The Next-Generation Very Large Array Technical Overview

Mark McKinnon, Robert Selina
National Radio Astronomy Observatory, Socorro, NM 87801

ngVLA Concept

The ngVLA will be a synthesis radio telescope constituted of approximately 214 reflector antennas each of 18 meters diameter, operating in a phased or interferometric mode. It will operate over a frequency range extending from 1.2 GHz to 116 GHz.

The signal processing center of the array will be located at the Very Large Array site, on the plains of San Agustin, New Mexico. The array will include stations in other locations throughout the state of New Mexico, west Texas, eastern Arizona, and northern Mexico.

Operations will be conducted from both the VLA Control Building and the Array Operations Center in Socorro, NM.

Table 2: ngVLA Key System Parameters

Parameter	Value
Antenna Diameter	18m Homogeneous Array
Number of Antennas	214
Antenna Optics	Offset Gregorian, Feed Low, Shaped
Frequency Range	1.2 GHz – 50.5 GHz, 70 GHz – 116 GHz
Front Ends	Single Pixel Feeds, Dual Linear Polarization
Instantaneous Bandwidth	Up to 20 GHz / pol.

ngVLA Configuration

The array configuration is shown in Figure 1. The array collecting area is distributed to provide high surface brightness sensitivity on a range of angular scales spanning from approximately 1000 to 10 mas. In practice, this means a core with a large faction of the collecting area in a randomized distribution to provide high snapshot imaging fidelity, and arms extending asymmetrically out to ~1000 km baselines, filling out the (u,v)-plane with Earth rotation and frequency synthesis.

Investigations are underway to improve the imaging sensitivity and fidelity while accounting for practical limitations such as utility availability.

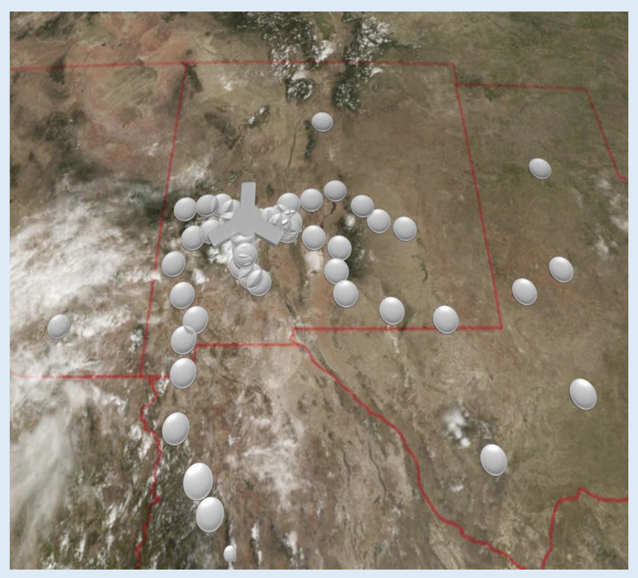


Figure 1: Approximate locations of ngVLA antennas.

Table 3: ngVLA Configuration Parameters

Parameter	Value
Antenna Locations	Fixed Configuration
(Minimum) Array Extent	500 km + (Evaluating 500-1000km scales)
Radial Distribution of Collecting Area	40/40/20 % at 2/50/500 km scales

ngVLA Antenna

The antennas will be constituted of a shaped paraboloidal reflector, with a subtended circular aperture of 18 m diameter. The optical configuration is an offset Gregorian feed-low design supported by an Altitude-Azimuth mount.

The subreflector will be supported so that neither it nor any of its supporting structure obstructs the aperture of the primary reflector. If necessary to meet the performance requirements, the position of the subreflector may be remotely adjusted with a controlled mechanism.

The off-axis geometry minimizes scattering, spillover, and sidelobe pickup, and the feed-low design facilitates maintenance and reduces shadowing in the core of the array.

The mount concept is presently undefined. Both wheel-and-track and pedestal concepts are under investigation (Figure 2), with the pointing specification a design driver.

The project is pursuing a reference design to specifications with General Dynamics Mission Systems. A parallel study into a composite design concept with National Research Council of Canada is also underway. Both costed designs will be delivered in the fall of 2018.

