Feed & Front End PDR

Q, Ka, K, Ku & X-Band Receivers

High Frequency Receivers

EVLA Receiver Bands:

- Q-Band : 40 → 50 GHz
- Ka-Band : 26 → 40 GHz
- K-Band : 18 → 26 GHz
- Ku-Band : 12 → 18 GHz
- X-Band : 8 → 12 GHz

Baseline Design

- What follows is the preliminary "baseline" design and is an extrapolation of the current VLA receiver concept
- To realize the linearity required to carry out Solar observing (with its 70 dB dynamic range requirements) we will need to adopt a new receiver design philosophy & make several major modifications to the current L, Q & K systems
    - See PAL's presentation

VLA Receiver History

- VLA originally built with L, C, Ku & K bands
  - All inside a single Dewar (ie: the "A-Rack")
  - Required long waveguide runs between Feeds & A-Rack Dewar
- For Voyager Encounter in 1986, new X-Band Rx mounted in a separate dewar on the Feed Circle
- Followed by VLBA-style L-Band in early 90's
- New Q & K-Band Rx's installed from mid 90's
- C & Ku-Band still in A-Rack

QAKUX Receivers

General Comments

- Receivers ≥ X-Band all have 8-12 GHz IF's
- Two Circular Polarization IF Pairs
  - Two independent LO's and 4 Mixers
  - Four 8-12 GHz IF's
  - *RCP-1 & LCP-1* and *RCP-2 & LCP-2*
  - Allows 8 GHz bandwidth per polarization (total BW = 16 GHz)
- Common 8-12 GHz IF Down-Converter (4 modules)
- K-Band design will be scaled in frequency for Ka, Ku and (probably) X-Band
- New feature - Non-Linear Threshold Detectors (NLTD)

QAKUX Receivers

Polarizers

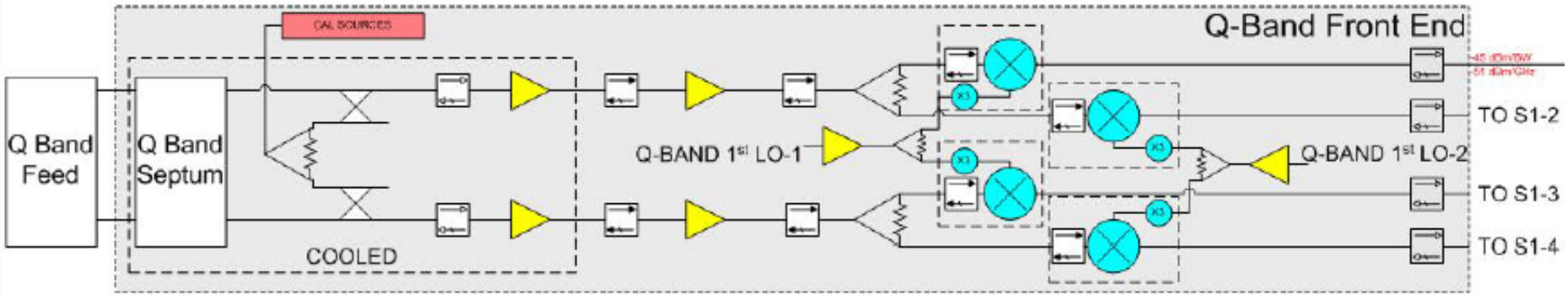
Receiver	Polarizer Type	Comment
Q-Band	Sloping Septum	Atlantic Microwave (already in use at VLA)
Ka-Band	Phase Shifter + Bøifot Symmetric Junction OMT	Scaled up in frequency from K-Band
K-Band	Phase Shifter + Bøifot Symmetric Junction OMT	Existing CDL Design (Wollack)
Ku-Band	Phase Shifter + Bøifot Symmetric Junction OMT	Scaled down in frequency from K-Band
X-Band	Phase Shifter + Bøifot Symmetric Junction OMT	Scaled from K-Band (or Quad Ridge+Hybrid ?)

T_{Rx} Estimates
VLBA vs. EVLA Comparison

Receiver	VLBA T_{Rx} (°K)	EVLA T_{Rx} (°K)
Q-Band	56	44
Ka-Band	-	38
K-Band	61	28
Ku-Band	34	21
X-Band	35	21

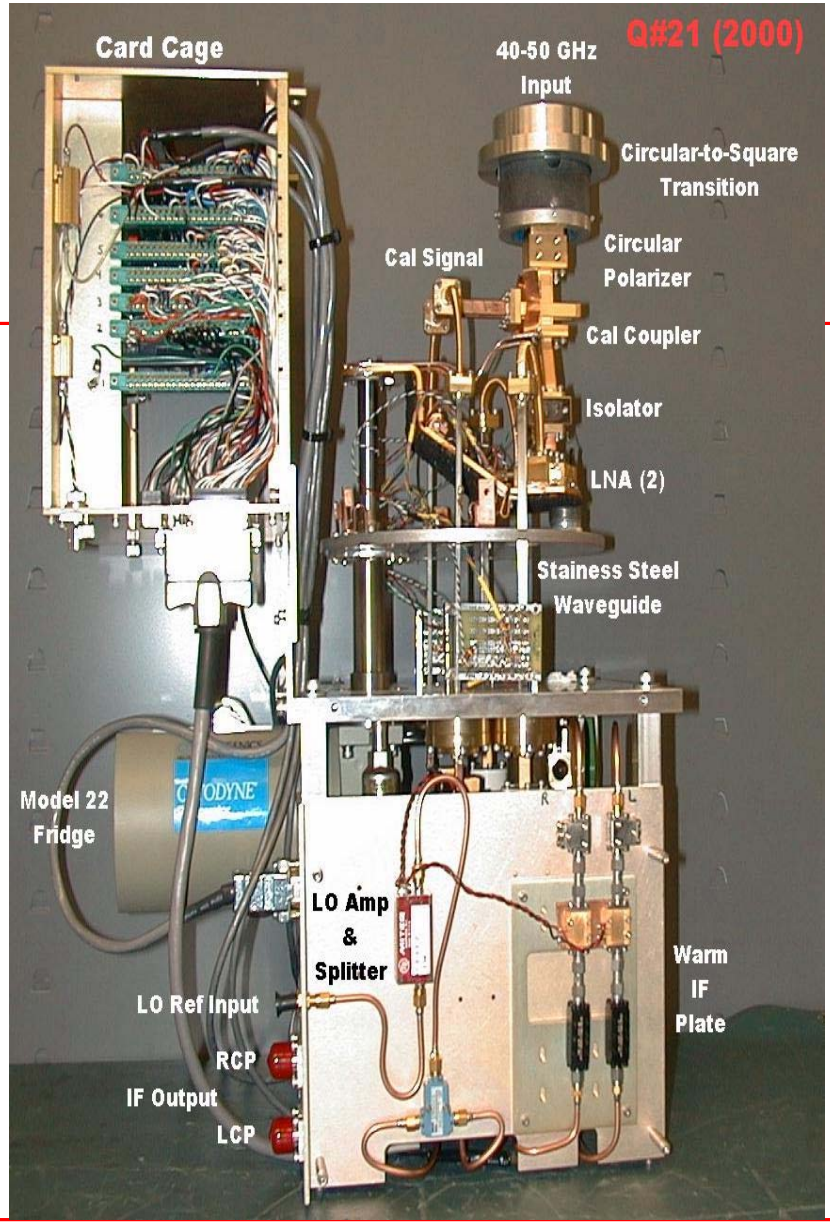
Note : Does not include noise contribution from Down-Converter Subsystem

