EVLA Planning Workshop
NRAO, Socorro, NM
August 23, 2001

NMA Antenna and Receiver Concepts

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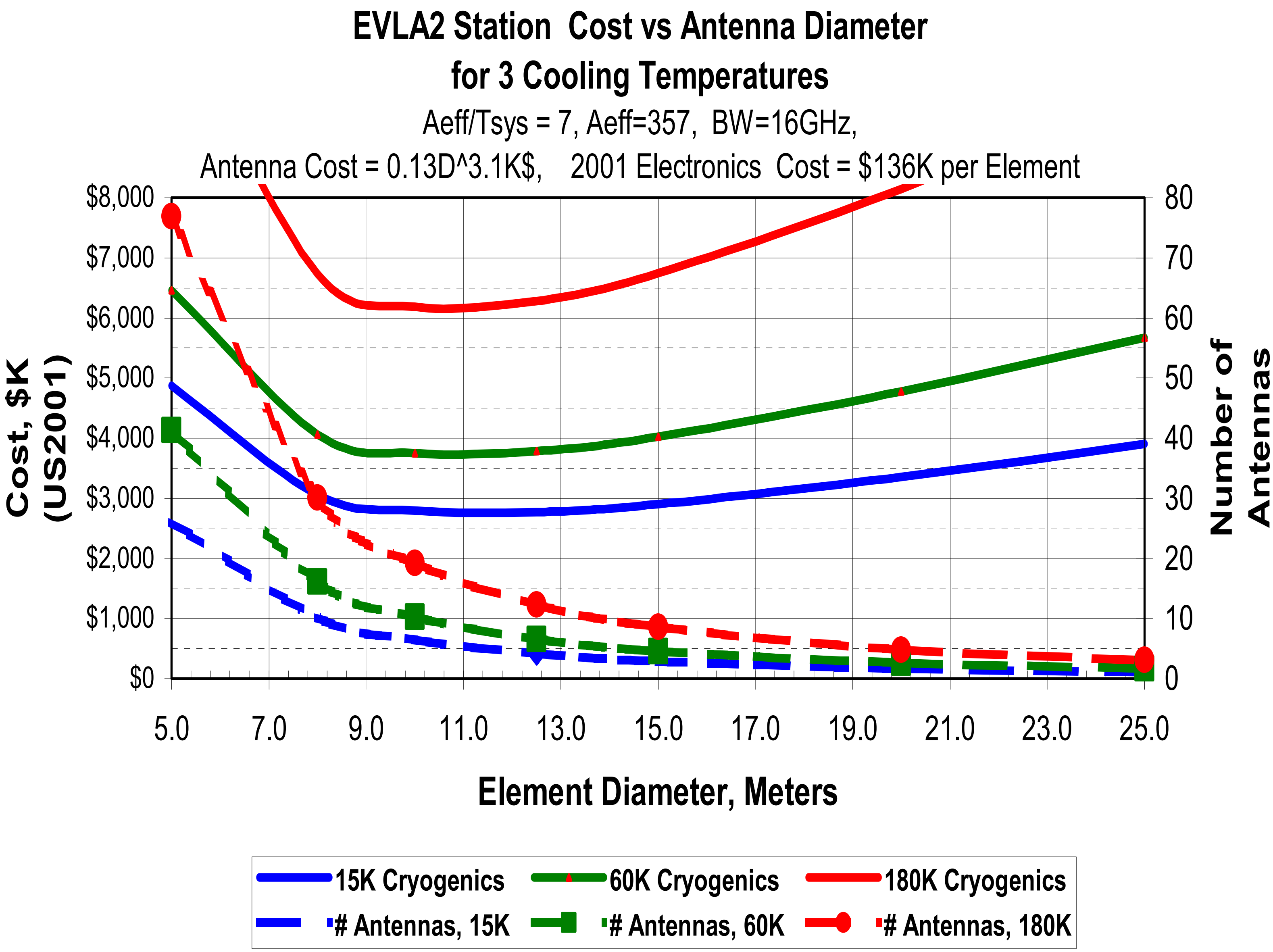
1. Station Cost Equation
2. Hydroformed Antennas
3. Wideband Receivers
4. Suggested Technology Developments

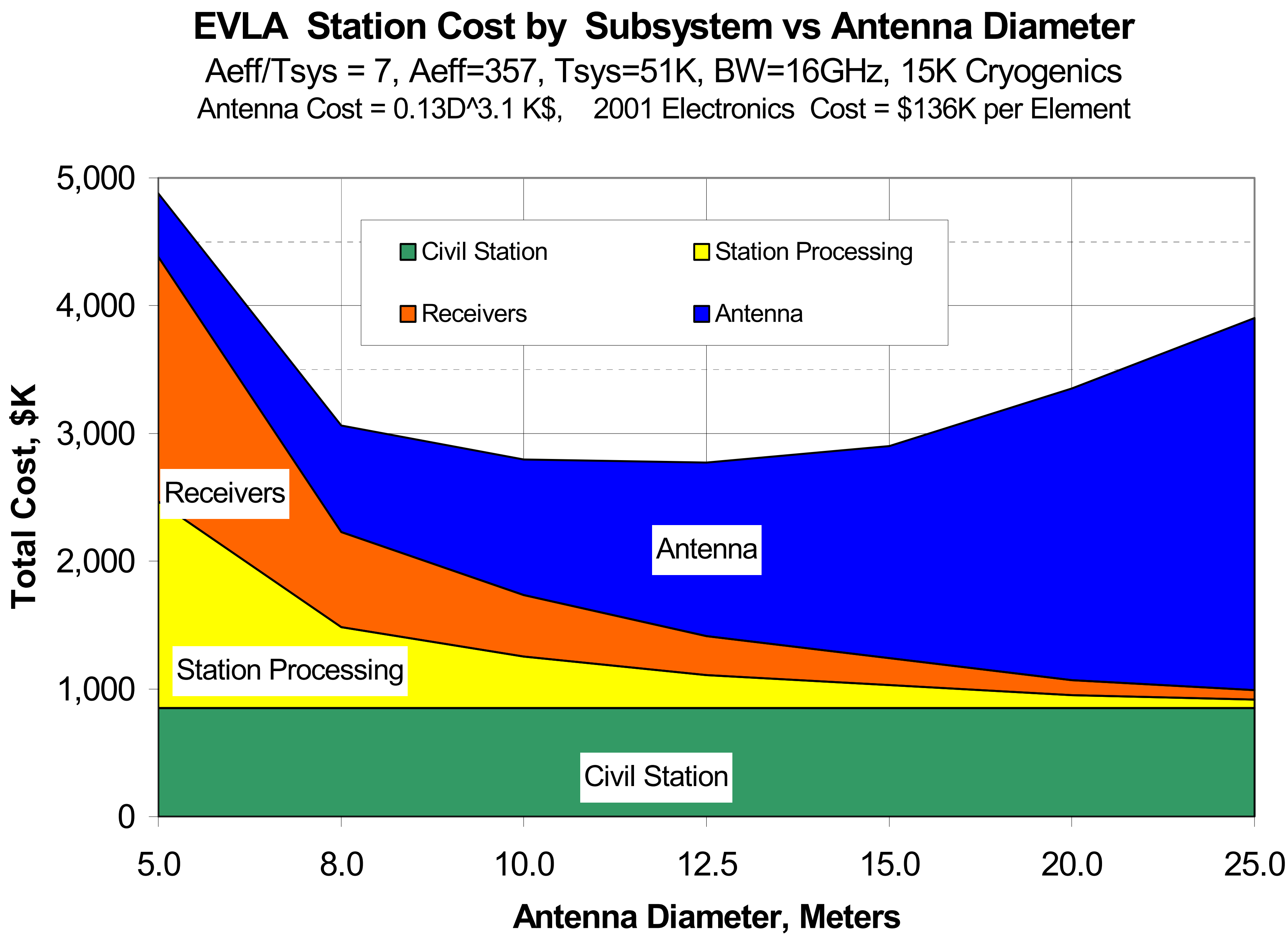
Cost Equation Spreadsheet – See *A Cost Equation for the SKA,* Daddario and Weinreb, for cost models and further explanation. http://www.skatelescope.org/skaberkeley/

