The NASA Deep Space Network (DSN) Array

Technology Progress, Recent Results, and Future Plans

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Today's Agenda

- Describe one solution to NASA's communications needs of the future
  - Array based Deep Space network
- Illustrate the Array Concept and associated Operations Concept
- Describe current breadboarding activities
- Preview some breadboard performance results

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.

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

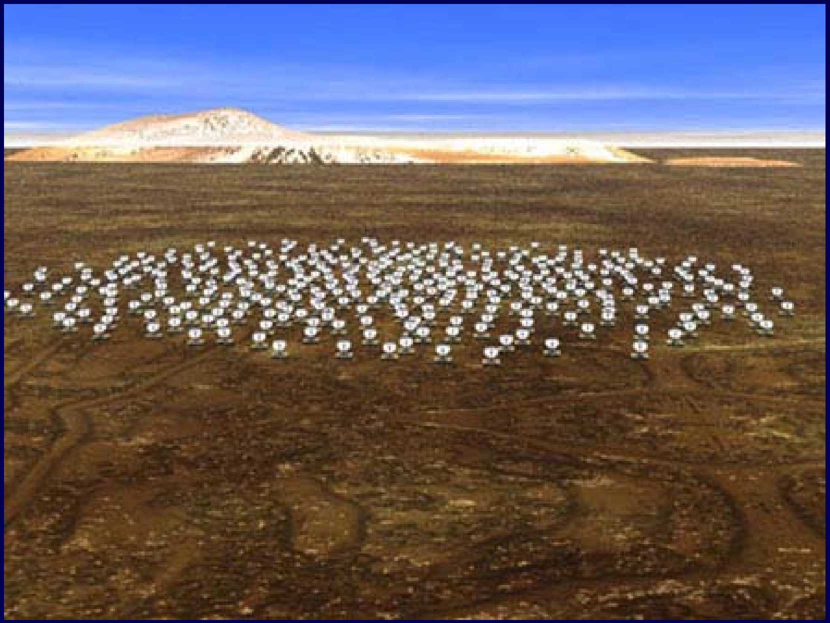
Comparison of Array Requirements for Space Communications and Radio Astronomy

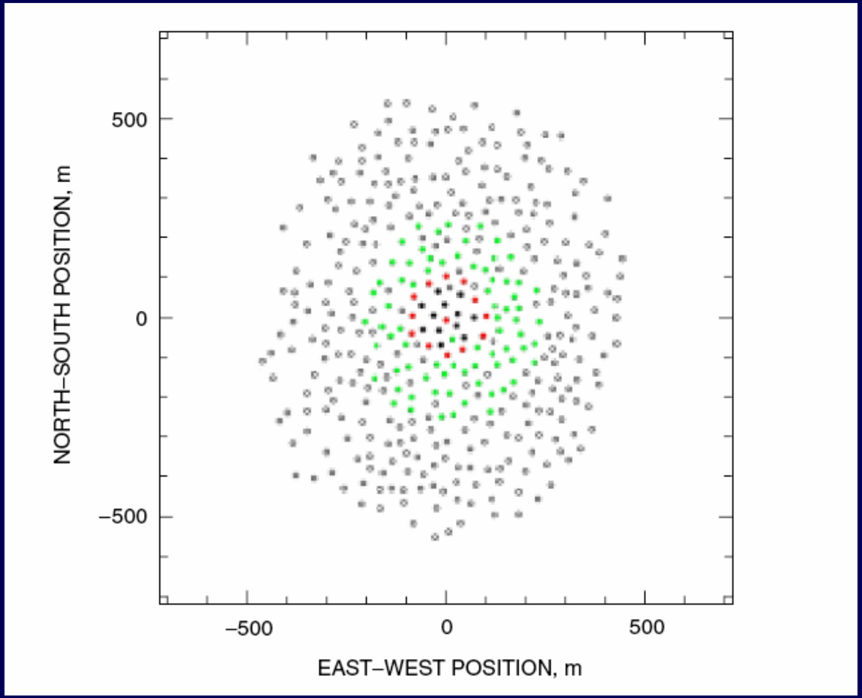
Parameter	Communication	Radio Astronomy
Frequency	8 and 32 GHz	.5 to 20 GHz
Array Configuration	Any but lower cost if closely packed	Sparse for better image sharpness
Element Size	Minimum cost probably in the 3.5 to 10 meter range	May be slightly larger because of more complex receivers
Data Processing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

Array architecture

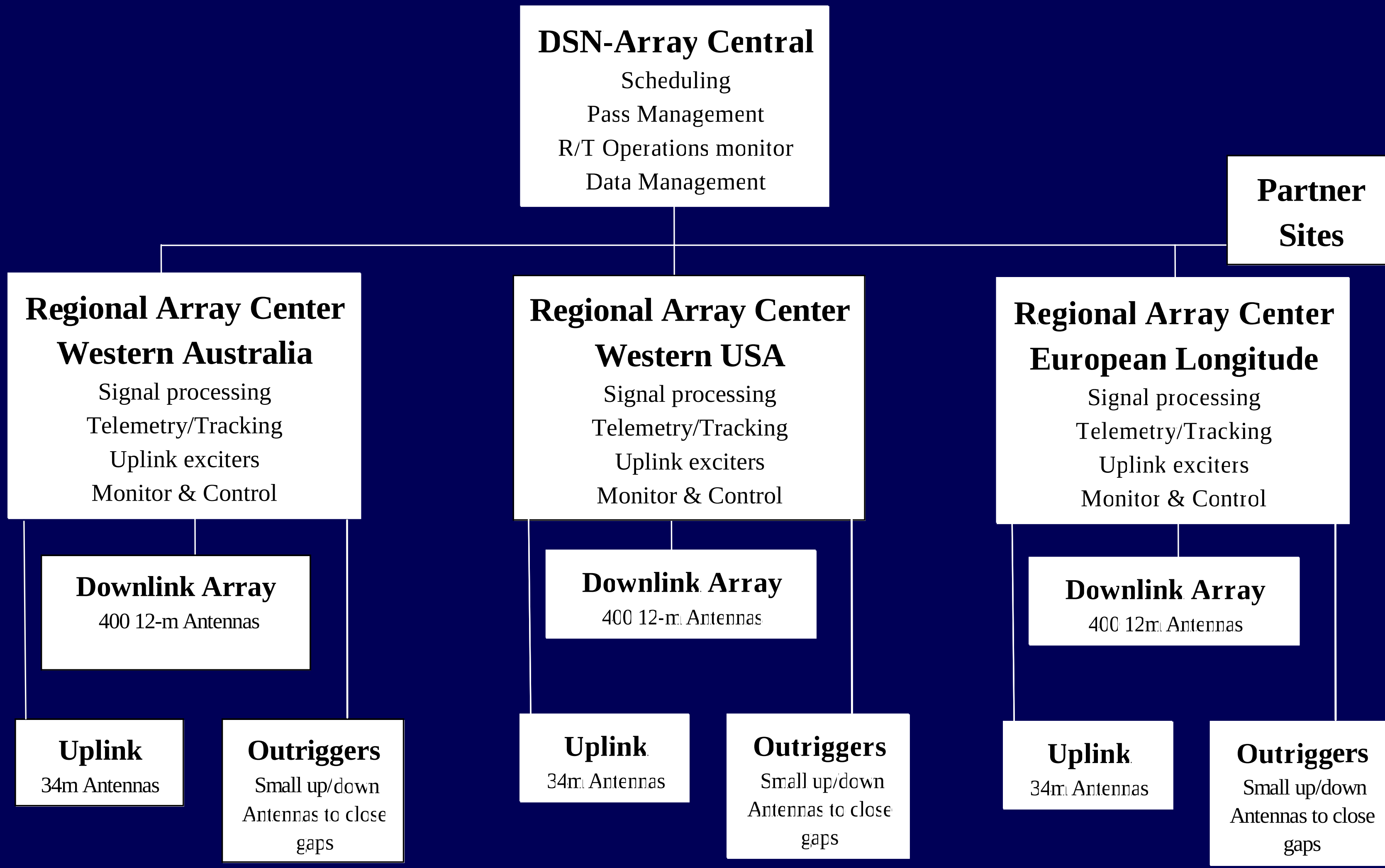
Artist's Concept of the Deep Space Network Array at the Mojave site

