# Overview of Specifications for the NGVLA


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The NRAO has announced the formation of working groups to discuss and develop the science case for a next-generation large array for centimeter-wave (0.3-30cm) astronomy. This is in preparation for the community workshop at the AAS meeting in Jan 2015. To aid in these discussions, we have prepared this short description of the expected specifications and trade-offs for each.

## Frequency Coverage

Spec: 5-100 GHz
Goal: 1-118 GHz

Notes: The choice of upper frequency limit has strong impact on required surface accuracy and pointing. Choice of lower frequency has strong impact on optics design. Also, outfitting of array need not be homogeneous. Inner array (<36km) could be outfitted to 100+ GHz, outer array to 50 GHz (perhaps with some stations at 100+ GHz). Will be driven by key science.

## Instantaneous RF Bandwidth

Refers to the bandwidth ratio ($\nu_{max}/\nu_{min}$) of a single feed or focal element giving the range of radio frequencies (RF) that are output by the receivers. This defines the maximum bandwidth that a given receiver can observe at once.

Spec: 3:1 (e.g. 5-15GHz, 15-45GHz)
Goal: 5:1-10:1 (e.g. 1-10GHz, 5-50GHz)
Stretch Goal: more than 10:1 (e.g. 1-100GHz!!)

Notes: ultra-wide band feeds (>5:1??) are unproven and generally have wide-angle patterns and thus place requirements on optics. There are likely sensitivity losses for wider bandwidth feeds compared to more standard 2:1 systems in use now.

## Instantaneous Processed Bandwidth

This is the bandwidth coming out of the correlator and accessible to the user. Ideally this is fully matched to the RF bandwidth of the receivers, but in practice this is limited by the digital sampling at the receiver and the correlator set-up (e.g. higher frequency resolution modes cover less bandwidth). Note that 2MHz resolution at 20GHz is $R=10^4$ (30km/s), twice that at 40GHz (15km/s).

Spec: all available RF bandwidth at 2MHz "continuum" resolution (e.g. JVLA)
Goal: all available RF bandwidth at 0.2MHz (3km/s at 20GHz)

## Total Collecting Area

Spec: 5x VLA
Goal: 10x VLA

Notes: this refers to physical area for simplicity, though the instantaneous sensitivity of the array really depends on effective area / Tsys. Note that having a large collecting area made out of small antennas has big impact on operations cost (e.g. number of cryo-cooled receivers) and interconnect (fiber and correlator/beamformer).

## Maximum Baseline Length

This gives the resolution in a naturally weighted image (other weightings give better resolution at decreased sensitivity). Current VLA gives 3″ at 1 GHz.

Spec: resolution ~ 0.6″ at 1GHz, 12 mas at 50GHz (180km max. baseline, 5xVLA)
Goal: resolution ~ 0.3″ at 1GHz, 6 mas at 50GHz (360km max. baseline, 10xVLA)

Notes: Impact on length of fiber runs, and surface brightness sensitivity (for a given antenna location density profile). This is for a "New Mexico" Array. A "Northern Hemisphere" Array with VLBI capability is also possible, and this array would be a key part of a new Ultra-High Sensitivity Array when combined with the new generation of large antennas being constructed by our international partners.

## Field of View (FOV)

Instantaneous (single pixel feed) IFOV: this is given by $\sim\lambda/D$ for dish diameter D.

- IFOV = 94′ at 1GHz, 1.9′ at 50GHz (D=12m)
- IFOV = 62′ at 1GHz, 1.25′ at 50GHz (D=18m)
- IFOV = 45′ at 1GHz, 0.9′ at 50GHz (D=25m)

Note: If the ability to employ multi-beam or phased-array camera receivers is desired, then there will be significant impact on the optics to enable a wide area of the focal plane to be usable. This will likely come at cost of on-axis performance (e.g. no shaped optics).

