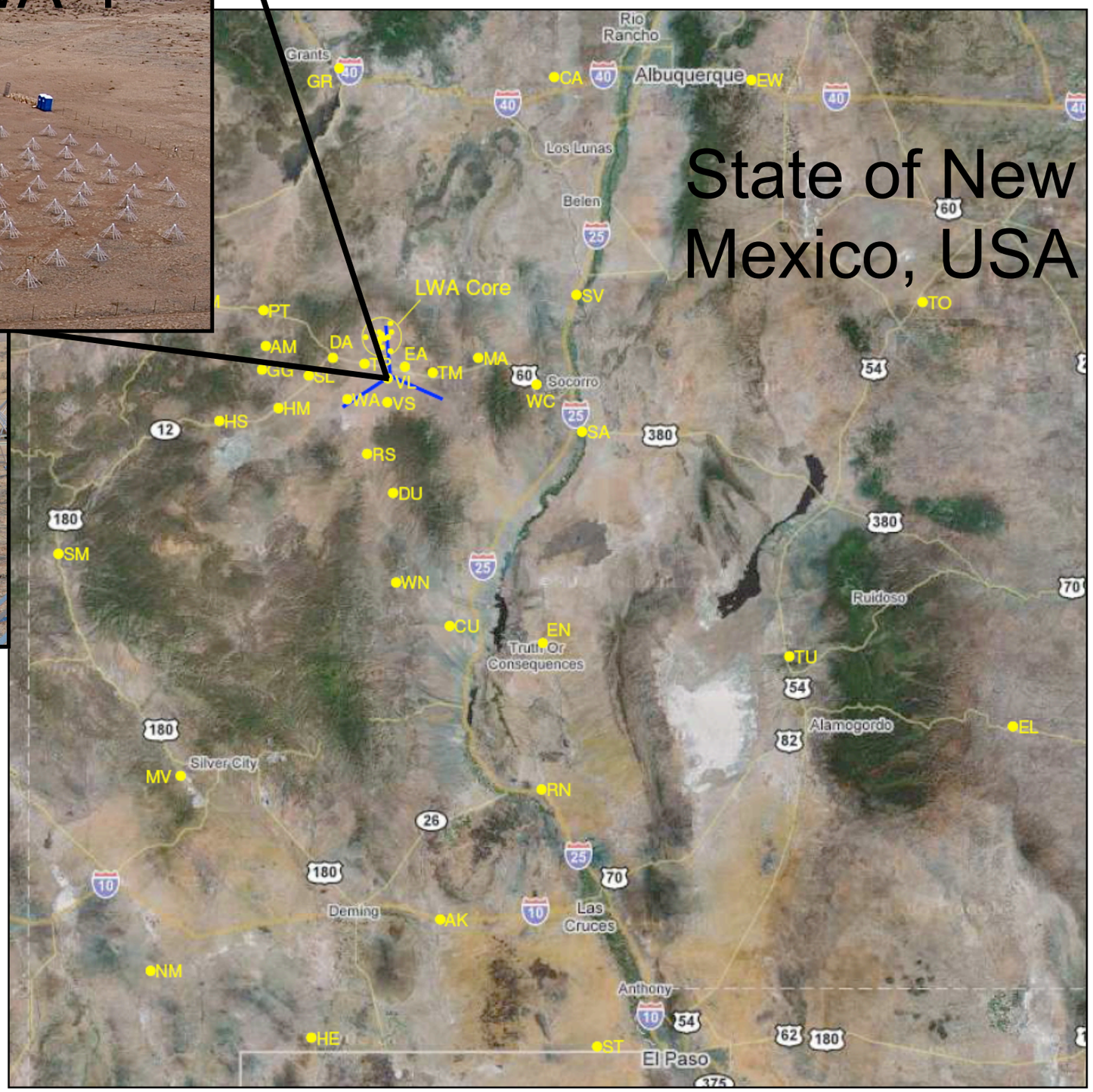
LWA1 As-Built Architecture and Status

Joe Craig - UNM

LWA Current and Future Users Meeting
May 12, 2011

The LWA Instrument

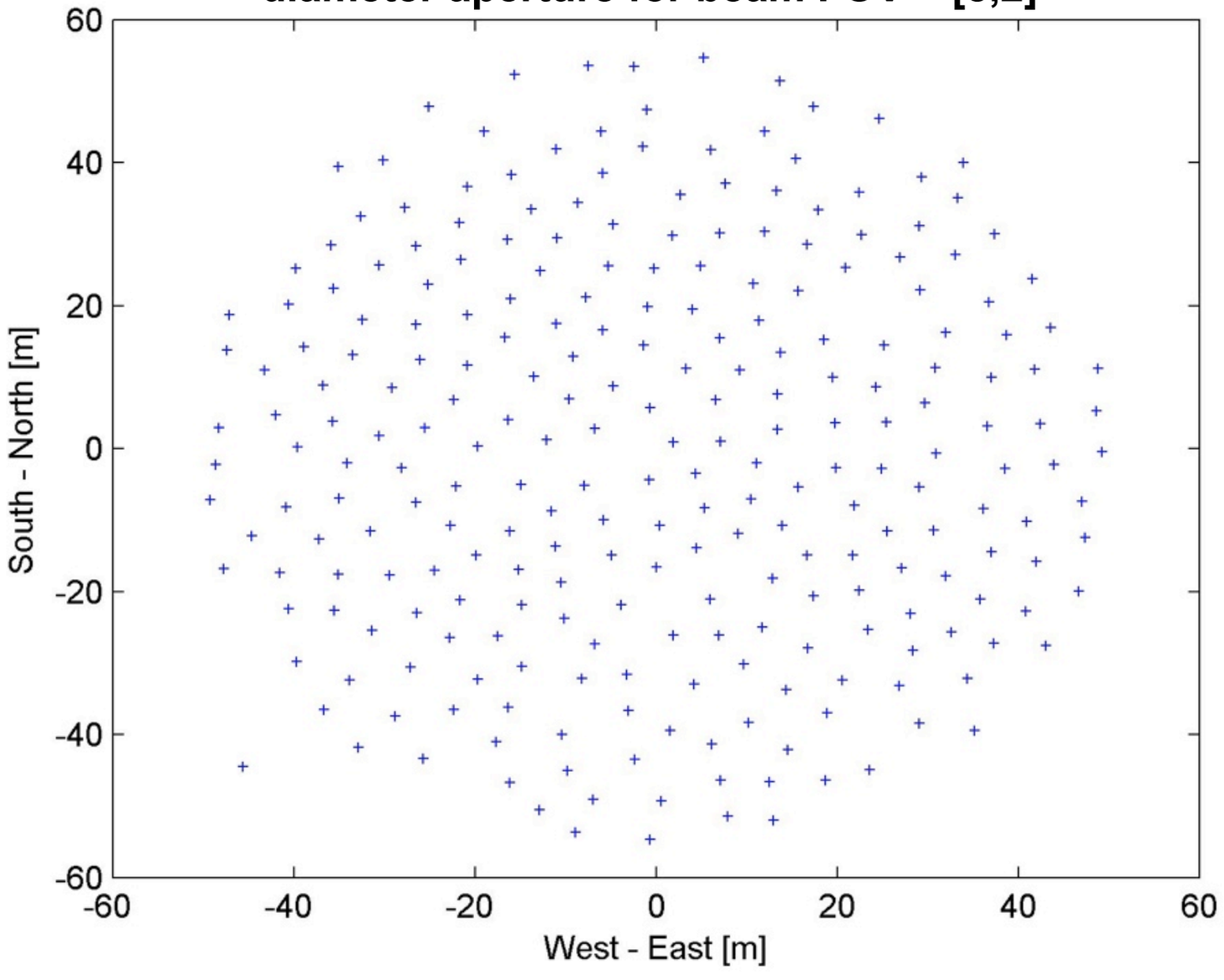
- **Frequency Range: 10-88 MHz**
- **4 beams x 2 pol. x 2 tunings x 17 MHz**
- **2 all-sky transient obs. modes**



- **First station ("LWA-1") construction completed, Commissioning started, Initial Operating Capabilities (IOC) Summer 2011**
- **Ultimately, 53 stations with baselines up to 400 km for resolution [8,2]" @ [20,80] MHz with mJy-class sensitivity**

LWA-1 Antenna Array

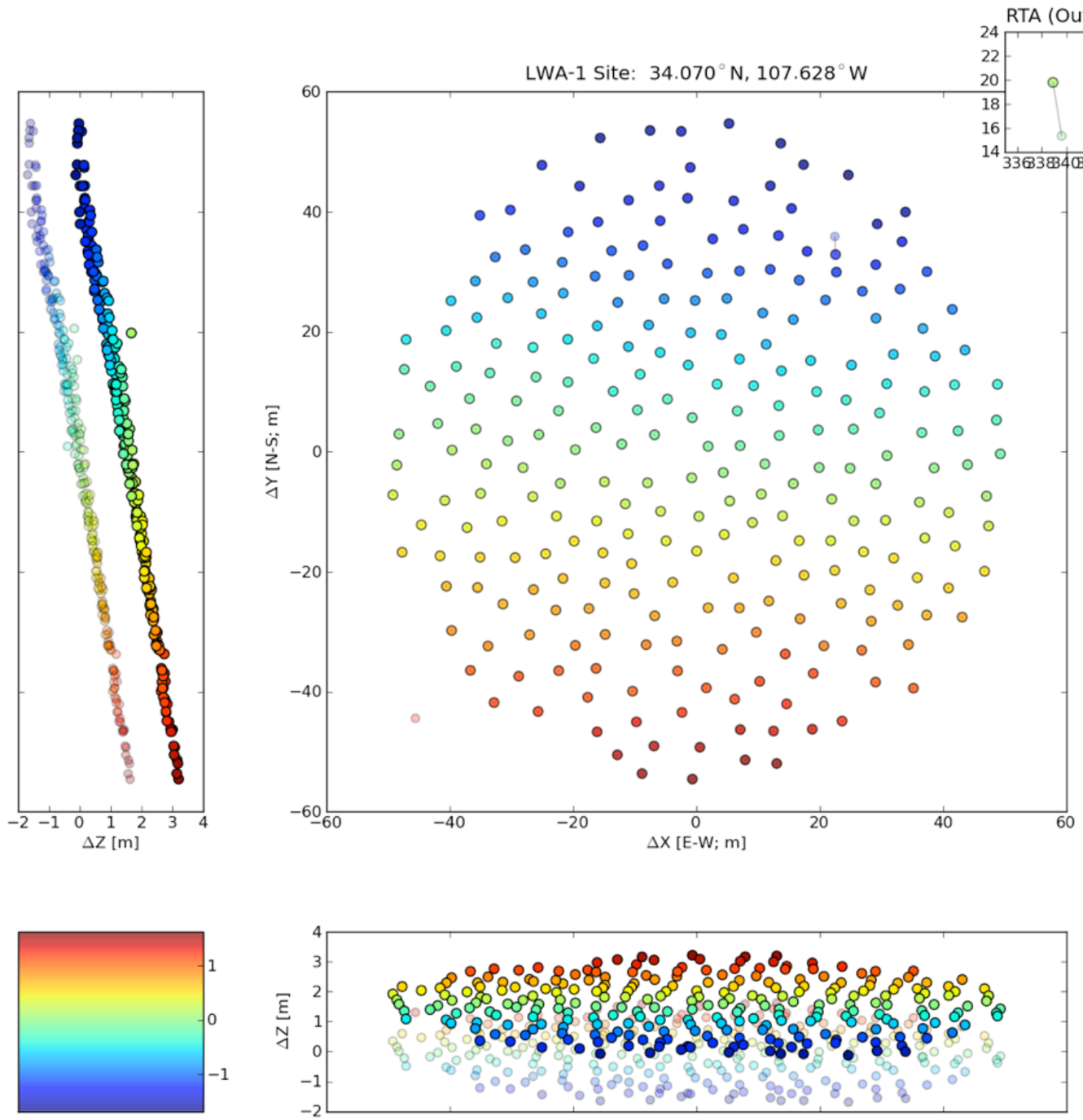
Arrays of dipole antennas in ~100 m diameter aperture for beam FOV = [8,2]°



- **Every element is digitized to allow independent pointing of beams and all-sky snapshot imaging**
- **256 dual-pol antennas results in spacings 3 x Nyquist at 80 MHz; Irregular spacings mitigate against aliasing**
- **Minimum separation 5 m for maintainability and also to reduce beam desensitization due to sky noise correlation**

- **4 simultaneous beams, each capable of repointing in < 10 msec**
- **A beam can cycle thru ~100 sources in less that 7 sec (ionospheric stability) with 50 msec integration on each source (calibration beam)**

As-Built Stand Locations

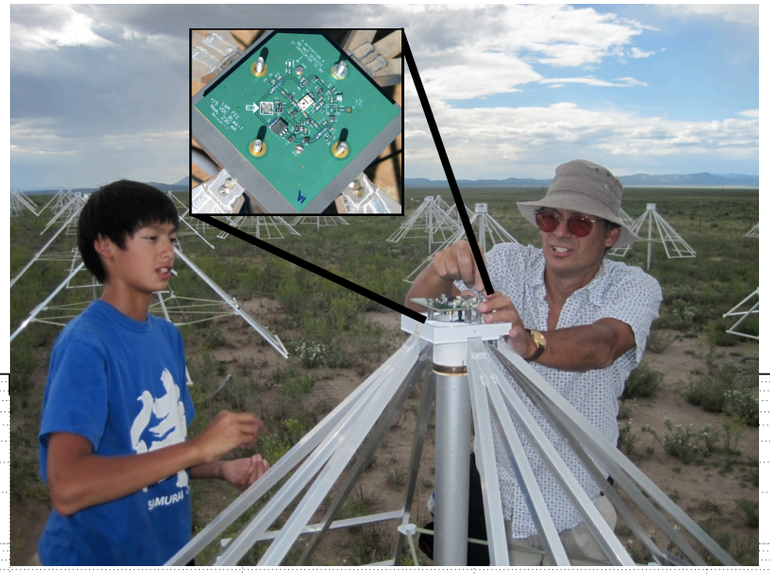


- **Requirement: 10 mm; corresponds to 1° of phase at 88 MHz.**
- **Initial measurements yielded ±20 mm**
- **Final measurement position accuracy of ±6.1 mm, relative to array center.**

