EVLA Front-End CDR

Overview
&
System Requirements

Overview & System Requirements

- Introduction to the EVLA Front-End Task
  - EVLA vs. VLA
  - Feeds
  - Receivers
- System Requirements, including:
  - System Temperatures
  - Linearity
  - Gain Flatness
  - Polarization
- FE CDR Presentation Overview

VLA versus EVLA

Band	VLA		EVLA	
	Freq (GHz)	Feed Horn Type	Freq (GHz)	Feed Horn Type
L	1.35 - 1.75	Lens + Corrugated	1 - (1.2) - 2	Compact Corrugated
S			2 - 4	Compact Corrugated
C	4.5 - 5.0	Lens + Corrugated	4 - 8	Compact Corrugated
X	8.0 - 8.8	Linear Taper Corrug	8 - 12	Linear Taper Corrug
Ku	14.4 - 15.4	Pyramidal	12 - 18	Linear Taper Corrug
K	18 - 26.5	Linear Taper Corrug	18 - 26.5	Linear Taper Corrug
Ka			26.5 - 40	Linear Taper Corrug
Q	40 - 50	Linear Taper Corrug	40 - 50	Linear Taper Corrug

EVLA Receiver Overview

Band	"L"	"S"	"C"	"X"	"Ku"	"K"	"Ka"	"Q"
Frequency (GHz)	1-(1.2)-2	2 – 4	4 – 8	8 – 12	12 – 18	18–26.5	26.5 – 40	40 - 50
T(Sys) (°K)	26	26	26	30	37	59	53	74-116
T(Sky) (°K)	12	12	10	10	12	25	13	26 - 68
T(Rx) (°K)	14	14	16	20	25	34	40	48
Polarizer Type	QR+Hyb	QR+Hyb	QR+Hyb	TBD	PS+WB	PS+WB	PS+WB	SS
LO Frequency (GHz)	N/A	N/A	N/A	N/A	N/A	15–18	12–16.7	16.7-20
LO Multiplier	N/A	N/A	N/A	N/A	N/A	x 2	x 3	x 3
Frequency Output	1 – 2	2 – 4	4 – 8	8 – 12	12 – 18	8 – 16.5	8 – 18	8 - 18
Output Power (dBm)	-38	-35	-34	-32	-35	-38	-35	-38
Headroom $P_{1\%}$(dB)	40	38	33	29	27	23	21	15
Output to Module	T302	T302	T302	T304	T303	T303	T303	T303
Refrigerator Model	1020	350	350	22	350	350	350	22

Overview Table Notes

T(Sky) (°K) : **A**ntenna & atmosphere contribution when pointed at zenith in dry winter weather. Includes 3°K cosmic background

T(Rx) (°K) : Averaged across full band, assumes LNA noise temperature of
- 4°K below 4 GHz (Balanced Amplifiers)
- 1°K/GHz 4-8 GHz & 0.5°K/GHz above 8 GHz.

Polarizer Type : All dual circular polarization.
- "QR+Hyb" = quad-ridge OMT followed by a 90° hybrid.
- "PS+WB" = waveguide Srikanth Phase Shifter followed by Wollack's implementation of a Bøifot class IIb OMT.
- "SS" = Sloping Septum polarizer.

LO Multiplier : The LO frequencies are multiplied by this factor in the receiver.

Output Power : Total power contained in the output band specified while observing "cold sky" at zenith over the specified bandwidth.

Headroom : With respect to the 1% compression point when on "cold sky".

Output to Module : RF/IF signal from receiver feeds the designated frequency converter module: T302 = LSC Converter , T303 = UX Converter , T304 = Down-Converter

Refigerator Model : CTI Incorporated model numbers.

