PASEO Meeting

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EVLA System Verification and Performance

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Atacama Large Millimeter/submillimeter Array
Expanded Very Large Array
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Very Long Baseline Array

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Overview

- EVLA Project Book, Chapter 2, contains the EVLA Project system performance requirements.
- Demonstrating that these requirements are met necessitates a wide suite of tests, mostly on the sky.
- Time does not permit an exhaustive review of performance.
- I give here results from system performance testing for some of the key project requirements.

- **Conclusions**
- We are meeting – or beating – project requirements in most areas.
- Much testing remains …
- Performance testing in some areas has been retarded due to issues with system stability and robustness, primarily involving the correlator and/or its surrounding software.

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Project Requirements

- EVLA Project Book, Chapter 2, contains the EVLA Project system performance requirements.
- Key performance areas include:
  - Pointing – blind and referenced
  - System sensitivity : antenna efficiency and receiver system temperature
  - Antenna/receiver cross-polarization – magnitude and stability
  - System amplitude gain stability
  - System phase stability
  - Antenna bandpass phase and amplitude characteristics (slope)
  - Bandpass amplitude and phase stability
  - System delay stability
- 'System Verification' is the process of generating protocols for measuring these characteristics, with the ultimate goal to verify the design and performance.

Protocol Generation

- Generating protocols for system verification is a non-trivial process.
- Many of these performance goals are very exacting, requiring new methods, considerable observing time and analysis, experienced analysis, and a stable observing/correlation/processing environment.
- Prior to this year, we utilized the VLA's well-tested, reliable, -- but limited -- correlator.
- We are now in a rather more dynamic, and unstable, environment – testing of fundamental system performance has (temporarily) slowed.

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System Sensitivity

- There are band-dependent requirements for:
  - Antenna Efficiency -- ε
  - Antenna System Temperature -- T_{sys}
- The key sensitivity parameter is their ratio:
  - the 'effective system temperature': T_{sys}/ε

    and
  - 'System Equivalent Flux Density': $S_E = 5.62 * T_{sys}/\varepsilon$ Jy (for a 25-meter antenna). This is the flux density of a source which doubles the system temperature.
- The noise-limited array sensitivity, per correlation, is given by:

$$\sigma = \frac{S_E}{\eta_c N \sqrt{BT}} \quad \text{Jy}$$

B = bandwidth, T = integration time, N = number of antennas, and η_c = 'correlator efficiency'.

Efficiency and Tsys Results

- Absolute measurements (hot and cold loads) are made on antenna 24.
- Other antennas are measured interferometrically w.r.t. antenna 24.

	Band (GHz)	Tsys		Aperture Effic.		SEFD (Jy)	
		Req'd	Actual	Req'd	Actual	Req'd	Actual
L	1 – 2	26	28 -- 40	.45	.40 – .45	325	400
S	2 – 4	26	27 -- 38	.62	.50 -- .55	235	310
C	4 – 8	26	24 -- 31	.56	.53 -- .61	245	285
X	8 -- 12	30	TBD	.56	TBD	300	TBD
Ku	12 -- 18	37	25 -- 33	.54	.55 -- .65	385	260
K	18 -- 26.5	59	36 -- 42	.51	.48 -- .57	650	410
Ka	26.5 -- 40	53	40 -- 50	.39	.36 -- .48	760	650
Q	40 -- 50	74 -- 116	55 -- 100	.34	.28 -- .37	1500	1300

- The high frequency data nicely fit a Ruze law, with $\varepsilon_0 = 0.60$, and $\sigma = 0.42$ mm.
- We are not meeting requirements at low frequencies, but easily beating them at high frequencies.

