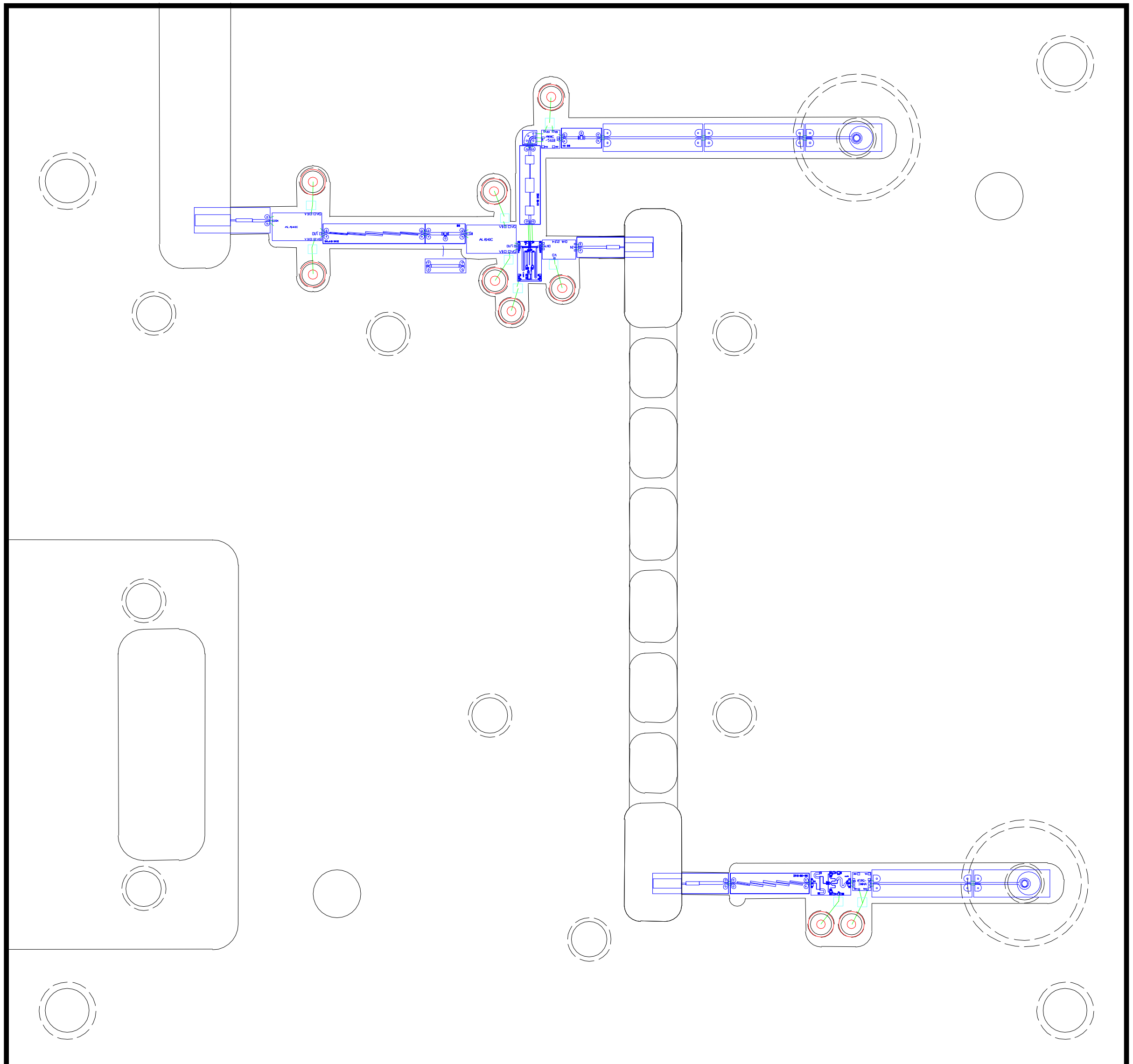
KaDCM Block Exterior and Bias Card



KaDCM MMIC Channels & LO Filter



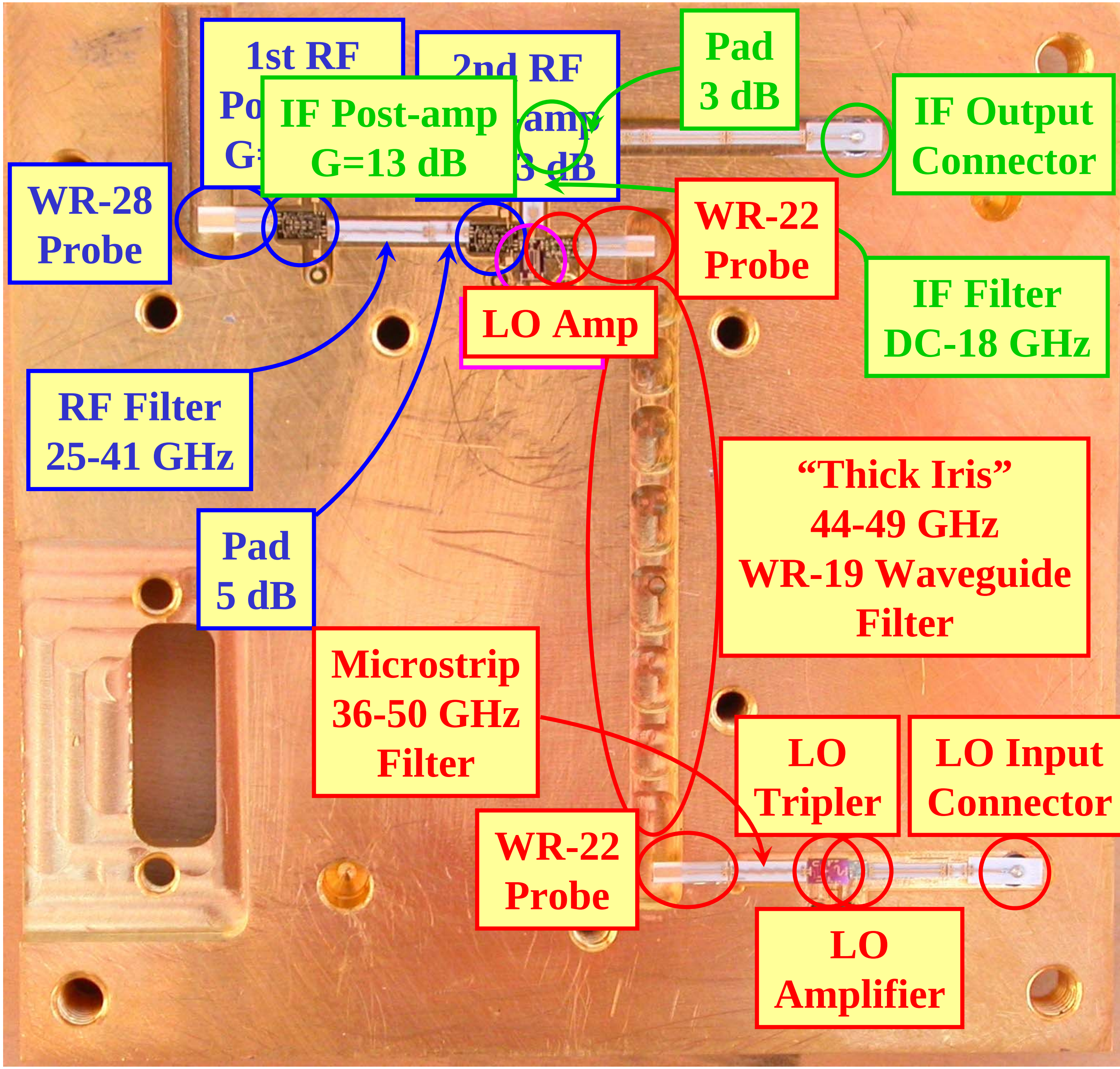
EVLA KaDCM



Co-Planar W/G Circuit Board & MMIC Component Layout

The KaDCM contains:

- 7 MMIC Devices
  - 5 Amplifiers (Agilent)
  - 1 Custom Mixer (UMS)
  - 1 Custom Tripler (UMS)
- 14 CPW boards
- Approx 75 wire bonds



1st RF Post-amp G=
2nd RF Post-amp 13 dB
IF Post-amp G=13 dB
Pad 3 dB
IF Output Connector
WR-28 Probe
WR-22 Probe
IF Filter DC-18 GHz
LO Amp
RF Filter 25-41 GHz
Pad 5 dB
"Thick Iris" 44-49 GHz WR-19 Waveguide Filter
Microstrip 36-50 GHz Filter
LO Tripler
LO Input Connector
WR-22 Probe
LO Amplifier