Q-Band Receiver Block Diagram

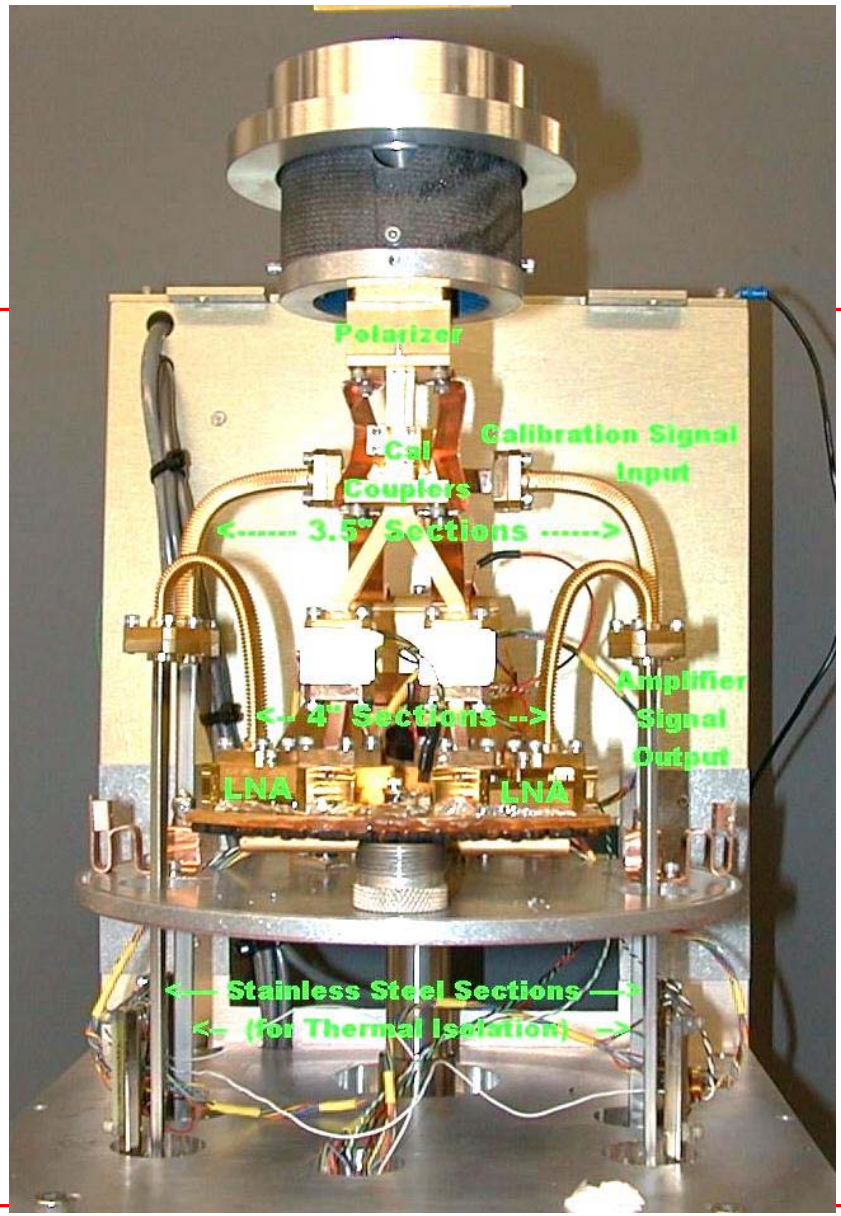


- Frequency Coverage = 40 → 50 GHz
- LO Ref Input = 16.6 → 20.0 GHz @ 0 dBm
- Uses Tripler to provide an LO of 50 → 60 GHz
- IF Output = 8-12 GHz @ approx -45 dBm
- CDL 4-stage LNA with $T_N \approx 25°K$
- Estimated $T_{Rx} \approx 44°K$

Current VLA Q-Band Receiver (side view)



Current VLA
Q-Band
Receiver
(side view)



Q-Band EVLA Modifications

- Retain:
  - Feed, Polarizer, Isolators, LNA's (most of them), LO Amp, Passive Triplers, Mixers, Noise Diode, Dewar, Model 22 Fridge
- Add:
  - 2 RF Splitters, 2 Post Amps, Isolators, 2nd Mixer pair, 2nd LO Amp, 2 Triplers (Active?)
- Remove:
  - IF Chain (Filter + Amp)
- Uncertain:
  - Cal Coupler (replace 30 with 20 dB), Card Cage

Q-Band Receiver Major Components

- Polarizer - Atlantic Microwave Septum
- LNA - CDL 4-stage InP HEMT
- Post Amp - Spacek Labs (2 x $3.5K)
  - G = 25dB, NF = 5dB, P_o = +4dBm
  - NRAO HMMC-5040 MMIC ?
    (20-30 & 40-60 GHz, 10 dB)
- Tripler/Mixer - Spacek M45-8.4 (2 x $9.1K)
  - x2/Mixer Option (2 x $5.6K)