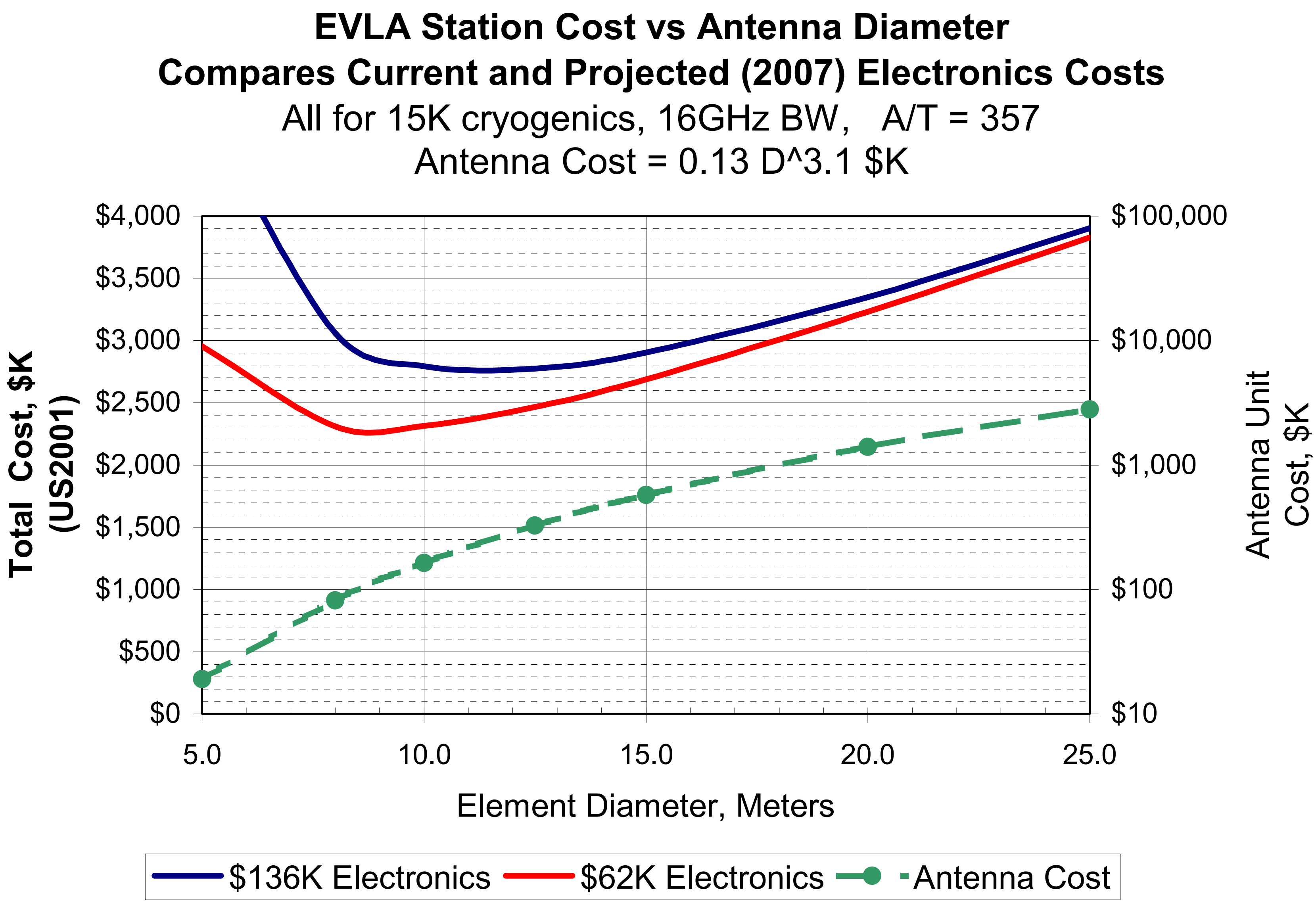
eVLA2 Cost Estimates August 19, 2001 **File: eVLAcosteq1.xls**