KaDCM Design Issues

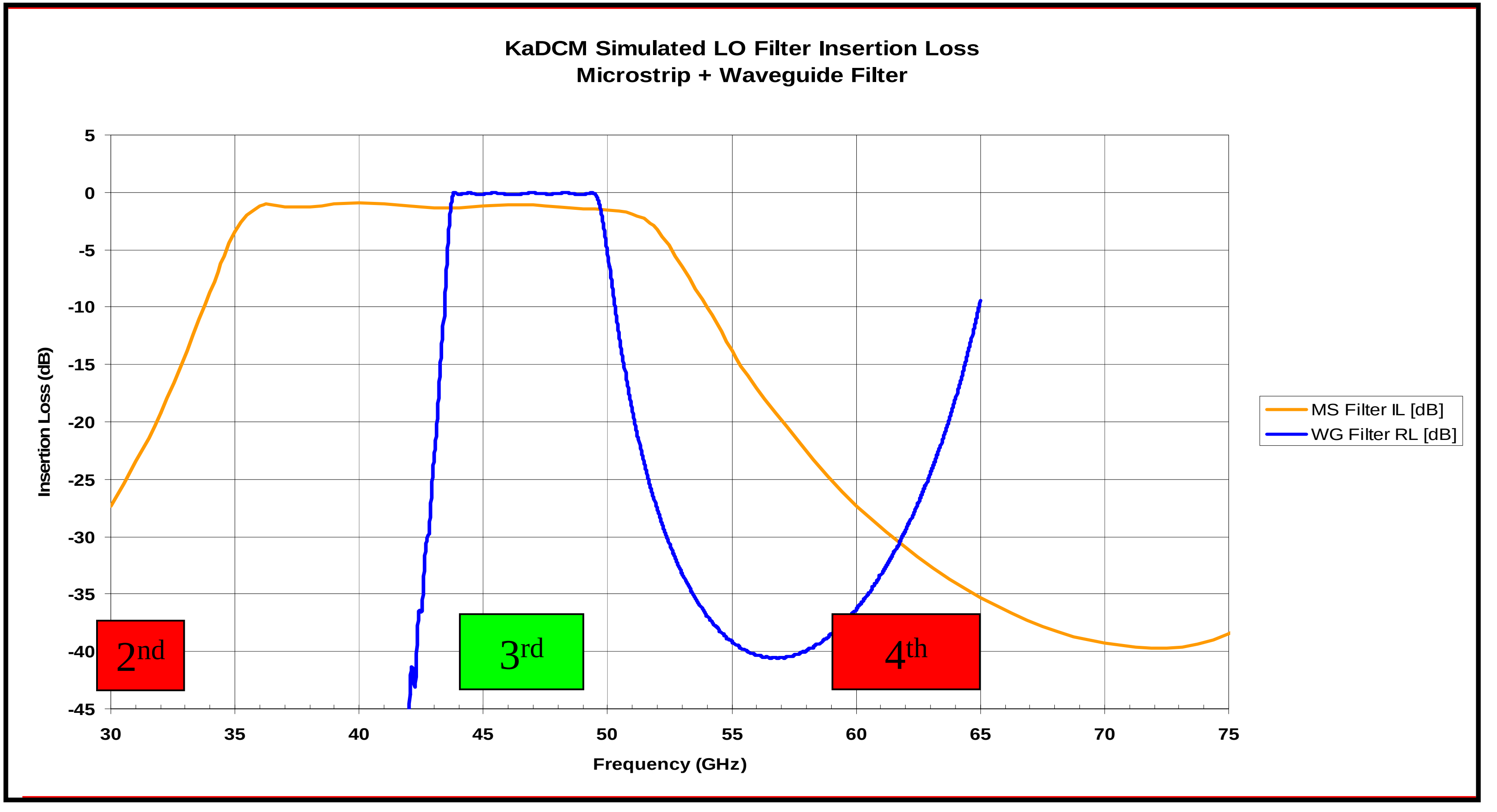
- The LO to IF leakage specification proved to be the most difficult requirement to meet.
  - The 14.7-16.3 GHz LO reference can leak into the 8-18 GHz IF output range
  - This type of direct coupling is minimized by a well designed physical layout
- A more subtle type of leakage arises from intermodulation products of the LO harmonics.
  - For example, when the LO fundamental input is set to 16.0 GHz, the desired 3rd harmonic of the LO reference will be 48.0 GHz while the 4th will be at 64.0 GHz.
  - If the mixer sees a strong 4th harmonic, it will generate a 4th minus 3rd intermod which will exit the mixer at 16.0 GHz, right in the middle of the EVLA 8-18 GHz IF.
  - Consequently the level of the unwanted 4th harmonic must be strongly rejected.
- To mitigate the detrimental effect of this in continuum observations, the 4th-3rd LO leakage term (as determined by Barry Clark) must be 25 dB below the broadband power in the 8-18 GHz IF.
  - The estimated output level when looking at cold sky of the KaDCM IF is about -35 dBm.
  - This means the 4th-3rd LO spur present in the IF will have to less than -60 dBm.
  - Since the mixer requires an LO power level of +10 dBm at the desired 3rd harmonic, the level of the unwanted 4th harmonic will be about -10 dBm, assuming its power is down by - 20 dB.
  - Balanced mixers typically have a 20 dB rejection of signals on the LO port. Using a more conservative 15 dB value, the resulting intermod level at the mixer IF port is about -25 dBm.
  - With the 10 dB IF postamp gain, the spur will be rise to -15 dBm, which is **45 dB too high**.