The Basic EVLA Receiver Plan

- Provide Core Receiver Bands for every newly outfitted antenna
  - **L, C, X(transition), K, Ka & Q-Band**
- Add brand new Future Receivers at a slower rate
  - **S, X, Ku-Band**

CDR Considerations
EVLA L-Band Receiver

- The L-Band (1-2 GHz) front-end is the most critical EVLA receiver to be reviewed
    - **Uses new octave bandwidth Circular Polarizer**
    - **Will be scaled for use in both the C and S-Band OMT's (perhaps even X-Band)**
- The FE CDR has been delayed until the EVLA L-Band Prototype Receiver underwent preliminary evaluation
- While waiting for completion of new EVLA design, "Interim" Rx's are being installed on upgraded antennas
    - **Modified with new EVLA balanced amplifiers**
    - **And 90E hybrid coupler polarizers**
- Delay is not affecting science capability with the EVLA and won't until the wideband WIDA Correlator is available
    - **Early tests start in late 2007**

CDR Considerations

EVLA K & Q-Band Receivers

- K-Band (18-26.5 GHz) & Q-Band (40-50 GHz) receivers are upgrades to existing VLA systems
- Design complete nearly 2 years ago & many of the production components have already been purchased
- We will be reporting on what modifications have been adopted and results of systems now on the Array
- Early systems installed on upgraded antennas use old VLA Card Cage and will need to be retrofitted at a later date to be EVLA compliant

CDR Considerations
EVLA C-Band Receiver

- The new EVLA C-Band (4-8 GHz) receiver will use an octave bandwidth OMT scaled up in frequency from L-Band
- Design not yet ready, so early C-Band receivers installed on upgraded antennas built as "Interim" systems
    - **Uses commercial (Atlantic Microwave) 4.5-5.0 GHz Sloping Septum Polarizer, similar to the units used on the VLBA receivers**
- To keep pace with Antenna overhaul, at least six of these narrowband systems will be built
- New C-Band system pioneers new the EVLA Common Dewar design which will be copied, as much as possible, by other new EVLA receivers (X, Ku & Ka-Band)
- To save money, many of the C-Band microwave production components have already been purchased, except for the OMT

CDR Considerations
EVLA X-Band Receiver

- As the VLA already has a decent (albeit narrowband) X-Band system, the EVLA will reuse the existing 8.0-8.8 GHz receiver until late in the Project.
- This so-called “Transition” receiver can be mounted to either an old or a new X-Band feed.
- Retaining an old receiver forces us to use the old Monitor & Control system.
- A new 8-12 GHz system will be prototyped in 2008 with production scheduled for 2010, funds permitting.

CDR Considerations

EVLA Ka-Band Receiver

- The Ka-Band (26.5-40 GHz) receiver provides a brand new discovery space for the VLA
- Due to other pressures and diversions, the Ka-Band receiver development has been slow than planned
- 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**
- Uses novel MMIC-based down converter
- Hope to complete design of prototype in 2006
- Production begins in 2007

CDR Considerations

EVLA S, Ku & X-Band Receivers

- S-Band (2-4 GHz) is a brand new receiver
  - **Will be based on a scaled L-Band system**
  - **Prototype development to start in 2006**
  - **Production begins in 2008**

- New Ku-Band (12-18 GHz) will (eventually) replace the "crummy" existing VLA 14.4-15.4 GHz A-Rack system
  - **Based on scaled K-Band system**
  - **Prototype development to start in 2007**
  - **Production begins in 2010**
  - **Ku-Band capability will be sacrificed as each antenna is outfitted**

