Antenna Technical Requirements

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Status: **RELEASED**

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Change Record

Version	Date	Author	Affected Section(s)	Reason
0.1	04/18/2017	R. Selina	All	Started first draft. Used ngVLA System Requirements as a template, and pulled in 'Strawman' requirements by P. Napier. Also incorporates text and structure from ALMA-34.00.00.00-006-C-SPE Version C.
0.2	04/24/2017	R. Selina	Appendix	Added coordinate system diagram by S. Sturgis.
0.3	05/02/2017	R. Selina	All	Updated efficiency tables. Added Verification and Documentation sections. Revisions & elaborations throughout.
0.4	05/08/2017	R. Selina	5.3, 5.14, 5.17	Incorporated feedback from T. Beasley. Updated close packing text. Added serviceability requirement. Updated lifecycle text.
0.5	05/09/2017	R. Selina	5.5, 5.6, 9	Incorporated feedback from W. Grammer. Revised aperture efficiency requirements. Added beam subtended half angle requirement. Updated verification text, etc.
0.6	06/05/2017	R. Selina	5.9, 5.13, 5.14	Updated MTBF, maintenance interval, slew rates and environmental specifications.
0.7	07/07/2017	R. Selina	1.1, 2.1, 2.2, 3.2, 3.3, 5, 9, 10, 11.	Updated post June Workshop. Revised aperture diameter to 18m. Updated associated parameters to match. Updated optical parameters consistent with Granet. Added Requirements for Design and Safety sections. Added Requirements Summary. Other minor additions.
0.8	07/24/2017	R. Selina	9, 13	Revised EMC requirements. Added EM performance simulation requirements as suggested by D. Chalmers. Updated coordinate system narrative to match Granet. Added representative optical sketch. Other misc. corrections throughout.
0.9	08/28/2017	R. Selina, D'Addario	All	Incorporated input from NRAO-Internal (Napier, Jackson, Grammer, Sturgis, Kern, Walker, etc.) and TAC (Tetsuo, Lamb, Kantor, and D'Addario) review. Struck path-length change requirements. Added focus stability requirements. Rescoped EM analysis and requirements.
0.91	09/06/2017	R. Selina	4.2	Struck mount geometry req. ANT0212.

Version	Date	Author	Affected Section(s)	Reason
0.92	09/11/2017	R. Selina, M. McKinnon	All	Incorporated comments from McKinnon and Beasley. Edits to narrative throughout. Added Design Life to KPP list.
1	2017-09-12	R. Selina, M. McKinnon	N/A	First Release for Antenna Reference Design contract.
1.1	2017-10-12	R. Selina	4.2, 4.5, 4.9, 4.13, 4.15, 4.16, 7.3.2, 10.	Updated to address requested corrections and questions from GDMS. Clarified MTBF and M&C requirements. Corrected irregularities in references.
2	2018-01-23	R. Selina	N/A	Second Release. Updated for the Antenna Reference Design Contract.
2.1	2018-11-06	D. Dunbar	Doc number and Title, 3.4, 4.14.1, 4.14.2	Updated document number (SPE to REQ) to conform to System Engineering protocol. Updated Precision and Normal wind velocities to match System Level Spec.
2.2	2018-11-14	D. Dunbar	2.1, 2.2, 4.13, 4.14, 8.1.4, 10	Added additional reference docs. Updated Environment Conditions to trace back to ENV requirements (and not Sys Req). Updated Electromagnetic table and requirements to match/point to EMC requirement doc. Added additional applicable environmental requirements. Updated Load Case Table (precision) wind loads to match lower velocity (5 m/s).
2.3	2019-05-29	R. Selina	3.2	Updated introduction materials to reflect LBA inclusion in project scope.
A	2019-07-29	A. Lear	All	Prepared PDF for signatures and release.
A.01	2020-01-22	D. Dunbar	3.4, 4.2, 4.3, 4.5, 4.9, 4.12, 8.1.3, 10, 11	3.4: Corrected value in Antenna Requirement Summary for Precision Pointing accuracy from 8 arcsec rms to 18 arcsec rms. 4.2: Modified the caption for Figure 1 (unshaped optics) and added Figure 2 (ray trace diagram of ngVLA optical design 6). 4.3: Minimum Spacing ANT0301 requirement change from 30m to 38m. 4.5: ANT0503 panel gap was replaced with total blockage allowed as a percentage of total aperture. 4.9: Changed tracking (AZ and EL) from a minimum value to a range of values 4.12: Updated the solar requirement, no longer associated with normal operating conditions and subsequent performance 8.1.3: Added a number for Table 6. Updated the nomenclature in new Table 6 from

Version	Date	Author	Affected Section(s)	Reason
				Thermal (Primary, Secondary) to Thermal (Precision, Normal), as well as changed the wind velocities from 10 m/s and 7m/s to 7m/s and 5m/s respectively. 10: Updated Table 9 for ANT0503 reword 11: Added Reflector Construction (ANT0503) to the list of KPPs in Table 10.
A.02	2020-02-27	R. Selina	Cover, 1.1, 1.2, 2.1, 3.1	Updates to title, and introduction materials to reflect baselined status. Clarified that foundation is out of scope in introduction. Updated associated documents to reference additional Level-1 specifications. Updated section cross-references.
A.03	2020-08-11	D. Dunbar	All	Updated sections to reflect final antenna requirements instead of preliminary or concept. Removed optics and associated figures, removed M&C content, removed coordinate system definition, updated requirements flow down from Environmental and System requirements.
A.04	2020-09-03	R. Selina	1, 2, 3, 3.4, 4.2, 4.7, 4.15, 8, 11.	Corrected antenna geometry and optical design specifications. Added path length error requirements, and new requirements from calibration requirements flow down. Removed ANT0303, ANT0803 as were not specified, and the associated issues are captured in the narrative. Updated ANT1434 to permit operation with minimal ice accumulation. Updated EMC requirements to match system specification. Updated Section 11 for consistency with SEMP terminology. Revised down MTBF. Added Environmental requirements for consistency with system spec.
A.05	2020-09-14	R. Selina	5, 8, 9, 13.	Reorganized reliability and maintainability requirements per A. Symmes, and other changes to outline. New sections for consistency with L1.1 Electronics Specifications. Added in electrical power distribution sections. Reconsidered Calibration-derived absolute pointing requirements to goals. Changed surface accuracy to be error in the aperture plane. Updated Safety chapter with input from J. Bolyard.

Version	Date	Author	Affected Section(s)	Reason
A.06	2020-09-19	R. Selina	5.7, 5.15, 8.3.1, 10, 11.5, 16	Incorporating corrections and comments from Antenna IPT. Clarified path length error spec and surface finishes. Struck references to gel-cell batteries. Reduced minimum overhaul period. Added missing e-stop and portable control unit requirements. Updates to verification methods. Other minor corrections throughout.
A.07	2020-09-21	R. Selina	5.2, 5.3, 13.3.2	Updates to narrative to clarify trade space available on optics, pedestal height, and 208V vs. 480V electrical services.
A.08	2020-09-25	R. Selina	5.11, 8.2, 8.4	Incorporated comments from MM and TAC. Fixed lifetime in hazard analysis. Clarified stow pin positions. Added door lock and access restriction requirements.
B	2020-09-30	A. Lear	All	Formatting, minor copy edits; prepared PDF for signatures and release.

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1 Introduction

1.1 Purpose

This document presents the set of Level-2 Technical Requirements to guide the design of the Next Generation Very Large Array (ngVLA) Main Array Antenna. These requirements flow down from the ngVLA Level-1 System Requirements [AD01] and its subsidiaries, which in turn flow down from the ngVLA Level-0 Science and Stakeholder Requirements.

1.2 Scope

The scope of this document is the ngVLA Main Array Antenna subsystem. The Main Array Antenna and Long Baseline Array Antenna are expected to have the same requirements and share a common design.

The antenna subsystem consists of the reflectors and their backup structure, the mount structure that permits motion in azimuth and elevation, the drive system, the feed selection and focus mechanism, and associated motion control electronics. All other instrumentation housed within the antenna, including the feed antennas and receiving electronics, are outside the scope of this element, though interfaces must be considered.

This specification establishes the performance, functional, design, and test requirements applicable to the ngVLA Main Array and Long Baseline Array antennas.

1.3 Verb Convention

This document uses "shall" to denote a requirement. The verbs "should" and "must" denote desired but not strictly required parameters. "Will" denotes a future happening. Desired but not required features are noted as "desirable" or "goals."

2 Related Documents and Drawings

2.1 Applicable Documents

The following documents are applicable to this Technical Specification to the extent specified. In the event of conflict between the documents referenced herein and the content of this Technical Specification, the content of the highest level requirements document shall be considered the superseding requirement.

Ref. No.	Document Title	Rev/Doc. No.
AD01	ngVLA System L1 Requirements	020.10.15.10.00-0003-REQ
AD02	International Standard: Protection Against Lightning	IEC 62305:2010
AD03	Protection Against Electric Shock: Common Aspects for Installation and Equipment	IEC 61140:2016
AD04	Electrical Standards for Industrial Machinery	NFPA 79
AD05	Safety of Machinery: Electrical Equipment of Machines	IEC 60204:2016
AD06	Insulation Coordination for Equipment within Low-Voltage Systems	IEC 60664
AD07	Hydraulic and Pneumatic Fluid Power Safety	ISO 4413
AD08	Occupational Safety and Health Standards for General Industry	29 CFR Part 1910

Ref. No.	Document Title	Rev/Doc. No.
AD09	Occupational Safety and Health Standards for Construction	29 CFR Part 1926
AD10	Military Handbook, Reliability Prediction of Electronic Equipment	MIL-HDBK-217F
AD11	Non-Electronic Parts Reliability Data	NPRD-95
AD12	Electromagnetic Compatibility	IEC 61000
AD13	System L1 Environmental Specifications	020.10.15.10.00-0001-SPE
AD14	System L1 EMC Compatibility and RFI Mitigation Requirements	020.10.15.10.00-0002-REQ
AD15	System L1 Safety Requirements	020.80.00.00.00-0001-REQ
AD16	Calibration Strategy and Requirements	020.22.00.00.00-0001-REQ
AD17	ngVLA 18m Optics Definition	020.25.01.00.00-0006-DSN
AD18	Interface Control Document – Interface Between Antennas and Antenna Electronics	020.10.40.05.00-0011-ICD
AD19	Antenna Coordinate Systems	020.25.00.00.00-0001-REQ
AD20	Interface Control Document - Antenna to Monitor and Control	020.10.40.05.00-0007-ICD
AD21	Interface Control Document – Antenna to Array Infrastructure	020.10.40.05.00-0008-ICD
AD22	Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment	MIL-STD-461G
AD23	General Purpose Screw Threads – Basic Profile – Part 1: Metric Screw Threads	ISO 68.1:1998
AD24	Chemical Conversion Coatings on Aluminum and Aluminum Alloys	MIL-DTL-5541E
AD25	Marking of Electronic Items	MIL-STD-13231
AD26	Plates, Tags, and Bands for Identification of Equipment, General Specification for	MIL-DTL-15024
AD27	Plates, Identification, or Instruction, Metal Foil, Adhesive Backed General Specification for	MIL-P-19834
AD28	Acceptability of Printed Circuits Boards	IPC-A-600K
AD29	RoHS 2: EU Directive on the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment	EU Directive 2011/65/EU (8 June 2011)
AD30	RoHS 3: EU Directive Amending Annex II to Directive 2011/65/EU as Regards the List of Restricted Substances (effective 22 July 2021)	EU Directive 2015/863 (31 March 2015)
AD31	Requirements for Soldered Electrical and Electronic Assemblies	IPC J-STD-001G
AD32	Administration Standard for Telecommunications Infrastructure	ANSI Standard TIA-606-C
AD33	US National Electric Code	NFPA 70

2.2 Reference Documents

The following references provide supporting context:

Ref. No.	Document Title	Rev/Doc. No.
RD01	RFI Emission Limits for Equipment at the EVLA Site	EVLA Memo #106. Perley, Brundage, Mertely.
RD02	USGS Coterminous US Seismic Hazard Map – PGA 2% in 50 Years	ftp://hazards.cr.usgs.gov/web/nshm/conterminous/2014/2014pga2pct.pdf
RD03	ngVLA Sub-System Interfaces N^2 Diagram	020.10.40.00.00-0001-DWG
RD04	Flying Qualities of Piloted Aircraft	MIL-STD-1797A, p678
RD05	Efficiency Loss and Pointing Offsets due to Feed Offsets on the ngVLA Reference Design Antenna	ngVLA Antenna Memo #8. Srikanth.
RD06	Practical Limits to Axis Offsets	ngVLA Antenna Memo #9. Selina.

3 Overview of Antenna Technical Requirements

3.1 Document Outline

This document presents the technical requirements for the ngVLA Main Array (MA) antenna element. These parameters determine the overall form and performance of the antenna.

The functional and performance specifications, along with detailed explanatory notes, are found starting in Section 4. The notes contain elaborations regarding the meaning, intent, and scope of the requirements. These notes form an important part of the definition of the requirements and should guide the verification procedures.

In many cases, the notes contain an explanation or an analysis of how the numeric values of requirements were derived. Where numbers are not well substantiated, this is also documented in the notes. In this way, the required analysis and trade-space available are apparent to scientists and engineers who will guide the evolution of the ngVLA antenna concept.

Subsystem interfaces are described in Section 10. Initial requirements are noted by interface, along with the identified parameters for Interface Control Documents (ICDs) that will fully define the interface requirements and will be updated as the design progresses.

Safety requirements applicable to both the design phase and the functional antenna are described in Section 8. Additional analysis requirements for the design phase are described in Section 9. Documentation requirements for both technical design deliverables and software are provided in Section 15.

Requirements for the verification and test of the antenna, from the conceptual design through to prototype, are described in Section 16.

Section 17 identifies Technical Performance Measures (TPMs) that should be evaluated and monitored throughout the design phase. These TPMs support the Key Performance Parameters (KPPs) of the system, and are therefore the driving requirements for the antenna. These TPMs are the identified metrics to assist in the trade-off analysis of various concepts, and help identify and resolve tensions between requirements as the design progresses.

3.2 Project Background

The ngVLA is a project of the National Radio Astronomy Observatory (NRAO) to design and build an astronomical observatory that will operate at centimeter wavelengths (25 to 0.26 centimeters, corresponding to a frequency range extending from 1.2 GHz to 116 GHz). The ngVLA will be a synthesis radio telescope composed 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.

The array's signal processing center 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. Long baseline stations are located in Hawaii, Washington, California, Iowa, Massachusetts, New Hampshire, Puerto Rico, the US Virgin Islands, and Canada.

3.3 General Antenna Description

The antennas will operate in free air, during daytime and nighttime, as long as the atmospheric conditions remain within the specified operating limits. When not in an operating condition, the antenna will be put in a safe "stow" configuration.

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

The subreflector shall 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. Space is required near the secondary focal point for installation of feed antennas, receivers, and other electronics. Additional space is required near ground level for electronics and instruments.

3.4 Summary of Antenna Requirements

The following table provides a summary of the major antenna requirements in order to provide the reader with a high-level view of the desired antenna. Should there be a conflict between the requirements listed here and the descriptions in Sections 4 through 16, the latter shall take precedence.

Parameter	Summary of Requirement	Reference Reqs.
Frequency Range	1.2–116 GHz	ANT0101 ANT0102 ANT0103
Diameter	18 m	ANT0202
Number of Antennas	244	ANT0401
Max. Aperture Plane Error	**Precision Operating Conditions:** 320 μm rms (surface equiv. to 160 μm rms , λ/16 @ 116 GHz) **Normal Operating Conditions:** 600 μm rms, primary and subreflector combined	ANT0501 ANT0502
Pointing Accuracy	**Precision Operating Conditions**: Absolute pointing: 18 arc sec rms Referenced pointing: 3 arc sec rms (3 deg angle, 15 min time) **Normal Operating Conditions:** Absolute pointing: 30 arc sec rms Referenced pointing: 5 arc sec rms (3 deg angle, 15 min time)	ANT0611 ANT0612 ANT0621 ANT0622
Tracking Range	**Azimuth:** ±270 deg **Elevation:** 12 deg to 88 deg	ANT0801 ANT0802
Movement Rate	**Slew:** Azimuth 90 deg/min, Elevation 45 deg/min. **Tracking:** Azimuth 7.5 deg/min, Elevation 3.5 deg/min	ANT0901 ANT0902 ANT0906
Antenna Geometry	Offset Gregorian, with focal point on bottom.	ANT0201 ANT0206 ANT0211
Environmental Conditions	**Survival Conditions at Stow Position:** wind ≤ 50 m/s, temperature ≥ –30 C, 2.5 cm radial ice, 25 cm snow in dish, 2.0 cm diameter hailstones **Precision Operating Conditions:** Nighttime only, wind ≤ 5 m/s, temperature ≥ –15 C, no precipitation **Normal Operating Conditions**: Day and night, wind ≤ 7 m/s, temperature ≥ –15 C, no precipitation	ANT1411 through ANT1447

4 Assumptions

The following assumptions are made in the definition of these subsystem requirements:

- Subsystem requirements apply to performance before any operational calibration corrections are applied unless explicitly stated otherwise.
- Hardware requirements apply to a properly functioning system under the normal operating environmental conditions unless explicitly stated otherwise.
- Hardware requirements assume that all system parts that would normally be in place during observations are working within their respective specifications (e.g., HVAC) unless explicitly stated otherwise.