KaDCM Design Issues

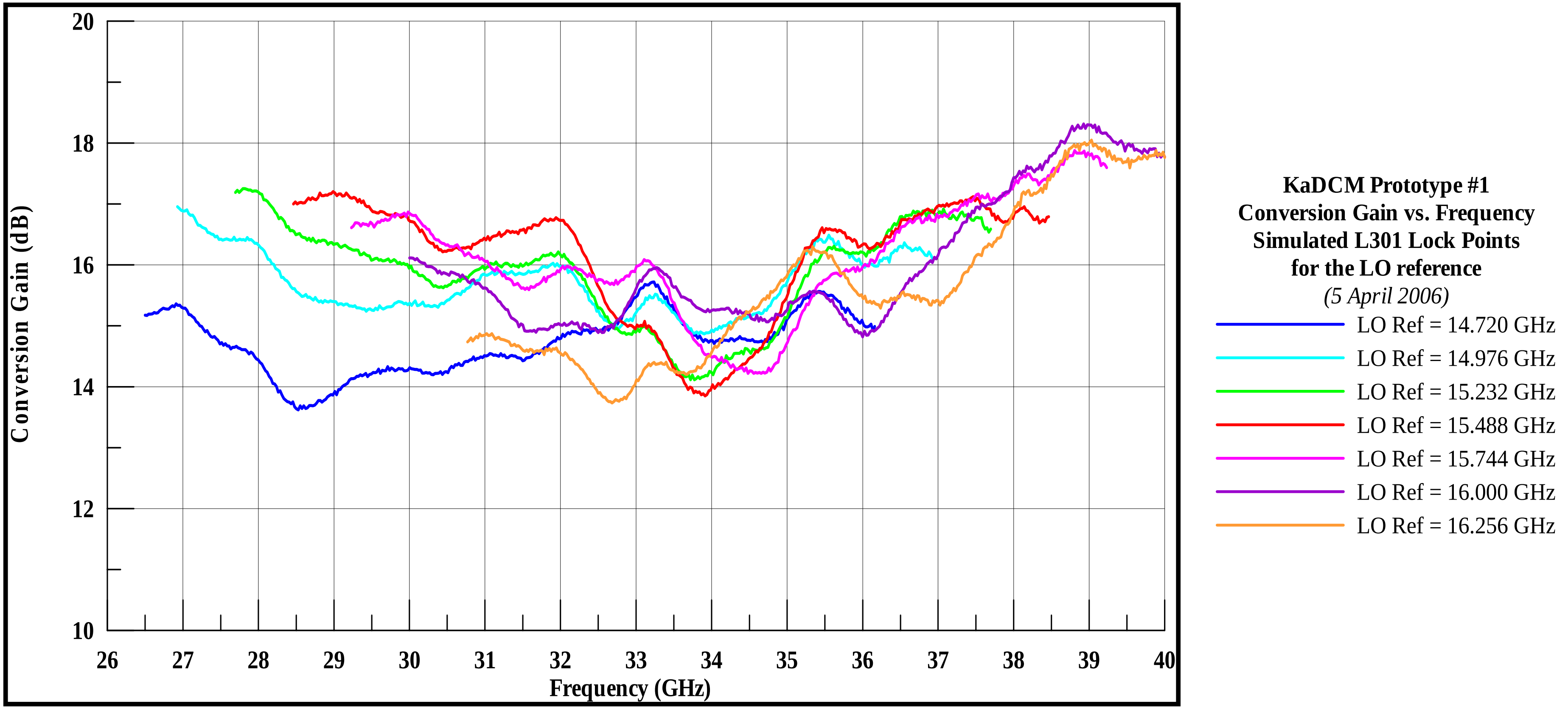
- Thus to meet the -60 dBm spec, the level of the unwanted 4^{th}-3^{rd} LO leakage term at the mixer must be reduced by at least 45 dB.
- To achieve this extra rejection, the output of the tripler requires an additional stage of filtering to reject the 4^{th} harmonic.
  - A microstrip filter does not have a very high Q but has high out of band rejection.
  - A waveguide filter has high Q but poor rejection at high frequencies where it becomes over-moded.