Measurements made by New Mexico Tech/MRO's mechanical engineering team

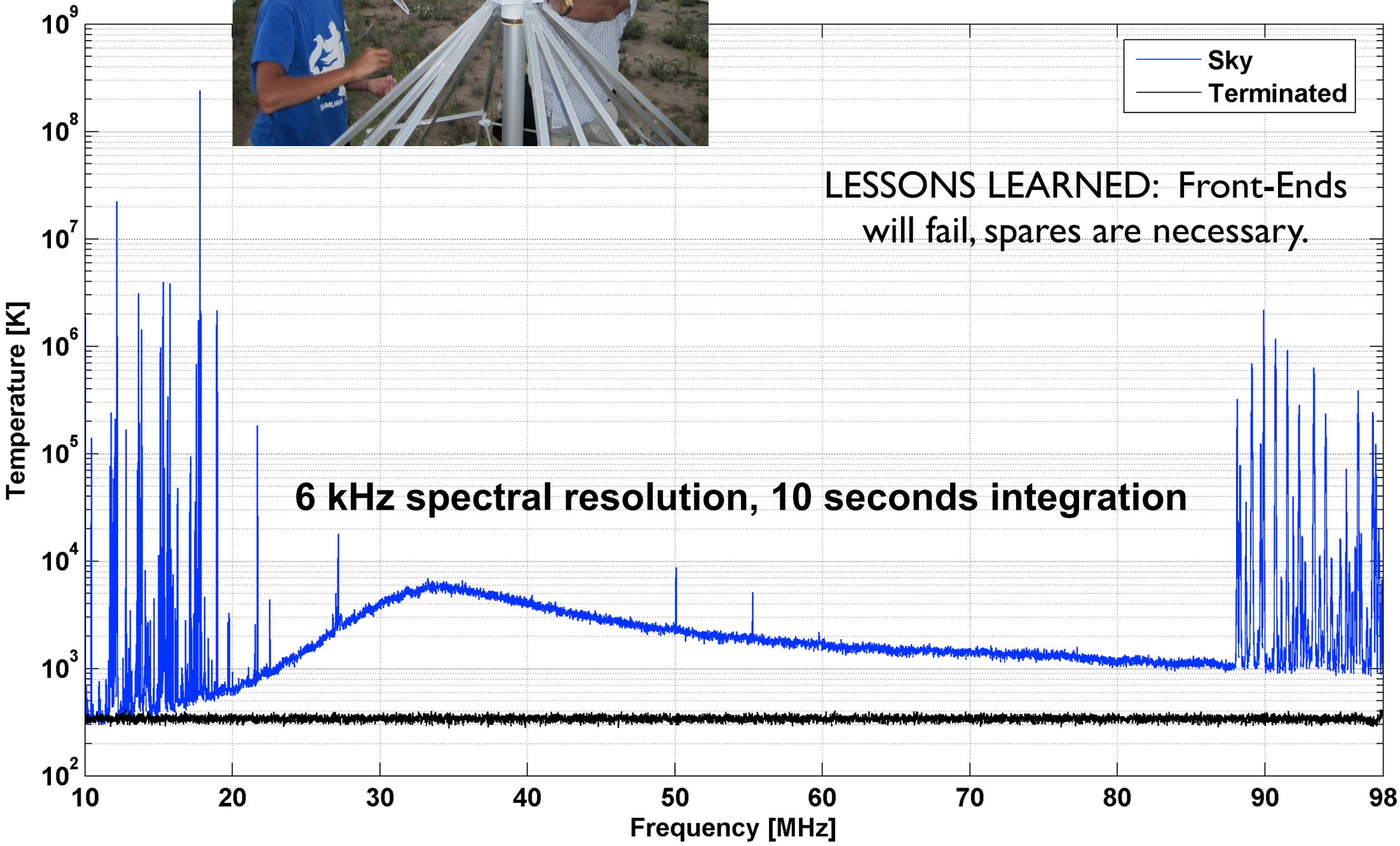
LESSONS LEARNED: As-built surveyed location accuracy is a function of personnel and equipment.

Active Antenna Temperature



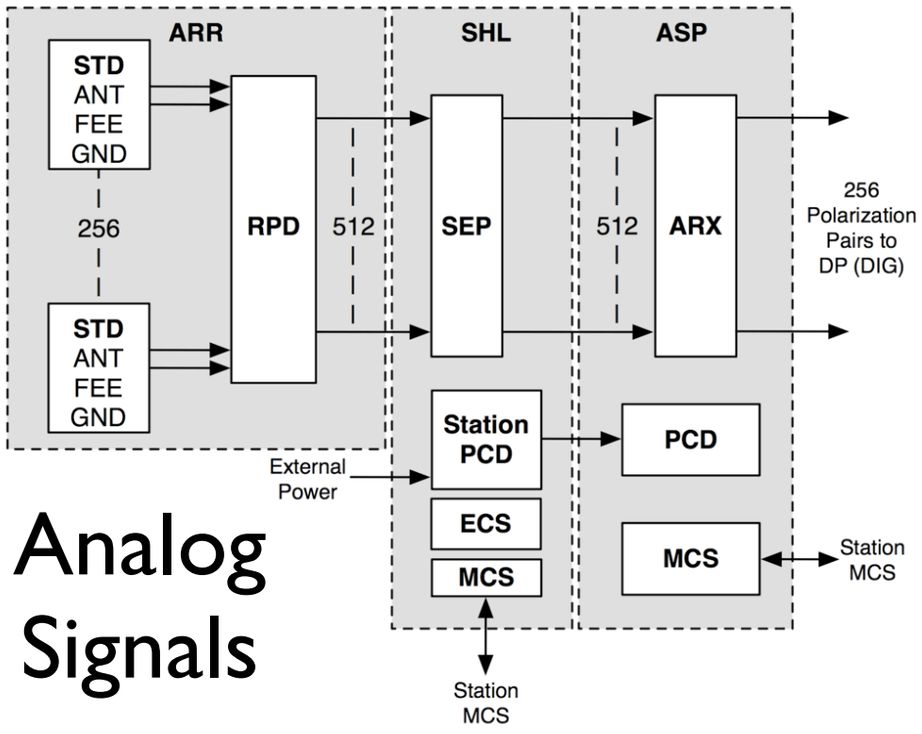
Active Antenna (ANT + FEE)

- **36 dB Gain**
- **2.7 dB Noise Figure**
- **Galactic Noise Dominated over 20-80 MHz**

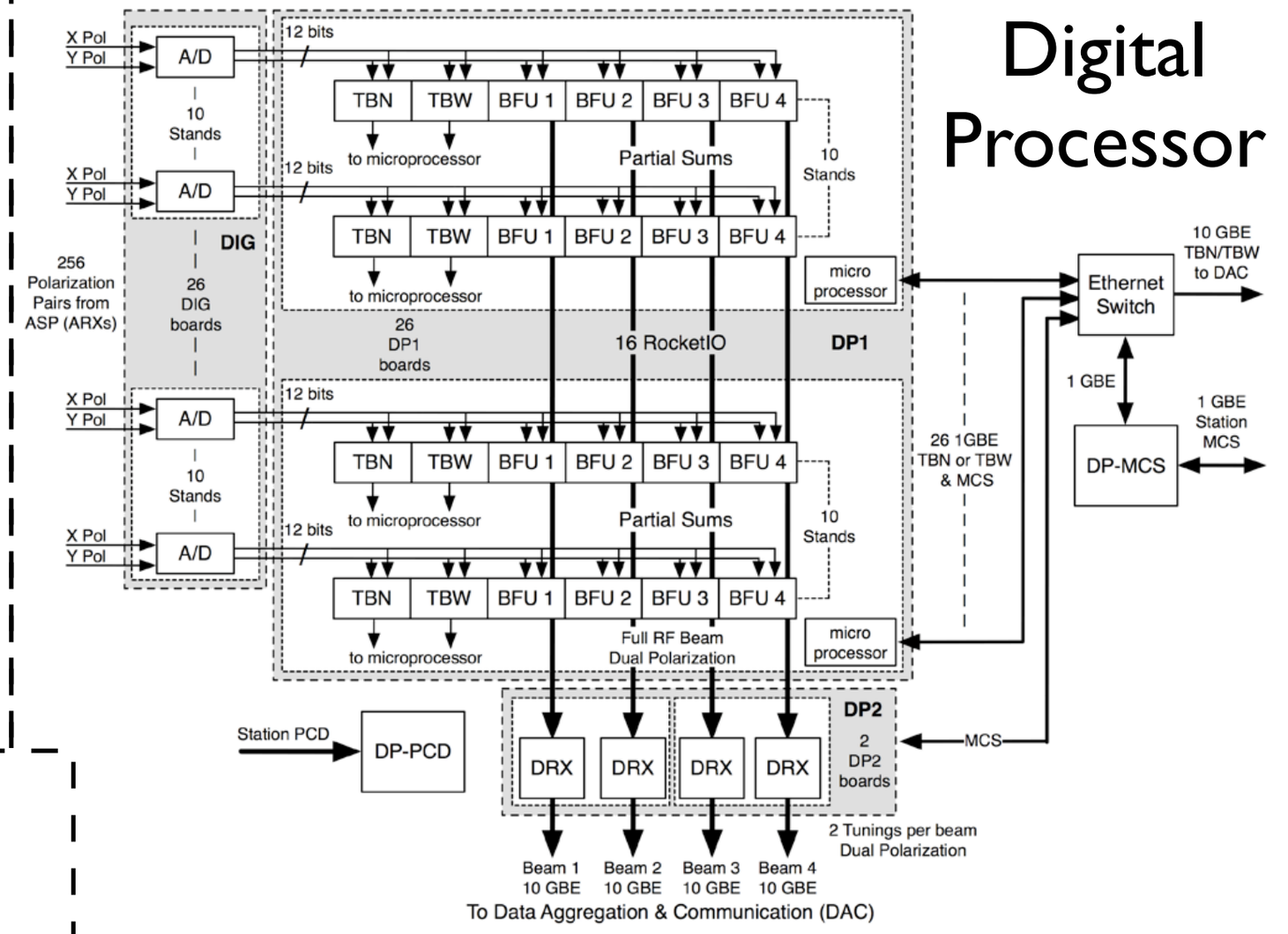


Station Architecture

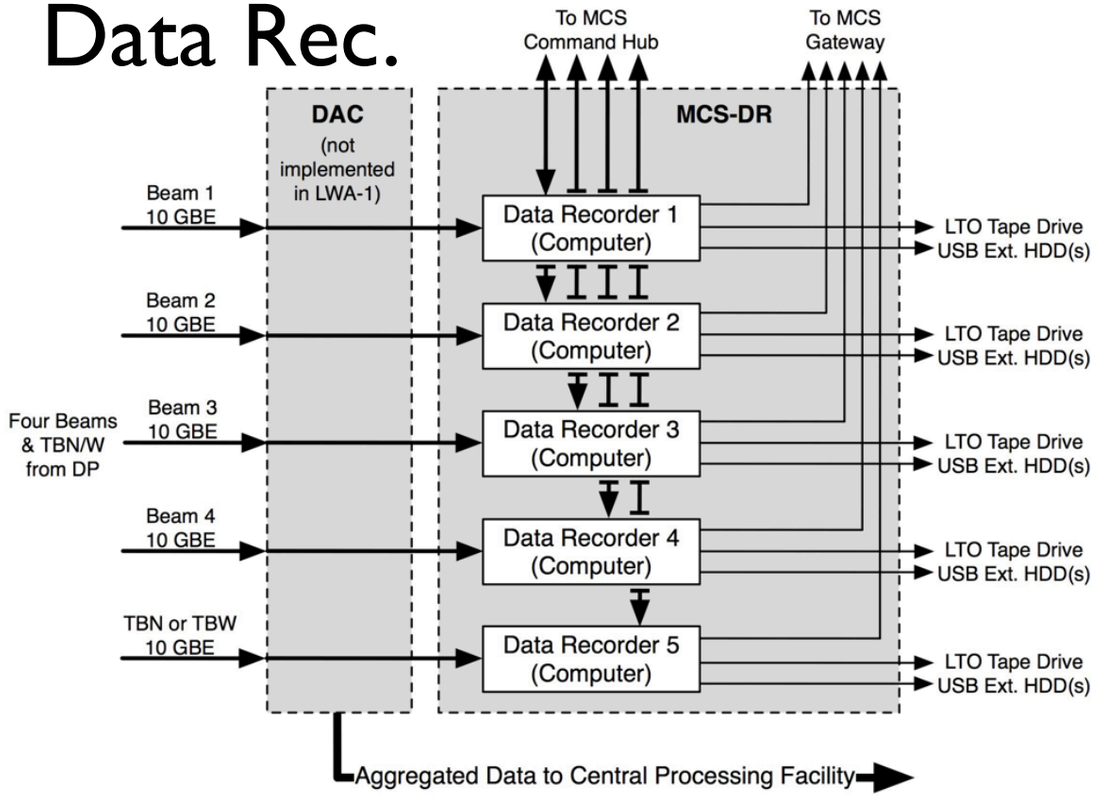
Analog Signals



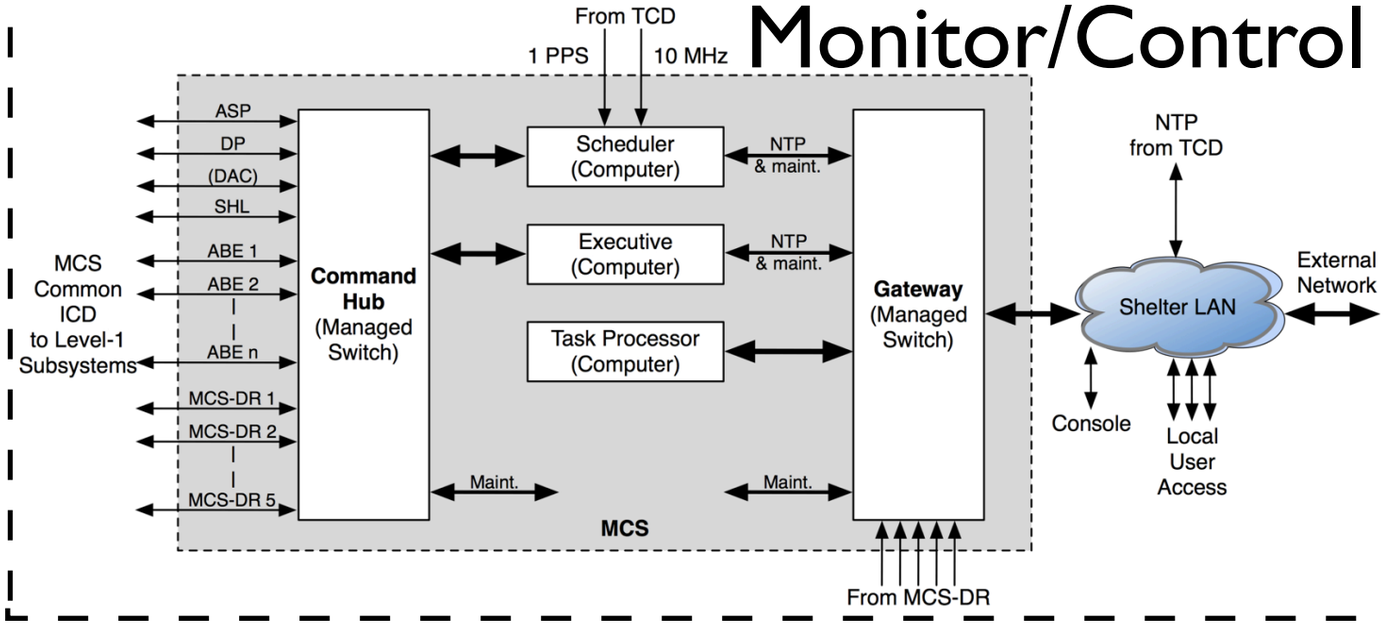
Digital Processor



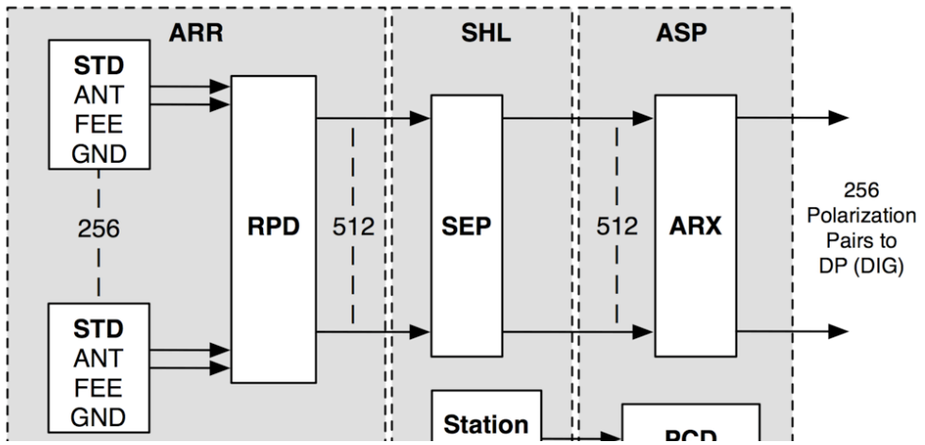
Data Rec.

