NATIONAL RADIO ASTRONOMY OBSERVATORY
SOCORRO, NEW MEXICO
VERY LARGE ARRAY PROGRAM

VLA ELECTRONICS MEMORANDUM NO. 213

FUTURE FRONT-END DEVELOPMENT FOR THE VLA

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September 1985

1. Present configuration

The original front-end design for the VLA was based on the 4.5-5 GHz parametric amplifiers. These provided direct amplification of the C-band signals and served as the first IF amplifier at the other 3 frequencies.

The product of system noise temperature times gain at each band was nearly the same, making the power input to the following stages (which are common to all bands) nearly constant.

Modifications to the original design have been made to improve performance and reliability, and further improvements are being proposed, which change both the gain and system temperatures. The purpose of this memo is to evaluate and recommend future changes to the system

2. Options

Proposed future improvements to the system include various combinations of:

1) Replacing the parametric amplifiers with FET amplifiers.
2) Replacing the cooled electromechanical band-select relay with one outside the dewar, or with a solid-state switch.
3) Adding FET (or HEMT) amplifiers before the K-band mixers.
4) Adding FET amplifiers after the K-band and U-band mixers.
5) Replacing the cooled mixers with mixers outside the dewar.

The amount of gain in the front end should be determined by two constraints:

It must be high enough that the noise contribution from the following stages (which we will call the "back-end") is negligible.

It should not be so high that the power delivered to the back-end is excessive.

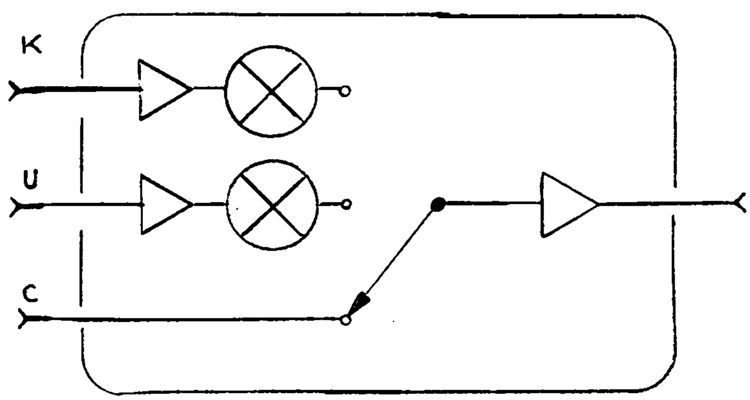
The effect of these constraints for C, U, and K bands, for solar and non-solar observing, is:

Band:	C	U	K
G min:	30	28	30 dB
G max:	34	37	35 dB

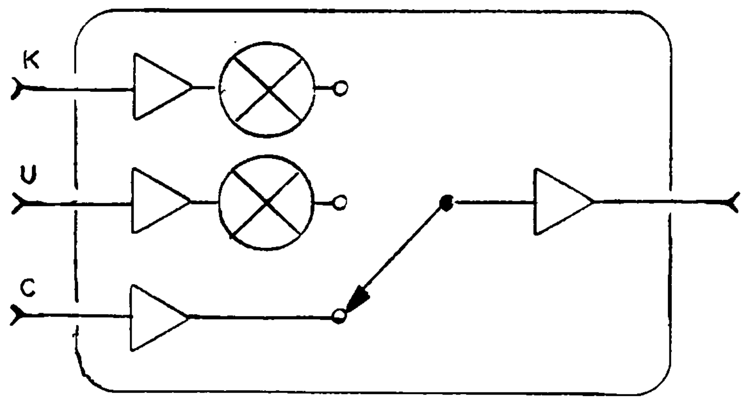
Where G is the gain up to the F9 postamp module.

