The Next-Generation Very Large Array Antenna Reference Design

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ngVLA Array Concept

The ngVLA will be a synthesis radio telescope constituted of approximately 244 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 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 1: 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.

General Dynamics Mission System Antenna Concept

The low-technical-risk antenna analog for the ngVLA antenna study was developed by General Dynamics Mission Systems. The design is to a specification developed by the ngVLA project team with an optical design advanced by the National Research Council of Canada.

The GDMS concept is scaled from the successful 13.5m MeerKAT antenna design. The offset Gregorian optics are provided by an aluminum segmented main reflector and a single piece subreflector. These are supported by a steel radial truss structure and feed arm. A central cavity in the backup structure eliminates interference with the pedestal while moving the azimuth axis closer to the reflector surface. This reduces the need for counterweight to allow for faster slew and settle times.

GDMS investigated several mount configurations and decided on a pedestal with turnhead concept due to favorable construction and operations cost (all else being equal). The servo system relies on a gear box drive for azimuth rotation and a jack screw for elevation.

Given the large number of antennas needed for the ngVLA, the design approach for the study was to select a cost effective antenna mount configuration to meet the economic and performance goals, determine the performance obtained from this structure using conventional materials (carbon steel and aluminum) and ultimately provide a baseline structure where cost/performance/specification trades can be conducted to resolve identified nonconformances.