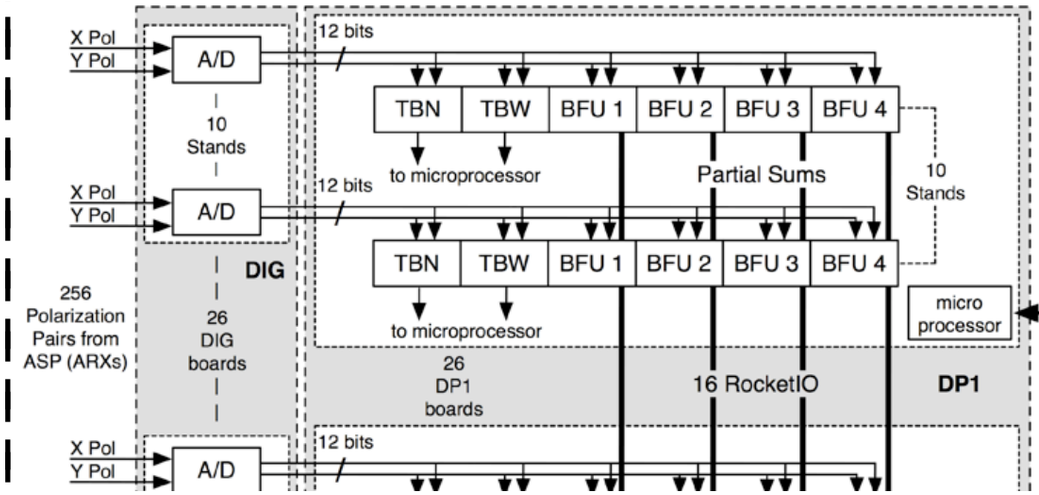


Monitor/Control

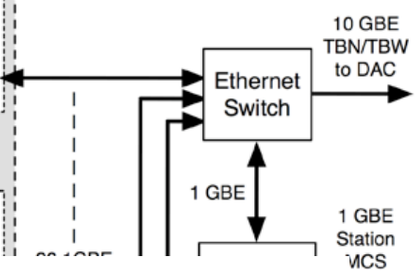


Station Architecture





Digital Processor

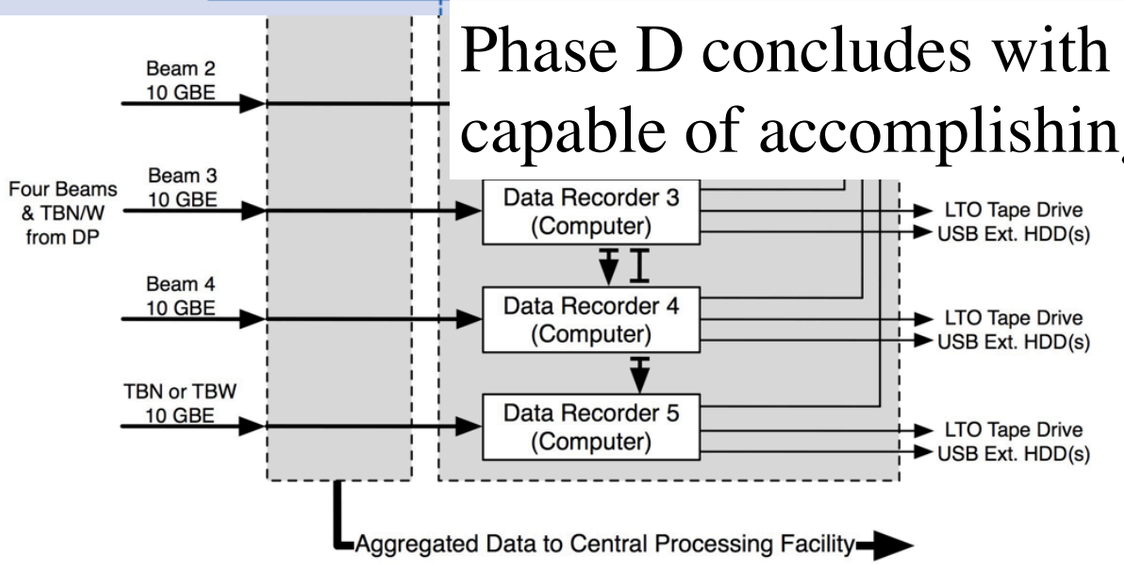


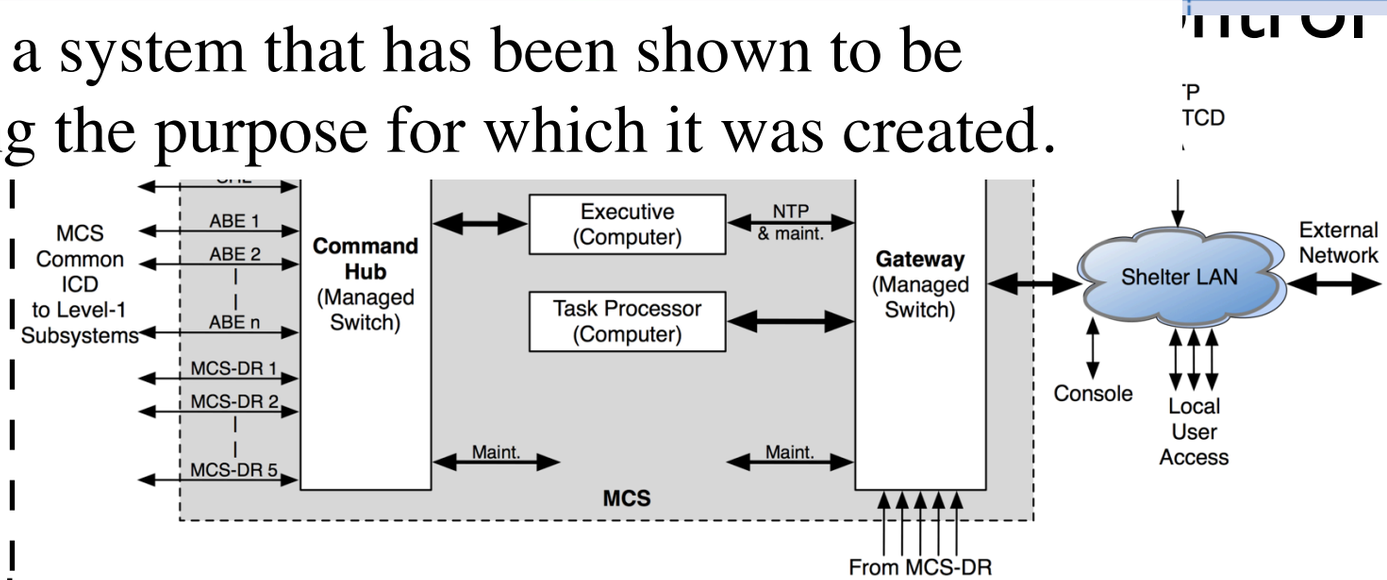
All Subsystems Installed

Now Performing System Verification

Project Life-Cycle Phases	Pre-Phase A: Concept Studies	Phase A: Concept & Technology Development	Phase B: Preliminary Design & Technology Completion	Phase C: Final Design & Fabrication	Phase D: System Assembly, Integration & Test, Launch	Phase E: Operations & Sustainment	Phase F: Closeout

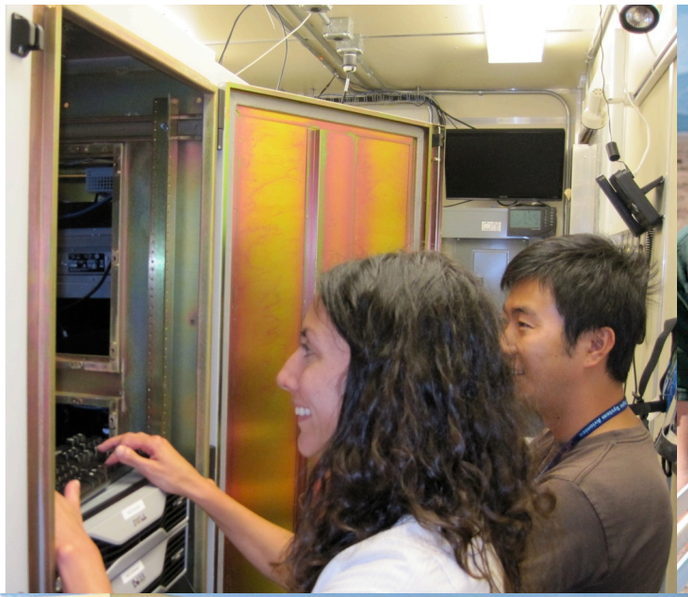
Phase D concludes with a system that has been shown to be capable of accomplishing the purpose for which it was created.

