EVLA Receiver Issues

EVLA Advisory Committee Meeting, March 19-20, 2009

Robert Hayward - Systems Engineer for EVLA Front-Ends
Gordon Coutts - Microwave Engineer, Front-End Group
Sri Srikanth - Scientist/Research Engineer, CDL
Mike Stennes - Microwave Engineer, Green Bank

Atacama Large Millimeter/submillimeter Array
Expanded Very Large Array
Robert C. Byrd Green Bank Telescope
Very Long Baseline Array

NRAO

Past Front-End Issues

- At the EAC Meeting in Sept 2007, the most pressing issue reported in the EVLA Front-End receiver program was the development of wideband Orthomode Transducers (OMTs)
- A plan was presented which laid out a roadmap for obtaining…
  - Octave band Quadridge OMTs at L, S & C-Band
  - Two paths for developing a compact OMT for X-Band
- This plan has been implemented and we can now report…
  - The L, S & C-Band Quadridge OMT designs are complete
  - The S & C-Band OMTs are now in full production
  - The L-Band OMT is undergoing final cryogenic tests
  - Two different X-Band OMT designs have been fabricated and are in the process of being evaluated

EVLA

OMT Requirements

All EVLA receivers use
Low-Loss Circular Polarizers

Band	Freq (GHz)	Bandwidth Ratio	Circular Polarizer Type
L	1-2	2.00:1	Quad-Ridge OMT + 90 degree Hybrid Coupler
S	2-4	2.00:1	
C	4-8	2.00:1	
X	8-12	1.50:1	? Planar or Turnstile Junction ?
Ku	12-18	1.50:1	Srikanth Phase-Shifter + Wollack OMT
K	18-26	1.44:1	
Ka	26-40	1.54:1	
Q	40-50	1.25:1	Commercial Sloping Septum

Wideband Quadridge OMT Development
Past History

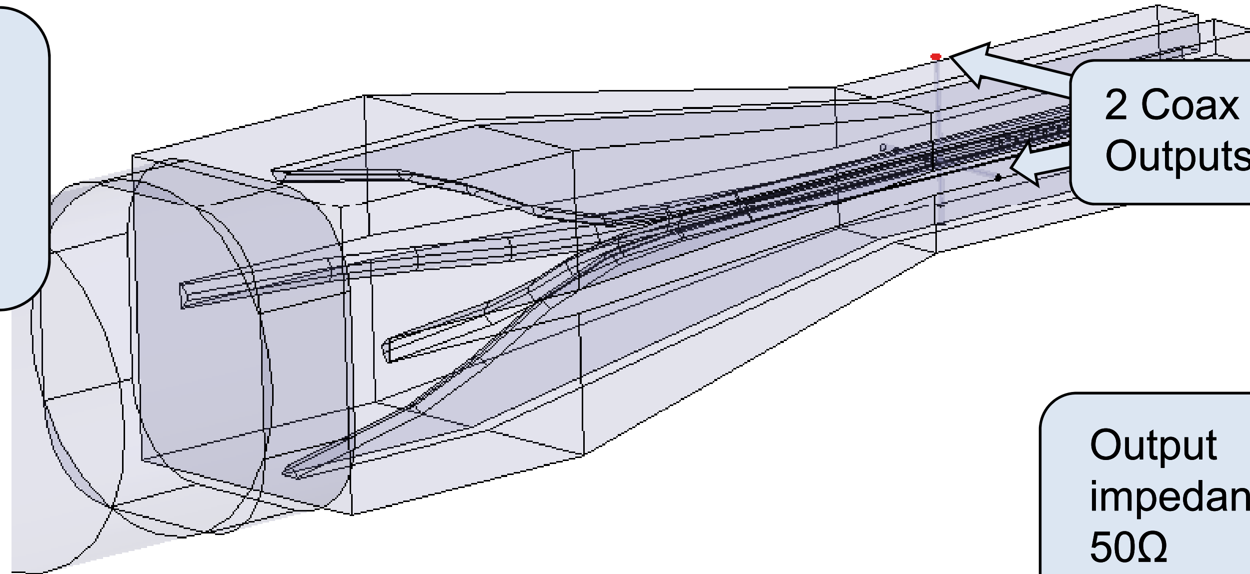
- Paul Lilie began OMT development effort in 2001
  - Novel square cross-section OMT structure for L-Band (1-2 GHz)
  - Trapped Mode suppression feature
  - After extensive HFSS simulations, a "Version 1" Prototype was machined & preliminary evaluation began in mid 2005
  - Cryogenic testing began Feb 2006 and this OMT was eventually installed in a modified VLA L-Band Dewar on Ant 14 in Oct 2006
  - Lilie retired in July 2006
- Lisa Locke hired in early 2004
  - Worked closely with Lilie
  - Helped scale L-Band OMT to C-Band (4-8 GHz)
  - Evaluation of machined "Version 1" Prototype began Oct 2006
  - Resigned in Dec 2006 to return to the NWT
- Mike Stennes at Green Bank was contracted in May 2007 to work on OMTs
  - Scaled the C-Band design to S-Band (2-4 GHz)
  - Evaluation of "Version 1" Prototype began in Jan 2008

Wideband OMT Development *Recent History*

- Gordon Coutts hired in Sept 2007
  - Worked on refining the Lilie "Version 1" design for improved performance, including a new taper profile, coaxial probe matching, shorting pins and a method to make the assembly easier and more repeatable
- C-Band:
  - With Hollis Dinwiddie (ME), the mechanical design was finalized and drawings prepared for mass production
  - C-Band "Version 2" began testing April 2008
  - First EVLA-compliant 4-8 GHz receiver installed on Antenna 2 in May 2008
  - Total of 7 antennas now outfitted
- S-Band:
  - With Dinwiddie, Mike Stennes & Jake Scarborough (ME), the mechanical design of the OMT was finalized & and the modifications necessary to use the old VLA L-Band Dewar were developed
  - S-Band "Version 2" began testing July 2008
  - Prototype S-Band receiver installed on Antenna 28 in Jan 2009
- L-Band:
  - L-Band "Version 2" began testing Sept 2008
  - New cryostat designed by Dinwiddie to accommodate the 2.75 foot long OMT (corresponds to $2.32\lambda_{max}$)
  - Cryogenic evaluation of the Prototype receiver & OMT currently underway

OMT Structure

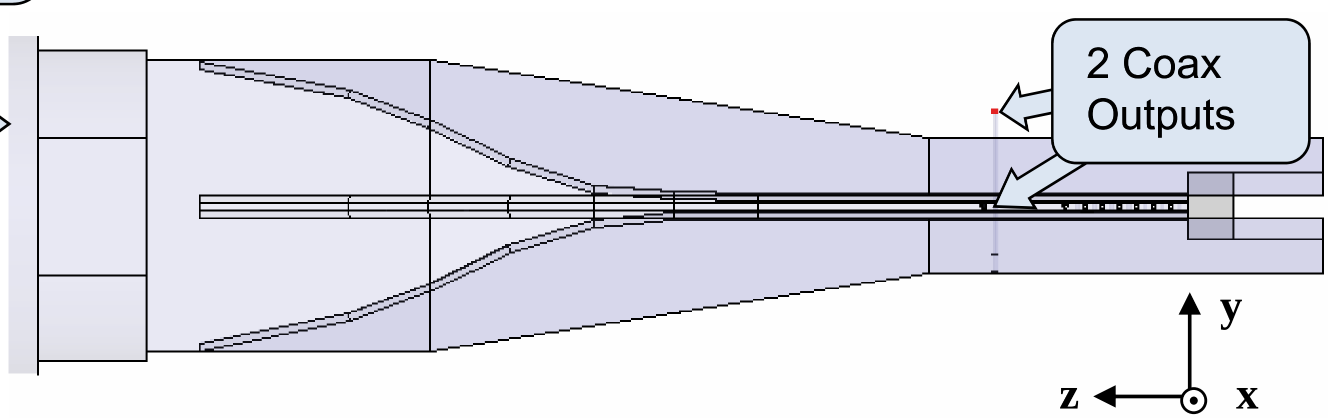
Input impedance:
≈1.1kΩ @ f_{min}
≈520Ω @ f_{max}