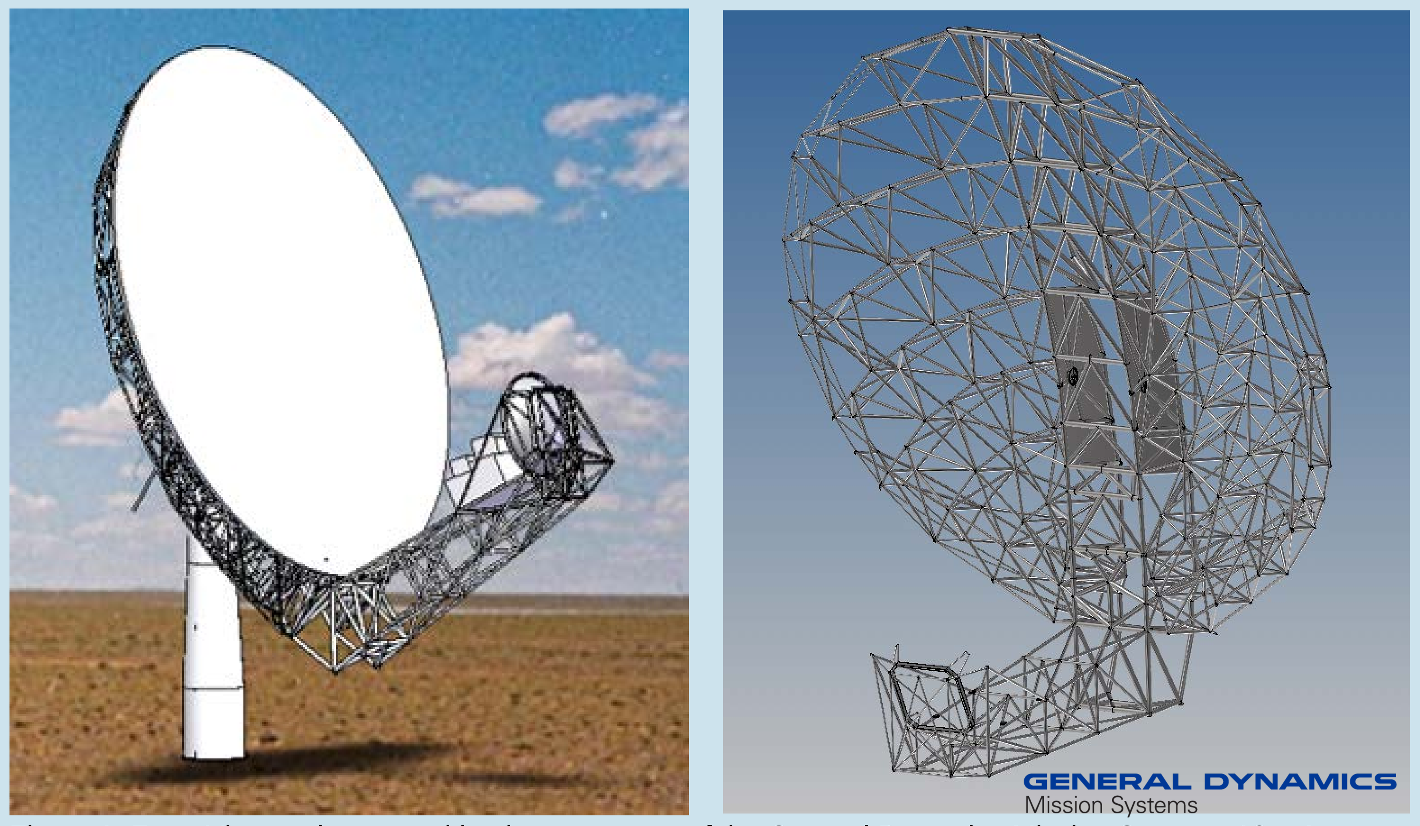

Figure 1: Front View and proposed back up structure of the General Dynamics Mission Systems 18m Antenna

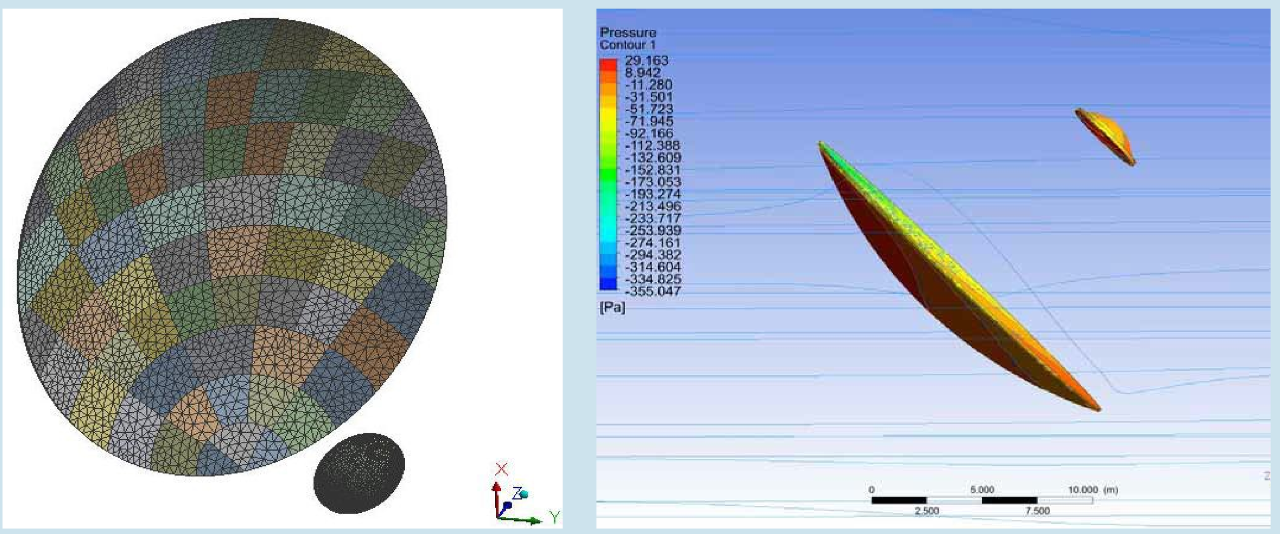

Figure 2: Proposed 84 segmented panels with FEA/CFD mesh applied (left). CFD stream lines,(right). CFD was used to identify associated wind torque constants, foundation loads, and drive loads

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.

Two studies were pursued for the Reference Design: a single piece composite primary (developed by the National Research Council Canada, NRCC) and a traditional multi-panel (General Dynamics Mission Systems). This presentation focuses on the GDMS study and highlights the antenna concept, initial surface analysis, and deflections of the back-up-structure. We will highlight further studies and design work as well as discuss areas of technical risk, and where technical advances may be required for successful antenna production and assembly.

Optical Design

The 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 benefits of this design include: subreflector and support do not block the primary, off-axis geometry minimizes scattering, spillover, and sidelobe pickup, and the wide subtended angle of the subreflector leads to very compact feed designs that can be combined into a limited number of cryogenic dewars, reducing operations costs.

The reference optical design was developed by Lynn Baker in collaboration with the National Research Council of Canada.

