National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

IEEE MTT Workshop

Agenda

- Introduction
  - NASAs new plans for deep space communications
  - Approaches to providing a system to meet these needs
- Overview of the DSN Array System
- Architecture of this new system
  - System Elements
  - Receive Array Elements
- Technology Developments through 6-m System Breadboard
  - Components of the Breadboard
  - Current results
  - Future Plans
- Summary of Array Project

Introduction – NASAs Future Plans

- Future deep-space science missions will require improvements in the telecommunications link by more than a factor of 1000. This increase will be allocated across the link as indicated in the following table:

Source of improvement	Level of improvement	Improvement to be achieved by…
Gain/T_{sys}	X10	Three sets of 400 12m antennas, a 10-fold increase in the collecting area, relative to the 70m antenna subnet
Frequency band	X4	Transition from X-band to Ka-band (including effects like increase in the system temperature at Ka-band compared to X-band, etc.)
Spacecraft Components	X50	Increase transmit antenna to 10 meter inflatable antennas from present about 1meter diameter antennas
	X25	Increase transmitter power from tens of watts to a few kilowatts

DSN Array Overview

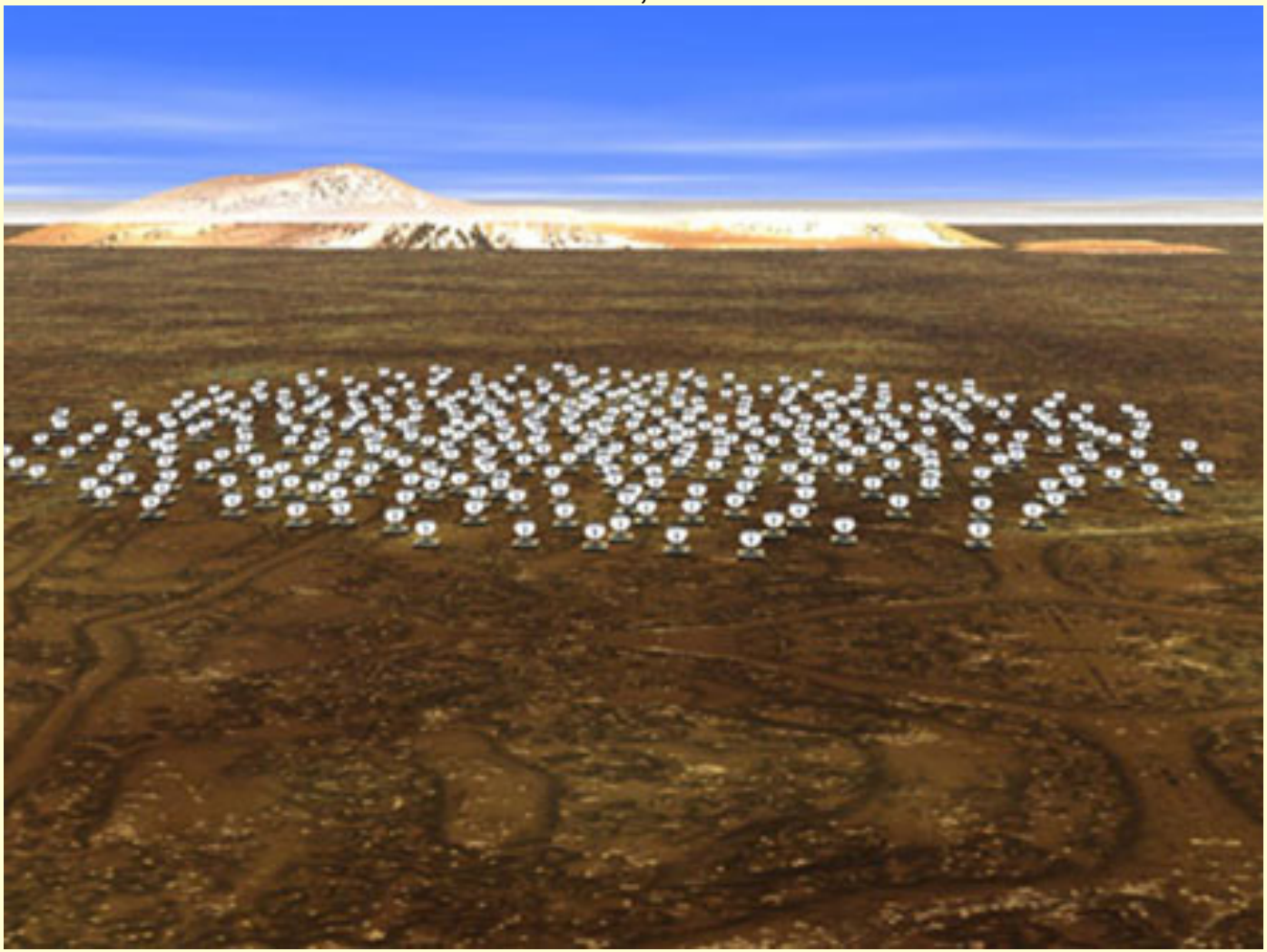
- The DSN Array will have a single site per longitude
  - Includes 400 12-m downlink antennas
  - Includes new uplink antennas; yet to be determined if these are part of the downlink array, or separate antennas (either many small or few large)
- Siting Assumptions
  - US site is at Goldstone
    - Can leverage on existing facilities
  - Overseas sites are TBD
    - i.e. new facilities at generic sites

The DSN Array

Array Concept

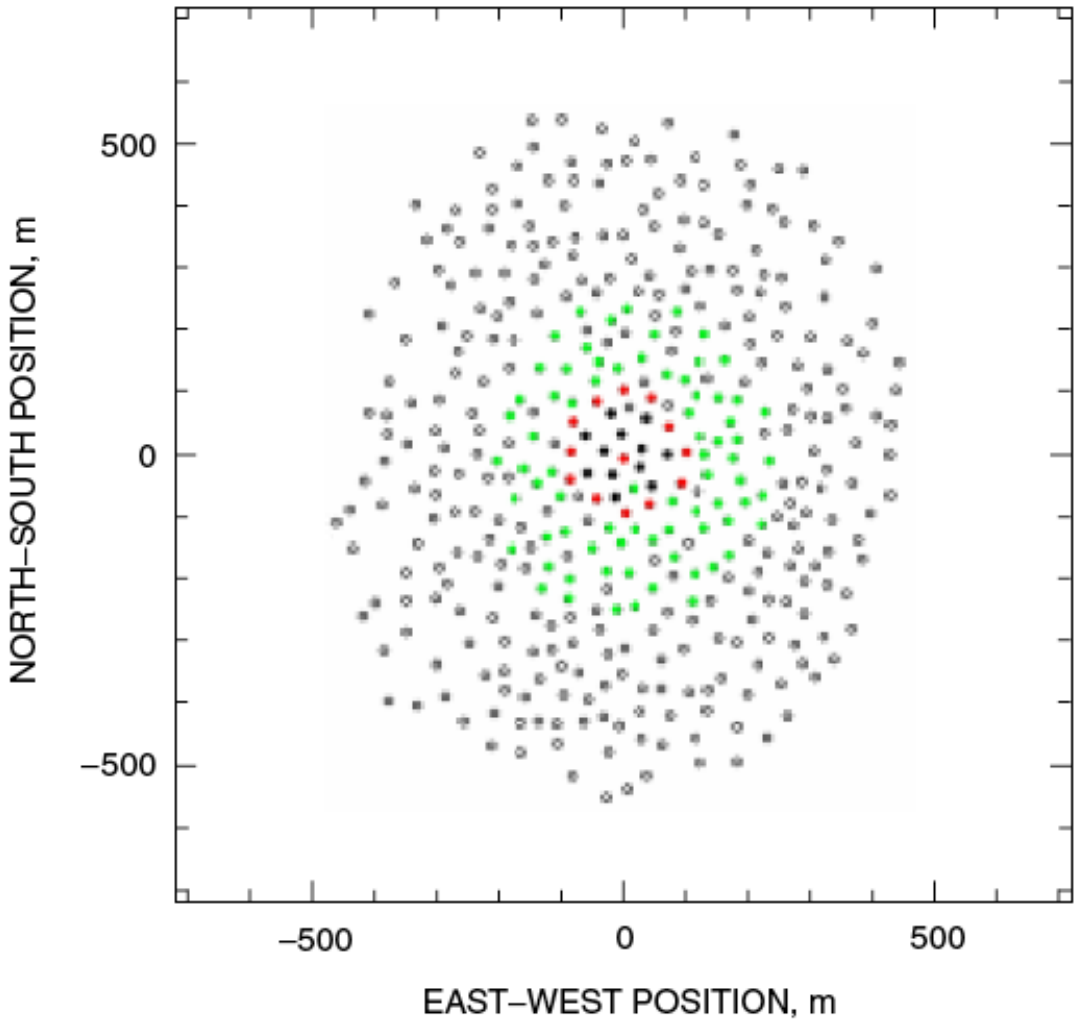
Artist's Concept of the Deep Space Network Array at the Mojave site