2 Coax Outputs

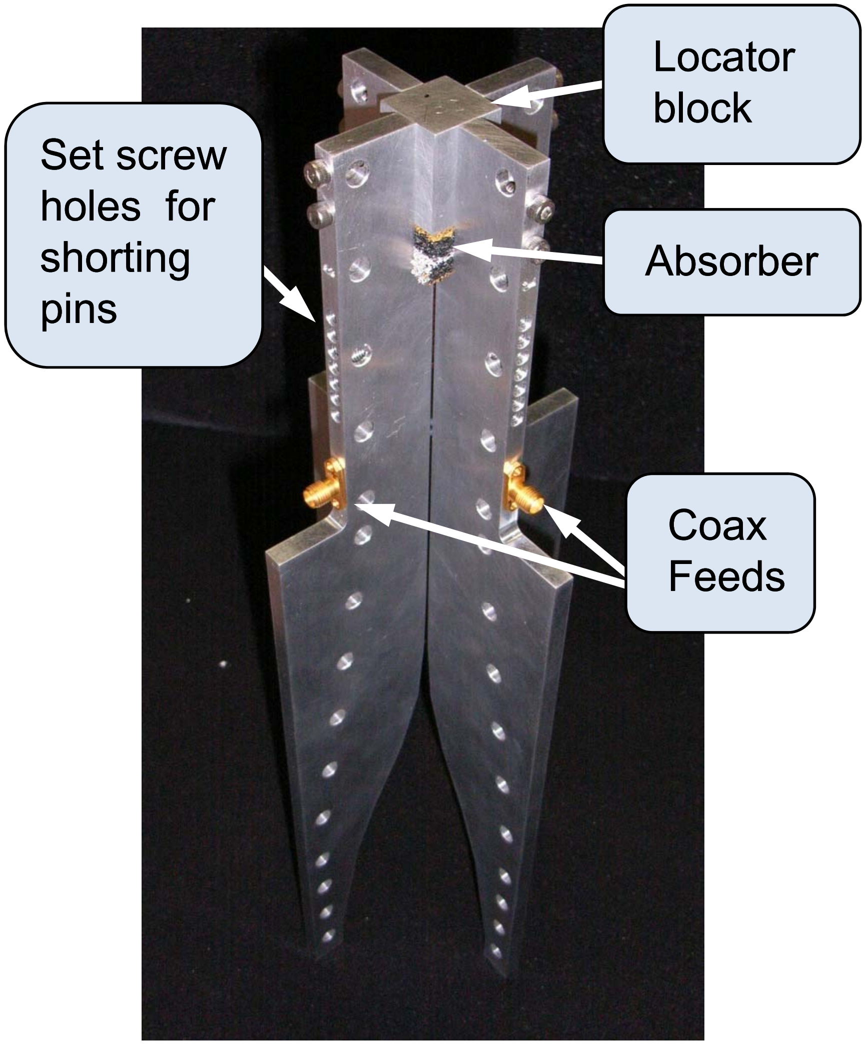
Output impedance: 50Ω

Circular Waveguide Input

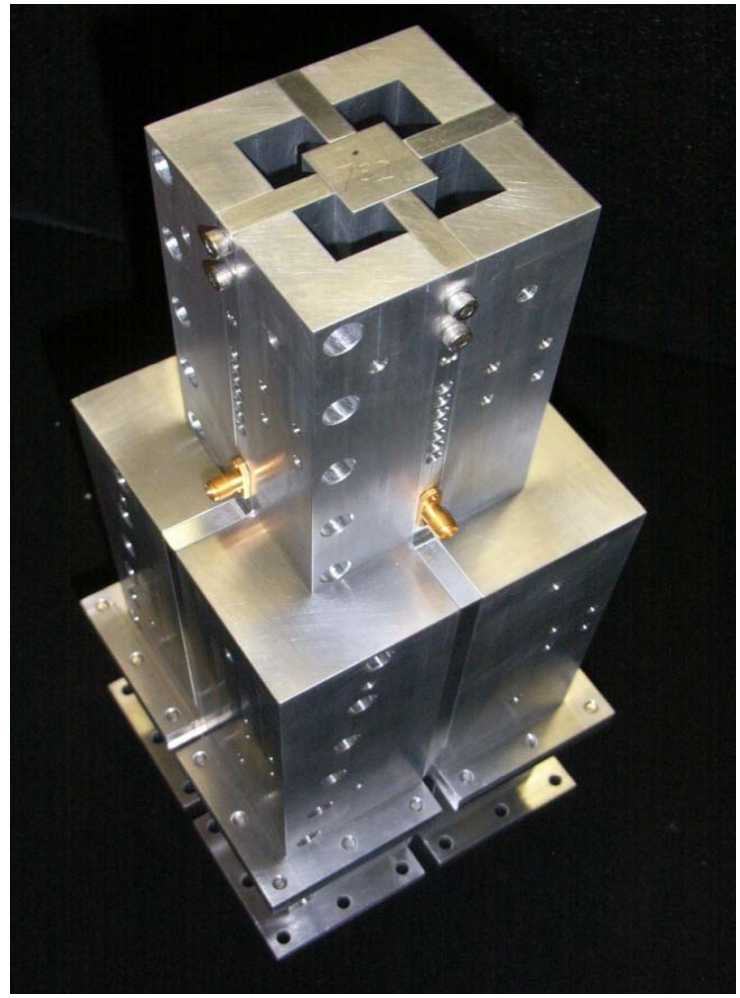


2 Coax Outputs

S-Band OMT Fabrication

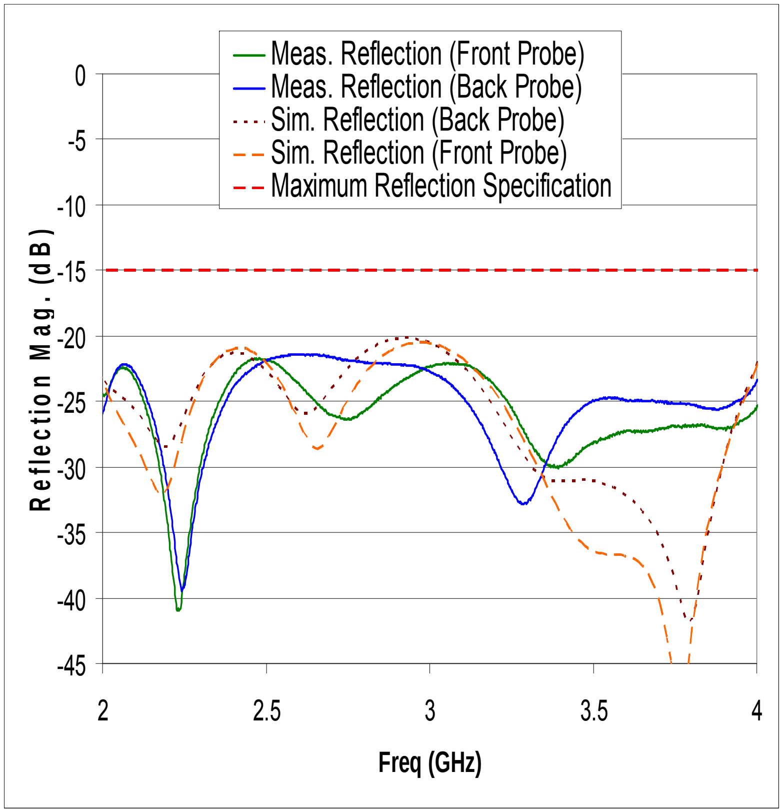


S-Band OMT ridge assembly

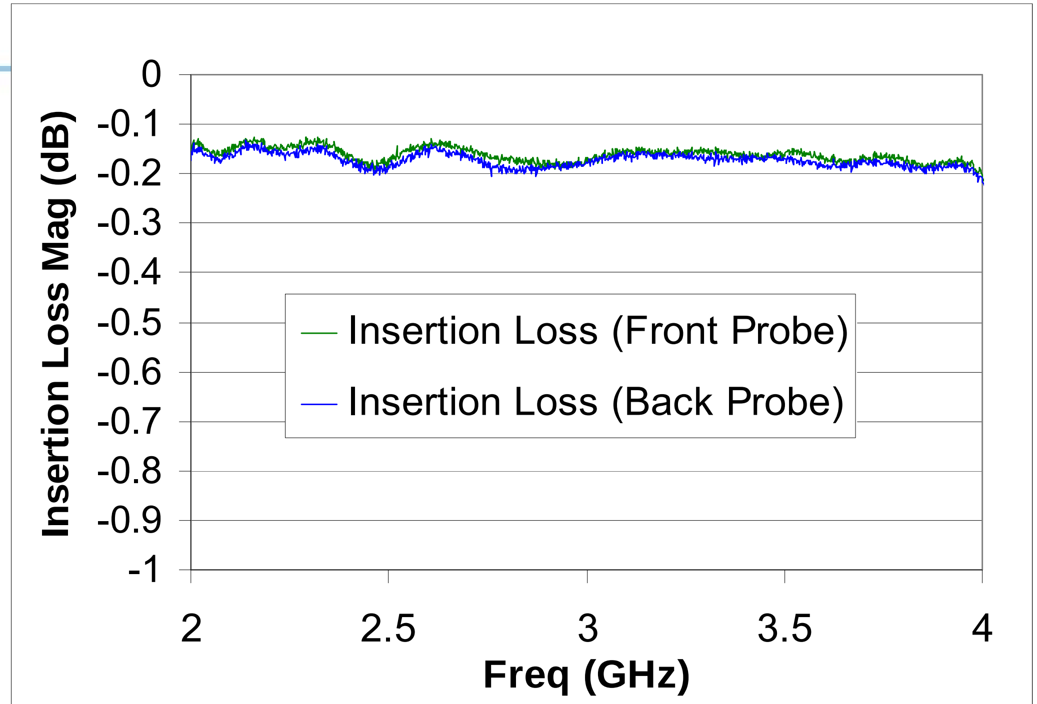


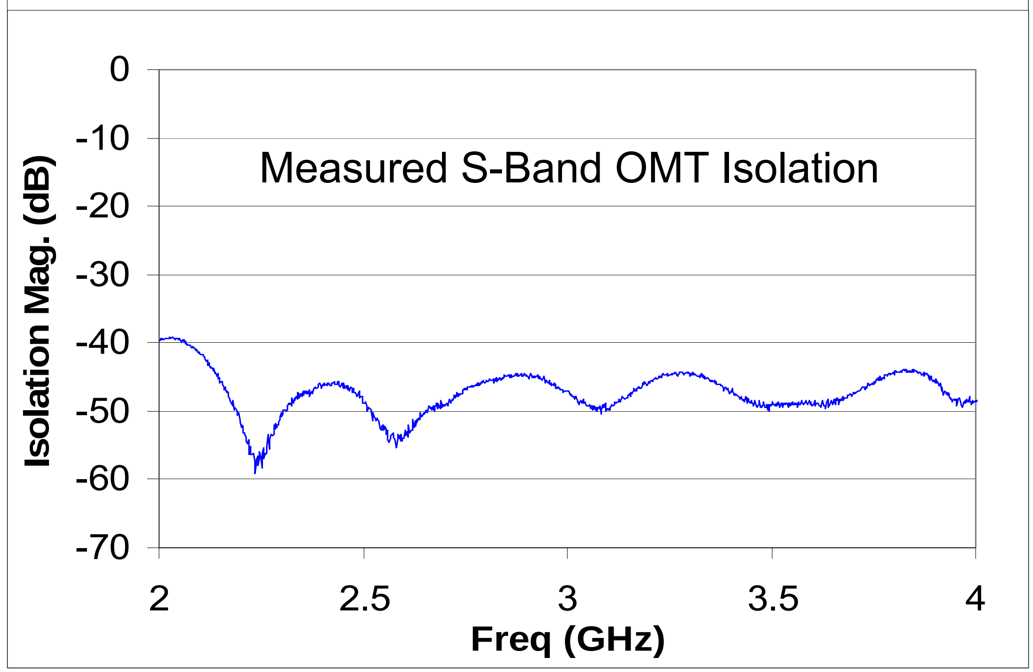
Fully assembled S-Band OMT

S-Band OMT Performance

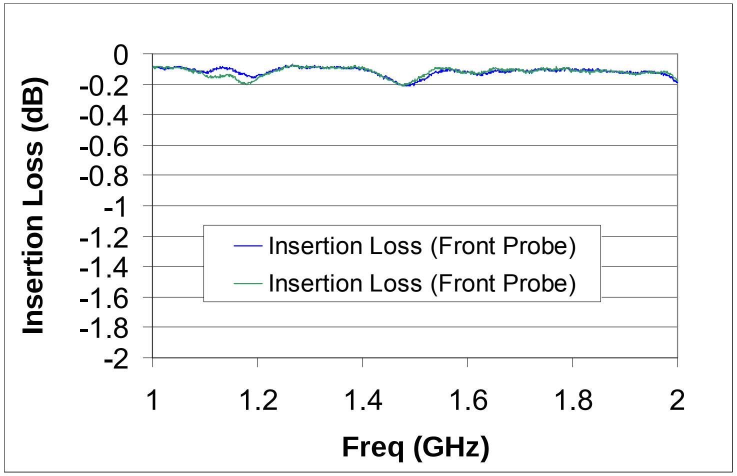


Measured S-Band Return Loss

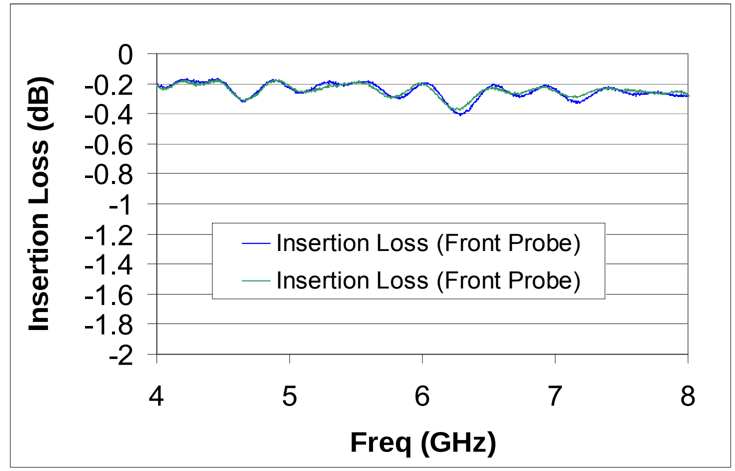




L & C-Band OMT Performance

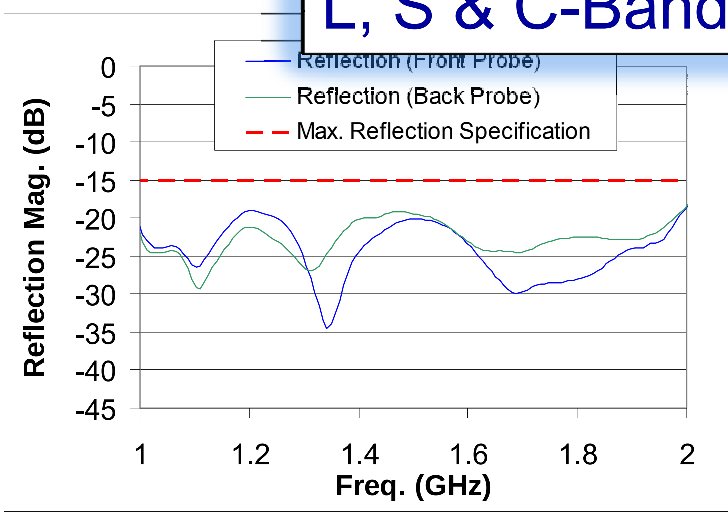


Measured L-Band Insertion Loss

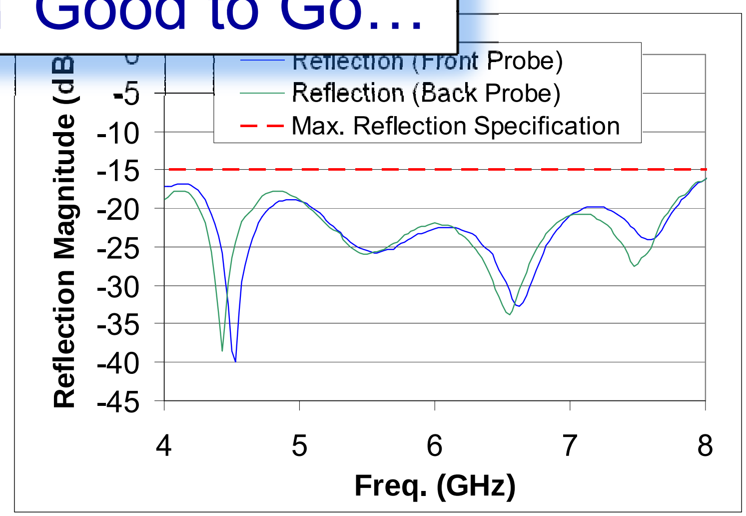


Measured C-Band Insertion Loss

L, S & C-Band OMT Good to Go…



Measured L-Band Return Loss



Measured C-Band Return Loss

X-Band (8-12 GHz)

Transition & EVLA Receivers

- VLA has a decent (albeit narrow) X-Band system
- These existing 8.0-8.8 GHz receivers have been installed on EVLA antennas
- Typically used for “First Fringes”
- New 8-12 GHz system prototyped in 2008-2009 with production scheduled for 2010
- But there are a number of design issues…

X-Band OMT Development Effort

Constraints

- The 8-12 GHz polarizer needed for the X-Band receiver presents us with several design problems:
  - **Quad-ridge OMT is impractical (very small coaxial probes)**
  - **Ku/K/Ka-style waveguide phase-shifter & OMT too large (over 2 feet long) and would be hard to cool**
- The current 8.0-8.8 GHz VLA X-Band Dewar uses a Model 22 refrigerator and we would prefer to use it rather than a new beefier Model 350 fridge
  - **Each EVLA Antenna's 3 compressors can cool <u>two</u> Model 350's plus a Model 22 but not <u>three</u> Model 350's**
  - **If the new X-Band Rx needs a Model 350, then we have to add a 4th compressor (~$250K plus increased operating costs) or modify one of the compressors on each antenna for extra capacity (~$30K) but with a sizable risk of reduced reliability**
- **The ideal solution would be to have the new wideband polarizer fit inside the existing X-Band Dewar with minimal modifications**
  - **Next best would be to have a design that might require a new taller and/or fatter Dewar but still allow us to reuse the Model 22 fridge**