3. Configurations

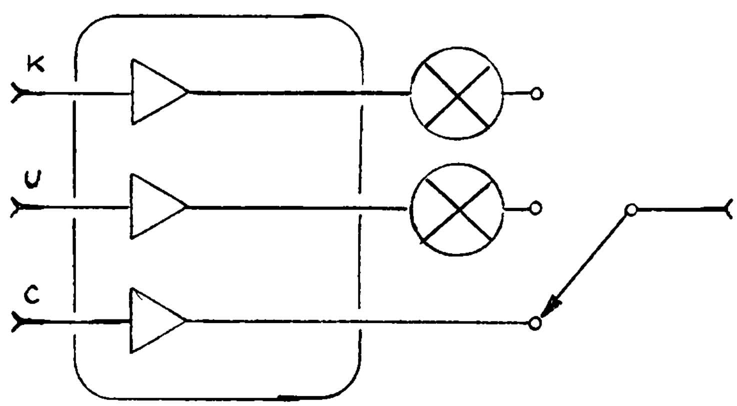
The pros and cons of these options can be best evaluated by looking at specific configurations. Block diagrams showing the components up to the F9 module are shown here. (L-band and X-band portions of the receiver system will be unaffected and are not shown.)



#0,#1: This configuration is most like the current VLA front ends. The U-band signal path is unchanged. At K-band, a 21dB cooled FET (or HEMT) amplifier has been added. The common C-band amplifier is the current 2-stage paramp (#0), or a two-stage version of the VLBA FET (#1).



#2: Here the C-band gain is split into a two-stage amplifier before the cooled coaxial relay (or diode switch) and a single stage after. This would permit the use of a four-stage (28dB) K band amplifier and an increase in the gain of the present u-band amplifier to 27dB.



#3: In both the above configurations, the bandswitch and mixers remain inside the dewar. With the increased gain available at U and K-band, we can move the mixers and bandswitch out to room temperature and dispense with the C-band amplifiers following the mixers. This requires the fewest amplifier packages, and gives a great increase in reliability and accessibility, both of which will reduce downtime sharply.

4. Summary

Appendix I lists the Tsys and power outputs resulting from various system configurations.

Appendix II gives a rough estimate of costs for implementing these configurations.

The following table summarizes these results. " Tsys" is the percentage increase in Tsys above the minimum possible which is taken to be 33.4, 99.3, and 220 at C, U, and K bands with the current VLA antenna systems and amplifiers of 18, 65, and 150 degrees, respectively.

Configuration:	#0	#1	#2	#3
Tsys (C)	37	14	1	2
Tsys (U)	6	5	2	8
Tsys (K)	2	1	1	3
$/Antenna	4300	6300	9500	7000
Man-Week/Ant	5.0	6.8	9.9	8.8 (1)
# Ant/year	26	16	10	13 (2)

(1) Including amplifier assembly & test.

(2) 2 men full time, not including K-band amplifier ass'y & test.

5. Recommendations

Modifications to the VLA front ends should be directed toward configuration #3, above. Our experience has been that well-designed cooled FET amplifiers are among the most reliable components in our system, while paramps, cooled switches and (K-band) mixers are among the worst.

The multi-port "warm" bandswitch is required for the X-band retrofit. The C-band amplifier can be identical to the VLBA design. The additional gain at U-band could be achieved by replacing the output attenuator of the current 20dB U-band FET amplifiers with an isolator.

Provision of independent signal paths through the dewar will mean that failure of any cooled component will affect one band only. It will also allow future retrofits to VLBA-style (individual Dewar & cooled transitions) front ends to be done on a band-by-band basis.

The simplification of the cooled components allows us to build a 29th front-end rack at reduced cost. This will in turn allow retrofits to be made with much less loss of observing time since the retrofit can be done on the extra front end, which will be swapped for the next one to be retrofitted and so on. The total man-hours will also be reduced since the work will be done in the lab with tools and parts at hand, and travel time to and from the antenna will be eliminated.

Appendix I. Cascaded Noise Temperature and Output Power.

The following tables are the output of a program which calculates noise temperature and output power of a cascade of amplifiers and attenuators. Input data are the noise temperature and gain of each amplifier and the physical temperature and gain (<0 dB) of each attenuator. These are listed in the columns "GAIN" and "Tstage", respectively. Outputs are the cumulative gain at the output of each stage ("CUM GAIN"), increase in Tsys which can be attributed to each stage ("DEL Tsys"), and "NOISE OUT" from each stage, in dBm/Hz.