5 Antenna Functional and Performance Requirements

5.1 Operating Frequency Range

Parameter	Req. #	Value	Traceability
Upper Operating Frequency	ANT0101	116 GHz	SYS0801
Lower Operating Frequency	ANT0102	1.2 GHz	SYS0801
Optimized Operating Frequencies	ANT0103	8 GHz – 50 GHz	SYS0801

The upper and lower operating frequencies for the antenna flow down directly from the system requirements. However, operation above 8 GHz is of higher importance, and the lower operating frequency should not be permitted to significantly increase the design cost or compromise performance at higher frequencies.

For example, optimizing performance at 1.2 GHz may necessitate a large subreflector, perhaps 4 to 5 m in diameter. Such a subreflector may increase the structural requirements on the feed/subreflector arm and make meeting the pointing specification more difficult due to increased wind loads. Therefore, the subreflector size is a compromise to provide minimal wind loading at high frequencies, with spillover temperature optimized for 8 GHz and up.

5.2 Optical and Mounting Geometry

Parameter	Req. #	Value	Traceability
Optical Configuration Type	ANT0201	The antennas shall have an Offset Gregorian geometry, supported with the feedarm closest to ground when at the lower elevation limit (i.e., feed low).	SYS1001
Primary Aperture Diameter and Shape	ANT0202	The antennas shall have a circular primary aperture of 18m diameter.	SYS1001, SYS1101
Mount Geometry	ANT0203	The optics shall be supported by an Altitude over Azimuth (Alt-Az) mount.	SYS1102
Optical Specification	ANT0204	The antenna reflector surface shape and orientation shall be consistent with the ngVLA 18m Optics Definition (020.25.01.00.00-0006-DSN).	SYS1001

Parameter	Req. #	Value	Traceability
El-Boresight Axis Offset	ANT0205	It is a goal to minimize the offset between the elevation axis and the optical boresight (Z_{MR} axis).	CAL0313
Az-El Axis Offset	ANT0206	It is a goal to minimize the offset between the elevation axis and azimuth axis.	CAL0313
Az-Boresight Axis Offset	ANT0207	It is a goal to minimize any offset between the azimuth axis and the optical boresight (Z_{MR} axis).	CAL0313

The common coordinate systems for the antenna optics, secondary focus, the mount azimuth and elevation axes, and the foundation are described in the ngVLA Antenna Coordinate Systems [AD19]. The size and shape of the reflectors and their orientation relative to the antenna coordinate system is described in the ngVLA 18m Optics Definition [AD17].

While the optical design is prescribed, NRAO can evaluate changes to the optics based on feedback from the antenna designer. The specified design is informed by earlier structural analyses that aimed to reduce the interference between a pedestal mount and the backup structure, while minimizing the Azimuth to Elevation axis offset. Alternative solutions have comparable RF performance, and can be considered based on mechanical design considerations.

Offsets between the various axes of the antenna are expected as part of a practical antenna structural design and realistic manufacturing tolerances, however, these offsets can introduce path length/delay errors when used as part of an interferometer or phased array like the ngVLA.

Offsets between the optical boresight and elevation axis introduce optical path length/delay errors proportional to pointing errors. Any effective offset (due to manufacturing tolerances) between the azimuth axis and optical boresight has the same effect.

The elevation-azimuth axis offset introduces a variable optical path length/delay error as a function of deflection or thermal expansion. Between the three terms, the offsets from the optical boresight to the elevation axis appear to be significantly more impactful.

Managing path length changes is fundamental to the operation of an interferometer, and limiting these offsets in the design is desirable. Hard limits on these offsets should be analyzed in the context of the path length error requirement, given in Section 5.7.

5.3 Allowable Design Volume and Mass

Parameter	Req. #	Value	Traceability
Minimum Spacing	ANT0301	Antennas whose azimuth axes are separated by 38m shall not collide for any combination of their orientations.	SYS1302, SYS1303
Height	ANT0302	At the lower limit of the elevation tracking range, no part of the movable structure shall be closer than 1.0 m to the nearest point on the ground.	SYS2700

The minimum spacing is a key input to the array configuration design. If the minimum spacing requirement proves difficult to accommodate, NRAO may evaluate a revision to this requirement, as alternative solutions are available to maintain the associated performance.

The height of the pedestal is limited to provide adequate clearance for snow and nearby equipment. For pointing performance and service access, a low feed arm is desirable, but the design height should also consider equipment interference and personnel safety concerns. The height requirement may be relaxed by NRAO if the proposed change is supported by a Hazard Analysis (Section 8.2)

The mass is an unconstrained free parameter, but lower mass is preferred in order to minimize cost.

The envelopes of NRAO-supplied equipment will be defined in the ICDs described in Section 10.2.

5.4 Number of Antennas

Parameter	Req. #	Value	Traceability
Number of Antennas	ANT0401	244	SYS1001

The number of antennas in the baseline design is provided as an input to the design manufacturability and lifecycle cost analysis.

5.5 Reflector Construction and Accuracy

Parameter	Req. #	Value	Traceability
Surface Accuracy, Precision	ANT0501	Errors in the aperture plane shall not exceed 320 µm rms when operating in the Precision operating environment.	SYS1001, CAL0204
Surface Accuracy, Normal	ANT0502	Errors in the aperture plane shall not exceed 600 µm rms when operating in the Normal operating environment.	SYS1001, CAL0204
Reflector Construction	ANT0503	The total blockage from any panel gaps or other obstructions to the aperture shall not exceed 1.0 percent of the total area of the aperture. It is a goal to achieve a total blockage of less than or equal to 0.25 percent of the total aperture.	SYS1001

The surface accuracy is specified as an aperture plane error, accounting for the surface deformations of both reflectors and any misalignment (displacement and/or rotation) of the reflectors and feed support. The aperture plane error can be determined from ray-trace analysis during the design phase and holography or forward gain measurements of the as-built antenna.

Note that the aperture plane error is approximately double the root sum square (RSS) of the surface error of the two reflectors, inclusive of any misalignment of the reflectors, since a transmitted wave traverses the surface error distance twice.

The aim with the reflector construction specification is to ensure high reflector efficiency over the operating frequencies (Section 5.1) with minimal transmission through gaps from electro-magnetic interference (EMI) or ground emission.

5.6 Pointing Accuracy

Pointing error is defined as the difference between the commanded position of the antenna and the actual direction of its radio frequency (RF) beam. The pointing accuracy is specified by the maximum allowable Absolute Pointing Error (referred to as Blind Pointing Error in AD16) and Referenced Pointing Error.

The Absolute Pointing Error is the maximum allowable error, over the full range of motion, after corrections from any antenna metrology and a pointing model are applied. Repeatable sources of error monitored by the antenna may be calibrated and removed in the control software.

To further correct the absolute errors, referenced pointing will be used. This involves an astronomical measurement of the pointing error at one point in the accessible sky, using observations of a known object near the desired pointing direction. Gross errors in the local pointing model are removed at this sky position. The residual pointing error is then composed of:

- The pointing error associated with geometric errors applicable over the given angular separation from the desired direction.
- Changes in the antenna pointing performance over a defined interval of time (e.g., due to wind and thermal effects).
- Non-repeatable errors associated with encoder read-out, bearing precision, and other sources.

Note that the referenced pointing calibration is performed at a fixed frequency, and therefore typically requires a change in receiver band between the referenced pointing calibration and the subsequent observation. The referenced pointing error budget shall account for the anticipated change in receiver band and associated receiver positioner errors.

The pointing requirements shall apply over the full operational range of motion. While described here as "pointing" errors, these can also be considered "tracking" errors, as maintaining a commanded sky position involves active tracking in both axes of the Altitude-Azimuth mount. The terms are used interchangeably in this document.

5.6.1 Pointing Accuracy in Precision Operating Environment

Parameter	Req. #	Value	Traceability
Absolute Pointing Error	ANT0611	18 arc sec rms. Goal of 15 arc sec rms.	CAL0201
Referenced Pointing Error	ANT0612	3 arc sec rms, within 3° of the target position and 15 mins time	CAL0201

The absolute pointing requirement under precision operating conditions is equivalent to full width half maximum over ten (FWHM/10) at 20 GHz, while the referenced pointing requirement under precision operating conditions is equivalent to the FWHM/10 at 116 GHz.

ANT0611 has been revised since the conceptual design phase based on an analysis in the system calibration requirements and expected reference calibration correction capabilities. Historically, referenced pointing calibration can correct for approximately 80% of the absolute pointing error, limiting the absolute pointing error to a factor of 5x larger than the referenced pointing error. The goal for absolute pointing reflects this prior experience, but slightly larger errors may be tolerable (as reflected in the requirement) depending on a more detailed analysis of the repeatable and non-repeatable sources of the pointing error unique to this antenna design.

The control loop used for referenced pointing within 3° shall not be unique—performance at larger offset angles is expected to degrade in a manner roughly proportional to the slew distance. Note that systematic pointing errors are more damaging than random errors, and this root mean square (rms) value assumes a random distribution of Referenced Pointing Errors after the application of the associated corrections.

5.6.2 Pointing Accuracy in the Normal Operating Environment

Parameter	Req. #	Value	Traceability
Absolute Pointing Error	ANT0621	30 arc sec rms. Goal of 25 arc sec rms.	CAL0201
Referenced Pointing Error	ANT0622	5 arc sec rms within 3°; must maintain spec for ≥15 mins time	CAL0201

The absolute pointing requirement under normal operating conditions is equivalent to FWHM/10 at 12 GHz, while the referenced pointing requirement under normal operating conditions is equivalent to the FWHM/15 at 50 GHz. The latter requirement ensures that the array operates effectively at frequencies below 50 GHz during typical good daytime environmental conditions.

ANT0621 has been revised since the conceptual design phase based on an analysis in the system calibration requirements and expected reference calibration correction capabilities. Note that historically, referenced pointing calibration can correct for approximately 80% of the absolute pointing error, limiting the absolute pointing error to a factor of 5x larger than the referenced pointing error. The goal for absolute pointing reflects this prior experience, but slightly larger errors may be tolerable (as reflected in the requirement) depending on a more detailed analysis of the repeatable and non-repeatable sources of the pointing error unique to this antenna design.

5.7 Path Length Stability

Parameter	Req. #	Value	Traceability
Non-Repeatable Residual Path Length	ANT2501	The non-repeatable residual path length shall not exceed 18 μm rms over a 5 minute period, with motion up to 5 degrees, in the precision operating environment.	CAL0313

The optical path length is defined by the Main Reflector Coordinate System documented in ngVLA Antenna Coordinate Systems [AD19]. The Optical Path Length is the polyline extending from F_0 to the subreflector and Q_i, before intersecting the X_{MR}-Y_{MR} plane, which defines the end of the polyline.

The path length stability is defined as a drift residual. Drift is defined as the perturbations with a period greater than 1 second, with faster perturbations reduced through averaging. The optical path length can be measured astronomically on a 5 minute cadence, enabling the subtraction of any linear trend in the drift. It is only the residual, after linear trend subtraction, to which this specification applies.

Path length errors as a function of load cases can be measured by holding the X_{MR}-Y_{MR} plane fixed, and the ground (earth) plane fixed, perturbing the structure, and measuring the resulting optical path to its new intersection normal to the X_{MR}-Y_{MR} plane. Rotation of the reference plane is possible by rotating about the *un-perturbed* elevation and/or azimuth axes.

Note that designing to this requirement will restrict the maximum offsets permissible between the optical boresight, elevation axis, and azimuth axis, as described in Section 5.2. A first-order analysis of the constraints introduced by ANT2501 is provided in RD06.

Should this requirement prove infeasible to meet, or require uneconomical choices in materials (e.g., composite structural elements), NRAO may explore a revision to this requirement.

5.8 Focus Stability & Feed Selection Mechanism

Parameter	Req. #	Value	Traceability
Secondary Focus Position Stability in Normal Operating Environment	ANT0702	The relative position of the receiving elements (feeds) and the position of the secondary focus shall not vary by more than the allowable tolerances given in Table 1 over the full range of elevation in the Normal Operating Environment.	SYS1001, CAL0205
Secondary Focus Rotation in the Normal Operating Environment	ANT0703	The combined rotation of the feed selection and focus mechanism interface platform and antenna structure shall not exceed 0.5 degrees about the Z-axis over the full range of motion.	CAL0205
Feed Selection Travel Rate	ANT0704	The feed selection mechanism shall traverse the full required range in the Y-axis (Specified in 020.10.40.05.00-0011-ICD) in less than 20 seconds. Goal of 10 seconds.	CAL0206

The stability of the secondary focus position is measured as the difference between the position of the secondary focus, given any optical deformations in the reflectors, and the position of the feed aligned on the feed selection mechanism.

Note that these allowable offsets account for the efficiency losses due to antenna defocus only. Feed position offsets will also introduce pointing errors, which shall be reflected in the pointing error budget. As described in Section 5.6, referenced pointing typically involves a receiver band change. The precision of the feed placement may need to be appreciably higher than the stability specified to support the referenced pointing error budget. See RD05 for a relevant analysis.

Parameter	Allowable Tolerance (+/-)	Comments
X_f Axis	2.20 mm	Gravity + thermal + wind loads; no active compensation assumed.
Y_f Axis	0.50 mm	
Z_f Axis	0.50 mm	
Notes:	1. The values represent the combined limit for both the antenna structure and the feed selection mechanism. 2. Coordinates are given in the Focal coordinate system shown in AD19. 3. The allocation to the X_f, Y_f, and Z_f axes assumes active compensation in the Y_f and Z_f axes only, reserving the bulk of the total error for gravitational deformations in the X_f axis.	

Table 1- Allowable offsets for focus position.

5.9 Range of Motion

Parameter	Req. #	Value	Traceability
Azimuth Tracking Range	ANT0801	+/-270° minimum, where zero is towards true south	SYS1102
Elevation Tracking Range	ANT0802	12° to 88° minimum from the local horizon	SYS1102

The Azimuth tracking range specified has a zero-degree fiducial vector pointing towards the celestial South Pole. The elevation range is relative to the local horizon. The coordinate system is further explained in the Antenna Coordinate Systems specification [AD19].

The lower elevation range permits observations over large portions the southern hemisphere. A lower elevation limit of 12 degrees allows observations of approximately -40 declination near the meridian (given the latitude of the ngVLA array core). The upper elevation limit enables pointing and delay calibration observations to distinguish between various error terms for the pointing and delay models.

The movement range should be larger than the tracking range. A margin should be provided for the normal limits of motion before limit switches are reached. The hard mechanical limits should be slightly wider still (see Section 5.15 for additional information). The maintenance and safety stow positions may also be outside the elevation tracking range.

5.10 Axis Rates

Parameter	Req. #	Value	Traceability
Slew: Azimuth	ANT0901	90 deg/min. minimum	SYS1103, SYS3005
Slew: Elevation	ANT0902	45 deg/min. minimum	SYS1103, SYS3005
Acceleration: Azimuth	ANT0903	4.5 deg/sec^2 minimum	SYS1103, CAL0207
Acceleration: Elevation	ANT0904	2.25 deg/sec^2 minimum	SYS1103, CAL0207
Slew + Settle Time	ANT0905	Move 3-deg on sky and settle to within Referenced Pointing Specification within 7 sec for elevation angles < 70°.	CAL0207
Tracking Rate: Azimuth	ANT0906	0 deg/min. – 7.5 deg/min.	SYS1104
Tracking Rate: Elevation	ANT0907	0 deg/min. – 3.5 deg/min.	SYS1104

The slew speeds and accelerations specified attempt to minimize time spent slewing between targets or calibrators, without significantly driving the antenna structural and servo system design. They also allow for rapid response to transient events, reaching anywhere on sky within approximately two minutes. The slew + settle time specification aims to reduce phase calibration overheads. The 70-degree elevation angle constraint is given so as not to drive the specification for azimuth slew rates at higher elevation. Should this specification prove to be a driving requirement it may be reviewed, as there are alternative approaches to phase calibration at the system level.