Goldstone, California





Array architecture



Operations Concept

AUTOMATION AND STAFFING

- Will not be operated as a "lights-out" network. The complexity of space operations, and the uniqueness of each mission would not make such a capability cost-effective.
- Will maximize schedule-driven operations, and minimize human-in-the-loop intervention.
- Real-time Operations at DSN Array Central
  - staffed by 5 24x7 operators.
  - monitor the schedule-driven operations and correct exceptions
  - Monitor real-time performance of the schedule driven operation and intervene if needed
  - Customer responsible for correct input via Mission Parameter Files (MPF)
  - The Regional Array Centers will optionally have 24x7 rovers for light repairs and security

Operations Concept - continued

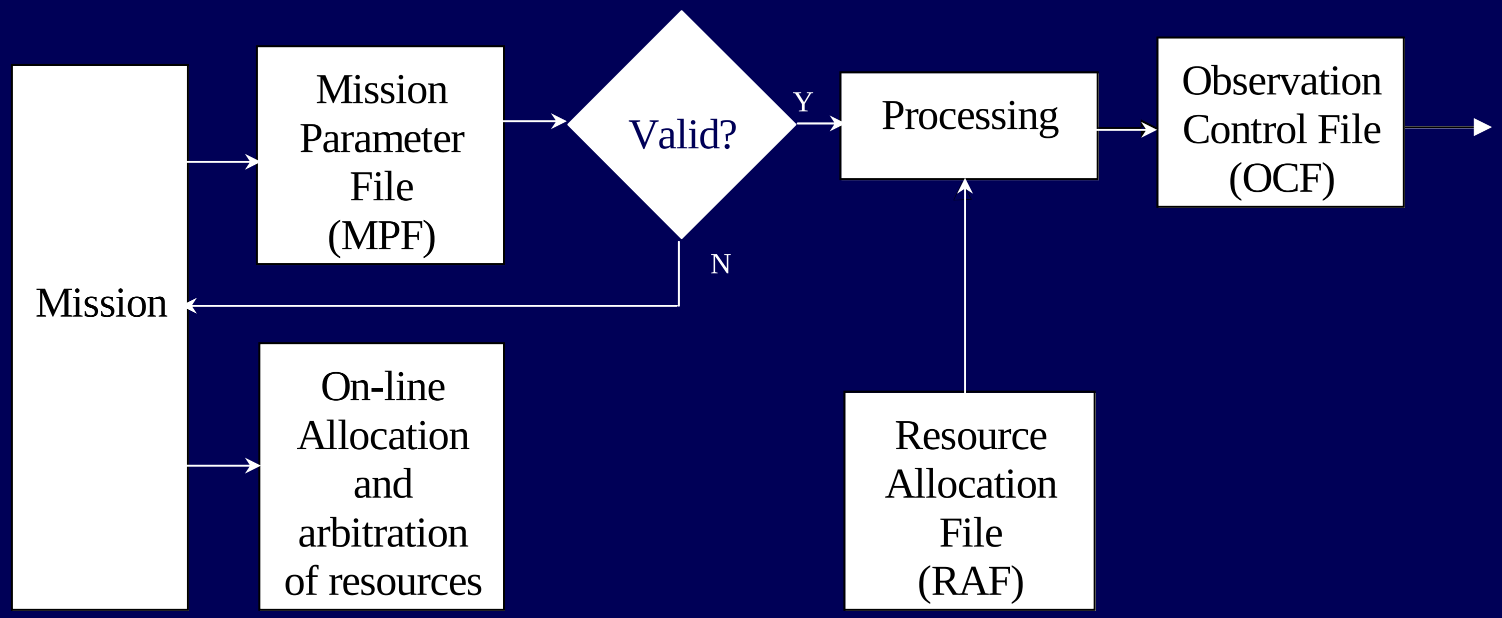
AUTOMATION AND STAFFING

- Non Real-time Operations at DSN Array Central
  - staffed by approximately 40 FTE 8x5 positions.
  - maintain customer interfaces, handle the logistics, and perform analysis, as needed
- Maintenance Operations
  - 50 8x5 full time equivalent (FTE) staff for each longitude (total of 150)
  - perform all maintenance on 1200 12m antennas, the uplink antennas, and the other equipment.
  - These staff will handle the logistics, and perform the first level of failure analysis and corrective actions.

