The Deep Space Network Array

Technology Progress, Recent Results, and Future Plans

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The DSN Array Overview

- A NASA/JPL study in 2001 looked at seven options to replace the 70-m antenna capability for deep space communications
  - Included 3 monolithic based and 4 array based options
  - The array based options provided capability in excess of the current 70-m
- In January 2002 JPL/NASA began a study focused specifically on array based options
  - One of two studies that included optical communications option
  - Began with a proposal for a prototype of 100 x 12m elements (based on initial cost modeling)
  - Extended to a proposal to replace the current DSN with 400 x 12m antennas each at three longitudes. Options for weather diversity were studied.
- In December 2004 a major review of an array based DSN replacement was held.
  - Included both the downlink and the uplink capabilities
  - Multiple *new* sites around the world

DSN Array Overview

- The concept of using an array for space communications is much less of a concern than the cost of implementing and operating such an array.
  - Within the cost question, the cost uncertainty of the front-end components (repeated "n-times") is of most importance.
  - Activities at JPL have focused on both these aspects of the cost
- Technical issues requiring demonstration include
  - Ability to provide high reliability at lower cost
  - Ability to provide functions with smaller form factor (esp. for equipment at front-end) to enable lower cost
  - Ability to provide signal processing system that operates in real-time and supports ever-increasing data rate requirements
  - Ability to operate and maintain array at lower cost
  - Ability to track a typical deep space mission
- A breadboard array of three antennas at JPL has been the vehicle to perform many (but not all) of these investigations.

Comparison of Array Requirements for Space Communications 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

High Level Requirements

Requirement		Value	
		X-band	Ka-band
Element size (diameter, m)		12	12
Antenna Efficiency (%) (6-m antenna in parenthe ses)		74-79 (65-68)	61-65 (55-58)
Antenna G/T (dB/K)		>46	>53.5
Antenna Reflector RMS		0.012”	0.012”
Sky Coverage	Elevation	6°–90°	6°–90°
	Azimuth	0°–360°+	0°–360°+
Tracking rate, max (°/sec)		0.4	0.4
Slew rate, max (°/sec)	Elevation	0.8	0.8
	Azimuth	3	3
RF Frequency Band (GHz)		8.0–8.8	31–38
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

DSN Array Breadboard

- The breadboard array is architecturally similar to proposed DSN array.
  - Includes 2 x 6-m antennas (hydroform aluminum, Anderson Mfg.) and 1 x 12-m antenna (aluminum panels, Patriot)
  - Front-end electronics developed at Caltech and JPL
  - Signal processing developed at JPL
  - Monitor and Control to operate this system and enable demonstration testing
- Located at JPL
- Will evaluate issues as described above as well as:
  - Evaluate antenna performance
  - Identify technological “tall tent-poles”

Breadboard Array: 6-m Antenna

Breadboard Array: 6-m Antenna

Breadboard Array: 6-m Antenna

Breadboard Array: 6-m Antenna

Breadboard Array: 12-m Antenna

Breadboard Array: 12-m Antenna

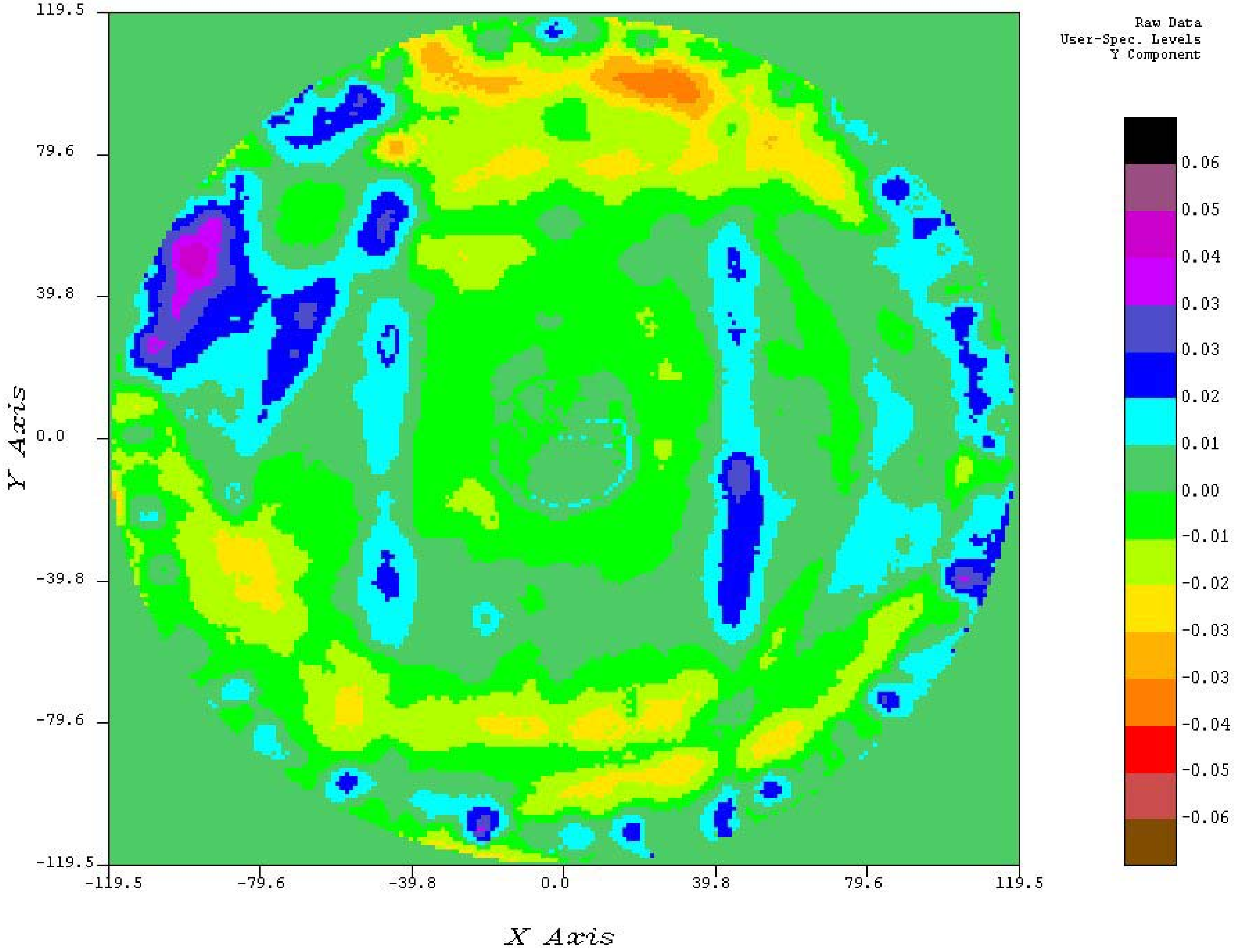
Breadboard Array Elements

- The major elements in the breadboard include
  - Antenna and servo system
    - G/T controlled at this level in the system by a specified optics and RMS
  - Electronics
    - Includes LNAs, frequency downconverters, local oscillators, frequency and timing
    - G/T controlled at this level by a specified amplifier gain and temperature
  - Signal Processing
    - Includes a correlator *and* a combiner
    - Required to provide real-time amplified and phase tracking
  - Monitor and Control
    - Required to “glue” the system together for operations, provide data storage, and interface to single user