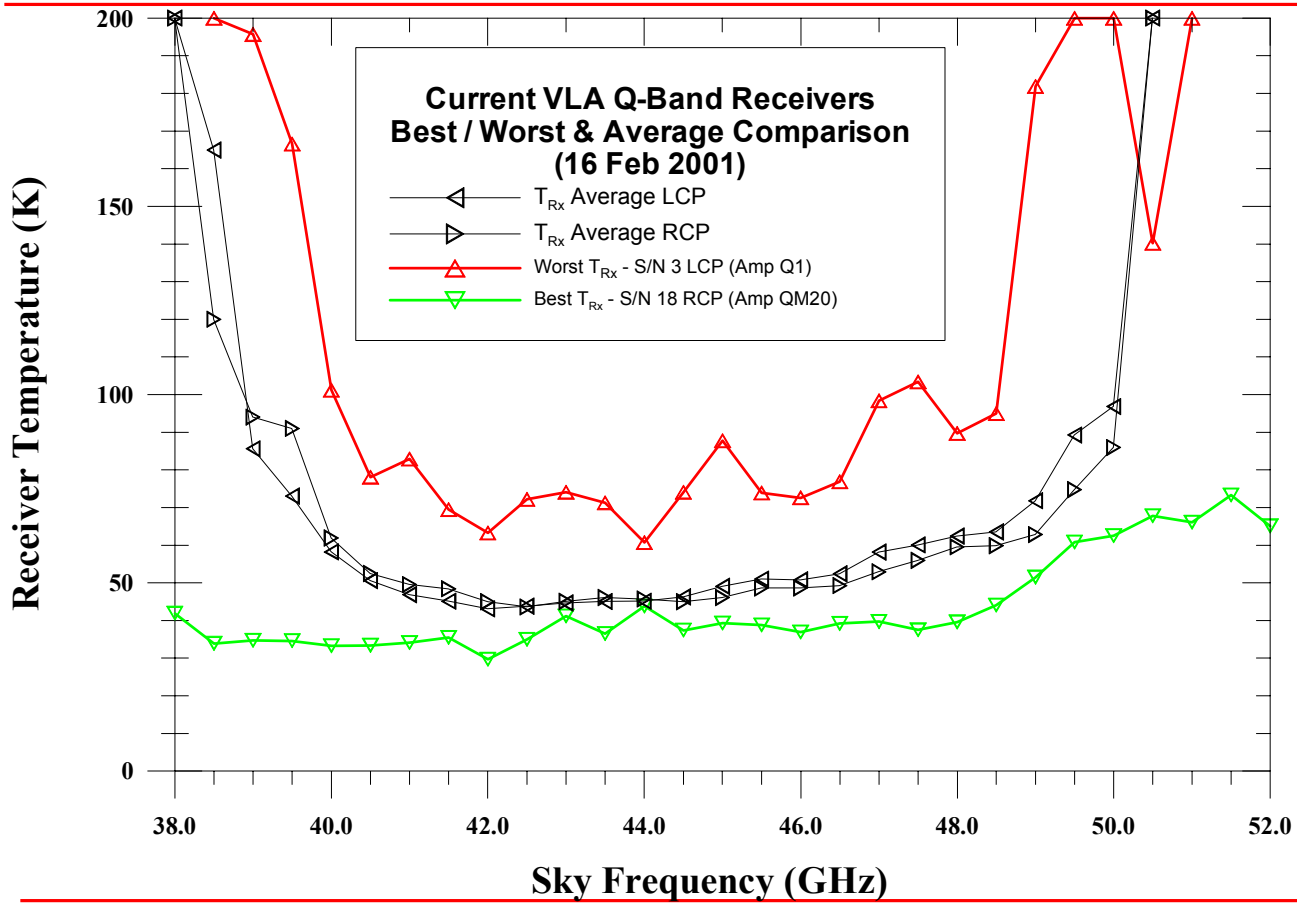
Q-Band Upgrade
Incremental Cost (Tripler)

Component	Item Cost	2 x 4 GHz IF's		4 x 4 GHz IF's	
		Qty	Cost ($K)	Qty	Cost ($K)
LO Amp	2.2	0	0	1	2.2
LO Splitter	0.2	0	0	1	0.2
LO Tripler / Mixer	7.8	0	0	2	15.6
RF Post Amp	3.5	2	7.0	2	7.0
RF Splitter	1.0	0	0	2	2.0
RF Isolators	1.0	2	2.0	2	2.0
IF Isolators	0.2	2	0.4	4	0.8
Total per Rx			$9.4K		$29.8K
Total for 30 Rx's			$282K		$894K

Q-Band Upgrade
Incremental Cost (Doubler)

Component	Item Cost	2 x 4 GHz IF's		4 x 4 GHz IF's	
		Qty	Cost ($K)	Qty	Cost ($K)
LO Amp	2.2	0	0	1	2.2
LO Splitter	0.2	0	0	1	0.2
LO Doubler/Mixer	5.6	0	0	2	11.2
RF Post Amp	3.5	2	7.0	2	7.0
RF Splitter	1.0	0	0	2	2.0
RF Isolators	1.0	2	2.0	2	2.0
IF Isolators	0.2	2	0.4	4	0.8
Total per Rx			$9.4K		$25.4K
Total for 30 Rx's			$282K		$762K

Sensitivity of Current Q-Band Systems



Of the 25 populated VLA antennas, we will want to replace 23 out of the 50 existing LNA's