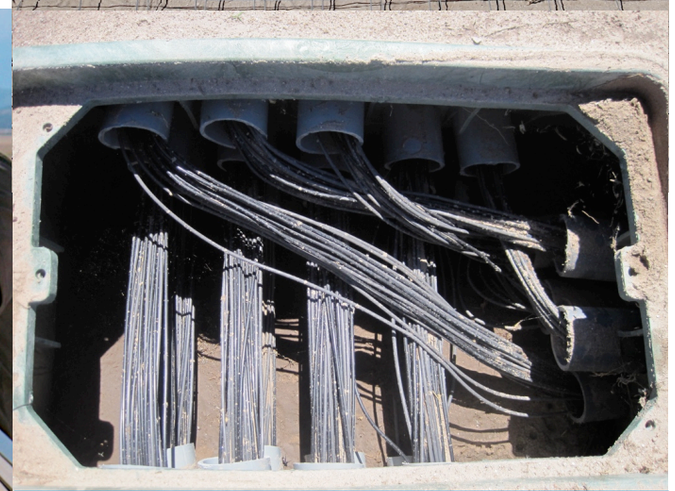


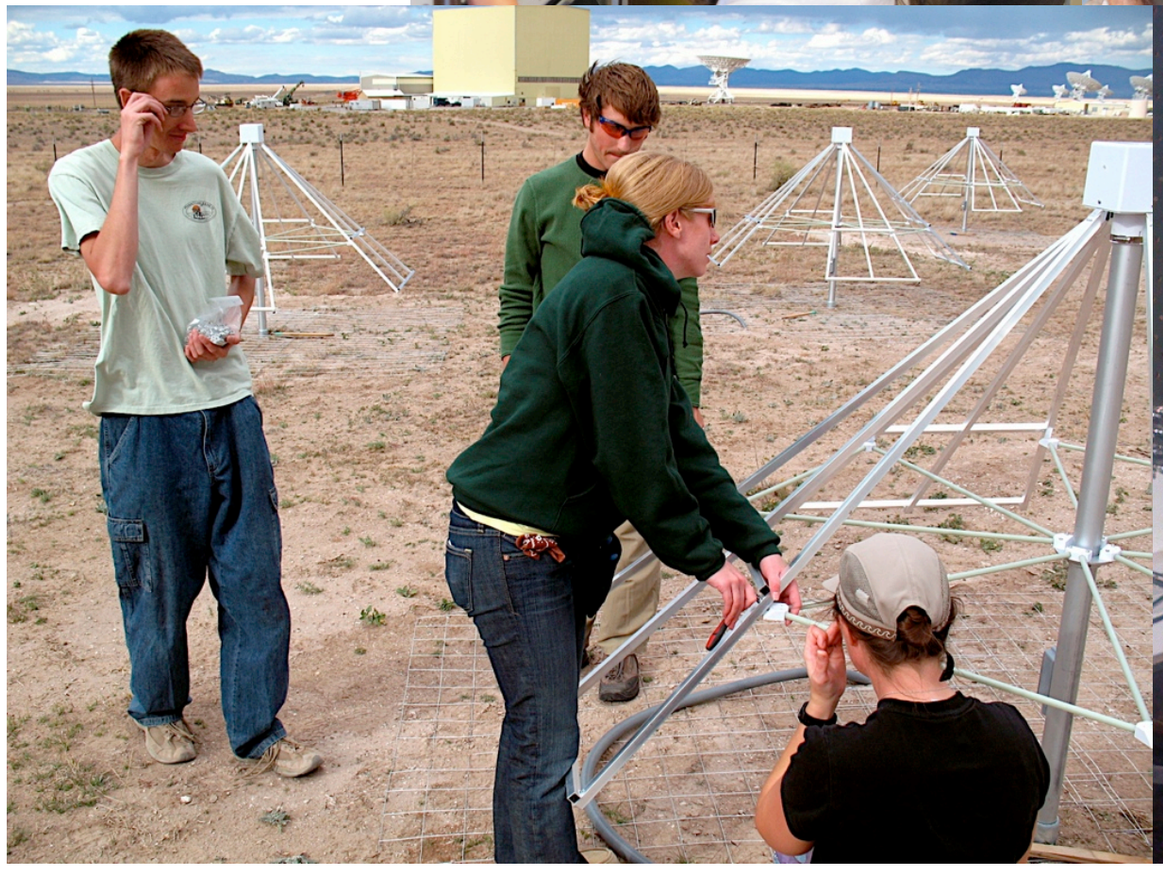


Building LWA-1

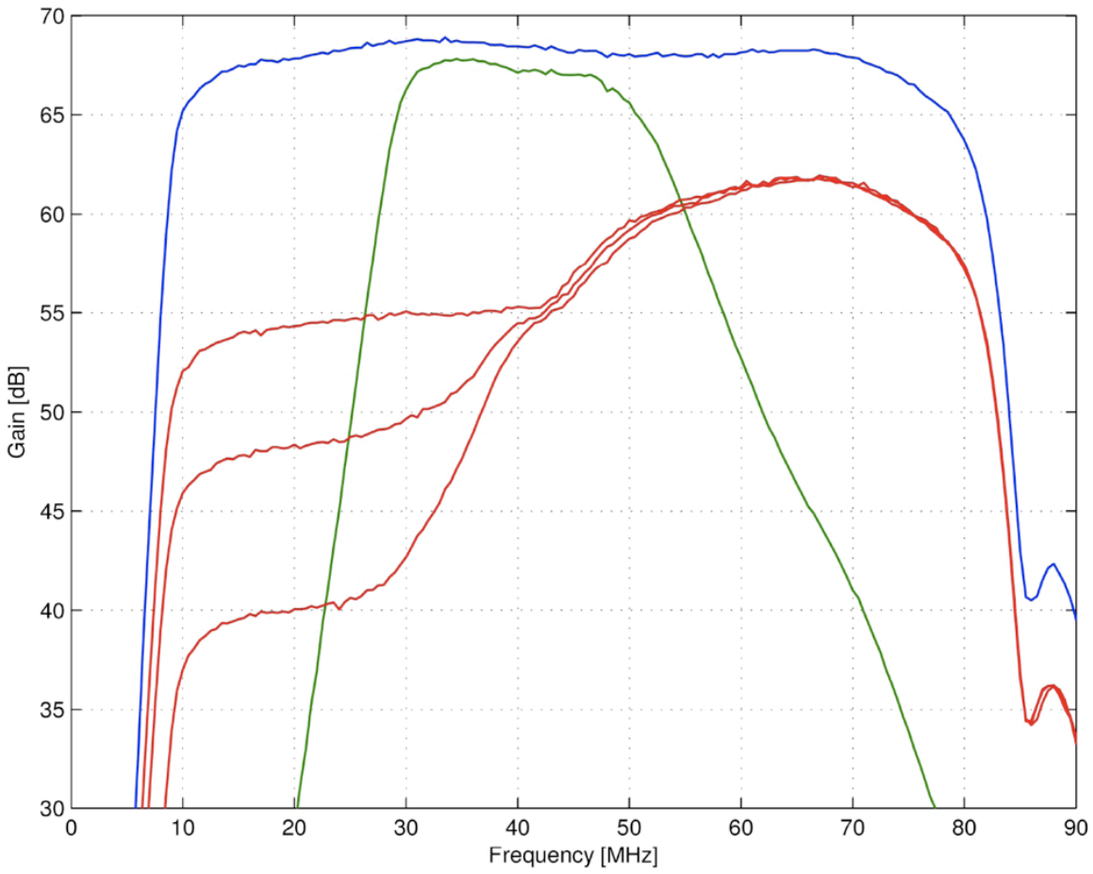
- **Site/Power/Coms/Shelter**
- **Trenching & Conduit for Cabling**
- **Antenna Installation**
- **Cable Installation**
- **Receivers, Digital Processor, Data Recorders, Electronics**





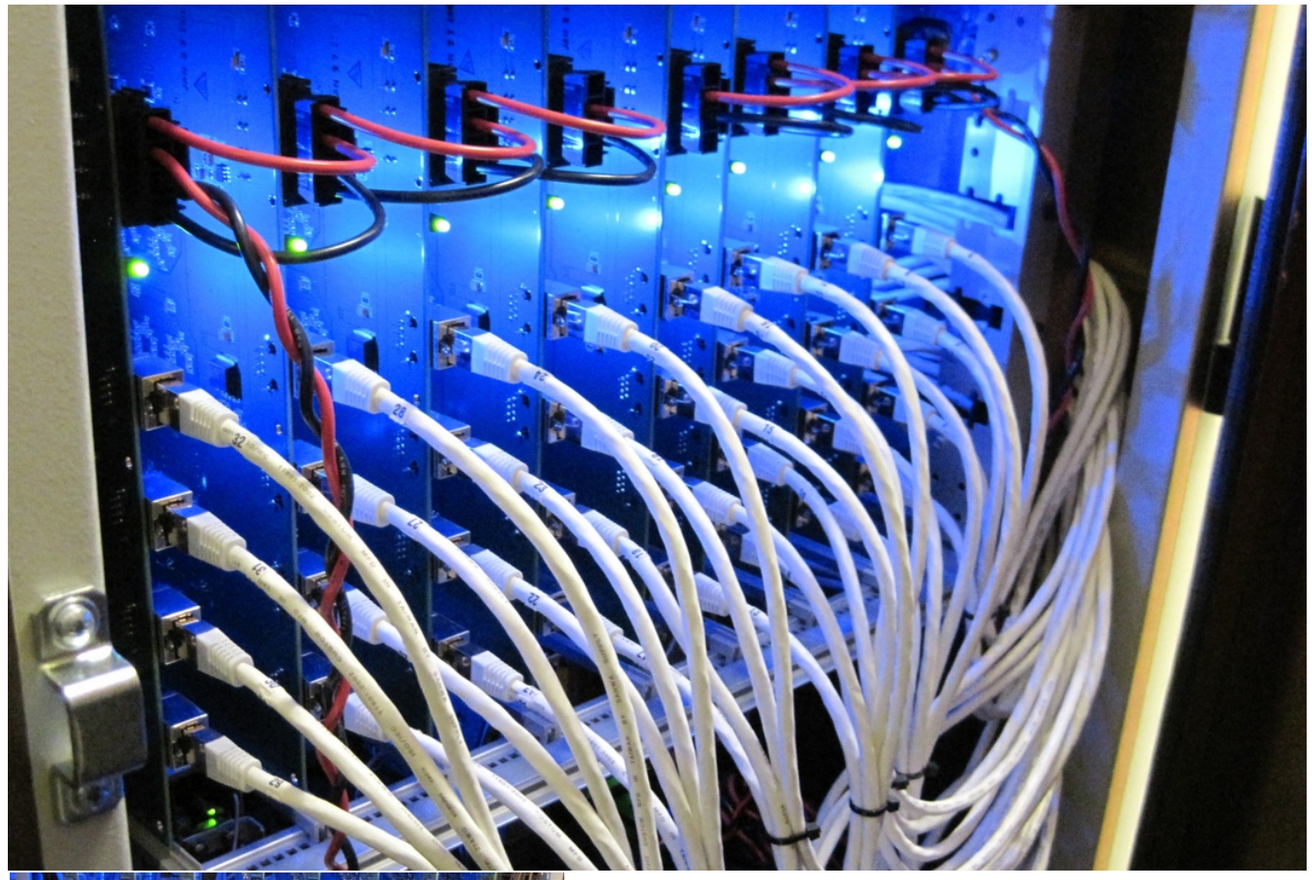


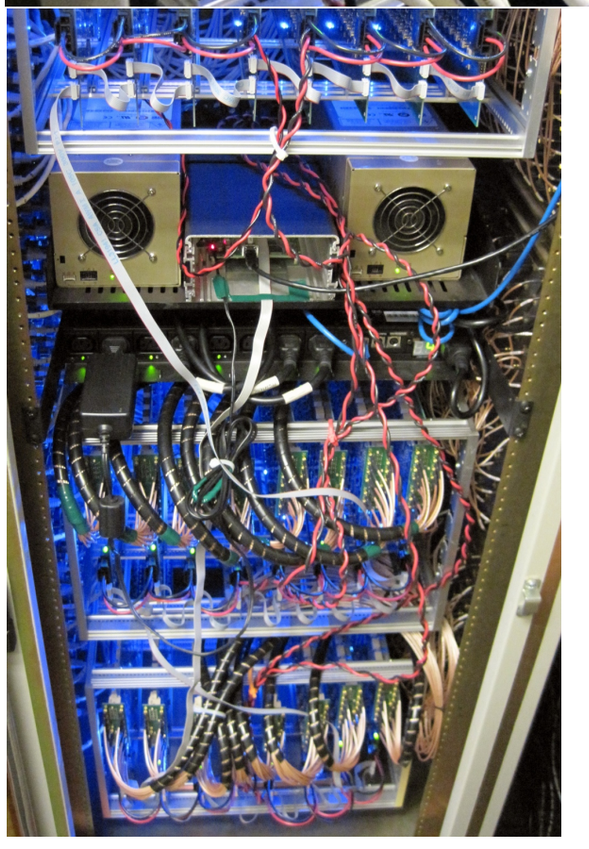
Analog Signal Processor



Analog Receivers

- 8 - 68 dB Gain (2 dB steps)
- 3 Filter Bank
  - Full BW: 10 - 88 MHz
  - Reduced BW: 28 - 54 MHz
  - Split BW: Gain controllable shelf filter (equalizer)
- Powers Active Antennas (Bias-Tee)



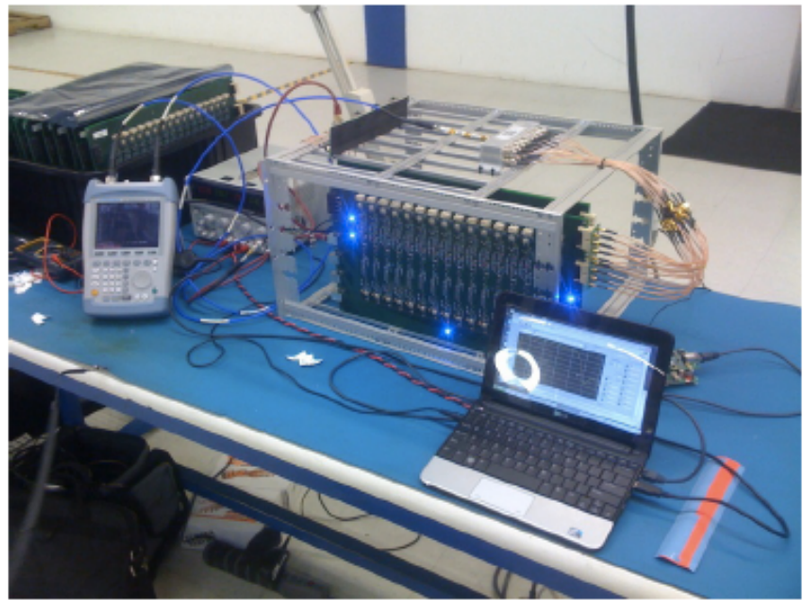


Status

33 ARX boards installed and functional

LESSONS LEARNED: ASP installation and cabling is a HUGE effort... from dipole to digitizer is 12 connections.

ARX Manufacturing

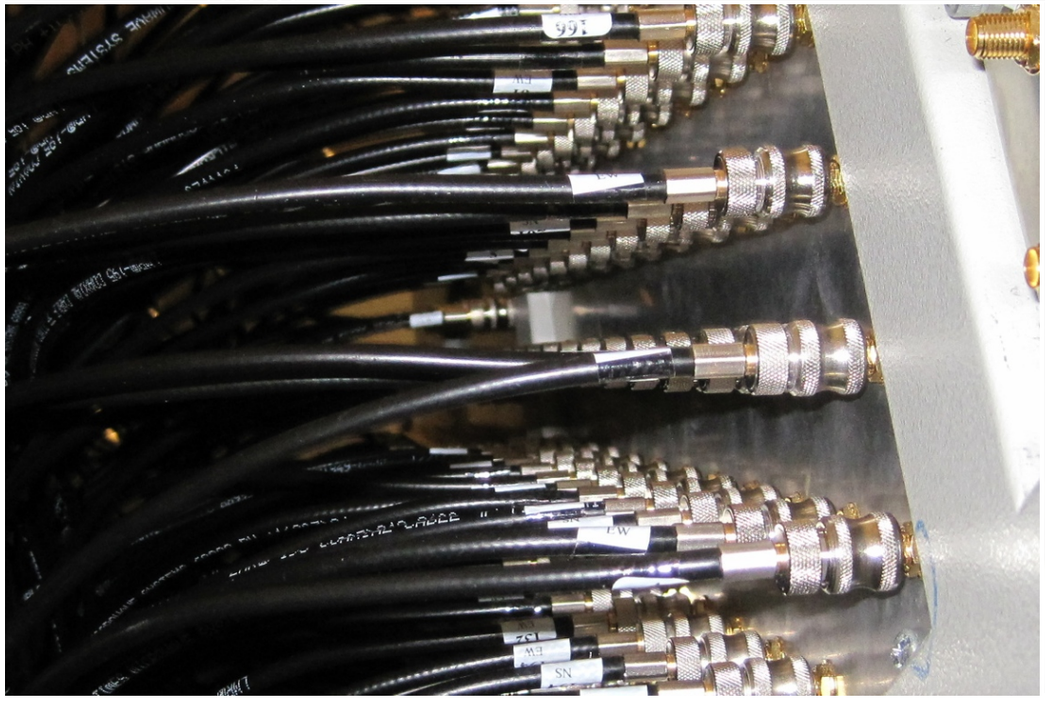


LESSONS LEARNED:
Allocate significant time for manufacturing test and rework; test at manufacturing facility.

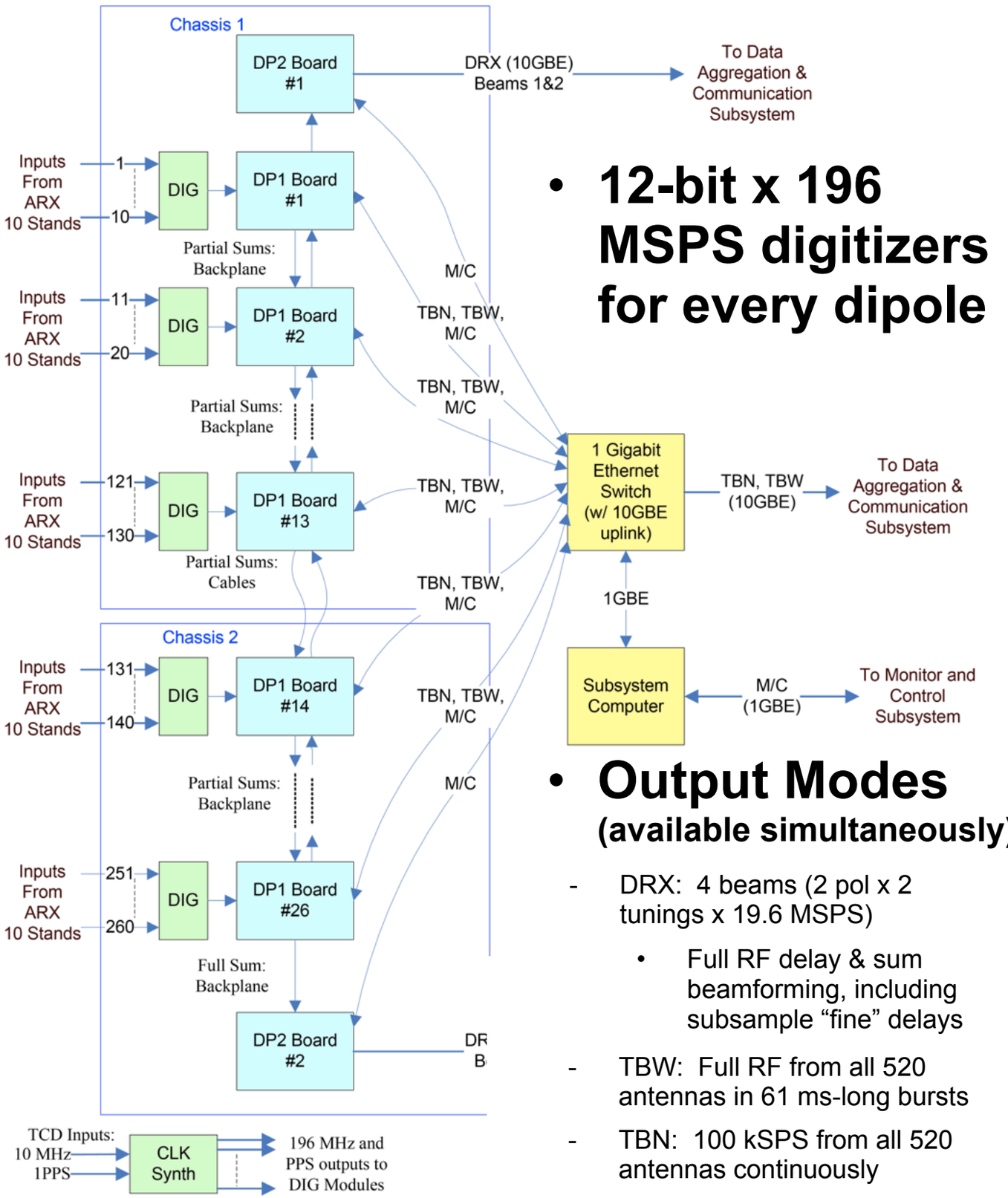
Shelter Racks and Interconnects

Shelter and racks meet EMI shielding requirements
Electrical and HVAC more than sufficient

LESSONS LEARNED: Cost effective racks require modification to meet shielding requirements.