Units K$US(2001), meters, GHz

	Antenna Diameter, Meters	**5.0**	**8.0**	**10.0**	**12.5**	**15.0**	**20.0**	**25.0**
Parameter	**Array Parmeters**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**	**Value**
C	Total array cost, fixed costs, elements, processing	4,877	3,061	2,796	2,774	2,903	3,350	3,904
Cat	Station antenna cost, Ne*Ca	496	832	1,063	1,359	1,661	2,279	2,913
Celt	Station receiver cost, Ne*Ce	1,913	747	478	306	213	120	77
Cps	Digitization and Summation Costs	1,618	632	404	259	180	101	65
Csot	Total civil costs at stations, Ns*Cso	850	850	850	850	850	850	850
Cs	Total station cost, elements + combining electronics	3,263	2,430	2,392	2,516	2,724	3,249	3,840
Cm	Total element cost, antenna + receivers + processing	93	156	237	400	649	1477	2876
Ns	**Number of stations in array**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
Ne	Number of elements per station	26	10	6	4	3	2	1
Deq	**Equivalent single-antenna diameter of station**	25	25	25	25	25	25	25
N	Total number of elements, N = Ns*Ne	26.0	10.2	6.5	4.2	2.9	1.6	1.0
A	Effective area of array, A=N*Ae	357	357	357	357	357	357	357
M	**Specified Figure of Merit, M = A/Tsys**	**7**	**7**	**7**	**7**	**7**	**7**	**7**
M	Computed Figure of Merit, M = A/Tsys	7	7	7	7	7	7	7
Tsys	System noise temperature at frequency, F	51	51	51	51	51	51	51
B	**Processed total continuum bandwidth**	**16.0**	**16.0**	**16.0**	**16.0**	**16.0**	**16.0**	**16.0**
R	Antenna/Electronics ratio, Ca/Ce	0.26	1.11	2.22	4.44	7.82	19.07	38.08
Ropt	Minimum cost ratio, Ropt = 1 / (X / 2 -1)	1.8	1.8	1.8	1.8	1.8	1.8	1.8
	Antenna Parameters							
D	**Physical diameter of element (meters)**	**5.0**	**8.0**	**10.0**	**12.5**	**15.0**	**20.0**	**25.0**
Ap	Physical area of element, Ap = 0.785*D^2	20	50	79	123	177	314	491
Ef	**Aperature efficiency**	**0.70**	**0.70**	**0.70**	**0.70**	**0.70**	**0.70**	**0.70**
Ae	Effective area of element, Ae=Ap*Ef	14	35	55	86	124	220	343
Tant	**Antenna noise temperature, Tant = 10 +4*(F/10)**	**30**	**30**	**30**	**30**	**30**	**30**	**30**
Cs	Cost per station, Cs =Cso + Ne*(Ca+Ce)	3,259	2,429	2,391	2,515	2,723	3,249	3,840
Cso	**Fixed cost per station, land, civil, bunker, cables**	**850**	**850**	**850**	**850**	**850**	**850**	**850**
Ca	Cost per antenna, Ca = Ka*D^X	19	82	164	327	575	1,403	2,803
Ka	**Antenna cost coefficient,**	**0.13**	**0.13**	**0.13**	**0.13**	**0.13**	**0.13**	**0.13**
X	**Antenna cost exponent**	**3.1**	**3.1**	**3.1**	**3.1**	**3.1**	**3.1**	**3.1**
Csm	Antenna cost per square meter physical area,K$/m^2	0.973	1.631	2.085	2.665	3.257	4.469	5.712
	Receiver Parameters							
Tsys	Tsys = Tln +Tant	51	51	51	51	51	51	51
Tln	Tln = Kln*F+1	21	21	21	21	21	21	21
Kln	**Lna noise coefficient dependant upon cooler**	**0.40**	**0.40**	**0.40**	**0.40**	**0.40**	**0.40**	**0.40**
Tphy	**Physical temperature of LNA**	**15**	**15**	**15**	**15**	**15**	**15**	**15**
F	**Frequency for system temperature specification**	**50**	**50**	**50**	**50**	**50**	**50**	**50**
Ce	Receiver cost per antenna, Goal	73.6	73.6	73.6	73.6	73.6	73.6	73.6
Ce	Ce = Ccl +Nbn*(Cfd +2* Cln) +Clo+Cif	73.6	73.6	73.6	73.6	73.6	73.6	73.6
Ccl	**Cooling cost per antenna**	**25.0**	**25.0**	**25.0**	**25.0**	**25.0**	**25.0**	**25.0**
Nbn	**Number of frequency bands**	**3**	**3**	**3**	**3**	**3**	**3**	**3**
Cfd	**Average dual-polariz feed cost**	**4.0**	**4.0**	**4.0**	**4.0**	**4.0**	**4.0**	**4.0**
Cln	**Average LNA + mixer cost**	**5.0**	**5.0**	**5.0**	**5.0**	**5.0**	**5.0**	**5.0**
Clo	**LO cost**	**3.0**	**3.0**	**3.0**	**3.0**	**3.0**	**3.0**	**3.0**
Cif	Dual IF cost, Cif =2* (Cifo+Kif*B/2)	3.6	3.6	3.6	3.6	3.6	3.6	3.6
Cifo	**Fixed IF cost per polarization**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**	**1.0**
Kif	**Dual IF cost per GHz of bandwidth**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**
	Signal Transmission Parameters							
Clk	Fiber transceiver cost, Clk = Klk*B	**8.00**	**8.00**	**8.00**	**8.00**	**8.00**	**8.00**	**8.00**
Klk	Tranceiver cost per GHz	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
Cfb	Fiber installed cost, per fiber per km	2	2	2	2	2	2	2
	Signal Processing Parameters							
	(FX architecture assumed for correlator)(Bandwidth shared among beams)							
Cdig	Digitization Cdig = (a1*(B/Kch)^e+a2) * Kch	34.00	34.00	34.00	34.00	34.00	34.00	34.00
a1	**_Digitization coefficient**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**
e	**_Digitization exponent**	**2.00**	**2.00**	**2.00**	**2.00**	**2.00**	**2.00**	**2.00**
a2	**_Digitization constant**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**	**0.50**
Kch	**_Number of separately digitized channels**	**4**	**4**	**4**	**4**	**4**	**4**	**4**
Ctre	Transmission, el to stn ctr (Klk*B + Le*Cfb)	16.20	16.20	16.20	16.20	16.20	16.20	16.20
Le	**_Average distance, element to station center**	**0.10**	**0.10**	**0.10**	**0.10**	**0.10**	**0.10**	**0.10**
Ctrack	Tracking, elements Ctrack = (d*B + f*Nbeams)	11.92	11.92	11.92	11.92	11.92	11.92	11.92
d	**_Tracking coefficient (per GHz)**	**0.72**	**0.72**	**0.72**	**0.72**	**0.72**	**0.72**	**0.72**
f	**_Tracking constant**	**0.10**	**0.10**	**0.10**	**0.10**	**0.10**	**0.10**	**0.10**
Nbeams	**_Beams per station**	**4**	**4**	**4**	**4**	**4**	**4**	**4**
Cpe	Element processing cost = Cdig+Ctre+Ctrack	62.12	62.12	62.12	62.12	62.12	62.12	62.12
Csum	Beam summation cost, c*B*(Ne-1)	4.0	1.5	0.9	0.5	0.3	0.1	0.0
c	_Summation coefficient	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**	**0.010**
Cps	Station processing cost = Cpe*Ne + Csum	1,618	632	404	259	180	101	65


EVLA2 Station Cost vs Antenna Diameter
for 3 Cooling Temperatures
Aeff/Tsys = 7, Aeff=357, BW=16GHz,
Antenna Cost = 0.13D^3.1K$, 2001 Electronics Cost = $136K per Element
Cost, $K (US2001)
Number of Antennas
Element Diameter, Meters
$8,000
$7,000
$6,000
$5,000
$4,000
$3,000
$2,000
$1,000
$0
80
70
60
50
40
30
20
10
0
5.0
7.0
9.0
11.0
13.0
15.0
17.0
19.0
21.0
23.0
25.0
15K Cryogenics
60K Cryogenics
180K Cryogenics
Antennas, 15K
Antennas, 60K
Antennas, 180K