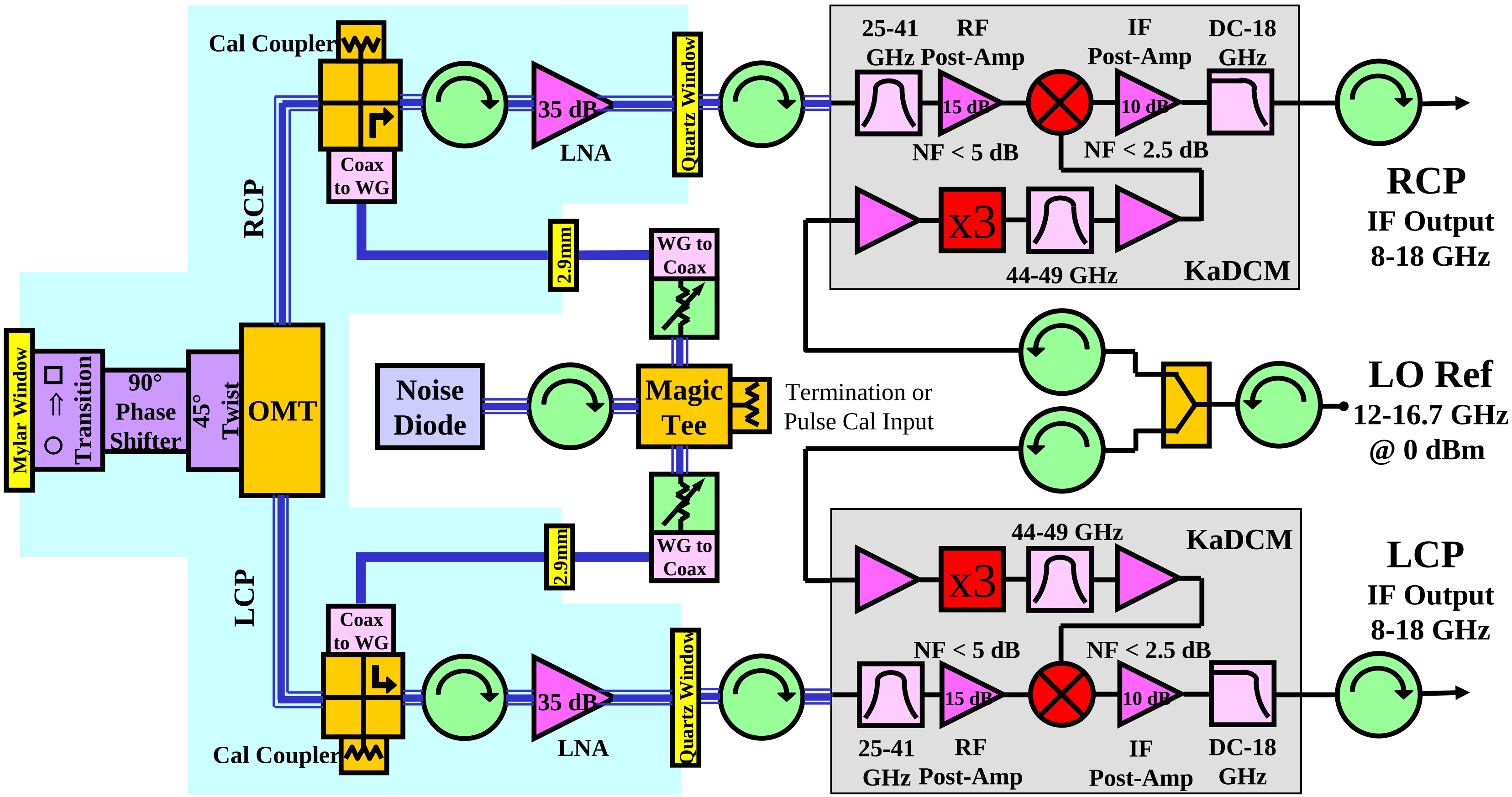
- New EVLA X-Band design will cover 8-12 GHz
  - **Polarizer design TBD**
  - **Prototype development to start in 2008**
  - **Production begins in 2010**

EVLA Ka-Band Rx Block Diagram

RHH : 6 Jan 2005

Key:

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



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)	9	-3	300		-14	0.0398	0.071			-43.8		26.8
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		