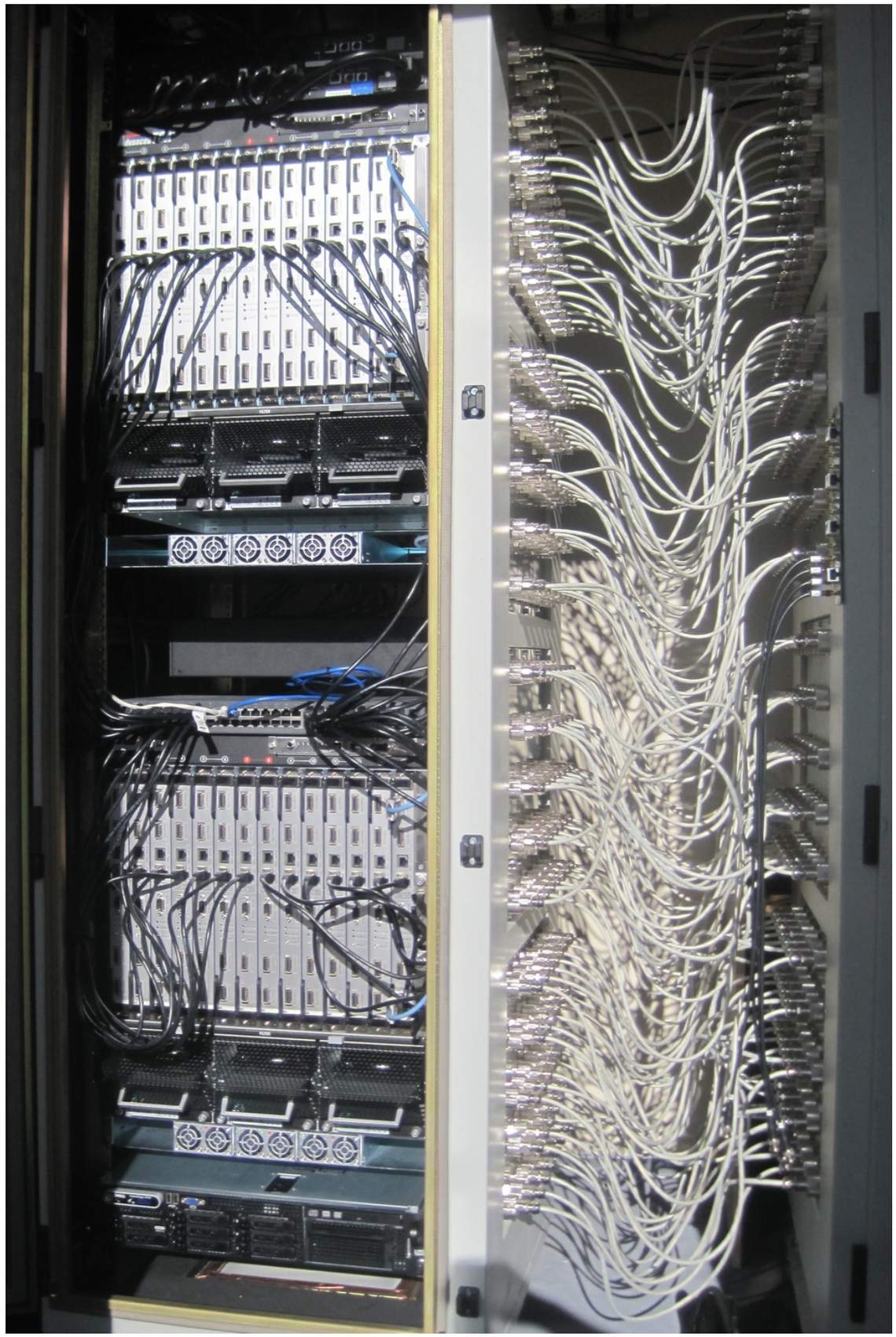


Digital Processor



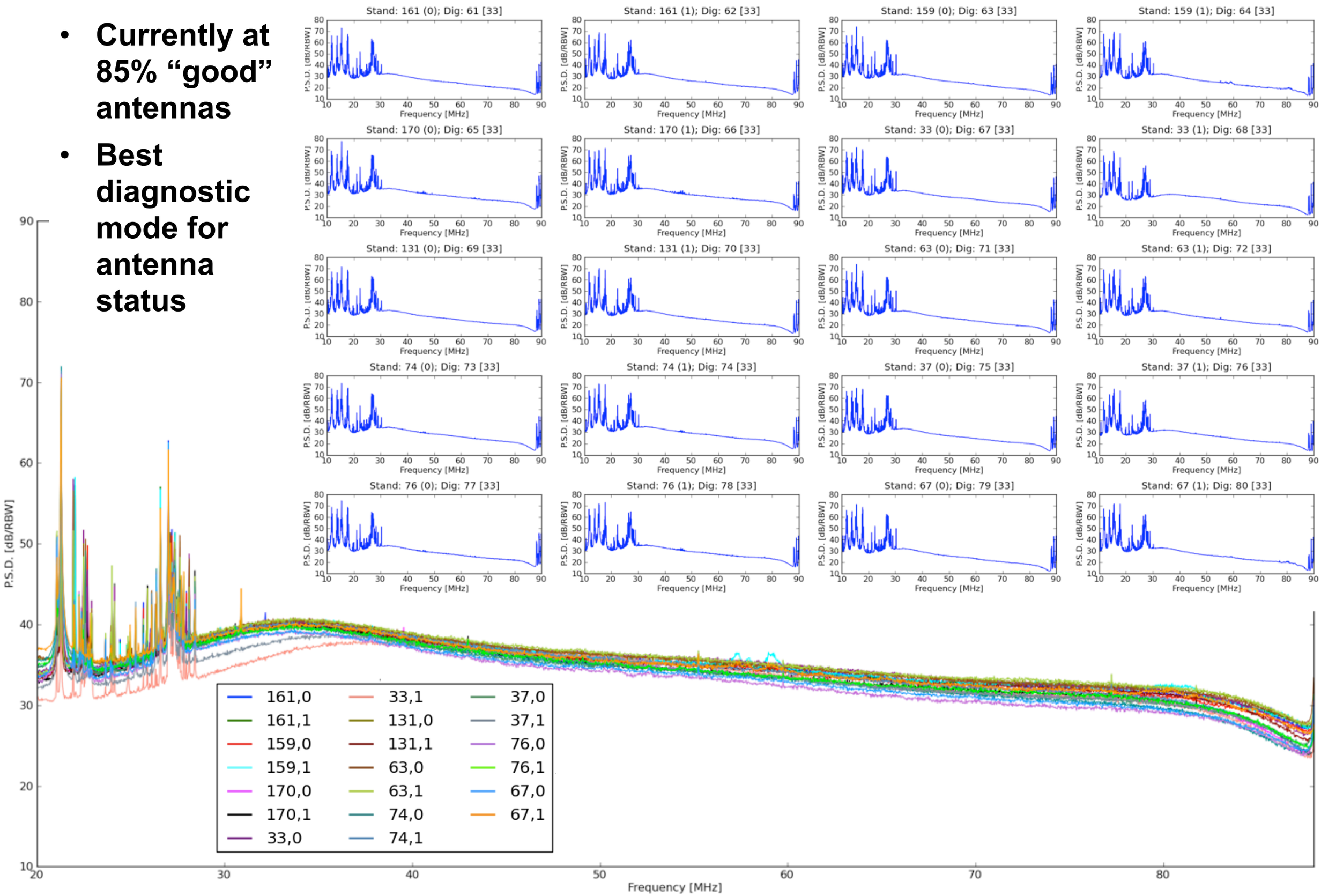
- **12-bit x 196 MSPS digitizers for every dipole**

- **Output Modes**
  (available simultaneously)
  - DRX: 4 beams (2 pol x 2 tunings x 19.6 MSPS)
    - Full RF delay & sum beamforming, including subsample “fine” delays
  - TBW: Full RF from all 520 antennas in 61 ms-long bursts
  - TBN: 100 kSPS from all 520 antennas continuously



520 TBW First Light

- **Currently at 85% “good” antennas**
- **Best diagnostic mode for antenna status**

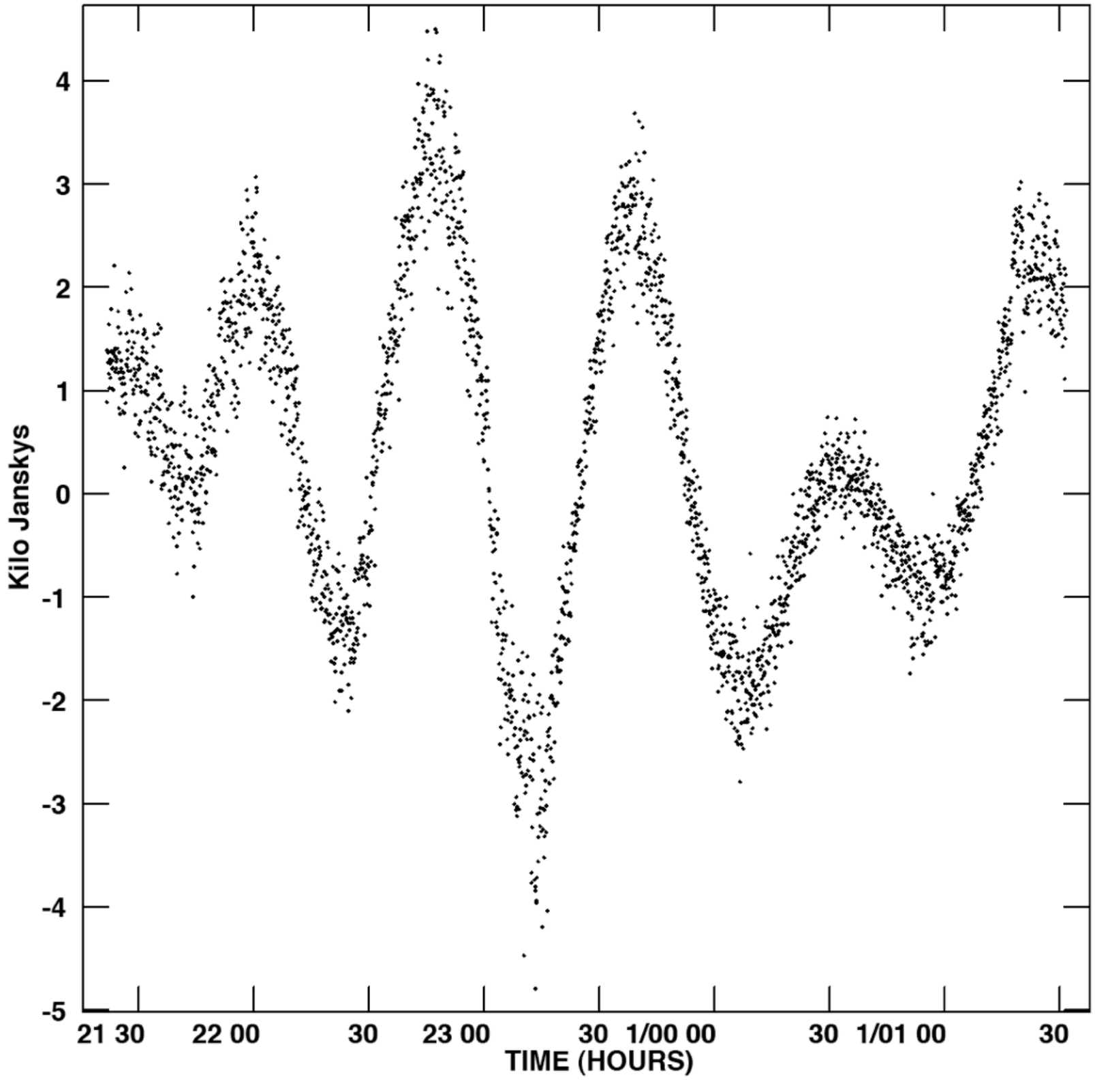


TBN Fringes with Outlier

- **Outlier to Stand 16**
- **(330 m baseline)**
- **North-South polarization**
- **38 MHz**
- **6 sec integrations**
- **4 hours continuous**

