



A DSN Array for the 21'st Century



- **Need** - More missions, at greater distance, with smaller spacecraft, and higher data-rate science instruments
- **Commercial Technology Developments Have Drastically Reduced Array Costs** - Satellite TV industry is producing small antennas and very low noise receivers at amazing costs.
- **Very Large Improvement is Feasible** - An 8000 element array of 5-meter antennas can provide a factor of 20 improvement of 8.4 GHz receiving capability compared to a 70m antenna at a cost of under \$300M.



Powerful Advantages of a Dispersed Array

- With 1000 km spacing tracking accuracy is 1km at the distance of Mars.
- Multiple beams can simultaneously communicate with several spacecraft
- Array partitioning allows “just enough” communication for multiple missions.
- Soft failure; weather diversity; low cost risk

Comparison of Existing Large Antennas and Future Arrays
February 28, 2000

Antenna	Elements	Effective Area	Upper Frequency	Tsys	A/Tsys
DSN 70m	1 x 70 m	2,607	8 to 32 GHz	18	145
GBT	1 x 100 m	5,700	100 GHz	20	285
VLA	27 x 25 m	8,978	43 GHz	32	280
Arecibo	1 x 305 m	23,750	8 GHz	25	950
ALMA	64 x 12 m	4,900	1000 GHz	50	98
1HT	509 x 5 m	6,770	11 GHz	35	193
SKA -1KT	TBD	1,000,000	20 GHz	50	20,000
DSN Array	8000 x 5 m	106,400	8 or 32 GHz	30	3,547

DSN Array Communication Improvement Relative to DSN 70m Antennas

Antenna	dB Improvement at 8.4 GHz	dB Improvement at 32 GHz
DSN 70m	0	+6 dB
DSN 34m	-6 dB	0
DSN Array	13.9 dB	19.9 dB

ABSTRACT

A Large Microwave Array Approach to Deep Space Communications

Sander Weinreb
JPL Section 386, 818-354-4065
Sander.Weinreb@jpl.nasa.gov

Many scientific programs, both space based and ground based, are limited by the microwave collecting area on earth. These include communication with distant low-power transmitters, emergency communications with failed spacecraft, microwave long baseline interferometry with spacecraft, and ground-based radar and radio astronomy. The cost of single antennas much larger than those already in existence becomes prohibitively large and an array approach is suggested.

Arrays now exist (the VLA) with sensitivity greater than the DSN 70m antennas and an international working group is considering the design of an array with of the order of 1km squared area and a sensitivity 21 dB above the DSN 70m. JPL considered an array approach to the DSN in 1994 (Publication 94-15) and reached a conclusion that there was no saving in cost to use array elements smaller than 35m. This report assumed a receiver cost of \$264K in a quantity of 344 for a dual frequency 2.4/8.4 GHz receiver providing $T_{sys} < 30K$. The resulting \$90.7M of receiver cost dominated the cost of an array with 5m elements.

New technologies beckon for a new look at this problem. These are: 1) Indium-phosphide HEMT transistors which can have low noise while operating at 80K, 2) Microwave monolithic integrated circuit (MMIC) technology which can mass manufacture 2000 low noise HEMT amplifiers a 3" wafer at a cost of less than \$100K, 3) New types of cryogenic refrigerators which can reach 80K with no cold moving parts, and 4) Spinoff of manufacturing technology from the direct broadcast satellite TV industry which is producing millions of small antennas and low noise receivers at amazing costs. Low noise receivers at 4 GHz with an advertised 17K receiver noise operating at 300K are being sold by several manufacturers for \$150 and 5m paraboloidal antennas operating up to 12 GHz are sold for approximately \$4000 in small quantity.

This talk will review the present state of development of other large antenna arrays, will summarize the status of HEMT LNA technology, will present cost estimates of possible DSN arrays, and will offer a road map leading to completion.

ADVANTAGES OF A LARGE ARRAY

- **LARGE DECREASE IN COST PER DECIBEL OF LINK MARGIN**
- **SIMPLIFIED SPACECRAFT TELEMETRY HARDWARE**
- **FLEXIBLE SCHEDULING – SIMULTANEOUS TRACKING OF MULTIPLE SPACECRAFT OVER WIDE AREA OF SKY**
- **NEW SPACECRAFT NAVIGATION CAPABILITY: REAL TIME, HIGH PRECISION ANGULAR POSITION MEASUREMENTS – COMPLEMENTS RANGE DATA AND PROVIDES FULL 3-D SPACECRAFT POSITIONS WITHOUT NEED FOR MODELING**
- **HIGH RELIABILITY – GRACEFUL DEGRADATION OF ARRAY PERFORMANCE IF INDIVIDUAL ANTENNA ELEMENTS FAIL; MOVING MECHANICAL PARTS ARE SMALL & LIGHT WEIGHT; SIMPLIFIED OPERATIONS AND LOW-TECH MAINTENANCE**
- **ARRAY IS CONTINUOUSLY EXPANDABLE AND UPGRADABLE**
- **INCREASE SCIENTIFIC OUTPUT OF DATA-RATE-LIMITED MISSIONS: NGST, SPACE-BASED INTERFEROMETERS**
- **ENABLE NEW TYPES OF MISSION: RADIO OCCULTATION MEASUREMENTS WITH VERY DISTANT SPACECRAFT, DIRECT RECEPTION OF LANDER/ROVER/PENETRATOR SIGNALS ON EARTH, MULTI-SPACECRAFT VLBI ARRAYS, SPACECRAFT WITH NO ON-BOARD DATA STORAGE, DOWN-LINKS WITH BOTH HIGH DATA RATES AND HIGH DUTY CYCLE**