Summary of Estimated EVLA Front-End System Temperature, Output Power & Headroom

EVLA Receiver Band	Receiver T_{Noise} (K)	Receiver $T_{@Dewar}$ (K)	Receiver P_{Out} (dBm)	Receiver Min HR (dB)	T303 UX-Converter T_{Noise} (K)	T303 UX-Converter P_{In} (dBm)	T303 UX-Converter P_{Out} (dBm)	T303 UX-Converter Min HR (dB)	T302 LSC-Converter T_{Noise} (K)	T302 LSC-Converter P_{In} (dBm)	T302 LSC-Converter P_{Out} (dBm)	T302 LSC-Converter Min HR (dB)	T304 Down-Converter T_{Noise} (K)	T304 Down-Converter P_{In} (dBm)	T304 Down-Converter P_{Out} (dBm)	T304 Down-Converter DAtt-1 (dB)	T304 Down-Converter DAtt-2 (dB)	T304 Down-Converter Min HR (dB)	Delta T_{Noise} (%)
L-Band	**13.91**	13.61	-32.7	**35.2**					**13.92**	-40.2	-40.2	**23.7**	**14.16**	-47.2	-33.6	*-8.0*	*-10.0*	**27.0**	1.8
S-Band	**14.78**	14.01	-34.3	**36.8**					**14.81**	-41.8	-41.8	**25.3**	**15.05**	-48.8	-32.5	*-3.0*	*-10.0*	**24.8**	1.9
C-Band	**15.34**	14.92	-31.3	**31.0**					**15.37**	-38.8	-38.8	**22.3**	**15.60**	-45.8	-33.2	*-3.0*	*-11.0*	**21.8**	1.7
X-Band	**19.57**	19.15	-32.3	**30.4**									**19.92**	-44.1	-33.0	*-8.0*	*-7.0*	**24.1**	1.8
Ku-Band	**24.86**	24.19	-35.1	**28.2**	**24.92**	-40.1	-31.2	**28.8**					**25.23**	-41.0	-33.0	*-8.0*	*-10.0*	**21.0**	1.5
K-Band	**33.79**	32.35	-36.1	**20.8**	**33.92**	-41.1	-32.2	**29.8**					**34.45**	-42.0	-33.0	*-8.0*	*-9.0*	**22.0**	1.9
Ka-Band	**39.95**	38.89	-34.3	**23.1**	**40.08**	-39.3	-32.9	**28.0**					**40.63**	-42.7	-33.6	*-8.0*	*-9.0*	**22.7**	1.7
Q-Band	**48.43**	46.42	-38.5	**15.5**	**48.84**	-44.3	-36.4	**33.0**					**49.71**	-46.2	-34.1	*-3.0*	*-11.0*	**22.2**	2.6
Goal =				>20		-40		>20		-40		>20		-45	-33			> 20	< 2.0

"Delta T_{Noise}" = Percent Difference between Receiver Noise Temperature at the Sampler Input compared to that at the Receiver Output *Goal = 1% (ie: S/N of 20 dB)*

"Headroom" = Ratio in dB below the 1% Compression Point (typically 12 dB below 1 dB Compression Point) Goal = 20 dB *Goal = 20 dB*

System Requirements

The following slides present the

Top Level

System Requirements

as specified in the EVLA Project Book

Note that many of these requirements pertain directly to the performance of the entire Telescope system. Consequently, the contribution from the antenna optics, feeds & IF/LO systems may sometimes dominate the effects coming from the receivers.

System Polarization Characteristics
(Project Book 2.2.2.5a)

- **Required**: Over an 8 hour period, and under stable weather, the RCP and LCP polarization ellipses within the inner 3 dB of the antenna primary beam (FWHP) shall be stable to:
  - 0.002 in Axial Ratio
  - 2 degrees in Position Angle

- **Note :** ***This is a mechanical stability issue, not only for the front-ends and feeds but for the entire antenna structure. The stability of the circular polarizers is likely to be very stable compared to the rest of the telescope. Unfortunately this spec is very hard, if not impossible, to measure in the lab. However, it can be done interferometricly with receivers on the Array.***

Limits on Ellipticity
(Project Book 2.2.2.5b)

- **Required**: The RCP and LCP on-axis polarization ellipse (voltage) axial ratios are to be between 0.9 & 1.0 (or 0.92 dB)
- **Required**: The axial ratios of the polarization ellipses are to be the same for all antennas at a given frequency, to within the same tolerances as given above.
- **Note :** ***The polarization will undoubtedly be dominated by mismatches arising between the polarizer & the LNA's or between other components along the input signal path.***