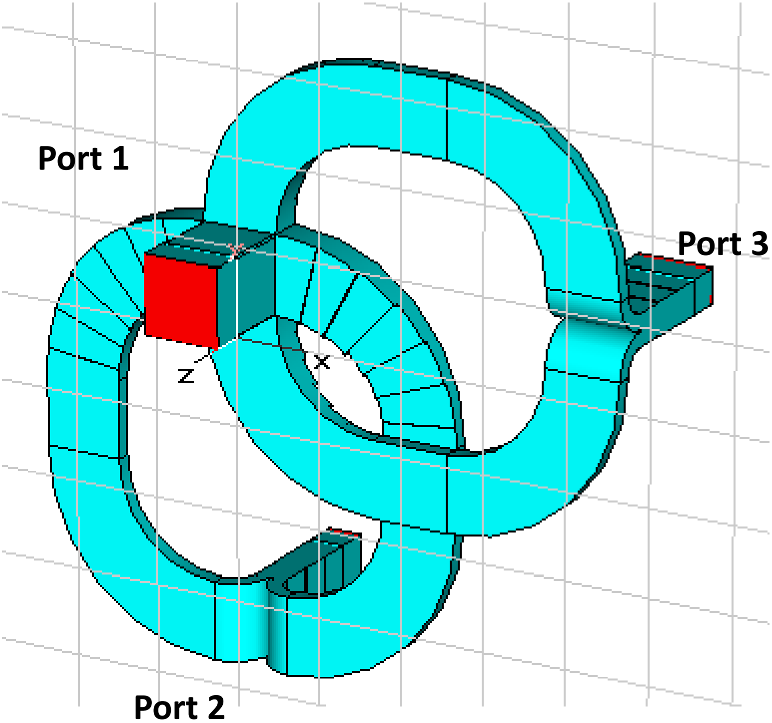
X-Band OMT Development Effort

Solutions

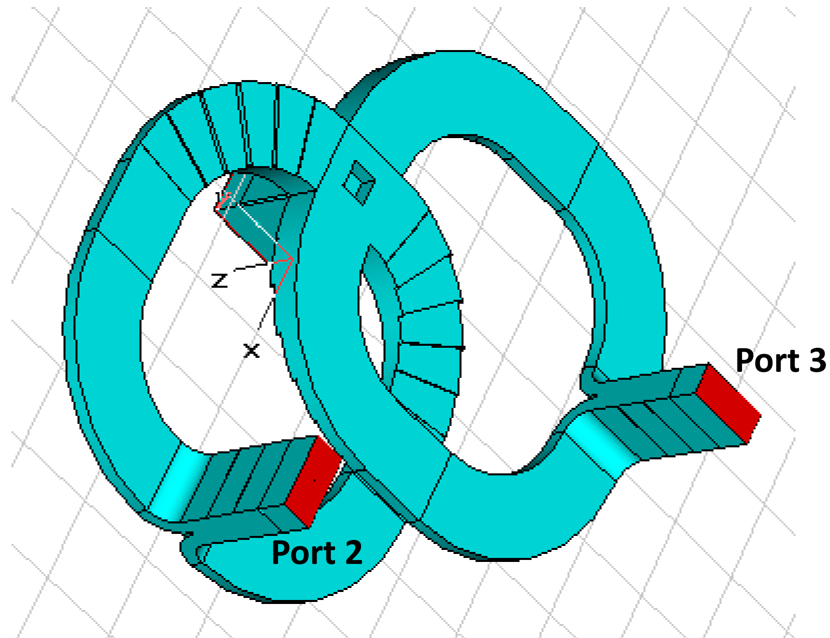
- The bulk of the X-Band OMT development effort has been farmed out to our NRAO sister labs:
  - At the CDL, Sri Srikanth has designed an all-waveguide solution
    - **Based on a "Mitsubishi" turnstile junction design**
  - At Green Bank, Mike Stennes has designed a planar OMT
    - **Design replaces the coaxial probes with a microstrip circuit and uses two 180° hybrid couplers to combine the signals from the opposing probes**
    - **Likely to be rather lossy but allows the 90°hybrid (needed to create circular polarization) and the Cal Coupler to be fabricated on the same circuit board**
    - **Two versions of microstrip circuits are being explored**
      - **Standard Gold on Alumina**
      - **High Temperature Superconductor (HTS)**
- Both OMT designs are currently being evaluated
  - By the middle of 2009 we should be in a position to select the design that best meets both our performance requirements and practical constraints so production can begin in early 2010 (schedule driven by budget)