The tracking requirements give the rates at which the specified pointing error limits must be maintained. In general, tracking error that contributes to the pointing error must be included in the pointing error budget for both Precision and Normal conditions. The azimuth tracking rate corresponds to approximately ten times sidereal at an elevation of 70 degrees. Tracking at super-sidereal rates will be important for multiple observation modes, such as on-the-fly mosaicking, or tracking objects that move across the celestial sphere, such as planets, asteroids, and satellites.

5.11 Stow Positions

Parameter	Req. #	Value	Traceability
Stow Position: Survival	ANT1001	The Survival Stow position shall limit wind load on the antenna while ensuring water and snow accumulation does not exceed safe structural allowances.	SYS2700
Stow Position: Maintenance	ANT1002	A Maintenance Stow position shall place the receiver enclosure as close to horizontal as possible.	SYS3202

It shall be possible to stow the antenna in two different positions, one used for occurrence of the survival atmospheric conditions, the other for specific maintenance to be performed. The stow pin (if provided) should be engaged in both positions, to enable safe maintenance of the antenna brakes, drives, and motors, and structural survival in the most demanding conditions. Alternative solutions may be accepted based on the results of the Hazard Analysis described in Section 8.2.

The maintenance position aims to provide a level working platform around the receiver enclosure mounted on the feed arm. In practice, this may be unattainable in some designs and will be constrained by the lower elevation limit.

In the survival position, the antenna shall withstand the survival conditions described in Section 6.5. The designer shall determine a single survival position that minimizes stress from wind and snow/ice loading (i.e., the survival stow position shall not be dependent or responsive to the environmental conditions).

5.12 System Noise Contributions

Parameter	Req. #	Value	Traceability
Resistive Losses	ANT1101	The primary and secondary reflector shall each have a surface resistive loss of less than 1.0% over the operating frequency range.	SYS1031, SYS1032

Resistive losses contribute to both a loss in efficiency and an increase to system noise from the antenna. Resistive loss of the primary and secondary reflector surfaces and scattering of ground noise into the feed, shall be minimized as much as possible without compromising the surface accuracy and pointing requirements.

5.13 Solar Observations

Parameter	Req. #	Value	Traceability
Solar Observations	ANT1201	It shall be possible to safely observe the sun within the Limits to the Operating Conditions.	SYS5800

Consistent with the definition of the Limits to the Operating Conditions (Section 6.3), no performance requirements are imposed on this functional capability.

5.14 Monitor and Control Requirements

Parameter	Req. #	Value	Traceability
Antenna Control Unit (ACU)	ANT1601	The antenna shall be equipped with an electronic control unit that will drive the azimuth and elevation axis motions according to commands received from either the Monitor and Control system (see Interfaces) or from a local manual interface(s).	SYS1102
Servo Loops	ANT1602	The ACU shall include servos with position and rate control loops on each axis, and the servo design shall account for the structure's dynamic behavior.	SYS1104
Self-Monitoring	ANT1603	The antenna shall measure, report, and monitor a set of parameters that allow for determination of its status and may help predict or respond to failures.	SYS2701
Weather Monitoring	ANT1604	The antenna shall be equipped with anemometers and thermometers to determine when safe operating conditions have been exceeded and to automatically stow the antenna.	SYS2502
Network Hardening/ Authentication	ANT1605	System remote control shall require an authentication process, and only respond to commands from authorized sources.	SYS2702
Remote Reset	ANT1606	It shall be possible to remotely reset each antenna over the M&C interface, including a reboot of the antenna control unit, and return the antenna to operational status.	SYS3112
M&C Commanded Reset	ANT1607	The ACU shall be provided with a physical reset line to allow remote reset commands to be sent via an independent NRAO-supplied M&C device.	ETR0909
On-Site Reset/Start-Up Sequence	ANT1608	The antenna shall be able to be started up and shut down locally, via the local manual interface, without the need of external network interfaces.	ETR0809
Periodic Self-Tests	ANT1609	The ACU shall perform self-tests at power-on and a commanded basis. Results shall be reported back to the M&C system.	ETR0910
Portable Control Unit	ANT1610	The antenna shall include a Portable Control Unit to permit a technician to command the antenna at the drive, motor, and receiver selection mechanism service locations identified in the maintenance manual.	SYS3202

For maintenance purposes, local control of the ACU near the point of service is desirable.

The expectation with self-monitoring (ANT1603) is that the antenna control system will expose lower-level sensors to the Monitor and Control System when queried. The cadence of access is flexible and not expected at high rates (typical access might be on second to minute scales). Any high-cadence monitoring should generally be internal to the antenna control system with summary output on the interface.

Exclusions from the remote reset requirement are hardware interconnects for safety, the disconnection of the power in the case of a fire alarm activation, and recovery from axis hard stops or safety limits.

The Antenna Monitor and Control interface requirements are defined in the Monitor and Control ICD [AD20].

5.14.1 Firmware Upgradability and Storage Location

The ngVLA system will contain many programmable devices such as FPGAs, PSOCs, micro-controllers, and other programmable logic. Firmware for all devices shall be stored locally at the antenna. Firmware for basic functional and diagnostic purposes but that may be configured remotely for normal operation satisfies this requirement. The antenna shall not be dependent on a connection to the central M&C system to boot up and become operational in a basic configuration.

It is desirable that devices with firmware be remotely upgradeable without visiting the antenna.

Parameter	Req. #	Value	Traceability
Local Firmware	ANT3241	All programmable devices shall have a local copy of the firmware provided by the ACU or an associated local computer.	ETR0906
Firmware Updates	ANT3242	It is a goal that any devices containing firmware be upgradeable remotely via the M&C network.	ETR0907

5.15 Motion Limiting Features

Parameter	Req. #	Value	Traceability
Software Limits	ANT1701	The antenna shall include logic to prevent motion beyond programmable limits in azimuth and elevation during normal operation.	SAF0030
Hardware Limits	ANT1702	The antenna shall be equipped with mechanically driven switches to inhibit operation outside its safe operating limits.	SAF0210
Elevation Hard Stops	ANT1703	The antenna shall be equipped with hard mechanical stops that physically prevent the antenna from exceeding elevation operating limits when damage is imminent.	SAF0130
Safety Lock-Out	ANT1704	The antenna shall be equipped with a safety lock-out that inhibits motion of the antenna during service.	SAF0590
Fire Alarm	ANT1705	The antenna shall be equipped with fire alarms in any equipment compartments. The fire alarm shall disconnect power to the antenna when triggered.	SAF0032
Fail Safe Brakes	ANT1706	The drive brakes shall engage when the antenna experiences a loss of power.	SAF0130, SAF0480
E-Stops	ANT1707	The antenna shall be equipped with emergency stop buttons at the locations identified by a Hazard Analysis.	SAF0590

The design of the software and hardware limits and other safety systems shall be informed by the hazard analysis described in Section 8.2.

Fire alarms may be necessary at additional locations as determined by the designer.

6 Environmental Conditions and Requirements

Based on historical weather data of the Jansky Very Large Array (VLA) site and other public weather databases, the following definitions of environmental conditions are adopted. These requirements are verbatim from the environmental specification outlined in [AD13].

6.1 Precision Operating Conditions

Parameter	Req. #	Value	Traceability
Solar Thermal Load	ANT1411	Nighttime only; no solar thermal load within last 2 hours.	ENV0311
Wind Speed	ANT1412	$0 \le W \le 5$ m/s average over 10 min time. 7 m/s peak gusts.	ENV0312
Temperature	ANT1413	$-15°C \le T \le 25°C$	ENV0313
Temperature Rate of Change	ANT1414	1.8°C/Hr.	ENV0314
Precipitation	ANT1415	No precipitation	ENV0315

The Precision operating environment defines the conditions under which the system is expected to meet the most stringent requirements and provide optimal system performance.

The solar thermal load requirement limits this environment to two hours after sunset through sunrise, so long as the other requirements of this section are met. The two-hour restriction is intended to allow sufficient time for the system to thermally equilibrate.

6.2 Normal Operating Conditions

Parameter	Req. #	Value	Traceability
Solar Thermal Load	ANT1421	Exposed to full sun, 1200W/m^2	ENV0321
Wind Speed	ANT1422	$W \le 7$ m/s average over 10 min time; 10 m/s peak gusts	ENV0322
Temperature	ANT1423	$-15°C \le T \le 35°C$	ENV0323
Temperature Rate of Change	ANT1424	3.6°C/Hr.	ENV0324
Precipitation	ANT1425	No precipitation	ENV0325

When the environment meets the constraints of normal operating conditions, system performance requirements are relaxed but still expected to provide adequate performance for operation below 50 GHz.

6.3 Limits to Operating Conditions

Parameter	Req. #	Value	Traceability
Solar Thermal Load	ANT1430	Exposed to full sun, 1200W/m^2	ENV0330
Wind	ANT1431	$W \le 15$ m/s average over 10 mins; $W \le 20$ m/s gust.	ENV0331
Temperature	ANT1432	$-20°C \le T \le 45°C$	ENV0332
Precipitation	ANT1433	5 cm/hr over 10 mins	ENV0333
Radial Ice	ANT1434	Less than 2.5 mm on structure.	ENV0334
Relative Humidity	ANT1435	$0 \le RH \le 100\%$; Condensation permitted.	ENV0335

A third categorization will establish hard limits to the operating conditions. While outside the bounds of the normal operating environment but within this regime, no performance guarantees are expected, but the system shall still be capable of safe operation. Once these limits are exceeded, the antenna will be moved to its "stow-survival" orientation to prevent damage.

6.4 Standby Conditions

Parameter	Req. #	Value	Traceability
Solar Thermal Load	ANT2001	Exposed to full sun, 1200W/m^2	ENV0360
Wind	ANT2002	0 m/s ≤ W ≤ 30 m/s average	ENV0361
Temperature	ANT2003	–25°C ≤ T ≤ 45°C	ENV0362
Precipitation	ANT2004	Up to 5 cm/hr over 10 mins	ENV0363
Radial Ice	ANT2005	Less than 2.5 mm on structure.	ENV0364
Relative Humidity	ANT2006	0 ≤ RH ≤ 100%; Condensation permitted.	ENV0365

After the limit to the operating conditions are exceeded, the antennas will be placed in the "stow-survival" position for equipment safety and the system placed in a standby state. While in standby, the system shall remain capable of resuming operation within five minutes of conditions returning to within the Limits of the Operating Conditions. Should the environment then reach the Normal Operating Conditions, the system shall perform to the performance specifications associated with that environment.

Subsystems may automatically shut down, or have temporarily degraded performance, once the environment exceeds the constraints of the Standby Conditions.

6.5 Survival Conditions at Stow Position

Parameter	Req. #	Value	Traceability
Wind	ANT1441	0 m/s ≤ W ≤ 50 m/s average	ENV0341
Temperature	ANT1442	–30 C ≤ T ≤ 52.5 C	ENV0342
Radial Ice	ANT1443	2.5 cm	ENV0343
Rain Rate	ANT1444	16 cm/hr over 10 mins	ENV0344
Snow Load—Antenna	ANT1445	25 cm	ENV0345
Hail Stones	ANT1446	2.0 cm	ENV0347
Antenna Orientation	ANT1447	Stow-survival, as defined by antenna designer	ENV0348

The survival conditions describe the environment that the antenna should be able to withstand without damage when placed in its least-vulnerable state. The designer must specify the orientation that will result in minimum stress to the structure at the maximum wind speed and maximum snow and ice loading. Note that 50 m/s survival wind is not high enough to survive tornadoes in eastern New Mexico and Texas. This issue should be considered in the Hazard Analysis described in Section 8.2.

The temperature limits, radial ice, snow load, and hail stone requirements are based on experience at the VLA site and a survey of conditions throughout the extent of the array. Should these requirements prove onerous or constraining, a risk versus loss analysis may be performed to evaluate the likely cost and time for repair, and the frequency of expected repairs, compared to the cost impact of meeting the requirement over the lifetime of the facility. This would be executed as part of the analysis described in Section 8.2.

6.6 Lightning Protection Requirements

Parameter	Req. #	Value	Traceability
Lightning Protection: Structure	ANT1451	The antenna and housed equipment shall be protected from both direct and nearby lightning strikes, achieving Protection Level I as defined in in IEC 62305-1/3 [AD02]	ENV0511
Lightning Protection: Electronics	ANT1452	The antenna electrical and electronics systems shall be protected against Lightning Electromagnetic Impulse in accordance with IEC 62305-4. [AD02]	ENV0512
Lightning Protection: Personnel	ANT1453	A safety hazard analysis shall be performed for anticipated preventive maintenance tasks that may place personnel at risk in the event of direct or nearby lightning strikes.	ENV0513

Given the extent of the array and the prevailing environmental conditions, direct and nearby lightning strikes, causing a lightning electromagnetic pulse (LEMP), should be anticipated and mitigated in the antenna design. The antenna and housed equipment shall be protected in any antenna orientation. The requirements for the antenna grounding electrode, provided as part of the antenna foundation, shall be documented in the relevant interface control document (ICD) as described in Section 10.1. All antenna bearings shall have bypass grounding connections. Grounding systems shall be designed to minimize ground loops. Multi-point grounding is a necessity imposed by the need for radio frequency interference (RFI) shielding, but the effects should be minimized in signal paths wherever possible.

The lightning protection system shall be designed to achieve Protection Level I as defined by [AD02] "IEC 62305-1 – Protection against Lightning." This level assures protection against 99% of strikes, with a residual risk of damage for strikes with parameters outside the defined range.

6.7 Seismic Protection Requirements

Parameter	Req. #	Value	Traceability
Seismic Protection	ANT1461	The antenna and foundation shall be designed to withstand a low probability earthquake with up to 0.2g peak acceleration in either the vertical or horizontal axis.	ENV0521

Low probability has been defined as a 2% probability of an event exceeding this magnitude over a 50-year period, consistent with data available from the USGS Seismic Hazard Model [RD02]. Equipment shall be designed to survive this standard in any operational condition and orientation.

6.8 Site Elevation

Parameter	Req. #	Value	Traceability
Altitude Range	ANT1471	The antenna and foundation shall be designed for survival and operation at altitudes from sea level to 2500 m.	ENV0351

The chosen design elevation accommodates the antennas on the plains of San Agustin and the identified main array sites. Some candidate long baseline sites may exceed this elevation and require design modifications on a case-by-case basis.

6.9 Vibration

Parameter	Req. #	Value	Traceability
Wind & General Vibration	ANT1481	All equipment shall be designed to withstand persistent vibration with a power spectral density defined in Figure 1. Line Replaceable Units (LRUs) shall be tested to this vibration specification along all three axes as defined in the MIL-STD-810H Method 514.8 Procedure I for General Vibration, for a period of 60 minutes.	ENV0531

The vibration mitigation requirement (Figure 1) is especially applicable to all mechanical connectors. All cables shall be mechanically supported to mitigate vibration loosening of connectors.

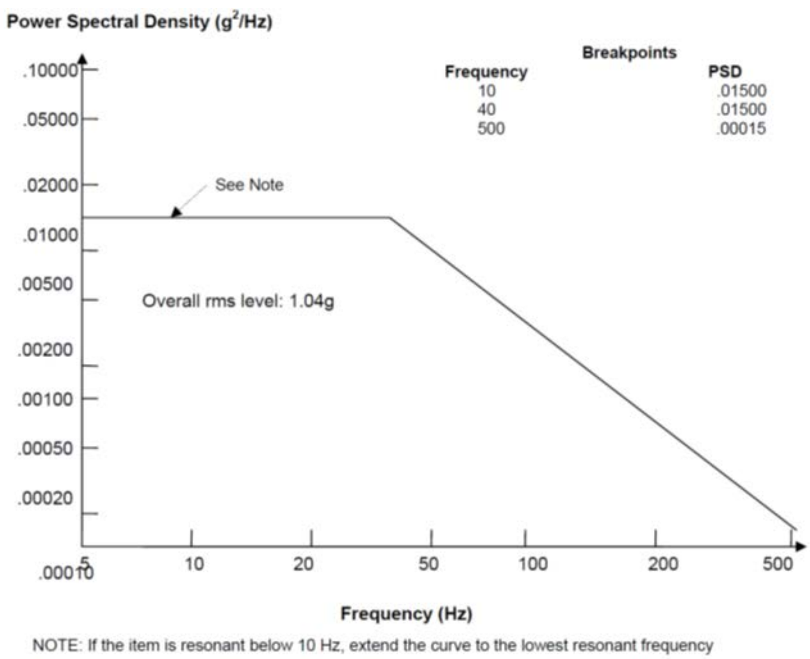

Figure 1 – Power spectral density of design spectra for vibration mitigation.

