The Next-Generation Very Large Array: A Technical Overview

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ngVLA Concept

The ngVLA will be a synthesis radio telescope constituted of approximately 244 reflector antennas each of 18 meters diameter, and 19 reflector antennas each of 6 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. Long baseline stations are located in Hawaii, Washington, California, Iowa, Massachusetts, New Hampshire, Puerto Rico, the US. Virgin Islands, and Canada.

Array Operations will be conducted from both the VLA Site and the Array Operations and Repair Centers in Socorro, NM. A Science Operations Center and Data Center will likely be collocated in a large metropolitan area and will be the base for science operations and support staff, software operations, and related administration. Research and development activities will be split amongst these centers as appropriate.

Table 2: ngVLA Key System Parameters

Parameter	Value
Antenna Diameter	18m Main Array, 6m Short Baseline Array, 18m Total Power
Number of Antennas	244 x 18m, 19 x 6m
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 and Figure 2. The array collecting area is distributed to provide high surface brightness sensitivity on a range of angular scales spanning from a few arcsececonds to a milliarcsecond. While a single array, it can be divided logistically into the following components:

A main array of 214 reflector antennas each of 18 meters diameter, operating in a phased or interferometric mode. The main array is distributed to sample a wide range of scales from 10s of meters to 1000 km. A dense core and spiral arms provide high surface brightness sensitivity, with mid-baseline stations enhancing angular resolution.

A short baseline array (SBA) of 19 reflector antennas of 6m aperture will be sensitive to a portion of the larger angular scales undetected by the main array. The SBA may be combined with 4 18m (main-array) antennas used in a total power mode to completely fill in the central hole in the (u,v)-plane left by the 6m dishes.

A long baseline array (LBA) with 30 reflector antennas each of 18m diameter in 10 clusters providing continental scale baselines (B_{MAX} ~ 8860 km). The LBA is designed to sample a broad range of scales for stand-alone sub-array use, as well as for integrated operation with the main array.

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

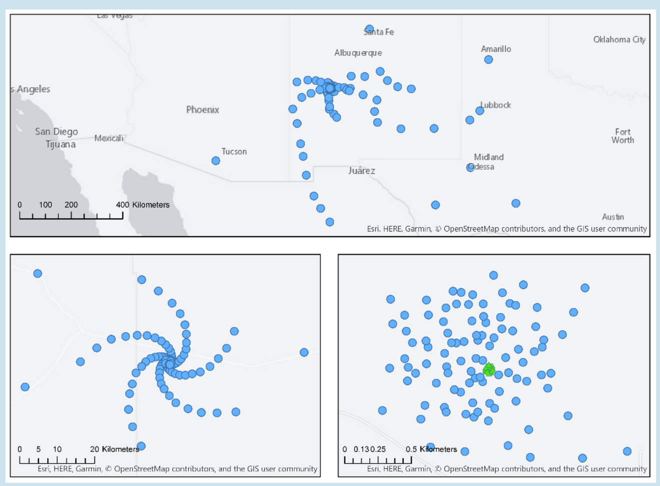

Figure 1 - Top: ngVLA Main Array Configuration Rev. C. Bottom Left: Zoom view of the plains of San Agustin. Bottom Right: Zoom view of the compact core. SBA antennas are shown in green

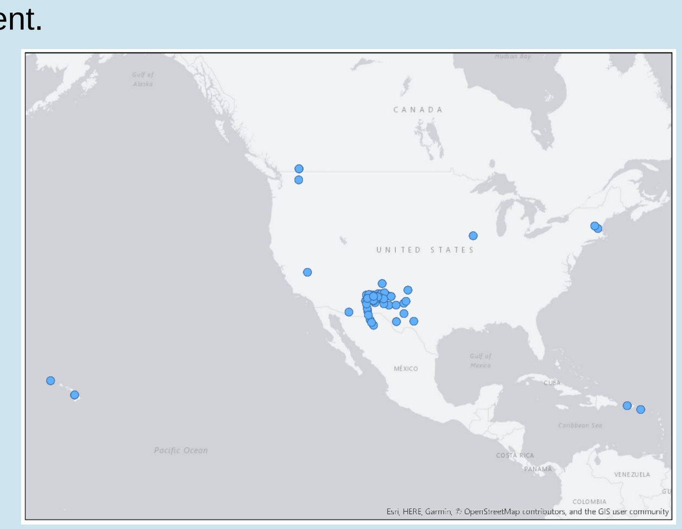

Figure 2 - View of the Main Array and Long Baseline Array stations. Multiple antennas are located at each LBA site. All antenna positions are still notional, but are representative for performance quantification and cost estimation

ngVLA Antenna

The main array antennas will be constituted of a shaped paraboloidal reflector, with a subtended circular aperture of 18m 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.