Examples of Non Real-Time Operations

- Priority & Array Time Allocation – Software(SW)/Script driven, with overrides by the 24x7 staff
- Resource allocation and scheduling - SW/Script driven, with overrides by the 24x7 staff
- Validation of customer provided MPFs - SW/Script driven, with instant feedback to the customer
- Generation of observation control files (OCFs) - SW/Script driven
- Addition of pre-pass and post-pass calibrations to OCFs, if required - SW/Script driven, with overrides by the 24x7 staff
- Instrument calibrations and routine test observations (passes) – 8x5 staff
- Maintenance of calibration catalogs and tables – 8x5 staff, with support of SW/Scripts
- Maintenance planning – 8x5 staff, with support of SW/Scripts
- Data calibration – 8x5 staff, with support of SW/Scripts
- Data quality analysis – 8x5 staff, with support of SW/Scripts and engineering staff

Resource Allocation and Scheduling



- RAF defines all the resources that require an allocation (antenna, comm capability, etc)
- MPF defines the pass parameters, that the mission must define.
- MPF & RAF can be produced long before the pass, or during the pass
- OCF is generated, just-in-time

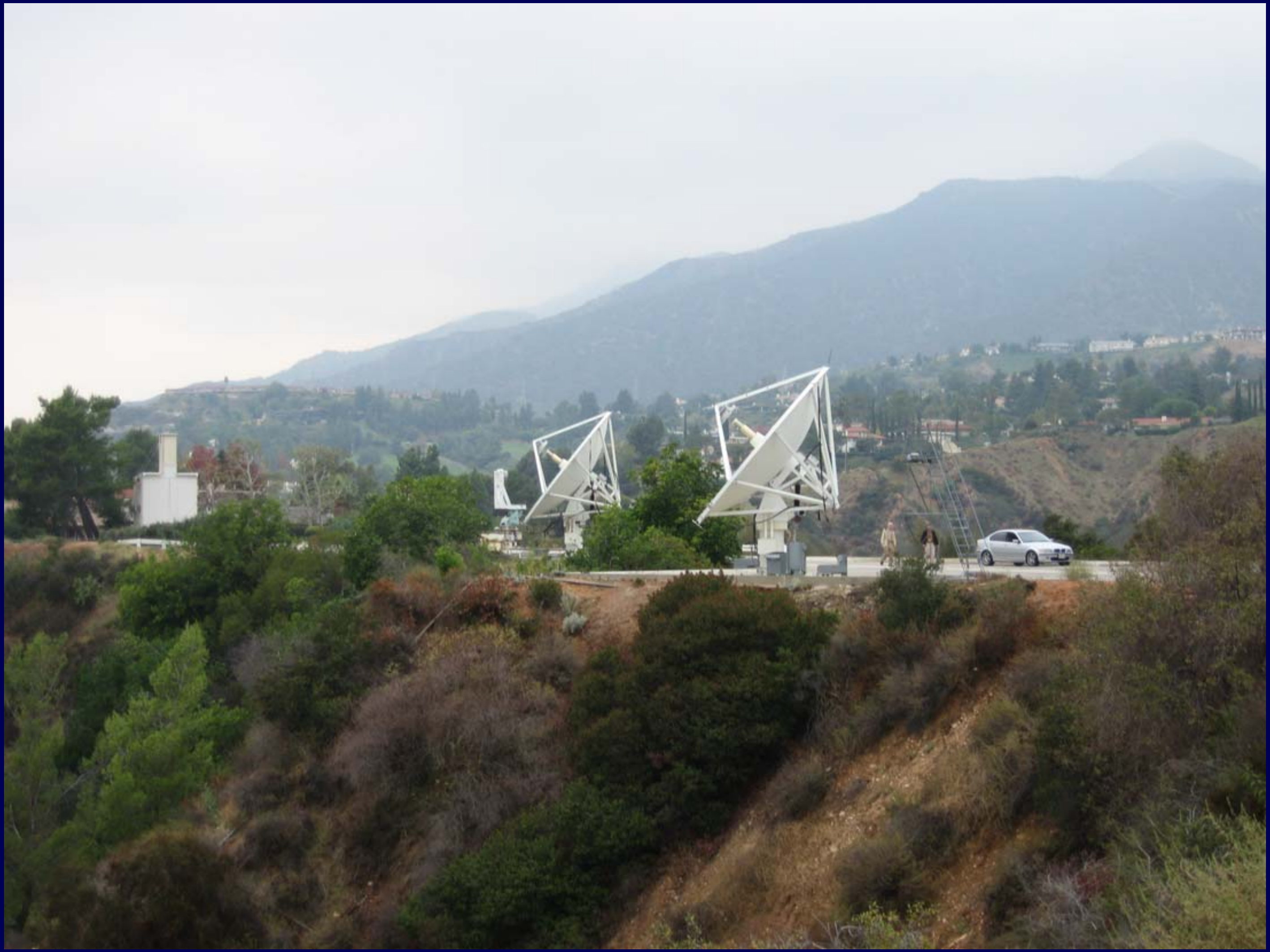
DSN Array Breadboard

- 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

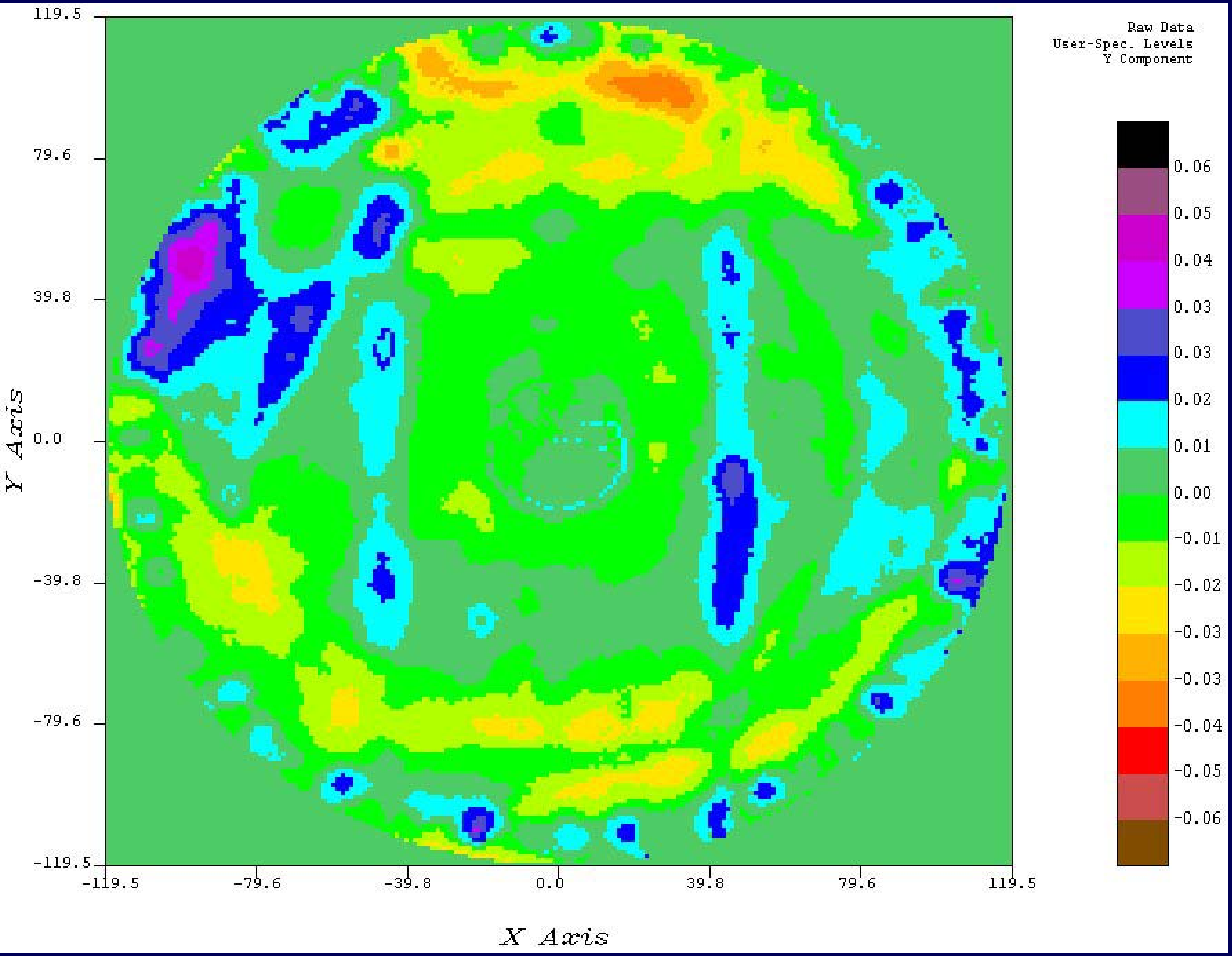
Breadboard Array Elements

- 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

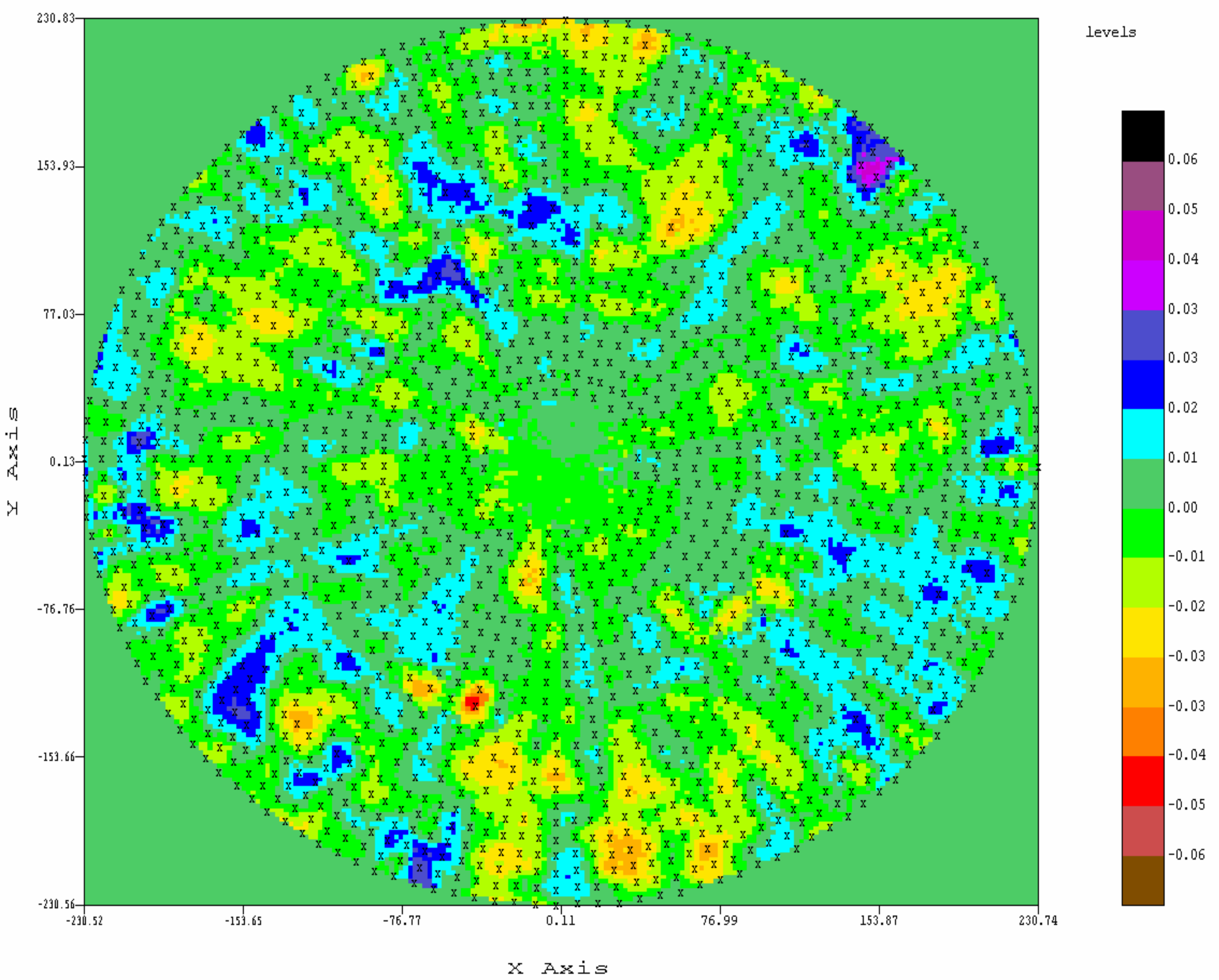
Breadboard Antennas

- 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 two 6-m and one 12-m antennas that meet these requirements.
  - Required painting of the dish surface (front and back)