Goldstone, California

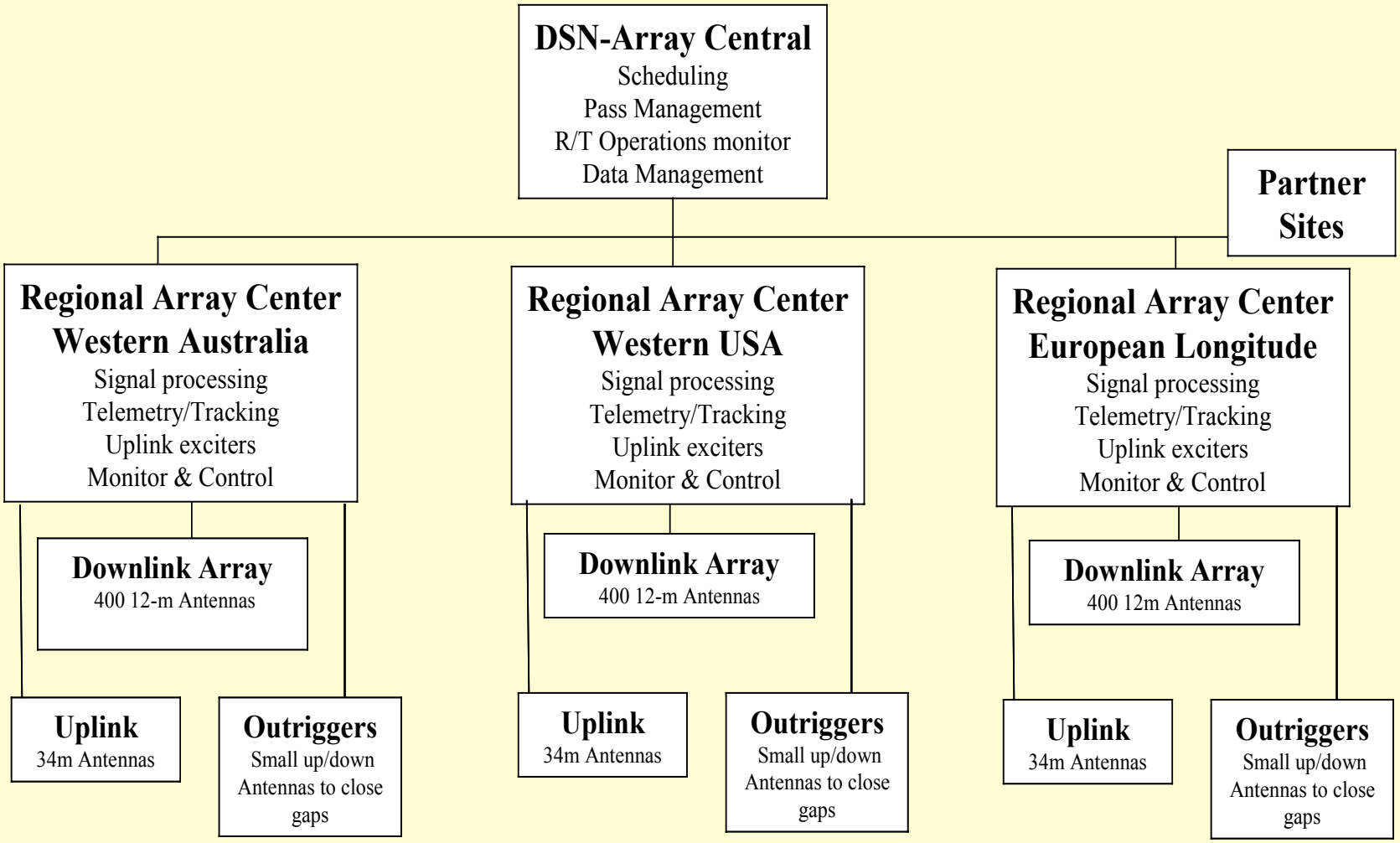


The DSN Array

Array Configuration



The DSN Array
Array architecture



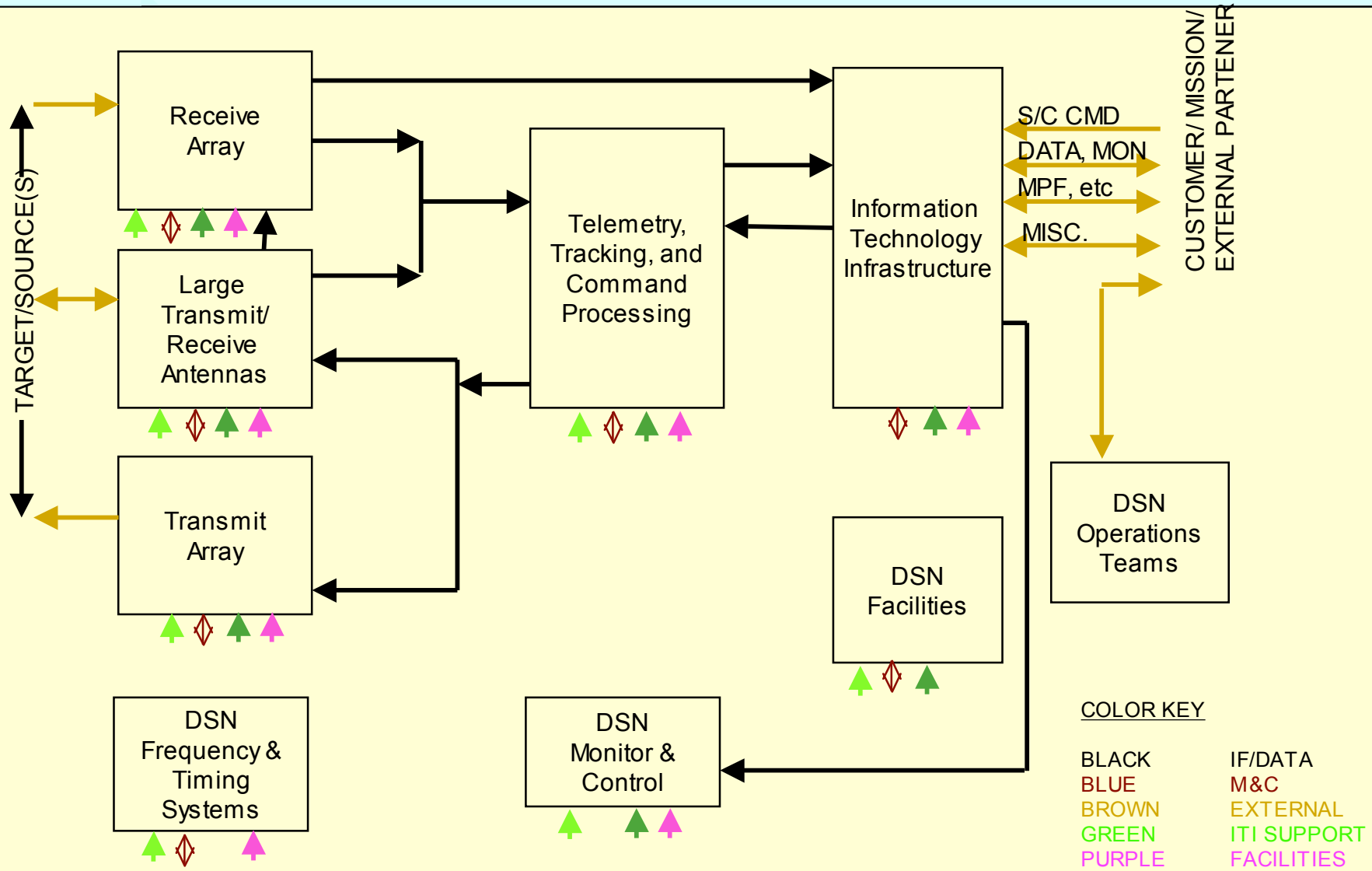
The DSN Array

Array Requirements

Requirement		Value	
		X-band	Ka-band
Element size (diameter, m)		12	12
Reflector surface accuracy (total, mm)		0.305	0.305
Array Size (N)		400	400
A/T (m^2/K)		620	1440
Sky Coverage	Elevation	6°–90°	6°–90°
	Azimuth	±270	±270
Tracking rate, max (°/min)		14	14
Slew rate, max (°/min)	Elevation	48	48
	Azimuth	180	180
RF Frequency Band (GHz)		8.0–8.8	26-32
IF Bandwidth (MHz)		500	500
Signal Processing Bandwidth (MHz)		100	100
Polarization		Dual CP	Dual CP
Array Beams/Cluster		16	16
Gain Variation (dB)		<0.2	<0.2
Phase Noise (dBc/Hz)	1 Hz offset	–65.7	–65.7
	10 Hz offset	–73.3	–73.3
	100 Hz offset	–75.2	–75.2
	1000 Hz offset	–75.2	–75.2
	100000 Hz offset	–75.2	–75.2
Allan Deviation	1 s integration	3.9×10^{-13}	3.0×10^{-13}
	10 s integration	4.6×10^{-14}	3.0×10^{-14}
	1000 s integration	4.5×10^{-15}	1.4×10^{-15}
	3600 s integration	4.5×10^{-15}	1.4×10^{-15}