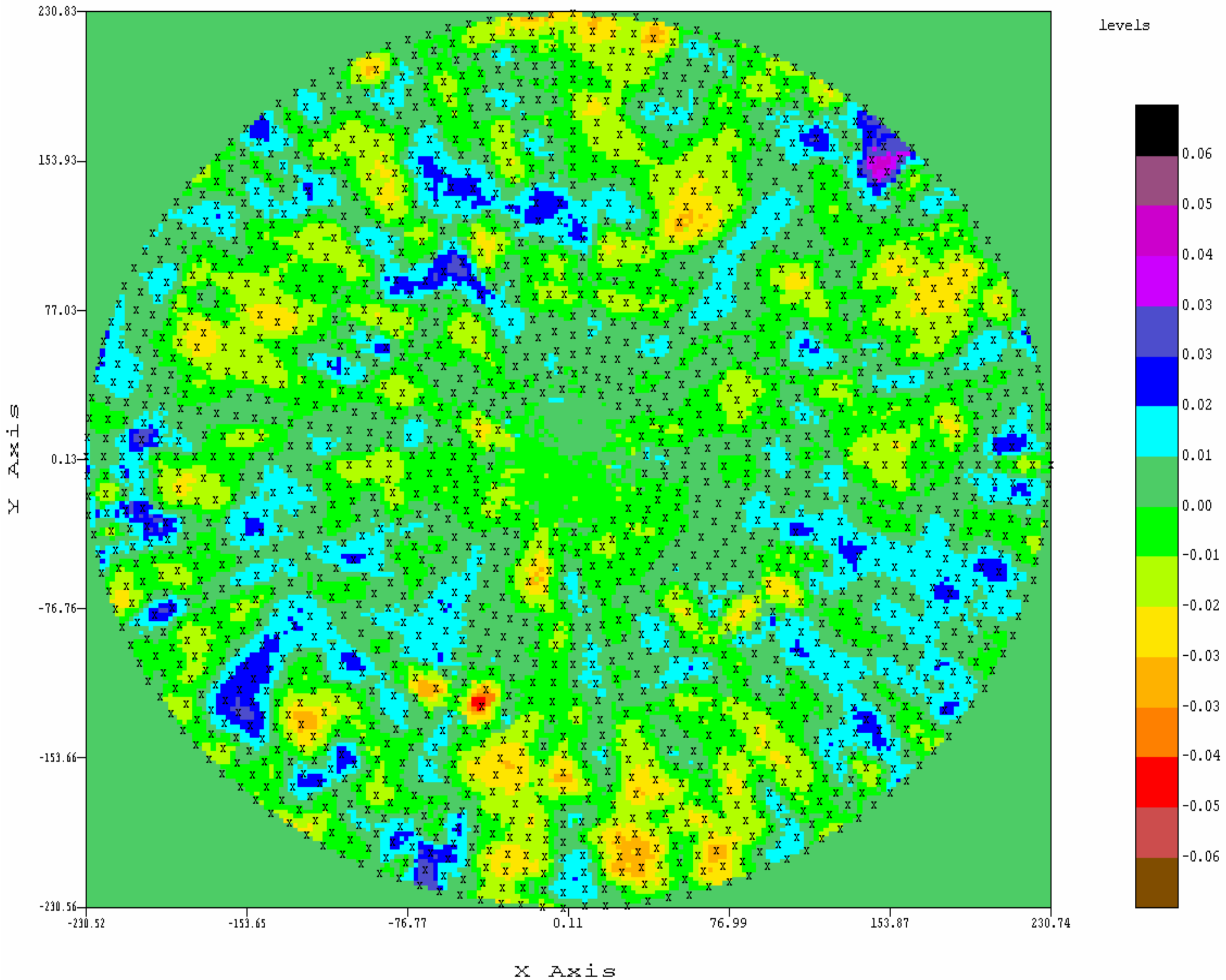
Breadboard Antennas

- Required to maintain an RMS of 0.012” that includes the original manufacturing surface as well as throughout the range of operating conditions including gravity, wind, and thermal excursions.
- During the period between 2004 and 2005 we have constructed 6-m antennas that meet these requirements.
  - Required painting of the dish surface (front and back)
- The Patriot antenna is in acceptance tests.
  - Initial results show that the total of the manufacturing and gravity is 0.010”.
  - Thermal testing underway

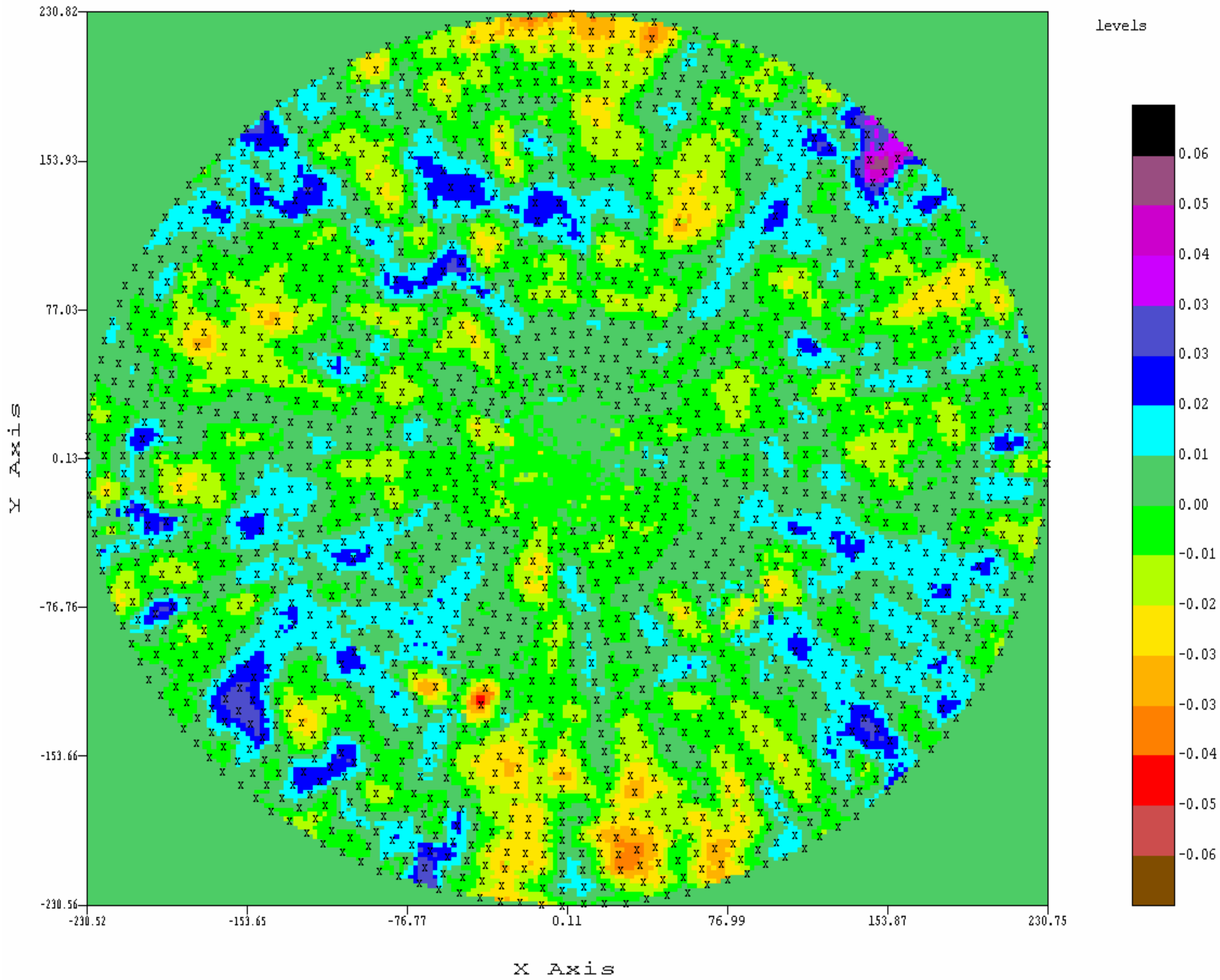
6-m DSN Array Prototype
Elevation = 45°, RMS = 0.0092"



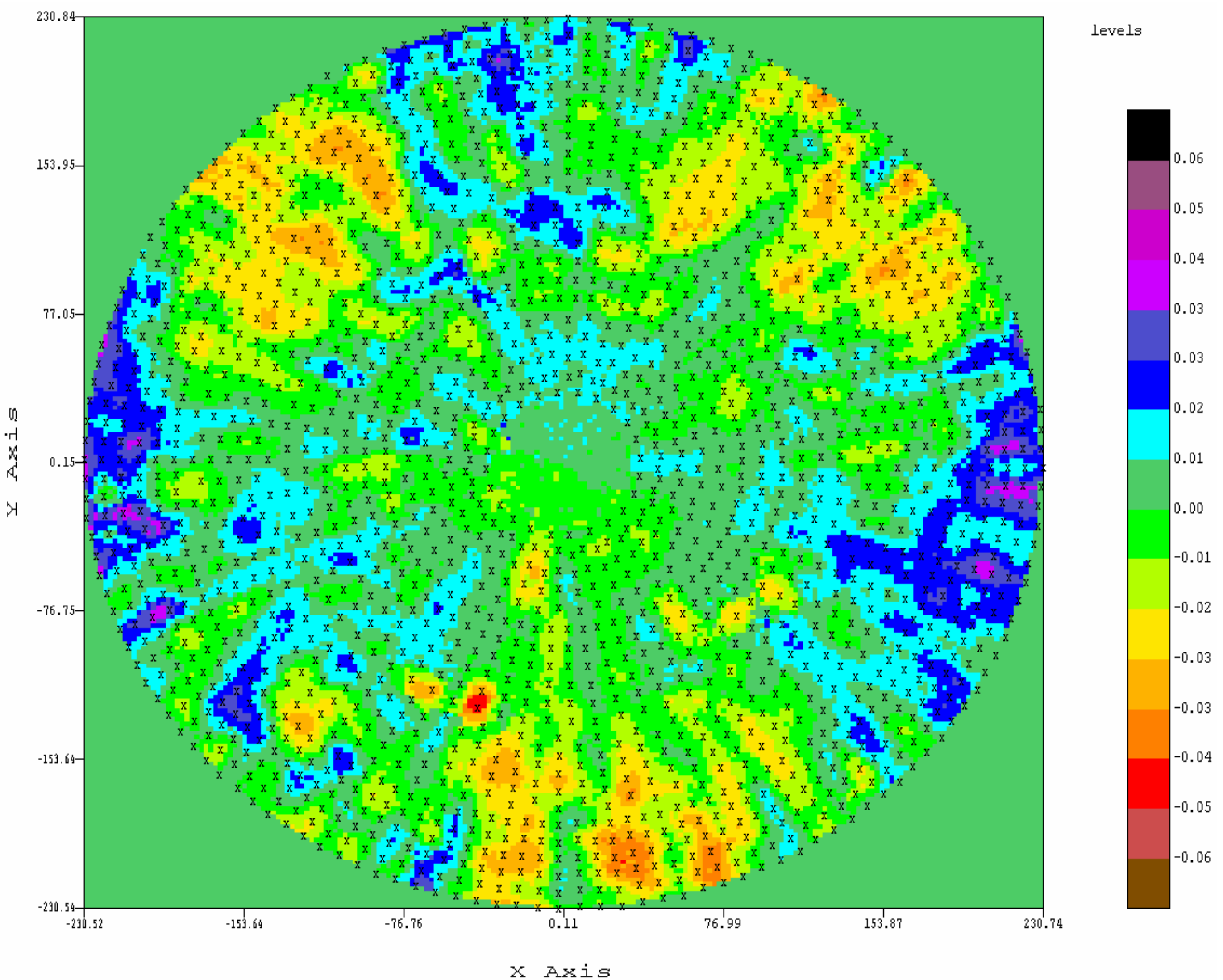
12 m DSN Array Prototype Antenna
Best Fit RMS = 0.00897”, El = 30º