Two concepts have been developed by General Dynamics Mission Systems (GDMS) and the National Research Council of Canada (NRCC). The GDMS design is based on the successful MeerKAT antenna concept, while the NRCC design employs a single piece composite reflector and composite outer backup structure on a steel yoke and pedestal mount. The project is in the process of awarding three additional contracts for costed antenna design concepts, in advance of a conceptual design down select in 2020.

Abstract

The next-generation Very Large Array (ngVLA) is an astronomical observatory planned to operate at centimeter wavelengths (25 to 0.26 centimeters, corresponding to a frequency range extending from 1.2 GHz to 116 GHz). The observatory will be a synthesis radio telescope constituted of approximately 244 reflector antennas each of 18 meters diameter, operating in a phased or interferometric mode.

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

Receiver Band	B1	B2	B3	B4	B5	B6	Notes
Band Lower Frequency [GHz]	1.2	3.5	12.3	20.5	30.5	70.0	a
Band Upper Frequency [GHz]	3.5	12.3	20.5	34.0	50.5	116.0	a
Field of View FWHM [arcmin]	24.3	7.3	3.6	2.2	1.4	0.6	b
Aperture Efficiency	0.77	0.76	0.87	0.85	0.81	0.58	b
Effective Area, $A_{eff,}$ x 10^3 [m^2]	47.8	47.1	53.8	52.6	50.4	36.0	b
System Temp, T_{sys} [K]	25	27	28	35	56	103	a, f
Max Inst. Bandwidth [GHz]	2.3	8.8	8.2	13.5	20.0	20.0	a
Sampler Resolution [Bits]	8	8	8	8	8	4	
Antenna SEFD [Jy]	372.3	419.1	372.1	485.1	809.0	2080.5	a, b, f
Resolution of Max. Baseline [mas]	2.91	0.87	0.44	0.26	0.17	0.07	c
Continuum rms, 1 hr [μJy/beam]	0.38	0.22	0.20	0.21	0.28	0.73	d
Line Width, 10 km/s [kHz]	80.1	266.9	533.7	900.6	1367.6	3102.1	
Line rms, 1 hr, 10 km/s [μJy/beam]	65.0	40.1	25.2	25.2	34.2	58.3	d

(a) 6-band 'baseline' receiver configuration.
(b) Reference design concept of 244 18m aperture antennas. Unblocked aperture with 160um surface. Center of band.
(c) Rev. C Configuration. Resolution in EW axis.
(d) Using Natural Weights, dual pol, and all baselines.
(f) Averaged over the band. Assumes 1mm PWV for W-band, 6mm PWV for others; 45 deg elev. on sky.