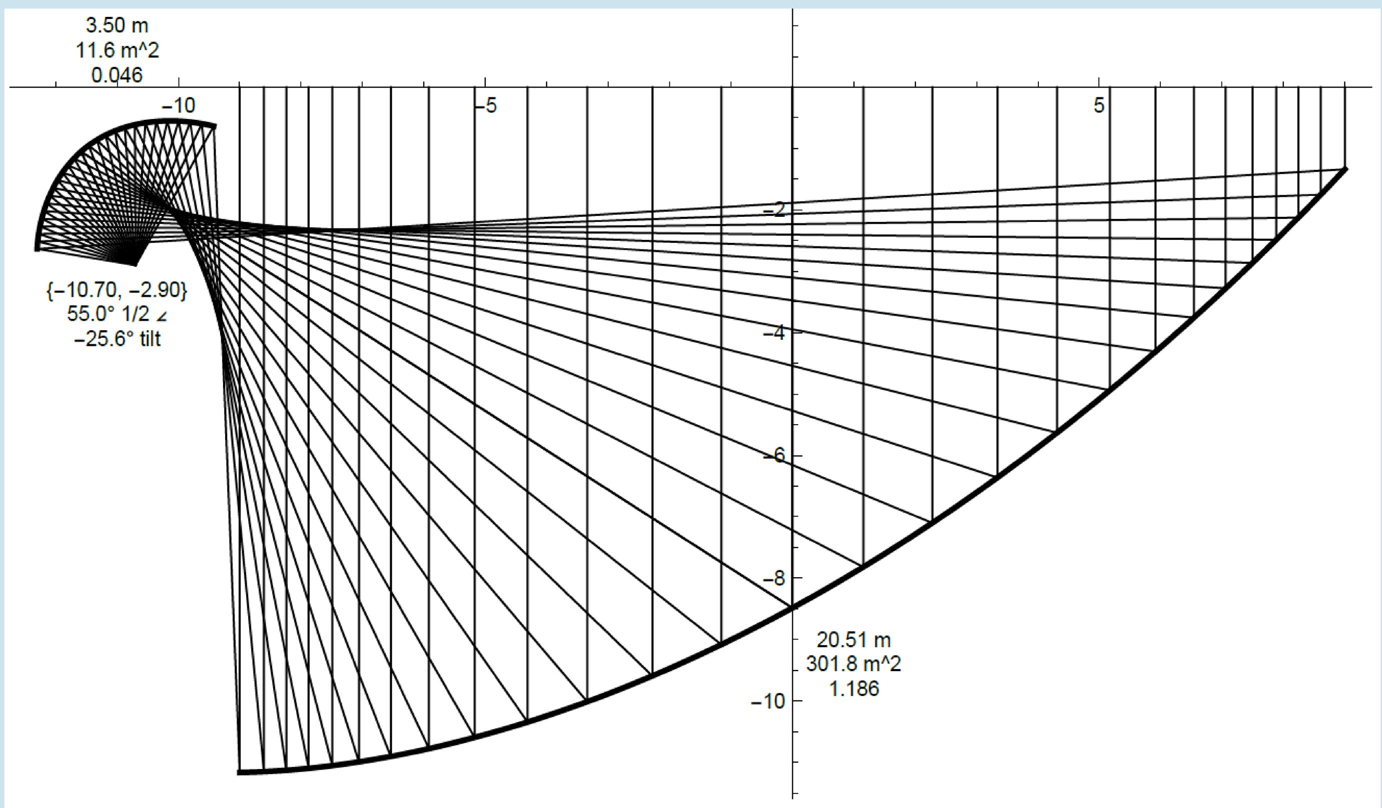

Figure 3: Optical Design Ray Trace Diagram and Aperture Illumination Pattern

Key Performance Parameters

Table 2: ngVLA Antenna Key Performance Parameters

Parameter	Summary of Requirement
Frequency Range	1.2-116 GHz
Diameter	18m
Number of Antennas	244
Surface Accuracy	**Precision Operating Conditions** 160 µm rms (λ/16 @ 116 GHz), primary and subreflector combined. **Normal Operating Conditions** 300 µm rms, primary and subreflector combined.
Pointing Accuracy	**Precision Operating Conditions:** (4 deg angle, 15 min time) Absolute pointing: 18 arc sec rms Referenced pointing: 3 arc sec rms **Normal Operating Conditions:** (4 deg angle, 15 min time) Absolute pointing: 35 arc sec rms Referenced pointing: 5 arc sec rms
Tracking Range	Azimuth: ± 270 deg Elevation: 12 deg to 88 deg
Movement Rate	Slew: Azimuth 90 deg/min, Elevation 45 deg/min. Tracking: Azimuth 7.5 deg/min, Elevation 3.5 deg/min.