The DSN Array

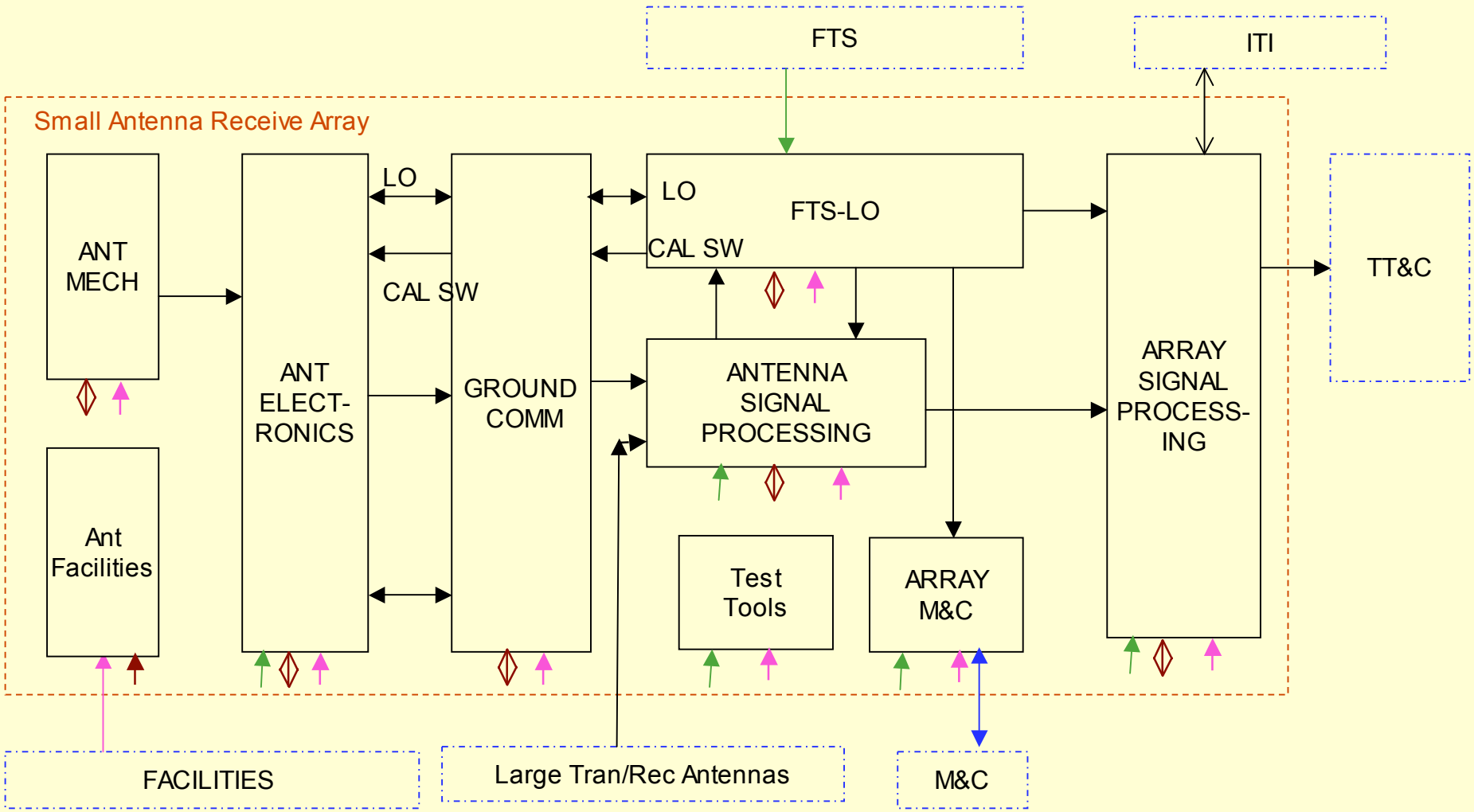
System Elements



COLOR KEY

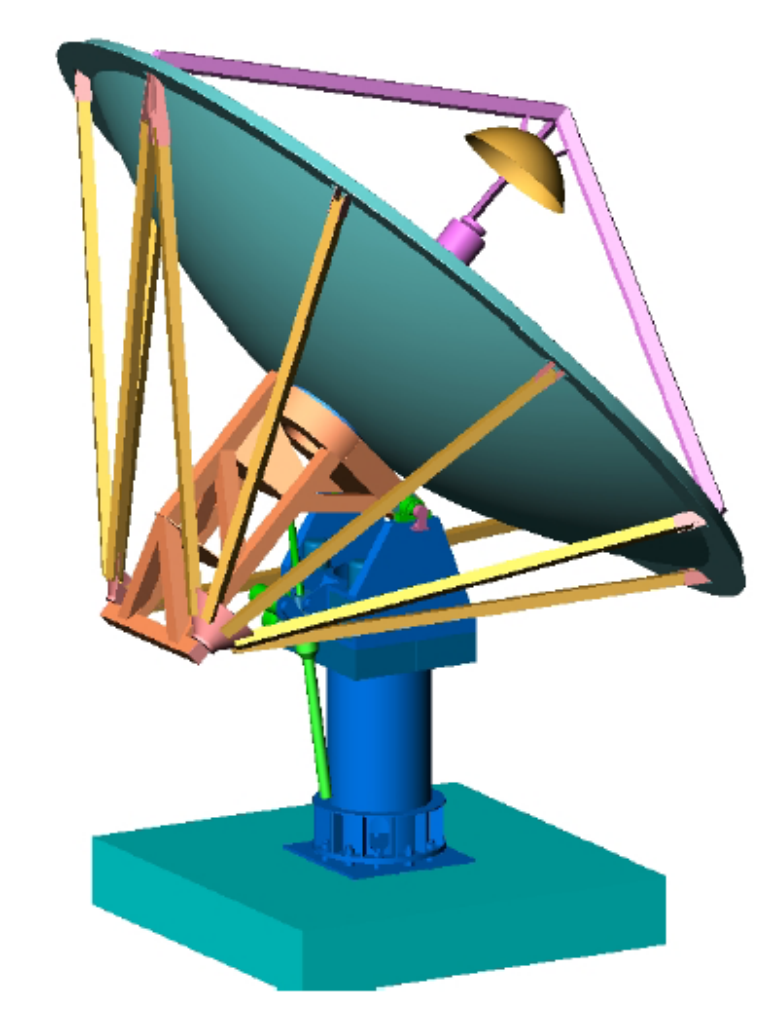
BLACK	IF/DATA
BLUE	M&C
BROWN	EXTERNAL
GREEN	ITI SUPPORT
PURPLE	FACILITIES
RED	FTS

