EVLA Scientific Commissioning and Antenna Performance Test Check List

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The following requirements come from Chapter 2 of the EVLA Project Book. Note that until the WIDAR correlator becomes available the sensitivity of the array will be the same as the VLA for most bands, and methodologies for the tests described will follow those currently used for the VLA. When the WIDAR correlator becomes available these methodologies are likely to change. It is planned that several tests, such as pointing and tracking stability, will eventually be carried out by Operations without the need for input from the Scientific Staff. However, for the first few antennas, it is expected that these tests will be coordinated with the EVLA Project Scientist. These items are indicated as "Operations" below.

The primary data products will be stored in the VLA data archive. However, there will also be a series of "internal" and "external" web pages that will report, in a user friendly and accessible way, tabular lists of test values, plots of time series, and alarms that should be communicated to Operations for values out of spec. It is expected that all test data directly relevant to users will be posted on the "external" web pages, while more detailed engineering data will be limited to the "internal" web pages. The failure of an antenna to pass any part of the performance tests listed below will be reported to engineering and Operations staff via Mainsaver or equivalent software.

1. Antennas

- Blind pointing at 8 GHz. — Operations.
  - *Requirement:* The rms blind pointing under good weather conditions (night time, wind speeds < 5 m s^{-1}) must be $6''$ or better for elevations between 30° and 70°.
  - *Test:* Full sky pointing run, noting number of failed solutions for each antenna.
- Collimation offsets for bands other than X band. — Operations.
  - *Requirement:* Accuracy of collimation offset measurements and stability of offsets for EVLA antennas must meet or exceed those currently achieved by the VLA. These numbers will need to be derived from archival data.
  - *Test:* Standard collimation measurements by Operations. It has not yet been tested whether the software works for an EVLA antenna.
- Referenced pointing. — Operations.
  - *Requirement:* For observations of a reference source within 5° and 15 min of time the rms referenced pointing must be $3''$ or better for elevations between 20° and 70°, at all frequencies higher than 2 GHz. It may not be possible to achieve this accuracy at L-band and lower frequencies owing to source confusion.

  - *Test:* Referenced pointing runs including secondary referenced pointing at all bands. At present primary referenced pointing corrections can be derived for an EVLA antenna, but cannot be applied to it. Thus more work on the software is needed before referenced pointing can be tested for EVLA antennas.

- Tracking stability. — Operations.
  - *Requirement:* PN3DB sinusoidal amplitude $\leq 6''$.
  - *Test:* PN3DB tests including referenced pointing, checking for short timescale deviations. EVLA antennas have not yet been included in a standard PN3DB run, and obs2script will have to be modified to allow it. As noted under "referenced pointing" above, corrections from referenced pointing cannot yet be applied to EVLA antennas, so referenced pointing cannot be included in this test until more work has been done on the software.

- Subreflector focus/rotation for each band. — Operations.
  - *Requirement:*
    - Focus: absolute position accuracy 0.6 mm, repeatability 0.3 mm.
    - Horizontal positioning stability: 0.3 mm on timescale $\sim$ 1 month, 0.15 mm on timescale $\sim$ 30 min.
    - Tilt positioning stability: $24''$ on timescale $\sim$ 1 month, $12''$ on timescale $\sim$ 30 min.
    - Rotation positioning accuracy: $480''$ on timescale $\sim$ 1 month, $240''$ on timescale $\sim$ 30 min.
    - Band change speed: 20 seconds or less.
    - Optimize antenna G/T relative to subreflector rotation, focus, and pointing.
  - *Test:* Determine antenna focus/rotation at three frequencies in each band, and perform tests to optimize focus/rotation with elevation at high frequency (K, Ka, Q). We will need to re-measure these parameters after 30 mins, 1 day, and 1 month in order to test the long term stability and repeatability. The G/T optimization can be established by maximizing the raw correlation coefficient. At present it is not possible to test or set the focus/rotation on EVLA antennas due to lack of software.