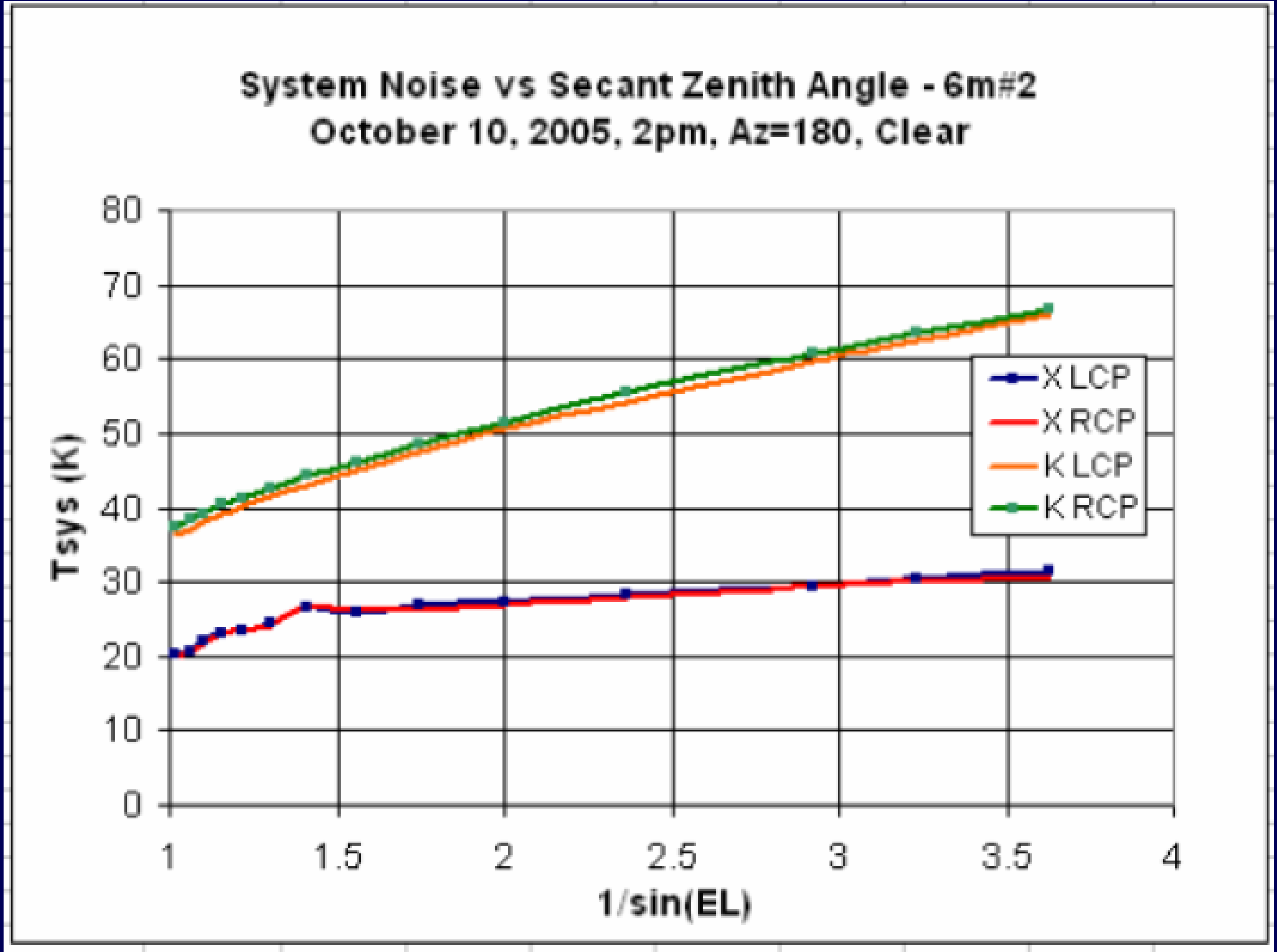
6-m DSN Array Prototype
Elevation = 45°, RMS = 0.0092”



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



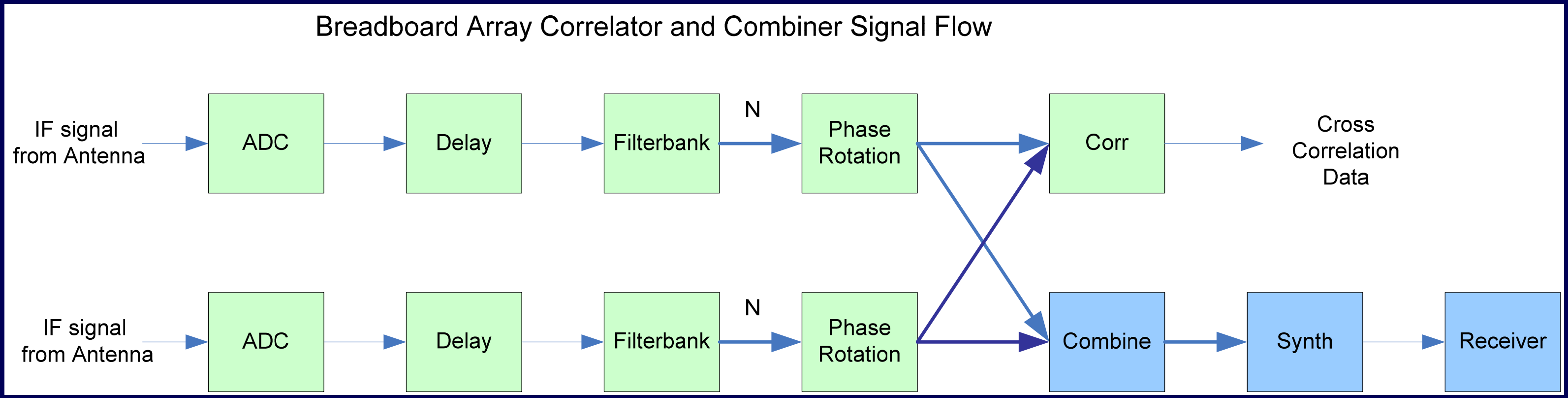
DSN Array Receive Electronics: System Noise Measurement



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.