Receive Array Element: Subsystems

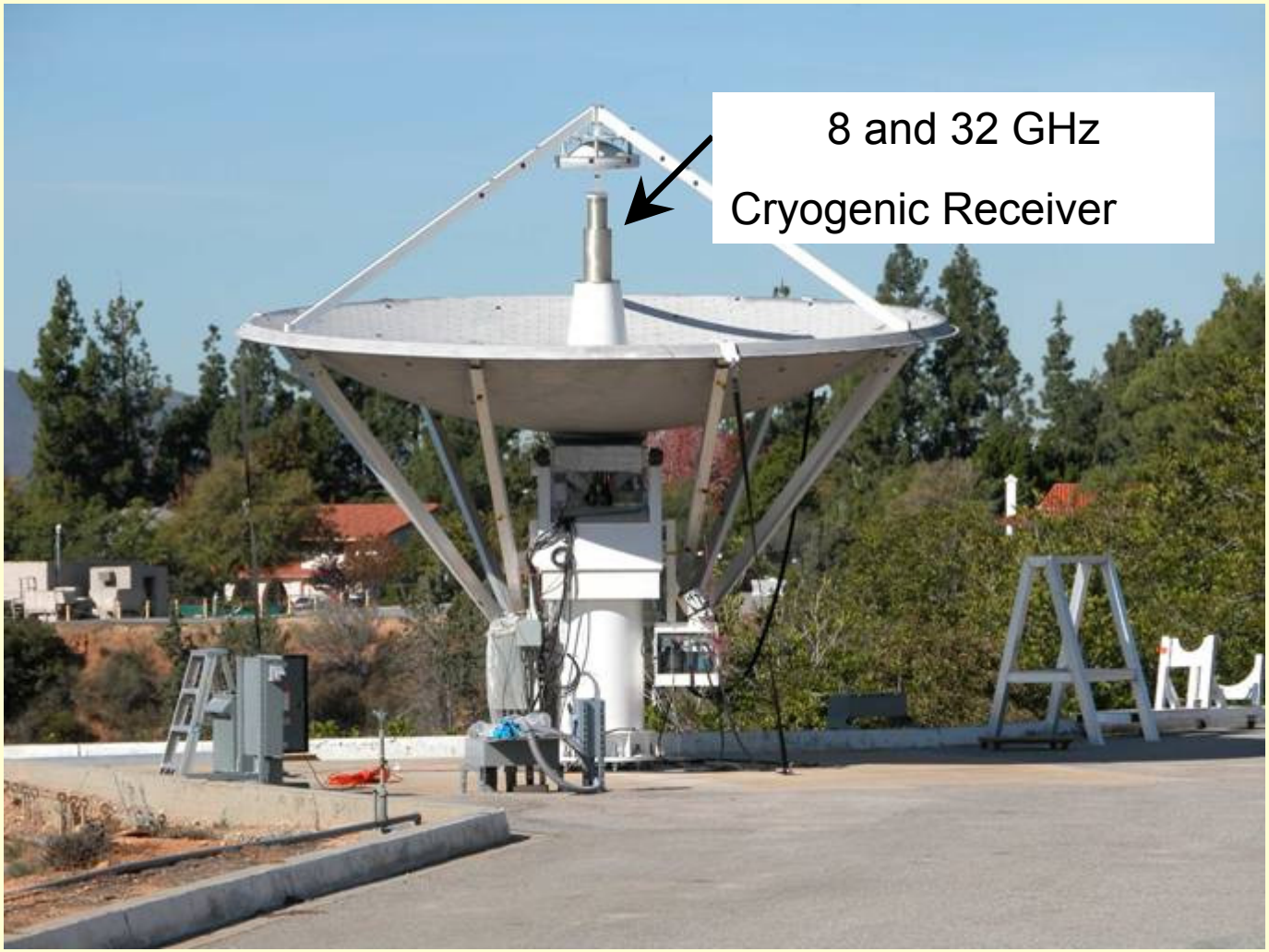


The DSN Array

6-m Breadboard Antenna



6m Breadboard Hydroformed Antenna at JPL

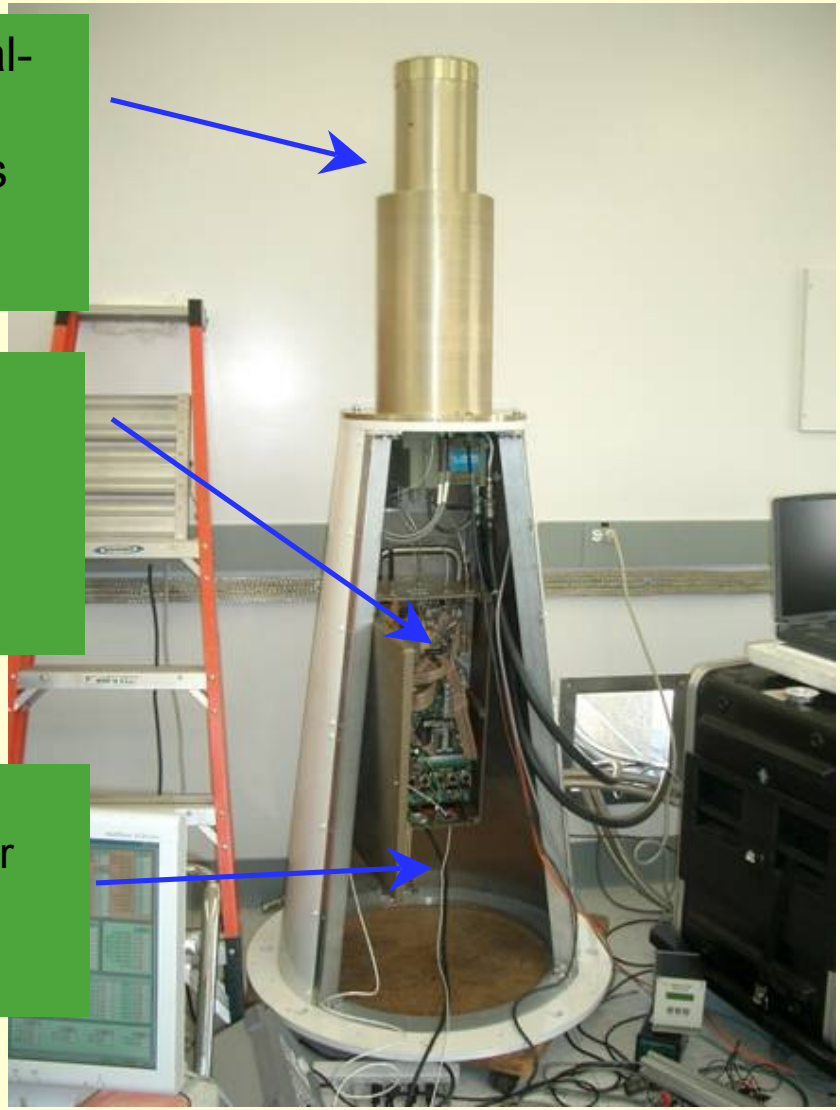


Receiver Cone – Cryogenic Dewar and Receiver Box

Vacuum dewar containing dual-frequency, dual circular polarization feed and 4 LNA's all cooled to 15K