Comparison of Array Requirements for Communication and Radio Astronomy

Parameter	Communication	Radio Astronomy
Frequency	8 and 32 GHz	.5 to 20 GHz
Array Configuration	Any but lower cost if closely packed	Sparse for better image sharpness
Element Size	Minimum cost probably in the 3.5 to 10 meter range	May be slightly larger because of more complex receivers
Data Processing	Digital beam forming of < 10 beams	Correlation processing of full image; > 10,000 beams
Bandwidth	<10 MHz	1000 MHz

Antenna Element Cost

February 5, 2000

Find the Antenna Diameter, D, which minimizes the cost of an array with a specified total area

Antenna element cost, $A = C \cdot D^X$

Electronics cost per element = E

Then minimum total cost is for $A/E = X/2 - 1$

X is in the range of 2.7 to 4

X=2.7 A/E = 2.86, X=3.5 A/E = 1.33, X=4.0 A/E = 1.0

Current Small Antenna Prices Including Mount

Skyvision 4.9 m - \$4K, 7.3m - \$16K, X=3.5

Prodelin 4.5 m - \$4.2K

Orbitron 4.9 m - \$2.5K (reflector only)

Andersen 5 m - \$15K (Ka band with mount)

SETI 1HT 5 m - \$9.9K

Ref: www.skyvision.com, www.anderseninc.com

Array Antenna and Electronic Cost

Use D = 5m, A = \$20K, E = \$15K , X=3.5

Equivalent Antenna	N Elements	Total Cost
34 m	46	\$1.6 M
70 m	196	\$6.9 M
40 x 70 m	7840	\$274 M

Request for Information and Cost Estimates Sent to Antenna Manufacturers by JPL

Specifications - January 26, 2000

Microwave Antenna Array Element

General Description - A parabolic reflector including motorized angular position drives, feed support system, and foundations is required for use in a receive-only large array located in the southwestern U.S.

Primary Reflector Diameter - 5 meters. Focal length and subreflector system are unspecified at present.

Surface and Pointing Accuracy - Two options, for 8 GHz and 32 GHz operation, are being considered with the following accuracy requirements:

	Option A - 8 GHz	Option B - 32 GHz
Surface Accuracy	1.2mm = .046"	0.3mm = .012"
Pointing Accuracy	.05 Degrees	.012 Degrees

Surface accuracy is the rms deviation from a best fit paraboloid caused by gravitational, wind up to 15 mph, and temperature variation of -10 to 55C.

Pointing accuracy is the rms deviation of non-repeatable difference between commanded position and RF beam position caused by drive system error, wind up to 15 mph, and temperature variation of -10 to 55C. A computer-generated pointing correction table for each antenna is allowable.

Slew and Scan Rates – The drive system must be capable of slewing to any commanded position within 2 minutes of the applied command (180 degrees per minute in azimuth). Accurate pointing of the antenna must be maintained at speeds of up to 2.5 degrees per minute.

Pointing Position Range – The antenna drive system must allow pointing from 10 degrees above the horizon to 10 degrees past zenith in elevation and 360 degrees in azimuth.

