The VLA Expansion Project: Phase I Overview

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1 Scope

The overall goal of Phase I of the VLA Expansion Project is to improve all aspects of the VLA's instrumental performance, except its angular resolution, by at least an order of magnitude. This will be done by combining modern technologies with the existing antennas, array, and infrastructure. A realistic assessment of the impact of these techologies leads to the following, more specific, goals:

- **Sensitivity:** The continuum (full-bandwidth) sensitivity will be improved by a factor between two (at 1.5 GHz) and twenty (at the 24 and 45 GHz bands), through a combination of improved receivers, improved feeds, improved antenna efficiency, and wider bandwidths (up to 8 GHz per polarization).
- **Frequency Accessibility:** All frequencies between 1 and 50 GHz will accessible, through the use of eight separate frequency bands. Six of these bands are currently available, but with limited tuning. These will be upgraded with new receivers. Two new bands (3 GHz and 33 GHz) will be added. Note that the continuum sensitivity will not be uniform across each band, as the best sensitivity can only be gained with full bandwidth.
- **Spectral Capabilities:** A new, exceedingly flexible and powerful correlator will be built which will provide 16384 spectral channels (without recirculation), and up to 16 times more channels with recirculation. This correlator will have 16 indepedently tunable sub-bands in each of eight 2 GHz basebands, and provide full polarization information, over 50 dB spectral dynamic range, spectral resolutions between 1 Hz and 2 MHz, minimum integration times of 11 msec, and a variety of special pulsar binning capabilities.
- **Operations and Data Access:** As part of the Data Management Division's "end-to-end" processing philosophy, the EVLA will sport a vastly improved interface to all users — scientists, engineers, programmers, and telescope operators. Near-real-time access to all data products will be provided, including default images. All data products will be archived, and will be on-line.

A convenient table summarizing the existing and planned capabilities is shown below.

Table 1: **Key Capabilities of the Current and the Expanded VLA.**

Parameter	VLA	EVLA – Phase I The Ultrasensitive Array	EVLA – Phase II The New Mexico Array
Point Source Sensitivity	10μJy	0.8μJy	0.6μJy
No. of baseband pairs	2	4	4
Maximum bandwidth in each polarization	0.1 GHz	8 GHz	8 GHz
No. of frequency channels at maximum bandwidth	16	16,384[1]	16,384[1]
Maximum number of frequency channels	512	262,144	262,144
Maximum frequency resolution	381 Hz	$\sim$ 1 Hz	$\sim$ 1 Hz
(Log) Frequency coverage, 0.3−50 GHz	25%	75%	100%
No. of baselines	351	351	666
Spatial Resolution (5 GHz)	0.4 arcsec	0.4 arcsec	0.04 arcsec

[1]Up to 262,144 with lower sensitivity

2 Timeline

Table 2 shows the current (draft!) timeline for Phase I of the VLA Expansion Project; this will likely change over the next few months, as the project is laid out in more detail.

Table 2: **Timeline for Phase I of the VLA Expansion Project.**

Date	Activity
Aug 02	Start installing fiber on array. No antennas connected.
Apr 03	Choose EVLA Test Antenna near array center. Install new IF/LO/FO system. Test with new prototype M/C system. Some new and some old front-ends. Not available for observing.
Jul 03	Start interferometry tests between EVLA Test Antenna and VLA.
Oct 03	Freeze electronics design. Start electronics production.
Mar 04	Start installation of new IF/LO/FO system on antennas at 7 antennas/year. Full M/C capabilities available. EVLA antennas available for observing. Start installation of highest priority new front-ends.
Q3, 05	1–3 element correlator available for testing at that VLA.
Q4, 07	Start installation of new correlator in new correlator room at VLA.
Q1, 08	New correlator available for beta testing.
Mar 08	Last antenna converted to EVLA design.
Q1, 09	New correlator on-line, start testing.
Q4, 09	New correlator debugged & fully operational.
May 10	Last new receiver installed.