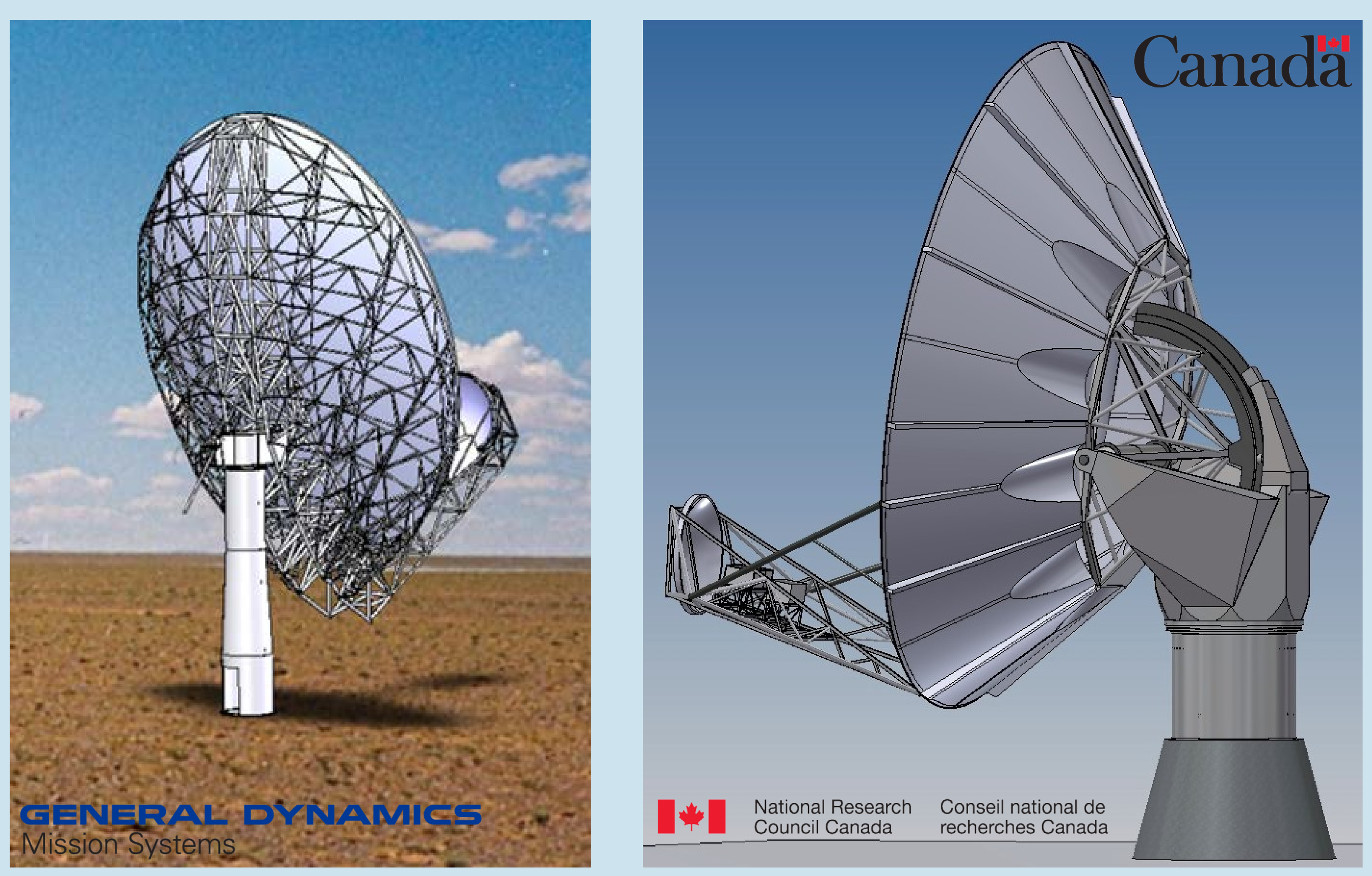

Figure 3: GDMS 18 m (Left) and NRCC 18m (Right) Antenna Concepts. Courtesy of GDMS and NRCC.

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 edges and system temperatures are shown in Table 1.

Bands 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 T_{SYS} 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.