6.10 Dust

Parameter	Req. #	Value	Traceability
Exterior Equipment Protection	ANT1490	Exposed equipment shall be protected against windblown dust, ashes, and grit.	ENV0541
Interior Equipment Protection	ANT1491	Equipment room envelopes shall be tight enough to mitigate penetration of dust. All air circulation penetrations shall be filtered.	ENV0542

6.11 Fauna

Parameter	Req. #	Value	Traceability
Rodent Protection	ANT1492	Exposed equipment shall be designed to prevent rodent damage. At a minimum this may involve protecting all cables with flexible or rigid conduit or equivalent. Any penetration within enclosures and raceways shall mitigate the risk of rodent damage.	ENV0551
Large Mammal Protection	ANT1493	Exposed equipment at ground level shall be protected against damage by large mammals such as cattle.	ENV0552

6.12 Solar Radiation

Parameter	Req. #	Value	Traceability
Maximum Solar Flux	ANT1494	All equipment exposed to outside environment shall be designed for a maximum diurnal solar flux of 1200 W/m^2 from 0.3–60 μm.	ENV0561
Maximum UV Radiation	ANT1495	All equipment exposed to outside environment shall be designed for a maximum diurnal UV radiated flux of 100 W/m^2 from 280–400 nm.	ENV0562

These values are intended for lifecycle and reliability analysis, and the appropriate selection of materials and finishes.

6.13 Rain/Water Infiltration

Parameter	Req. #	Value	Traceability
Rain/Water Infiltration	ANT1496	Exposed equipment enclosures shall be designed to withstand rainfall intensity up to 16 cm/hr, with droplets sized 0.5 to 4.5mm, at wind velocity of 15 m/s from the vertical to horizontal direction.	ENV0571

Survival rain rates correspond to 50-year events as defined in [RD02].

6.14 Corrosion Protection

Parameter	Req. #	Value	Traceability
Corrosion Protection	ANT1497	Exposed equipment shall be designed to prevent corrosion that may impact the performance or structural integrity of the equipment over the system design life.	ENV0591

6.15 Mechanical Shock

Parameter	Req. #	Value	Traceability
Mechanical Shocks	ANT1498	Equipment and packaging of Line Replaceable Units shall be designed to survive mechanical shock levels from handling as defined in the MIL-STD-810H Method 516.8 Logistic Transit Drop Test, modified to use the drop heights specified in Table 2.	ENV0582

Mass of Package	Height of Drop	Number of Drops
0 kg to 25 kg	75 cm	Drop on each face and corner. Total of 26 drops.
25 kg to 50 kg	75 cm	Drop on each corner. Total of 8 drops.
50 kg to 100 kg	35 cm	Drop on each bottom edge and bottom face. Total of 5 drops.
> 100 kg	25 cm	Drop on each bottom edge and bottom face. Total of 5 drops.

Table 2 – Modified drop heights for logistic transit drop test.

7 Lifetime, Maintainability and Reliability Requirements

7.1 Lifecycle Requirements

Parameter	Req. #	Value	Traceability
Design Life	ANT1801	The antenna shall be designed for a service life of 30 years.	SYS2801
Lifecycle Optimization	ANT1802	The antenna design shall minimize its lifecycle cost assuming 30 years of operation.	SYS2802
Country of Origin	ANT1803	The antenna should meet US federal procurement regulations for country of origin content.	N/A

The design life shall be based on 24-hr per day of operation in the environmental conditions specified in Section 6. It is a goal that the service life not require significant overhaul work, e.g., replacement of azimuth or elevation bearings, or structural repairs. An exception to the overhaul work definition is painting, which shall not be required for 10 years or more. Lifecycle costs include manufacturing, transportation, construction/assembly, operation and decommissioning.

The ngVLA will be designed and constructed with a large contribution of federal funds. Provisions to "buy American" are expected, and the design and costing should presume the use of US steel (if steel is included in the design) and limits on total foreign content.

7.2 Maintainability and Reliability Requirements

Parameter	Req. #	Value	Traceability
Preventive Maintenance Cycle	ANT1501	Preventive maintenance shall not be required at intervals shorter than 12 months.	SYS2301
Preventive Maintenance Effort	ANT1502	Periodic preventive maintenance shall require no more than a 2-person team and no more than 2 8-hour workdays.	SYS2301
Mean Time Between Failures	ANT1503	MTBF ≥25,000 hrs. Goal of MTBF ≥35,000 hrs.	SYS2302

The maintenance and reliability requirements support high-level requirements that limit total array operating cost.[1] The preventive maintenance effort is intended to be averaged over the array design life and need not be equal on all 12-month cycles.

The MTBF requirement corresponds to an annual failure rate of 30% for the antenna electro-mechanical systems alone. Monitor points/sensors should be included in the MTBF/MTTR analysis, but sensors and other components that can be reasonably deemed to be ancillary to operation may be removed from the determination of compliance with the MTBF requirement (ANT1503).

"Failure" will be defined as a condition which places the system outside of its performance specifications (pointing, slew, tracking, etc.), or into an unsafe state, requiring repair. For example, a malfunction on one of three redundant anemometers would not meet the standard for failure in the MTBF analysis, and should not factor into compliance with ANT1503. Similarly, the malfunction of a gearbox temperature sensor would not be considered a failure for the purposes of ANT1503. However, the malfunction of a metrology sensor required for pointing model corrections would be considered a failure.

7.3 Maintenance Approach and Line Replaceable Units

Parameter	Req. #	Value	Traceability
LRU Designation	ANT3001	An assembly that is replaceable at the antenna site shall be designated as a Line Replaceable Unit (LRU).	ETR0301

Required preventive maintenance tasks shall be minimized. Corrective maintenance shall be mainly performed at assembly and subassembly level by exchange of Line Replaceable Units (LRUs). LRUs are defined as units which can be easily exchanged (without extensive calibration, of sufficient low mass and dimension for easiness of handling, etc.) by maintenance staff of technician level.

A step-by-step procedure for safe exchange of every LRU shall be provided in the Maintenance Manual. The following antenna equipment shall be considered an LRU as a minimum:

- Subreflector mechanism (if provided)
- Feed selection & focus mechanism
- Elevation encoder(s)
- Azimuth encoder(s)
- Drive motors

[1] For comparison the VLA Antenna MTBF appears to be approximately 7600 hrs. Number of antennas and budget caps constrain the ngVLA to MTBF ≥ 24,000 as useful parameter space. ALMA specs are equivalent to MTBF ≥ 27,000, but there are differences in the definition of counted failures.

- Electronic cards and drives
- Stow pin assemblies (if provided)
- Metrology sensors (if provided)
- Temperature sensors (if provided)
- Anemometers
- Limit switches
- Elevation hard stops
- Elevation cable wrap parts (excluding cables and cable installation)
- Locking pins
- Lightning arrestors

Other LRUs shall be defined by the antenna designer, depending on the design. The LRUs will be maintained by the ngVLA project (with or without industrial support).

7.4 Preventive Maintenance

7.4.1 Periodic Preventive Maintenance

Preventive maintenance is performed at planned intervals in order to maintain the antenna operational and within its specified performance. This includes checking, greasing, substitution of consumables, visual inspection, etc. All maintenance operations shall be planned in a Programmed Check and Intervention List (PCIL) of the Maintenance Manual, which shall list the tools, the procedures and the time necessary for their execution and their periodicity.

The antenna design shall enable these maintenance activities to be performed with the antenna stowed in the "maintenance stow" position as defined in Section 5.11. The normal preventive maintenance shall not exceed the requirements established in Section 7.2. Any greasing operation or lubrication activity that needs to be performed at interval shorter than 12 months shall be automatic.

7.4.2 Overhaul

Overhaul is a planned major maintenance operation that is performed at the antenna site. The following applies:

- No overhaul operation shall last longer than three weeks.
- No overhaul operation shall be required at intervals shorter than 15 years, with a goal of 20 years. Note that inspections at shorter intervals are permitted as part of the preventive maintenance program.
- Periodic painting and surface protection shall not be necessary more often than every 10 years.
- Overhaul activities, including painting and possible exchange of azimuth and elevation bearings, shall be described in the Maintenance Manual.

7.5 Alignment of the Primary Reflector

ngVLA will realign the reflector panels (assuming a panelized design) when the rms surface accuracy has degraded by more than the total ageing component included by the designer in the error budget (Backup Structure, adjusters and reflector panels). This should not be necessary at interval shorter than 10 years.

A full primary reflector surface adjustment should require no more than 18 hours (or 3 work days) of work for two people, with the use of a boom lift and the antenna in the designer-defined surface setting position identified in the antenna maintenance manual.

7.6 Corrective Maintenance

Replacement or repair will take place only in case of failure of an item. On site repair is normally limited to the in-situ exchange of LRUs as identified in Section 7.3. LRU exchange shall be possible by two trained personnel within four (4) working hours on the installed antenna. It is desirable that LRU replacement be possible without a boom truck, basket, or scissor lift, using only standard tools and special tools identified in the antenna maintenance manual.

7.7 Reliability, Availability, Maintainability Analysis

A Reliability, Availability, Maintainability analysis shall be performed to locate weak design points and determine whether the design meets the Maintenance and Reliability requirements. ngVLA suggests to apply the Parts Count Method for predicting the reliability of the system as described in the MIL-HDBK-217F [AD10], but the designer may propose to use other methods. For non-electronic parts, the values of NPRD-95 [AD11] or data from manufacturers or other databases may be used.

Another, but more time consuming (and considered more accurate) method, the Parts Stress Analysis Prediction, is also described in MIL-HDBK-217F [AD10]. This may be used if the results of the Parts Count Method do not comply with the Maintenance and Reliability requirements.

Some ngVLA antennas will be operated at an elevation of 2500m above sea level, where temperature and pressure might decrease the MTBF relative to that at low elevations. These conditions shall be taken into specific account in the reliability prediction by using the environmental factor given in MIL-HDBK-217F. The analysis shall result in estimates of the Mean Time Between Failures (MTBF) and the Mean Time To Repair (MTTR), assuming that scheduled preventive maintenance is performed.

7.8 Lifetime Motion Assumptions

For the computation of the system lifetime, reliability, failure rate, and maintenance limits, it shall be assumed that each antenna will execute the following motions during its lifetime[2]:

- A total of 263,000 complete cycles of elevation motion, equivalent to 1 cycle per hour, where a complete cycle of elevation motion is defined to be movement of the reflector from its lower elevation limit up to its upper elevation limit and back down to its lower elevation limit (12° to 88° to 12°).
- A total of 263,000,000 degrees of total motion about each axis[3], equivalent to approximately 2 full Azimuth rotations or 6.5 elevation cycles per hour.
- A total of 16 million fast switching cycles during its lifetime[4], where a fast switching cycle is a 4-degree move on sky, with two movements in a 30 second period.
- A total of 526,000 complete cycles of the feed selection Y-axis positioner during its lifetime, where a complete cycle is motion from the –Y limit to +Y limit and back. This is equivalent to two complete cycles each hour of operation.
- A total of 263,000 complete cycles of the feed focus Z-axis positioner during its lifetime, where a complete cycle is motion from the –Z limit to the +Z limit and back. This is equivalent to one complete cycle each hour of operation.

[2] Total Number of Hours in ngVLA Lifetime = (30 years)*(365.25 days/year)*(24 hr/day) = 262980 hours of operation in ngVLA lifetime.

[3] 1000 degrees of rotation per hour = approx. 2 full rotations in Azimuth (± 270 degrees) or 6.5 elevation cycles (152 degrees per cycle) per hour.

[4] Fast Switch cycles: Two movements in a 30 second period, for a maximum of 25% of the Total ngVLA observing time (2 cycle/ 30 secs.)*(3600 secs/hr)*0.25*262980 hours = approx. 16 million FS cycles.

8 Safety Requirements

8.1 General

To achieve protection against all possible hazards, the antenna shall be considered a piece of machinery, and its design and construction shall comply with the requirements set forth in Table 3.

Parameter	Req. #	Value	Traceability
Code Compliance	ANT7001	The design shall comply with all relevant federal, State of New Mexico, and State of Texas building codes.	SAF0050
Safety of Personnel	ANT7002	The design shall allow the Observatory to comply with all relevant federal and state occupational health and safety regulations for personnel servicing the antenna.	SAF0047, SAF0046
Ergonomic Principles	ANT7005	Ergonomic principles shall be applied to maintenance activities in order to reduce the discomfort, fatigue, and psychological stress associated with the activity in the operational environment.	SAF0190
Use of Personal Protective Equipment	ANT7006	The maintenance procedures shall account for the constraints to which the technician is subject as a result of the necessary or foreseeable use of personal protection equipment (such as footwear, gloves, etc.).	SAF0200
Lighting for Safe Operation	ANT7007	The design shall account for the integral lighting required for planned maintenance activities. Internal spaces requiring frequent inspection, adjustment, or maintenance shall provide appropriate lighting for these activities.	SAF0230

Table 3 – Antenna hazards code compliance.

While antennas will reside outside of the state of New Mexico and Texas, approximately 85% of the 18m antennas in the array are expected to be installed within these two states. Therefore, any code compliance issues unique to the remaining 15% of antennas will be assessed on a case-by-case basis. An assessment of any required changes should be performed by the CDR/FDR, once the array configuration is sufficiently stable to determine all relevant codes and enforcement agencies. Any changes to the safety requirements based on this assessment would be subject to project change control processes, where both NRAO and the antenna designer are represented.

8.2 Hazard Analysis Requirements

Parameter	Req. #	Value	Traceability
Hazard Analysis	ANT7003	A Safety Hazard Analysis shall be performed by the designer to ensure that hazards present in the design are evaluated and mitigated when they present an unacceptable risk to personnel or property.	SAF0032
Residual Risks	ANT7004	Where risks remain in the design, these risks shall be identified using pictogram labels on the associated equipment and in the documented maintenance procedures.	SAF1010

The Hazard Analysis shall be performed in accordance with the design requirements established in this section.

8.2.1 Hazard Severity

Hazard severity categories are defined in Table 4 to provide a qualitative measure of the mishap.

Category	Description	Definition
I	Catastrophic	Death, severe injury, or system loss.
II	Critical	Major injury, major occupational illness, major system damage.
III	Marginal	Minor injury, minor occupational illness, minor system damage.
IV	Negligible	Less than minor injury/occupational illness and minor system damage.

Table 4 – Hazard severity categories.

System loss: the antenna and/or the housed systems cannot be recovered and restored to full specification for less than 25% of construction cost. For hazards that impact many antennas concurrently, the threshold shall be 2% of total antenna construction cost.

Major system damage: the antenna and/or the housed systems can be recovered for less than 25% of the construction cost, but extensive industrial support is necessary and/or the system is inoperable for more than three weeks.

Minor system damage: the antenna and/or the housed systems can be repaired by ngVLA without any support from industry, using parts identified in the spare parts list, and the system is expected to be inoperable for less than three weeks.

8.2.2 Hazard Probability

Table 5 shows the probability classification of hazards occurring during the 30 years of expected antenna lifetime.

Level	Definition	Description
A	Frequent	Likely to occur frequently (once a year or more)
B	Probable	Will occur several times (10 to 15 times in 30 years)
C	Occasional	Likely to occur (3 to 9 times in 30 years)
D	Remote	Unlikely but possible to occur (typically 1 to 2 times in 30 years)
E	Improbable	So unlikely that occurrence can be assumed not to be experienced (>30 years)

Table 5 – Probability levels.

8.2.3 Hazard Risk Acceptability Matrix

The following two matrices (Table 6 and Table 7) define the degree of acceptability of the various hazard categories:

Frequency of Occurrence	I Catastrophic	II Critical	III Marginal	IV Negligible
Frequent	I A	II A	III A	IV A
Probable	I B	II B	III B	IV B
Occasional	I C	II C	III C	IV C
Remote	I D	II D	III D	IV D
Improbable	I E	II E	III E	IV E

Table 6 – Hazard classification matrix.

Hazard risk index	Assessment criteria
I A to I D, II A, B; III A	Unacceptable
II C, D; III B; IV A	Undesirable (ngVLA decision required)
I E; II E; III C; IV B	Acceptable with review by ngVLA
III D, E; IV C, IV D, IV E	Acceptable without review by ngVLA

Table 7 – Hazard acceptability matrix.