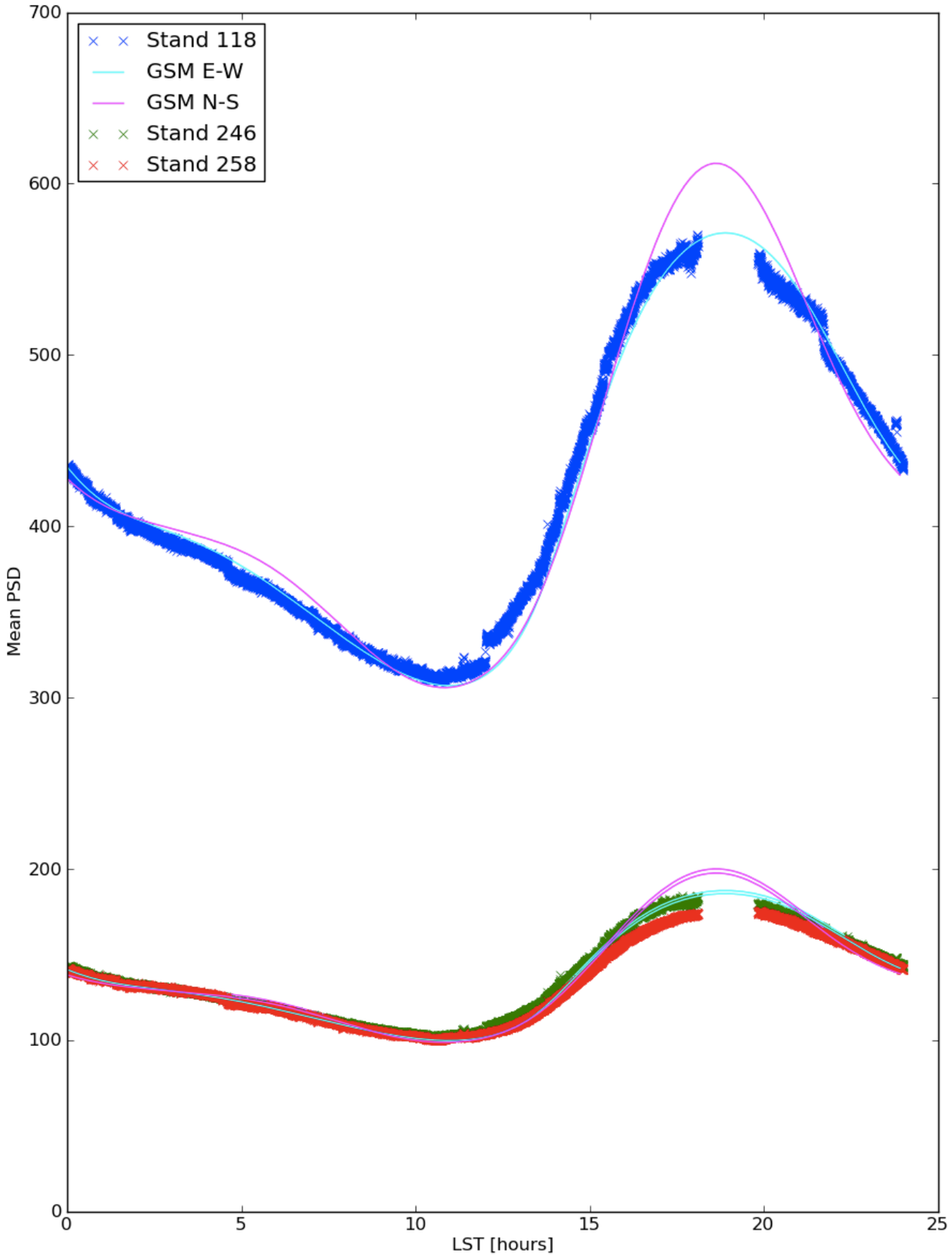
- **Demonstrates confidence in using *a priori* cable delays and antenna geometry for beamformer calibration**

- **Using the outlier to map the station beam will be crucial to understanding the beamshape.**



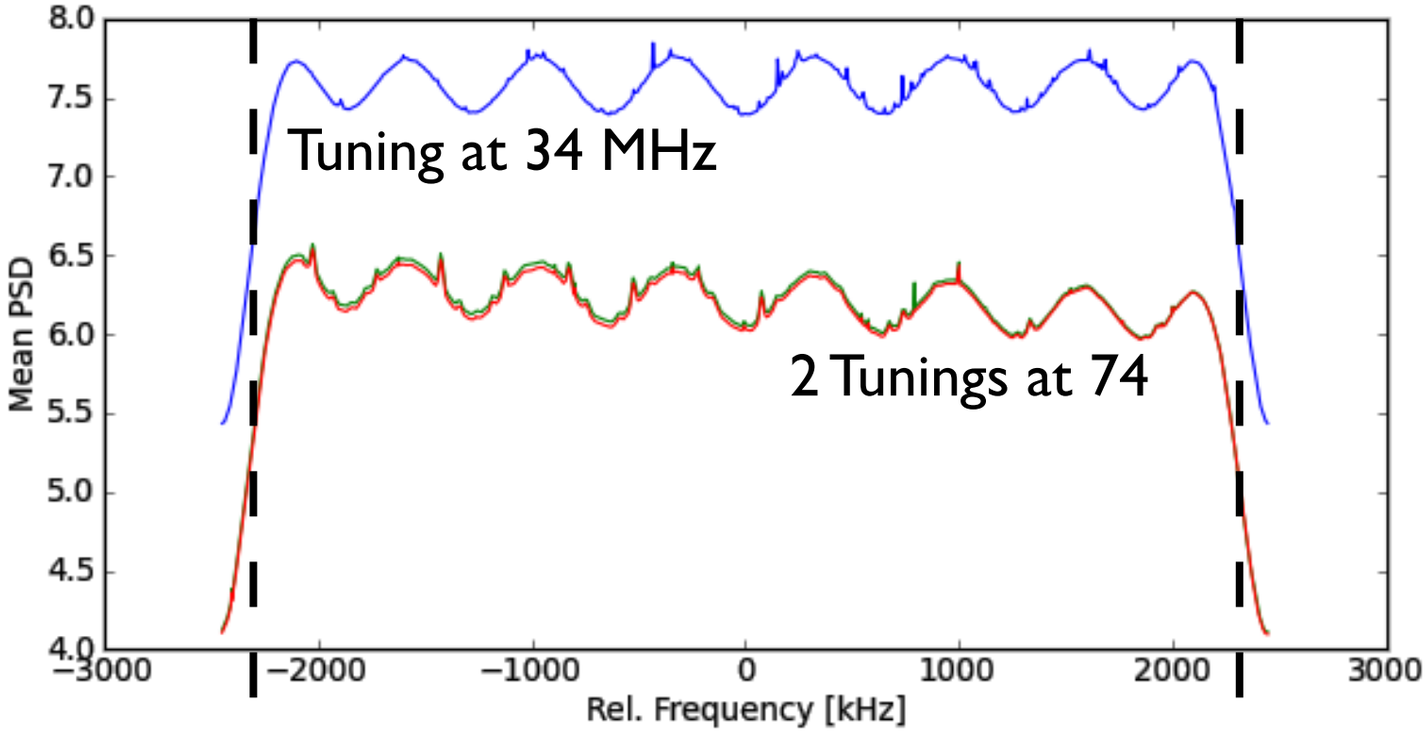
TBN Drift Scans

- **Demonstrates sky-noise dominance even at galactic minimum**
- **Comparison to model confirms polarization**
- **Work in progress to demonstrate repeatability**



Beamformer Acceptance Testing

1.4 Hours of integration on noise injected to 8 inputs and beamformed coherently



Sinusoid (& noise) injected at 17 MHz

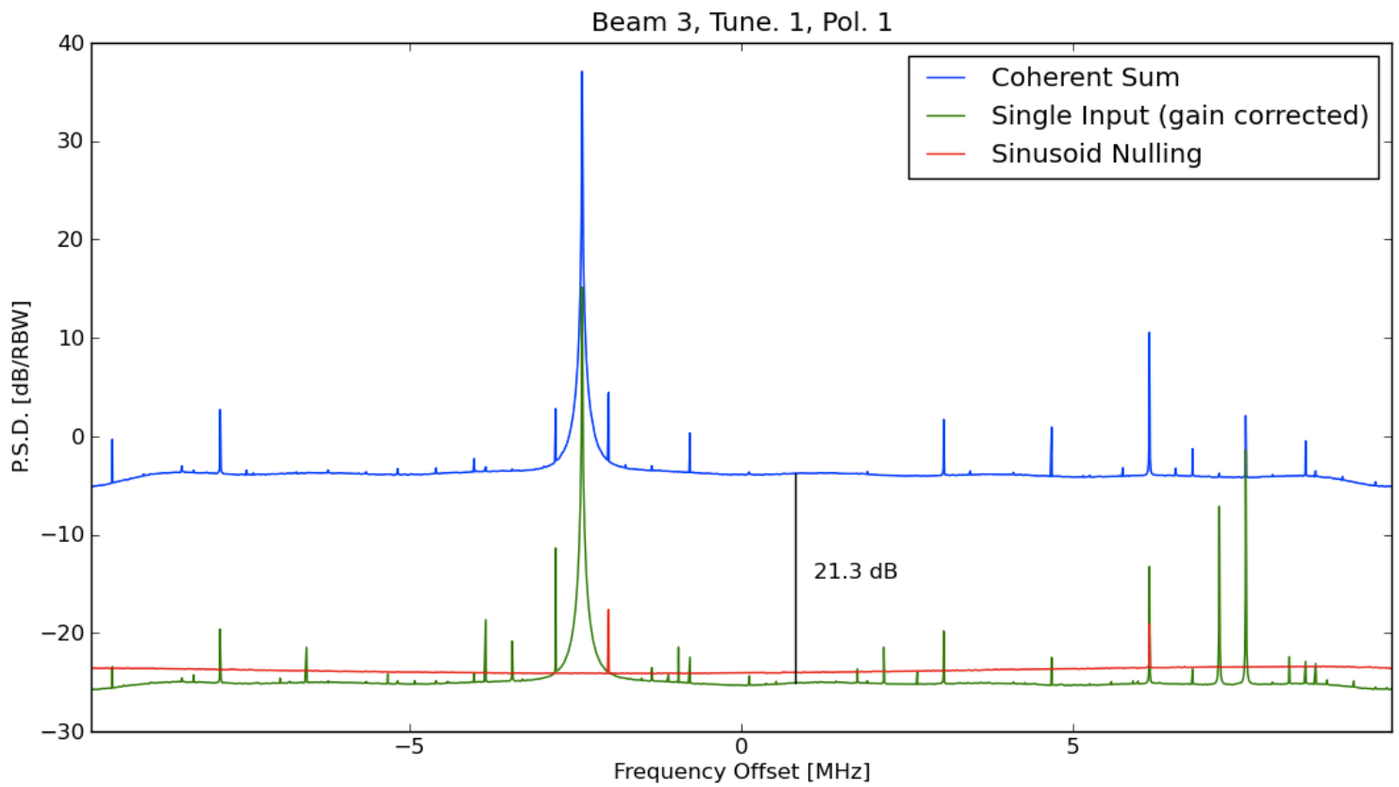
Validates DRX tuning, dynamic range, and beamformer delays (both coarse & fine)

Sinusoid nulled through beamforming (1/2 inputs set to 180° phase-shift)

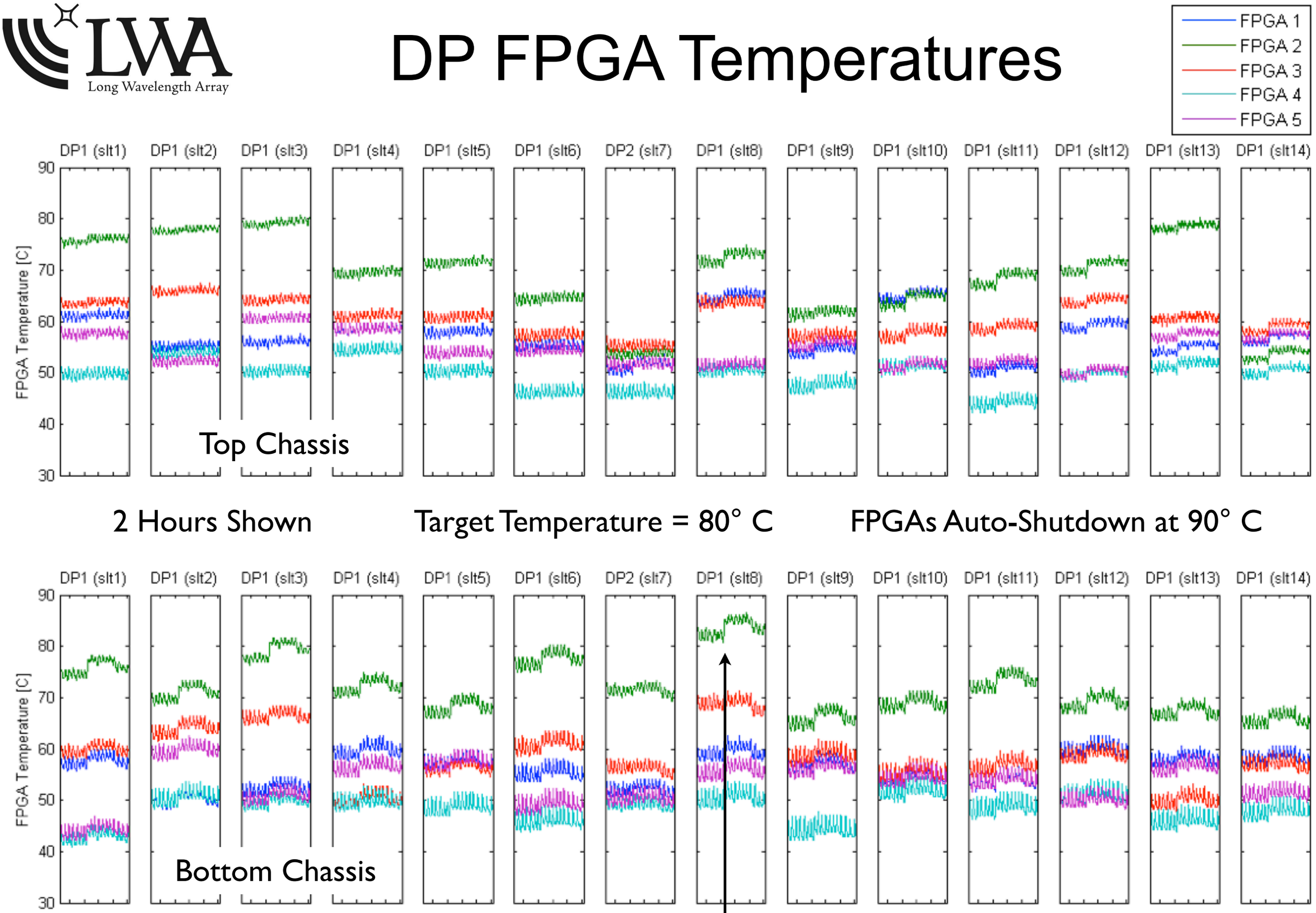
Coherent sum increases power over single input