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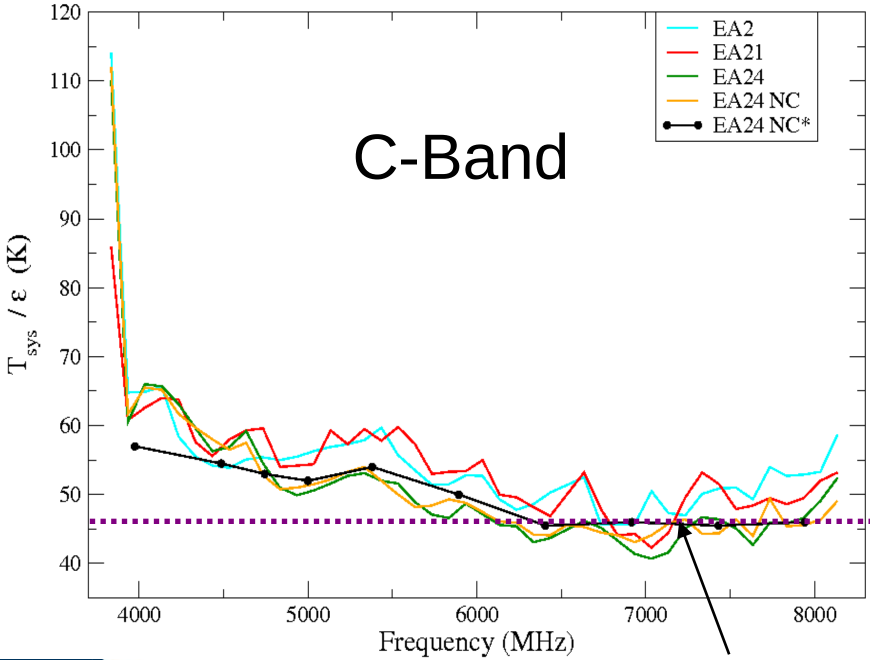
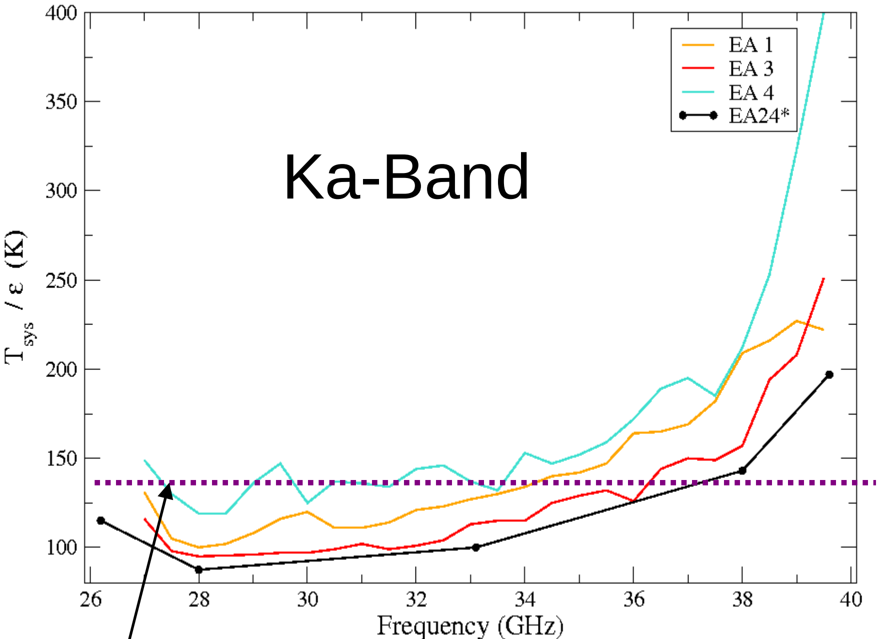
C and Ka Band Sensitivity Detail

- Sensitivity is not uniform across the bands – especially at high frequencies
  - Colored lines are derived via correlation coefficients
  - Black line with dots are from absolute measurements on ant. 24.





Project Requirement

Polarization

- Polarization purity (D-term)
  - Less than 5% leakage of total intensity into 'RL' and 'LR' cross-products.
- Cross-polarization ('D' term) stability
  - Stable to 0.1% in leakage.
- Although high polarization purity (small 'D'-term) is useful and desirable, the **stability** of the cross-polarization is critical for accurate polarimetry.
  - A 1% stability is sufficient to determine fractional linear polarization with an accuracy ~0.1%.
  - The 0.1% stability is required to achieve noise-limited performance in the presence of a strong unpolarized source.

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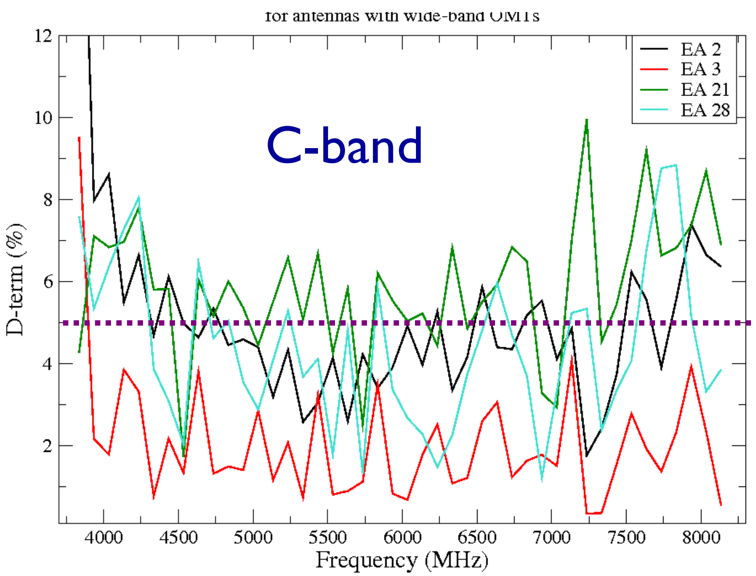
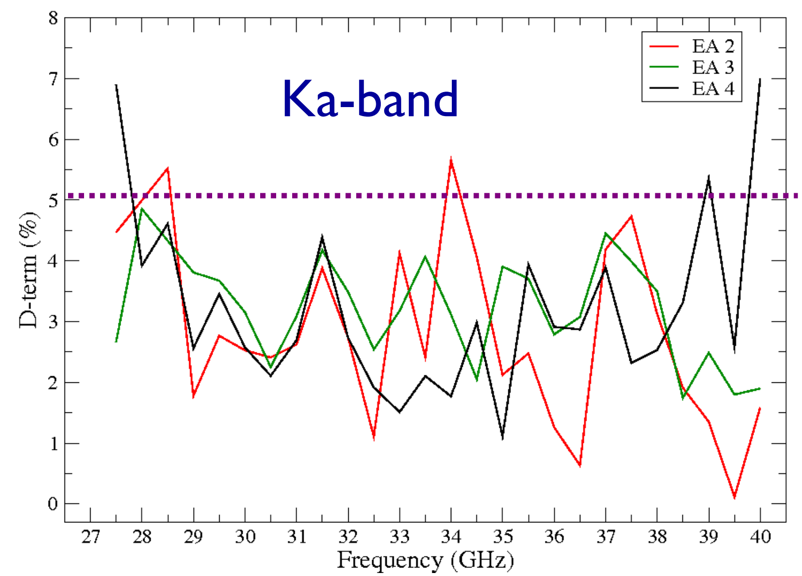
C and Ka-Band Cross-Polarization