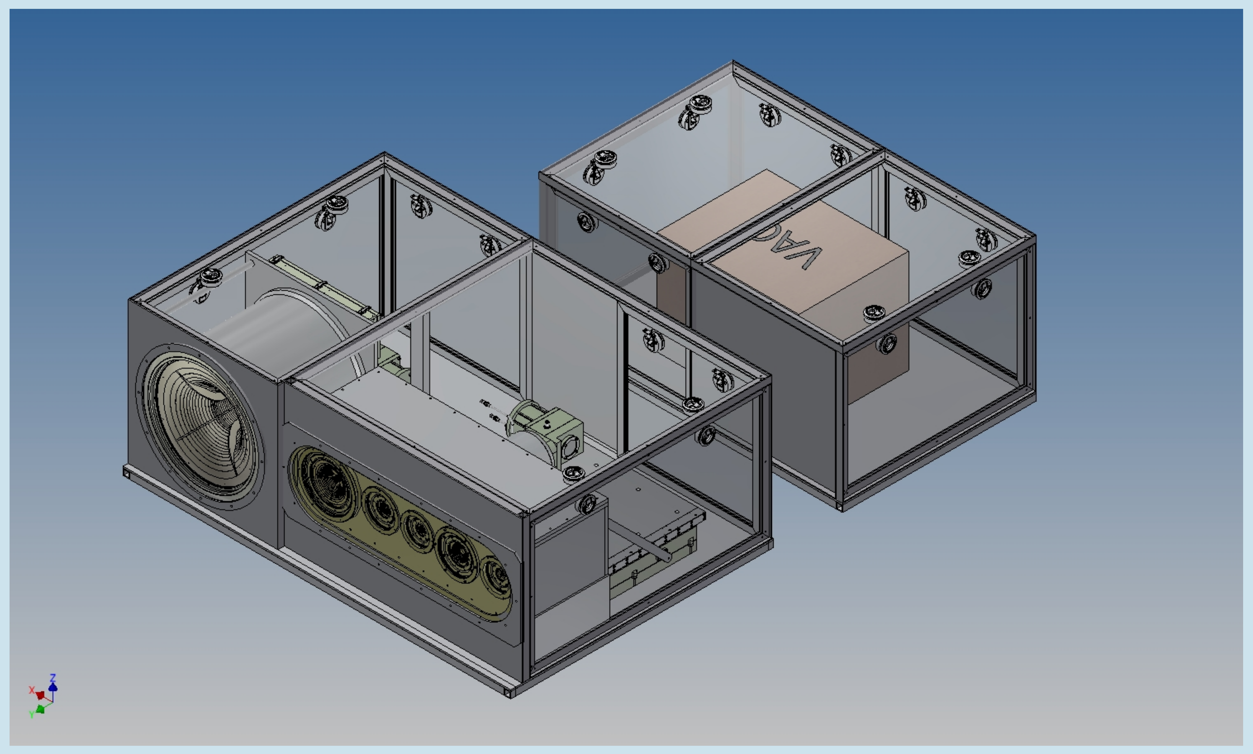

Figure 4: Front end component packaging at the secondary focus of the antenna. Band selection and focus are achieved with a dual-axis translation stage.

Signal Processor & Data Pipelines

The CSP ingests the voltage streams recorded and packetized by the antennas and transmitted via the data transmission system, and produces a number of low-level data products to be ingested by the archive. In addition to synthesis imaging, the CSP will support other capabilities required of modern telescopes to enable VLBI and time-domain science. The functional capabilities of the CSP include: auto-correlation, cross-correlation, beamforming, pulsar timing, pulsar search, and VLBI recording.

The CSP data products will vary by operation mode. The most common will be raw/uncalibrated visibilities, recorded in a common data model. The CSP will include all necessary "back end" infrastructure to average visibilities and package them for the archive, where they will be recorded to disk in a standard format. Calibration of these data products will be the responsibility of asynchronous data post-processing pipelines that are outside the scope of the CSP element.

The ngVLA correlator will employ an FX architecture, and will process an instantaneous bandwidth of up to 20 GHz per polarization. The correlator-beamformer Frequency Slice Architecture developed by NRC Canada for the SKA Phase 1 CSP Mid Telescope has been scaled for the ngVLA reference design implementation and a variant is under consideration for the conceptual design. This architecture will scale to the additional ngVLA apertures, bandwidth, and commensal mode requirements. Leveraging this existing development effort would significantly reduce the non-recurring engineering costs during the design phase, while additional improvements in electrical efficiency can be expected from one additional FPGA manufacturing process improvement cycle due to ngVLA's later construction start date.

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 detailed definition of the standard observing modes is in progress, including the identification of common high-level data products that will be delivered to the Principal Investigator and the data archive to facilitate data reuse.

Further Information

R. Selina et. al. *The Next-Generation Very Large Array: A Technical Overview.* , SPIE Astronomical Telescopes & Instrumentation, AS18, 10700-55, (2018)

R. Selina et. al. *The Next-Generation Very Large Array: Reference Design, Vol I-III. (2019)*

http://ngvla.nrao.edu/

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