8.2.4 Requirements on Operational Hazards

None of the items in the following list (not meant to be exhaustive) shall lead to an unacceptable or undesirable hazard risk for the antenna or human beings:

- One or two independent operator errors;
- One operator error plus one hardware failure;
- One or two hardware failures;
- One or two software failures;
- Partial or complete loss of energy, reference signals, or control communications to the antenna;
- Emergency braking of the antenna;
- Earthquakes occurring in any position of the antenna; or
- Specified wind loads in any position of the antenna.

8.2.5 Hazard Analysis Report

The purpose of a Hazard Analysis is to identify safety critical areas, evaluate hazards, and identify the safety measurement to be used. The Hazard Analysis shall list all possible hazards, including an assessment of their severity and probability, and shall show that safety considerations are included in all stages of the project including assembly, training, operation, maintenance, etc.

Safety provisions and alternatives needed to eliminate hazards or reduce their associated risk to a level acceptable to ngVLA shall be described. As the design of the system progresses, the Hazard Analysis shall be kept up to date reflecting new considerations, data, and/or information. The following issues shall be considered:

- Safety-related interface considerations among various system elements, e.g., material compatibility, electromagnetic interference, inadvertent activation, fire initiation and propagation, hardware and software controls, etc.
- Environmental hazards including handling and operating environments.
- All hazards related to operating, testing, maintenance, and emergency procedures.
- Any other identified hazards.
- A description of any risk reduction methods employed for each hazard like safety-related equipment, safeguards, interlocks, system redundancy, hardware or software fail-safe design considerations, etc., taking into account the design requirements noted in Section 5.15 and 8.3.

8.3 Safety Design Requirements

8.3.1 Fire Safety

Smoke detectors are required in any equipment compartment and shall be interlocked to shunt trip all electric power in the antenna. When smoke is detected, the detector shall immediately close a contact used by ngVLA for a remote fire alarm and will energize a local audible alarm. The shunt trip of all power shall occur five seconds after smoke detection. Emergency power for the smoke detectors and local alarm shall utilize long-life batteries with a minimal reserve of six hours and less than a 24-hour recharge cycle. The ACU shall remain powered after alarm activation for a period sufficient to send an alert via the M&C system.

Parameter	Req. #	Value	Traceability
Reduce Risk of Fire	ANT7011	The antenna shall be designed to avoid the risk of fire or overheating posed by the machinery/equipment itself or by gases, liquids, dust, vapors or other substances produced or used by the machinery/equipment.	SAF0770
Smoke Detectors	ANT7012	Smoke detectors shall be provided in all equipment compartments and shall be interlocked to shunt trip all electric power in the antenna.	SAF0770

8.3.2 Mechanical Safety

For each component under design, all the possible criteria of mechanical failure relevant to the component under examination shall be considered (strength, fatigue, buckling, etc.). Unless otherwise required by the Standards applicable to this specification or by any applicable standard the minimum safety margins to be used are those provided herein.

- A minimum stress safety factor of 1.5 with respect to the yield point shall be used in the design of all mechanical components which in case of a failure lead to an unacceptable or undesirable hazard risk.
- This stress safety factor may be reduced to 1.1 in case of survival and accidental conditions.
- For metallic materials where the relevant failure criteria is not linked to plasticity (e.g., fatigue), an equivalent minimum stress safety factor of 1.5 shall be used in the design of all those mechanical components, which in case of a failure lead to an unacceptable or undesirable hazard risk.
- For CFRP parts, the equivalent stress safety factor shall be applied to the relevant failure mode to be considered for the part under examination. All relevant failure criteria shall be considered (delamination, fatigue, cracking, gluing failure, etc.). An equivalent stress safety factor of 1.5 shall be used in the design of all those components, which in case of a failure lead to an unacceptable or undesirable hazard risk. This value shall also apply to accidental and survival conditions.

Parameter	Req. #	Value	Traceability
Machinery – Sharp Edges	ANT7021	As far as their purpose allows, accessible parts of the machinery/equipment should have no sharp edges, no sharp angles, and no rough surfaces likely to cause injury.	SAF0540
Machinery – Noise Control	ANT7022	Machinery/equipment shall be designed such that risks resulting from the emission of noise are reduced to the lowest level (Category IV or less).	SAF0800

8.3.3 Electrical & Electronics Safety

Electrical equipment installed on the antenna shall comply with their relevant international or US product standard. The Antenna as a whole shall be in conformity with either IEC 60204-1 [AD05] or NFPA 79 [AD04] and with IEC 61140 [AD03].

Electrical installations and equipment shall be specifically built and/or derated in order to safely perform their intended functions under the applicable environmental conditions. Insulation shall be coordinated in conformity with IEC 60664 [AD06] while taking into account the altitude of up to 2500 m above sea level.

The antenna shall be designed, manufactured, and erected to exhibit functional safety with regard to electromagnetic phenomena as outlined in Section 13.2.3. Any electromagnetic disturbances internal to the antenna that may impact the safety of the antenna shall be mitigated in the antenna design.

8.3.3.1 US National Electric Code (NEC) Compliance

All AC and DC high-voltage (>= 50 Volts) and safety grounding shall be in compliance with the US NEC.

Parameter	Req. #	Value	Traceability
US National Electric Code Compliance	ANT3301	All wiring operating at or above 50 Volts DC or 50 Volts rms AC and all safety grounding shall be in compliance with the US NEC.	ETR1001

8.3.3.2 Contact with High Voltages

All circuitry, connectors, terminals, and wiring carrying high voltages (i.e. >= 50 Volts) shall be insulated or protected to prevent accidental contact during operation, inspection and routine maintenance. In situations where exposure must be possible during in-depth diagnosis & repair, procedures for minimizing risk of contact shall be provided in a maintenance manual for the subsystem or equipment under repair.

Parameter	Req. #	Value	Traceability
Contact with High Voltages	ANT3311	All circuitry, connectors, terminals and wiring carrying high voltages (i.e. at or above 50 Volts DC or 50 Volts rms AC) shall be insulated or protected to prevent accidental contact during operation, inspection and routine maintenance.	ETR1003
Contact with High Voltage during Diagnosis & Repair	ANT3312	In situations where exposure to high voltages (i.e. at or above 50 Volts DC or 50 Volts rms AC) must be possible during in depth diagnosis and repair, procedures for minimizing risk of contact shall be provided in a maintenance manual for the subsystem or equipment under repair.	ETR1004
Safety Interlocks	ANT3313	Safety interlocks shall be used in situations where high voltages (i.e. >= 50 Volts) could be exposed.	ETR1008

8.3.3.3 Protection of Electrical Storage Devices

Devices that store electricity such as capacitors and batteries can represent serious hazards for electrical shock, fire and damage to equipment if not adequately discharged or protected.

Parameter	Req. #	Value	Traceability
Discharge of Capacitors Operating at High Voltages	ANT3321	Any capacitor operating at 50 VDC or above shall be provided with a resistive path to discharge the capacitor to safe levels within 60 seconds of the circuit being de-energized. This discharge circuitry shall operate regardless of the condition of downstream electronics.	ETR1005
Contact with Terminals of Storage Devices	ANT3322	Electrical terminals of high-capacity storage devices such as batteries and large value capacitors shall be insulated or protected to prevent accidental contact during operation, inspection, and routine maintenance.	ETR1006

Parameter	Req. #	Value	Traceability
Contact with Terminals of Storage Devices During Diagnosis and Repair	ANT3323	In situations where exposure to terminals must be possible during in depth diagnosis and repair, procedures for minimizing risk of contact shall be provided in a maintenance manual for the subsystem or equipment under repair.	ETR1007

8.3.3.4 Electrical Safety Labeling

Proper labeling of any equipment where potential exposure to hazards exists is critical to prevent Injury to personnel, damage to equipment and compliance with codes and Occupational Safety and Health Administration (OSHA) requirements.

Parameter	Req. #	Value	Traceability
High Voltage Labels	ANT3331	Any equipment or assembly containing voltages above 50 Volts DC or 50 Volts rms AC shall contain at least one clearly visible "High Voltage" label compliant with applicable standards at the time of installation.	ETR1008
Battery Labels	ANT3332	Any equipment that contains a battery that powers internal circuitry, even if the device is de-energized or disconnected from the system, shall contain at least one clearly visible label indicating the presence of the battery. This label shall be compliant with applicable standards at the time of installation. The label shall also contain space allowing for permanent marking of the battery install date.	ETR1009
Power Switch Labels	ANT3333	Any equipment containing a power switch shall contain at least one clearly visible label indicating the existence and location of that switch. The label shall be compliant with applicable standards at the time of installation.	ETR1010
Emergency Cutoff Switch Labels	ANT3334	Any equipment containing an Emergency Cutoff Switch shall contain at least one clearly visible label indicating the existence and location of that switch. The label shall be compliant with applicable standards at the time of installation.	ETR1011
Safety Ground Labels	ANT3335	Any equipment containing a critical safety ground connection shall contain at least one clearly visible label indicating the existence and location of that connection. The label shall be compliant with applicable standards at the time of installation.	ETR1012
Hazardous Condition or Operation Labels	ANT3336	Any equipment that produces hazardous or startling conditions at startup, at shutdown, or in normal operation shall contain a least one clearly visible label identifying the condition. This could include any motion, startling sounds or bright light. The label shall be compliant with applicable standards at the time of installation.	ETR1013

Parameter	Req. #	Value	Traceability
Safety Instruction Labels	ANT3337	Any critical instructions required to safely remove, install, or interact with a piece of equipment shall be affixed to the device on at least one clearly visible label. The label shall be compliant with applicable standards at the time of installation.	ETR1014

8.3.4 Hydraulic and Pneumatic Safety

Any hydraulic or pneumatic systems shall be designed in accordance with ISO 4413 [AD07].

Parameter	Req. #	Value	Traceability
Non-Electric Energy Sources	ANT7031	Where machinery/equipment is powered by energy other than electricity (e.g., hydraulic, pneumatic or thermal energy, etc.), the design shall avoid and mitigate hazards associated with these types of energy.	SAF0720

8.3.5 Handling, Transport, and Storage Safety

The design of the antenna shall incorporate all means necessary to preclude or limit hazards to personnel and equipment during assembly, disassembly, test, and operation.

Parameter	Req. #	Value	Traceability
Safe Lifting/Rigging	ANT7041	Where the weight, size, or shape of machinery/equipment or its various component parts prevents them from being moved by hand, each component part shall be fitted with attachments for lifting gear, or designed so it can be fitted with such attachments (e.g., threaded holes), or shaped so that standard lifting gear can easily be attached	SAF0250
Moveable Machinery	ANT7042	Where machinery/equipment is to be moved by hand, it shall be easily movable or be equipped for picking up (e.g., hand-grips, etc.)	SAF0260
Errors of Fit	ANT7043	Errors when fitting or refitting certain parts that could be a source of risk must be made impossible by design or mitigated by information on the parts themselves and/or the housings.	SAF0730

8.3.6 Toxic Substances

No use of toxic substances (asbestos, formaldehyde, lead, etc.), or of their derivatives, shall be permitted in the antenna. An exception may be made for lead-based solders, when necessary to meet maintainability or reliability requirements. Any requests for exceptions to this requirement shall be submitted in writing for review by NRAO. Insulation material and paint specifications shall be reviewed by NRAO.

8.3.7 Confined Space

Considerations of confined space in the sense of OSHA Standards 29 CFR Part 1910 [AD08] and 29 CFR Part 1926 [AD09] shall be taken into account in the design where applicable (e.g., base, yoke, etc.).

Parameter	Req. #	Value	Traceability
Prevent Enclosed Entrapment	ANT7051	Machinery/equipment shall be designed with a means of preventing a person from being enclosed within it. If impossible, a means of summoning help shall be provided.	SAF0870

8.4 Physical Security

Reasonable protection against unauthorized personnel access and theft shall be provided in the antenna by means of lockable and caged access ladder, locks on cabinets, doors, and similar design provisions. Sensors shall be installed to monitor the condition "door open" and to relay the information to the ACU in order to detect unauthorized intrusion.

Parameter	Req. #	Value	Traceability
Ensure Safe Access	ANT7061	The antenna shall provide means of access (stairs, ladders, catwalks, etc.) to allow safe access to all areas used for adjustment and maintenance operations.	SAF0920
Monitor Doors	ANT7062	Sensors shall be provided to monitor the state of all doors. This status shall be relayed by the ACU.	SYS2704
Door Locks	ANT7063	Any doors and hatches accessible from ground level shall include deadbolt locks, or equivalent.	SYS2704
Access Restriction	ANT7064	Any stairs or ladders accessible from ground level shall include measures to restrict access to authorized personnel.	SYS2704

Note that the safe access requirement (ANT7061) does not apply to the reflector panel adjustment procedure, or other overhaul procedures that require access via a boom truck.

9 Analysis and Design Requirements

9.1 Finite Element Structural Analyses

All the Finite Element Analyses (FEA) necessary for the verification of the performance of the antenna must be performed with an internationally recognized numerical code. The structural models used shall be adapted to the particular analysis for which they are going to be used and shall be accurate enough to provide a good description of the behavior of the structure under examination in terms of displacements, stress and frequencies.

The analysis error due to mesh discretization shall be $\leq$10% in terms of finite element internal criteria like the "Percentage error in energy norm". Alternatively, this type of error can be evaluated by mesh refining. The analyses which are required to be performed are listed and specified below. In case during the design phase it appears that other analyses are necessary, the list below shall not be considered exhaustive.

The FEA analysis must also support the EM Analysis described in Section 9.4.

9.1.1 Static Analysis

Static analyses shall be used in the calculation of the effect of:

- Gravity loads (stress and deflection)
- Sudden braking (stresses)
- Thermal deformation (input loads derived from the thermal analysis)
- Wind under precision and normal operating conditions (deflections)
- Wind under survival conditions (stresses).

9.1.2 Modal Analysis

A modal analysis shall be performed in order to obtain accurate information concerning the Eigen frequencies and the Eigen modes of the antenna, when integrated in the antenna station, i.e. the combined stiffness of the soil and foundation of the antenna stations shall be adequately represented in the dynamic FE Model. The number of degrees of freedom shall be such as to have a good representation of the frequency range required. Care must be exerted to correctly represent the boundary conditions of the system under examination.

9.1.3 Seismic Analysis

The structural model used for the seismic analysis shall adequately represent the distribution of stiffness and mass so that all significant deformation shapes and inertia forces are properly accounted for under the seismic action considered. Non-structural elements[5], which may influence the response of the main resisting structural system, shall also be accounted for. The response of all vibration modes contributing significantly to the global response shall be taken into account. This may be demonstrated by either of the following:

- the sum of the effective modal masses for the modes, taking into account at least 80% of the total mass of the structure, or
- all frequencies below 50 Hz are taken into account.

The above conditions have to be verified for each spatial direction. The seismic analysis shall be based on the modal response spectrum technique, using a linear-elastic model of the structure. It shall be assumed that the structural damping is 1.5% of critical damping.

The Square Root Sum of the Square method (SRSS) may be used in order to combine the contribution of the various modal responses. The three spatial components of the response may also be combined with the SRSS method. Alternatively, the designer may propose combination rules for the modal and spatial components consistent with a relevant international earthquake resistance standard.

9.1.4 Wind Analysis

The force distribution on the antenna caused by wind in the precision and normal operating conditions can be derived by either of the following:

- Computational Fluid Dynamic (CFD) analysis, or
- Extrapolated wind tunnel measurement results of similar structures.

[5] An architectural, mechanical or electrical element, system or component which, whether due to lack of strength or the way it is connected to the structure, is not considered in the seismic design as load carrying element.

The force distribution caused by survival wind loads may also be derived by both means. These forces may be applied as quasi-static.

When analyzing pointing performance, servo loop behavior, and other relevant parameters that require a spectral power distribution of the wind, the designer shall propose a turbulence model (e.g., Von Karman, Davenport, Simiu, etc.) and describe the mapping of the model to ngVLA requirements. E.g., the designer could use a Von Karman [RD04] model with the three sigma values mapped to the specified wind gust velocity.

9.2 Thermal Modeling and Analysis

A thermal model of the antenna shall be used to compute the temperature distribution in the antenna during Precision and Normal operating conditions. The model shall also be used to determine the equilibration period duration from sunset (i.e., the time required to reach thermal equilibrium after sunset). The thermal model shall be able to simulate adequately the effects of thermal conduction, convection and radiation (solar flux). The calculated temperature distribution shall be applied as thermal load to the structural finite element model to predict the thermal error contribution to the pointing and surface error budgets.