- The KaDCM utilizes a 36-50 GHz microstrip filter followed by a “Thick Iris” 44-49 GHz waveguide filter by (both designed by M. Morgan, NRAO-CDL). This cascaded filter is well matched to the desired 44-49 GHz 3^{rd} harmonic.

- **Note that in spectral line mode, when using a 10 KHz bandwidth, a level -41 dB below noise power in the 8-18 GHz IF is ideally required.**

LO Harmonic Filtering



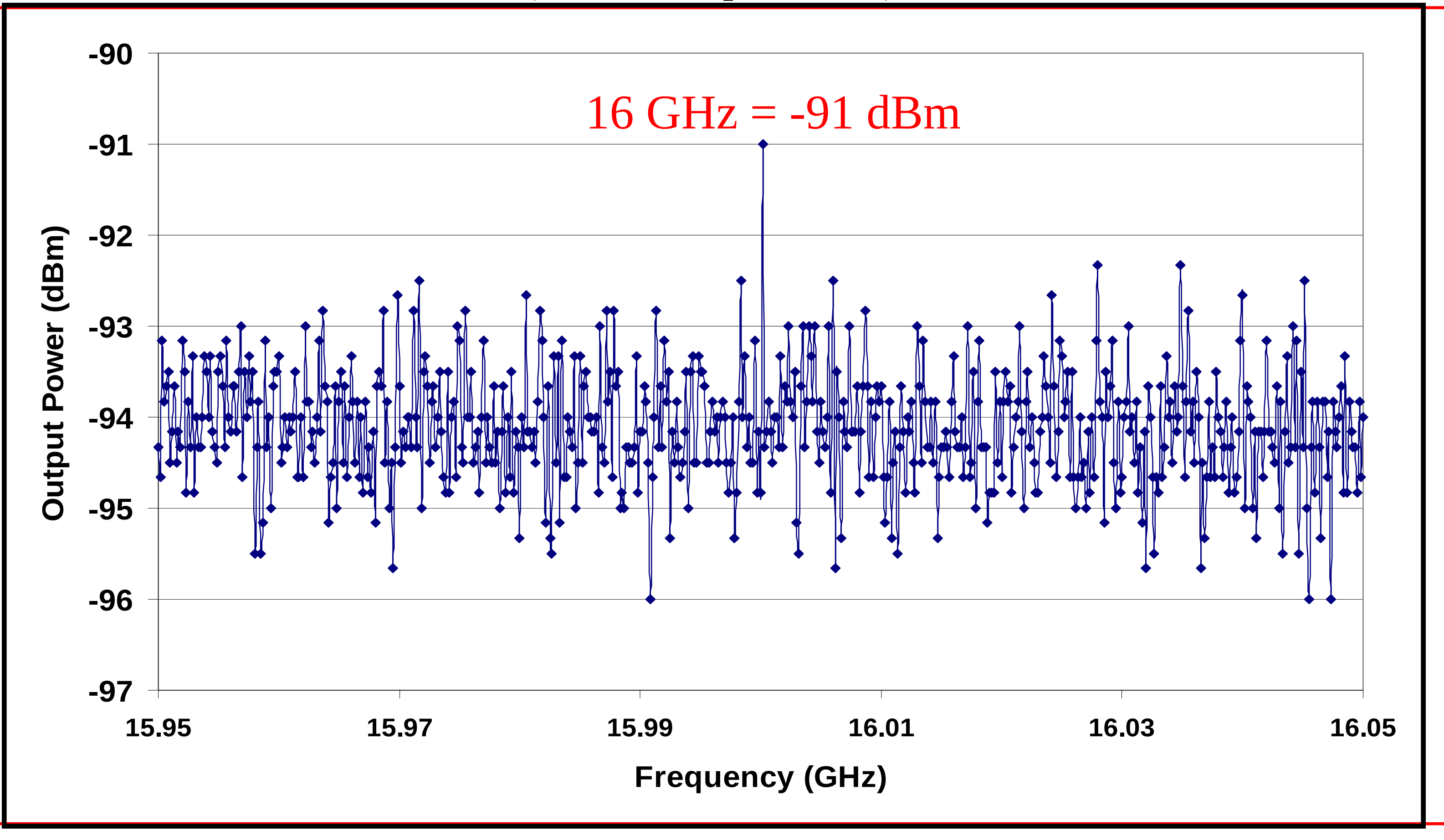
KaDCM Prototype #1
Conversion Gain vs. Frequency
Simulated L301 Lock Points