- Antenna ‘D-Term’ polarization with the new OMT design close to the specs at C-band.
- Ka-band polarization, with waveguide OMT meets specs, except at the band edges.
- These are ‘relative’ Ds – setting the reference antenna at zero.



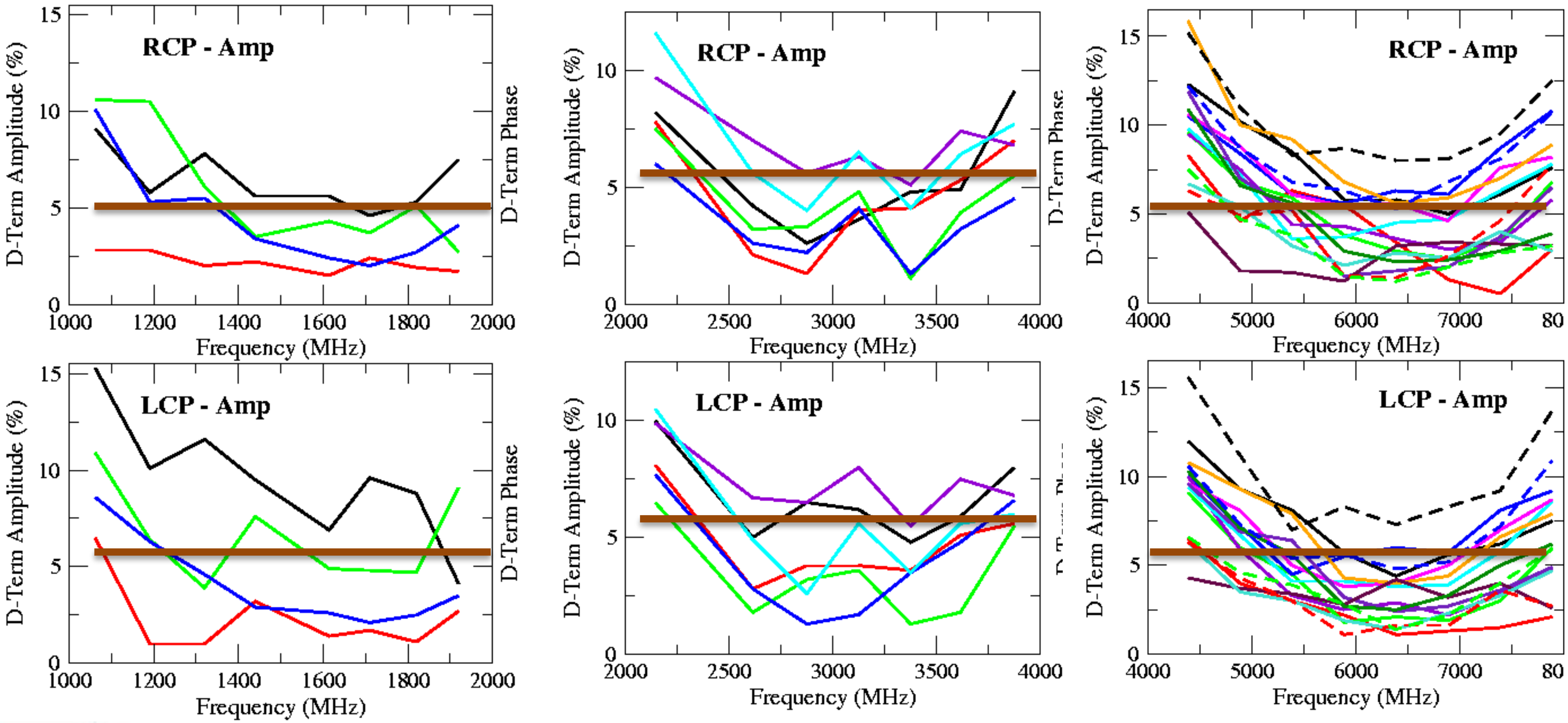


Absolute D-term Measurements

- A cute trick, which measures the absolute cross polarization, is to make two measures, one with all antennas in the normal configuration, and one with a single antenna rotated by 90 degrees.
- An elementary analysis provides the absolute Ds for all antennas.
- For EVLA, we cannot rotate the antennas like this, but we can rotate the low-frequency receivers (L, S, C, and X bands).

Absolute D-terms at L, C, and S bands

- Shown are the absolute cross-polarizations for L, S, and C bands, for those antennas outfitted with final receivers and polarizers.
- These are higher than we want – but new, improved quad hybrids are being installed.