12 m DSN Array Prototype Antenna
Best Fit RMS = 0.00946”, El = 8º



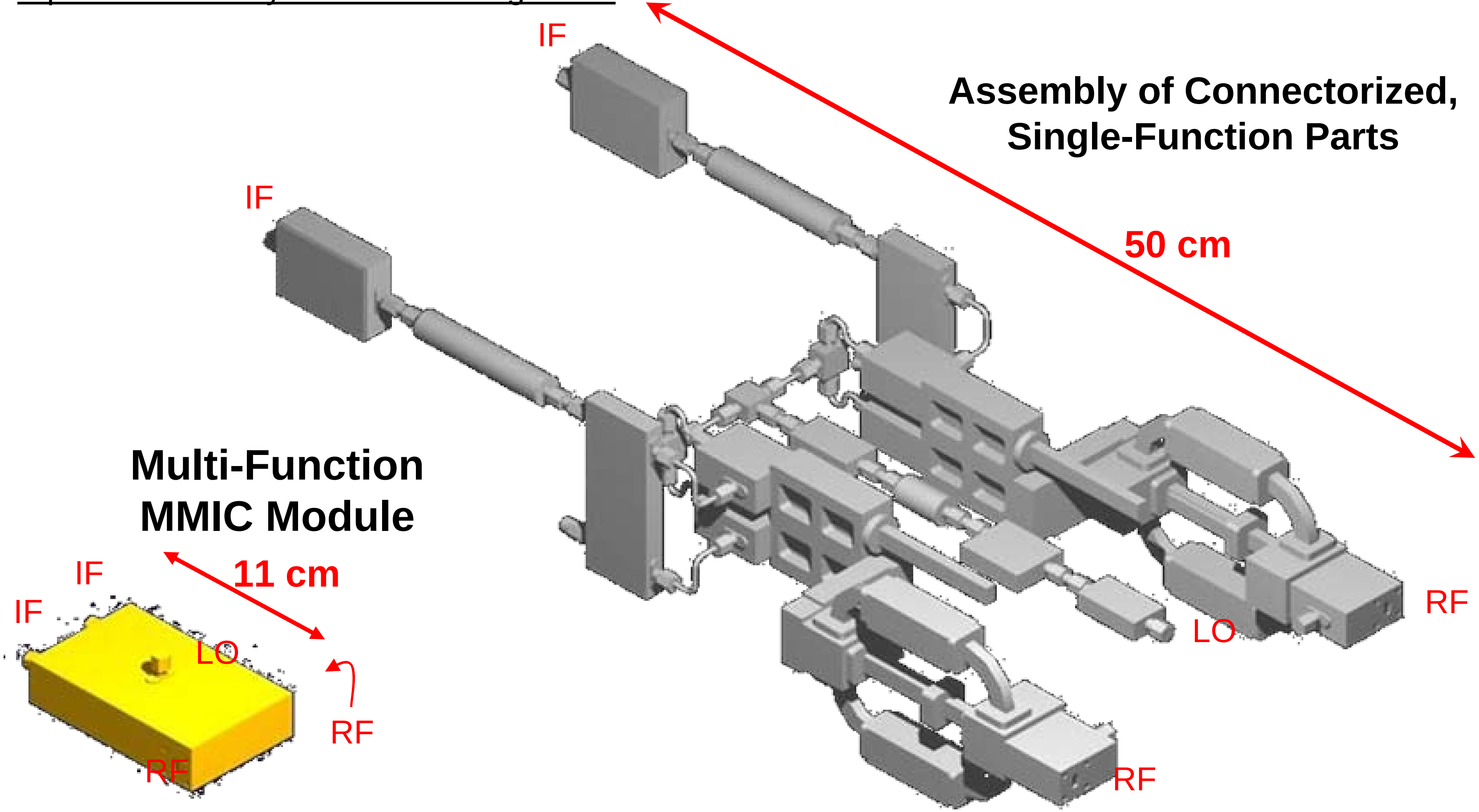
12 m DSN Array Prototype Antenna
Best Fit RMS = 0.01128", El = 88º



DSN Array Receive Electronics: Reduced Form Factor

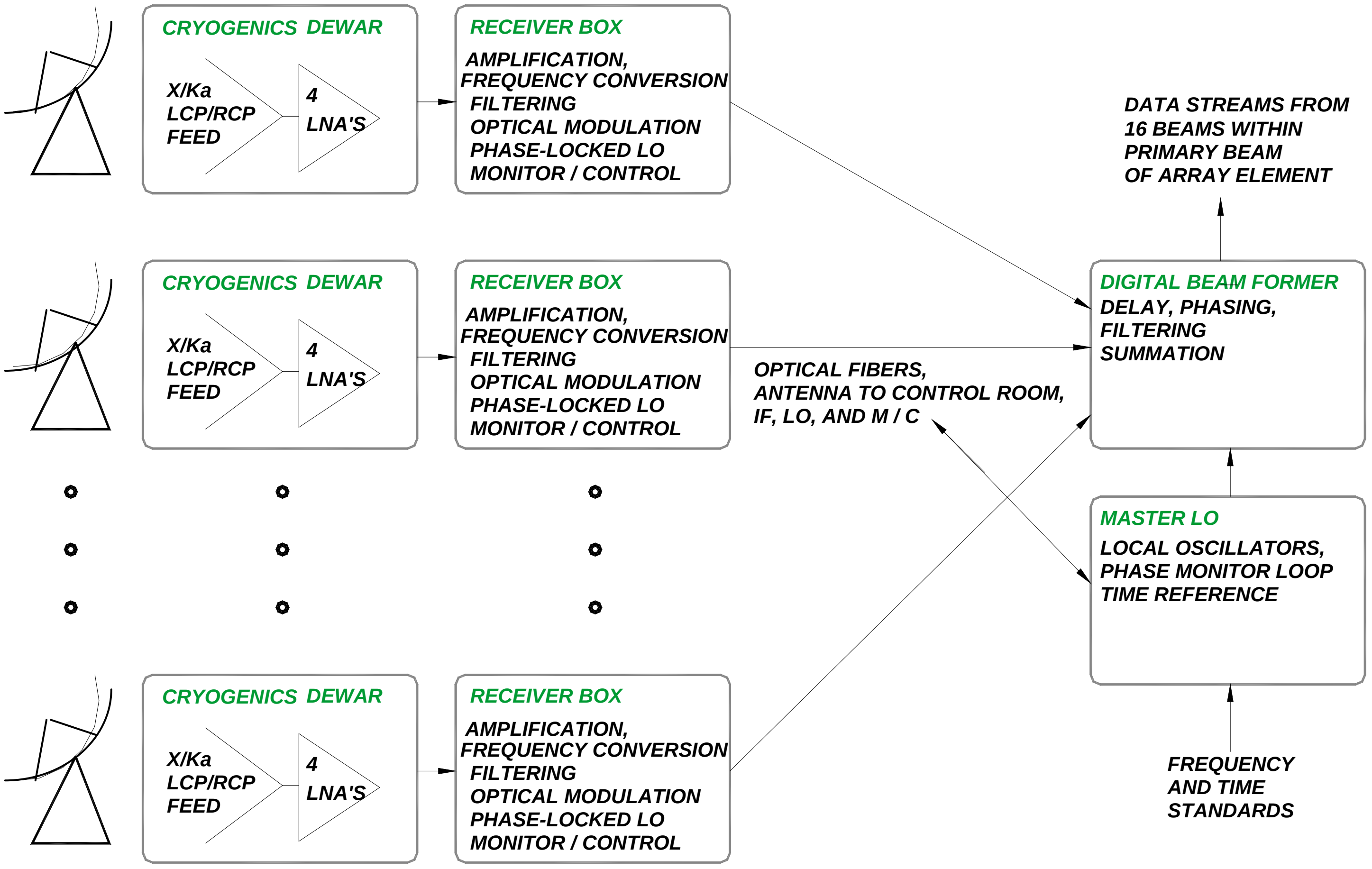
- MMIC Technology to Decrease Array Receiver Cost

Multifunction MMIC packaging of Ka band dual-downconverter for the DSN array reduces size and replication cost by an order of magnitude