1 dB bandwidth = 90% of filter rate

Filter Rate (MSPS)	1 dB BW (MHz)
19.6	17.6
9.8	8.8
4.9	4.4
2	1.8
…	…



DP FPGA Temperatures

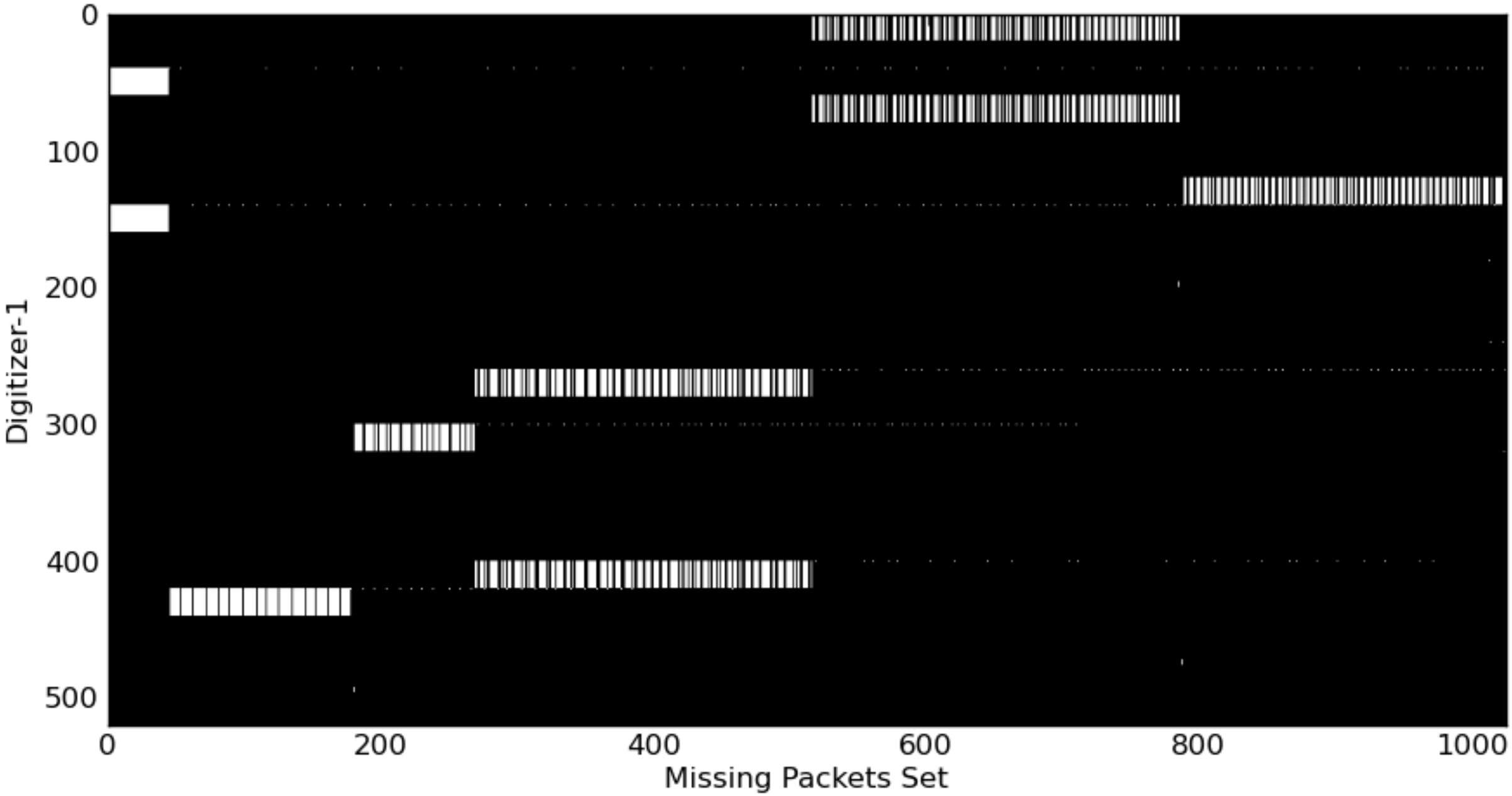


2 Hours Shown Target Temperature = 80° C FPGAs Auto-Shutdown at 90° C

All 4 Beams Turned On

LESSONS LEARNED: Test system *in situ* and as close to actual operating environment as possible.

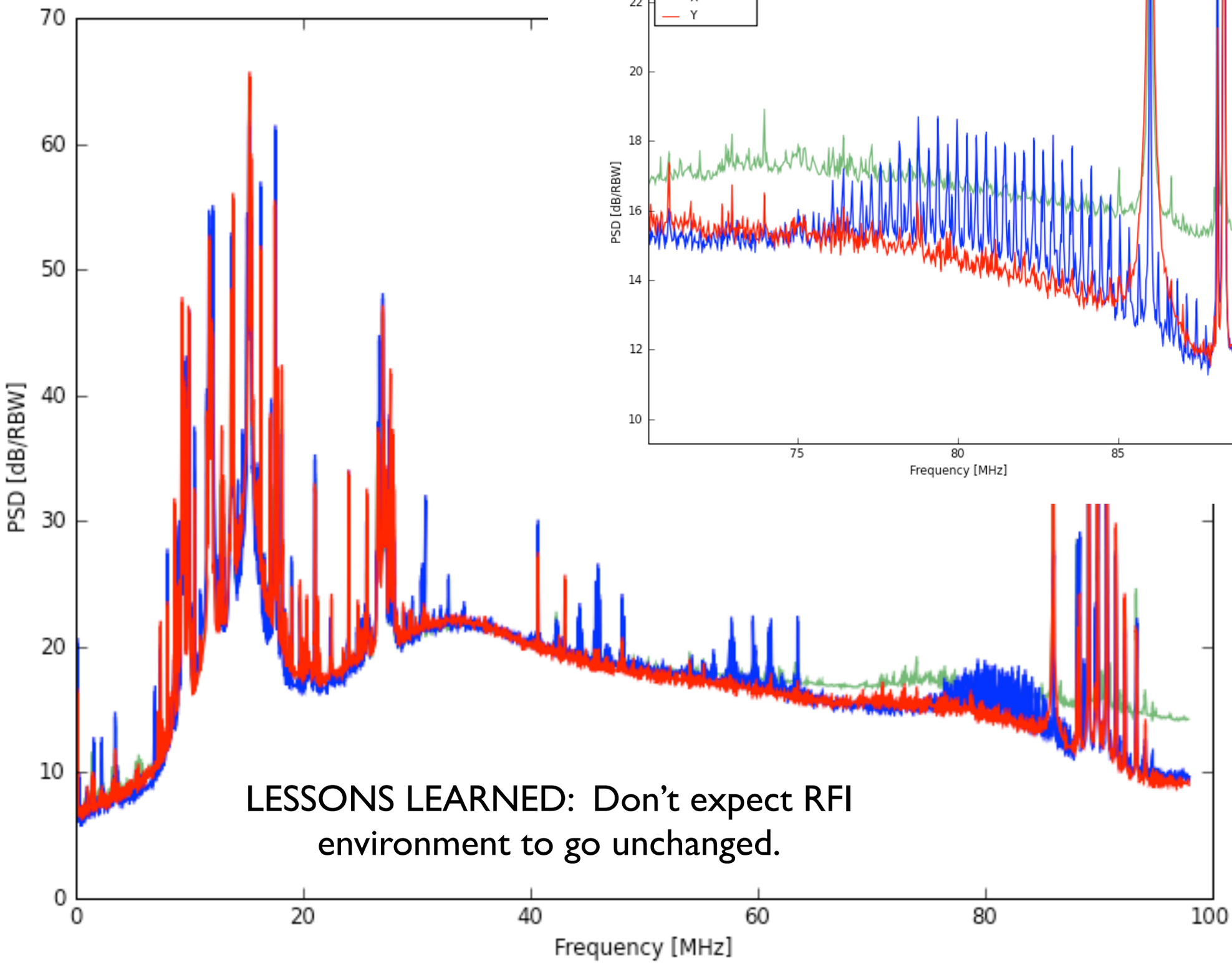
Packet Loss



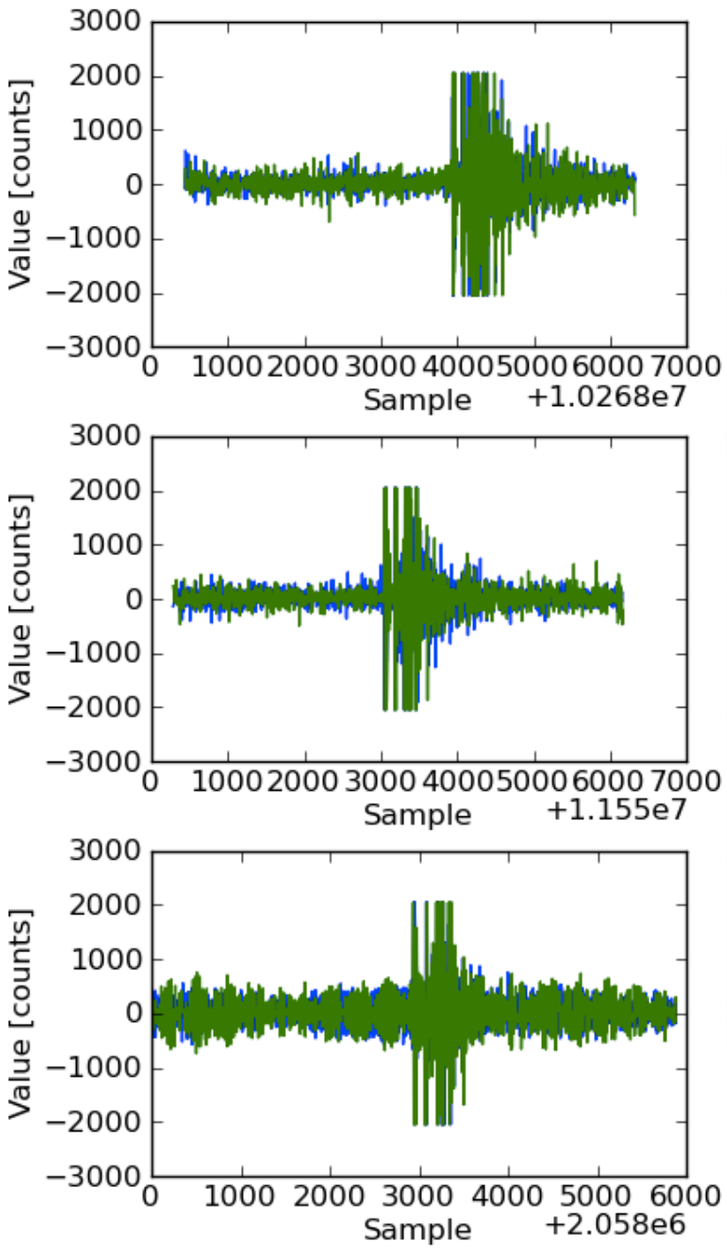
UNM purchased DR Storage Unit drives had different firmware than qualified by VT, which decreased write speed performance and lead to packet loss.

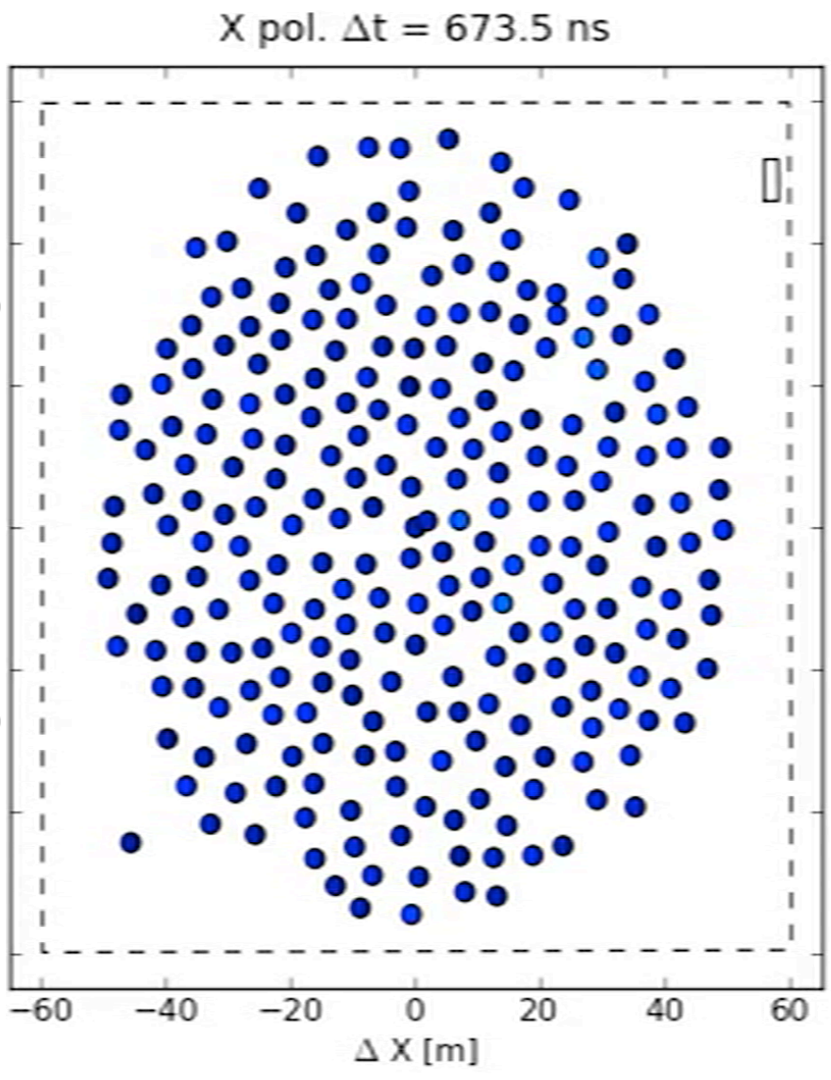
LESSONS LEARNED: Although part numbers are the same, COTS computer component vendors may not provide the same qualified hardware.