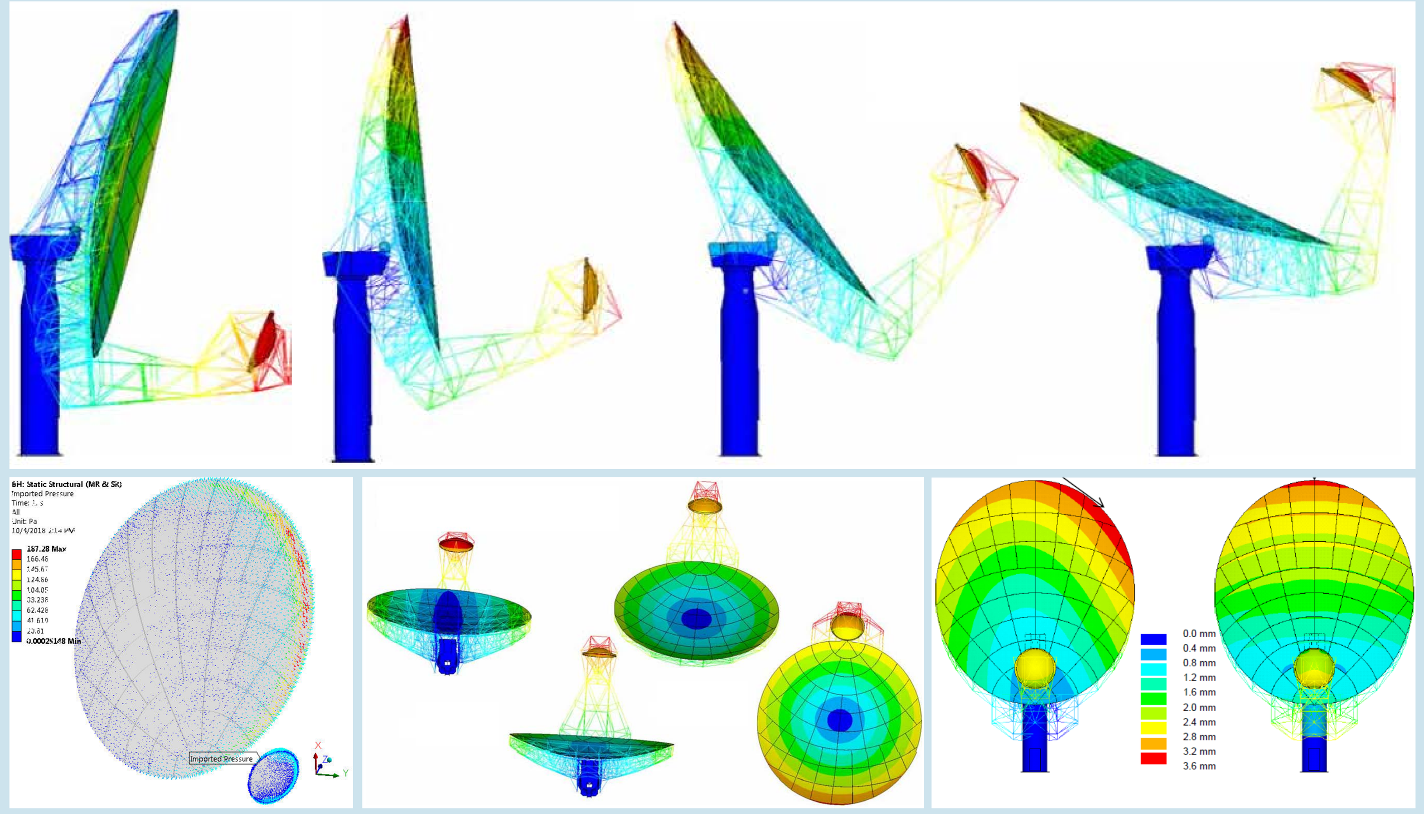

Figure 4: FEA iterations were performed with optimizations being made to the Antenna structure. FEA was performed for gravity loading, thermal loading, and differential wind pressure as well as locked rotor analyses that provided input for the servo control dynamic design.