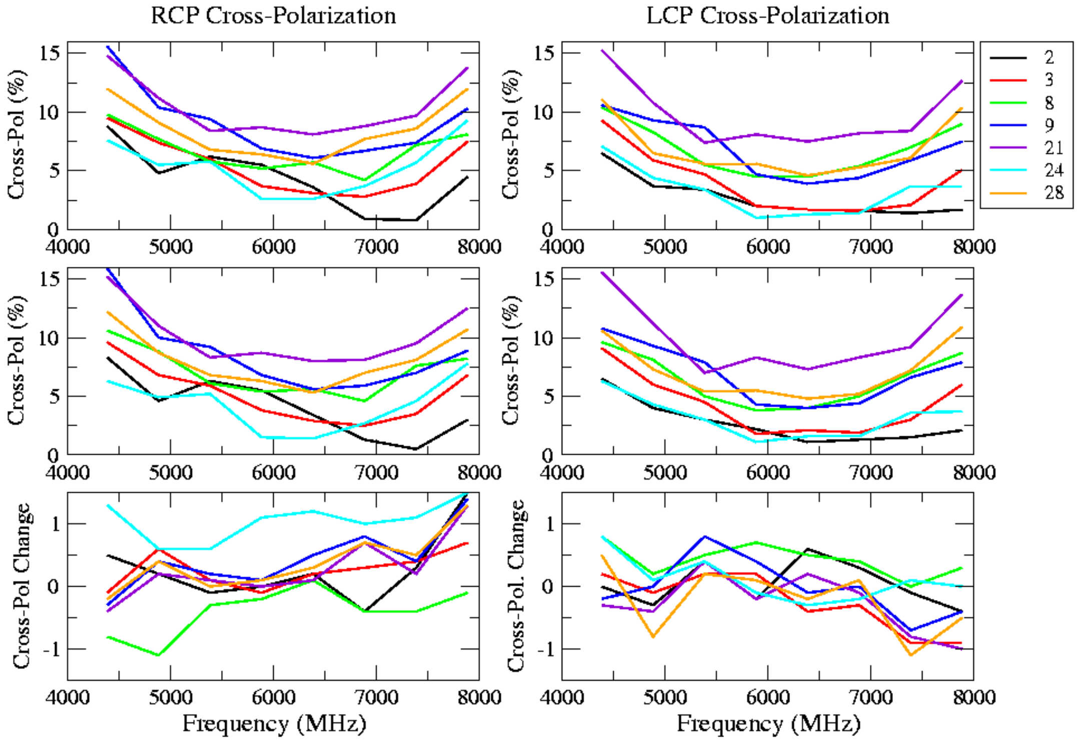


L S C

Cross-Polarization Stability

- More important than the absolute cross-polarization is its stability.
- Sault and Perley (EVLA Memos 134 and 135) show polarizer stability is better than 0.1% on ~12 hour timescale.

- Even on 8-month timescales, stability is excellent.
- Top: X-polarization at C-band April 2009
- Middle: In Jan 2010
- Bottom: The difference.



Antenna Gain Determination

- The overall goal is to be able to determine the source spectral flux density, relative to an established standard, with an accuracy of
  - 0.5% for non-solar observations, and
  - 2% for solar observations.
- These place requirements on:
  - Correlator linearity
  - Stability and linearity of system temperature determination (switched power)
  - Accuracy of correction for antenna elevation gain dependence
  - Accuracy of correction for atmospheric absorption (at higher frequencies).
- Earlier results utilized the VLA correlator.
- No final results via WIDAR are possible – switched power (to account for system gain variations) not yet available.

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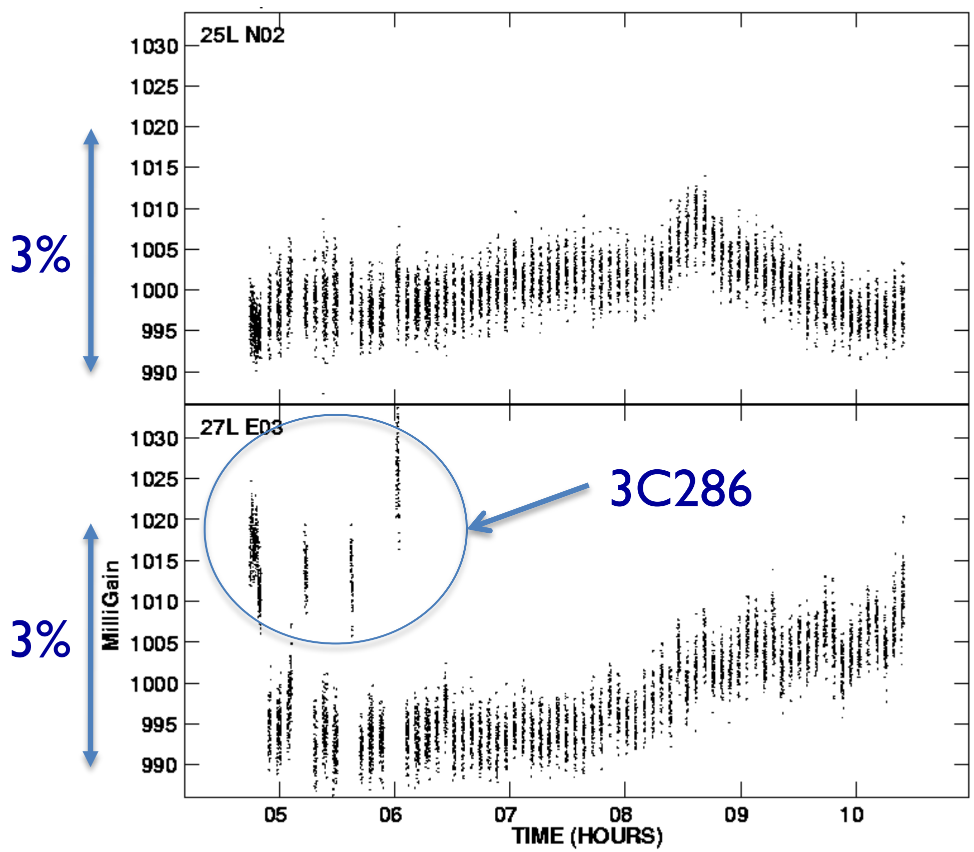
Raw Amplitude Stability – X-band alone