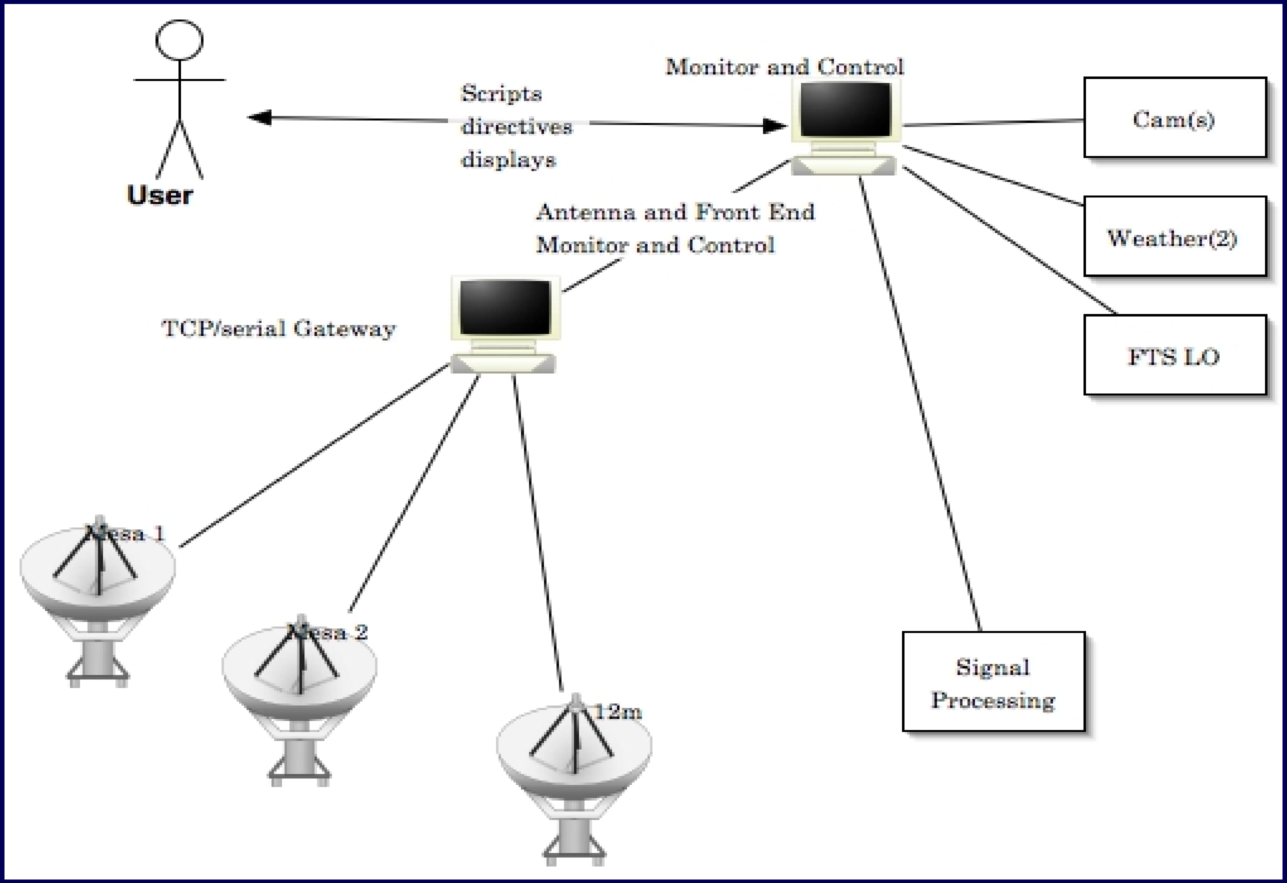
DSN Array Signal Processing: Breadboard Results Summary

- 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 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



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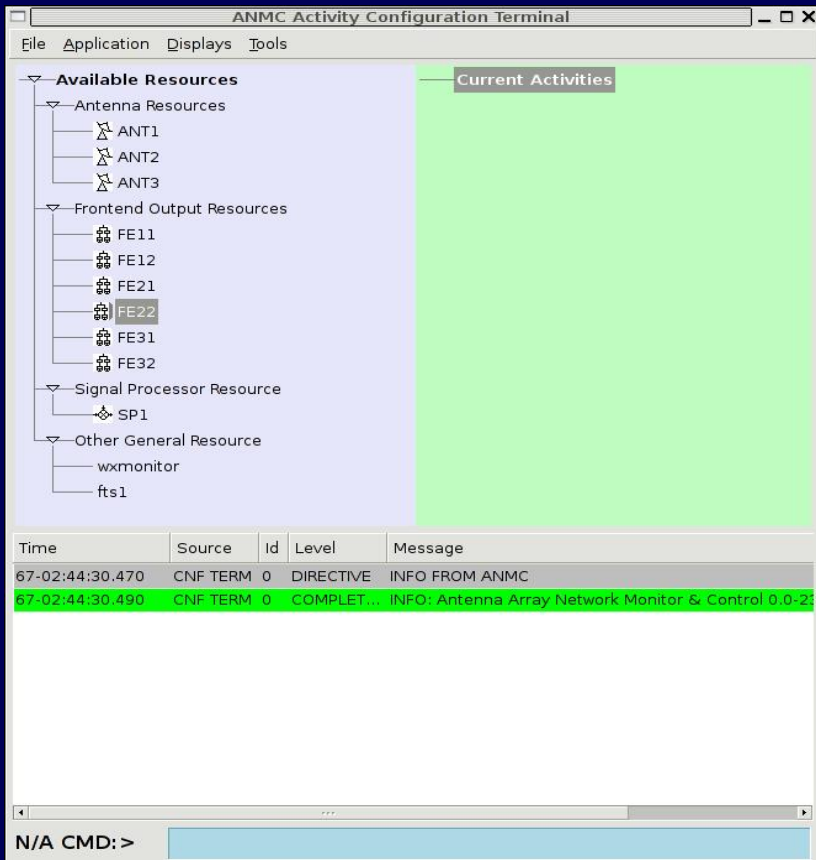
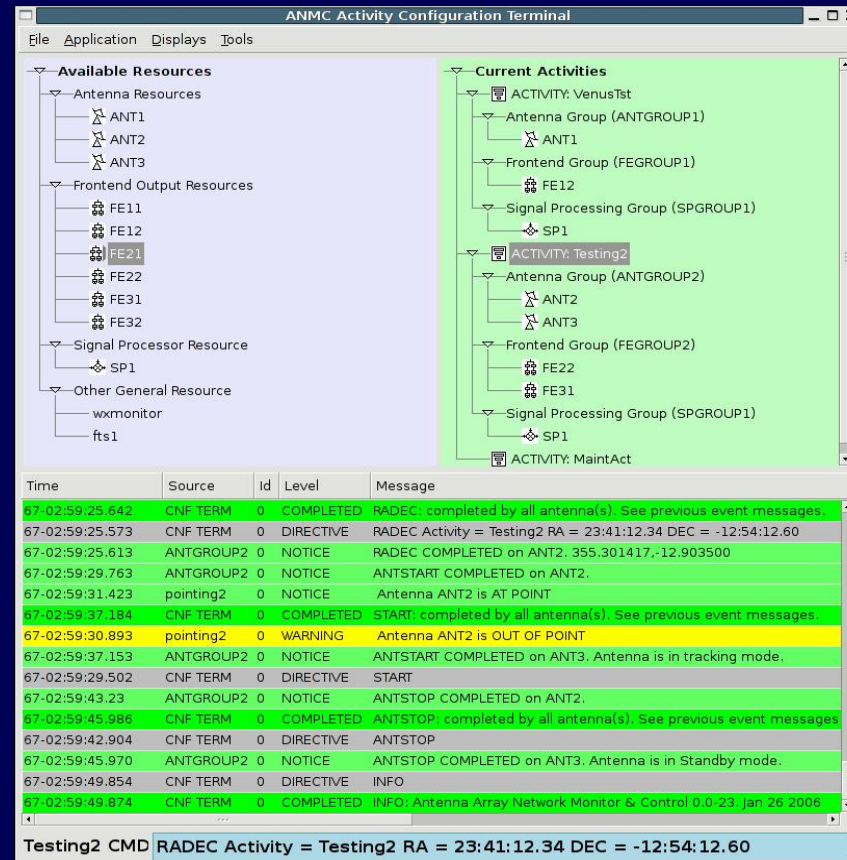
DSN Array Monitor & Control: Breadboard Configuration Interface