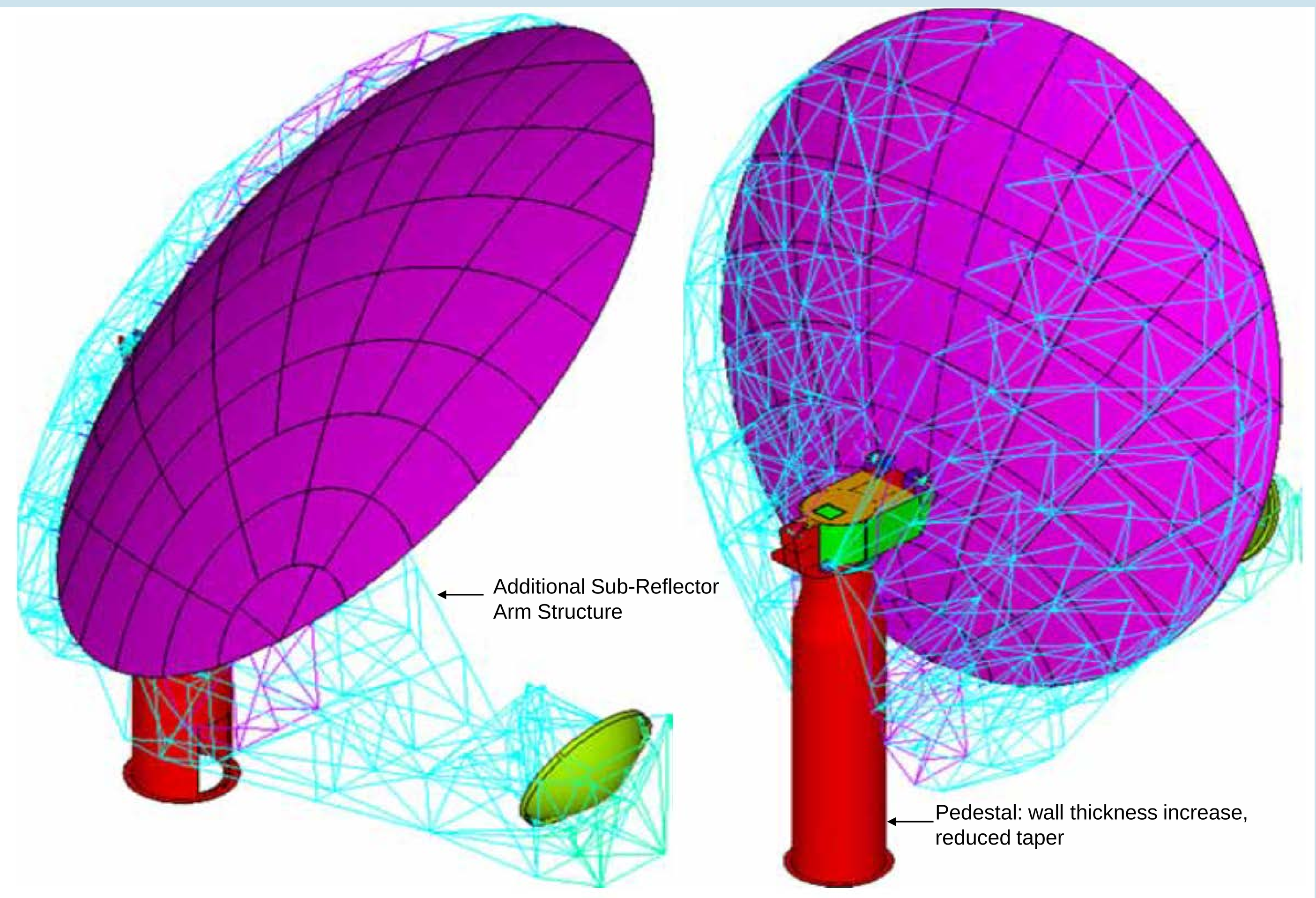

Figure 5: Antenna structure changes as a result of the FEA analysis. Additional structure was added to the sub-reflector feed arm and the pedestal mount was modified (wall thickness increase and shape change).

Analysis & Expected Performance

As stated, the proposed antenna study delivers a baseline cost and performance model to use as a benchmark for future trade studies. Given this approach, the baseline design does not meet all the design requirements, most notably the pointing and surface accuracy requirements. GDMS has provided incremental changes that, when adopted, should provide a suitable design that will meet the design requirements.

GDMS identified that thermal loading, based on the CFD and FEA analysis, is the largest contributor to the proposed antenna's inability to meet the surface accuracy (rms) specification. GDMS identified several material changes that could be incorporated that will significantly reduce the variability associated with the thermal load. The current design uses conventional carbon steel for the structure which has a high coefficient of thermal expansion (CTE). Alternatives for carbon steel include high nickel steel (invar), Carbon Fiber, or a hybrid of the two (invar in some locations and CFRP in other locations). The CTE for carbon steel is 10x that of invar and 40x that of carbon fiber. Additionally the panels for the baseline design are rolled aluminum panels, which could be improved by switching to machined aluminum (greater manufacturing tolerances) or carbon fiber.

To meet the pointing specification the open loop stiffness in the elevation axis would need to improve. This can be accomplished by improving the performance of the feed arm (stiffening) and the use of lower density structural components (ie carbon fiber).

Further Information

D. Dunbar et. al. *ngVLA Antenna: Preliminary Technical Requirements*. ngVLA Doc. 020.25.00.00.00-0001-Req. Rev B. 2018.

http://ngvla.nrao.edu/

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