EVLA Station Cost by Subsystem vs Antenna Diameter
Aeff/Tsys = 7, Aeff=357, Tsys=51K, BW=16GHz, 15K Cryogenics
Antenna Cost = 0.13D^3.1 K$, 2001 Electronics Cost = $136K per Element
Civil Station
Station Processing
Receivers
Antenna
Total Cost, $K
5,000
4,000
3,000
2,000
1,000
0
Receivers
Antenna
Station Processing
Civil Station
5.0
8.0
10.0
12.5
15.0
20.0
25.0
Antenna Diameter, Meters

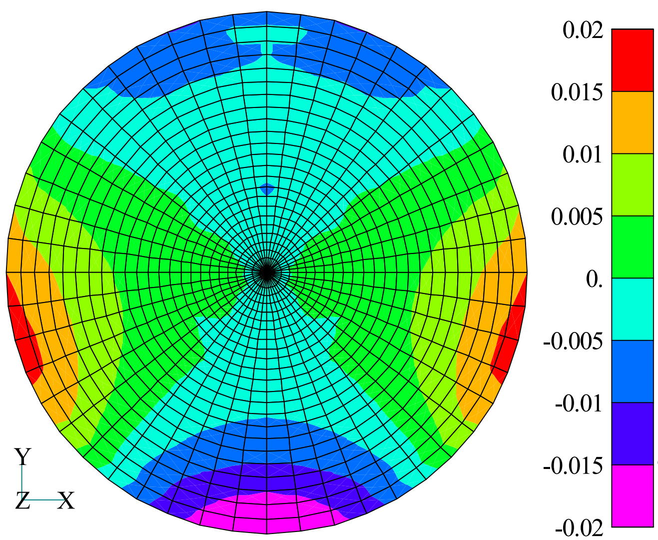

EVLA Station Cost vs Antenna Diameter
Compares Current and Projected (2007) Electronics Costs
All for 15K cryogenics, 16GHz BW, A/T = 357
Antenna Cost = 0.13 D^3.1 $K
Total Cost, $K
(US2001)
$4,000
$3,500
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
$100,000
$10,000
$1,000
$100
$10
Antenna Unit
Cost, $K
5.0
10.0
15.0
20.0
25.0
Element Diameter, Meters
$136K Electronics
$62K Electronics
Antenna Cost

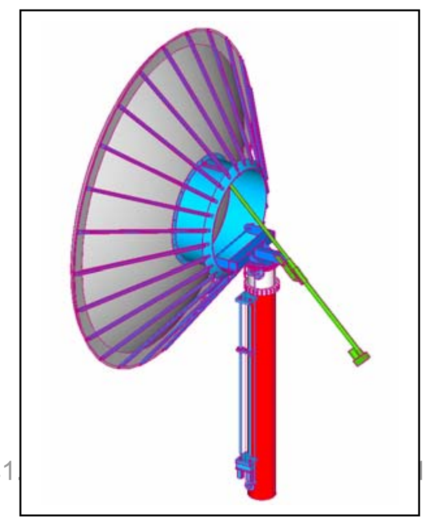
Hydroformed Aluminum Antennas

Hydroforming is a process of using a fluid or gas at very high pressure to force aluminum sheet to conform to a mold. The result is a stiff, accurate, and low cost reflector.

JPL has performed a structural analysis of 5m and 8m hydroformed reflectors manufactured by www.andersenInc.com and has found that the wind and gravitational distortions would allow operation at frequencies as high as 100 GHz.

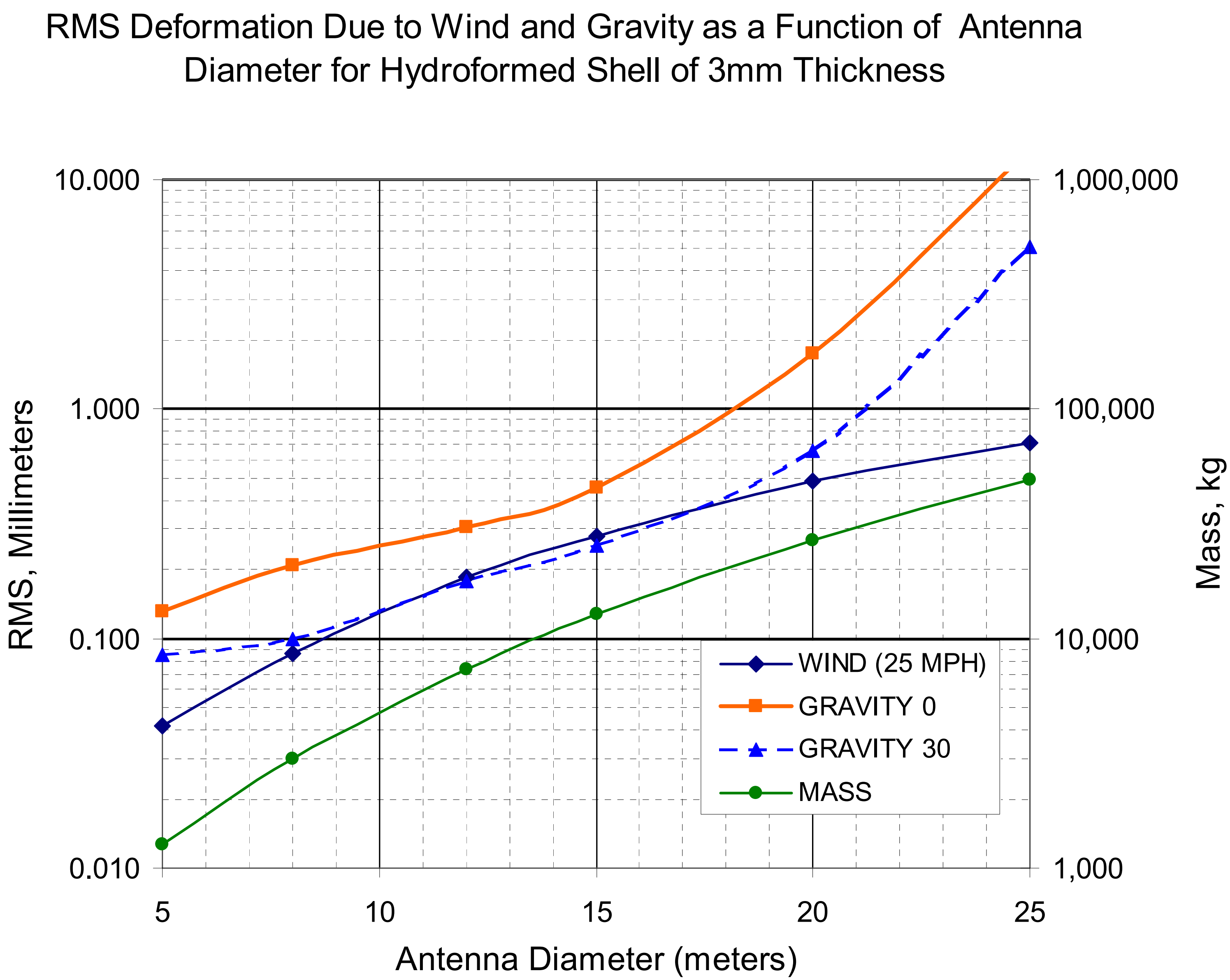
Example	Antenna Diameter	Cost per Antenna	Cost per m^2	Cost per km^2
New 70m DSN antenna	70m	$100M	$40.8K	$40.8B
25m VLBA antenna	25m	$3M	$9.6K	$9.6B
6m ATA antenna	6m	$30K	$1.7K	$1.7B
Target SKA cost	10m	$30K	$600	$0.6B
Hydroformed DBSTV antenna	4m	$2.8K	$350	$0.35B
Aluminum, 3mm thick sheet	Any	NA	$30	$.03B