Compact OMT

Sri Srikanth – NRAO-CDL



Top View - Input

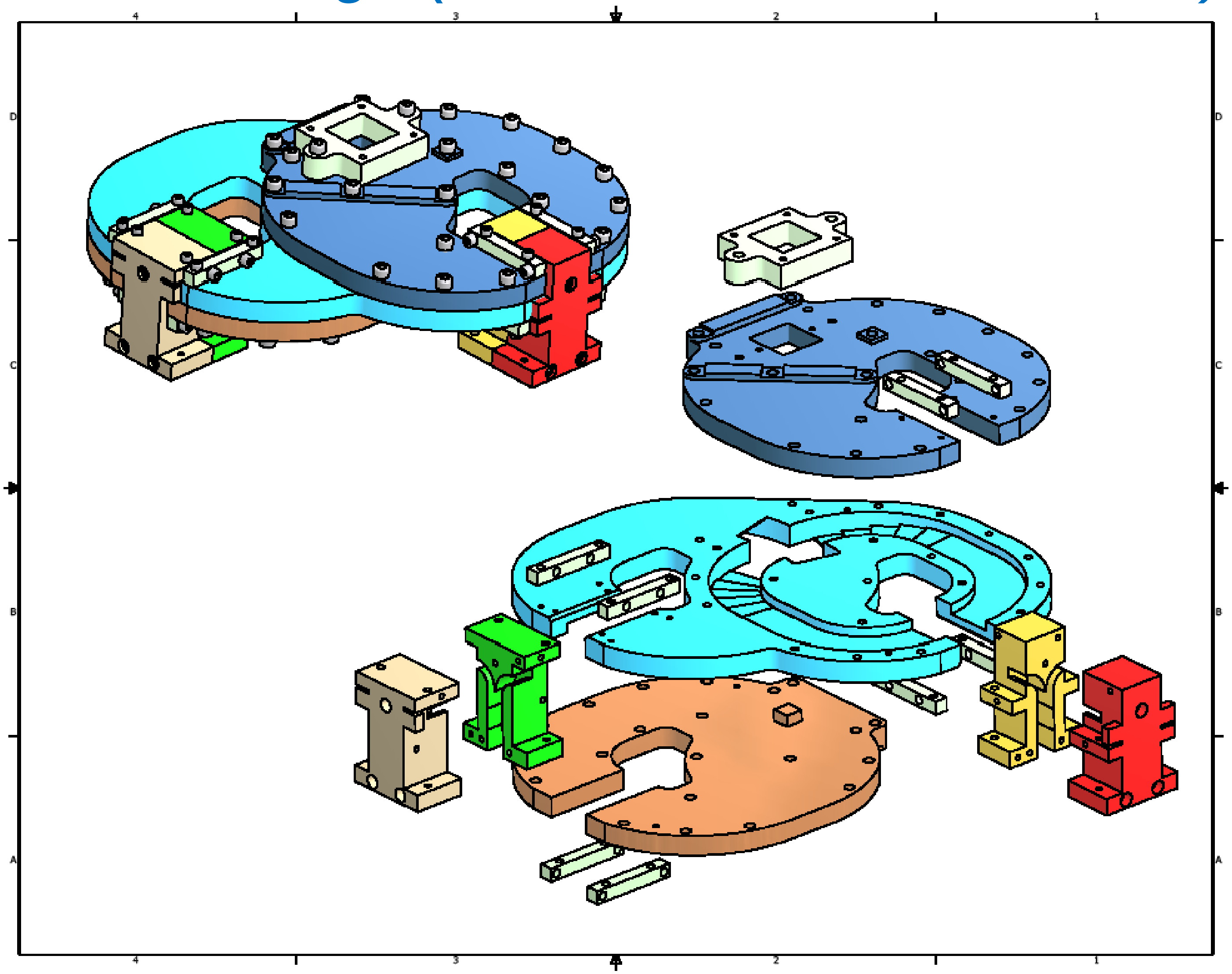


Bottom View - Outputs

CST Microwave Studio Model

Compact OMT

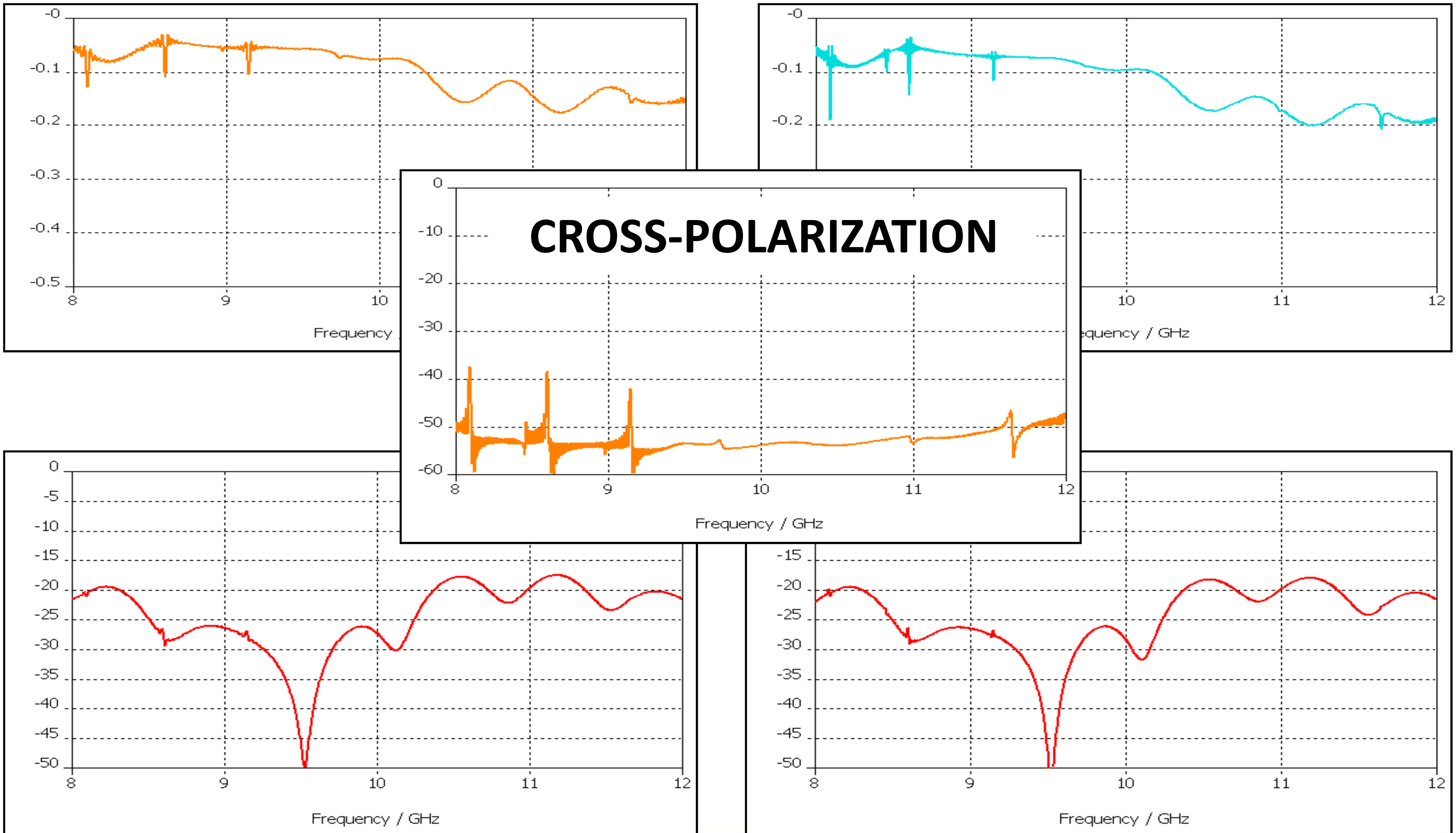
Mechanical Design (Mike Solatka, NRAO-CDL)



EVLA

Compact OMT – *CST Simulations*

INSERTION LOSS

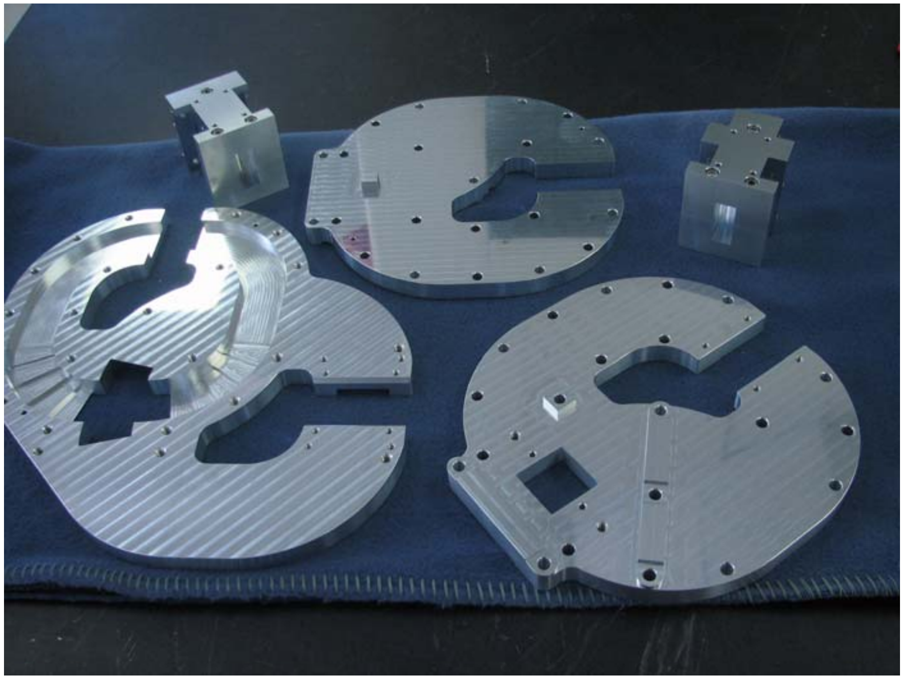


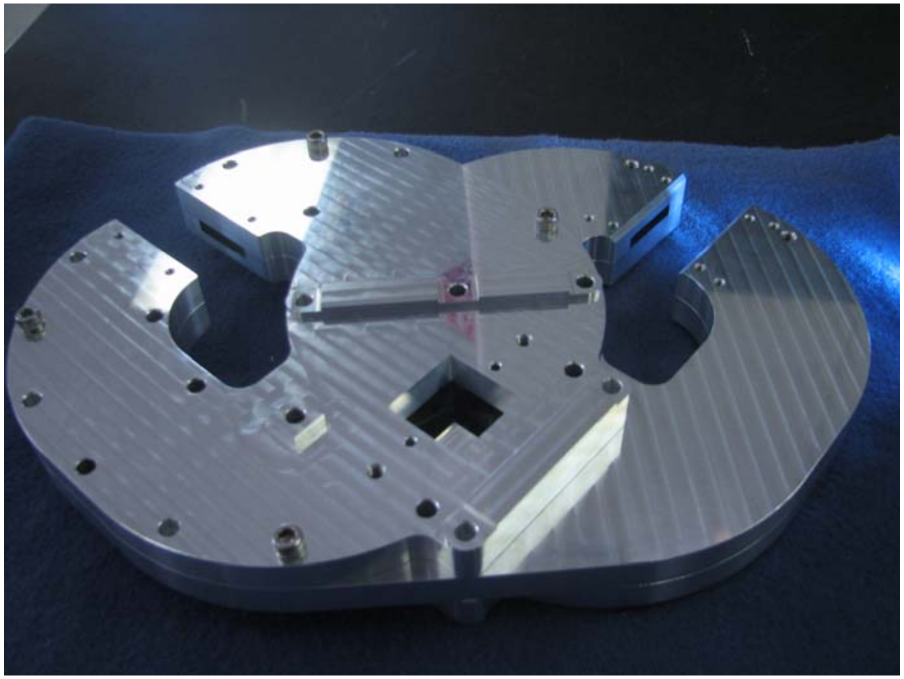
INPUT RETURN LOSS

NRAO

Compact OMT

Machined Hardware (Robert Meek, CDL machinist)