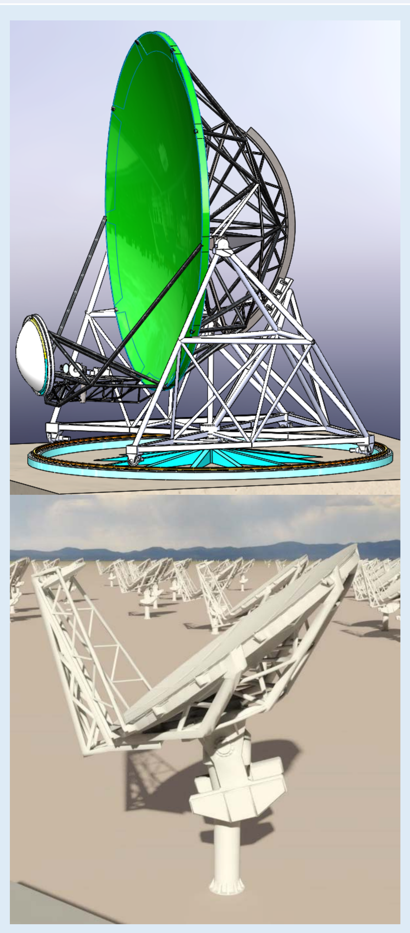


Figure 2: NRC & NRAO Antenna Concepts.

Abstract

As part of its mandate as a national observatory, the NRAO is looking toward the long range future of radio astronomy and fostering the long term growth of the US astronomical community. NRAO has sponsored a series of science and technical community meetings to consider the science mission and design of a next-generation Very Large Array (ngVLA), building on the legacies of the Atacama Large Millimeter/submillimeter Array (ALMA) and the Very Large Array (VLA).

The basic ngVLA design emerging from these discussions is an interferometric array with approximately ten times the sensitivity and ten times higher spatial resolution than the VLA and ALMA radio telescopes, optimized for operation in the wavelength range 0.3cm to 3cm (1.2 GHz to 116 GHz). The ngVLA will open a new window on the Universe through ultra-sensitive imaging of thermal line and continuum emission down to milliarcsecond resolution, as well as unprecedented broadband continuum polarimetric imaging of non-thermal processes. The specifications and concepts for major ngVLA system elements are rapidly converging.

We provide an overview of the current system design of the ngVLA. The concepts for major system elements such as the antenna, receiving electronics, and central signal processing are presented. We also describe the major development activities that are presently underway to advance the design.

Table 1: ngVLA Key Performance Metrics

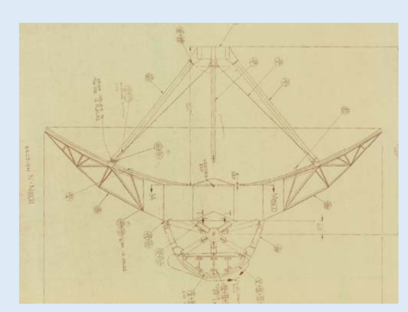
Parameter [units]	2.4 GHz	8 GHz	16 GHz	27 GHz	41 GHz	93 GHz	*Notes*
Band Lower Frequency, f_L	1.2 GHz	3.5 GHz	12.3 GHz	20.5 GHz	30.5 GHz	70.0 GHz	*a*
Band Upper Frequency, f_H	3.5 GHz	12.3 GHz	20.5 GHz	34.0 GHz	50.5 GHz	116.0 GHz	*a*
Field of View FWHM [arcmin]	24.4	7.3	3.7	2.2	1.4	0.6	*b*
Aperture Efficiency [%]	0.75	0.75	0.77	0.75	0.72	0.53	*b*
Effective Area, $A_{eff,}$ x 10^3 [m^2]	40.8	40.8	41.9	40.8	39.2	28.9	*b*
System Temp, T_{sys} [K]	19 K	21 K	19 K	28 K	45 K	61 K	*a, f*
Max Inst. Bandwidth [GHz]	2.3 GHz	8.8 GHz	8.2 GHz	13.5 GHz	20.0 GHz	20.0 GHz	*a*
Antenna SEFD [Jy]	280.5	310.0	273.2	413.4	692.0	1274.4	*a, b*
Resolution of Max. Baseline [mas]	**26**	**8**	**4**	**2.3**	**1.5**	**0.7**	*c*
Resolution FWHM @ Natural Weighting [mas]	**163**	**49**	**24**	**14**	**10**	**4**	*c, d*
Continuum rms, 1 hr [μJy/beam]	0.35	0.20	0.18	0.21	0.29	0.53	*d*
Line Width, 10 km/s [kHz]	80.00	266.67	533.33	900.00	1366.67	3100.00	
Line rms, 1 hr, 10 km/s [μJy/beam]	58.9	35.6	22.2	25.9	35.1	43.0	*d*
Resolution [mas]	**1000**						
Continuum rms, 1 hr, Robust [μJy/beam]	0.68	0.43	0.41	0.51	0.72	1.41	*e*
Line rms 1 hr, 10 km/s Robust [μJy/beam]	115.7	77.9	51.4	62.4	87.4	113.3	*e*
Brightness Temp (T_B) rms continuum, 1 hr, Robust [K]	0.1441	0.0082	0.002	0.0008	0.0005	0.0002	*e*
T_B rms line, 1 hr, 10 km/s, Robust [K]	24.43	1.48	0.24	0.10	0.06	0.02	*e*
Resolution [mas]	**100**						
Continuum rms, 1 hr, Robust [μJy/beam]	0.54	0.35	0.34	0.42	0.60	1.18	*e*
Line rms 1 hr, 10 km/s Robust [μJy/beam]	90.8	62.9	42.0	51.4	72.5	95.2	*e*
Brightness Temp (T_B) rms continuum, 1 hr, Robust [K]	0.1804	0.0954	0.114	0.0651	0.0360	0.0387	*e*
T_B rms line, 1 hr, 10 km/s, Robust [K]	1917.16	119.44	19.95	8.57	5.25	1.34	*e*
Resolution [mas]	**10**						
Continuum rms, 1 hr, Robust [μJy/beam]	-	0.26	0.26	0.33	0.48	0.96	*e*
Line rms 1 hr, 10 km/s Robust [μJy/beam]	-	47.8	32.6	40.5	57.7	77.0	*e*
Brightness Temp (T_B) rms continuum, 1 hr, Robust [K]	-	2.5188	6.4845	6.0060	4.6955	6.3142	*e*
T_B rms line, 1 hr, 10 km/s, Robust [K]	-	9078.35	1548.66	674.89	417.13	108.22	*e*