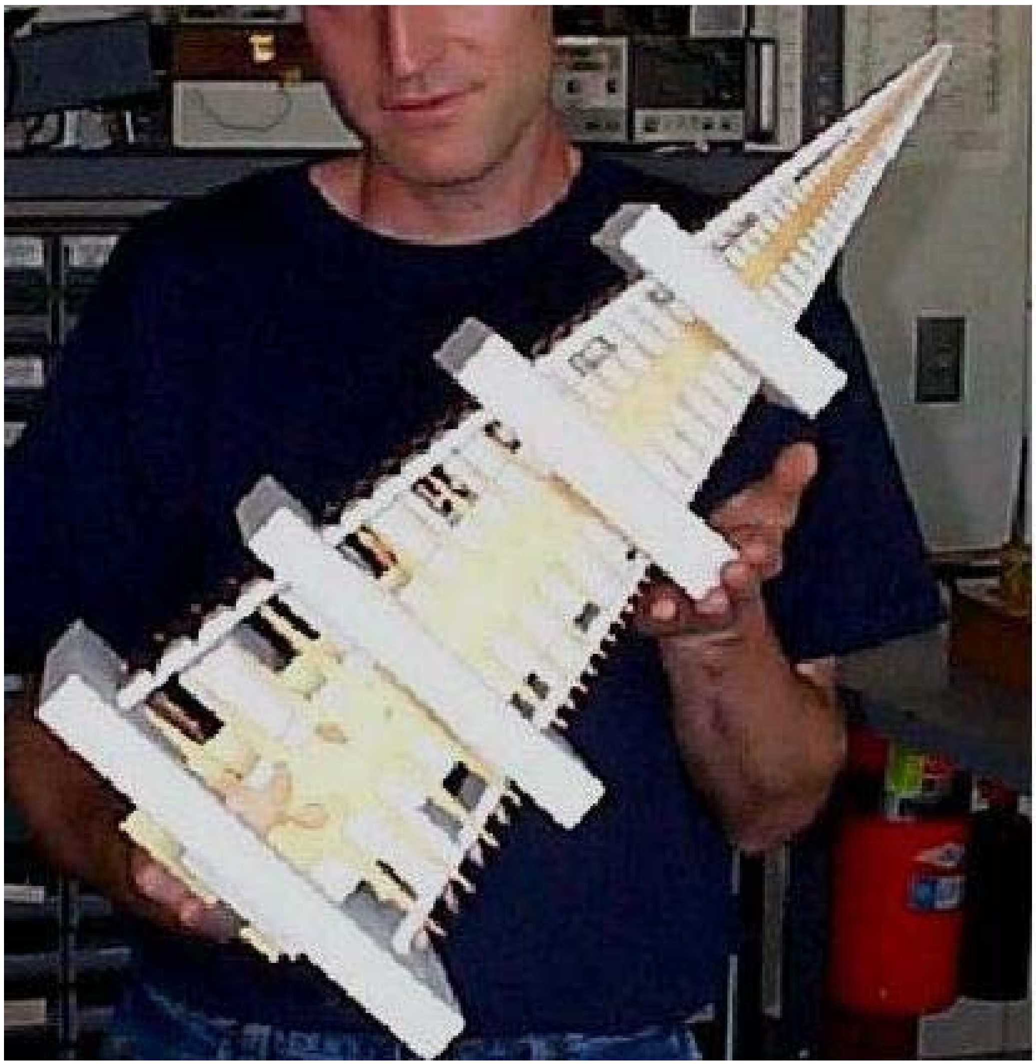
JPL/Swales Finite-Element CAD Analysis of Hydroformed Shells

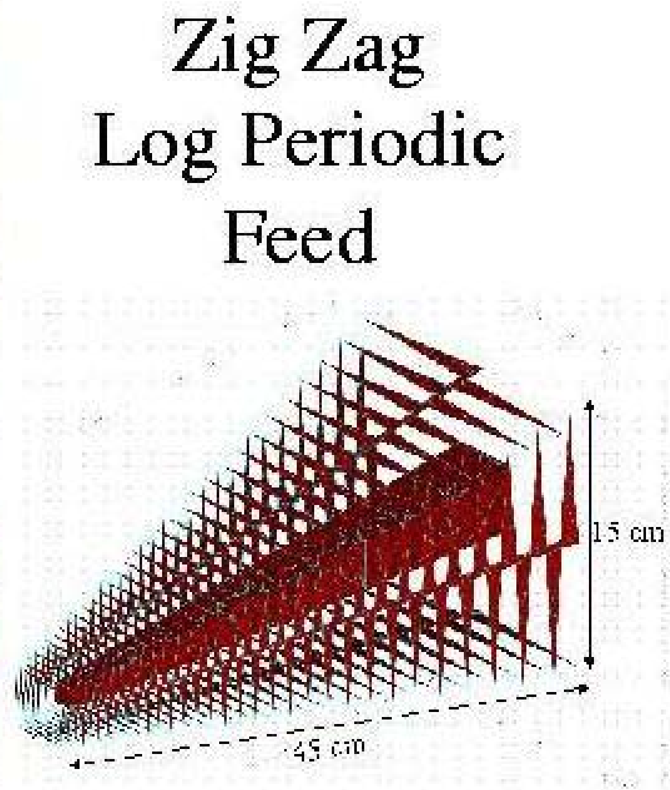
(0.1mm RMS is Required for an Efficient 100 GHz Antenna)