FILE names are a bit cryptic, since we are limited to six characters, no extensions. The first character designates the band as C, U, or K. The following characters designate the major devices in the cascade in the order of signal flow. Amplifiers are denoted by a single digit giving (roughly) the gain in multiples of 10dB . NRAO mixers are indicated by the letter M. Commercial mixers are designated B. A coaxial relay is designated R. A solid state bandswtich is designated S. The letter D is used to denote the passage through the Dewar wall.

For example, CR2D is the current VLA C-band signal path and K3MR1D is the proposed K-band signal path shown in configuration #2.

Configuration #1

C-BAND/COLD COAX RELAY/COLD 2-STAGE C-FET
FILE:CR2D
SYSTEM TEMP = 38.2 K. NOISE FIG. = 0.54 dB
SYSTEM GAIN = +68.7 dB OUTPUT POWER = -114.1 dBm/Hz

#	NAME	GAIN	CUM GAIN	Tstage	DEL Tsys	NOISE OUT
1	SUBREFLECTOR	+0.00	+0.00	8.0	8.0	-189.57
2	WAVEGUIDE	-0.10	-0.10	300.0	7.0	-186.94
3	COLD COAX RELAY	-0.20	-0.30	40.0	1.9	-186.62
4	COLD 2-STAGE C-FET	+26.00	+25.70	18.0	19.3	-157.31
5	COLD CABLES	-2.00	+23.70	100.0	0.2	-159.29
6	WARM CABLES	-1.00	+22.70	300.0	0.3	-160.25
7	F9	+43.00	+65.70	270.0	1.5	-117.09
8	CABLES	-2.00	+63.70	300.0	-0.0	-119.09
9	F6	-13.00	+50.70	300.0	0.0	-132.09
10	F4 FILTER-ISOL.-MIX	-8.00	+42.70	300.0	0.0	-140.08
11	F4 AMP	+26.00	+68.70	630.0	0.0	-114.08

U-BAND/CURRENT FET/COLD COAX RELAY/COLD 2-STAGE C-FET
FILE:U2MR2D
SYSTEM TEMP = 104.1 K. NOISE FIG. = 1.33 dB
SYSTEM GAIN = +66.5 dB OUTPUT POWER = -111.9 dBm/Hz

#	NAME	GAIN	CUM GAIN	Tstage	DEL Tsys	NOISE OUT
1	SUBREFLECTOR	+0.00	+0.00	10.0	10.0	-188.60
2	WAVEGUIDE	-0.28	-0.28	300.0	20.0	-184.11
3	COLD U-FET	+20.00	+19.72	65.0	69.3	-158.91
4	U-MIX	-5.00	+14.72	170.0	3.9	-163.74
5	COLD COAX RELAY	-0.20	+14.52	40.0	0.1	-163.94
6	COLD 2-STAGE C-FET	+26.00	+40.52	18.0	0.6	-137.91
7	COLD CABLES	-2.00	+38.52	100.0	0.0	-139.91
8	WARM CABLES	-1.00	+37.52	300.0	0.0	-140.91
9	F9	+43.00	+80.52	270.0	0.0	-97.91
10	CABLES	-2.00	+78.52	300.0	-0.0	-99.91
11	F6 (MAX ATTN)	-30.00	+48.52	300.0	0.0	-129.91
12	F4 FILTER-ISOL.-MIX	-8.00	+40.52	300.0	0.0	-137.91
13	F4 AMP	+26.00	+66.52	630.0	0.1	-111.91

K-BAND/21dB COLD FET/COLD MIX/COLD COAX RELAY/COLD 2-STAGE C-FET
FILE:K2MR2D
SYSTEM TEMP = 223.9 K. NOISE FIG. = 2.48 dB
SYSTEM GAIN = +67.3 dB OUTPUT POWER = -107.8 dBm/Hz