9.3 Stress Analysis and Load Combination

A detailed stress analysis of the Antenna shall be performed. The stress analysis shall combine the individual design loads and conditions specified under Section 9.1.1. In general, the load combinations to be verified are given in Table 8, whereby for specific components different load combinations may apply.

Load Combination: Operational Condition
Gravity + Thermal (Normal) + Wind (7 m/sec)
Gravity + Thermal (Precision)+ Wind (5 m/sec)
Load Combination: Accidental Condition
Gravity + Thermal (Limit) + Wind (20 m/sec) + Emergency braking
Load Combination: Survival Condition
Gravity + Wind (50 m/sec)
Gravity + Thermal (–30 °C) + Wind (30 m/sec)
Gravity + Wind (30 m/sec) + Icing + Snow
Gravity + Seismic + Wind (20 m/sec)

Table 8 – Load cases for antenna stress analysis.

9.4 Antenna EM Analysis

Verification of the aperture plane error requirements (Section 5.5) will require optical ray trace analysis to determine the aperture plane error associated with the load cases analysed by FEA. The requirement being specified as an aperture plane error (instead of gain loss) eliminates the need for more detailed electromagnetic analysis on the part of the antenna designer. Verification of the focus stability requirements (Section 5.8) will also require the determination of the secondary focus position, relative to the feed, via ray tracing.

NRAO will also perform electromagnetic analysis of the deformed optics, integrated with the candidate feed designs, to determine if the integrated antenna performance satisfies higher-level system requirements. The antenna designer shall provide deformed reflector surfaces, in the main reflector coordinate system defined in [AD19], for the NRAO electromagnetic performance analysis.

At a minimum, the following load cases and combinations shall be provided:

- Gravity (Worst case elevation; 12°, 50°, 88° elevation)
- Thermal (Normal environment, worst case)
- Thermal (Precision environment, worst case)
- Wind (7 m/sec, worst case orientation)
- Wind (5 m/sec, worst case orientation)
- Gravity (Worst case elevation)+ Thermal (Normal) + Wind (7 m/sec)
- Gravity (Worst case elevation) + Thermal (Precision)+ Wind (5 m/sec)

This list is intended to be consistent with the Operational Condition load cases given in Table 8.

9.5 Control Loop Design and Analysis

Dynamic simulations of the control loops shall be performed, including nonlinear effects like friction, stick-slip, sensor noise, etc. For each function to be controlled, the stability margins shall be computed.

10 Interface Requirements

This section provides information about the interfaces of the antenna and the associated interface requirements. Interface Control Documents (ICDs) are required between the antenna and all interfacing sub-systems as outlined below. This list summarizes the relevant relationships defined in the System N^2 Diagram [RD03]. Sub-systems developed by the Antenna Electronics team are aggregated into a single ICD for convenience and readability. The scope of each ICD includes:

1. Antenna to Array Infrastructure (INF) ICD
    a. Antenna Foundation
    b. Electrical Infrastructure
    c. Fiber Optic Infrastructure
2. Antenna to Antenna Electronics ICD
    a. Front End Electronics (FED) Equipment
        i. Receiver Enclosure
        ii. Receiver Enclosure Positioner/Indexer (provided by Antenna)
        iii. Auxiliary Enclosure
    b. Electronics Environmental Control (EEC) Equipment
        i. Glycol Chiller
        ii. Glycol Piping
        iii. Air Handler
    c. Cryogenics System (CRY) Equipment
        i. Helium Compressor Unit
        ii. Helium Pressure Regulation Assembly

iii. Helium Supply Tank

iv. Helium Buffer Tank

v. Cryo-Compressor Helium Lines

d. Bins, Modules and Racks (BMR)

i. Electronics Rack

ii. Electronics Rack Air Handler Unit

iii. Electronics Rack Chiller Unit (outside the Pedestal or Azimuth Structure)

iv. Electronics Rack Battery Enclosure

v. RFI Enclosure (for Compressor VFD and M&C Module)

e. Water Vapor Radiometer (WVR) Front End Assembly

3. Antenna to Monitor and Control (MCL) ICD

In some cases, definitions and specifications for the interfaces cannot be developed until later in the design, but the broad scope of the ICD has been defined. These interface definitions shall be developed and documented by the antenna designer and NRAO, and then governed by formal project change control processes. Approved ICDs shall be considered part of the requirements baseline.

10.1 Interface to the Array Infrastructure

10.1.1 Antenna to the Antenna Foundation/Station

The ngVLA will be spread out over a large geographic area. This results in antennas being located at sites with varying geological makeup and soil compositions. NRAO shall be responsible for development of foundation designs suitable for each of these locations that meets the stiffness requirements of the antenna design. The Antenna designer and NRAO shall work together to ensure the final foundation design meets the agreed upon requirements of the antenna to foundation interface.

The details of the interface between the antenna and the Antenna Foundation/Station shall conform to the Antenna to Array Infrastructure ICD [AD21]. The ICD will define the geometry of the antenna mounting attachment and the mechanical characteristics of the foundation. The foundation refers to all stations where an antenna can be mounted, irrespective of location.

10.1.2 Antenna to the Electrical Infrastructure

The details of the interface between the antenna and the electrical power infrastructure shall conform to the Antenna to Array Infrastructure ICD [AD21].

Electrical power will be routed to the antenna through a vault adjacent to or integrated into the antenna foundation. Most antenna foundation locations are expected to be connected to the commercial power grid, but some remote sites may use locally generated power. However, all locations are expected to conform to a common interface. Electrical distribution within the antenna shall account for the electrical power distribution and interface requirements in the Antenna to Antenna Electronics ICD [AD18].

10.1.3 Antenna to the Fiber Optic Infrastructure

The details of the interface between the antenna and the fiber optic infrastructure shall conform to the Antenna to Array Infrastructure ICD [AD21].

A number of fibers will be distributed to each antenna for monitor and control, data transmission, and time and frequency distribution. The fiber optic cables will be physically routed through a vault adjacent to or integrated into the antenna foundation and will terminate at a splice box within the antenna. The interfaces to the fiber distribution system inside the antenna are defined by the Antenna to Antenna Electronics ICD [AD18]. The communications interface to the antenna shall be considered part of the monitor and control system interface [AD20].

10.2 Interface to the Antenna Electronics Subsystems

The details of the interface between the antenna and the antenna electronics subsystems shall conform to the Antenna to Antenna Electronics ICD [AD18].

This ICD document contains a definition of the following subsystem's interfaces to the Antenna: Front End Electronics (FED); Cryogenics (CRY); Electronics Environmental Control System (EEC); Bins, Modules and Racks (BMR); Water Vapor Radiometer (WVR); and Antenna Fiber Distribution (AFD). While additional antenna electronics reside within the antenna, they have no direct interfaces, and associated needs are captured within the aforementioned interface definitions.

10.2.1 Interface to the Receiver Selection Mechanism (Feed Indexer)

A key interface to the antenna electronics is a receiver selection mechanism (feed indexer) and focus adjustment mechanism, which are the responsibility of the antenna designer. It is expected that a two-axis positioner, providing adjustment in the Z_F and Y_F axes (see the coordinate system definition in AD19), will be required at a minimum. Adjustment in the X_F range may be necessary depending on the degree of gravitational deformation, but this design choice is within the purview of the antenna designer. Interface requirements for the receiver selection mechanism, and other details of the antenna to front end electronics interface, are defined in the Antenna to Antenna Electronics ICD [AD18].

10.2.2 Interface to Internal Cables and Piping

Fiber optic cables, multi-conductor electrical cables, cryogenic piping, and other cooling system piping distribute signals and fluids to customer-supplied equipment. While the cables and piping are supplied by customer systems, the antenna must provide suitable routing spaces, mount support (hangers and trays), and wrap protection.

The Antenna to Antenna Electronics ICD [AD18] describes the point-to-point connections, cable or piping cross-sections, bend radii, and other mechanical parameters necessary for internal cable and piping routing.

10.3 Interface to the Monitor and Control System

The Antenna Control Unit (ACU), to be provided by the Antenna, shall govern the local control of the antenna, processing higher-level commands into lower-level commands suitable for each axis drive and ancillary mechanisms.

The communication protocol, physical interface, and other monitor and control interface requirements shall conform to the Antenna to Monitor and Control ICD [AD20]. This ICD shall be extended by the vendor, in coordination with NRAO, to include all monitor and control commands necessary to safely operate the antenna and to achieve the functional and performance requirements.

11 Materials, Parts, and Processes

11.1 Type of Steel

The steel used in the antenna mount shall be a carbon or a low-alloy steel. The selection of the steel shall take into account the low temperature to be expected during antenna operation and stow, under the point of view of embrittlement. In particular, the nil-ductility transition temperature of the selected steel shall not exceed –45°C. The nil-ductility transition temperature is the temperature at which the material starts to exhibit cleavage fracture with very little evidence of notch ductility.

When necessary (e.g., gears and pinions, if applicable) materials with suitable hardness or surface hardened shall be used, in order to ensure the life of the system.

11.2 Stress Relieving

All structural welded parts shall be stress-relieved by means of an appropriate method to reduce stresses and ensure dimensional stability (unless proven by the antenna designer to be unnecessary).

11.3 CFRP

If Carbon Fiber Reinforced Plastic (CFRP) is used, the material and fabrication processes shall be selected, examined, and if necessary qualified with respect to strength, fatigue, and life. All CFRP structures shall be protected against solar radiation and humidity with suitable paints and or sunshades.

11.4 Fasteners

All fasteners should be metric except those on Commercial Off-The-Shelf (COTS) units. The use of standard metric cross-sections for construction materials is not required.

Parameter	Req. #	Value	Traceability
Metric Hardware	ANT3731	Electronics should be assembled utilizing "M" Series metric screws, nuts, and other hardware as defined in ISO 68.1:1998 General Purpose Screw Threads – Basic Profile – Part 1: Metric Screw Threads.	ETR1161
Hardware Labeling	ANT3732	All LRUs and assemblies shall contain at least one clearly visible label identifying the type of hardware used within the assembly. Labels will indicate whether "Metric," Imperial," or "Mixed" hardware is used.	ETR1162
Assembly Hardware: Galvanic/ Corrosion Properties	ANT3733	All assembly hardware shall be of a material, plating and/or coating appropriate for its location based on galvanic corrosion properties.	ETR1163
Assembly Hardware: Electrical Properties	ANT3734	All hardware shall be of a material, plating, and/or coating appropriate for its location based on electrical conductivity.	ETR1164
Assembly Hardware: Strength Properties	ANT3735	All hardware shall be appropriate grade and material for its location based on strength.	ETR1165

Parameter	Req. #	Value	Traceability
Heads and Drivers for Pan Head Screws	ANT3736	All pan head screws should utilize Textron Torx type 6-point star shaped screw heads driven by Torx type drivers.	ETR1166
Heads and Drivers for Flat Head Screws	ANT3737	All flat head screws should utilize Textron Torx type 6-point star shaped screw heads driven by Torx type drivers.	ETR1167
Heads and Drivers for Cap Head Screws	ANT3738	All cap head screws should utilize hexagonal Allen type screw heads driven by hex type drivers.	ETR1168
Hardware Retention	ANT3739	All nut and bolt type hardware interfaces shall utilize retention techniques to prevent loosening. Examples include lock washers, adhesives, cotter pins, and safety wiring.	ETR1169
Fastener Torque Specifications	ANT3740	Torques for all fasteners shall be specified on assembly drawings referenced in the maintenance manual.	ETR1171
Fasteners in Electrically Conductive Applications	ANT3741	Anodized and black oxide fasteners shall not be used at mechanical interfaces requiring electrical conductivity to maintain electrical grounds or RFI/EMC integrity.	ETR1184

11.5 Surface Finishes

Parameter	Req. #	Value	Traceability
Chromate Converted Surfaces	ANT3701	Aluminum surfaces where electrical conduction is required (RFI/EMI or safety grounding) shall be treated using a Chromate Conversion process as outlined in MIL-DTL-5541E. Either Class 1A or Class 3 can be used based on requirements determined by the designer.	ETR1143
Stainless Steel Surfaces	ANT3702	Stainless steel may be used for RFI/EMC housing where deemed feasible by the designer. Surfaces can be painted but shall be left bare where electrical conduction is necessary.	ETR1144
Anodized Surfaces	ANT3703	Non-structural aluminum surfaces, where no electrical conductivity is required, may be anodized. Anodizing shall be of a color not mistakable for chromate (i.e. not clear, yellow, brown, or gold). Anodizing shall not be used on surfaces requiring electrical conductivity for RFI/EMI shielding or good safety ground conduction and shall never be scraped or sanded to achieve conductivity.	ETR1145
Painted Surfaces	ANT3704	Surfaces requiring paint shall be painted with white paint suitable for the surface material and environmental conditions the surface will experience, with a design life of 10 years or longer. Proper surface preparation suitable for the material and paint shall be used.	ETR1146

Parameter	Req. #	Value	Traceability
Colored Paint Marking	ANT3705	Surfaces which need to be painted specific colors for safety and/or maintenance marking shall be painted with the appropriate color paint suitable for the surface material, environmental conditions, and wear and tear the surface will experience. Proper surface preparation suitable for the material and paint shall be used.	ETR1147

11.5.1 Surfaces Requiring Electrical Conductivity for RFI/EMC or Grounding

Where high-quality grounds, especially safety grounds, are required, one should not paint any of the current carrying surfaces. Chromate conversion, often referred by trade names like Alodine and Irridite, provides the best combination of corrosion protection and electrical conductivity for aluminum parts. There are two general processes for chromate. The MIL-C-5541E [AD24] Class 3 process enhances the corrosion protection capabilities at the expense of slightly reduced electrical conductivity.

MIL-DTL-5541E, Military Specification, Chemical Conversion Coatings on Aluminum and Aluminum Alloys [AD24] covers chemical conversion coatings formed by the reaction of chemical conversion materials with the surfaces of aluminum and aluminum alloys. Class 3: Provides protection against corrosion where low electrical resistance is required. This is a thin coating providing low contact resistance, and the coating weight is lower as is the corrosion resistance.

It is also often suitable to use stainless steel in this application. The stainless steel may be painted except for areas where electrical conduction is needed.

Anodized aluminum is not electrically conductive and is not acceptable for any surface requiring electrical conductivity. Anodized aluminum used anywhere on the antenna shall be of a color not mistakable for chromate converted aluminum and the anodized coating shall never need to be scraped off at any point to provide for electrical conductivity.

Housings and assemblies designed to be RFI shielded should not be directly exposed to an exterior environment. An outer environmental protective cover shall be provided for any RFI shielding housing exposed to the elements.

11.5.2 Surfaces Not Requiring Electrical Conductivity

Antenna structural components, housings, etc. could be made from painted steel, painted aluminum (after chromate conversion), painted or unpainted stainless steel, or fiberglass. If used, anodized aluminum must be of a color not mistakable for chromate-converted aluminum and the anodized coating should never need to be scraped off at any point.

To limit the effect of solar heating and associated differential expansion of structural members and to protect the antenna structure against atmospheric corrosion, the antenna structure shall be painted with white solar reflecting paint. The paint shall be chosen to last at least 10 years without repainting.

The designer may propose other surface treatments in place of white solar reflecting paint, especially for the reflector surfaces, subject to NRAO review and approval.

Any unpainted surfaces shall be treated against corrosion.

11.6 Thermal Insulation

Thermal insulation, when used in an exterior application by the antenna designer, shall be protected with a metal cover.

12 Physical and Network-Based Product Identification

12.1 Marking

References for Section 12:

- MIL-STD-13231: Department Of Defense Standard Practice: Marking of Electronic Items (02 Nov 1999) [AD25] – This standard specifies the DoD's uniform marking requirements for electronic items.
- MIL-DTL-15024: Detail Specification: Plates, Tags, and Bands for Identification of Equipment, General Specification for (28 Nov. 1997) [AD26] – This performance specification covers the physical characteristics of plates, tags, and bands (identification devices) used for identification of equipment. Examples of information to be marked on the identification devices are covered in the applicable specification sheets.
- MIL-P-19834: Detail Specification: Plates, Identification, or Instruction, Metal Foil, Adhesive Backed General Specification for (06-Jul-2006) [AD27] – This detail specification covers adhesive-backed metal foil identification or instruction plates for use as internal and external equipment identification or instruction.