- Two calibrators, tracked over 6 hours.
- A target source fills the gaps.
- Data only normalized – no time or direction corrections.
- Most antennas stable to better than 1% (!!!)
- Some have 'issues'…
- Changing bands causes further problems.



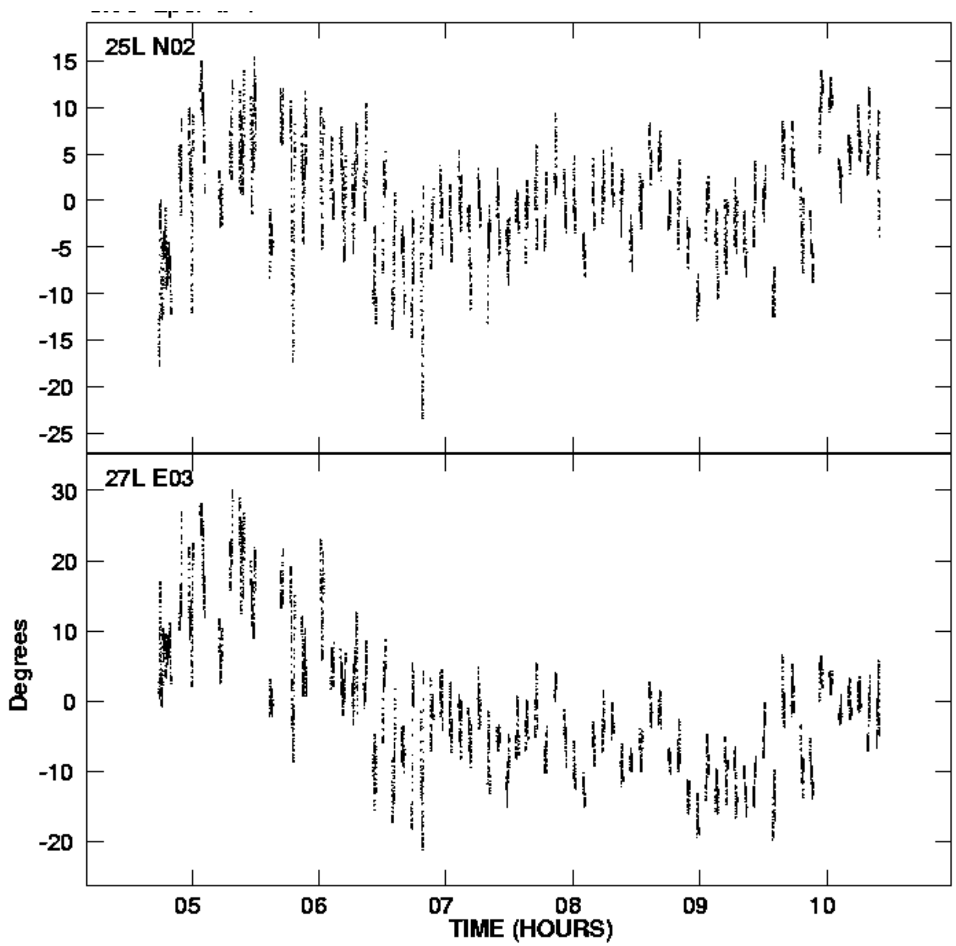
Slow variations will be removed by switched power monitoring.

System Phase Stability

- A detailed list of requirements on different time and angular scales (all at 50 GHz):
  - 1-second rms phase jitter < 10 degrees.
  - Phase change over 30 minutes < 100 degrees
  - Fluctuations about mean slope over 30 minutes < 30 degrees.
  - Phase change upon source change < 15 degrees.
- Results with VLA correlator showed the system met specs in most cases.
- Current results, using WIDAR, are variable.
  - Simple single-frequency experiments are generally good.
  - Multiple band, multiple frequency experiments give less clear results.
  - The dynamic state of the system makes reliable testing difficult.
  - We are now in summer, so phase stability testing is dominated by weather.