#	NAME	GAIN	CUM GAIN	Tstage	DEL Tsys	NOISE OUT
1	SUBREFLECTOR	+0.00	+0.00	15.0	15.0	-186.84
2	WAVEGUIDE	-0.50	-0.50	300.0	36.6	-181.97
3	COLD K-FET/3-STAGE	+21.00	+20.50	150.0	168.3	-154.68
4	COLD K-MIX	-5.00	+15.50	170.0	3.3	-159.61
5	COLD COAX RELAY	-0.20	+15.30	40.0	0.1	-159.81
6	COLD 2-STAGE C-FET	+26.00	+41.30	18.0	0.5	-133.80
7	COLD CABLES	-2.00	+39.30	100.0	0.0	-135.80
8	WARM CABLES	-1.00	+38.30	300.0	0.0	-136.80
9	F9	+43.00	+81.30	270.0	0.0	-93.80
10	CABLES	-2.00	+79.30	300.0	0.0	-95.80
11	F6 (MAX ATTN)	-30.00	+49.30	300.0	0.0	-125.80
12	F4 FILTER-ISOL.-MIX	-8.00	+41.30	300.0	0.0	-133.80
13	F4 AMP	+26.00	+67.30	630.0	0.0	-107.80

Configuration #2

C-BAND/COLD 2-STAGE C-FET/COLD DIODE SWITCH/COLD 1-STAGE C-FET
FILE:C2S1D
SYSTEM TEMP = 33.7 K. NOISE FIG. = 0.48 dB
SYSTEM GAIN = +68.9 dB OUTPUT POWER = -114.4 dBm/Hz

#	NAME	GAIN	CUM GAIN	Tstage	DEL Tsys	NOISE OUT
1	SUBREFLECTOR	+0.00	+0.00	8.0	8.0	-189.57
2	WAVEGUIDE	-0.10	-0.10	300.0	7.0	-186.94
3	COLD 2-STAGE C-FET	+26.00	+25.90	18.0	18.4	-157.46
4	COLD DIODE SWITCH	-2.00	+23.90	40.0	0.1	-159.45
5	COLD 1-STAGE C-FET	+13.00	+36.90	20.0	0.1	-146.44
6	COLD CABLES	-2.00	+34.90	100.0	0.0	-148.44
7	WARM CABLES	-1.00	+33.90	300.0	0.0	-149.44
8	F9	+43.00	+76.90	270.0	0.1	-106.42
9	CABLES	-2.00	+74.90	300.0	0.0	-108.42
10	F6	-24.00	+50.90	300.0	0.0	-132.42
11	F4 FILTER-ISOL.-MIX	-8.00	+42.90	300.0	0.0	-140.42
12	F4 AMP	+26.00	+68.90	630.0	0.0	-114.42

U-BAND/ISOL/.COLD MIX/COLD DIODE SWITCH/COLD 1-STAGE C-FET
FILE:U3MS1D
SYSTEM TEMP = 101.2 K. NOISE FIG. = 1.30 dB
SYSTEM GAIN = +64.2 dB OUTPUT POWER = -114.3 dBm/Hz

#	NAME	GAIN	CUM GAIN	Tstage	DEL Tsys	NOISE OUT
1	SUBREFLECTOR	+0.00	+0.00	10.0	10.0	-188.60
2	WAVEGUIDE	-0.28	-0.28	300.0	20.0	-184.11
3	COLD U-FET/NO ATTN.	+27.00	+26.72	65.0	69.3	-151.91
4	ISOL.	-0.50	+26.22	20.0	0.0	-152.41
5	U-MIX	-5.00	+21.22	170.0	0.9	-157.37
6	COLD DIODE SWITCH	-2.00	+19.22	40.0	0.2	-159.36
7	COLD 1-STAGE C-FET	+13.00	+32.22	20.0	0.2	-146.35
8	COLD CABLES	-2.00	+30.22	100.0	0.0	-148.35
9	WARM CABLES	-1.00	+29.22	300.0	0.1	-149.35
10	F9	+43.00	+72.22	270.0	0.3	-106.34
11	CABLES	-2.00	+70.22	300.0	0.0	-108.34
12	F6	-24.00	+46.22	300.0	0.0	-132.33
13	F4 FILTER-ISOL.-MIX	-8.00	+38.22	300.0	0.0	-140.33
14	F4 AMP	+26.00	+64.22	630.0	0.1	-114.33