Spectrum Analyzer Measurement of KaDCM LO Ref Leakage

LO Ref = 16 GHz @ 0 dBm & RF = Off

(RHH : 5 April 2006)



KaDCM Headroom ?

- Recent tests indicate that the prototype KaDCM does not achieve the expected compression level.
  - **Input power P(1dB) spec = -16 dBm**
  - **Measured Input P(1dB) < -22 dBm**
- Hopefully can play with RF & IF gains to mitigate the mixer compression.
- If this cannot be improved, it would adversly affect the Ka-Band Rx Headroom (defined as how far the typical operating point (i.e., cold sky) is below the 1% compression point).
  - **Would reduce current 21 dB Headroom to 15 dB**
  - **Project Book Spec = 20 dB**

KaDCM Unit Cost

- Assumes minimum of 66 KaDCM units
- Direct Cost = $2,200
- Indirect Cost = $5,000
  - if include pro-rated costs (with QPAM) of
    - Caltech contract
    - Wafers
    - 50 GHz test equipment
    - Wire bonder & accessories, etc.

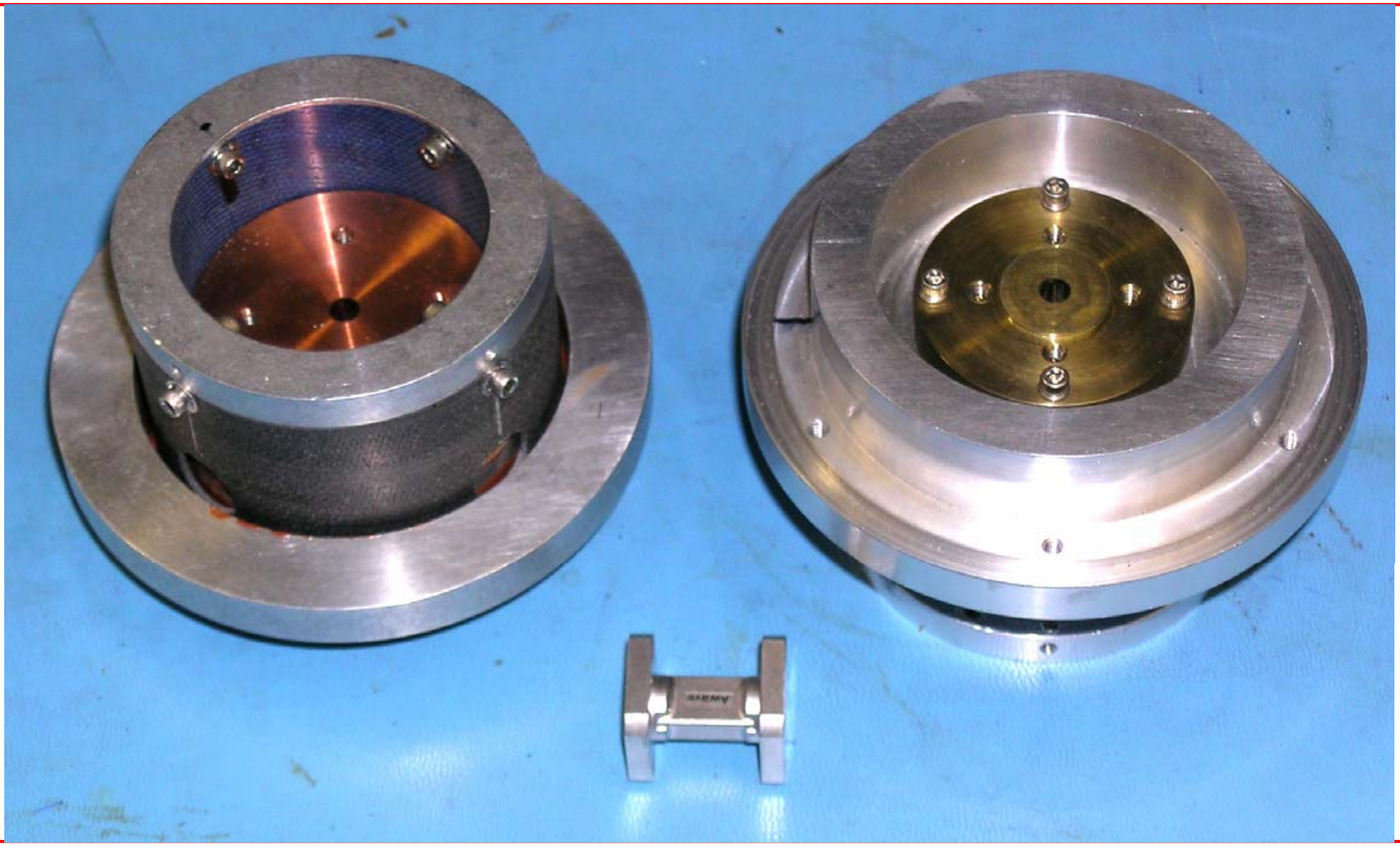
Ka-Band Receiver Project Status

- Due to other pressures and diversions, the development of the Ka-Band receiver has been slower than originally planned.
- Most of the commercial components and custom waveguide components for the prototype system are in-house.
- Hope to complete the design, construction and evaluation of the prototype in 2006.
- Production slated to begin in 2007.
  - **Receivers will be built at or exceed the antenna outfitting schedule.**

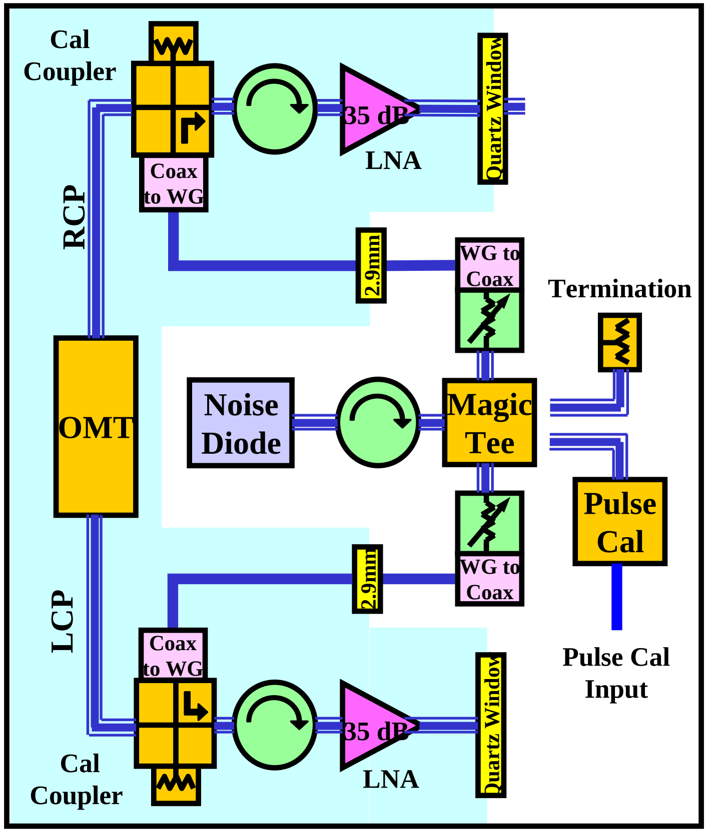
Questions ?

Backup Slides

Thermal Gap Assembly (Q-Band Example)