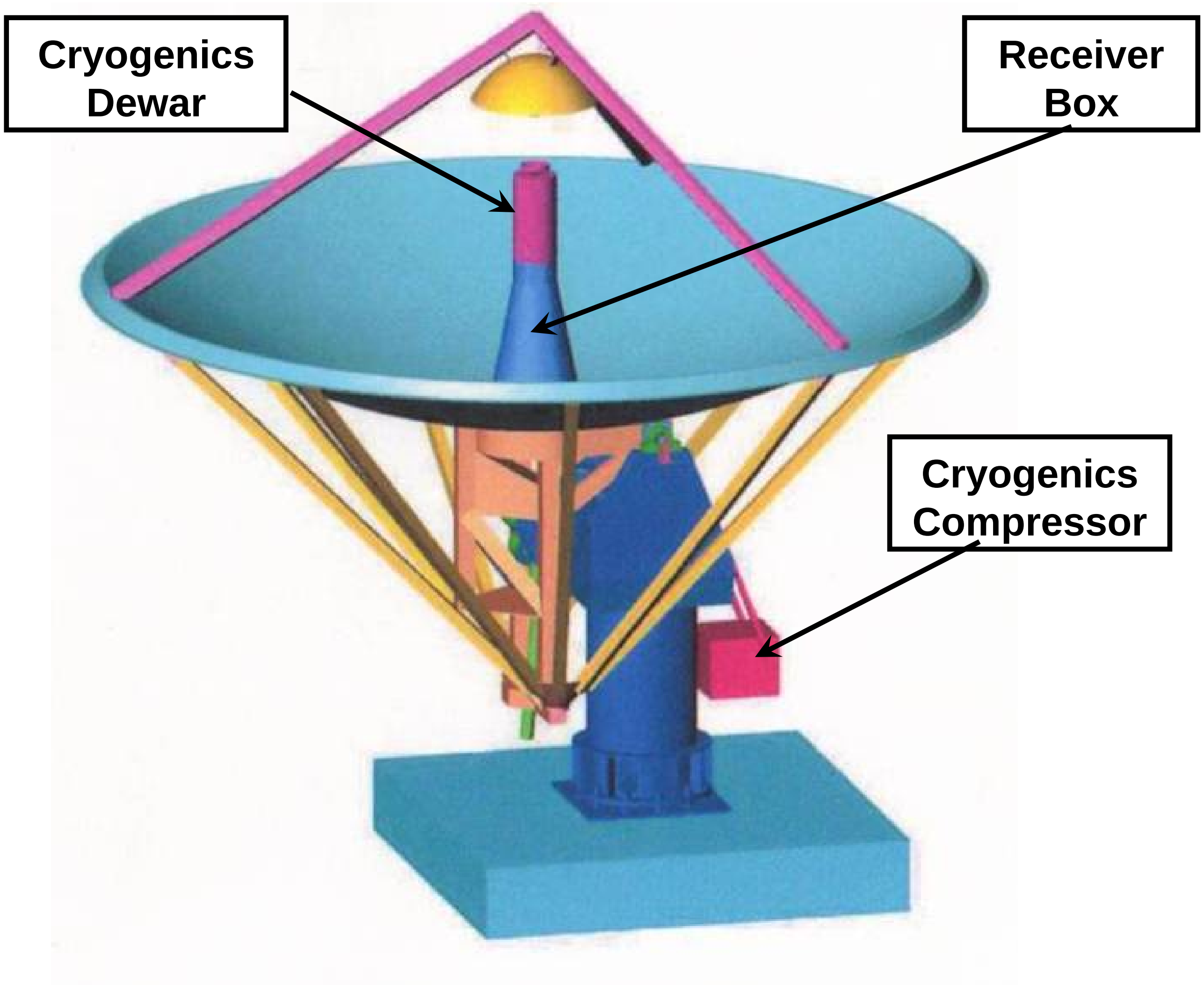
DSN Array Receive Electronics: Block Diagram

- Phased array of moderate size antennas, digitally beam-formed
- Two easily replaced equipment packages per antenna



DSN Array Receive Electronics: Antenna Locations

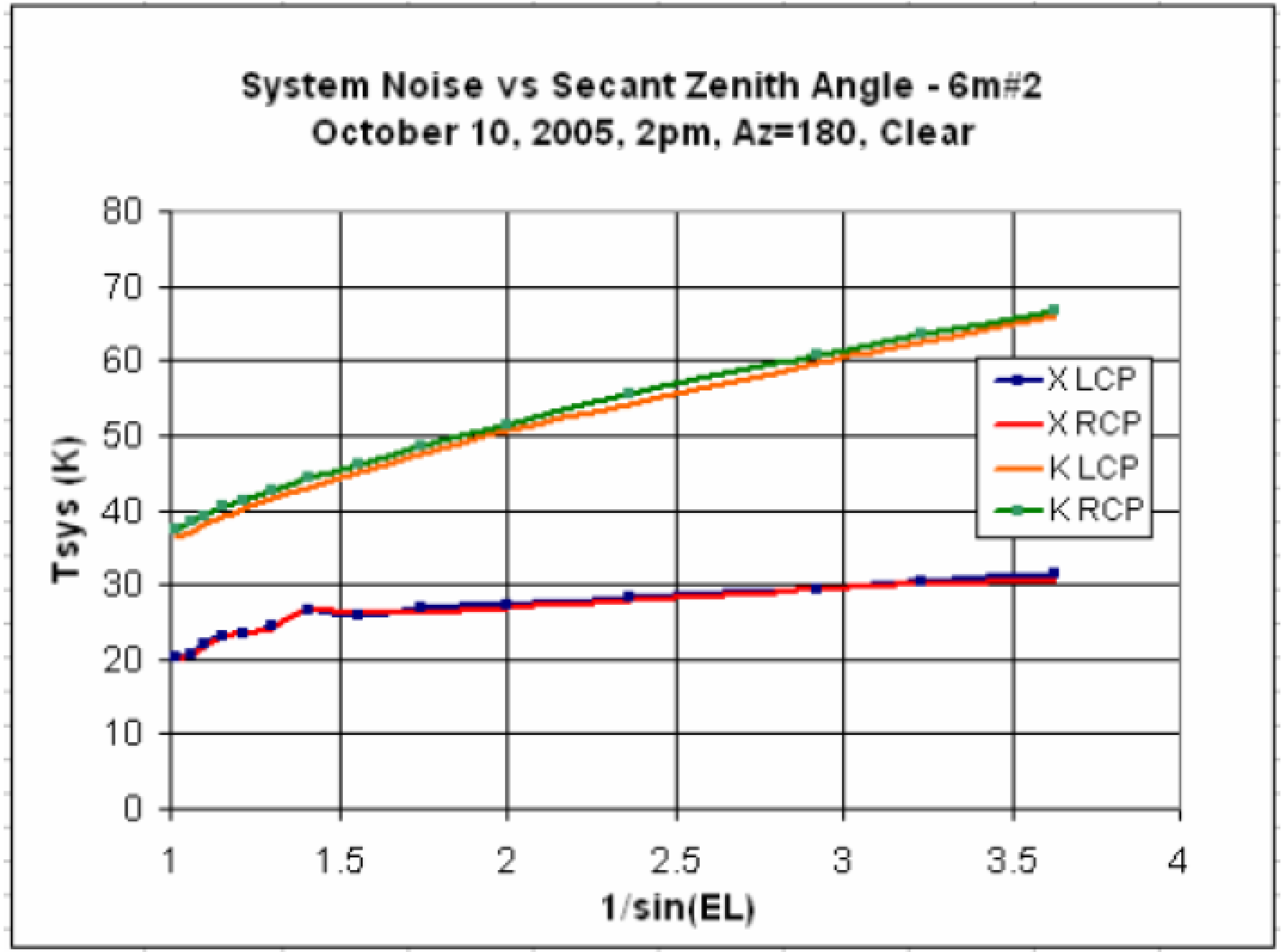
Receiver Equipment on DSN Arrray Antenna



DSN Array Receive Electronics: Feed/LNA Test Results

Measured Quantity	XL	XR	KaL	KaR
LNA Noise	6K	6K	12K	14K
Receiver Noise, 7/23/04 Includes Feed and Window	9.6K	10.0K	22K	27K
Predicted System Noise, 10/08/04 Includes Sky	15K	14.8K	35K	35K
Goal Including Sky and Spillover	20K	20K	40K	40K
Measured on 6m Antenna, 11/1/04	**17K**	**19K**	**39K**	**38K**

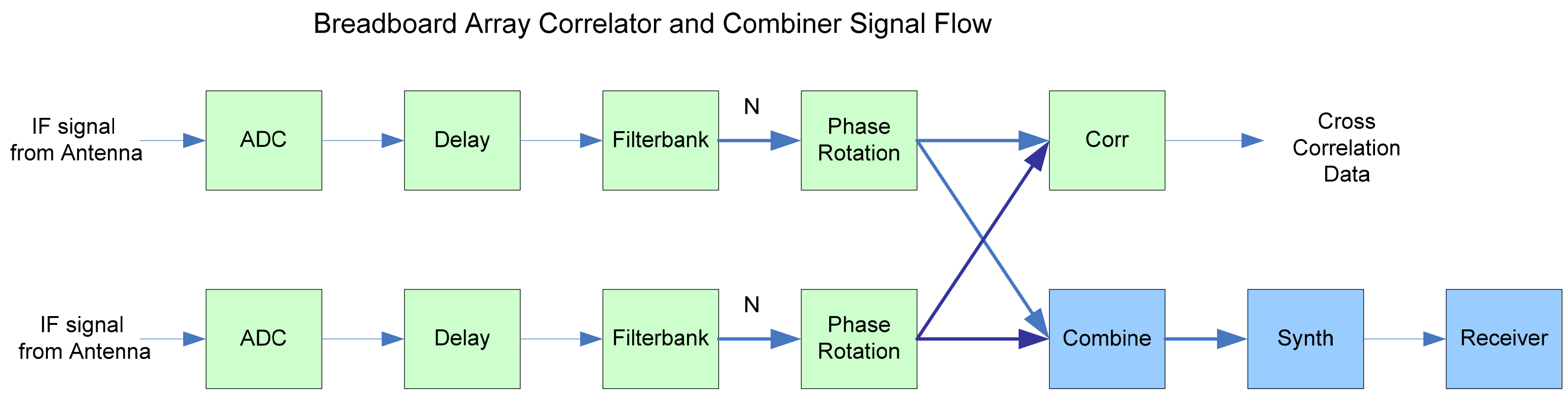
DSN Array Receive Electronics: System Noise Measurement