K-BAND/28dB COLD FET/COLD MIX/COLD DIODE SWITCH/COLD 1-STAGE C-FET
FILE:K3MS1D
SYSTEM TEMP = 221.5 K. NOISE FIG. = 2.46 dB
SYSTEM GAIN = +61.5 dB OUTPUT POWER = -113.6 dBm/Hz

#	NAME	GAIN	CUM GAIN	Tstage	DEL Tsys	NOISE OUT
1	SUBREFLECTOR	+0.00	+0.00	15.0	15.0	-186.84
2	WAVEGUIDE	-0.50	-0.50	300.0	36.6	-181.97
3	COLD K-FET/4-STAGE	+28.00	+27.50	150.0	168.3	-147.68
4	COLD K-MIX	-5.00	+22.50	170.0	0.7	-152.66
5	COLD DOIDE SWITCH	-2.00	+20.50	40.0	0.1	-154.66
6	COLD 1-STAGE C-FET	+13.00	+33.50	20.0	0.2	-141.66
7	COLD CABLES	-2.00	+31.50	100.0	0.0	-143.66
8	WARM CABLES	-1.00	+30.50	300.0	0.1	-144.66
9	F9	+43.00	+73.50	270.0	0.2	-101.65
10	CABLES	-2.00	+71.50	300.0	-0.0	-103.65
11	F6	-28.00	+43.50	300.0	0.0	-131.65
12	F4 FILTER-ISOL.-MIX	-8.00	+35.50	300.0	0.1	-139.65
13	F4 AMP	+26.00	+61.50	630.0	0.2	-113.65

Configuration #3
Recommended for VLA

C-BAND/VLBA FET/WARM COAX RELAY
FILE:C3DR.PRT
SYSTEM TEMP = 34.0 K. NOISE FIG. = 0.48 dB
SYSTEM GAIN = +68.7 dB OUTPUT POWER = -114.6 dBm/Hz

#	NAME	GAIN	CUM GAIN	Tstage	DEL Tsys	NOISE OUT
1	SUBREFLECTOR	+0.00	+0.00	8.0	8.0	-189.57
2	WAVEGUIDE	-0.10	-0.10	300.0	7.0	-186.94
3	COLD VLBA C-FET	+32.00	+31.90	18.0	18.4	-151.46
4	COLD CABLES	-2.00	+29.90	100.0	0.0	-153.46
5	WARM COAX RELAY	-0.20	+29.70	300.0	0.0	-153.65
6	WARM CABLES	-1.00	+28.70	300.0	0.1	-154.64
7	F9	+43.00	+71.70	270.0	0.4	-111.60
8	CABLES	-2.00	+69.70	300.0	0.0	-113.60
9	F6	-19.00	+50.70	300.0	0.0	-132.60
10	F4 FILTER-ISOL.-MIX	-8.00	+42.70	300.0	0.0	-140.60
11	F4 AMP	+26.00	+68.70	630.0	0.0	-114.59

U-BAND/ISOL/.WARM MIX/WARM COAX RELAY/NO C-FET
FILE:U3DMR
SYSTEM TEMP = 107.5 K. NOISE FIG. = 1.37 dB
SYSTEM GAIN = +64.0 dB OUTPUT POWER = -114.3 dBm/Hz