System Temperature and Sensitivity (*Project Book* 2.2.3.1)

Band	T_{Sys}(EK)
L	26
S	26
C	26
X	30
Ku	37
K	59
Ka	53
Q	74-116

- **The indicated T_{Sys} values apply to the middle 50% of each band and include antenna, 3EK Cosmic BG radiation, atmospheric absorption and emission when pointed at zenith in dry winter weather.**
- **Required : Degradation of receiver temperature within any band with respect to the mean defined in the central 50% is to be by less than 3 dB at any frequency, by less than 1 dB over the inner 85% of each band, and by less than 2 dB over 95% of the band.**
- **Note :** ***Using conservative LNA noise temperature estimates suggests these receiver temperatures should, in general, be readily achieved.***

EVLA Rx Band Noise Temperatures

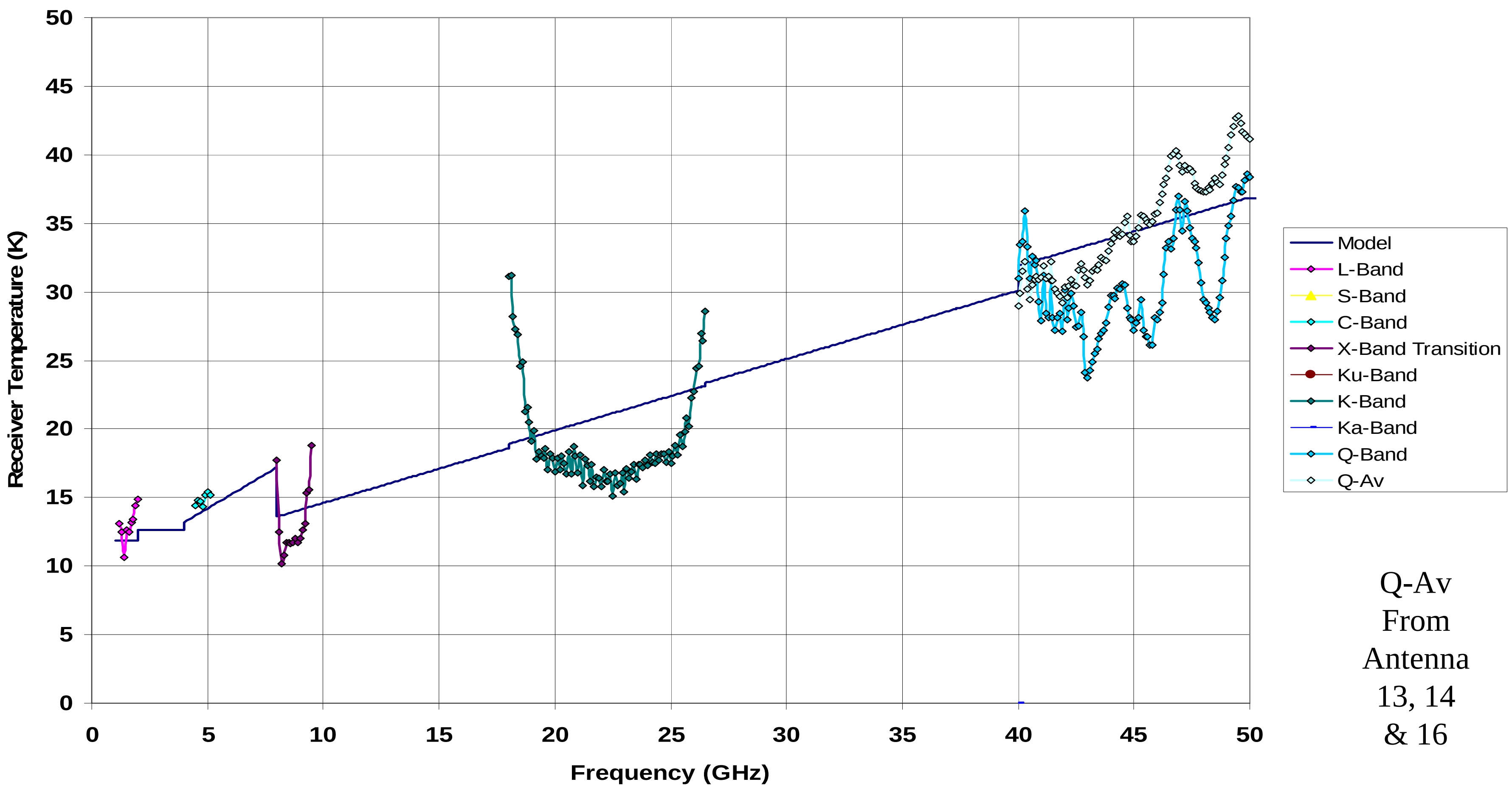
(Project Book 5.0)