- 20 old GaAs
- 3 sub-standard InP

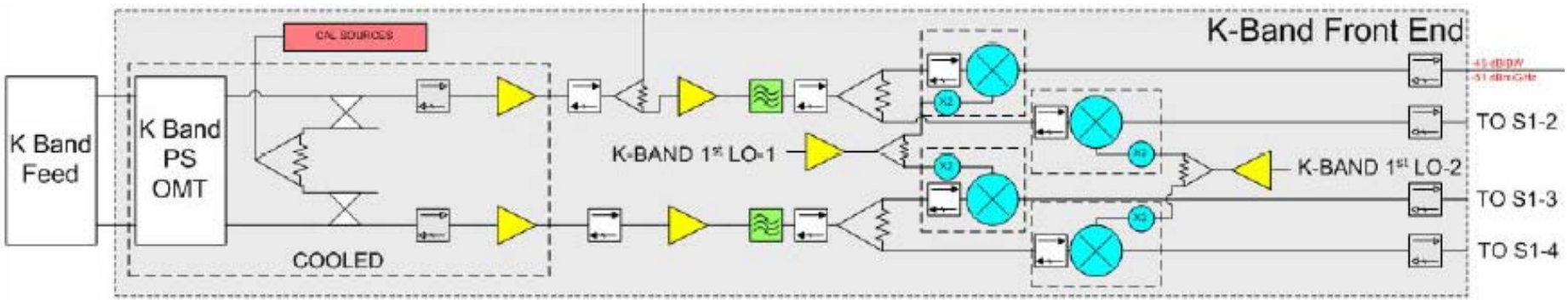
Q-Band Noise Budget

Component	Temp(K)	L/G (dB)	ΔT_{Rx} (K)
Feed	300	-0.05	3.474
Vacuum Window	300	-0.05	3.474
Polarizer	18	-0.3	1.287
Cal Coupler	18	-0.2	0.848
Isolator	18	-0.5	2.196
LNA	Tn = 25	+35	32.206
Cold WG / Coax	150	-2	0.036
Warm WG / Coax	300	-0.5	0.024
Post Amp	NF=5 dB	+25	0.462
Splitter	300	-4	0.001
Mixer	300	-10	0.016
IF Cable	300	-3	0.017
Total T_{Rx}			44.0

Q-Band Noise Budget (no Post Amp)

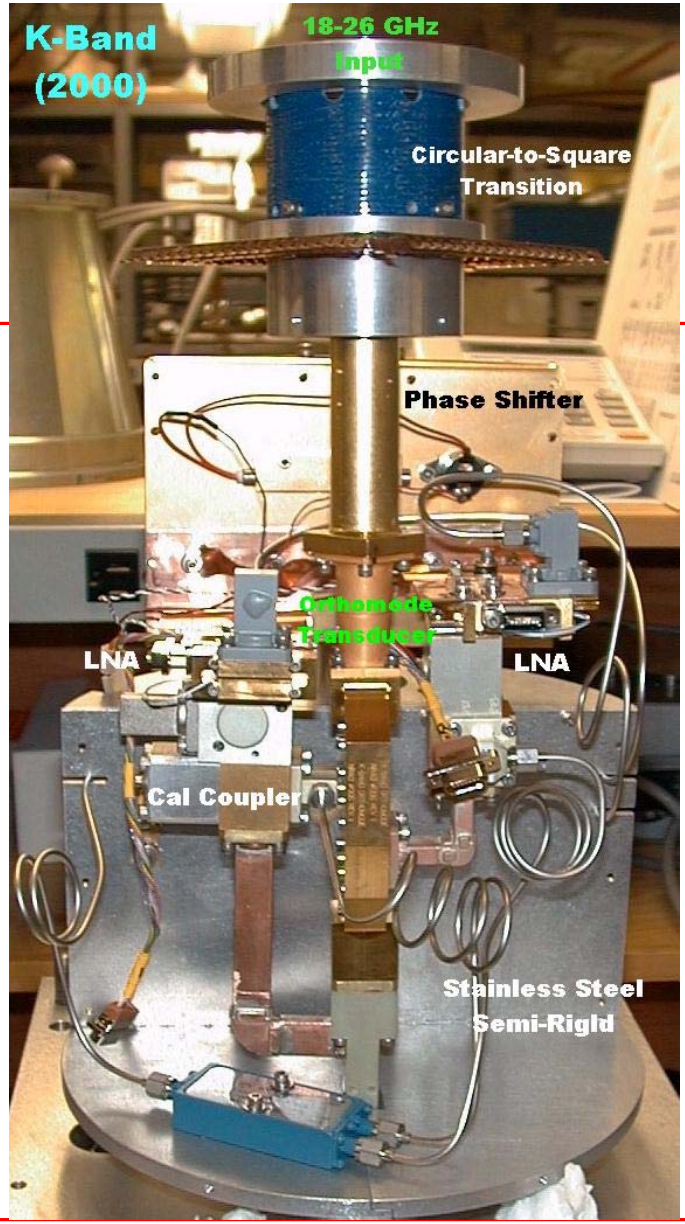
Component	Temp (K)	L/G (dB)	ΔT_{Rx} (K)
Feed	300	-0.05	3.474
Vacuum Window	300	-0.05	3.474
Polarizer	18	-0.3	1.287
Cal Coupler	18	-0.2	0.848
Isolator	18	-0.5	2.196
LNA	Tn = 25	+35	32.206
Cold WG / Coax	150	-2	0.036
Warm WG / Coax	300	-0.5	0.024
Post Amp	-	-	-
Splitter	300	-4	0.329
Mixer	300	-10	4.913
IF Cable	300	-3	5.433
Total T_{Rx}			54.2

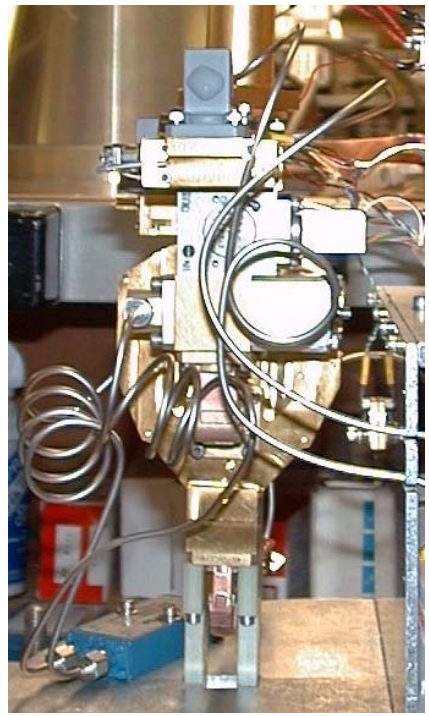
K-Band Receiver Block Diagram



- Frequency Coverage= 18 → 26.5 GHz
- LO Ref Input = 14.0→18.25 GHz @ 0 dBm
- Uses Doubler to provide an LO of 28 → 36.5 GHz
- IF Output = 8-12 GHz @ approx -45 dBm
- CDL 4-stage LNA with $T_N \approx 15°K$
- Estimated $T_{Rx} \approx 28°K$