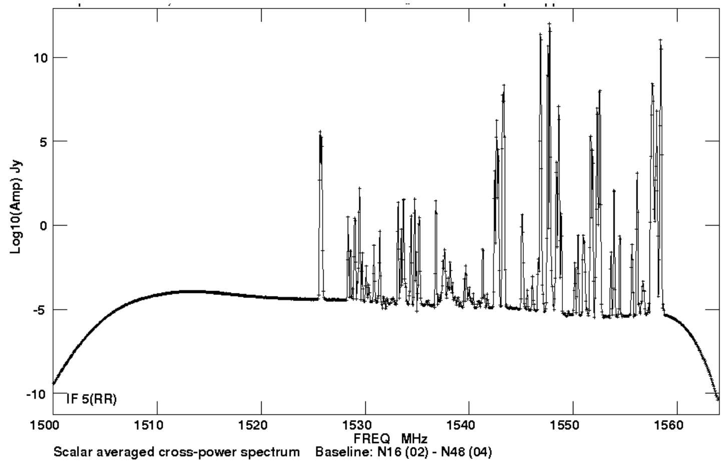
Raw System Phase Stability – X-band

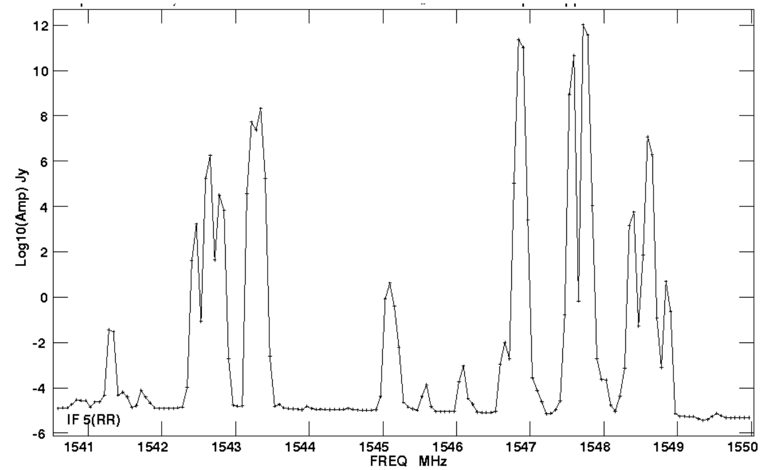
- Same X-band observations – 3C286 and J2007+4029.
- Single frequency – no changes.
- Typical summer weather.
- D-configuration.
- Results on all antennas is good.
- But when frequencies change, or when bands change, various jumps can occur.



Correlator Linearity

- The correlator needs to have high linearity too.
- WIDAR designed to provide more than 50 dB linearity.
- Early tests are very encouraging:





- Left: Scalar averaged spectrum of 3C84, showing INMARSAT
- Right: Closeup, showing astronomical signal between emissions.
- There is no sign of correlator saturation, at a level 40 dB below the peak signal strength.

Bandpass Requirements

- Gain (power) slope and ripple limitations
  - Spectral power density slope to 3-bit digitizer < 3 dB over 2 GHz.
  - Fluctuations about this slope < 4 dB
- Amplitude Stability (in frequency and time)
  - Amplitude bandpass stable to 0.01%, over 1 hour, over frequency span of 0.1% of frequency. (i.e. over 6 MHz at 6 GHz).
- Phase Stability (in frequency and time)
  - Variations less than 6 milli-degrees (over same span as above)
- WIDAR tests show outstanding results in some cases:
  - No changes in frequency or band.
- System attenuator changes clearly results in BP change.
- Band changes can also result in BP changes.

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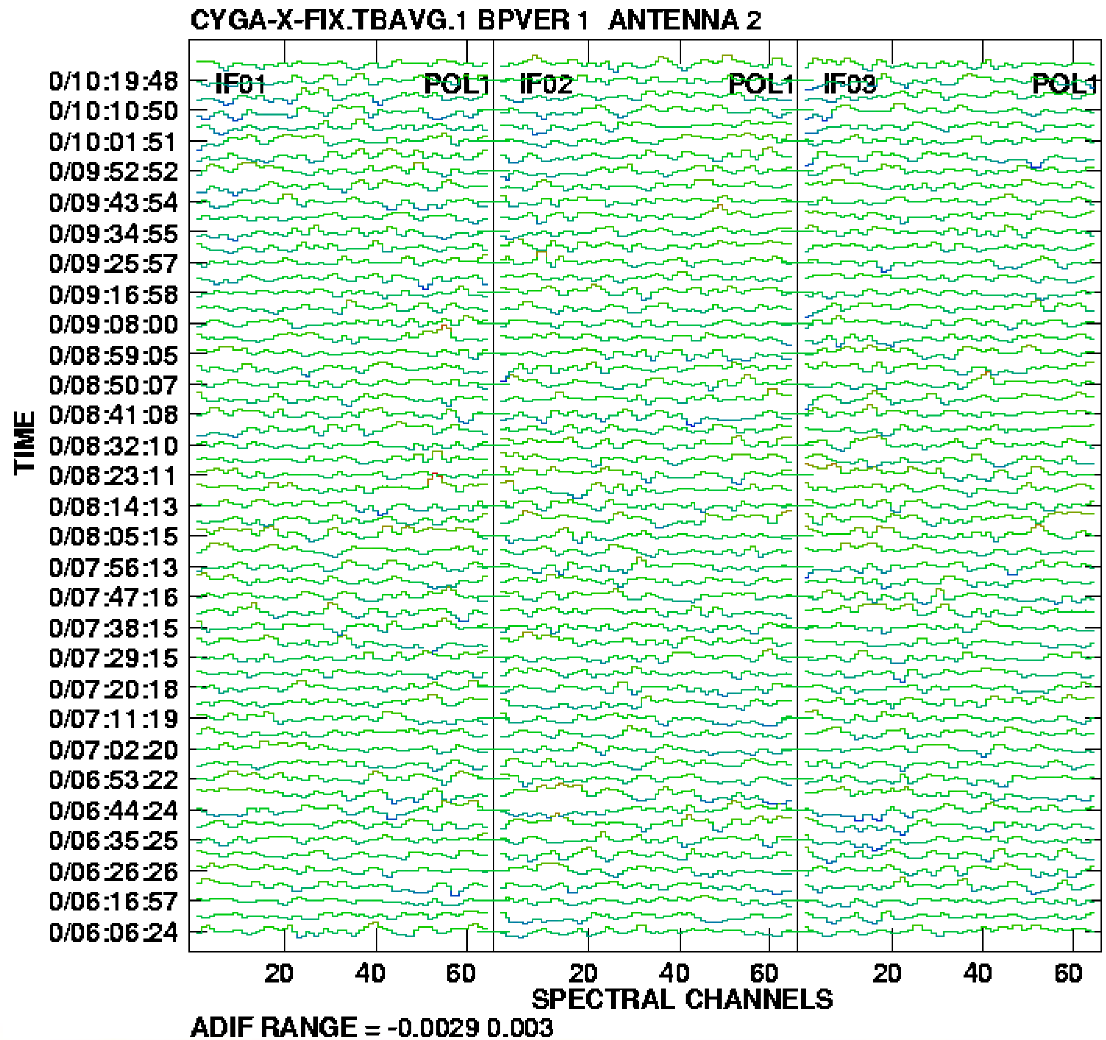
Example of Current State