Band	$T_{receiver}$ (°K) †	T_{Sky} (°K) ‡	T_{System} (°K)
L	14	12	26
S	14	12	26
C	16	10	26
X	20	10	30
Ku	25	12	37
K	34	25	59
Ka	40	13	53
Q	48	26 - 68	74 - 116

† ***Receiver temperature averaged across full band.***

‡ ***Antenna, CBG & atmospheric contribution to T_{Sys} when pointed at zenith in dry winter weather.***

VLA/EVLA Receiver Temperature Performance vs. Frequency



Q-Av From Antenna 13, 14 & 16

LNA's : L & S @ 4EK ; C @ 1EK / GHz ; X, Ku, K, Ka & Q @ 0.5EK/ GHz

Linearity of Power Gain to System Power Variations *(Project Book 2.2.3.2)*

Band	Headroom (dB)
L	47
S	48
C	43
X	42
Ku	40
K	33
Ka	35
Q	27

- **Required : The following table gives the headroom requirements for the signal delivered to the sampler. The headroom is defined as the power ratio between the quiescent cold sky power and the power at which the 1 dB compression occurs.**
- **Note :** ***To mitigate the effects of RFI we want to operate 20 below the 1% compression point (which is 32 dB blow the P1dB compression point).***
- **Note :** ***These are requirements are for both the RF & IF systems. In general, the IF Chain compresses before the receiver (except at Q-Band).***
- **Required : Changes in total system power monitored with an accuracy of better than 2% over an input power range between 15 and 50 dB above quiescent cold sky values.**
- **Note :** ***This applies only to receivers with the coupler-fed solar observing scheme.***

Bandpass Characteristics *(Project Book 2.2.3.4)*

a. Amplitude Stability

- **Required :** Variations in bandpass (power units) are to be less than 1 part in 10,000 on timescales of less than 1 hour, on frequency scales less than the band frequency/1000.

b. Phase Stability

- **Required :** Phase variations within the bandpass are to be less than 0.006 degrees, on timescales less than 1 hour and frequency scales less than the RF frequency/1000.

- **Note :** ***This is not the absolute total power stability of the RF/IF system but addresses bumps or dips appearing in the spectra of the correlator which could generate artifacts that look like absorption lines. At C-Band, the frequency scale is -5 MHz; at Q-Band it is -45 MHz***

- **Note :** ***The spectral bandwidth & resolution needed to measure these on the Array will require the new WIDAR correlator.***

Gain Slope

(Project Book 2.2.3.4)

c. Gain Slope

- **Required :** The spectral power density slope at the input to the 3-bit sampler is to be less than 1.5 dB/GHz (or 3 dB across the full 2 GHz wide input).
- **Required :** The spectral power density slope of the signals input to either the 3-bit or 8-bit samplers is to be less than:
  - i) 12 dB/MHz at L-Band
  - ii) 6 dB/MHz at S-Band
  - iii) 3 dB/MHz at C & X-Band
  - iv) 1.5 dB/MHz at Ku, K, Ka & Q band.

d. Gain Ripples

- **Required :** Fluctuations in the spectral power density about the mean slope are to be less than 4 dB, peak-to-peak, for signals input to the 3-bit digitizer.