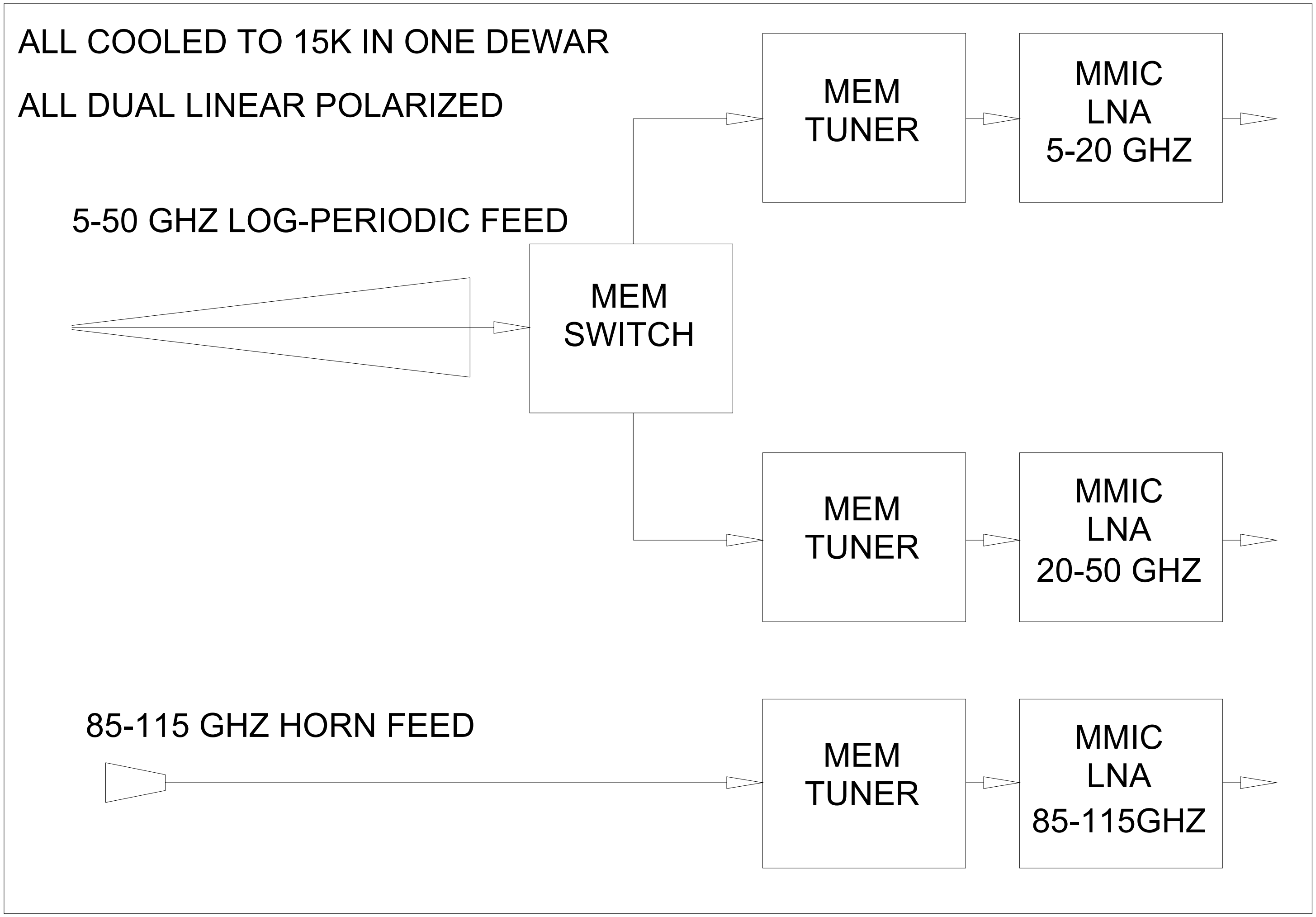
0.5 to 11 GHz Dual-Polarized Feed Developed by SETI/UCB for the ATA

Efficiency > 60% expected over entire frequency range

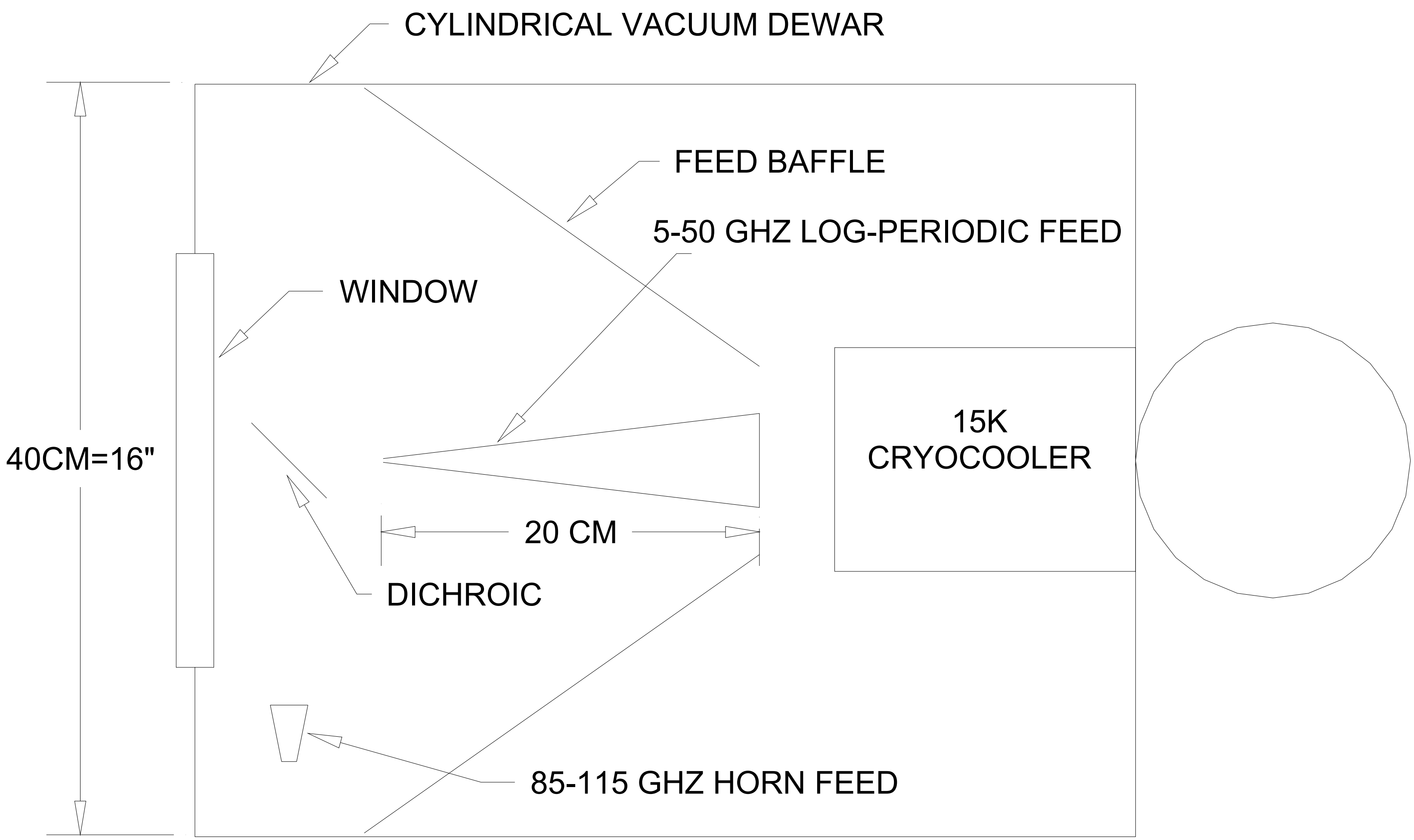




5-115 GHZ RECEIVER BLOCK DIAGRAM



5-115 GHZ CRYOGENIC RECEIVER LAYOUT CONCEPT



Publication (IEEE 2001 MTT Symposium) describing micro-electro-mechanical (MEM) microwave switches which could be integrated with cryogenic MMIC LNA's to provide very wideband receivers.