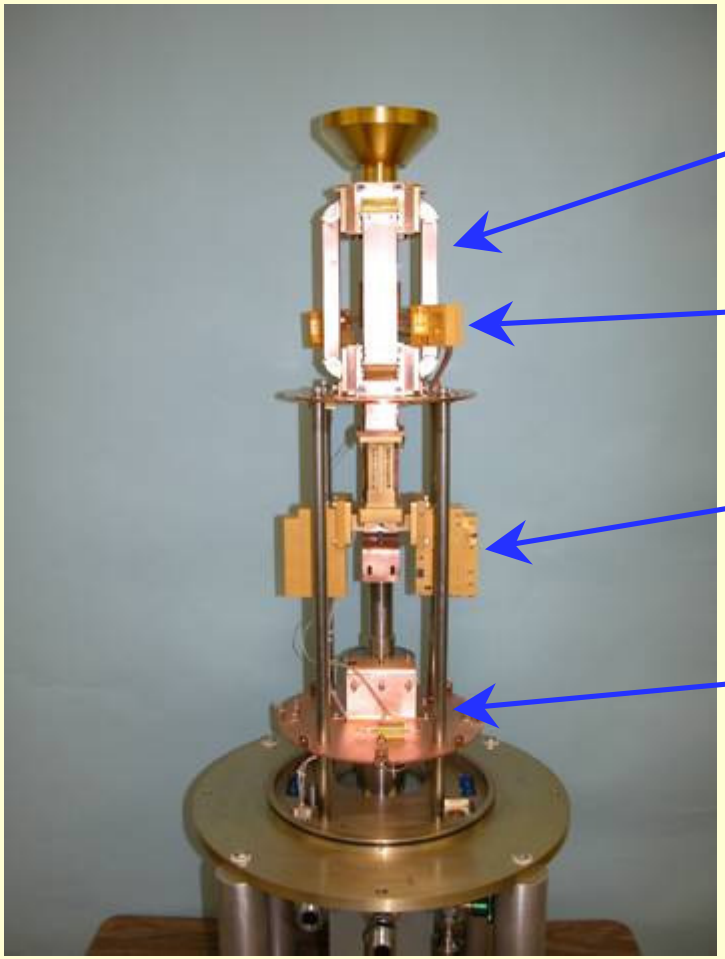
Receiver box containing downconversion, LO, and IF modules mounted on a temperature controlled plate

Connections to control room are AC power and 6 optical fibers for LO, IF, monitor, and control.



The DSN Array

Vacuum Dewar Interior



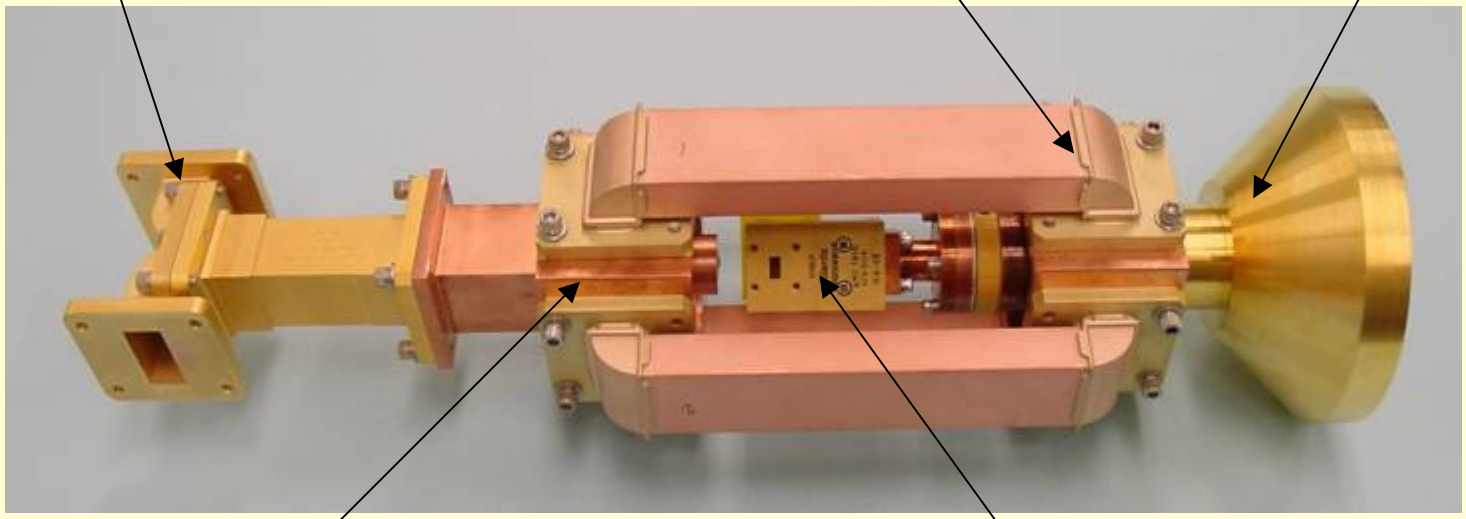
Dual frequency feed – dielectric rod in corrugated horn