Current VLA
K-Band
Receiver
(front view)





K-Band EVLA Modifications

- Retain:
  - Feed, Polarizer, Isolators, LNA's (most of them), Post Amp,
  - LO Amp, Noise Diode, Dewar, Model 350 Fridge
- Add:
  - 2 RF Splitters, Isolators, 2nd LO Amp, 2 LO Doublers,
  - 4 new wideband Mixers (last 8 Rx's have WB Mixers - need 104)
- Remove:
  - Mixers, IF Filters
- Uncertain:
  - Cal Coupler (replace 30 with 20 dB), Card Cage
  - Post Amps (35 vs 25 dB)

K-Band Receiver Major Components

- Polarizer - Phase-Shifter + Symmetric OMT
- LNA - CDL 4-stage InP HEMT
- Post Amp - Quinstar QLN-2240J0 (2 x $1.1K)
  - G = 25dB, NF = 4dB, P_o = +10dBm
- Doubler - TBD (2 x $?K)
- Mixer - Miteq TB0440LW1 (4 x $1.1K)
  - RF/LO=4-40 GHz, IF=0.5-20 GHz

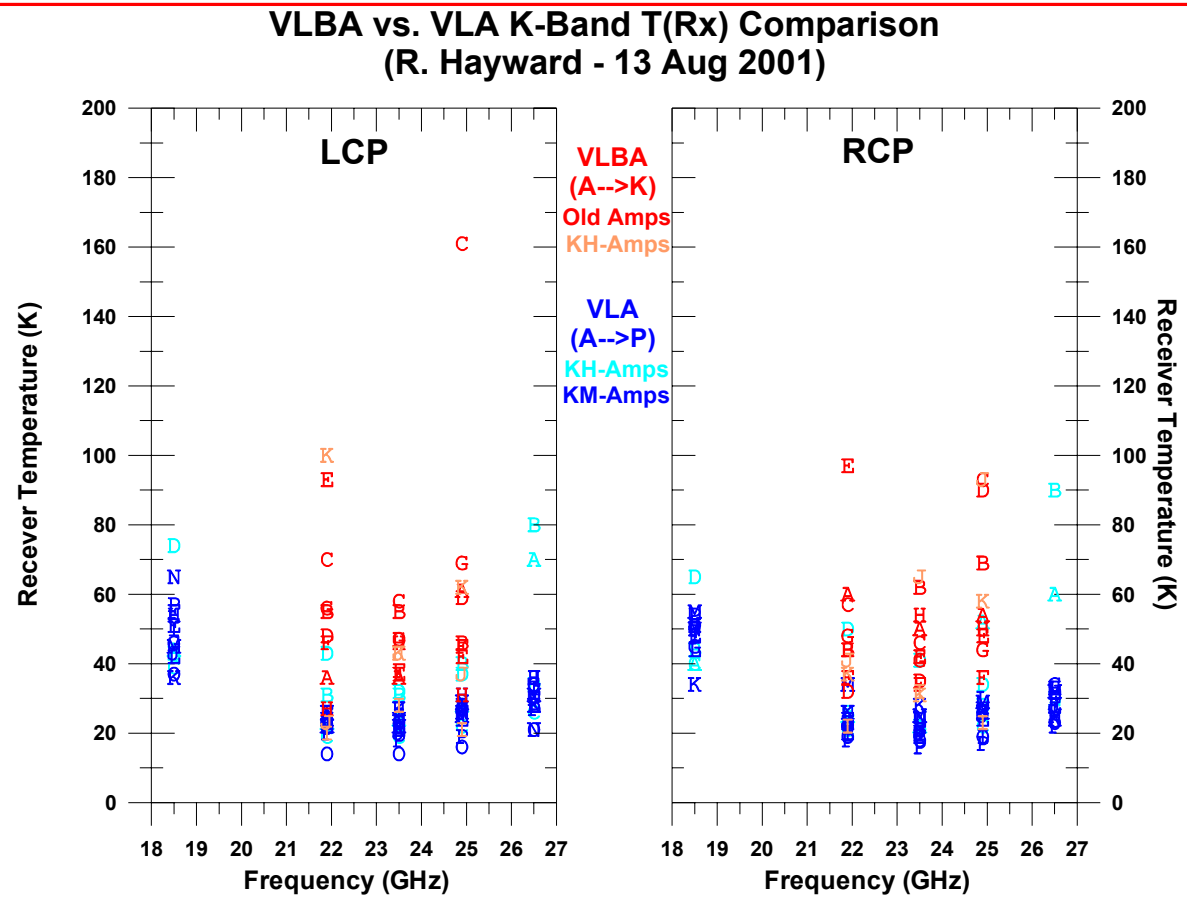
K-Band Upgrade Incremental Cost

Component	Item Cost	2 x 4 GHz IF's		4 x 4 GHz IF's	
		Qty	Cost ($K)	Qty	Cost ($K)
LO Amp	1.0	0	0	1	1.0
LO Splitter	0.2	0	0	1	0.2
LO Doubler	1.5	2	3.0	4	6.0
LO Mixer	1.1	2	2.2	4	4.4
RF Post Amp	1.1	2	2.2	2	2.2
RF Splitter	1.0	0	0	2	2.0
RF Isolators	0.5	0	0	4	2.0
IF Isolators	0.3	2	0.6	4	1.2
Total per Rx			$8.0K		$19.0K
Total for 30 Rx's			$240K		$570K

K-Band
Other Considerations

- Water Vapor Radiometer
  - Plans for bolting a WVR system to the bottom of Rx
  - Temperature stabilize system with Noise Diode, RF splitter, Post Amp plus WVR back end
- K-Band design will be scaled up/down in frequency for Ka, Ku & (probably) X-Band
  - Drawings for K-Band being updated and improved