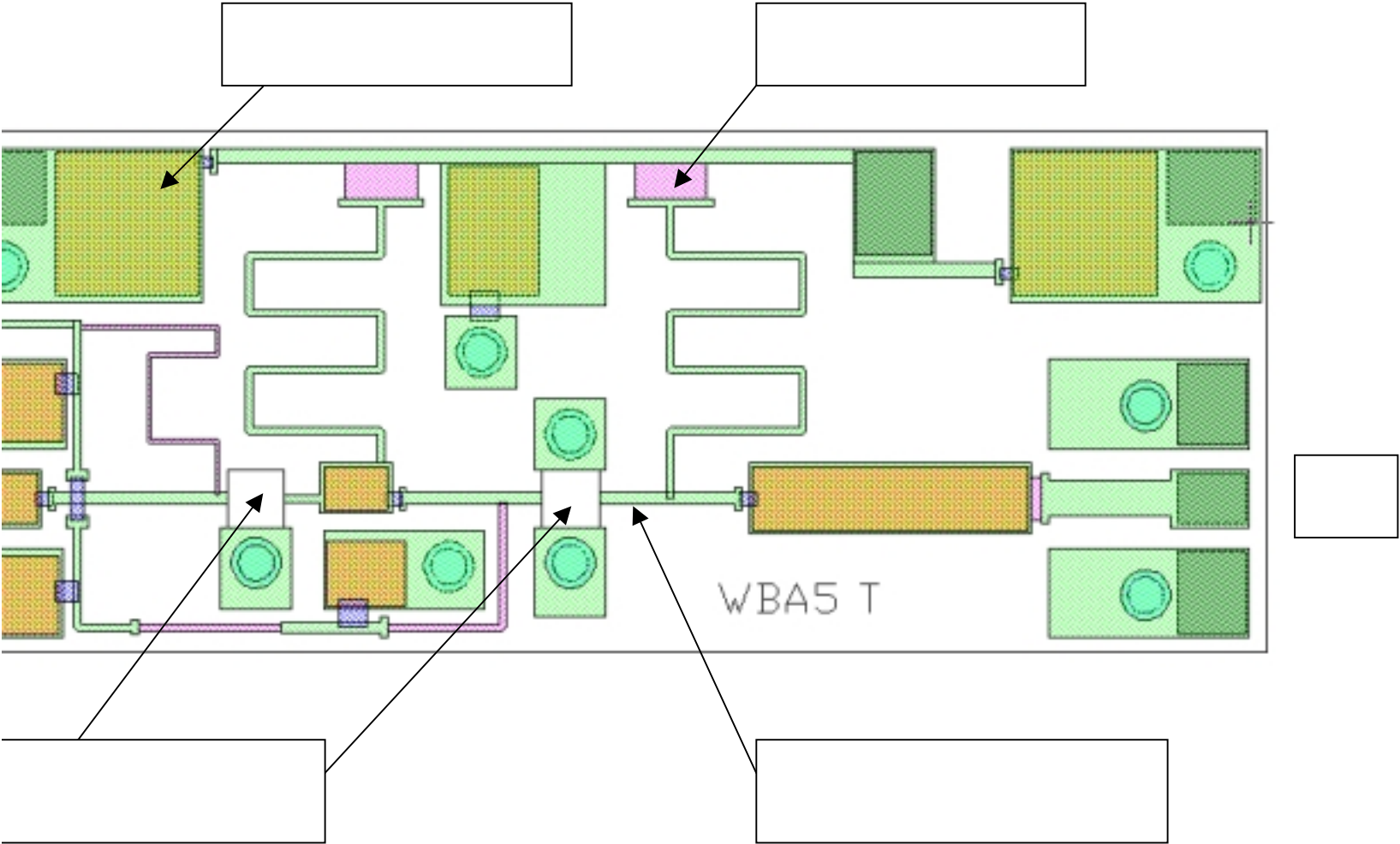
Control Interface – Monitor and control interface of antenna position shall be through an optically-isolated serial interface.

Receiver Mounting – The antenna shall include provision for mounting a 50 lb receiver feed and front-end assembly.

Wind Survival - The antenna drive system shall be capable of driving to stow position in a 40 mph wind and survive in stow position with 100 mph wind.