## Operating Modes and Other Specifications

These are specifications that impact overall design and cost less, and we do not want at this time to unduly restrict the exploration of science drivers. However, input to us on what is needed will help guide the final design (e.g. of the correlator and observing system). These include:

- Number of independent "spectral sub-band windows" : several anticipated. To be determined by science use cases.
- Minimum Channel Width: down to 1Hz using correlator recirculation over reduced bandwidth
- Minimum Time resolution: <1ms for limited periods or for commensal processing.
- Number of simultaneous subarrays: several anticipated. To be determined by science use cases.
- Antenna Feed Polarization Basis: not decided. Either circular or linear.

## Site

We are envisioning this as a future array built out from the VLA in New Mexico, to make maximal (re)use of existing infrastructure and radio-quiet environment, and to exploit the proven high-frequency observing conditions in the high-plains of this region.

## Array Configuration

Fixed pads in outer array, likely at stations located near existing fiber. Core array (within the VLA C-configuration footprint) also likely using antennas on fixed pads.

## Sensitivity

The point-source and surface brightness sensitivity of the array depend upon the other parameters of the instrument, including the detailed configuration of the array with antenna locations. For the purposes of discussion, we can take the VLA sensitivity (e.g. from the exposure calculator) and scale with collecting area (and resolution for surface brightness). This assumes the receiver performance (Tsys) is as good as the JVLA. As an example, for 10 hours of observing, the image rms (natural weighting) is:

| Image rms (natural weighting) | | |
|---|---|---|
| **Collecting Area** | **σ (10hrs, 5-15GHz)** | **σ (10hrs, 20-40GHz)** |
| 1 x VLA | 500 nJy | 920 nJy |
| 5 x VLA | 100 nJy | 184 nJy |
| 10 x VLA | 50 nJy | 92 nJy |

These numbers were calculated using the VLA online Exposure Calculator, assuming wide-band digitizer performance similar to our current 8-bit system.

The surface brightness corresponding to a given flux density limit for a fixed array depends only upon the baseline distribution (not frequency in Rayleigh-Jeans limit). Scaling to the VLA distribution (A configuration with 36.5km baselines), it is approximately given by

$$T_b \approx 0.14\ \mathrm{K} \left(\frac{S}{1\ \mu\mathrm{Jy}}\right) \left(\frac{B}{36.4\ \mathrm{km}}\right)^2$$

for flux density S and maximum baseline B. The details of the antenna location distribution matter, and can perhaps improve this by a factor of two if you move from the VLA 3-arm power law to a more tapered distribution better matched to naturally weighting the uv-plane. However, for arrays going out to 150-400 km, it is not clear at this time how optimal we can make the configuration (particularly as we do not yet know the size and thus number of antennas and stations). Keep this in mind when using these conservative estimates of surface brightness sensitivity.

Thus, the surface brightness limits for our above flux density limits and maximum baselines of 1, 5, and 10 times VLA A-configuration are:

| **Continuum Image rms in Kelvin (10 hours, natural weighting)** | | | | | | |
|---|---|---|---|---|---|---|
| | **Max B (5-15GHz)** | | | **Max B (20-40GHz)** | | |
| **Area** | **36.4km** | **182km** | **364km** | **36.4km** | **182km** | **364km** |
| 1 x VLA | 0.070 | 1.75 | 7.0 | 0.129 | 3.23 | 12.9 |
| 5 x VLA | 0.014 | 0.35 | 1.4 | 0.026 | 0.65 | 2.6 |
| 10 x VLA | 0.007 | 0.17 | 0.7 | 0.013 | 0.32 | 1.3 |

Finally, the line sensitivities in mJy and Kelvin in 1 km/s frequency resolution (0.1MHz at 30 GHz) again for 10 hours of observation are:

| | | **Max B (5-15GHz)** | | |
|---|---|---|---|---|
| **Area** | **Image rms σ (10hrs, 30GHz)** | **36.4km** | **182km** | **364km** |
| 1 x VLA | 340 μJy | 47.6 K | 1190 K | 4760 K |
| 5 x VLA | 68 μJy | 9.5 K | 238 K | 952 K |
| 10 x VLA | 34 μJy | 4.8 K | 119 K | 476 K |

## Useful References

Jansky VLA Sensitivity Calculator: https://obs.vla.nrao.edu/ect

Astro2020 White Paper "The North America Array": http://science.nrao.edu/A2010/rfi/PPP-NAA-edited.pdf