All LRUs must be marked with a physical label containing a clear set of visible markings. The information required includes (but is not limited to):

- The model number/name of the equipment – as defined in MIL-STD-13231 [AD25]
- The serial number of the device – as defined in MIL-STD-13231
- The hardware revision level – as defined in MIL-STD-13231
- The part number that is cross referenced to the documentation of the associated device/equipment. In the case of a custom assembly, this part number should correspond to a CIL that fully defines the documentation associated with the assembly.

This label shall be placed on an accessible external surface of the assembly. These permanent markings must be impervious to the hardware's operational, storage, transport, and maintenance environments as defined in the United States Department of Defense (DoD) Standards MIL-DTL-15024 [AD26] and MIL-P-19834 [AD27]. A complete history and status, with a comparable level of detail, shall be readily available from the database under which they are managed.

Parameter	Req. #	Value	Traceability
LRU Physical Marking Label Contents	ANT3011	Each LRU shall be marked with the model number/name, serial number and hardware revision level as defined in MIL-STD-13231 and the part number that is cross referenced to product documentation.	ETR0401
LRU Physical Marking Label Ruggedness	ANT3012	The attached LRU Physical Marking Label shall comply with MIL-DTL-15024 to ensure durability and longevity of the label.	ETR0409

12.2 Physical Tracking

Parameter	Req. #	Value	Traceability
LRU Physical Tracking Device	ANT3021	Each LRU shall be equipped with a standardized physical tracking label or device, e.g., bar code or RFID tags, which provides for quick and unique identification via a UID and IUID as described in US DoD Standard MIL-P-19834.	ETR0402
LRU Tracking Label & Tag Specifications	ANT3022	The Physical tracking label and/or or device attached to each LRU shall conform to the specifications outlined in US DoD Standards MIL-DTL-15024 and MIL-P-19834.	ETR0405

Items that require tracking will also be uniquely identified through a reliable and standardized tracking system. A unique identification device will be attached to the device at the start of each unit's construction and can be used as the assembly, testing & installation traveler. Examples include a printed bar code or electronic radio frequency identification (RFID) tags which can be read by portable handheld readers.

Unique Identification (UID) and Item Unique Identification (IUID) data are stored in or on this device. These IDs are part of the identification marking process mandated by the DoD as defined in AD25, AD26, and AD27 (listed above). The UID and IUID are permanent identifications used to give military property and Government-Furnished Property (GFP) the necessary Unique Item Identification (UII) information.

12.3 Remote Monitor and Control Identification

Parameter	Req. #	Value	Traceability
Remote Identification	ANT3031	Any electronic LRU with connectivity to the M&C system via the ACU shall identify itself when polled via the M&C network. Minimum information to be reported includes • Module/Model Number • Serial Number • Part Number which leads to all documentation • Hardware Revision Level • Software Revision Levels (if applicable) • Firmware Revision Levels (if applicable) • UID and IUID from Physical tracking tag or device	ETR0403

To aid in configuration control, maintenance tracking, and planning of maintenance visits, all electronic LRUs with any connectivity to the M&C System shall provide identification when polled via the M&C network. At a minimum, information reported shall include

- Module/Model Number
- Serial Number
- Part Number which leads to all documentation
- Hardware Revision Level
- Software Revision Levels (if applicable)
- Firmware Revision Levels (if applicable)
- UID and IUID from the physical tracking device

At the discretion of the designer or to meet other array reporting requirements, more detailed data such as calibration files, etc., may also be reported when polled.

12.4 Labels for Physical Safety

All LRUs shall conform to the following labeling requirements for safety.

Parameter	Req. #	Value	Traceability
LRU Weight Labels	ANT3051	All LRUs with a mass greater than 4.5kg (10 lbs) shall include at least one clearly visible label indicating the weight of the LRU in pounds. The mass may also be noted in kg. The label shall be compliant with applicable standards at the time of installation.	ETR0406
LRU Multiple Person Lift Labels	ANT3052	If the LRU is sufficiently heavy to require "Multiple Person Lift," a clearly visible label indicating that requirement along with the number of persons required shall be included. The label shall be compliant with applicable standards at the time of installation.	ETR0407
Lift and Hoist Points	ANT3053	Clearly visible label(s) shall be included identifying the presence and location of all lift or hoist points on the LRU. The label shall be compliant with applicable standards at the time of installation.	ETR0408

13 Electrical and Electronic Requirements

13.1 Electronics Standards

13.1.1 Printed Circuit Boards

The ngVLA antenna and housed systems will contain numerous Printed Circuit Boards (PCBs). For reliability, maintainability and documentation purposes, it is important that these PCBs all be designed to a consistent set of standards. For the ngVLA project, all *custom* PCBs will adhere to the current version of IPC standard, IPC-A-600K: Acceptability of Printed Circuits Boards [AD28].

PCBs shall be compliant with RoHS 2/3 standards as described in:

- RoHS 2: EU Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment - EU Directive 2011/65/EU (8 June 2011). [AD29]
- RoHS 3: EU Directive Amending Annex II to Directive 2011/65/EU as regards the list of restricted substances (effective 22 July 2021) - EU Directive 2015/863 (31 March 2015). [AD30]

Exemptions from IPC and RoHS requirements will be considered by NRAO where lifecycle, manufacturability, and/or reliability issues are a concern.

It is unlikely that COTS PCBs will fully meet these requirements. In the case of COTS PCBs, these requirements become goals. The designer shall make a best attempt to procure COTS equipment with PCBs that meet as many of these standards as possible.

Parameter	Req. #	Value	Traceability
Printed Circuit Board IPC Standard Compliance	ANT3101	PCBs shall be designed and manufactured to meet IPC Standard IPC-A-600K: Acceptability of Printed Circuits boards	ETR0701
Printed Circuit Board RoHS Compliance	ANT3102	PCBs shall be designed and manufactures to meet RoHS 2 and 3 standards as described in EU Directive 2011/65/EU (8 June 2011) and EU Directive 2015/863 (31 March 2015)	ETR0712

13.1.2 Soldered Electrical Connections

All electronic connections will shall follow the IPC J-STD-001G Requirements for Soldered Electrical and Electronic Assemblies [AD31]. This standard describes the materials, processes and acceptability criteria for producing electronic assemblies.

The standard recognizes that electrical and electronic assemblies can be subject to classifications by the intended end-item use. Three general end-product classes have been established to reflect differences in the functional requirements, reliability and inspection frequency. The product class can be used in the statement of work during procurement.

- **Class 1 General Electronic Products**: Includes products suitable for applications where the major requirement is the function of the completed assembly
- **Class 2 Dedicated Service Electronic Products**: Includes products where continued performance and extended life is required, and for which uninterrupted service is desired but not critical. Typically the end-use environment would not cause failures.
- **Class 3 High-Performance/Harsh Environment Electronics Products**: Includes products where continued high performance or performance on demand is critical, equipment down time cannot be tolerated, end-use environment may be uncommonly harsh, and the equipment must function when required, such as life support or other critical systems.

The ngVLA electrical and electronic assemblies shall be manufactured using Class 2 or higher. Exceptions will be considered by NRAO for COTS equipment.

Parameter	Req. #	Value	Traceability
Soldering and Electrical Connections	ANT3103	All electronic connections shall follow Class 2, or higher, of the IPC J-STD-001G Requirements for Soldered Electrical and Electronic Assemblies. This standard describes the materials, processes and acceptability criteria for producing electronic assemblies.	ETR1301

13.2 Electromagnetic Compatibility Requirements

13.2.1 Radio Frequency Interference Emission Requirements

Parameter	Req. #	Value	Traceability
Spurious Signal Level	ANT1301	The radio frequency emissions from the antenna shall not exceed the equivalent isotropic radiated power limits in Table 9.	EMC0310

The electronics within the antenna must be shielded to avoid radio frequency interference (RFI) being received by the Front End electronics, degrading system sensitivity. Table 9 is based on the analysis presented in RD01, updated for longer integrations consistent with SCI0116.

Freq. (GHz)	**1**	**2**	**4**	**6**	**8**	**10**	**20**	**30**
BW (kHz)	0.33	0.67	1.33	2	2.67	3.33	6.66	10
F_h (w/m²)	1.5E-19	1.1E-18	8.9E-18	2.9E-17	6.3E-17	1.2E-16	1.2E-15	4.3E-15
$EIRP_h$ (W)	1.9E-16	1.4E-15	1.1E-14	3.7E-14	7.9E-14	1.5E-13	1.6E-12	5.4E-12
$EIRP_h$ (dBm)	**–127**	**–119**	**–110**	**–104**	**–101**	**–98**	**–88**	**–83**

Table 9 – Allowable radiation power for electronic components, assuming 10 m distance from the antenna feed.

The table is based on unity gain, assuming the RFI enters through a sidelobe of the antenna. F_h is the harmful power flux density level, and $EIRP_h$ is the harmful effective isotropic radiated power. The ratio of the emitting device EIRP to the harmful EIRP ($EIRP_h$) is the shielding required. For example, a device with an EIRP of 1nW @ 2GHz would require of order 59dB of shielding.

Table 9 assumes the radiator is 10 m from the antenna feed. For other distances, the $EIRP_h$ can be calculated as follows:

$$EIRP_h = \frac{4\pi r^2 S F_h}{G}$$

where r is the distance in meters, S is the device shielding ratio, G is equal to 1, and F_h is from Table 9.

Radiated Power shall be computed over a bandwidth that corresponds to a spectral resolution of 100 m/s. This can be calculated as 333 Hz * ν_G, where ν_G is the RF frequency in GHz. The calculated bandwidths vary with center frequency and are not always even multiples. A practical test setup will sweep at a fixed channel resolution (i.e., at fixed resolution bandwidth). It is preferable that the swept channel width be *narrower* than the radiated power bandwidth given in the preceding section. Measured EIRP can then be averaged over multiple channels and scaled by the bandwidth ratio, assuming a noise-like distribution of radiated power within each channel.

E.g., at a resolution bandwidth of 1 kHz, evaluating the performance at 10 GHz, the power in four adjacent 1kHz channels could be summed, and then corrected by bandwidth (3.3kHz/4kHz) to produce an $EIRP_h$ for the device to be compared to Table 9.

Should the test system noise floor require a *wider* resolution bandwidth, the assumption of a noise-like distribution of radiated power will need to be substantiated for the device under test.

When shielded enclosures are employed, independent testing of the device emissions without shielding, and the shielding effectiveness of the enclosure, is permitted. In this scenario, the device may be emission tested with an access panel removed to determine the baseline emission level. The shielding of the enclosure can be determined by placing a calibrated higher-power emitter in the shielded enclosure and determining the attenuation over frequency. The effective EIRP, in dBm, is then the sum of the baseline emission level and the attenuation provided by the enclosure.

13.2.2 Electromagnetic Emission Design Requirements

All ngVLA equipment shall exhibit complete electromagnetic compatibility (EMC) among components (intra-system electromagnetic compatibility). Prevention of electromagnetic interference (EMI) between the antenna and other sub-systems (inter-system electromagnetic compatibility) is also critical.

The following requirements shall be fulfilled *as a minimum* to support the emission requirements for the design, but the designer may propose alternatives if quantitative evidence is provided that the alternatives are at least as effective as the specification. Shielding requirements may be computed as described in Section 13.2.1.

Parameter	Req. #	Value	Traceability
Drive System Shielding	ANT2320	Drive motors shall be shielded and all motor leads, both power and control, shall be filtered.	EMC0320
Relay Contact Arcing	ANT2321	All relay contacts and actuators shall be properly bypassed with snubber circuits, shielded, and/or filtered.	EMC0321
Amplifiers & Oscillators	ANT2322	All amplifiers and oscillators shall be mounted in shielded enclosures that will provide effective shielding of radio frequency energy.	EMC0322
Silicone Controlled Rectifiers	ANT2323	Silicon-controlled rectifier switching devices shall not be used unless phase controlled and zero current crossing switching techniques are used.	EMC0323
Gaseous Discharge Devices	ANT2324	No gaseous discharge devices shall be employed in active circuits, except as noise sources for test and calibration. Use of such devices for lightning and ESD protection is permitted.	EMC0324
Static Discharge Mitigation	ANT2325	Means shall be employed to reduce static electricity and the consequent radio frequency noise generated in any rotating machinery.	EMC0325
Display Shielding	ANT2326	All displays (LCD, plasma, LED, CRT) shall have fully enclosed RFI shields, including an RFI shield in front of the display. This requirement may be waived if the screen is powered off during typical operation and is used for maintenance purposes only. It must be possible to monitor and turn off such emitting devices remotely (via the M&C System).	EMC0326
Digital Equipment Shielding	ANT2327	All digital equipment, whether a simple logic circuit, embedded CPU, or rack mounted PC shall be shielded and have its AC or DC power line and communication line(s) filtered at the chassis.	EMC0327

The goal of these requirements is to limit the use of devices that are likely to cause harmful emission levels, and shield the remaining necessary emitters. This list is not comprehensive, and the designer should exercise due diligence in limiting the harmful emissions generated by their design. Design for RFI emission mitigation is expected to be a significant effort in most electronic components of the ngVLA.

13.2.3 Electromagnetic Immunity Requirements

The following requirements establish the required robustness of the system to perform without degradation in the presence of defined electromagnetic disturbances. Thresholds where a defined degradation in performance is permitted are also listed.

13.2.3.1 Commercial off the Shelf Equipment

Parameter	Req. #	Value	Traceability
COTS Immunity Standards	ANT2401	Commercial off-the-shelf (COTS) equipment shall conform to IEC product family standards for immunity standards, or to the generic standard IEC 61000 – Part 6: Generic Standards if no product family standard is given.	EMC0401
COTS Certification	ANT2402	All commercial equipment shall have a CE mark or FCC compliance identification.	EMC0402

Commercial-off-the-shelf equipment will be accepted in the system where it does not degrade the overall system functionality and ensures that the performance criteria established later in this section is maintained at the sub-system and system level.

The requirements listed in this section aim to ensure that otherwise acceptable COTS components are not made ineligible due to testing compliance with ngVLA EMC standards. These COTS standards are applicable to electromagnetic immunity only, with emission requirements applicable to all equipment present during observations at the ngVLA antenna sites.

13.2.3.2 Performance Criteria

The following performance criteria will be applied in subsequent sections of this specification.

Performance Standard	Description
A	Normal performance within specifications.
B	Temporary loss of function, or degradation of performance, which ceases after the disturbance ceases. The equipment recovers to normal performance, without Operator intervention.
C	Temporary loss of function, or degradation of performance, the correction of which requires Operator or software supervisory system intervention.
D	Loss of function, or degradation of performance, which is not recoverable. Examples include damaged hardware or loss of firmware or software images.

13.2.3.3 Conducted Immunity

13.2.3.3.1 Step Voltage Fluctuations

Parameter	Req. #	Value	Traceability
AC Supply Step Fluctuation	ANT2411	The immunity limit for rectangular (step) voltage changes on the AC supply lines shall be a ±12% change in supply voltage, for a duration of up to 3 sec, while meeting Performance Standard A.	EMC0411

Parameter	Req. #	Value	Traceability
DC Supply Step Fluctuation	ANT2412	The immunity limit for rectangular (step) voltage changes on the DC supply lines shall be a ±12% change in supply voltage, for a duration of up to 3 sec, while meeting Performance Standard A.	EMC0412

Verification of step voltage fluctuation immunity shall be based on test results whenever possible. Exceptions may be made for systems drawing over 30A (e.g., antenna drives), where tests become impractical. Verification in such cases may be based on inspection of manufacturer certifications (in the event of COTS equipment) or by analysis.

For polyphase systems, the voltage fluctuation should be applied to a single phase and to all three phases as separate tests.

13.2.3.3.2 Voltage Dips

Parameter	Req. #	Value	Traceability
AC Supply Short Voltage Dip	ANT2421	The immunity limit for voltage dips on the AC supply lines shall be -30% change in supply for a period of 10 msec, while meeting Performance Standard B.	EMC0421
AC Supply Long Voltage Dip	ANT2422	The immunity limit for voltage dips on the AC supply lines shall be -50% change in supply for a period of 100 msec, while meeting Performance Standard C.	EMC0422
DC Supply Short Voltage Dip	ANT2423	The immunity limit for voltage dips on the DC supply lines shall be -30% change in supply for a period of 10 msec, while meeting Performance Standard B.	EMC0423
DC Supply Long Voltage Dip	ANT2424	The immunity limit for voltage dips on the DC supply lines shall be -50% change in supply for a period of 100 msec, while meeting Performance Standard C.	EMC0424

Verification of long and short voltage dip immunity shall be based on test results whenever possible. Exceptions may be made for systems drawing over 30A (e.g., antenna drives), where tests become impractical. Verification in such cases may be based on inspection of manufacturer certifications (in the event of COTS equipment) or by analysis.