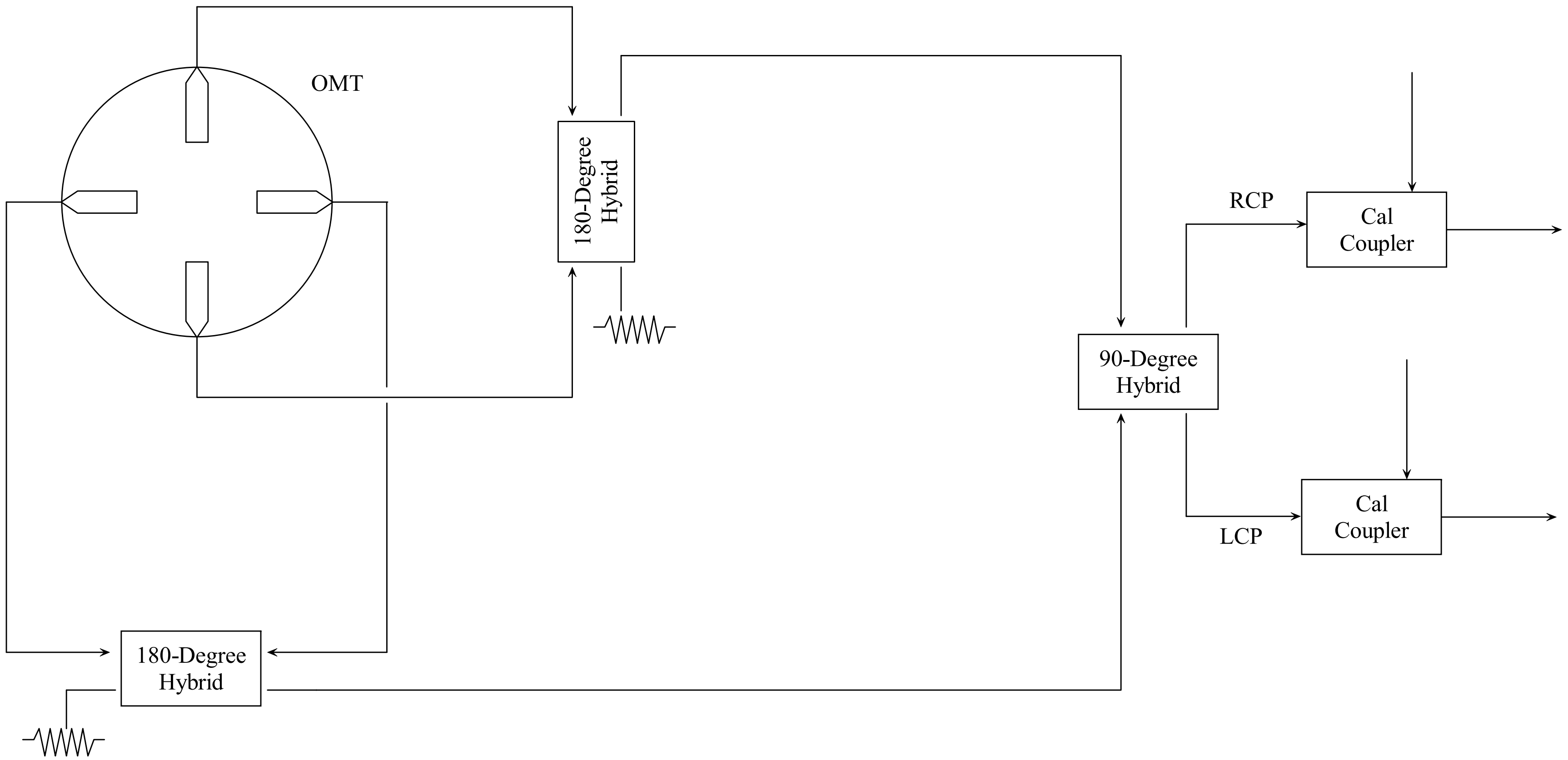


Compact OMT - *Summary*

- Full waveguide band (8-12 GHz) seems feasible (CST simulation)
  - Return loss ≤ -18 dB
  - Insertion loss ≤ -0.2 dB
  - Crosspol. ≤ -50 dB
- Compact Design : Height = 2.7” & Cross-section = 9.3” diameter
- Fabrication - all parts are machined (no electroforming required)
- Length of Circular Polarizer:
  - Circular to square transition = 2.3"
  - Phase Shifter = 8.1"
  - 45° Twist = 3.5”
  - OMT = 2.7”
- Dimensions of RF tree L x W = 16.6“ x 9.3”
  - Indeed “compact” but too big to fit in the existing VLA Dewar
- Will likely provide the solution with lowest-loss and best ellipticity
- Testing to begin in late March 2009

Planar OMT Schematic Diagram

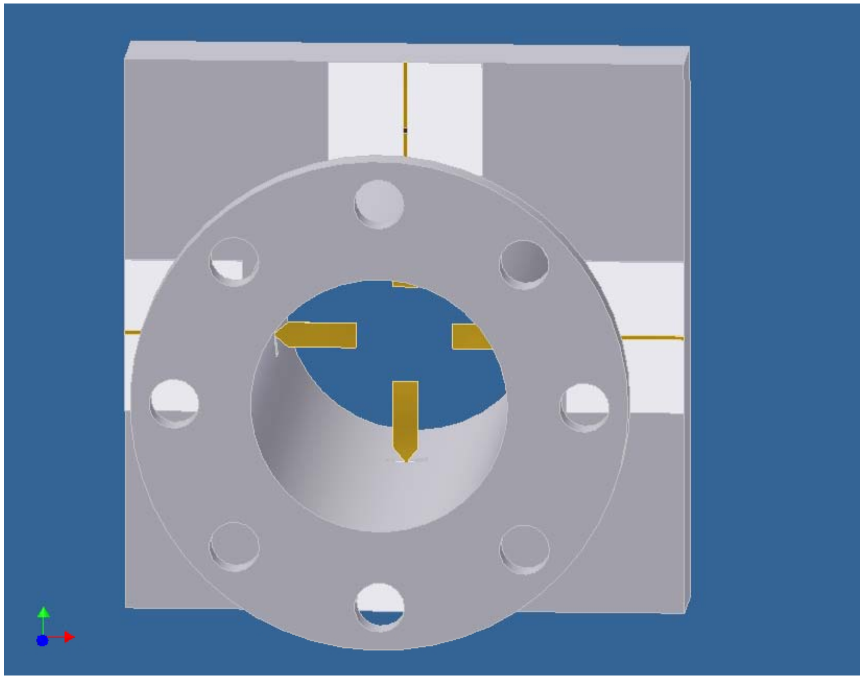
Mike Stennes, NRAO-Green Bank

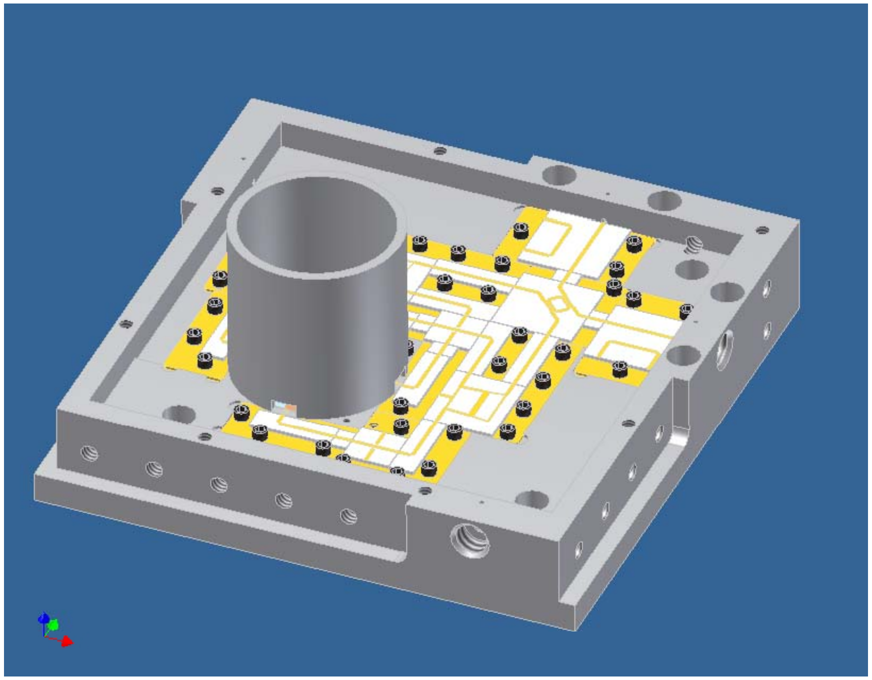


Schematic diagram of planar OMT

Planar OMT

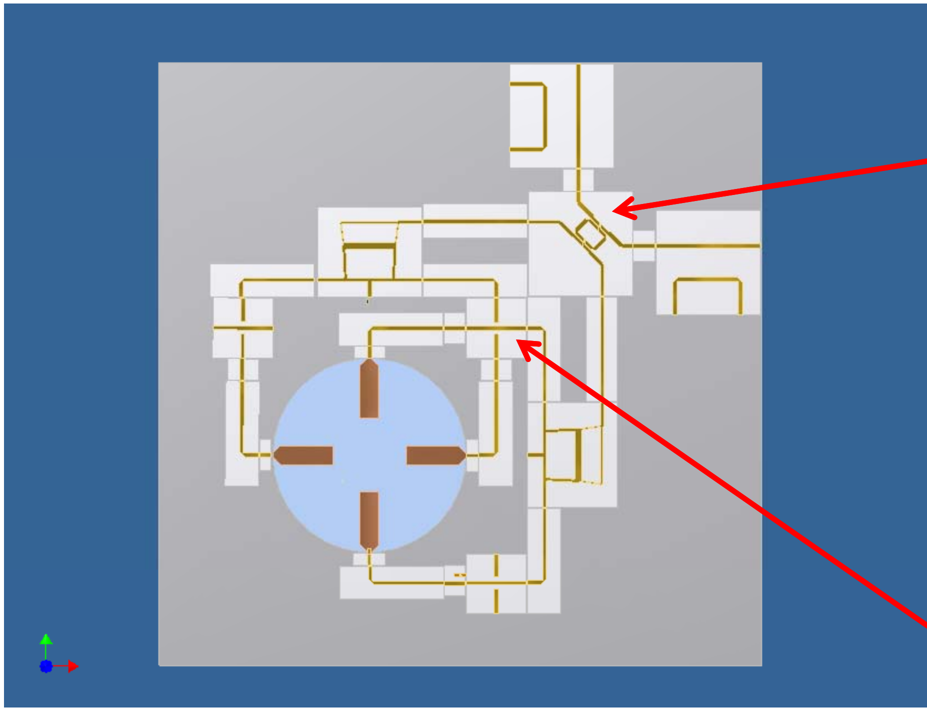
Circular Waveguide Interface





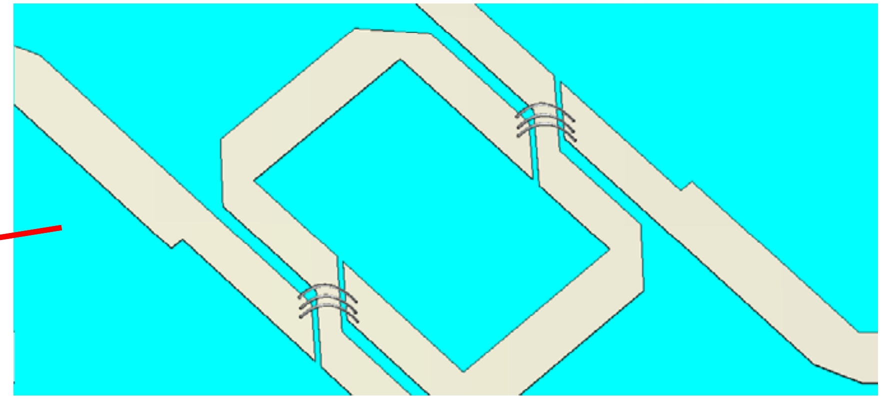
Planar OMT with circular waveguide interface