- Antenna slew and settle time. — Operations.
  - *Requirement:* Antenna slew and settle time must be less than 5 sec when separation is less than 30 arcmin. Assuming the same definition of "on-source" as is currently used by the VLA online system, i.e., when the antennas are within $0.1\theta_{\rm beam}$ of the source position, this requirement will be frequency dependent and will be most stringently exercised at the highest operating frequency, 50 GHz.
  - *Test:* Measure antenna slew and settle time; not currently a standard test, details will have to be devised in collaboration with Operations. This can probably be incorporated

into the PN3DB tests. Possible test: fast switching between two positions with high time resolution (1 sec) at 43 GHz, then check to see how many records are flagged by the on-line system as being off-source based on encoder values.

- Antenna electrical performance.
  - *Requirement:*
    - Aperture efficiencies (at the rigging angle):

Band	ν (GHz)	Required
L	1.2–2.0	0.45
S	2.0–4.0	0.62
C	4.0–8.0	0.60
X	8.0–12.0	0.56
Ku	12.0–18.0	0.54
K	18.0–26.5	0.51
Ka	26.5–40.0	0.39
Q	40–47	0.34
Q	47–50	TBD

    - Beam shapes: the normalized primary power pattern of an antenna must not vary by more than 3% from the average of all antennas, within the 3dB ellipse.
    - Feed alignment and illumination: a feed at the cassegrain focus must be aligned to within 10 arcmin of the center of the subreflector; the antenna illumination centroid must be within 5 cm of the center.
    - Beam squint: the angular separation between the R and L beams must remain constant to $6''$ over a period of 8 hours.
  - *Test:* Make full beam maps in holography mode of each antenna at one frequency in each band. These maps will be sampled at ~ 4 times Nyquist out to approximately the third null, requiring a $\sim 25 \times 25$ raster (~ 2 hours of observing). The stability of the beam squint can be obtained from referenced pointing runs and/or multiple beam maps.

2. Receivers

- System temperature.
  - *Requirement:* Across the center 50% of each band, the required system temperatures are:

Band (GHz)	T_{sys}
1–2	27
2–4	27
4–8	27
8–12	31
12–18	38
18–26.5	61
26.5–40	55
40–50 (low end)	70
40–50 (high end)	112

Degradation of receiver temperature within any band with respect to the mean defined in the central 50% is to be less than 3dB at any frequency, less than 1dB over the inner 85%, and less than 2dB over 95% of the band.

- *Test:* Determine system temperatures and T_{cal} values for all bands at three frequencies per band, using hot and cold loads (high frequencies) or a hot load and cold sky (low frequencies). If feasible at low frequencies a liquid N_2 cold load should be used for one or two antennas in order to measure the cold sky system temperature.

• Antenna sensitivity.

- *Requirement:* The following sensitivity requirements supersede both the efficiency and T_{sys} requirements:

Band (GHz)	A_e/T_{sys} (m^2/K)	SEFD (Jy)
1–2	8.2	335
2–4	11.3	245
4–8	10.9	250
8–12	8.9	310
12–18	7.0	395
18–26.5	4.1	680
26.5–40	3.5	790
40–50 (low end)	2.4	1150
40–50 (high end)	1.0	2760

- *Test:* cold sky, low s/n observations to determine the noise statistics and measure SEFD and G/T at three frequencies in all bands.

• Complex gain stability of each receiver.

- *Requirement:* After all round trip phase corrections, but not including atmospheric instability or antenna deformation, the following is required:
  * Rms phase on timescale < 1 sec must be less than 0.5 psec.
  * Phase slope over a 30 minute time frame must be less than 0.2 psec/min.
  * Phase rms about the phase slope over 30 minutes must be less than 1.4 psec.

    * Phase change due to antenna motion must be less than 0.07 ps/degree of antenna move, up to 10 degrees, and 0.7 ps for any larger angle.
    * R–L phase must be < 0.5 ps for all timescales.
  - *Test:* Note that although there are as yet no formal requirements on amplitude stability, long-term monitoring of total power by an antenna pointed at the zenith, in clear, dry weather, at night and in winter, are needed to establish the amplitude stability. For the phase stability long-term monitoring of strong sources over several hours of observation is needed, at night, in winter, with short spacings, and in good weather. Pairs of widely-separated calibrators are needed to assess the effects of antenna motion.