3 Scientific Capabilities

3.1 Frequency and Sensitivity

- Line and continuum point source sensitivities as shown in Figure 1, and listed in Table 3.
- Equivalent surface brightness sensitivities for the four configurations, assuming an object of angular size equal to the synthesized beam, as given in Table 4.

Table 3: **Frequency Coverage and Point Source Sensitivity of the EVLA, after Phase I.** Assumes dual-polarization observations with 27 antennas.

Band	Freq. [GHz]	Freq. Range [GHz]	$T_{\rm sys}$ [K]	η	Continuum $\Delta\nu$ [GHz]	Continuum rms noise [μJy] 2 min	Continuum rms noise [μJy] 12 hr	Line (1 km/sec) $\Delta\nu$ [kHz]	Line (1 km/sec) rms noise [mJy] 2 min	Line (1 km/sec) rms noise [mJy] 12 hr
L	1.5	1.0– 2.0	26	0.50	0.5	36	1.9	5	11	0.58
S	3.0	2.0– 4.0	29	0.62	1.5	21	1.1	10	7.6	0.40
C	6.0	4.0– 8.0	31	0.60	3.0	16	0.82	20	5.7	0.30
X	10	8.0–12.0	34	0.56	3.0	18	0.95	33	5.1	0.28
U	15	12.0–18.0	39	0.54	4.0	19	0.98	50	5.1	0.27
K	22	18.0–26.5	54	0.51	6.0	23	1.2	74	6.1	0.32
K_a	33	26.5–40.0	45	0.39	8.0	21	1.1	111	5.3	0.28
Q	45	40.0–50.0	66	0.34	5.0	46	2.4	150	7.6	0.40

Explanation of Table Entries

η: a general efficiency factor, including both aperture efficiency and correlator losses. Assumes a two-bit, four-level correlator.

$\Delta\nu$: the frequency width, per polarization, used in calculating the noise. For the continuum case, the width assumed is limited by the RFI environment at low frequencies, and by atmospheric opacity at the highest frequencies; for the spectral line case, this width corresponds to 1 km/sec at the central frequency of the band.

rms noise: the root-mean-square (1σ) thermal noise, assuming dual-polarization observations and a data weighting scheme chosen to give low noise with a reasonably small beam size (Briggs' robustness $\mathrm{R} = 0$).

Table 4: **Surface Brightness Sensitivity of the EVLA: A-Configuration.** For the **B**, **C**, and **D** configurations, multiply the beam size by 3.2, 10, and 32, and divide the rms noise by 10, 100, and 1000, respectively.

Freq. Range [GHz]	Synthesized Beam size [arcsec]	Continuum rms noise [K]		Line (1 km/sec) rms noise [K]	
		2 min	12 hr	2 min	12 hr
1.0- 2.0	1.6	11	0.57	3,300	170
2.0– 4.0	0.80	6.3	0.33	2,300	120
4.0– 8.0	0.40	4.8	0.25	1,700	90
8.0–12.0	0.25	5.4	0.30	1,500	84
12.0–18.0	0.17	5.7	0.30	1,500	81
18.0–26.5	0.12	6.9	0.36	1,800	96
26.5–40.0	0.08	6.3	0.33	1,600	84
40.0–50.0	0.06	14	0.72	2,300	120

Assumes the same parameters as in Table 3.

Beam size: full width at half maximum for the frequency at the center of the band, assuming the same data weighting as in Table 3.

rms noise: the root-mean-square (1σ) thermal noise as in Table 3, converted to the surface brightness sensitivity assuming a source whose size is equal to the beam size.