#	NAME	GAIN	CUM GAIN	Tstage	DEL Tsys	NOISE OUT
1	SUBRELFECTOR	+0.00	+0.00	10.0	10.0	-188.60
2	WAVEGUIDE	-0.28	-0.28	300.0	20.0	-184.11
3	COLD U-FET/NO ATTN.	+27.00	+26.72	65.0	69.3	-151.91
4	ISOL.	-0.50	+26.22	20.0	0.0	-152.41
5	COLD CABLES	-2.00	+24.22	100.0	0.1	-154.40
6	WARM U-MIX	-5.00	+19.22	300.0	2.5	-159.30
7	WARM COAX RELAY	-0.20	+19.02	300.0	0.2	-159.49
8	WARM CABLES	-1.00	+18.02	300.0	1.0	-160.45
9	F9	+43.00	+61.02	270.0	4.3	-117.27
10	CABLES	-2.00	+59.02	300.0	0.0	-119.27
11	F6	-13.00	+46.02	300.0	0.0	-132.27
12	F4 FILTER-ISOL.-MIX	-8.00	+38.02	300.0	0.0	-140.27
13	F4 AMP	+26.00	+64.02	630.0	0.1	-114.27

K-BAND/28dB COLD FET/WARM MIX/WARM COAX RELAY/NO C-FET
FILE:K3DMR
SYSTEM TEMP = 227.7 K. NOISE FIG. = 2.52 dB
SYSTEM GAIN = +60.3 dB OUTPUT POWER = -114.7 dBm/Hz

#	NAME	GAIN	CUM GAIN	Tstage	DEL Tsys	NOISE OUT
1	ANTENNA	+0.00	+0.00	15.0	15.0	-186.84
2	WAVEGUIDE	-0.50	-0.50	300.0	36.6	-181.97
3	COLD K-FET/4-STAGE	+28.00	+27.50	150.0	168.3	-147.68
4	COLD CABLES	-3.00	+24.50	100.0	0.2	-150.67
5	WARM K-MIX	-5.00	+19.50	300.0	2.3	-155.63
6	WARM COAX RELAY	-0.20	+19.30	300.0	0.2	-155.83
7	WARM CABLES	-1.00	+18.30	300.0	0.9	-156.81
8	F9	+43.00	+61.30	270.0	4.0	-113.73
9	CABLES	-2.00	+59.30	300.0	-0.0	-115.73
10	F6	-17.00	+42.30	300.0	0.0	-132.73
11	F4 FILTER-ISOL.-MIX	-8.00	+34.30	300.0	0.1	-140.73
12	F4 AMP	+26.00	+60.30	630.0	0.2	-114.72

Appendix II. Cost estimates

Rough estimates of materials and man-hours were run up in a spreadsheet program. Costs are for materials only. Man-days are for assembly, test, and installation only. Design and development are assumed to have been covered by for VLBA.

Three categories of man-day totals are given. the first is the total for all assembly, test, and installation. The second, marked by an asterisk, is the total man-days expended by VLA personnel if the K-band and C-band amplifiers are assembled and tested elsewhere. The third, marked by a double asterisk, is the total man-days that must be performed on the stowed antenna. With a two-man crew giving 10 man-days per week, each antenna would be down between 1 and 2 weeks for any of the configurations listed. If the 29th front end is built, the antenna down time would only be about 2 days.