- Linearity of power gain measurements to system power variations.
  - *Requirement:*
    * Changes in total system power must be monitored with an accuracy better than 0.5% for input powers up to 15dB above quiescent cold sky values.
    * Changes in total system power must be monitored with an accuracy better than 2% for input powers ranging from 15 to 50dB over quiescent cold sky values.
    * The headroom (input power ratio between the quiescent cold sky value and that at which 1% gain compression occurs) must be from 36dB at L-band to 25dB at Q-band, as specified in the EVLA Project Book.
  - *Test:* Use (1) a hot load to raise the system temperature by a known amount (for most bands, the increment over cold sky will be by about 10dB), and (2) observe the Sun. Compare the changes of the relevent total power monitors in the antenna to this known increment.

3. Polarization

- Cross-polarization response.
  - *Requirement:* Over an 8 hour period and under stable weather the on-axis RCP and LCP polarization ellipses must be stable to 0.002 in axial ratio, and 2° in position angle. The RCP and LCP on-axis polarization ellipse axial ratios must be between 0.9 and 1.0. This requirement corresponds to a maximum cross-polarization (D-term) of 5%.
  - *Test:* The relative cross-polarization responses can be measured using standard POLCAL runs and/or observations of an unpolarized source. Absolute cross-polarization responses can be obtained by including an EVLA antenna as part of VLBA polarization measurements.

4. Bandpass

- Bandpass amplitude and phase stability (full array).
  - *Requirement:* Variations in bandpass shape are to be less than 1 part in 10000, on a timescale of less than one hour, over frequency scales less than the band frequency/1000. Phase variations on the same frequency and time scales as given above are to be the same to within 6 millidegrees.
  - *Test:* A 10 minute integration on a 50 Jy object, with the full array, using a spectral resolution of $\sim 1/30$ of the requirement (e.g., 100 kHz at S-band) should enable measurement to this accuracy, presuming noise-limited performance is achieved.
- Bandpass amplitude and phase structure.
  - *Requirement:* The spectral power density slope at the input to the 3-bit sampler is to be less than 1.5 dB/GHz (or 3 dB across the full 2 GHz wide input). Fluctuations in the spectral power density about the mean slope must be less than 3 dB at the input to the sampler, and the spectral power is to vary by less than 3dB, and the phase is to vary by $< 2^\circ$, over a frequency scale of
    - 250 kHz at L-band
    - 500 kHz at S-band
    - 1 MHz at C and X bands
    - 2 MHz at all other bands
  - *Test:* Interferometric observations of a strong continuum source at all bands, initially for narrow bands with current correlator, and eventually wide band with WIDAR. Note that the prototype correlator may also be useful for these tests.

5. Transition phase specific tests

Not all of the above requirements need to be met in order for an EVLA antenna to be accepted back into the array during the transition from VLA to full EVLA. In particular, some of the receiver bands will not be available until later in the project. However, for those bands that do exist, an EVLA antenna should perform at least as well as the VLA antennas. Furthermore, there are other tests specific to the successful combined operation of EVLA and VLA antennas that need to be carried out during the VLA/EVLA transition.

Note that we assume here standard antenna acceptance by Operations, including determination of pointing models, baselines, delays, etc.

Astronomical EVLA/VLA transition phase tests include, but are not limited to:

- Check for large closure errors between VLA and EVLA antennas, possibly due to bandpass mismatch in continuum mode, through observations of a strong, unresolved, celestial calibrator. Assess the success of the FPGA fix for the phase gradient across the VLA bandpass relative to EVLA antennas.

- Check that the EVLA antennas can be phased up with the VLA antennas for VLBI work.
- Several observational tests are needed once two or more EVLA antennas are incorporated into the array. These are meant to represent typical, standard user observations. Initially (i.e., when there are only a few EVLA antennas), the main goals are to test for deleterious effects of the EVLA antennas on standard observations, and to monitor the performance of the EVLA antennas relative to VLA antennas (e.g., complex gains, data weights, bandpass shapes, D terms).
  - A deep (4–6 hour) integration: blank field? what frequency?
  - A dynamic range test on a bright source.
  - A short continuum and line observation at each band.
  - A polarization image.
  - A spectral line image.
  - An image requiring Doppler tracking.
  - A high spectral resolution line observation comprising a few hours on a bright calibrator. This can be used to check: (i) system sensitivity using rms phase and/or amplitude across the band, for a simple cross correlation spectrum between two antennas, and (ii) does this rms decrease with root time?
- A fast switching observation to determine source change times.