DC-26 GHz MEMS Series-Shunt Absorptive Switches

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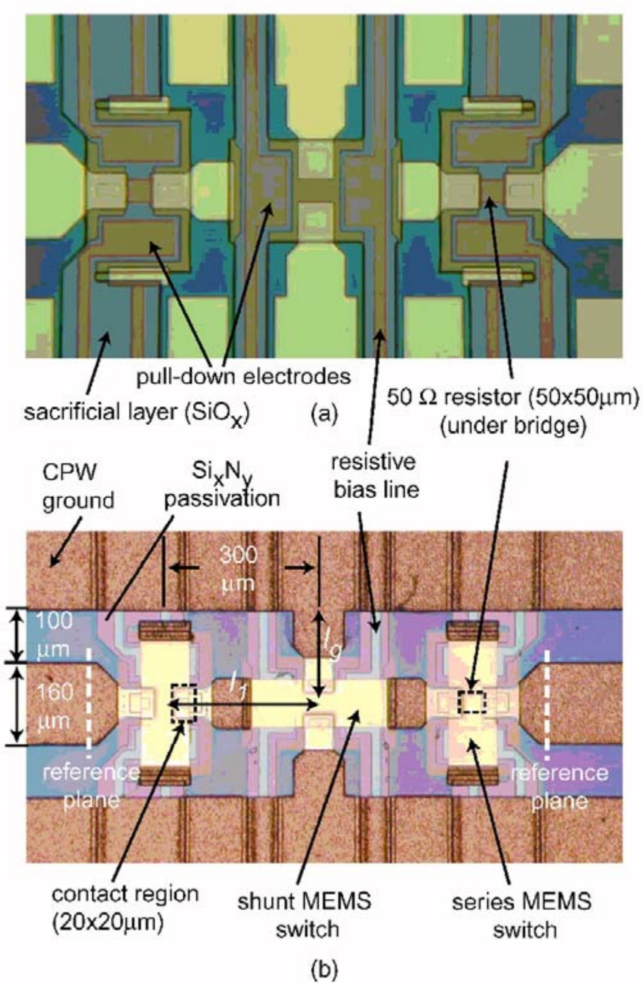
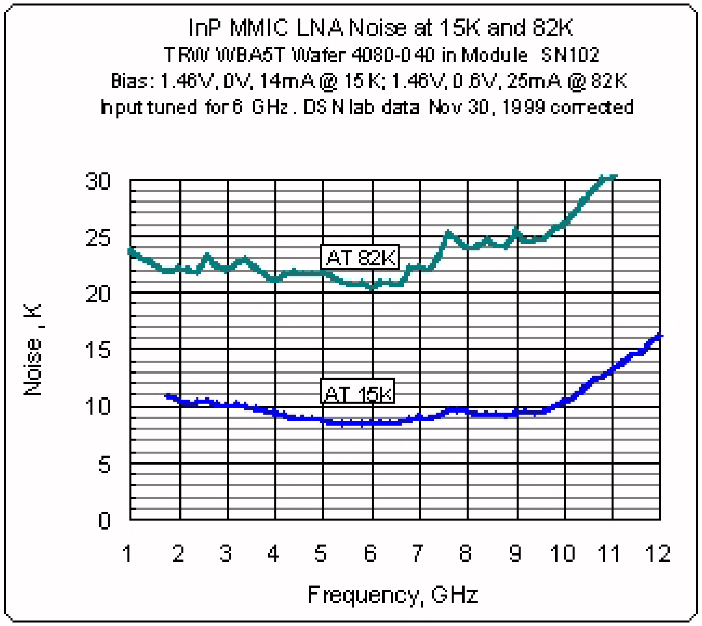
Abstract **The design and performance of a wide-band coplanar waveguide (CPW) DC-26 GHz MEMS absorptive switch on silicon substrate is presented. The absorptive switch utilizes novel DC-contact series and shunt fixed-fixed beam MEMS switches with 'dimples' at the contact area for improved contact resistance. An insertion loss of 0.5 dB or better is achieved from DC-26 GHz. The isolation is -40 dB at 5 GHz, -35 dB at 10 GHz and -25 dB at 26 GHz. These switches are useful in applications where good return loss is required in the isolation state.**

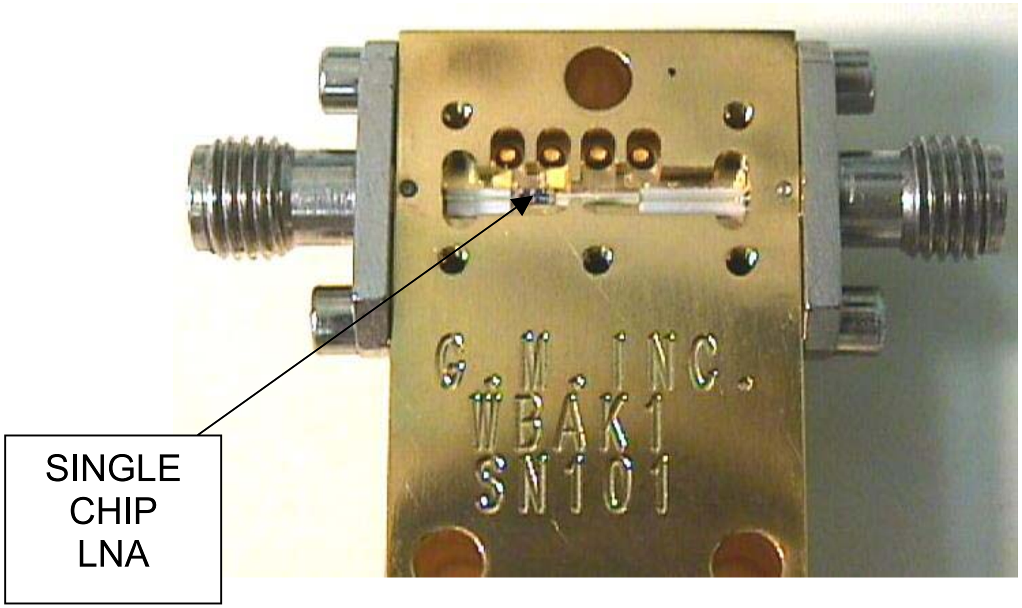
The wideband absorptive switch is designed using two MEMS DC-contact series switches and an in-line shunt DC-contact switch. A 50 Ω tantalum nitride resistor is connected across the gap of each series switch. The resistor is shorted when the switch is actuated, providing a low-loss path from the input to output ports. The switches are cascaded together using short lengths of transmission lines, resulting in a configuration shown in Fig. 1, with the shunt switch placed between the two series switches.