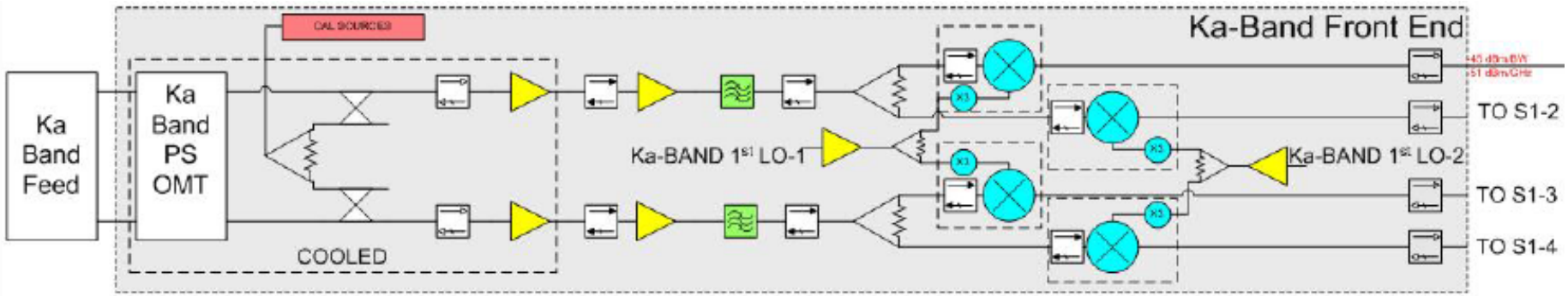
K-Band Sensitivity
VLA & VLBA



K-Band Noise Budget

Component	Temp (K)	L/G (dB)	ΔT_{Rx} (K)
Feed	300	-0.05	3.474
Vacuum Window	300	-0.01	0.692
PS + OMT	18	-0.3	1.287
Cal Coupler	18	-0.2	0.848
Isolator	18	-0.5	2.196
LNA	Tn = 15	+35	19.147
Cold WG / Coax	150	-2	0.035
Warm WG / Coax	300	-0.5	0.023
Post Amp	NF=4 dB	+25	0.320
Splitter	300	-4	0.001
Mixer	300	-10	0.015
IF Cable	300	-3	0.017
Total T_{Rx}			28.1

Ka-Band Receiver Block Diagram



- Frequency Coverage= 26.5 → 40 GHz
- LO Ref Input = 12.1→16.6 GHz @ 0 dBm
- Uses Tripler to provide an LO of 36.3 → 49.8 GHz
- IF Output = 8 -12 GHz @ approx -45 dBm
- CDL 4-stage LNA with $T_N \approx 20°K$
- Estimated $T_{Rx} \approx 38°K$

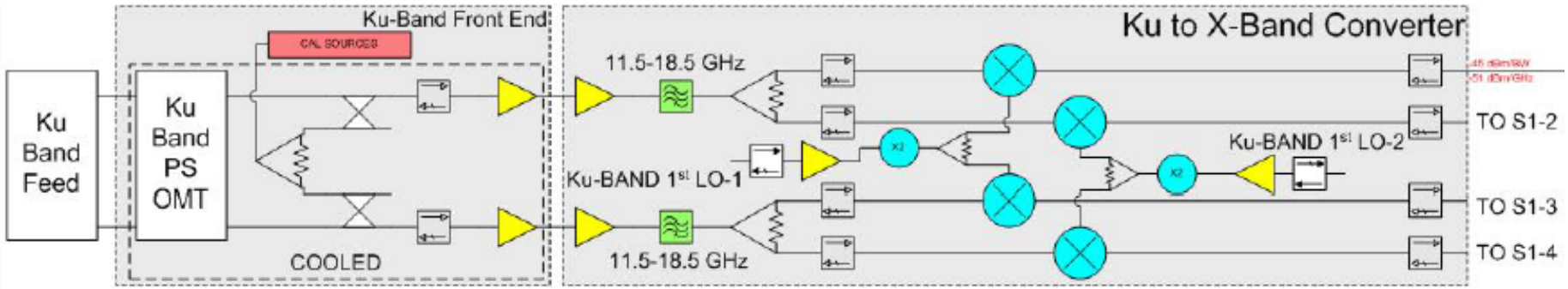
Ka-Band Receiver Major Components

- Polarizer - Phase-Shifter + Symmetric OMT
- LNA - CDL 4-stage InP HEMT
- Post Amp - G = 25 dB, NF = 5dB, P_o = +8dBm
  - Spacek Labs (2 x $2.8K)
  - NRAO HMMC-5040 MMIC ?
    (20-30 & 40-60 GHz, 10 dB)
- Tripler/Mixer - Spacek (4 x $5.3K)

Ka-Band Noise Budget

Component	Temp (K)	L/G (dB)	ΔT_{Rx} (K)
Feed	300	-0.05	3.474
Vacuum Window	300	-0.05	3.474
PS + OMT	18	-0.3	1.287
Cal Coupler	18	-0.2	0.848
Isolator	18	-0.5	2.196
LNA	Tn = 20	+35	25.765
Cold WG / Coax	150	-2	0.036
Warm WG / Coax	300	-0.5	0.024
Post Amp	NF=5 dB	+25	0.462
Splitter	300	-4	0.001
Mixer	300	-10	0.016
IF Cable	300	-3	0.017
Total T_{Rx}			37.6