CONFIG. #	#0	#1	#2	#3	$	MAN-DAY	*	**	#0	#1	#2	#3	#0	#1	#2	#3	
	-- QTY/ANT---				EACH	EACH			---------$ PER ANTENNA ------				---MAN-DAYS/ANT---				
C-BAND:																	
circulator	0	2	4	2	$400	0			$0	$800	$1,600	$800	0.0	0.0	0.0	0.0	
housing	0	2	4	2	$200	2			$0	$400	$800	$400	0.0	4.0	8.0	4.0	
fet	0	4	6	6	$60	0			$0	$240	$360	$360	0.0	0.0	0.0	0.0	
hdwe	0	4	6	6	$100	0.5			$0	$400	$600	$600	0.0	2.0	3.0	3.0	
cables	0	4	8	4	$12	0.1	1		$0	$48	$96	$48	0.0	0.4	0.8	0.4	
drill & mount	0	2	4	2		1	1	1	$0	$0	$0	$0	0.0	2.0	4.0	2.0	
dwr feedthru	0	2	4	4	$60	0.25	1		$0	$120	$240	$240	0.0	0.5	1.0	1.0	
bandswitch	2	2	2	0	$800	1	1	1	$1,600	$1,600	$1,600	$0	2.0	2.0	2.0	0.0	
C-BAND TOTAL:									$1,600	$3,608	$5,296	$2,448	2.0	10.9	18.8	10.4	
DELTA Tsys:									37%	14%	1%	2%					
U-BAND:																	
circulator	0	0	2	2	$350	0.25	1		$0	$0	$700	$700	0.0	0.0	0.5	0.5	
cables	0	0	4	8	$12	0.1	1		$0	$0	$48	$96	0.0	0.0	0.4	0.8	
drill & mount	0	0	2	2		0.5	1	1	$0	$0	$0	$0	0.0	0.0	1.0	1.0	
dwr feedthru	0	0	0	2	$45	0.25	1		$0	$0	$0	$90	0.0	0.0	0.0	0.5	
WG-coax trans'n	0	0	0	0	$125	0.5	1		$0	$0	$0	$0	0.0	0.0	0.0	0.0	
U-BAND TOTAL:									$0	$0	$748	$886	0.0	0.0	1.9	2.8	
DELTA Tsys:									6%	5%	2%	8%					
K-BAND:																	
circulator	2	2	2	2	$350	0			$700	$700	$700	$700	0.0	0.0	0.0	0.0	
housing	2	2	2	2	$200	2			$400	$400	$400	$400	4.0	4.0	4.0	4.0	
fet	6	6	8	8	$120	0			$720	$720	$960	$960	0.0	0.0	0.0	0.0	
hdwe	6	6	8	8	$50	0.5			$300	$300	$400	$400	3.0	3.0	4.0	4.0	
cables	4	4	4	8	$15	0.1	1		$60	$60	$60	$120	0.4	0.4	0.4	0.8	
drill & mount	2	2	2	2		1	1	1	$0	$0	$0	$0	2.0	2.0	2.0	2.0	
dwr feedthru	0	0	0	2	$45	0.25	1		$0	$0	$0	$90	0.0	0.0	0.0	0.5	
WG-coax trans'n	4	4	4	4	$125	0.25	1		$500	$500	$500	$500	1.0	1.0	1.0	1.0	
K-BAND TOTAL:									$2,680	$2,680	$3,020	$3,170	10.4	10.4	11.4	12.3	
DELTA Tsys:									2%	1%	1%	3%					
RACK:																	
warm,cool	1	1	1	1	0	4	1	1	$0	$0	$0	$0	4.0	4.0	4.0	4.0	
modify	1	1	1	1	0	4	1	1	$0	$0	$0	$0	4.0	4.0	4.0	4.0	
wires	1	1	2	2	$6	0.5	1		$6	$6	$12	$12	0.5	0.5	1.0	1.0	
DC conn'r	0	0	1	1	$30	0.5	1		$0	$0	$30	$30	0.0	0.0	0.5	0.5	
bias module I	1	1	1	1	$0	4	1		$0	$0	$0	$0	4.0	4.0	4.0	4.0	
bias module II	0	0	1	1	$400	4	1		$0	$0	$400	$400	0.0	0.0	4.0	4.0	
waveguide	0	0	0	1	$100	1	1		$0	$0	$0	$100	0.0	0.0	0.0	1.0	
RACK TOTAL:									$6	$6	$442	$542	12.5	12.5	17.5	18.5	
CONFIG. #									#0	#1	#2	#3	#0	#1	#2	#3	
TOTAL/ANTENNA:									$4,286	$6,294	$9,506	$7,046	24.9	33.8	49.6	44.0	
WEIGHTED (C=2, U=K=1) DELTA Tsys:									21%	9%	1%	4%	17.9	20.8	30.6	29.0	*
													12.0	14.0	17.0	13.0	**

* MUST BE DONE AT VLA. ** MUST BE DONE WHILE ANTENNA DOWN UNLESS 29th FE IS BUILT