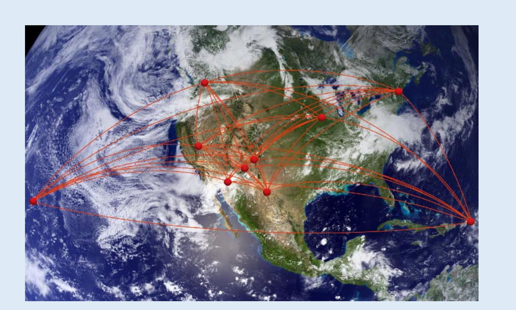
(a) 6-band 'baseline' receiver configuration.
(b) Reference design concept of 214 18m aperture antennas. Unblocked aperture, shaped optics, with 160um surface rms.
(c) 'South West' Configuration by E. Greisen, with 1000km baselines added. Resolution in EW axis.
(d) Using Natural Weights, dual pol, and all baselines.
(e) Using Weights as described in ngVLA Memo #16, scaled by frequency.
(f) At the nominal mid-band frequency shown. Assumes 1mm PWV for W-band, 6mm PWV for others; 45 deg elev. on sky for all.

Options

The baseline design of the ngVLA provides a highly capable, coherent and expandable instrument. Three options (not presently included in the baseline design) are under evaluation to better support the astronomical community:

- A low-frequency (<1 GHz) array, consisting of aperture arrays at the remote sites, leveraging infrastructure that serves the reflector antennas. Commensal feeds may also be installed for <1GHz observation on the reflector antenna array.
- A pulsar timing telescope installing ngVLA technology on the VLA antennas in order to reduce their operation cost in a tailored installation. Up to 80% of clock hours could be available for pulsar timing employing a 1-3.5 GHz receiver system.
- Upgrading the VLBA sites with ngVLA technology, and possibly ngVLA dishes, to integrate the ngVLA into a continental-scale VLBI network for astrometry and geodesy applications.





Feed / Receiver Configuration

The baseline ngVLA receiver configuration consists of the low-frequency receiver (1.2 – 3.5 GHz) in one dewar, and receivers spanning from 3.5 to 116 GHz in a second dewar.

Band 1 and 2 employ wideband feed horns and LNAs, each covering L+S band, C+X band.

Quad-ridged feed horns (QRFH) are used, with coaxial outputs. Due to improved optical performance (reducing T_{SPILL}), cooled feeds, and the simplified RF design sensing linear polarization, the T_{SYS} is lower than current VLA L, S bands and comparable for C and X bands. Overall aperture efficiency and Tsys is slightly degraded from optimal due to the wider bandwidths spanned by each receiver, but it permits a compact package that can be affordably constructed and operated.

The four high-frequency bands (12.6 – 116 GHz) employ waveguide-bandwidth (~1.67:1) feeds & LNAs, for optimum noise performance. Axially-corrugated feed horns, with circular waveguide output ensure even illumination over frequency and minimal loss.