- Bandpass stability can be exceptional!
- Single frequency, single source example.
- X-Band, ea02, RCP
- Three subbands, each 128 MHz wide.
- Rms stability over 4 hours is about 0.02%
- But it's not always like this …
- Something changes when we change bands…



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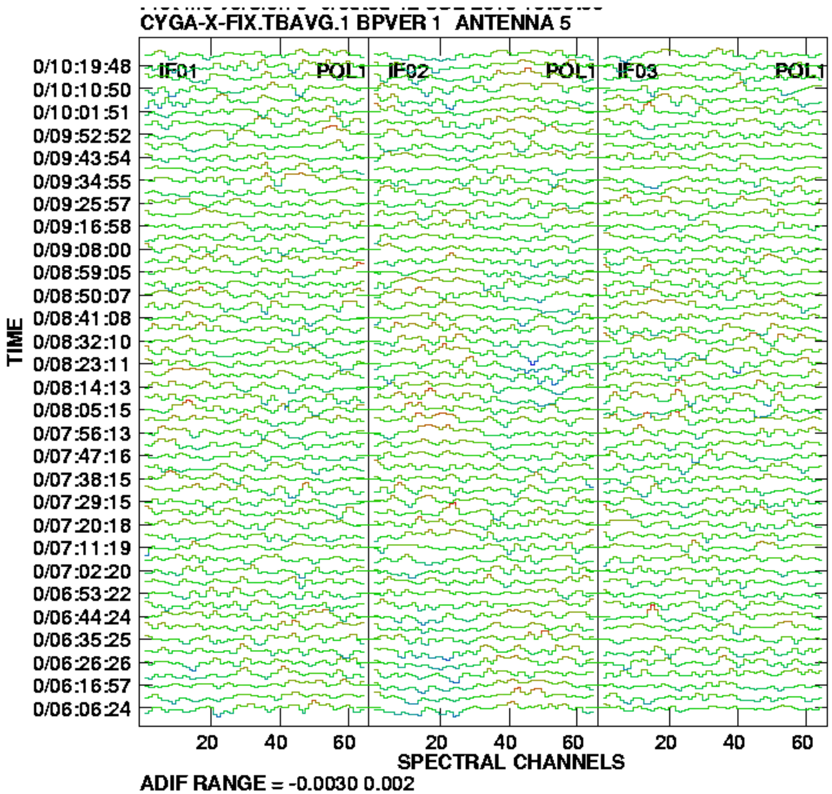
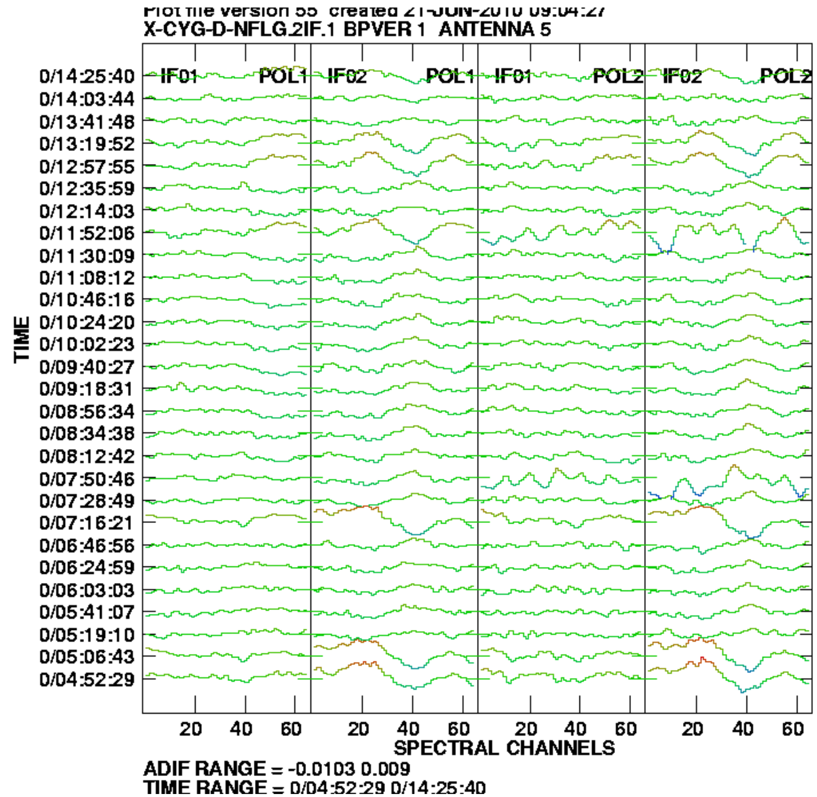
Perturbing the System …