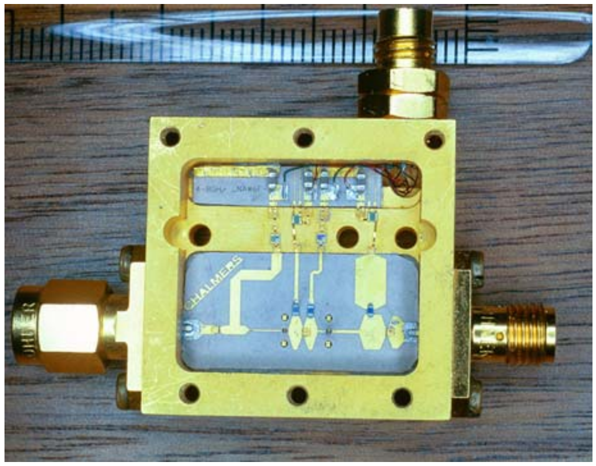
Low-Noise Amplifiers Under Development at Caltech and JPL

Frequency Range, GHz	Application	Noise
.5-11	ATA	23K @ 80K now, 15K later
4-12	ALMA IF	4K @ 4K, good input match
8-20	SIS IF Amplifer	10K @ 4K, good input match
1-60	NASA Atmospheric Sensor	400K @ 300K, 40K @ 15K
90-110	Planck, Cosmic Background	35K @ 15K
100-140	Atmospheric Sensor	600K @ 300K
170-210	Atmospheric Sensor	1500K @ 300K

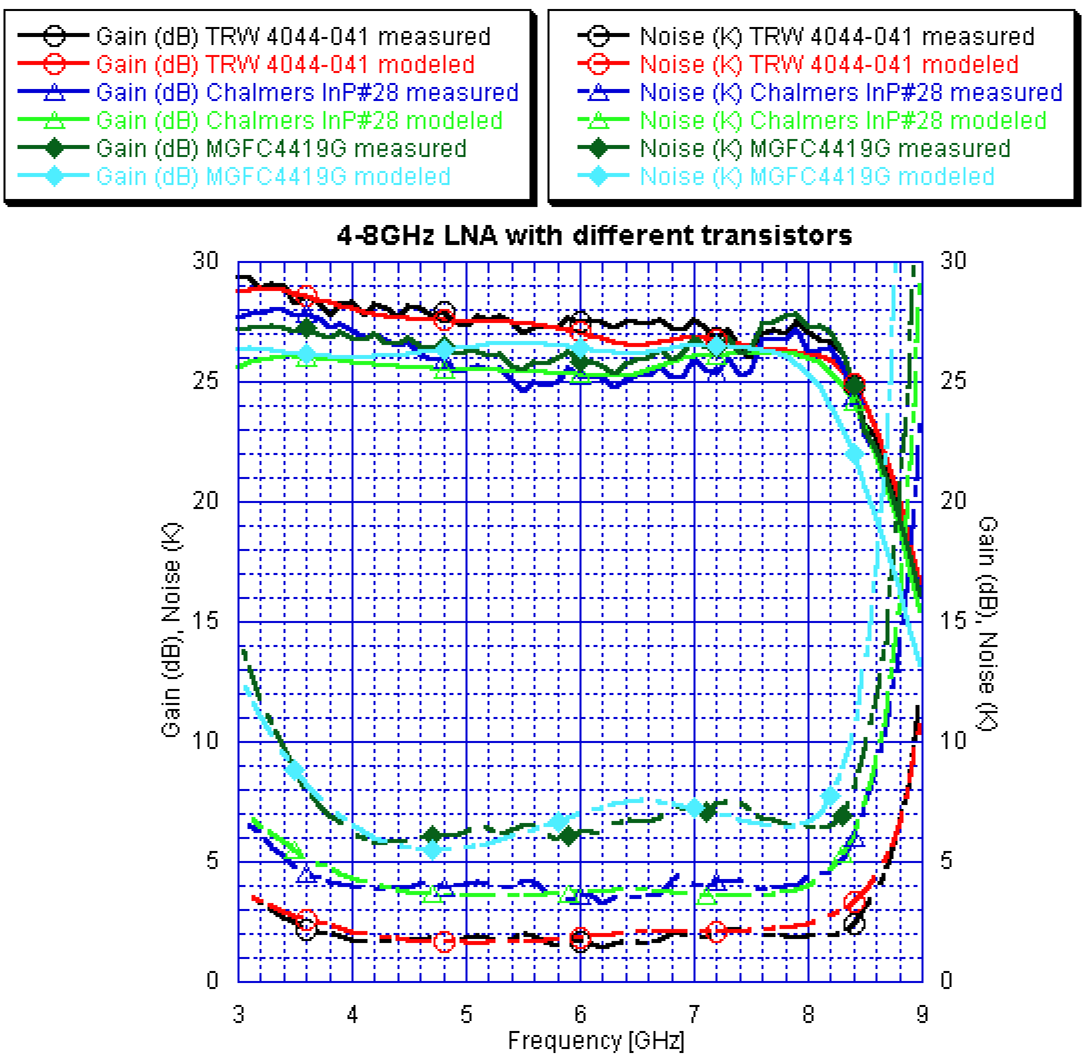




Chalmers 4-8 GHz Cryogenic Low Noise Amplifier



World record 2K noise temperature, measured in 4 laboratories, achieved with TRW 0.1um InP HEMT



Suggested Technology Developments for EVLA2

1. **Antenna Cost Reduction** – Investigate methods of reducing costs for antennas in the 10 to 25 meter range including reflector manufacture, drive systems, and optics.

2. **Wideband Feed Design** – Scale the ATA 0.5 to 11 GHz feed to 2.5 to 55 GHz and investigate integration into a cryogenic dewar. Also consider a 0.3 to 6 GHz version of the feed for prime focus use. Study efficiency optimization and optimum subreflector optics for wideband feeds.

3. **Wideband Receivers** – Design and test very wideband cryogenic low-noise amplifiers. Consider MEM switching and tuning.

4. **Cryogenic Life-Cycle Cost Reduction** – Evaluate and stimulate development of lower cost, longer life, cryocoolers including possibility of 60K operation for receivers 1 to 6 GHz range.

5. **Wideband Digitization Design** – Investigate components to reduce costs for 8 GHz bandwidth digitization and optical transmission.