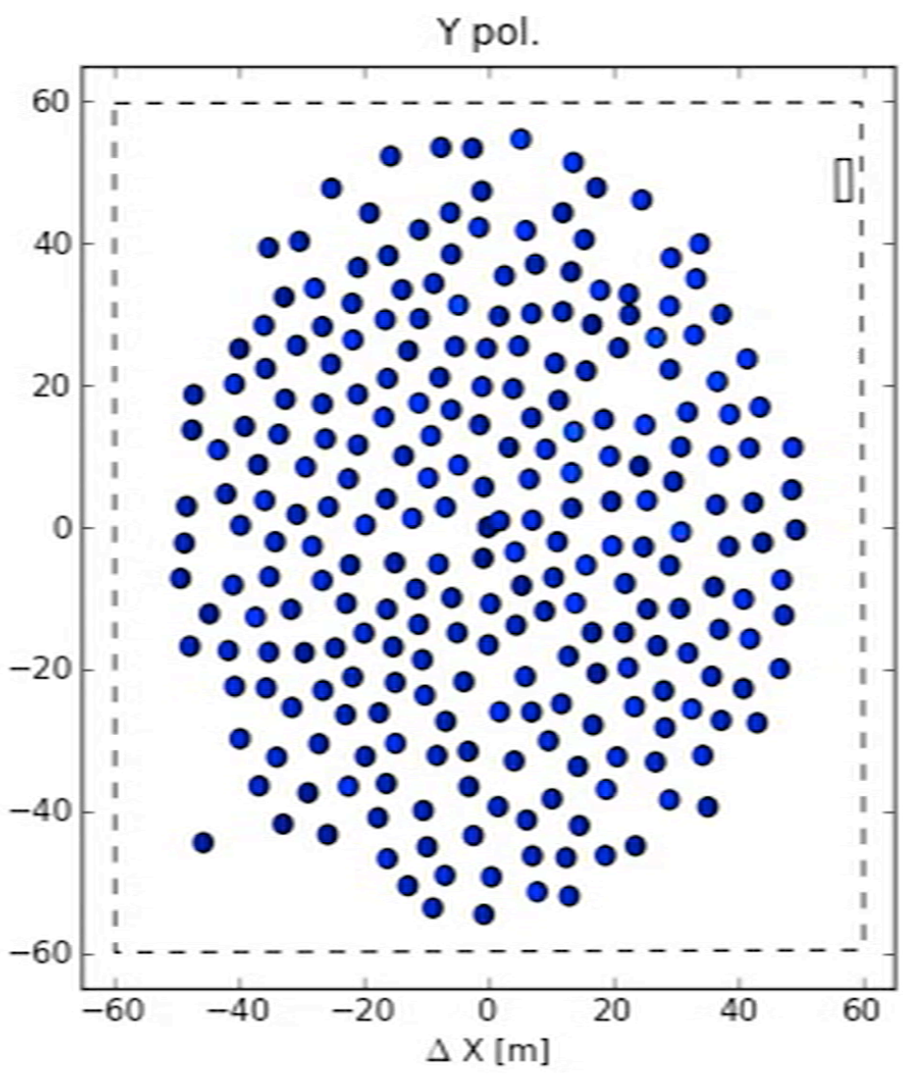
Recent Interference

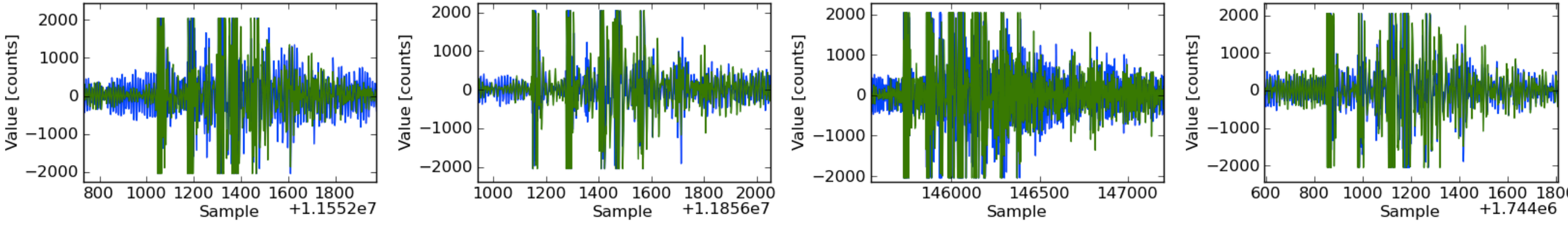


Recent Interference









Commissioning Roadmap

- Basic Signal Path Verification
- Spectrum Orientation Verification throughout the System
- Spur Checks
- Path-Path Isolation Tests
- Antenna based Integration Tests
- Beam Pointing Check
  - Zenith Beam Check
  - Off-zenith Pointing
  - NCP Pointing
  - Transient Response Test
- Flux Ratio Test
- RFI Survey
- ARX Filter Test
- Polarization Test
- Beam Shape Measurement
- Brightest Available Pulsars
- Solar Bursts

Commissioning Roadmap

- Basic Signal Path Verification ✓
- Spectrum Orientation Verification throughout the System ✓
- Spur Checks ✓
- Path-Path Isolation Tests Subsystem measurements indicate ~ 35 dB
- Antenna based Integration Tests Processing software started
- Beam Pointing Check
  - Zenith Beam Check
  - Off-zenith Pointing
  - NCP Pointing
  - Transient Response Test
- Flux Ratio Test
- RFI Survey
- ARX Filter Test
- Polarization Test
- Beam Shape Measurement
- Brightest Available Pulsars
- Solar Bursts

Surface has been scratched, but still a lot to do before IOC.

Transient buffer mode completely functional. Beam modes still need to be verified.

LESSONS LEARNED: Field test hardware as soon as possible to catch issues early.

Deviations from SRR Architecture

Array

- One stand position 3 meters off from specified location
- Sky-Noise Dominance > 6 dB over 20-88 MHz
- Elliptical station footprint

Digital Processor

- No channelization performed to DRX data
- Beam 3 exhibits "calibration" problems
- Rapid Repointing - Required 120/sec, capable of 80/sec

Data Aggregation and Communications (DAC)

- Dropped for LWA-1, replace by MCS-DRs

For more information:

J. Craig (2009), “Long Wavelength Array Station Architecture,” [LWA Memo 161]

S. Ellingson, “Sensitivity of Antenna Arrays for Long-Wavelength Radio Astronomy,” *IEEE, Trans. Ant. & Prop.* [LWA Memo 166]

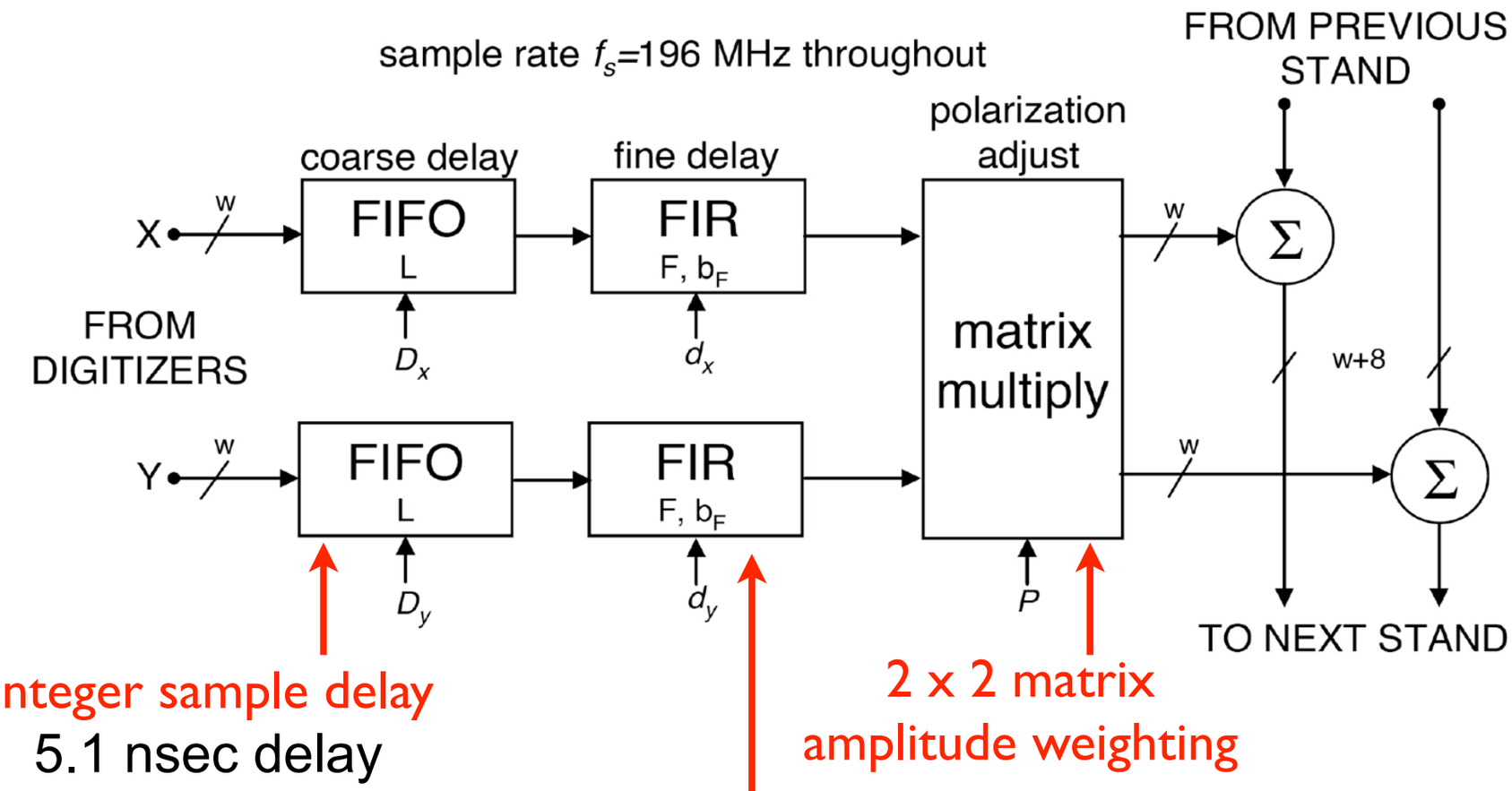
M. Soriano, *et al.* (2011), “Implementation of a Digital Processing Subsystem for a Long Wavelength Array Station,” *IEEE Aerospace Conf.* [LWA Memo 179]

Project Web Site:
http://lwa.unm.edu

Memo Series:
http://www.phys.unm.edu/~lwa/memos

The LWA is on Facebook
http://www.facebook.com/LWArray

Beam Submodule



Integer sample delay
5.1 nsec delay

sub-sample delay

2 x 2 matrix
amplitude weighting

Antennas and cables have non-uniform dispersion which will affect delay-beam shape

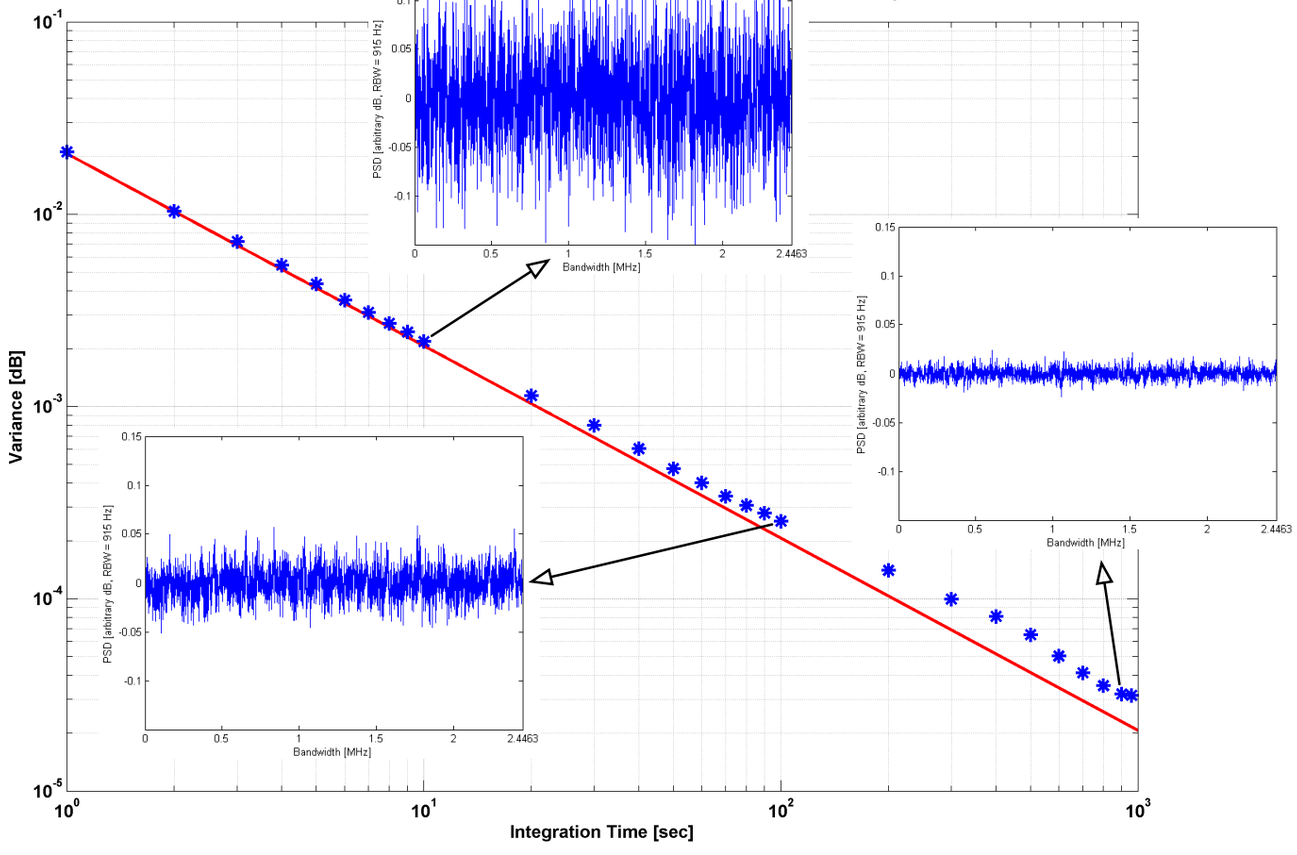
Delay corrections across entire band (10 to 88 MHz) require accuracies of at least 1.28 nsec to keep maximum loss of synthesized beam to under 7%.

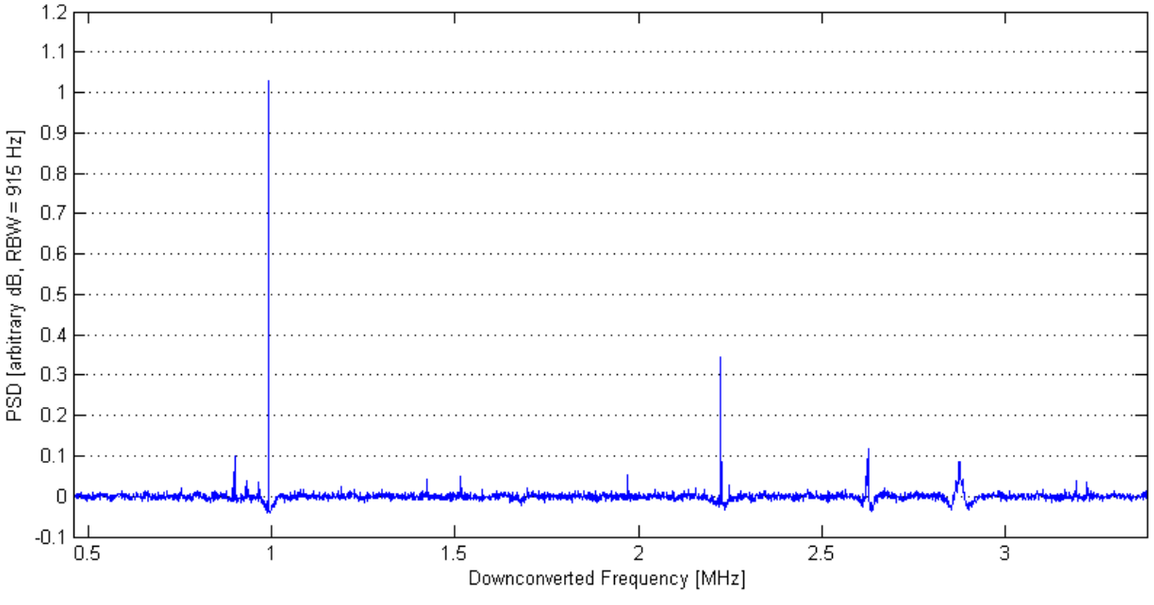
Since every dipole is digitized, unlike analog beamforming techniques, we have the ability to apply per-dipole calibration filters for dedispersion of cables and other non-uniform effects.

Radiometric Stability

After 1 Hour, noise still going down!

$$\frac{\Delta T}{T_{sys}} = \frac{1}{\sqrt{\Delta\nu \cdot \tau}}$$





- **Center Freq: 72.24 MHz**
- **2.45 MHz Bandpass**
- **915 Hz per channel**
- **2600 channels shown**
- **RFI...**
  - **Freq. domain blanking only**
  - **Discarded 20% of band (generous) due to weak RFI**
- **Data collected between 2 - 3 AM continuously**
- **Production hardware from antennas to ARX**
- **Analog beamforming of 8 dipoles (static pointing)**
- **Sampled & downconverted by s60 system**
- **Model fit the diurnal total power, measured every 1 sec**
- **Spline interpolant model fit of bandpass**

TBN Radiometric Stability