DSN Array Signal Processing: Goals

- Provide a means to evaluate the performance of the Breadboard Array antennas.
- Design and build prototype hardware
  - High density IF digitizer, current design supports 6 Antennas (12 IF inputs) in one chassis
  - High speed FPGA digital signal processing board for AdvancedTCA chassis
- Demonstrate and evaluate proposed signal processing techniques
  - Polyphase FIR filter and a FFT for Analysis filterbank
  - Synthesis filterbank for reconstruction of beamformer output
- Gain experience with various technologies that may be used in the Large Array
  - High speed serial digital signal interconnects (Xilinx RocketIO 3-10Gbit/s)
  - High speed analog to digital converters (1280 Ms/s, 8 bit, Atmel)
  - AdvancedTCA Chassis with high speed serial backplane
  - Field Programmable Gate Arrays for digital signal processing (Xilinx)
  - Linux OS for use in embedded processors (MontaVista)

DSN Array Signal Processing: Signal Processing Flow

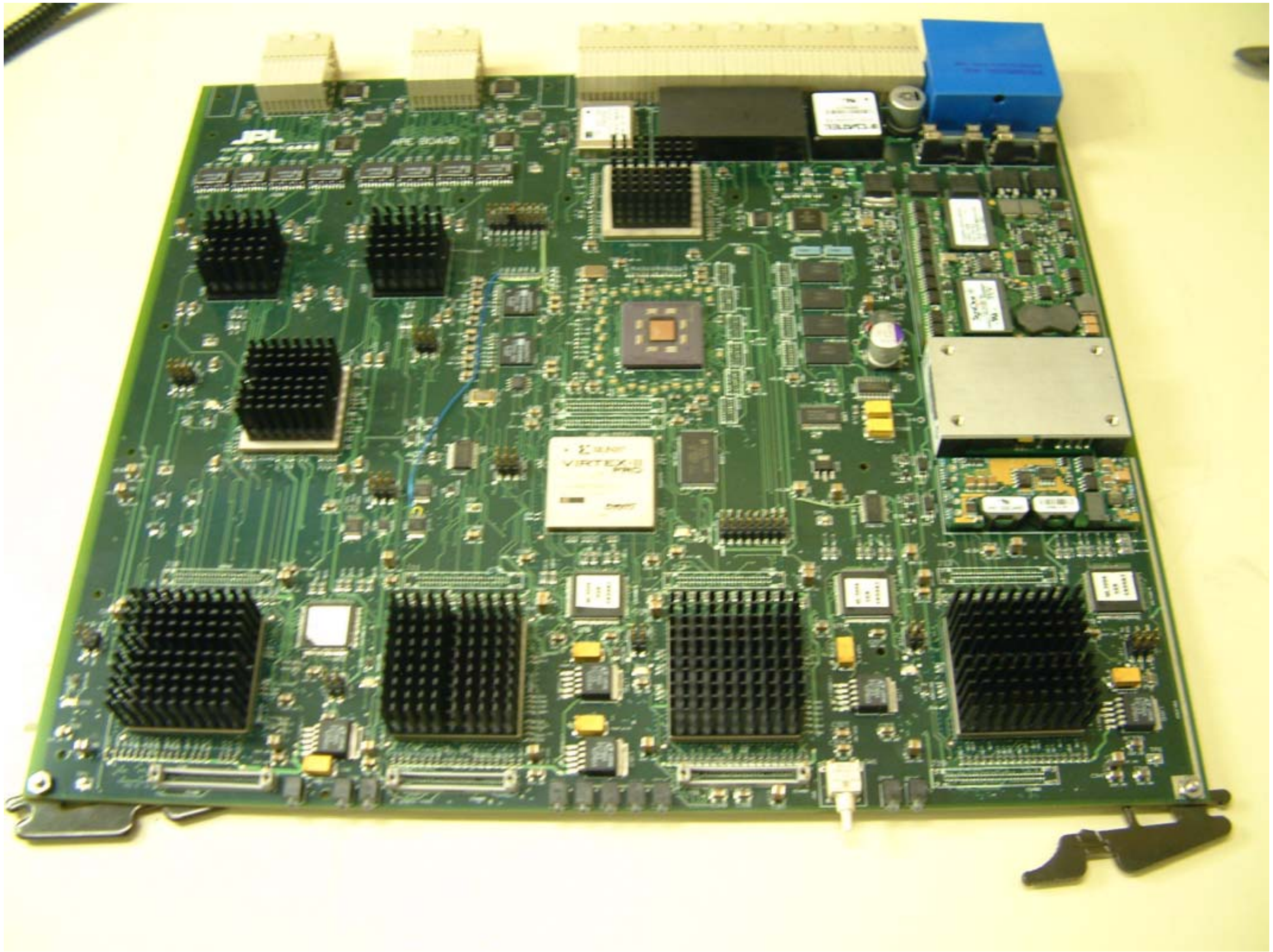


- Functional Blocks in green are implemented.
- Functional Blocks in blue are in development
- The correlator in the larger system will *not* be a full system.

DSN Array Signal Processing: Breadboard Results Summary

- Built and Tested Hardware: 3 Array Sampler Modules (ASM) for the IF Digitizer (IFD) and 3 AdvancedTCA Processor Engine (APE) boards for the Real Time Signal Processor (RSP).
- Software and Signal Processing Firmware (FPGA code) for the wideband correlator completed and tested.
- Successfully demonstrated these technologies for BBA:
  - High Speed A/D (1280 Ms/sec, 10 bit digitizer)
  - Analog Fiber link from Antenna to signal processor
  - High Speed Serial links (3.2 Gb/sec) between Filterbanks and Correlator blocks.
  - Real-time Linux OS for Embedded PowerPC processors.
  - Wideband (640 MHz) Discrete Fourier Transform Analysis Filterbank implemented in FPGA.

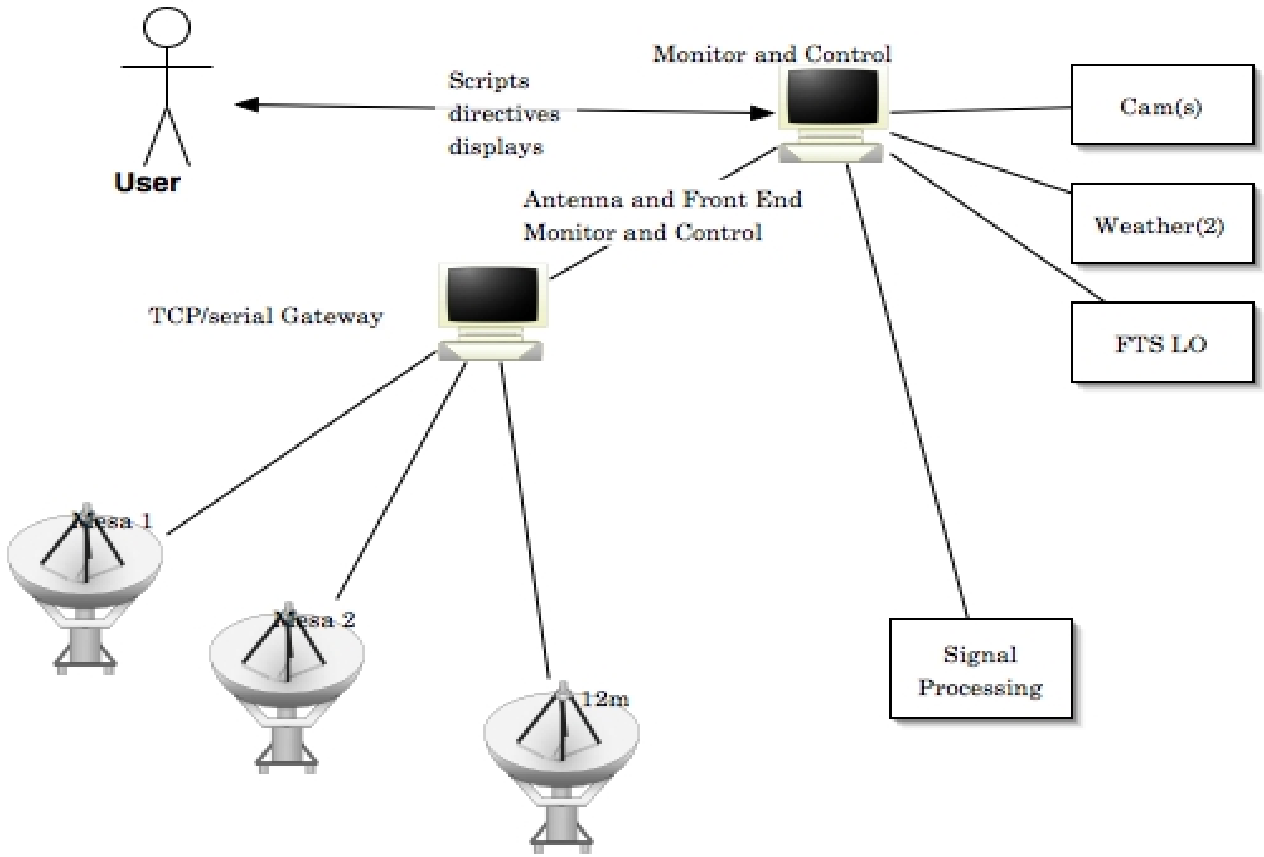
DSN Array Signal Processing: Real-time Signal Prosser APE Board