- **Note :** ***This is the peak-to-peak gain ripple remaining after the slope across the inner 90% of the 2-4 GHz digitizer input has been removed by the Gain Slope Equalizer system. They are relatively gernerous.***

Gain Flatness and Passband Ripple
(Project Book 3.2.3.3)

- Required : The overall gain flatness of the EVLA FE/LO/IF system is specified as 5 dB over any 2 GHz bandwidth with a design goal of 3 dB over any 2 GHz bandwidth. These specifications have been divided as follows:
  - one-third to the Front-End
  - one-third to the T304 Downconverter
  - one-third to the 4/P, LSC and UX converter combination.

- **Note :** ***This spec was only made possible by the adoption of the Gain Slope Equalizer scheme in the T304 Downconverter.***

- Required : Passband ripple is specified to be a maximum of 0.2 dB for ripple with a period less than 2 MHz.

Overview of FE CDR Presentations

Paul Lilie	- OMT Development
Lisa Locke	- New L, S, X & Ku-Band
Dan Mertely	- New C-Band
Bob Hayward	- Upgraded K & Q -Band, New Ka-Band
Chuck Kutz	- Existing LF Receivers & EVLA LO/IF System
Hollis Dinwiddie	- Receiver Mounting
Rudy Latasa	- Cryogenic & Vacuum Systems
Keith Morris	- New Receiver Card Cage
Wayne Koski	- Receiver Monitor & Control
Darrell Hicks	- Vertex Cabin Infrastructure