The electronics concept relies on integrated receiver packages to further amplify the signals provided by the cryogenic stage, down convert them if necessary, digitize them, and deliver the resultant data streams by optical fiber to a moderately remote collection point where they can be launched onto a conventional network for transmission back to the array central processing facility. Hooks are needed to provide for synchronization of local oscillators (LO's) and sample clocks, power leveling, command and control, health and performance monitoring, and diagnostics for troubleshooting in the event of component failure.

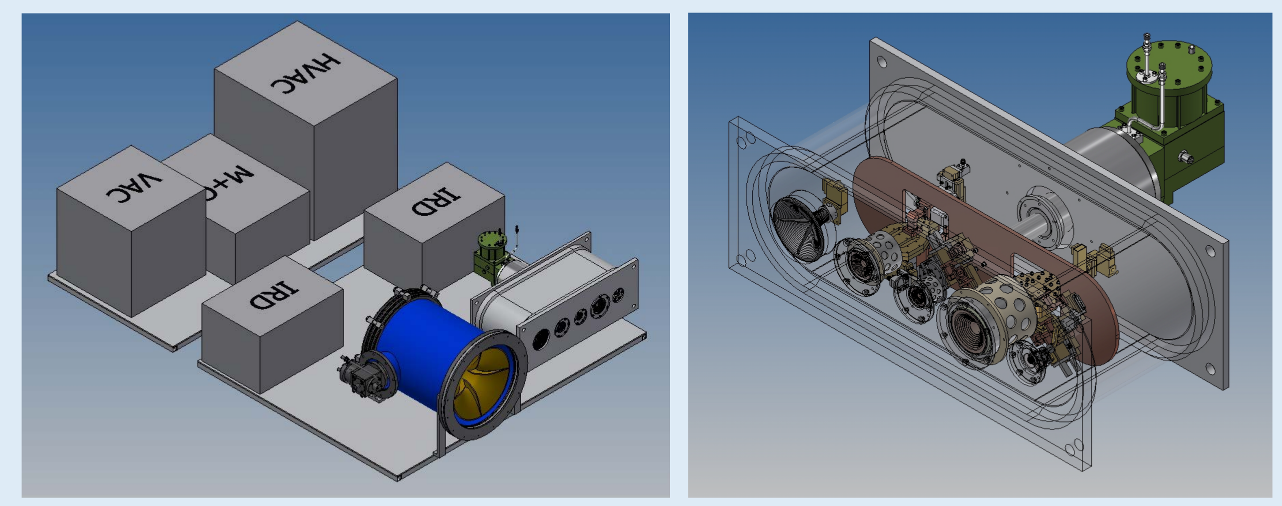


Figure 3: Front end component packaging at the secondary focus of the antenna. Band selection and focus are achieved with a dual-axis translation stage.

Signal Processor & Data Pipelines

The correlator is the central signal processor for the voltage streams recorded and packetized by the antennas and transmitted via the data transmission system. An FX correlator architecture will be employed, with an instantaneous processed bandwidth of up to 20 GHz. A distributed F-engine and coarse channelizer is under consideration, as is the technology platform (FPGA vs ASIC).

The central signal processor will include commensal observing capabilities to permit the division of the array into sub-arrays and the processing of single-dish and single-baseline data in multiple ways, such as concurrent cross-correlation and transient search. Phased array modes will support VLBI recording, pulsar timing, pulsar search, and transient search with multiple beams within the antenna primary beam. The degree of commensality required is presently under evaluation, as is the sub-system architecture to most efficiently support the identified operating modes.

The correlator's fundamental data product to the archive will be raw/uncalibrated visibilities. The correlator will include all necessary infrastructure to average visibilities and package them for the central archive, where they will be recorded to disk in a standard format.

Automated post-processing pipelines will calibrate the raw data and create higher level data products (typically image cubes) that will be delivered to users via the central archive. Data analysis tools will allow users to analyze the data directly from the archive, reducing the need for data transmission and reprocessing at the user's institution.

The VLA and ALMA "Science Ready Data Products" project will be an ngVLA pathfinder to identify common high-level data products that will be delivered to the Principal Investigator and the data archive to facilitate data reuse.

References

R. Selina, E. Murphy. *ngVLA Reference Design Development & Performance Estimates*, *ngVLA Memo #17*. (2017)
R. Selina et al. *ngVLA Antenna: Preliminary Technical Specifications*. Version A. (2017)
W. Grammer et al. *ngVLA Baseline Receiver Configuration*. Version 4.2 (2017)
E. Murphy et al. *ngVLA Overview* (2017)
M. Morgan, S. Wunduke. *An Integrated Receiver Concept for the ngVLA, ngVLA Memo #29.* (2017)
R. Selina et al. ngVLA Operations Concept. Version 14/Draft (2017)

ngvla

NRAO

NSF

Associated Universities, Inc.

The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.