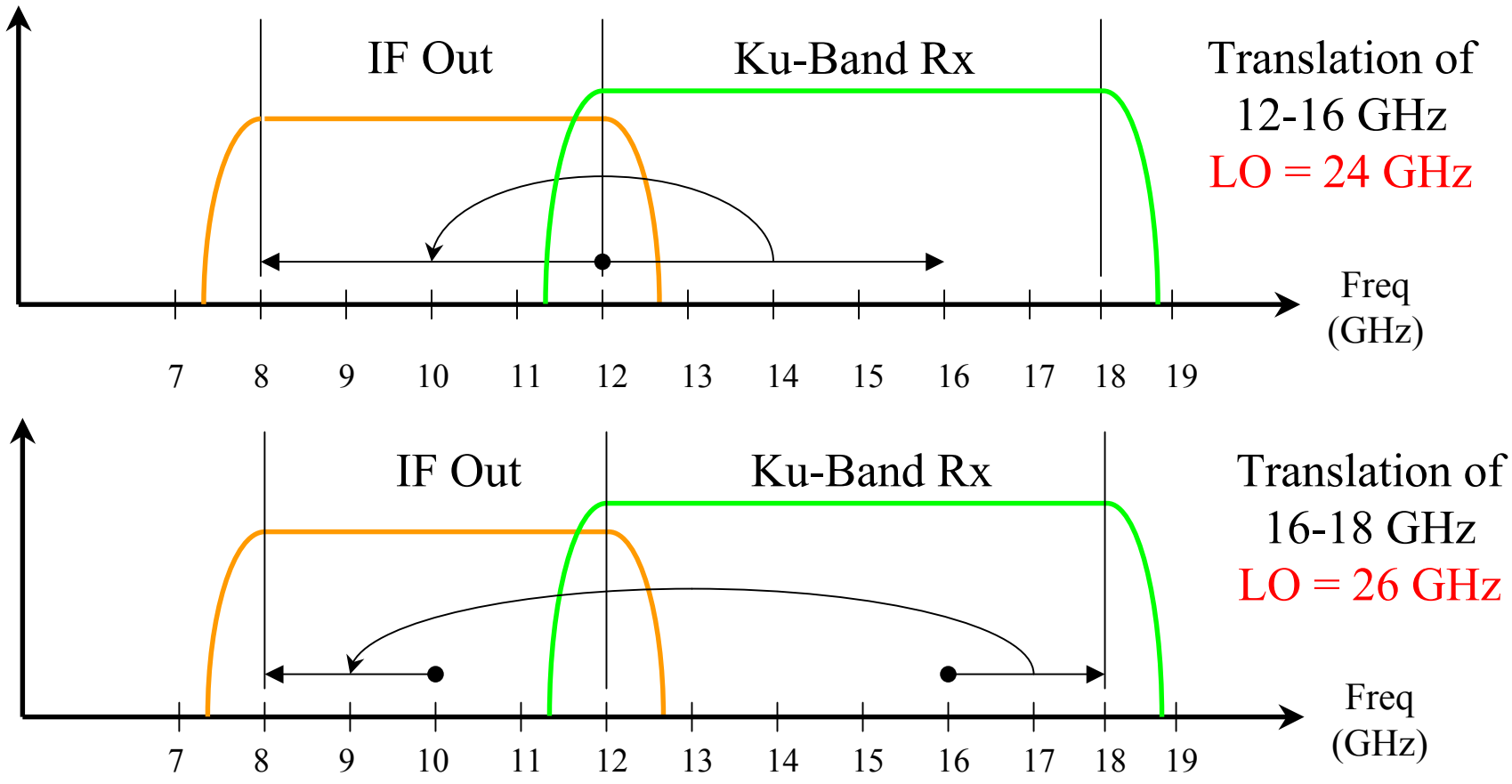
Ku-Band Receiver Block Diagram



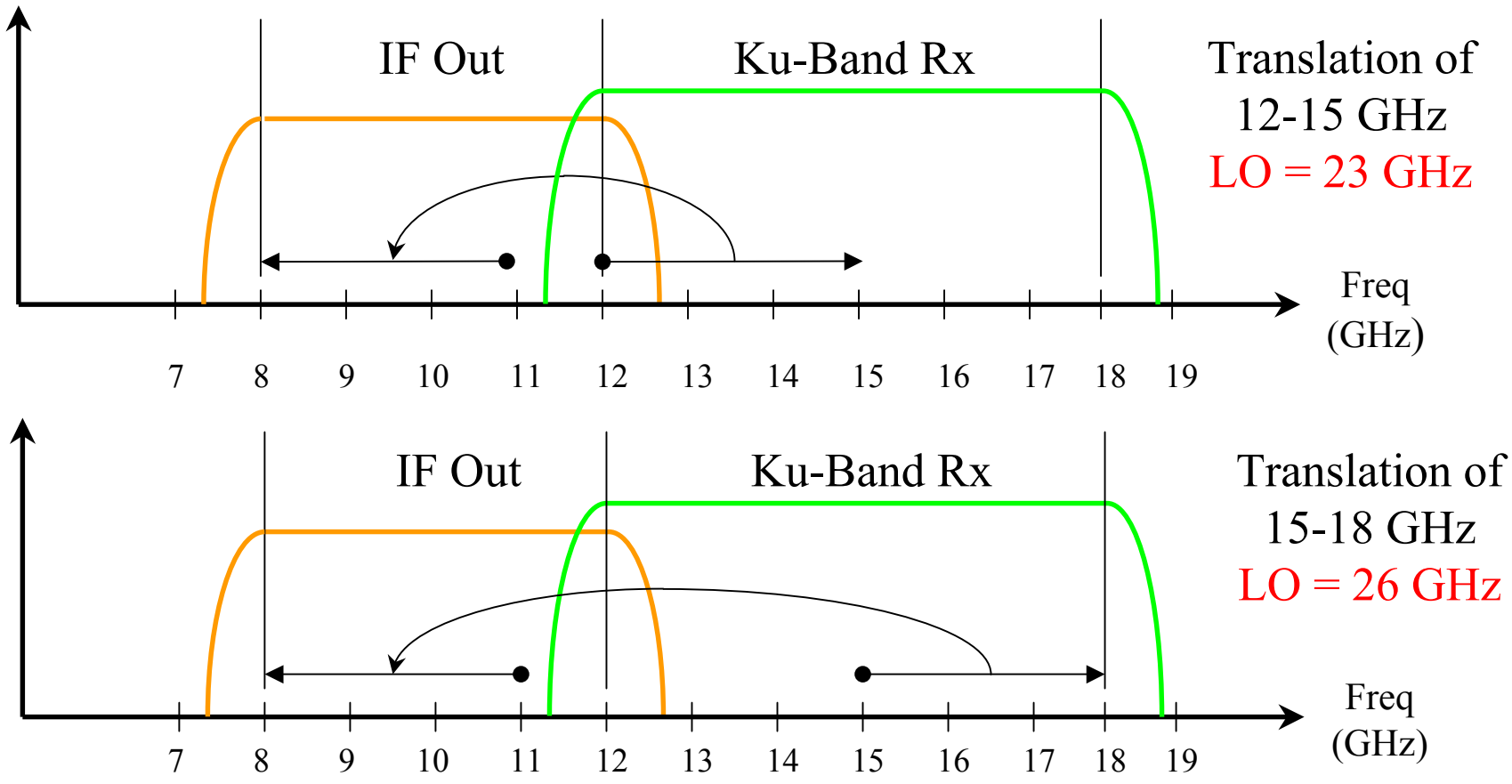
- Frequency Coverage= 12 → 18 GHz
- LO Ref Input = 12.0† → 14.0 GHz @ 0 dBm
- Uses Doubler to provide an LO of 23 → 28 GHz
- IF Output = 8 -12 GHz @ approx -45 dBm
- CDL 3-stage LNA with $T_N \approx 10°K$
- Estimated $T_{Rx} \approx 21°K$