DSN Array Monitor & Control: System Description

- Hosted on PC platform using Debian Linux
- Written in C
- PythonCard used for graphical interfaces
  - 42K Logical lines of C and PythonCard source code
- User-written activity scripts in Python
- Central control of antennas, front-end electronics, signal processing, cameras, LO monitoring, weather stations
  - Interfaces are TCP/IP and serial
- Network-based remote user interface provided for monitor and control
- Capability to divide the assets in multiple subarrays

DSN Array Monitor & Control: Breadboard



National Aeronautics and Space Administration
Jet Propulsion Laboratory
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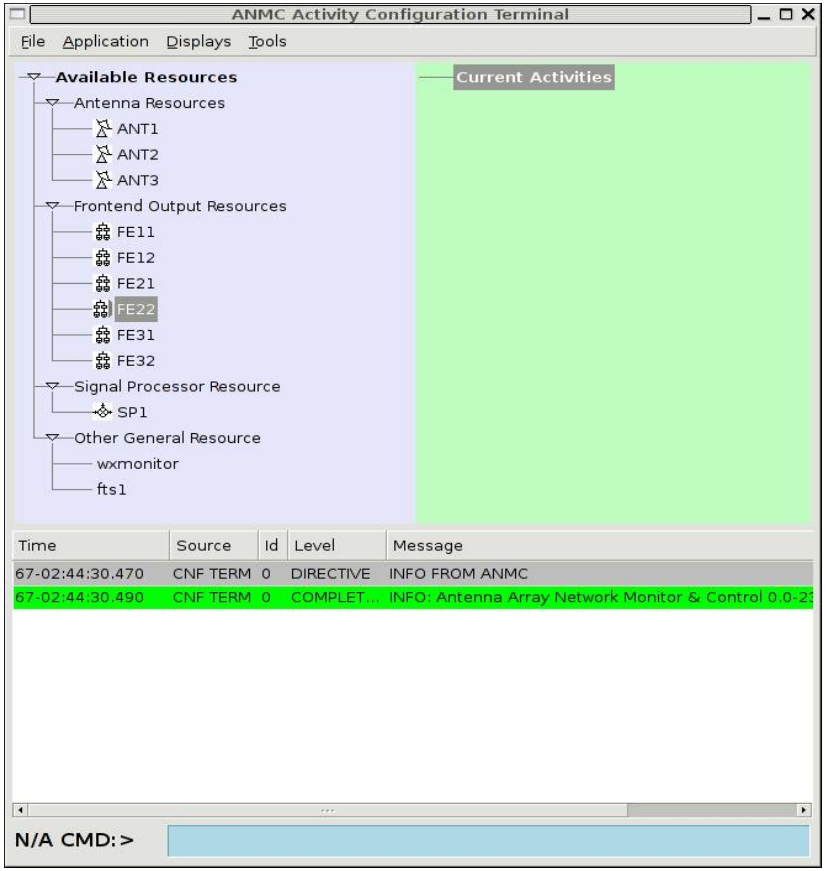
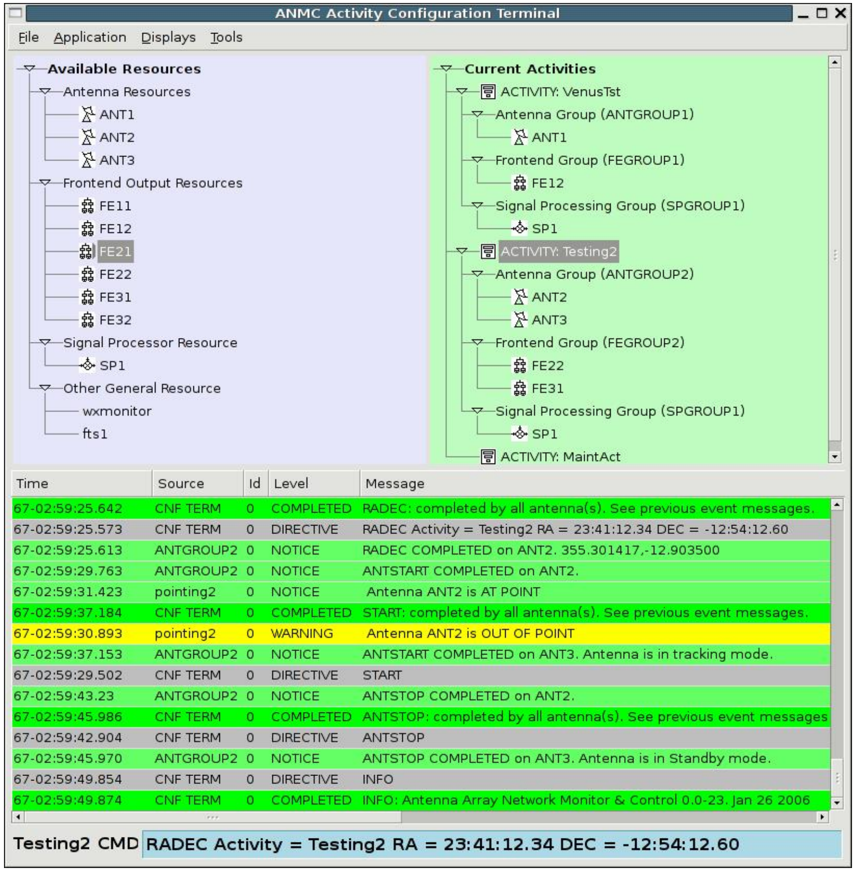
DSN Array Monitor & Control: Breadboard Configuration Interface



Preconfiguration



Multiple Subarray Configuration

DSN Array Monitor & Control: Breadboard Future Work

- Provide input for AIPS tools
- Replace some serial interfaces with TCP/IP
- Build up library of user scripts for common activities
- Educate more user-operators
- Add combiner interface
- Add telemetry interface
- Add interface for spacecraft tracking support products
- Schedule-driven automation

DSN Array Monitor & Control: Larger System Future Activities

- Initiating survey of COTS products for use in larger arrays
  - Monitor and control products, infrastructure products, support products
  - Desire is to assemble COTS components with project-specific software to reduce cost
- Research underway on automation requirements/capabilities and array scheduling
- Refine software architecture
  - New cost estimate

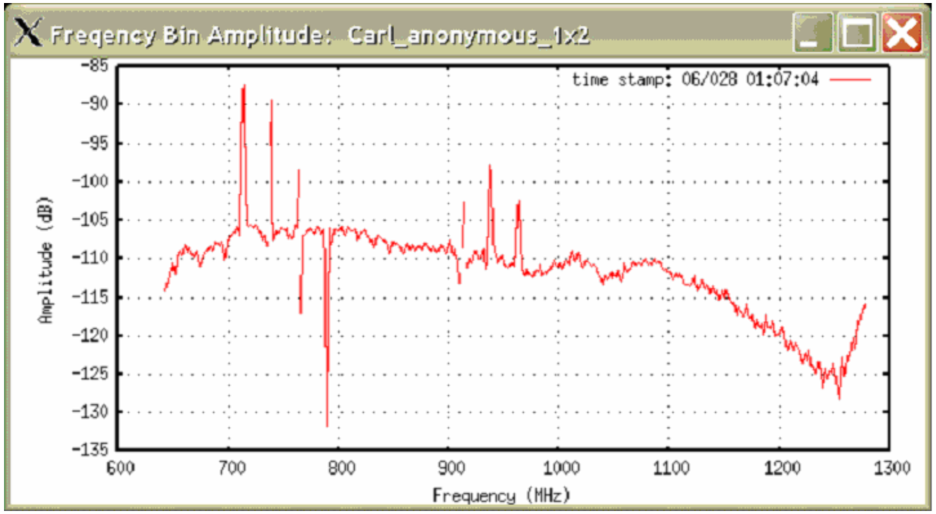
DSN Array System Tests: Results

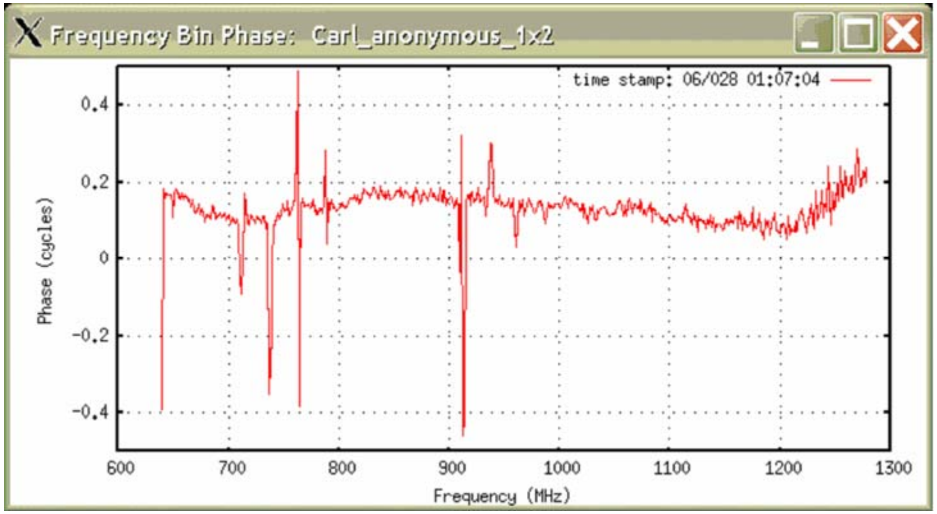
- Testing on various natural radio sources (Venus, Cyg-A, Jupiter, etc.) and deep space missions (MRO) have been useful in checking out the system and has provided calibrations of the 6-m antennas.
  - 12-m calibrations to started beginning of March 2006
- Successfully detected interferometric fringes from two 6 meter antennas using Venus as the source in Dec 2005.
- Successfully stopped interferometric fringes using Geometric models while viewing Venus, Cygnus A, and Cassiopeia A with the two 6 meter antennas on the mesa in January 2006.
- Signal Processing Monitor plots give visibility to confirm correlation and measure delay offsets but not to do detailed analysis of data.
- Correlation Data is archived for later processing to determine more accurate antenna position.