31-38 GHz, Ka LNA's

8.0-8.8 GHz, X LNA's

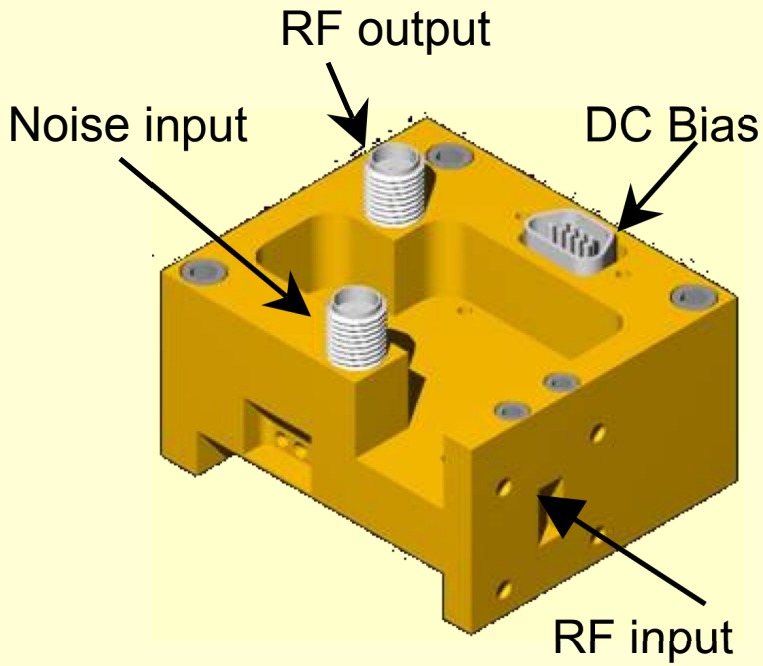
CTI 15K cryocooler

X/Ka Band Dual Circular Polarized Feed

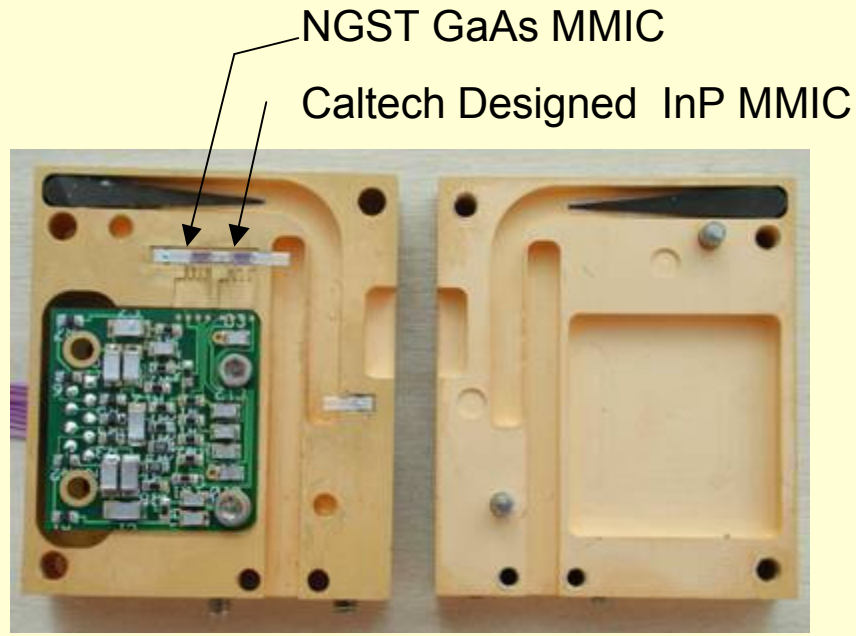


- Feed covers 8.0 to 8.8 GHz and 31 to 38 GHz
- Entire feed is cryogenically cooled for very low noise performance

Ka Band Low Noise Amplifiers



Dimensions 1.75 x 1.5 x 0.9”

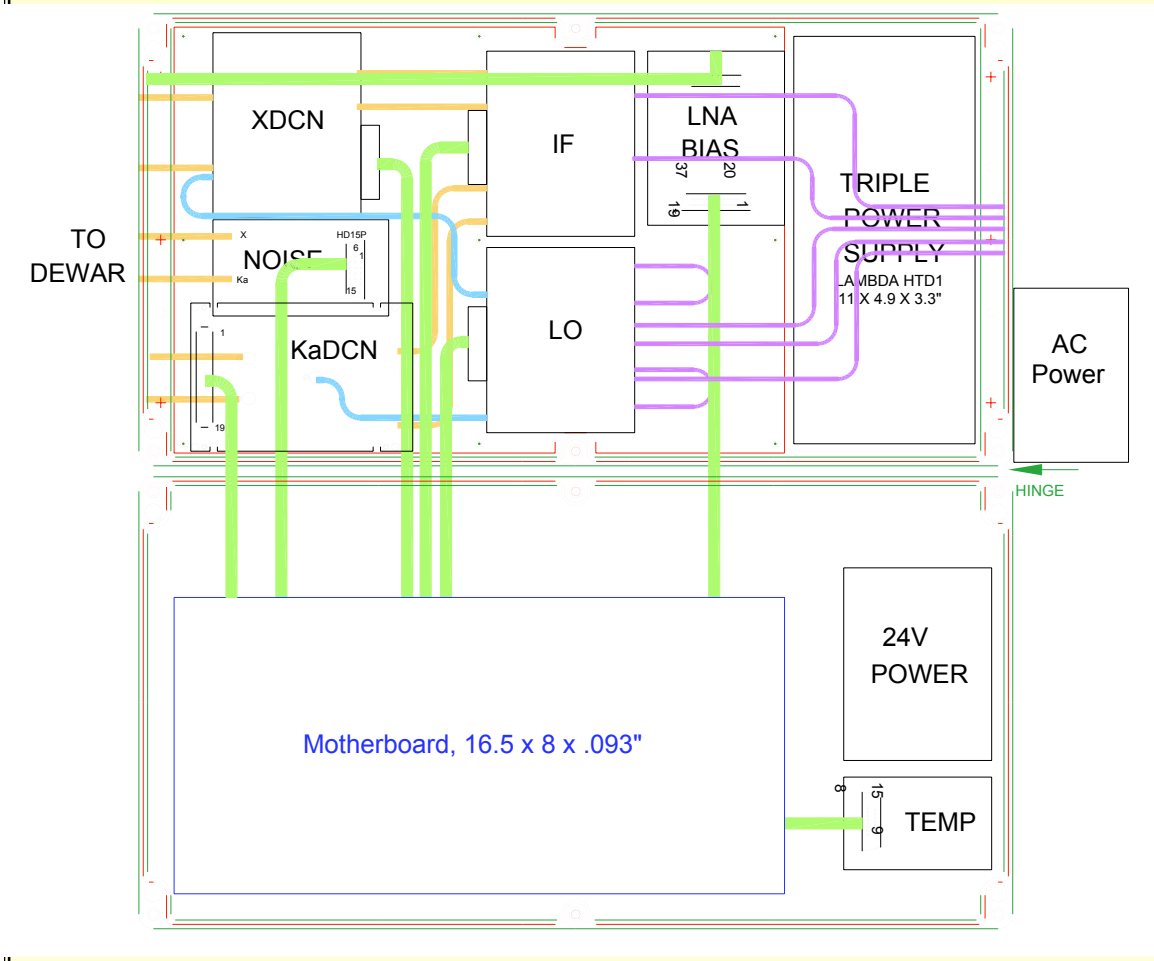


Interior View of Split Block – LNA includes Directional Coupler for Noise Calibration Injection

Performance

- Noise temperature 11K
- Gain > 40 dB

The DSN Array
Receiver Box



- All receiver components on antenna mount in one 24” x 12” x 7” box
- Box mounts in cone under cryogenics dewar
- Connects to control room with fiber cable and AC power.
- All monitor and control and DC bias for RF modules is supplied through one large PC motherboard