Preconfiguration



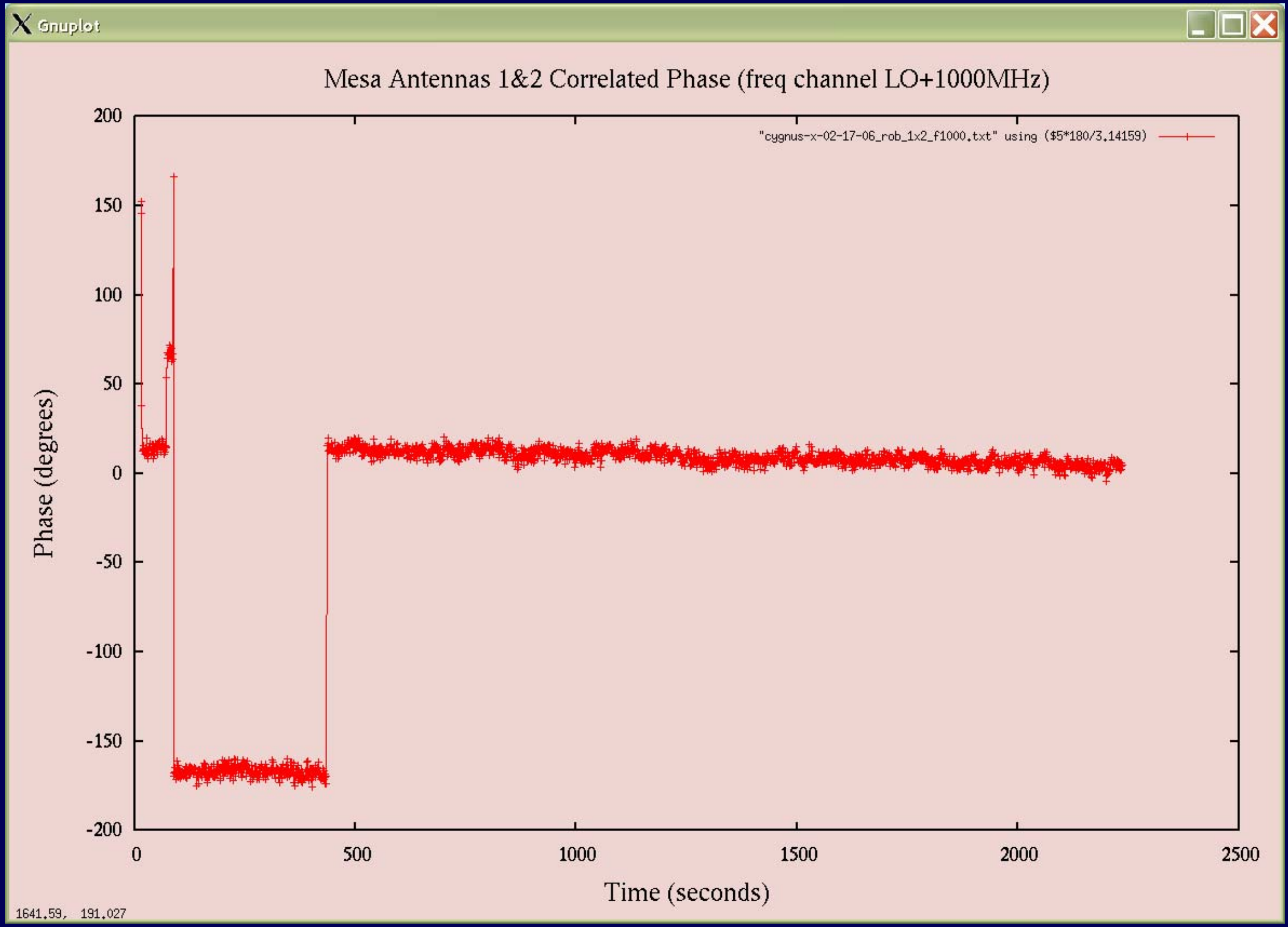
Multiple Subarray Configuration

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 both the 6-m antennas and 12-m antenna.
- 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.