Planar OMT Layout



Microstrip Circuit Layout

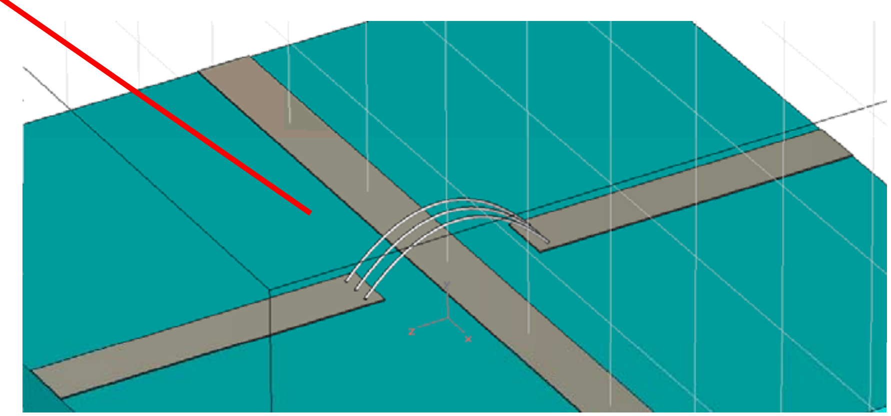
Version 1: Gold on Alumina
Version 2: HTS - YBCO/MgO
(Yttrium Barium Copper Oxide on a *Magnesium Oxide* buffer Layer)