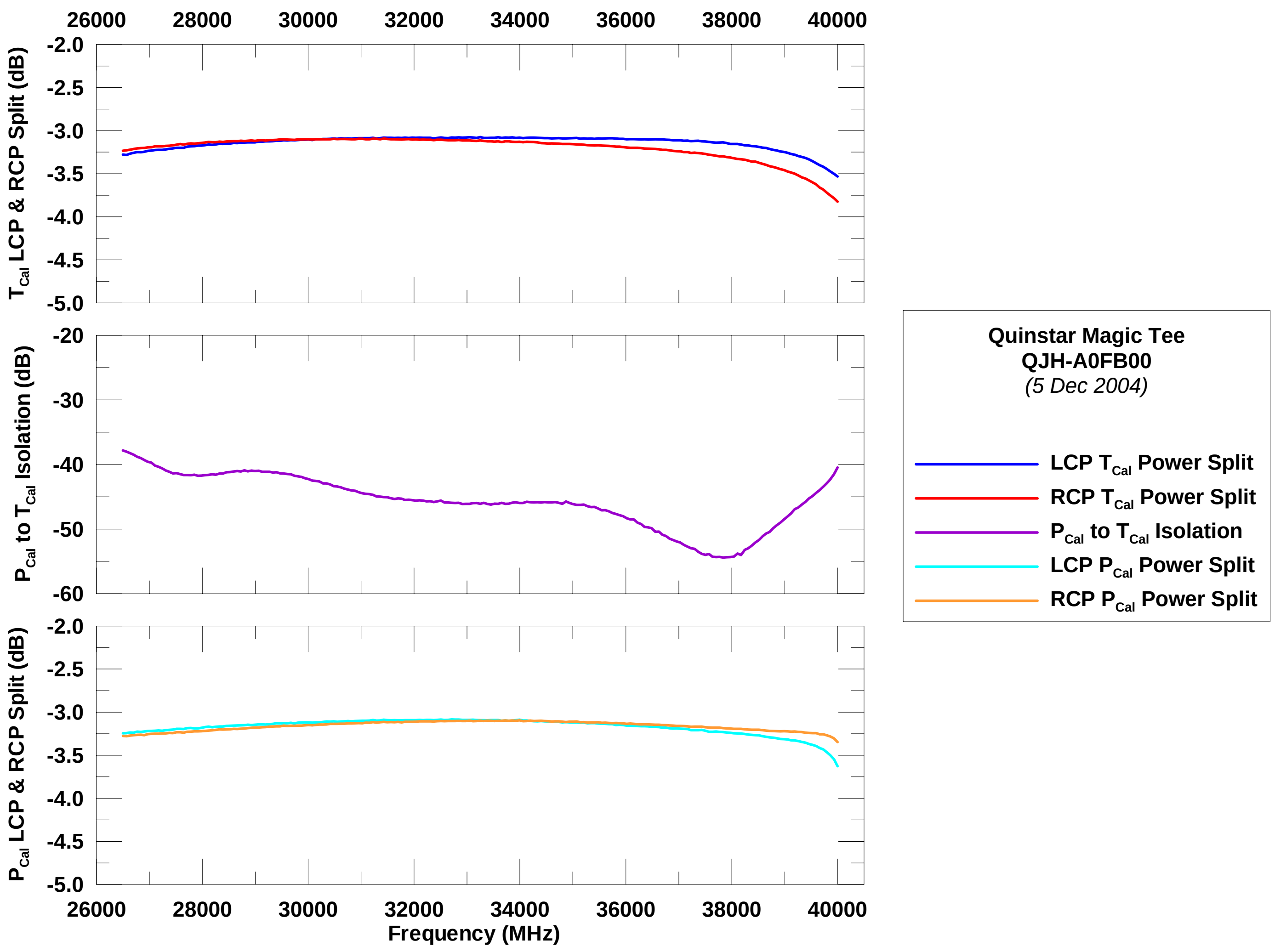
Calibration Path

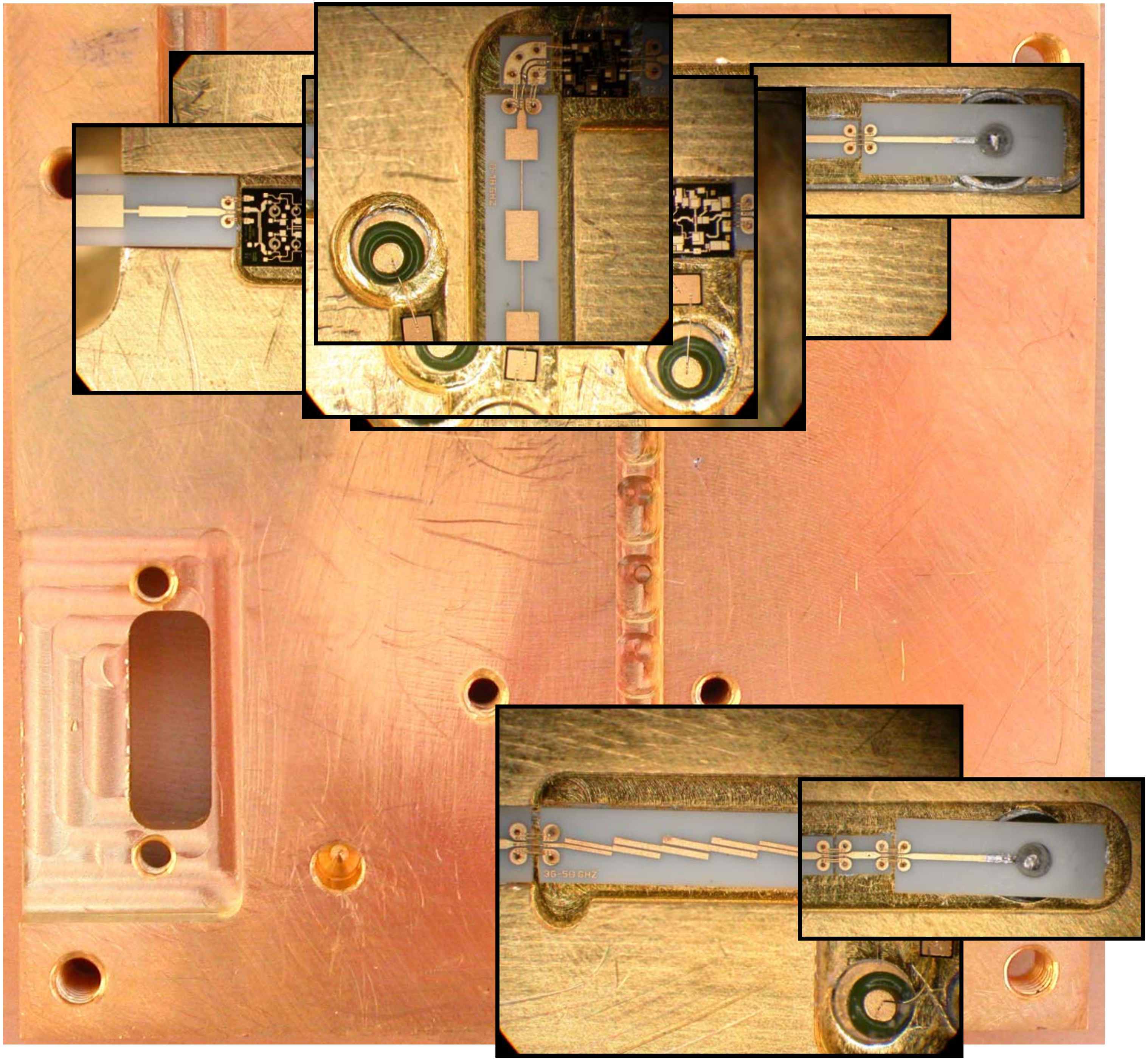


- Broadband Noise Source
- Magic Tee Splitter
- Separate Variable Attenuators
  - From old A-Rack 32 GHz Paramp
  - Have found 34 out of the 60 needed
  - Will have to purchase the rest
- Hermetic 2.9 mm Coax Bulkhead Feedthru Connectors
- Commercial Stainless Steel Cables with K-Connectors
- VLA/GBT WR-28 Cal Couplers (30 dB)