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



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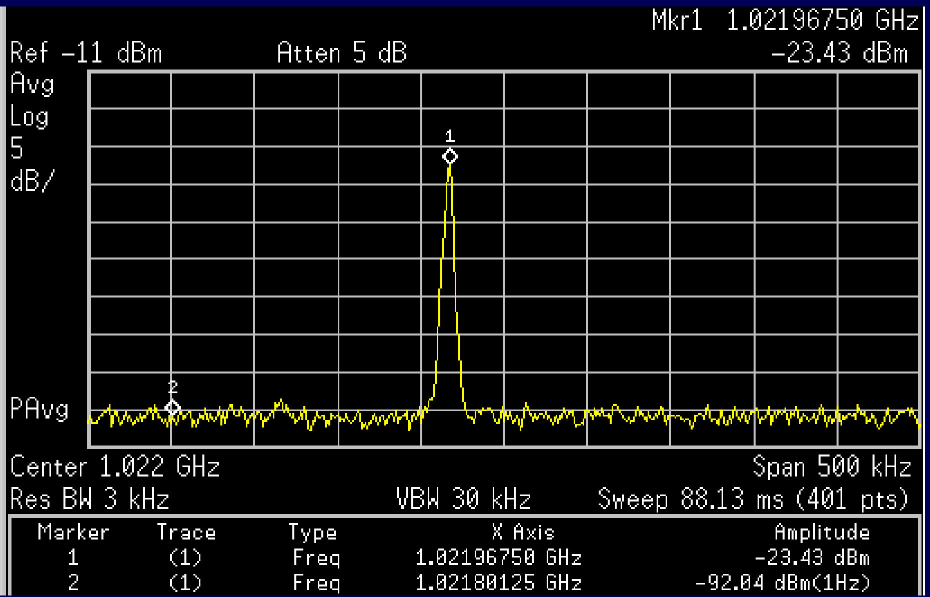
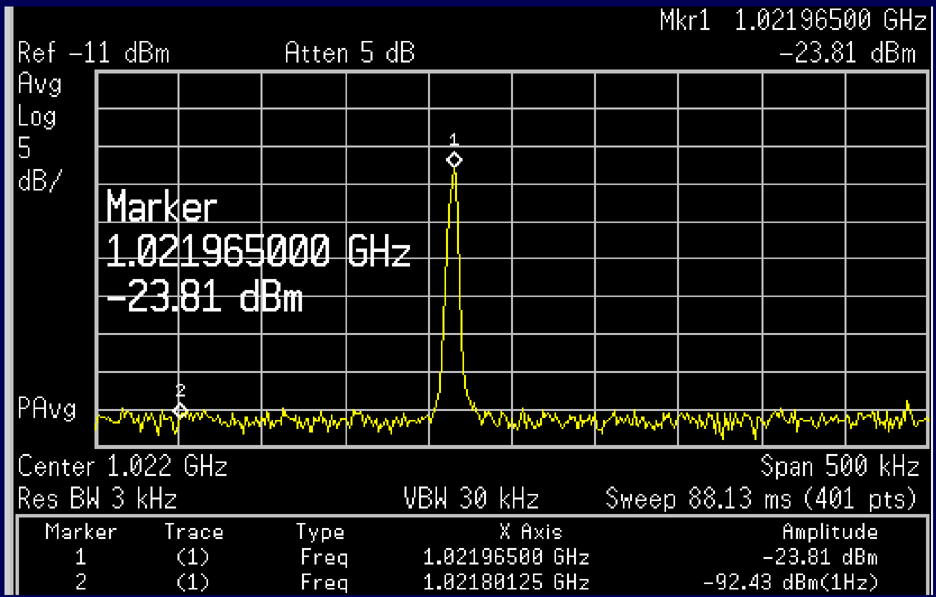
Ka Band Carrier from Mars Reconnaissance Observer (MRO) S/N of 69 dB-Hz at ~ 0.3 AU Range

Antenna 2



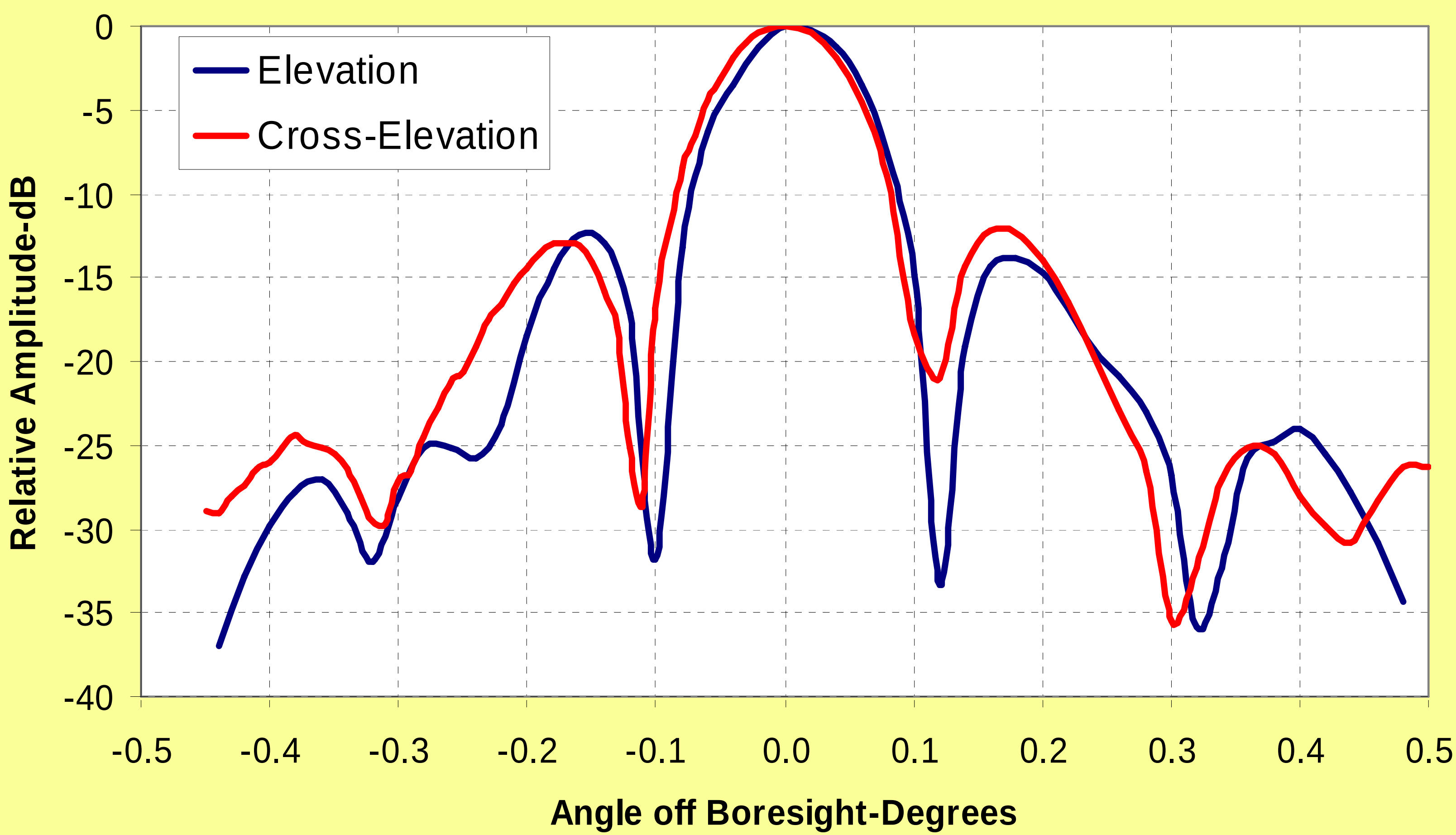
Antenna 1



- 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

- 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 possible
  - 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

Change is Required

- The "bottom line"…and the take-home message for this talk:

The current method of operating the DSN ABSOLUTELY MUST change in order to accomplish these goals.

Automation of the system is required

Changes like those proposed here have been carried out on a smaller scale by other space operations organizations (ESA in particular).