Experiment Results: Interferometry Phase and Amplitude

Results from two 6 meter antennas looking at Cygnus A:

- Amplitude and Phase shown over 640 MHz complex sampling band.
- Large spikes in Amplitude and Phase from RF noise at X-band
- Geometric models and offsets for path delay applied to bring delay to zero.
- For zero delay, the plot of phase versus frequency should have a slope of zero across the band.

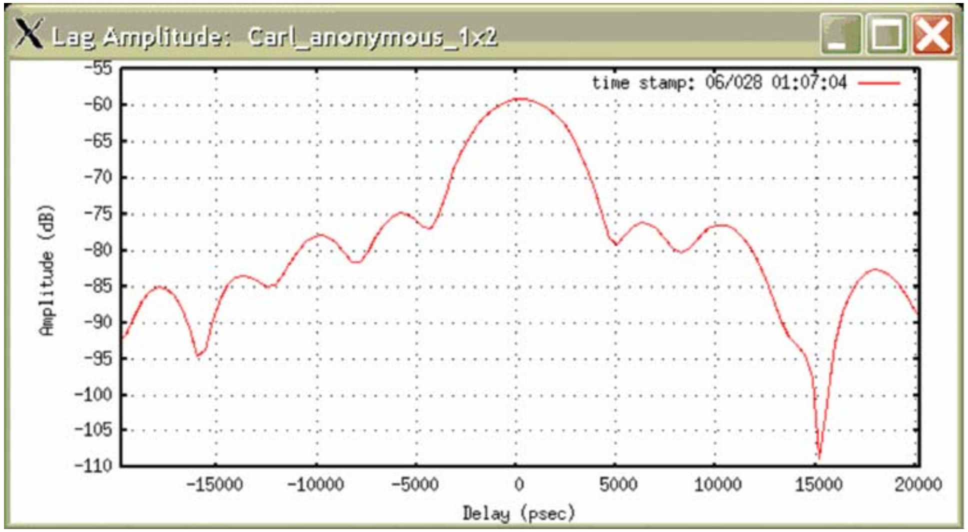


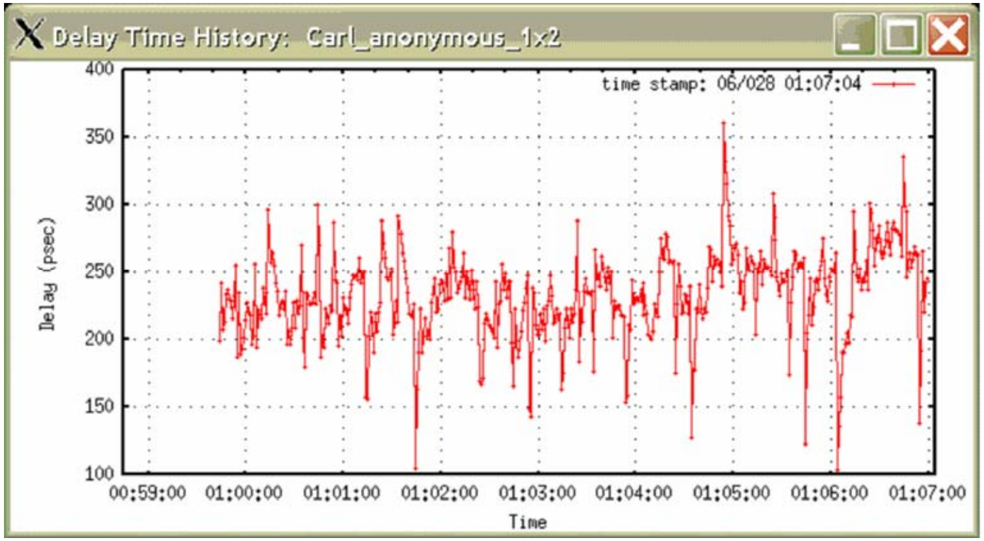


Experiment Results: Lag and Time Delay Plots

Results from two 6 meter antennas looking at Cygnus A:

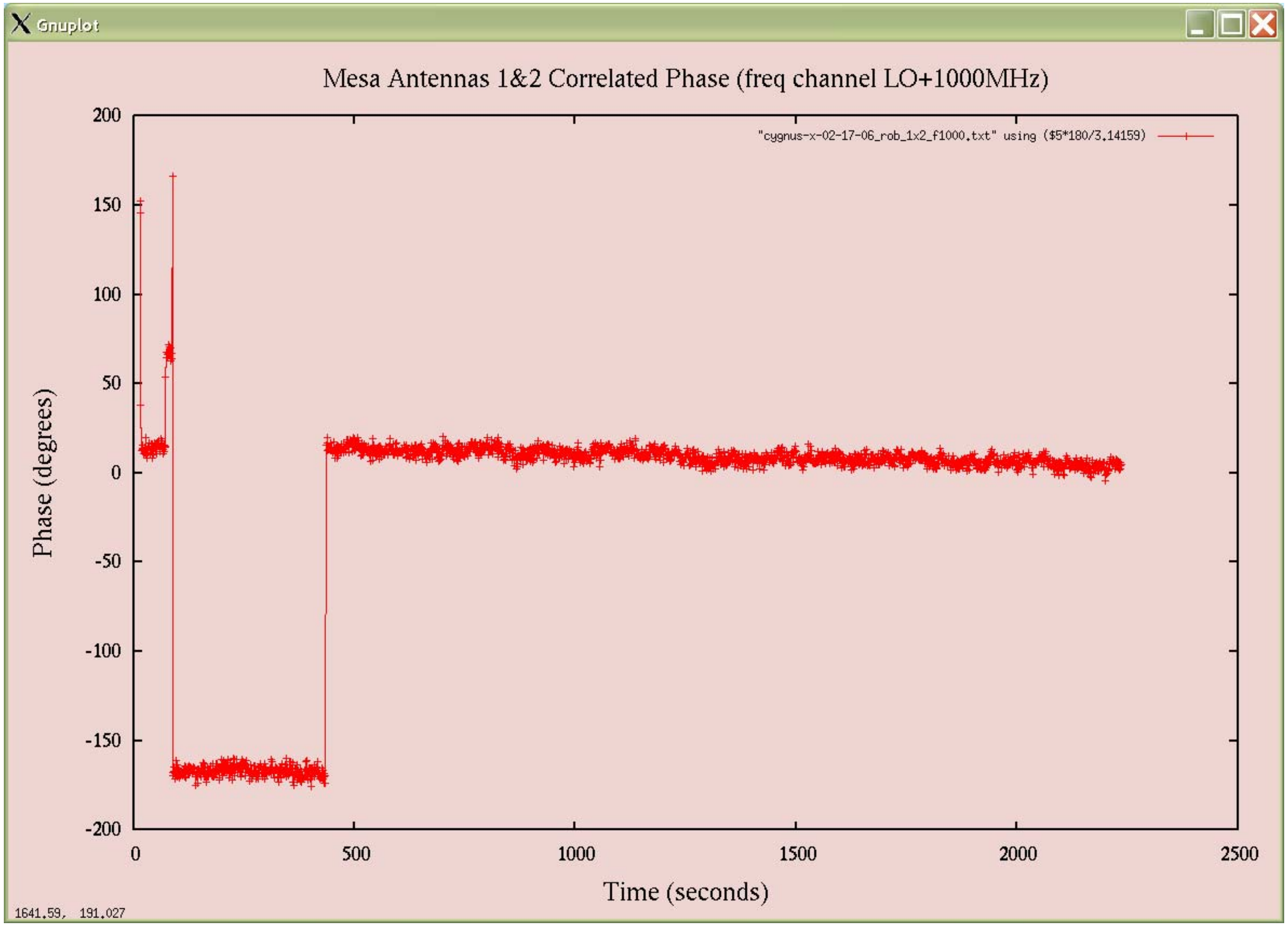
- Plot of Lag Amplitude made by taking inverse FFT of frequency channel data.
- Main Lobe of lag plot centered at delay of Antenna2 to Antenna1.
- Noisy frequency channels excluded in calculating these plots.
- Delay Time history tracks peak of Lag Amplitude plot.