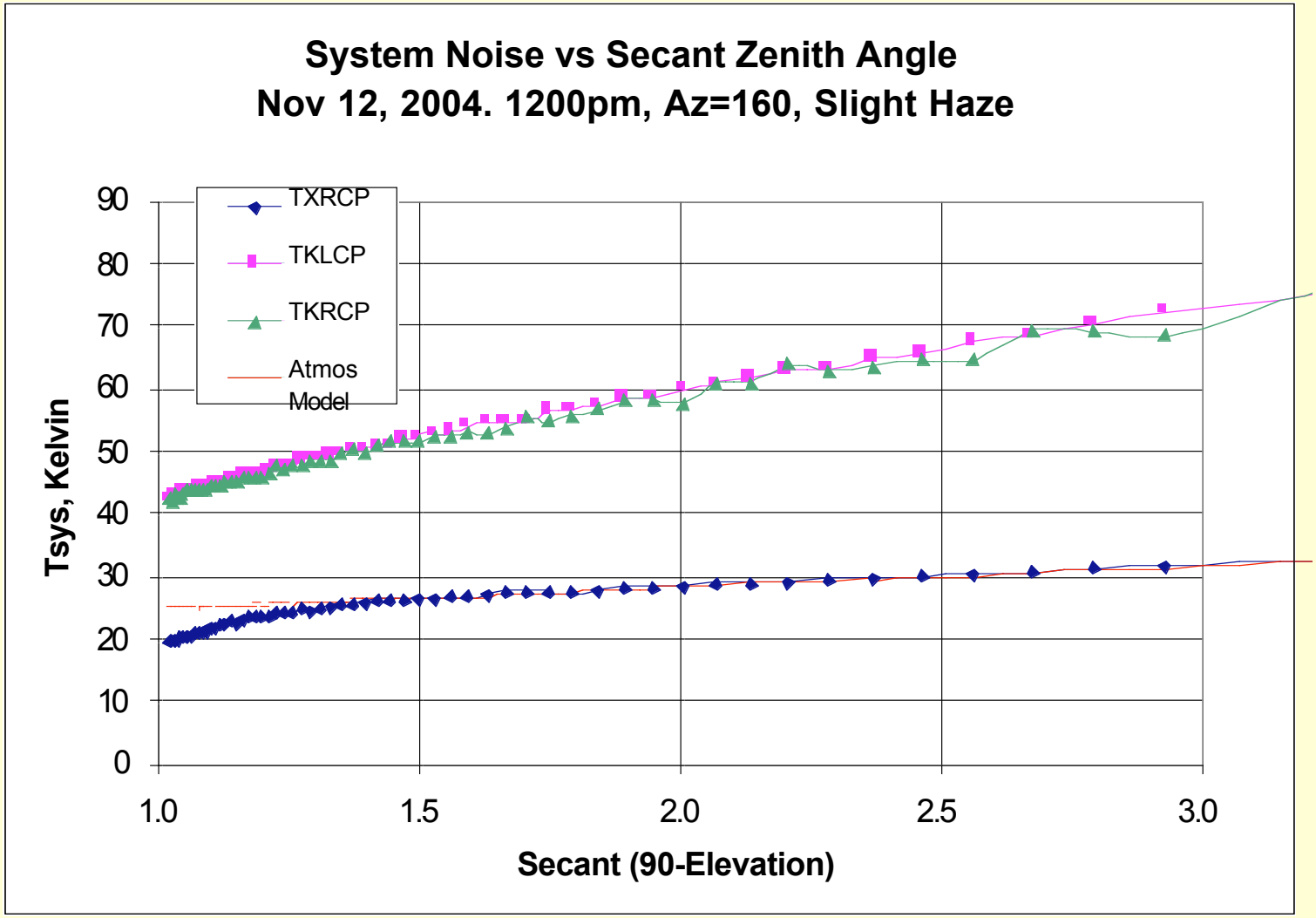
Example of Array RF Module

IF processing module provides LNA selection, gain control, filtering, power monitoring, and conversion to fiber for transmission to control room which may be a few km away. Size is approximately 5” square.

Array Cryogenic Feed/LNA Test Results

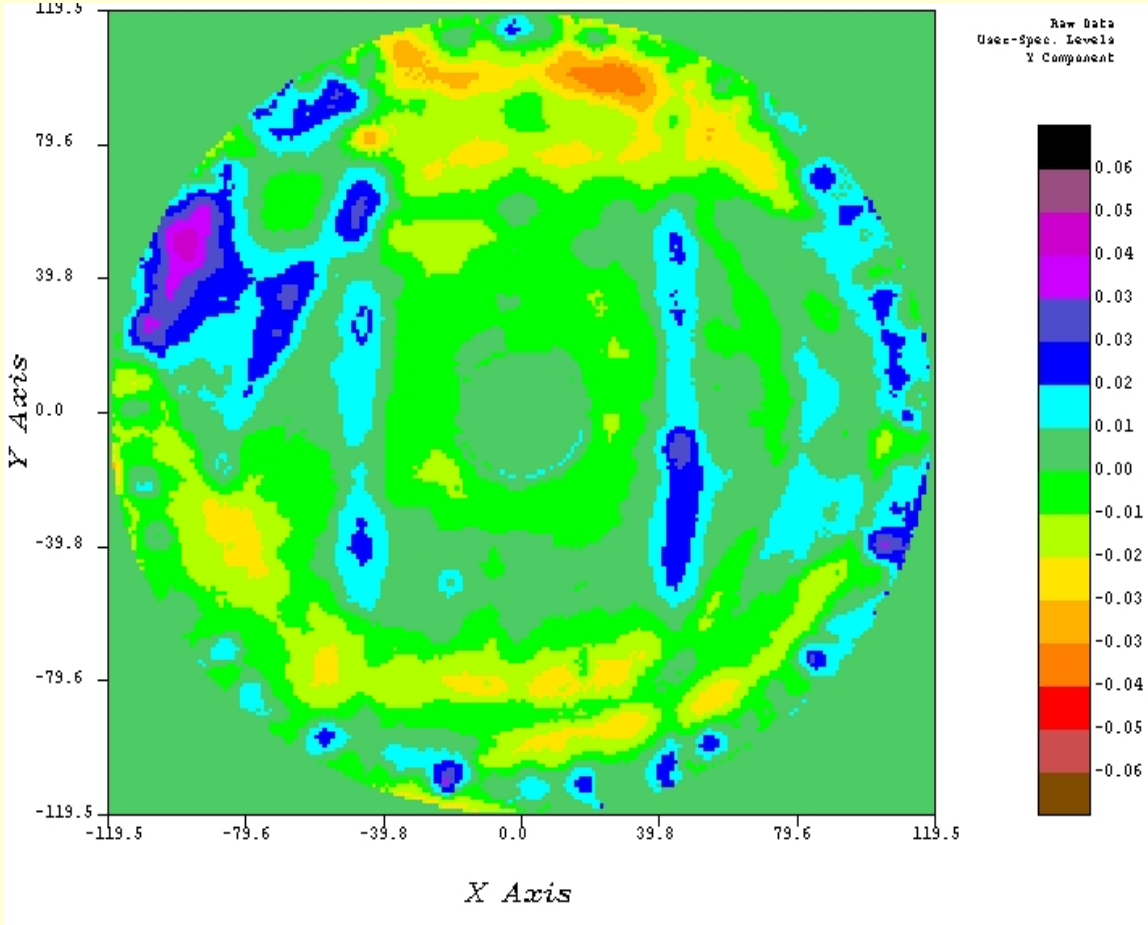
Measured Quantity	XLCP	XRCP	KaLCP	KaRCP
LNA Noise	6K	6K	12K	14K
Receiver Noise, 7/23/04 Includes Feed and Window	9.6K	10.0K	22K	27K
Goal Including Sky and Spillover	20K	20K	40K	40K
Measured System Noise on 6m Antenna, 11/1/04, Includes Spillover, Atmosphere and Cosmic Background	17K	19K	39K	38K