Monolithic Integrated Circuit Very Low Noise 0.5 to 11 GHz Amplifier

Chip Size – 2mm x 0.74mm x 0.1mm, Material – Indium Phosphide



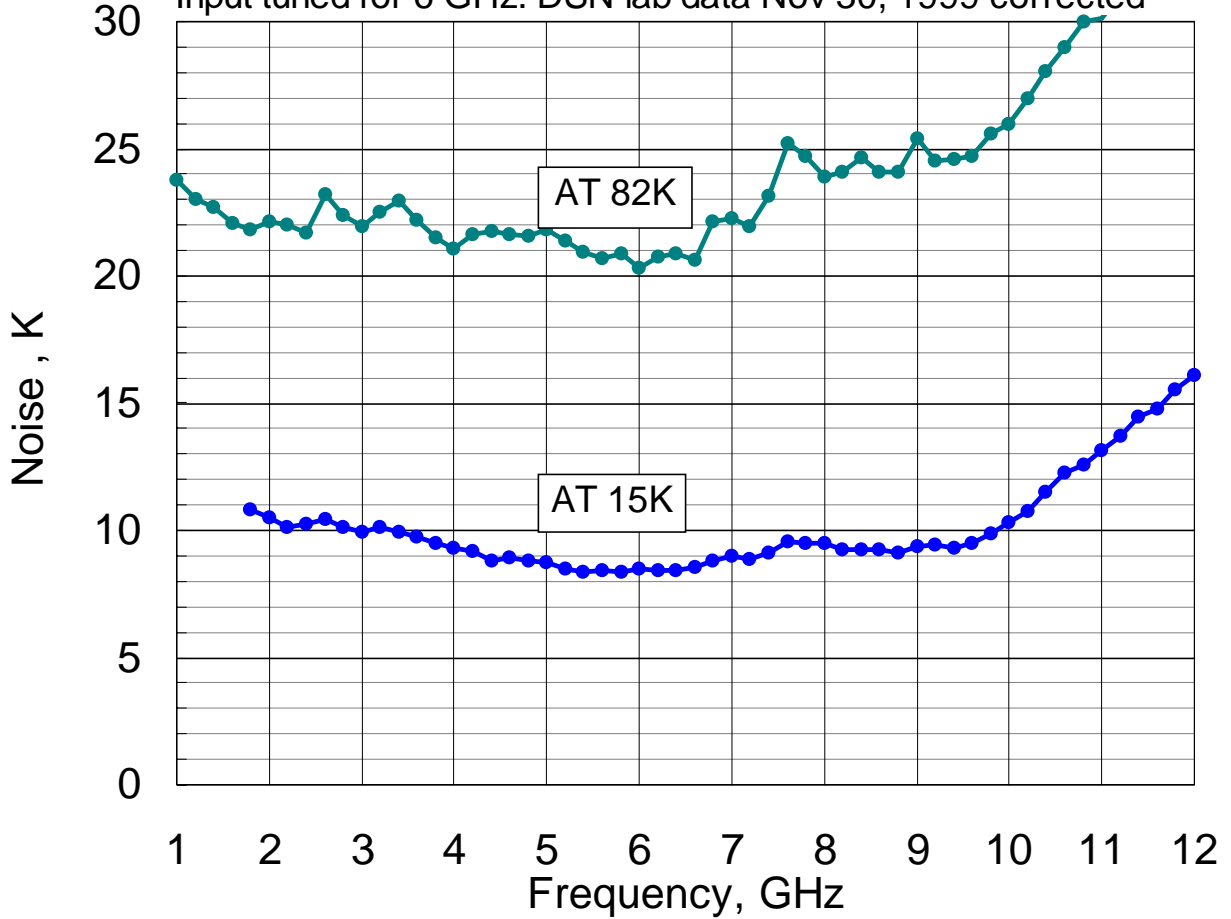
Low-Cost, Wideband MMIC Cryogenic LNA

InP MMIC LNA Noise at 15K and 82K

TRW WBA5T Wafer 4080-040 in Module SN102

Bias: 1.46V, 0V, 14mA @ 15K; 1.46V, 0.6V, 25mA @ 82K

Input tuned for 6 GHz. DSN lab data Nov 30, 1999 corrected



SINGLE
CHIP
LNA

DSN Array for the 21'st Century
Outline for Design Proposal (Persons per year, 3 years)

- 1.0 Impact of a Large Array on NASA Missions (2)
Communications, Navigation, HEDS
- 2.0 Science Applications (0.5)
Ground-based astronomy, interferometry
- 3.0 Array Configuration (2)
Antenna locations, transmitter, clusters, site cost
- 4.0 Array Element (3)
Specifications, manufacturing methods, cost vs size,
drives, optics
- 5.0 Receivers (2)
Feed Interface, LNA, , manufacturing plan
- 6.0 Cryogenics (1)
Low-cost coolers, central gas compressor system
- 7.0 Array Communication (2)
LO Phasing methods, commercial fiber trunks, cost vs
bandwidth and distance
- 8.0 Data Processing (1)
Beam-forming algorithms and cost, science system
- 9.0 Operations and Life Cycle Cost (1)
- 10.0 Development Plan
WBS, schedule, milestones, reviews, budget for design
- 11.0 Summary of Strawman Design (Total 14.5)

JPL DSN/SKA Development Schedule

March 3, 2000

Near Term Milestones

Date	Action
Nov, 1999	Elachi meeting; decision to write proposal
Feb 28-29, 2000	Meeting of U.S. SKA Consortium at Arecibo
Mar 1, 2000	Industry replies to JPL request for cost estimates on 5m 8 and 32 GHz antennas
Apr 1, 2000	Five page development proposal to NASA
May 15, 2000	Decadal plan for astronomy to NSF and NASA
Aug 2000	Jodrell SKA Meeting
Sep 2000	Caltech to NSF SKA development proposal
Dec 2000	Expect start of NASA development funds
Feb 2001	Expect start of NSF development funds

Far Term Milestones

Date	Action
Dec 2002	Test two-element interferometer
Mid 2004	Prototype array complete – 34m or 70m equivalent
Jan 2006	Start construction of large DSN array
Jan 2008	Start construction of SKA array
Jan 2009	Complete large DSN array
Jan 2011	Complete SKA array