- Same antenna, same band, same source, different days.

No Band Changes



Cycling around Four Bands



Pk-Pk Range: 0.5%

Pk-Pk Range: 1.9%

Bandpass Phase and Amplitude Stability

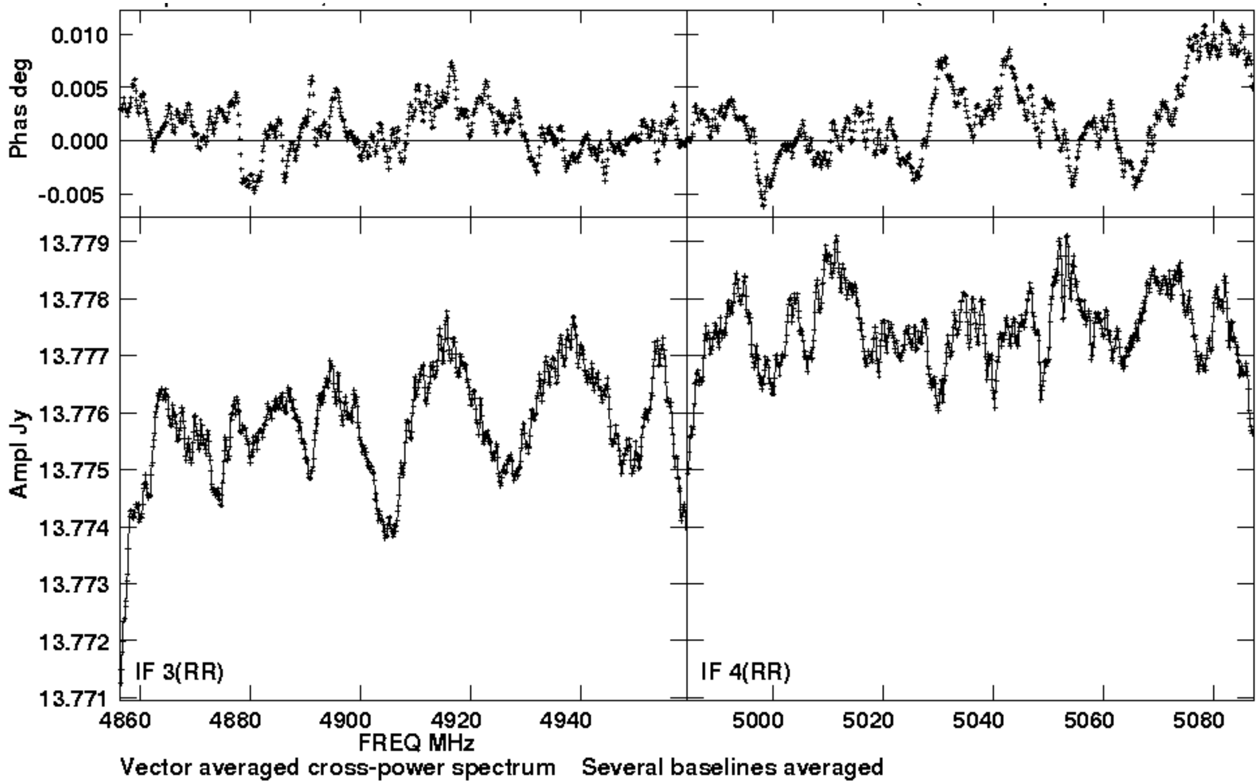
- From the prototype correlator, observations at 6cm of 3C84 – a strong calibrator – with four antennas.
- Residual ripple in vector sum meets requirements.

Observations made hourly, each 20 minutes long.

Bandpass calibration done each 10 minutes.

Vector averaged spectrum shown.

Edge channels not shown.



Summary

- System performance tests ongoing
- We are confident we have met, or will meet, most performance requirements.
- Some requirements require new, sophisticated testing protocols to demonstrate compliance.
- General system instability (following conversion to WIDAR) is slowing testing.
- Clear evidence that perturbing the system (frequency changes, band changes, configuration changes) changes system gain parameters by small by significant amounts.
- Much work to be done to clarify these.