First 6m Antenna on JPL Mesa



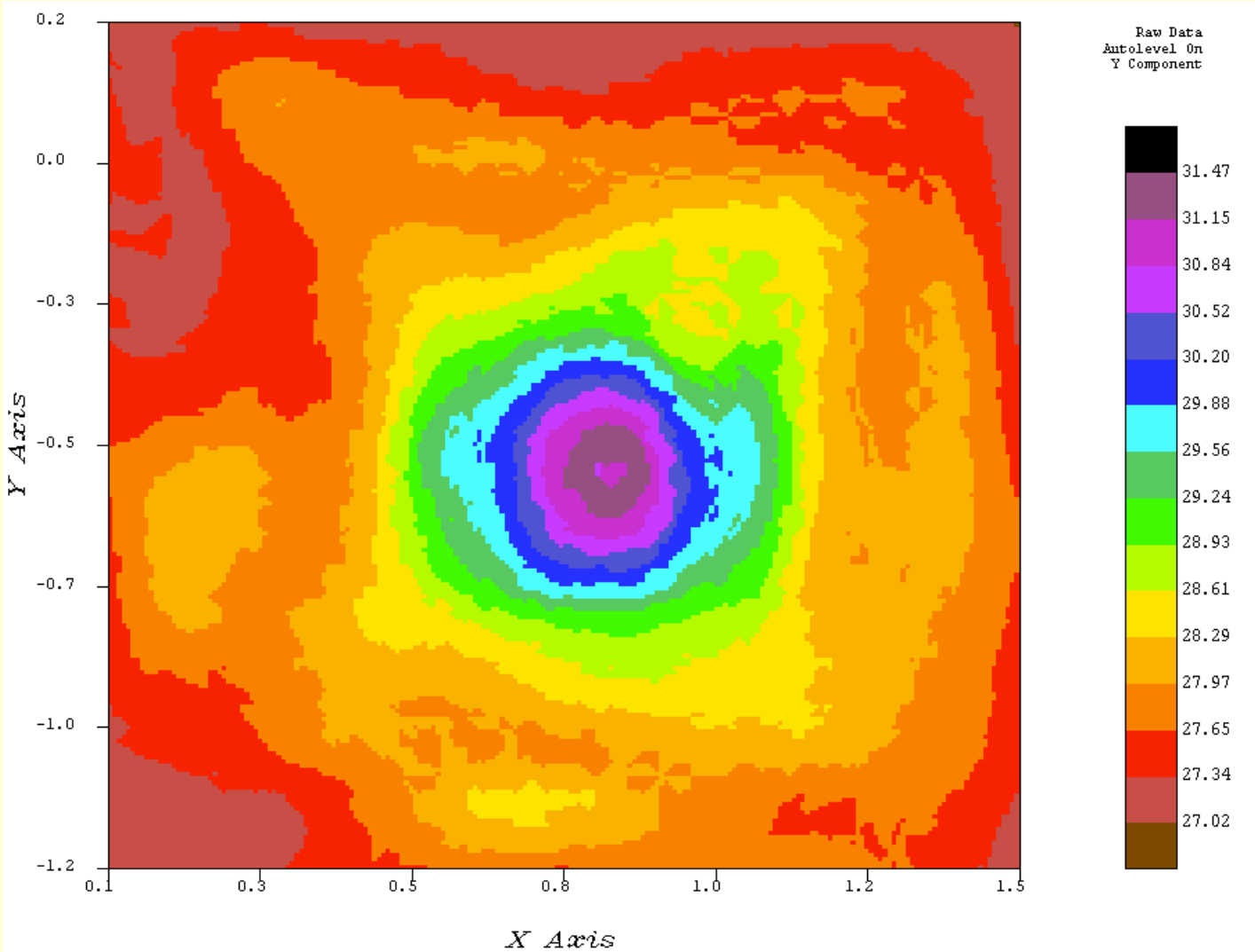
First 6m Antenna on JPL Mesa

- 11/02/04
  RMS = .0092”, Avg Temp = 12 Deg C
  Measurements taken from 7:20 pm to 8:00 pm (Reflector Front Side)



First 6m Antenna "First Light"

First 6m Antenna Performance – Antenna efficiency, pointing, T_{sys}, …



On Cassiopia-A
@ X-band
on 11/18/04
Tsource ~ 3.5 K →
Antenna Eff. ~ 65%
Tsys (X) =20K (Zenith)
Tsys (Ka)=42K(Zenith)

Two Philosophic Approaches

- Two different philosophic approaches for arrays are:
  - Separate arrays for uplink and downlink
  - Same arrays for uplink and downlink

- Why are these differences philosophic?
  - The uplink array needs receive capability, if only to enable interferometry to accurately locate the phase centers of the antennas.
  - To do this interferometry, the uplink array also needs all or almost all of the electronics, other equipment, and processing capability of a receive array.
  - The receive capability should be pretty good, to facilitate the phase center calibrations, although this approach would concentrate on uplink capability.
  - Therefore, it is likely that the uplink antennas will have enough receive capability that they will be used as part of the downlink array, even if they are philosophically considered to be a separate uplink array.

- Although it appears likely that the uplink antennas will be used for downlink also, the option is retained to have totally separate uplink and downlink arrays.

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IEEE MTT Workshop on Arrays

The DSN Array
Project Summary

What it is…

Breadboard Activities
- 2 ea x 6-m hydroform aluminum
- 1 ea x 12-m paneled aluminum
- fabrication and test of one panel of a 12-m composite antenna
- 3-element interferometer with radio sources and spacecraft

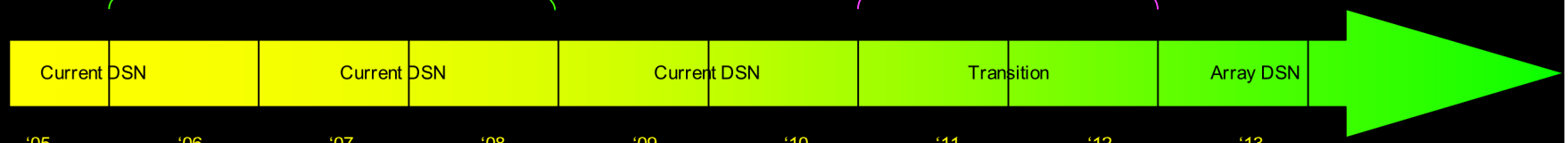
Operational Demo
- 12-element prototype
  - 6 ea x 12-m Technology 1
  - 6 ea x 12-m Technology 2

Build 1
- 300 x 12m downlink antennas
  - 100 at each complex
- 6 x 34m new uplink antennas
  - 2 ea in US
  - 2 ea in AU
  - 2 ea in Eur

Build 2
- 600 x 12m downlink antennas
  - 200 at each complex
- 1 x 34m new uplink antennas
  - 1 ea in AU
- 6 x 34m existing antennas converted to uplink

Build 3
- 300 x 12m downlink antennas
  - 200 at each complex
- 2 x 34m new uplink antennas
  - 1 ea in AU
  - 1 ea in Europe

Missions Supported By…



What it does…

'05–'06
- Develops and validates technologies for the array system
  - Electronics
  - Antenna
- Provides test-bed for electronics
- Demonstrates combining of small antennas with s/c systems
- Develops cost models for electronics and antennas

'07–'08
- Demonstrates arraying with 34-m equivalent capability
- Shadow mode operations on various s/c
- Validates ops concept
- Validates O&M Cost Models
- Determines final reflector technology
- Defines final electronics cryogenic technology

'09–'10
- Develops infrastructure at all complexes
- Provides initial DSN Array downlink Capability
  - Most with X- and DSN Ka-band
  - Some with X- and Cat A Ka-band
- Provides Initial DSN Uplink Capability using array era operations paradigm
  - X-band only
  - 6 uplink antennas total

'11–'12
- Incrementally adds to both the downlink and uplink capability
- Assimilates existing 34-m into array era operations paradigm
- Brings uplink total to 13 antennas
- Allows decommissioning of 70-m antennas

'13
- Completes the array capability to meet the 2010 Level 1 Requirements
  - 1200 x 12-m downlink antennas (400 at each longitude)
  - 15 x 34-m uplink antennas (5 at each longitude)
- Meets all 2020 Level 1 requirements *except* total number of uplinks
- Provides foundation and infrastructure to incrementally add G/T