† poor RF-to-IF isolation at 12 GHz

Ku Down-Conversion The Wrong Way



Ku Down-Conversion The Right Way



Ku-Band LO Requirements

- Requires that the 1st LO Synthesizer be able to provide 11.5 GHz
  - Current specification is only 12-20 GHz

Ku-Band Receiver Major Components

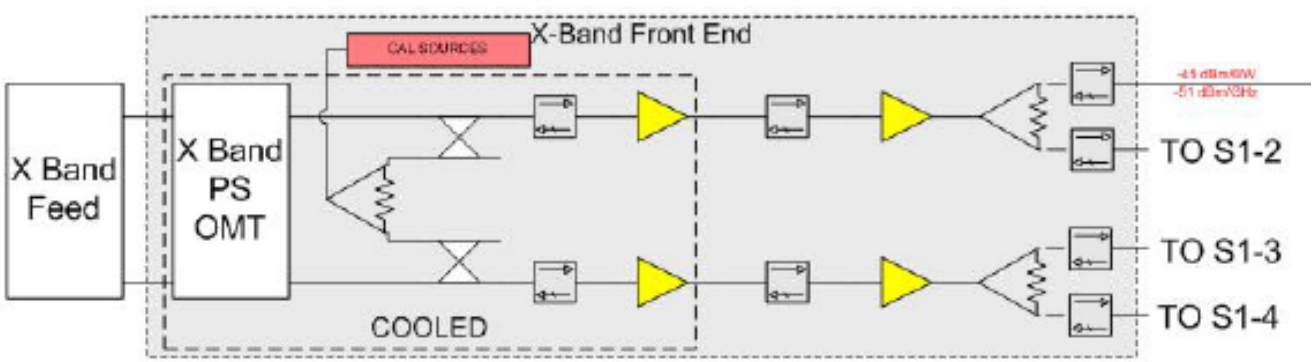
- Polarizer - Phase-Shifter + Symmetric OMT
- LNA - CDL 3-stage InP HEMT
- Post Amp - G = 25 dB, NF=3dB, P_o = +10dBm
  - TBD (Quinstar 2 x ~$1K)
- Doubler/Mixer - TBD (4 x $?K)

- We hope to equip EVLA modified antennas with new Ku-Band Rx's as they come out of the Barn but the Transition plan also calls for an interim Up-Converter to allow the old "A-Rack" Ku Rx's to be used if needed (components will eventually be incorporated into new Ku-Band Rx later)

Ku-Band Noise Budget

Component	Temp (K)	L/G (dB)	ΔT_{Rx} (K)
Feed	300	-0.05	3.474
Vacuum Window	300	-0.01	0.692
PS + OMT	18	-0.3	1.287
Cal Coupler	18	-0.2	0.848
Isolator	18	-0.5	2.196
LNA	Tn = 10	+40	12.764
Cold WG / Coax	150	-2	0.011
Warm WG / Coax	300	-0.5	0.007
Post Amp	NF=3 dB	+25	0.067
Splitter	300	-4	0.000
Mixer	300	-10	0.005
IF Cable	300	-3	0.005
Total T_{Rx}			21.4

X-Band Receiver Block Diagram



- Frequency Coverage= 8 → 12 GHz
- LO Ref Input = None
- "IF" Output = approx -45 dBm
- CDL 3-stage LNA with $T_N \approx 10°K$ (?)
- Estimated $T_{Rx} \approx 21°K$

X-Band Receiver Major Components

- Polarizer - Phase-Shifter + Symmetric OMT
  (or Quad-Ridge OMT + Hybrid)
- LNA - CDL 3-stage InP HEMT
- Post Amp - G = 25 dB, NF = 2dB, P_o = +10dBm
  - TBD (Quinstar 2 x ~$1K)

X-Band Receiver Package

Receiver Design	Polarizer (inches)	Dewar (inches)	Receiver (inches)
"Old" X-Band	3.25	7.6	14.0
Current K-Band	13.0	14.5	23.2
X (PS+Sym OMT)	29.3	30.8	39.5
X (Quad-Ridge 2.2λ)	2.2	< "Old"	≤ "Old"
X (Quad-Ridge 3.2λ)	3.25	= "Old"	= "Old"

X-Band Polarizer Options

- Phase Shifter + Symmetric Junction OMT:
  - Proven design at K-Band
  - Least-risk option for guaranteed RF performance
  - But very large Rx package (~40 inches)

- Quad-Ridge OMT + Hybrid:
  - Nice & small
  - Will fit inside current Rx footprint
  - But difficult to fabricate & RF performance unknown

What About the Old X-Band Receiver?

- X-Band : VLBA & VLA Rx's are identical
- Nope:
  - Septum Polarizer only spec'd for 8.0-8.8 GHz
  - LNA's, Post Amps, Model 22 (?)
  - DT500 Temp Sensors (now use DT471)
- Maybe:
  - Noise Diode (MC 7084) ???
  - Cal Splitter, Couplers & Isolators ???
  - Hasting Vacuum Sensors (Hastings DV-6R)

X-Band Noise Budget

Component	Temp (K)	L/G (dB)	ΔT_{Rx} (K)
Feed	300	-0.05	3.474
Vacuum Window	300	-0.001	0.069
PS + OMT	18	-0.3	1.287
Cal Coupler	18	-0.2	0.848
Isolator	18	-0.5	2.196
LNA	Tn = 10	+40	12.738
Cold WG / Coax	150	-2	0.011
Warm WG / Coax	300	-0.5	0.007
Post Amp	NF=2 dB	+25	0.039
Splitter	300	-4	0.000
Mixer	300	-10	0.005
IF Cable	300	-3	0.005
Total T_{Rx}			20.7

Estimated Receiver IF Output Power

Rx	BW (GHz)	T(Sky) (°K)	IF Power (dBm)
L	1	25	-43.9
S	2	25	-45.9
C	4	25	-42.5
X	4	25	-42.1
Ku	4	25	-42.1
K	4	25	-46.7
Ka	4	25	-46.1
Q	4	25	-45.1