- Pulse/Phase Cal Option
  - Desirable for VLBA
  - Not needed on EVLA (use Termination)

Prototype Ka-Band Calibration Components

Magic Tee
Test Results

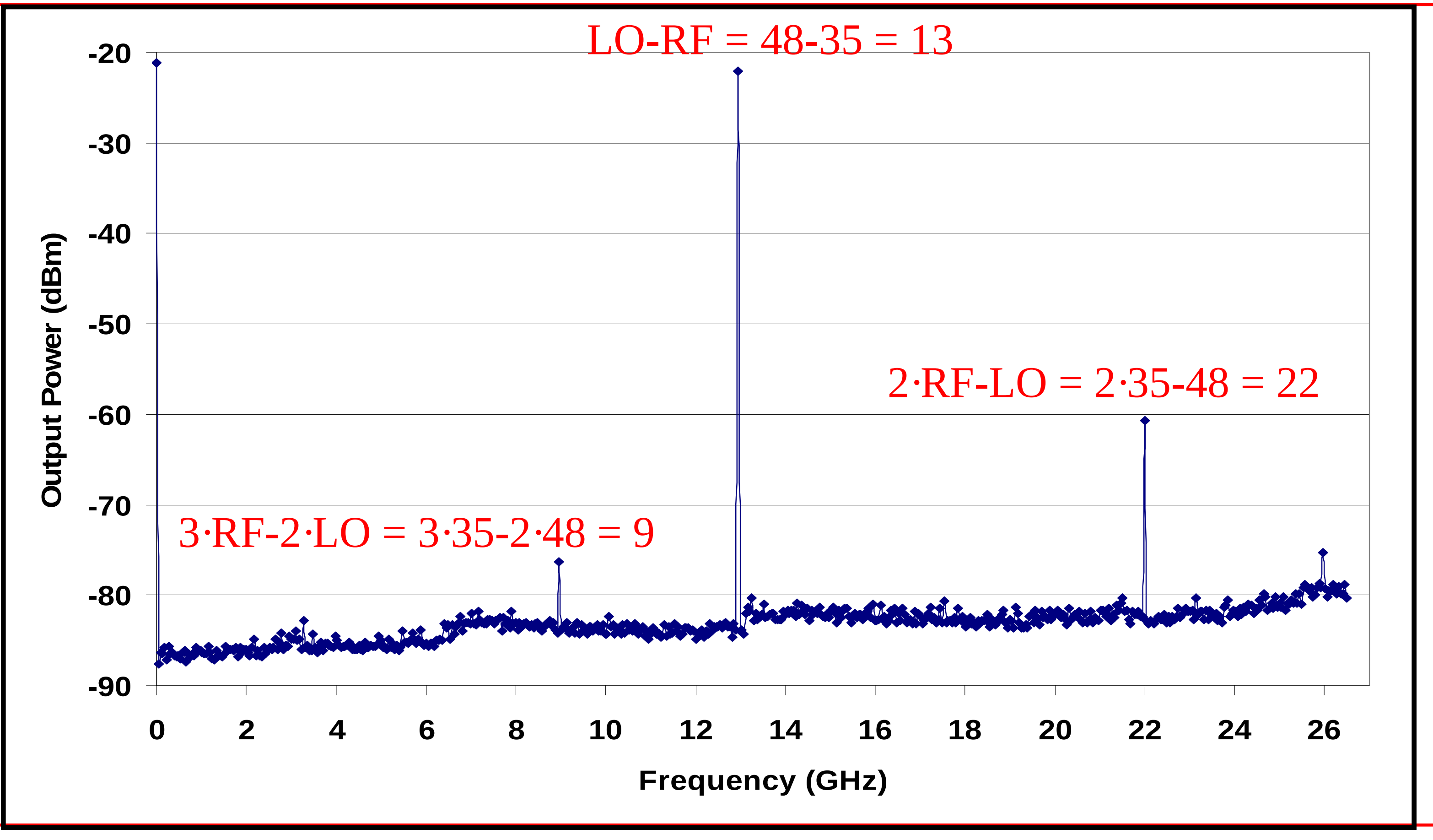



36-50 GHZ

Spectrum Analyzer Measurement of KaDCM LO Intermods

LO Ref = 16 GHz & RF = 35 GHz @ ???

(5 April 2006)



Spectrum Analyzer Measurement of KaDCM Output

LO Ref = 16 GHz & Swept RF = 30-40 GHz

(5 April 2006)