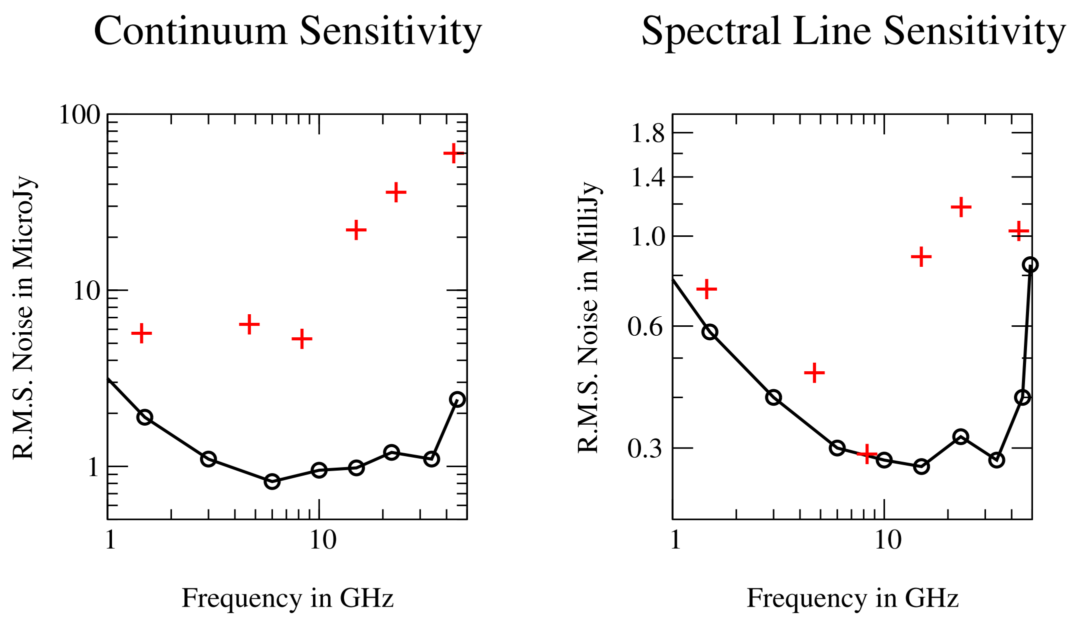

Figure 1: The current (+), and projected (o) continuum (left) and spectral line (right) point source sensitivity (1σ in 12 hours) of the VLA after Phase I of the Expansion Project is completed. For the continuum plot, the bandwidths of Table 3 are assumed. For the spectral line plot, the assumed bandwidth corresponds to a velocity width of 1 km/sec. The width of the '+' symbols demonstrates the approximate range of tuning with the current VLA. The EVLA will be continuously tunable over the entire band.

3.2 Bandwidths

The WIDAR correlator will accept up to 8 independent inputs (basebands) each up to 2 GHz wide, normally constituting 4 pairs of oppositely-polarized signals. The correlator digitially sub-divides each baseband into 16 sub-bands, with bandwidths selectable from 128 MHz to 31 kHz, in steps of a factor of two.

3.3 Correlator Modes

This defies short description. In its fundamental, full-bandwidth mode, the correlator offers 16,384 channels per baseline over 16 GHz total bandwidth (summing over both polarizations). The correlator can operate in reduced bandwidth with more bits (to allow higher spectral dynamic range at the lower frequencies), or at higher frequency resolution. Recirculation can be used to increase the number of channels up to 262,144[1]. Also, one can trade basebands or sub-bands for spectral

[1]This can be done even at the widest bandwidths, at a cost in sensitivity proportional to the increase in number of channels.

resolution in a very flexible way. There can be any number of 'normal' subarrays, and up to five phased-array subarrays per sub-band.

3.3.1 Pulsar Processing

There are two bandks of 1000 time bins each per baseline; one bank is active while the other is being downloaded, or one can use them as a single bank of 200 bins with the consequent correlator down time for dumping. If all spectral channels are dumped, the minimum bin width is $\sim 200\,\mu$sec; if only 64 channels/sub-band/baseline are dumped, the time bin can be as narrow as $\sim 15\,\mu$sec. Pulsar gating is available, with one timer and multi-gate generator for each of the eight 2 GHz analog basebands. The multi-gate generator can produce 16 pulsar gates with configurable delays so that each sub-band can be gated "on" at different times to track the pulse across frequency.