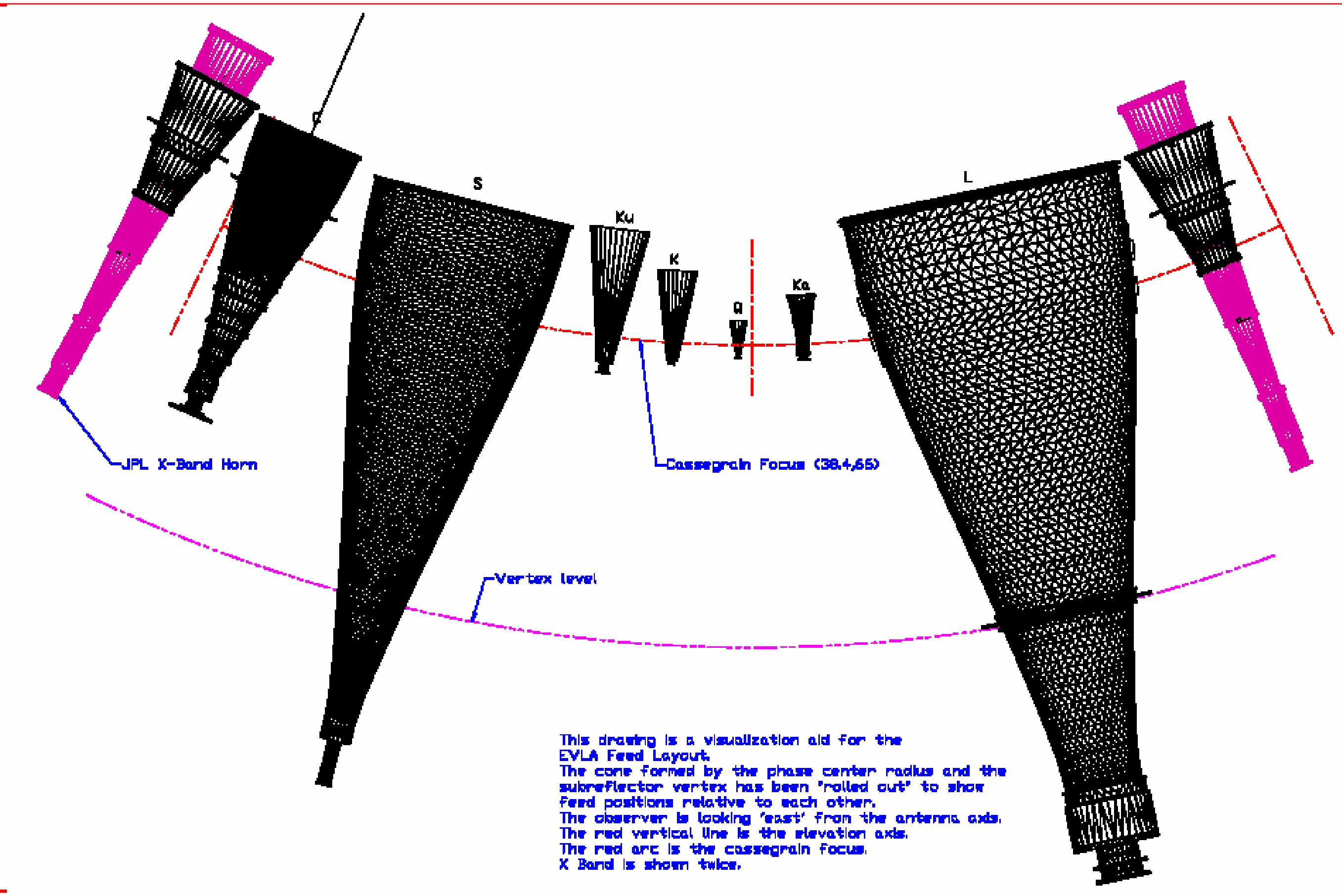
Overview of FE CDR Presentations

Bob Hayward	- Lab Receiver Testing
Paul Lilie	- Solar Mode
Brent Willoughby	- WVR Option
Gerry Petencin	- LNA Procurement
Brent Willoughby	- Receiver Production
Bob Hayward	- Project Schedule & Budget

Questions ?

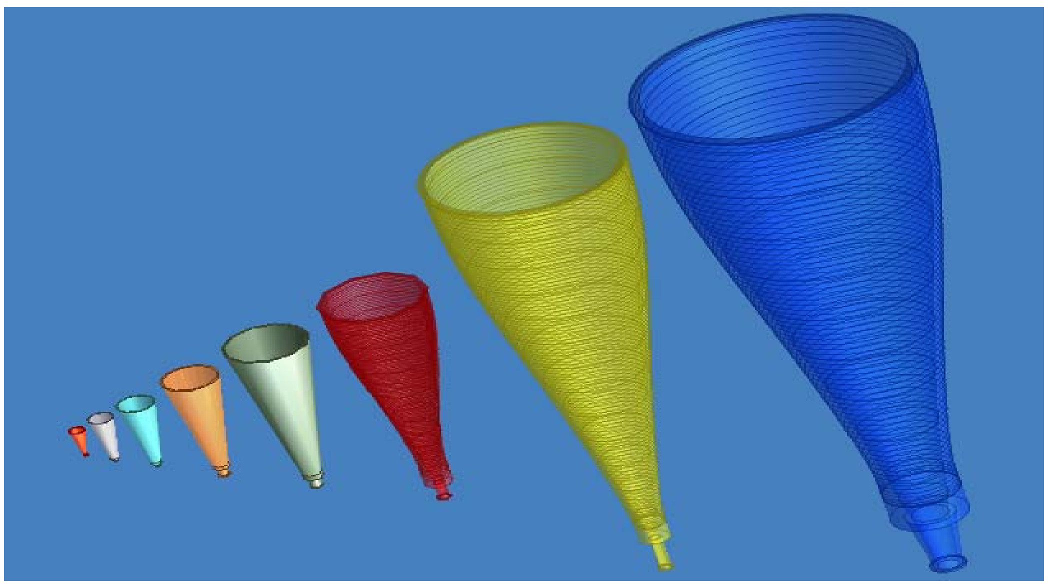
Backup Slides

EVLA Feeds Rolled Out View



EVLA Feed System

All feeds are compact or linear taper corrugated horns with ring loaded mode converters



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