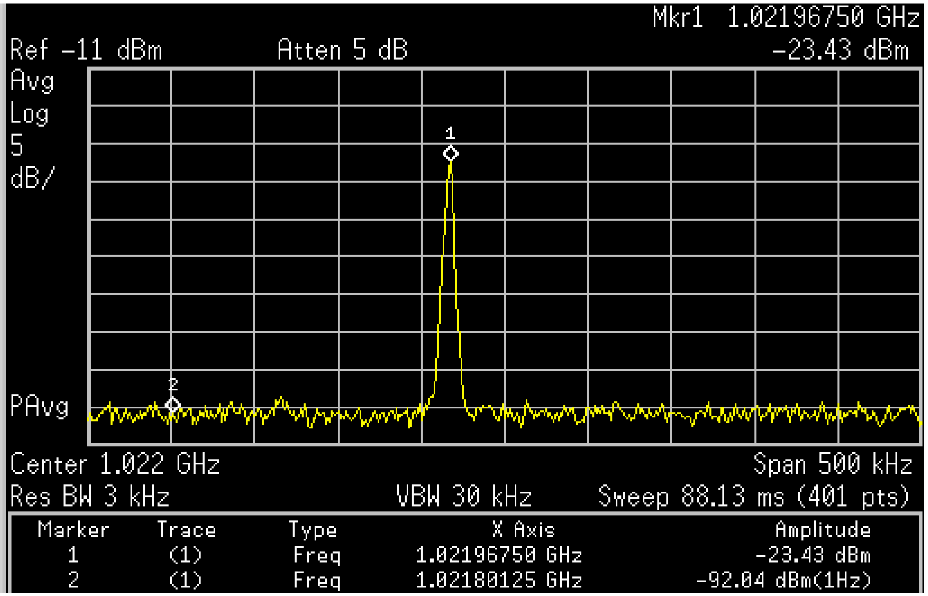
DSN Array System Tests: Results

- Fringe phase -vs-time for one fixed frequency (out of 512 available channels).
- 40 minute time span
- Initial offset is a calibration intentionally introduced
- Feb 17, 2006
- Cygnus A
- X-band



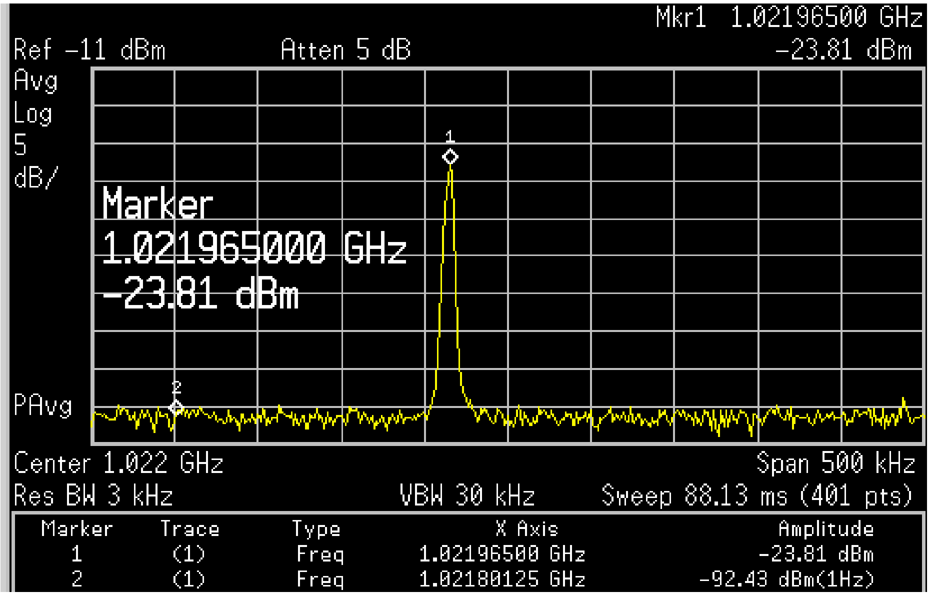
Ka Band Carrier from Mars Reconnaissance Observer (MRO) S/N of 69 dB-Hz at ~ 0.3 AU Range

Antenna 2



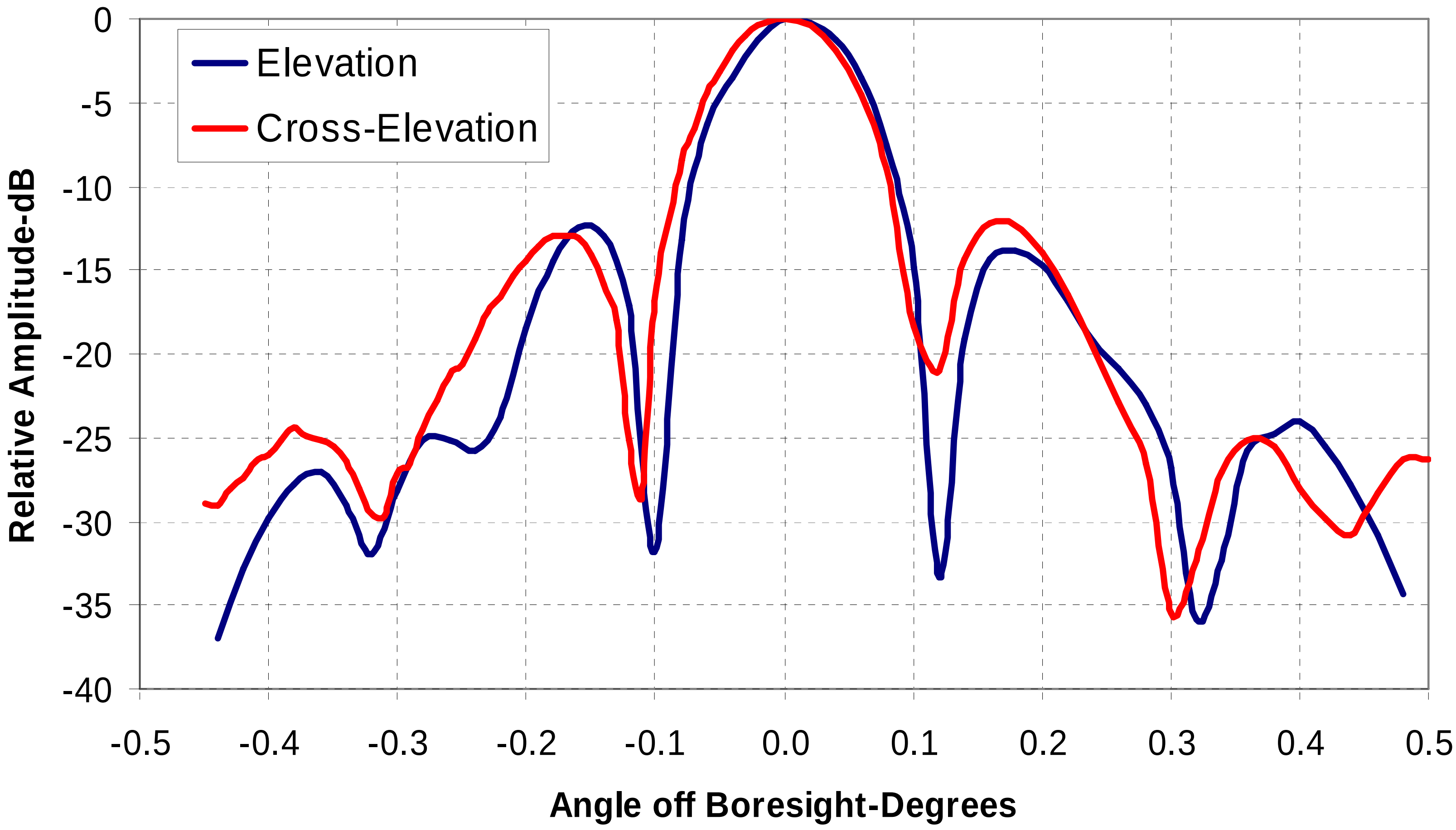
- Sky frequency = 32 GHz
- Tsys 36K
- No -92 dBm
- Pc -23.4
- Pc/No 68.6 dB-Hz
- P received (LNA) -114.4dBm
- Pointing offsets -.060 el -.060xel

Antenna 1



- Sky frequency = 32 GHz
- Tsys 32K
- No -92.4 dBm
- Pc -23.1
- Pc/No 69.3 dB-Hz
- P received (LNA) -114.2dBm
- Pointing offsets -.080 el -.030xel

Pattern of 6m Antenna 2 Measured at 32 GHz with MRO Spacecraft, Nov 18, 2005



Future Activities

- The DSN Array Project is currently working with Senior Management at both JPL and NASA to develop strategies towards starting a major implementation project.
  - Several studies within NASA are concluding, all of which recommend that any future DSN capability include arraying of antennas to increase performance.
  - Support of Deep Space, Lunar, and CEV (crewed exploration vehicle) missions is included
  - High data rate and TDRSS formatting is being investigated
- Any future DSN capacity must include Uplink
  - Current studies ongoing to investigate and develop technologies for uplink arraying; provides advantages in three ways:
    - N^2 effect. EIRP grows as N^2 (-vs- N for a downlink array)
    - Improved architectural options (can separate uplink and downlink)
    - Potential for more cost effective transmitters for fixed EIRP