90°Hybrid

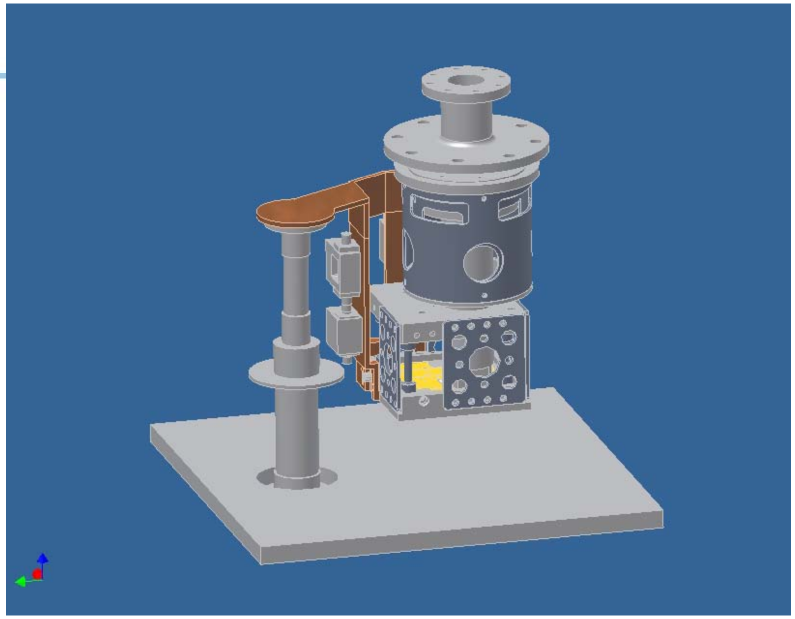
Wire Bonding

Trace Jump

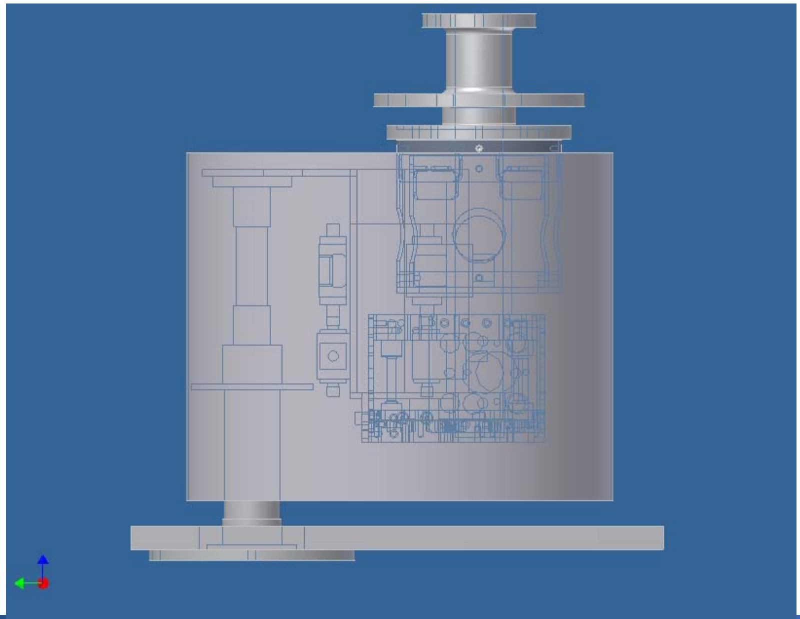


Planar OMT Package

Photograph of the OMT Prototype #1



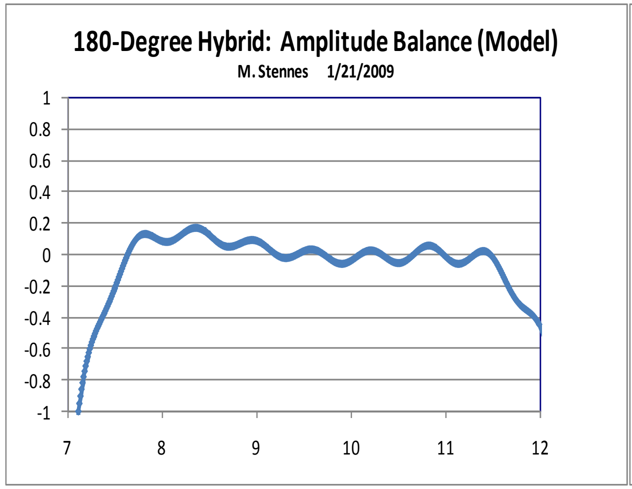
Mechanical model of cryostat layout

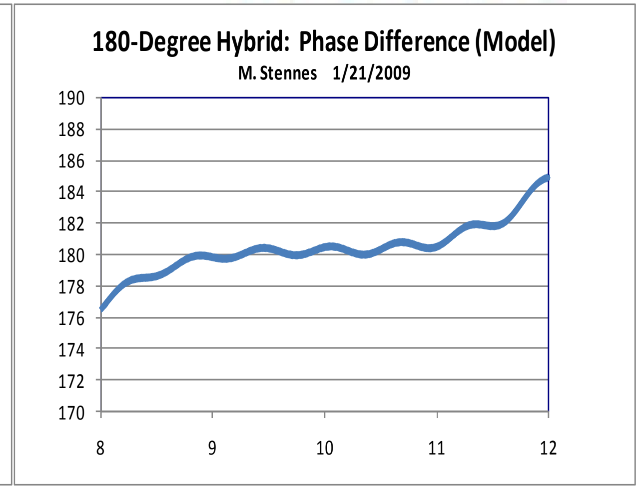


EVLA

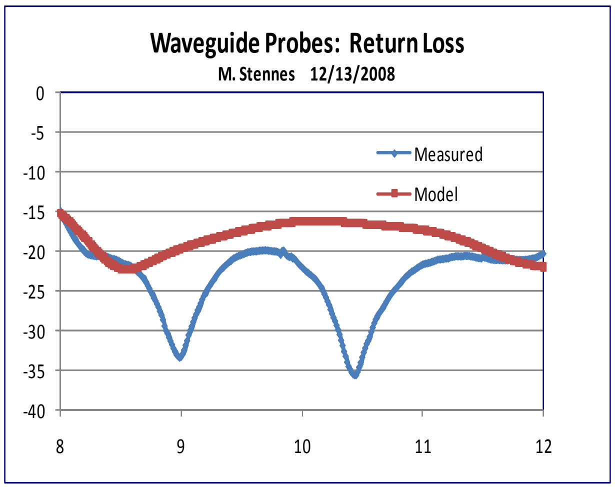
Planar OMT

Simulations and Early Test Results



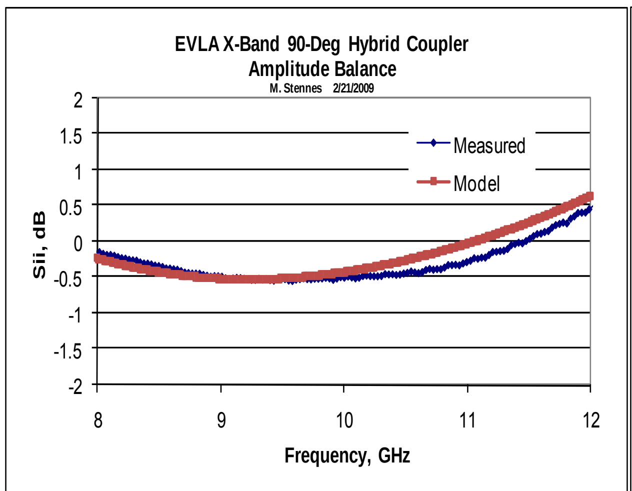


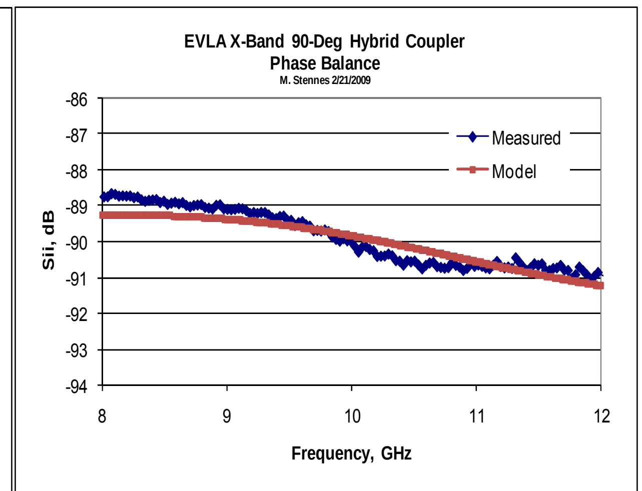
180° Hybrid Coupler



Waveguide probes

90° Hybrid Coupler





Planar OMT – Estimates

Frequency (GHz)	LNA Noise Temperature	Receiver Temperature (K)	
		Au/Alumina	HTS
8	6.9	19.5	14.0
10	5.0	16.6	11.5
12	4.8	15.6	10.8

Item	Au/Alumina	HTS
Microstrip circuits	325	2500
Gold plating of chip carriers	CDL	600
G10 fiberglass	50	50
Brass, aluminum blocks	45	45
Kovar sheet	25	25
Totals	$445	$3,220

Planar OMT

Parameter	Au/Alumina at Room Temperature	Au/Alumina at Cryogenic Temperature	HTS at Cryogenic Temperature
Mechanical Fit of OMT	Done	Done	Done
Matching dissimilar coefficients of thermal expansion (alumina & MgO substrates vs. brass housings) to avoid breakage	Done	Done	Done
Hermetic Packaging of YBCO film	-	-	TBD
Return Loss	-14 dB	TBD	TBD
Insertion Loss	-1.5 dB	TBD	TBD
Polarization Isolation	-16 dB	TBD	TBD

- Still to come (March – April 2009):
  - Additional tests on Au/Alumina OMT
  - Cryogenic tests of Au/Alumina OMT
  - More testing of HTS circuits
  - Cryogenic tests of HTS OMT

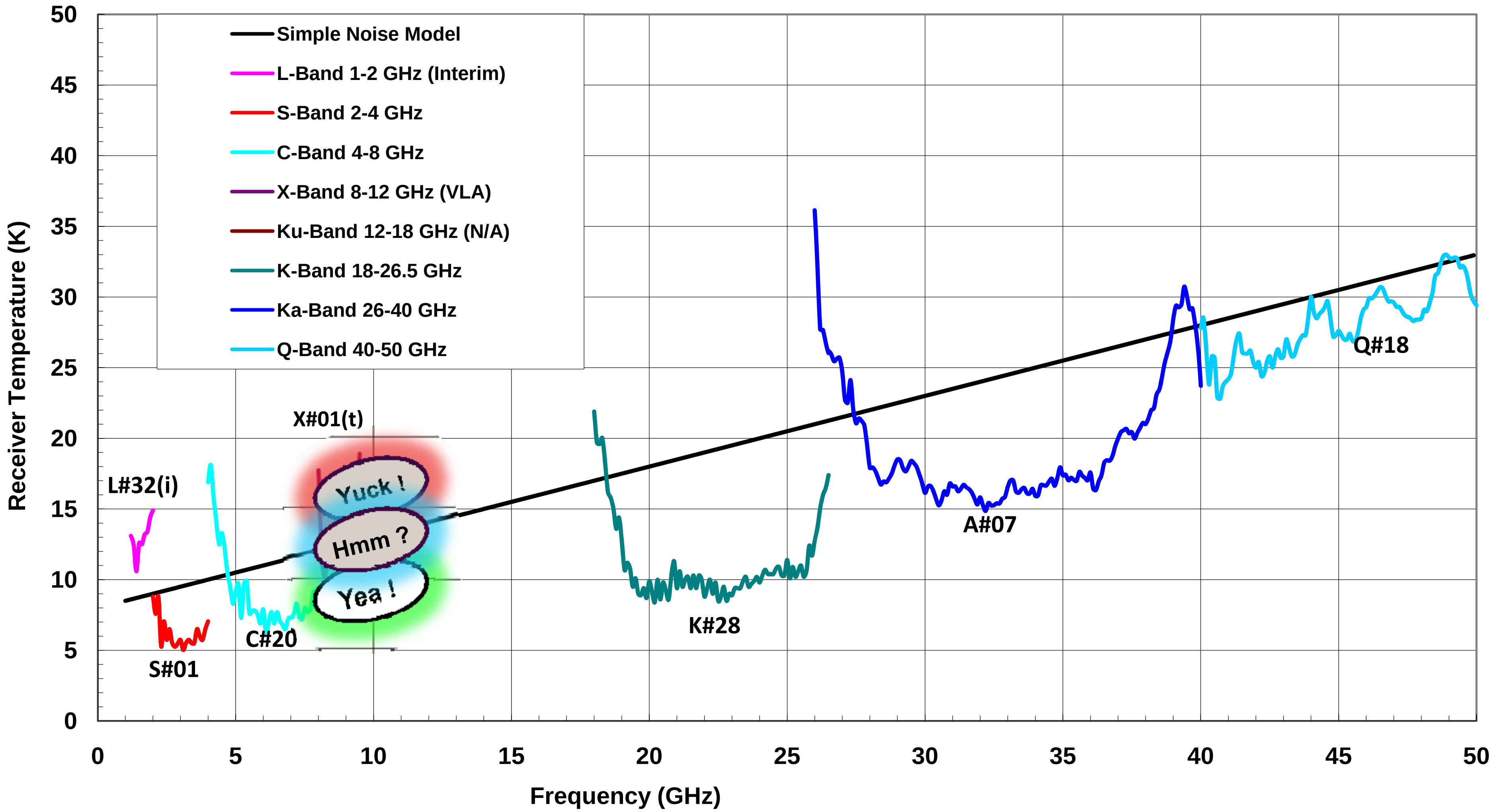
How Do We Decide on Which X-Band OMT to Adopt?

- For the <u>Planar OMT</u> design, which has the highest risk, we will have full system tests in a modified VLA receiver.
  - Including a comparison of Au/Alumina versus HTS circuits
- For the all-waveguide <u>Compact OMT</u> design, we will have bench tests of the IL & RL of the various components in the RF tree.
  - Will not have any cryogenic tests (since this would require a brand new cryostat to be designed and built)
  - But we can easily predict the cryogenic performance of an all-waveguide circular polarizer based on the K & Ka-Band designs
- So we will have to compare the cryogenic performance of the Planar OMT in a prototype Rx with bench tests of a warm Compact OMT
  - As the performance of the Planar design is much more critical on temperature (especially the HTS option), this plan works for us…

VLA/EVLA

T_{Rx} versus Frequency

EVLA Project Book - T_{Rx} Requirements (Band Center)								
Band	L	S	C	X	Ku	K	Ka	Q
T_{Rx}	14	15	16	20	25	34	40	48



$$T_{Rx} = m \cdot F + b \; ; \; m = 0.5^{o}K/\,GHz \; ; \; b = 8^{o}K$$

Receiver Production Status Summary

(as of March 2009)

	Interim	EVLA	Comment
Antennas	-	21	Target to complete upgrades in 2010-Q3
L (1-2 GHz)	21	0	Prototype testing; Production begins 2009-Q2
S (2-4 GHz)	-	1	Prototype evaluated; Production underway
C (4-8 GHz)	14	7	Wideband Rx Production/Retrofits underway
X (8-12 GHz)	21	0	OMT Testing & Rx Prototyping; Production 2010-Q1
Ku (12-18 GHz	-	0	Prototype Rx being assembled; Production 2009-Q4
K (18-26 GHz)	-	21	Full Production
Ka (26-40 GHz)	-	8	Accelerated Production (1/month)
Q (40-50 GHz)	-	21	Full Production

Prototype L-Band Receiver

- New cryostat designed by Hollis Dinwiddie to accommodate the 2.75 foot long OMT
- Hope to use a Model 350 fridge (backup plan = Model 1020)
- First cool-down March 2009
- Future tests include…
  - Cryogenic
  - RF
  - Axial Ratio

Questions ?