For polyphase systems, the voltage dips should be applied to a single phase and to all three phases as separate tests.

13.2.3.3.3 Voltage Interruptions

Parameter	Req. #	Value	Traceability
AC Supply Voltage Interruptions	ANT2431	The immunity limit for voltage interruptions on the AC supply lines shall be a voltage drop of 95% or more for a period of 5 seconds, while meeting Performance Standard C. This applies to both Uninterruptible Power Supply (UPS) and non-UPS supplied equipment.	EMC0431

Parameter	Req. #	Value	Traceability
DC Supply Voltage Interruptions	ANT2432	The immunity limit for voltage interruptions on the DC supply lines shall be a voltage drop of 95% or more for a period of 5 seconds, while meeting Performance Standard C.	EMC0432

Verification of voltage interruption immunity shall be based on test results. No exceptions are anticipated, given that the experimental test setup is expected to be practical for all ngVLA electronics systems. The supply lines may be grounded or float in the test setup. For polyphase systems, the voltage interruptions should be applied to a single phase and to all three phases as separate tests.

13.2.3.3.4 Voltage Surges and Bursts

Parameter	Req. #	Value	Traceability
AC Supply Burst Immunity	ANT2451	The system shall conform to MIL-STD-461G CS117 for transients and burst immunity for AC powered systems, while meeting Performance Standard C. Safety critical systems (as defined by the Hazard Analysis) shall meet or exceed Performance Standard B.	EMC0451
DC Supply Burst Immunity	ANT2452	The system shall conform to MIL-STD-461G CS117 for transients and burst immunity for DC powered systems, while meeting Performance Standard C. Safety critical systems (as defined by the Hazard Analysis) shall meet or exceed Performance Standard B.	EMC0452

The purpose of these requirements is to ensure equipment safety and reliable operation when subjected to high-energy disturbances on power and signal interconnects caused by overvoltage from switching and lightning transients.

Verification of burst immunity shall be based on test results whenever possible. Exceptions may be made for systems drawing over 30A (e.g., antenna drives), where tests become impractical. Verification in such cases may be based on inspection of manufacturer certifications (in the event of COTS equipment) or by analysis.

UPS-protected COTS devices may be exempted from this requirement if mitigation of the conducted burst risk can be demonstrated by inspection or analysis.

13.2.3.3.5 Conducted Noise

Parameter	Req. #	Value	Traceability
AC Supply Conducted Noise Immunity	ANT2461	The system shall conform to MIL-STD-461G CS101 conducted susceptibility for all AC powered systems, while meeting Performance Standard A.	EMC0461
DC Supply Conducted Noise Immunity	ANT2462	The system shall conform to MIL-STD-461G CS101 conducted susceptibility for all DC powered systems, while meeting Performance Standard A.	EMC0462

The conducted noise immunity requirements confirm that system performance is not impacted by noise on AC and DC mains supply conductors over the span of frequencies from 30 Hz to 150 kHz. Verification of conducted noise immunity shall be based on test results whenever possible.

13.2.3.4 Electrostatic Discharge (ESD) Requirements

Parameter	Req. #	Value	Traceability
ESD Low Air Discharge	ANT2471	Enclosed systems shall conform to MIL-STD-461G CS118 with an air discharge level up to 8kV while meeting performance criteria A. Testing to this discharge level at ESD Compliance Level 4 per IEC 61000-4-2 will also be accepted.	EMC0471
ESD High Air Discharge	ANT2472	Enclosed systems shall conform to MIL-STD-461G CS118 with an air discharge level up to 15kV while meeting performance criteria B. Testing to this discharge level at ESD Compliance Level 4 per IEC 61000-4-2 will also be accepted.	EMC0472
ESD Direct Contact Discharge	ANT2473	Enclosed systems shall conform to MIL-STD-461G CS118 with a direct contact discharge level up to 8kV while meeting performance criteria A. Testing to this discharge level at ESD Compliance Level 4 per IEC 61000-4-2 will also be accepted.	EMC0473

The ESD air-discharge and direct contact thresholds assume the devices are enclosed in any provided enclosures, as they would be found in the operational environment. Test locations are any accessible point outside of a closed cabinet (e.g., door handles or panels).

Service personnel will be provided with wrist bands at site service points and at all repair locations to prevent the occurrence of ESD to equipment within racks or enclosures during service.

13.3 Power, Grounding, and Circuit Protection

13.3.1 AC Power and Grounding System Design

All AC power and grounding must conform to the current US National Electric Code Requirements.

Parameter	Req. #	Value	Traceability
AC Power and Grounding Design	ANT3201	Design and installation of all AC Power and Grounding wiring shall conform to US National Electrical Code NFPA 70 (RD23).	ETR0801

13.3.2 AC Power Distrubution

The antenna shall be operated from a 480Y/277 VAC (480V being the phase-to-phase voltage and 277V being phase-to-neutral), 60 Hz service. The size of the electrical service entrance at the base of the antenna shall be established in the Antenna – Array Infrastructure ICD (See Section 10.1.2).[6]

Electric power shall be distributed within the antenna by means of five distinct conductors insulated from each other, namely L1, L2, L3, N and PE (US: equipment grounding conductor). Therefore the neutral conductor N shall be kept insulated from the protective conductor PE as well as from any other

[6] 480Y/277 is assumed to be preferable for the antenna servo system design, and to provide the most economical system-level solution. NRAO would consider revising the main service to 208Y/120 VAC if preferred by the antenna designer.

conductors of the earth grounding system (earth electrodes, earth conductors, equipotential conductors, exposed and extraneous conductive parts, etc.).

The antenna shall provide a local 208Y/120 VAC, 60 Hz service via a transformer powered from the main 480Y/277 VAC service. The antenna shall be responsible for both 480Y/277 VAC and 208Y/120 VAC AC power distribution throughout the interior spaces for convenience receptacles and lighting in addition to distribution necessary for antenna function. The antenna shall distribute AC power to the locations of customer-furnished equipment established in the Antenna – Antenna Electronics ICD (See Section 10.2). The loads associated with this equipment shall be accounted for in the sizing of the various subpanels located within the antenna, and for the sizing of the electrical service entrance at the base of the antenna. The antenna design report(s) shall include calculation of the average and peak loads, and representation of the most onerous power demand waveforms.

13.3.3 Fusing and Protection

13.3.3.1 AC Distrubtion Protection

The distribution system shall include single phase and reverse phase protection, disconnecting all AC power on the antenna. When a single phase or reverse phase problem is detected the detector shall immediately close a contact which will be used by ngVLA for a remote alarm. The shunt trip of all power shall occur within 5 seconds after detection of the problem. This shunt trip shall automatically reset after proper conditions are restored.

Connected devices shall be protected by surge protective devices (SPDs) on the main panel, or each subpanel, as determined by the EMC and Lightning Protection requirements.

This electrical distribution system shall include a disconnecting device (supplied under this contract) that will allow resetting all servo and encoder power supplies, motor faults, and other faults. The disconnecting device will be actuated by an NRAO-supplied remote DC signal.

Instantaneous tripping currents of overcurrent operated circuit breakers shall be so selected as to avoid false operation due to large inrush currents.

13.3.3.2 LRU Over Current Protection

All LRU power supply inputs and outputs shall be properly current limited to prevent damage to the LRU, any other connected LRU, power supply subsystems and all interconnect wiring. Protection devices shall be selected to:

- Prevent excessive current from damaging any component, connectors, or wiring on the antenna or causing a fire.
- Minimize nuisance tripping / blowing of the protective device.
- Minimize long term degradation of the protection device.

Note that poly-silicon fuses can degrade from continuous high current that is still below the rating of the device. Circuit Breakers and PTC (self-resetting) fuses can degrade from repeated tripping.

The design shall provide for easy access or renewal wherever in-place replacement or resetting of the protection device is required.

In the case where the protection device is also used as a power switch, it shall be a component designed specifically for the purpose of also being a switch (i.e. it is not allowable to use a circuit breaker as a switch unless it is specifically designed for that purpose).

To enable remote diagnosis of failures in the antenna electronics, the ngVLA M&C system shall be able to sense and report activated over-current protection devices wherever possible.

Parameter	Req. #	Value	Traceability
Overcurrent Protection	ANT3211	The antenna shall include overcurrent protection for electronic LRUs.	ETR0805
Overcurrent Protection Device Monitoring	ANT3212	The ngVLA M&C system, via the ACU, should be able to monitor the state of antenna-provided overcurrent protection devices.	ETR0806

13.3.3.3 Thermal Protection

All electronic LRUs shall contain features to remove power or go into a low-power operating mode if a temperature outside safe operating conditions is detected.

A two layered approach is desired. The device shall report an alert to the M&C system, via the ACU, when temperature goes outside of a desired range but continue to operate, potentially giving operations and maintenance personnel time to react to and correct the problem. Then, at a second limit, the LRU shall protect itself with no external intervention required.

Parameter	Req. #	Value	Traceability
Thermal Protection	ANT3221	All antenna electronic LRUs shall be thermally protected.	ETR0807
Thermal Protection Monitoring	ANT3222	The antenna should monitor the state of thermal protection features in antenna-provided electronic LRUs.	ETR0808

13.3.4 Batteries

Batteries typically represent a reliability concern, require regular maintenance or replacement and can be a safety concern. With the exception of the NRAO-supplied Antenna -48 VDC power system [AD18], batteries should not be used in the ngVLA antenna. Exemptions will be considered on a case by case basis. If a device requires an uninterruptible power supply, interfaces to the NRAO-supplied -48V VDC system can be evaluated as part of the associated interface definition described in Section 10.2. Batteries may be considered if the runtime of the -48V system does not support the intended function.

Parameter	Req. #	Value	Traceability
Battery Use	ANT3231	It is a goal to avoid the use of batteries in the antenna sub-systems.	ETR0817

13.4 Wiring and Cables

The following requirements should be applied to all wiring and cables in the system, both electrical and optical.

13.4.1 Labeling of Wiring and Cables

Clear and concise labeling of cables is critical to the reliability and maintainability of any electronic system. In the ngVLA system, all cables shall be labeled in accordance with ANSI Standard TIA-606-C.

Parameter	Req. #	Value	Traceability
Cable Labeling	ANT3401	Wiring, cables and harnesses shall be labeled in accordance with ANSI Standard TIA-606-C.	ETR1102

13.4.2 DC Power and Low Voltage Signal Wiring Color Standards

To minimize confusion during assembly and service, and maximize safety, wiring carrying commonly used DC voltages and low voltage signals should be of a consistent color across all ngVLA electronics systems. Those signal types and colors are defined in the table below. It is a goal to conform to this standard for custom wiring harnesses within the antenna. Existing COTS devices are understood to not comply, and exceptions are also expected for multi-conductor cables in a common jacket.

Parameter	Req. #	Value	Traceability
+3.3 VDC Wire Color	ANT3402	+3.3 VDC Wiring should be Solid Pink in color.	ETR1103
+5.0 VDC Wire Color	ANT3402	+5.0 VDC (+4.7 to +5.3 VDC) Wiring should be Orange in color	ETR1104
+7.5 VDC Wire Color	ANT3403	+7.5 VDC (>+5.3 to <+10.0 VDC) Wiring should be White w/Orange stripe.	ETR1105
–5.0 VDC Wire Color	ANT3404	–5.0 VDC (–4.7 to –5.3 VDC) Wiring should be Solid Brown in Color	ETR1106
–7.5 VDC Wire Color	ANT3405	–7.5 VDC (>–5.3 to <–10.0 VDC) Wiring should be White w/Brown stripe.	ETR1107
+12 VDC Wire Color	ANT3406	+12 VDC (+10.0 to +12.5 VDC) Wiring should be Solid Blue in color.	ETR1108
+13.5 VDC Wire Color	ANT3407	+13.5 VDC (>+12.5 to <+14.7 VDC) Wiring should be White w/Blue Stripe.	ETR1154
–12 VDC Wire Color	ANT3408	–12 VDC (–10.0 to –12.5 VDC) Wiring should be Solid Tan in color	ETR1109
–13.5 VDC Wire Color	ANT3409	–13.5 VDC (>–12.5 to <–14.7 VDC) Wiring should be White w/Tan Stripe	ETR1155
+15 VDC Wire Color	ANT3410	+15 VDC (+14.7 to <+15.5 VDC) Wiring should be Solid Red in color.	ETR1110
+17.5 VDC Wire Color	ANT3411	+17.5 VDC (>+15.5 to <+20.0 VDC) Wiring should be White w/Red stripe.	ETR1111
–15 VDC Wire Color	ANT3412	–15 VDC (–14.7 to <–15.5 VDC) Wiring should be Solid Yellow in color	ETR1112
–17.5 VDC Wire Color	ANT3413	–17.5 VDC (>–15.5 to <–20.0 VDC) Wiring should be White w/Yellow stripe.	ETR1113
+20 to <+30 VDC Wire Color	ANT3414	+20 to <+30 VDC Wiring should be Solid Grey or Slate in color.	ETR1114
+30> VDC Wire Color	ANT3415	>+30 VDC Wiring should be White w/ Grey or Slate	ETR1115
–48 to –54 VDC Wire Color	ANT3416	–48 to –54 VDC Wiring should be Solid Purple or Violet in color.	ETR1116
DC Power & Signal Return Wire Color	ANT3417	All return wiring for DC voltages and low voltage signals should be Solid Black in color.	ETR1117
Earth, Chassis, Safety Ground Wire Color	ANT3418	All Earth, Chassis (structure), and Safety Grounds should be Solid Green or Green w/a Yellow Stripe.	ETR1118
TTL Digital Signal (+5V based) Wire Color	ANT3419	Standard TTL level Digital Signal wiring should be Solid White w/Black and Orange Stripes.	ETR1119

Parameter	Req. #	Value	Traceability
LVTTL Digital Signal (+3.3V) Wire Color	ANT3420	Standard LVTTL level Digital Signal wiring should be Solid White w/Black and Violet stripes.	ETR1120
LVDS Digital Signal Wire Color	ANT3421	Standard LVDS digital signal wiring pairs should be Yellow w/a Blue stripe (+ signal) and Blue w/a Yellow stripe (– signal).	ETR1121
RS422/485 Digital Signal Wire Color	ANT3422	Standard RS422/485 digital signal wiring pairs should be Orange w/a Blue stripe (+ signal) and Blue w/an Orange stripe (– signal).	ETR1122
Low Voltage Analog Signal Wire Color	ANT3423	Low Voltage Analog Signal Wiring should be Solid White in color.	ETR1123

13.4.3 AC Power Wiring Colors

All AC power wiring will conform to current US National Electric Code Requirements for colors.

Parameter	Req. #	Value	Traceability
AC Wiring Colors	ANT3431	All AC wiring colors shall conform to US NEC requirements.	ETR1124

13.4.4 Protection of Wiring & Cables Exposed to Sunlight & UV Light

Parameter	Req. #	Value	Traceability
UV Protection of Wire & Cables	ANT3441	Wiring and cables exposed to sunlight and UV shall be either UL rated for "Sunlight Resistance" or enclosed to prevent exposure.	ETR1125

13.4.5 Protection of Wiring and Cables Exposed to Moisture

Parameter	Req. #	Value	Traceability
Moisture Protection of Wire & Cables	ANT3451	Wiring and cables exposed to moisture shall be either UL rated "Wet" or enclosed to prevent exposure.	ETR1126

13.4.6 Protection of Wiring and Cables Vulnerable to Rodents

Parameter	Req. #	Value	Traceability
Rodent Protection of Wire & Cables	ANT3461	Wiring and cables installed in areas vulnerable to rodents shall utilize armoring or a rodent deterrent insulation. Alternatively, the cables can be enclosed to prevent vulnerability.	ETR1127

13.4.7 Specifications of Cables Installed into Plenums

Parameter	Req. #	Value	Traceability
Plenum Cable Specifications	ANT3471	Wiring and cables installed in designated air plenums shall comply with the plenum cable specifications in the US National Electrical Code.	ETR1128

13.4.8 Use of Riser Grade Cables

Parameter	Req. #	Value	Traceability
Riser Grade Cables	ANT3481	Wiring and cables installed in significant vertical runs shall utilize riser grade cables designed for this application.	ETR1129

13.4.9 Cables Subject to Repeated Bending or Motion

Parameter	Req. #	Value	Traceability
Flexible Cables	ANT3491	Wiring and cables installed in applications where repeated bending and/or small bend radii shall utilize materials specifically designed for this purpose.	ETR1130
Bend Radius	ANT3492	The minimum bend radius of all cables shall be limited by the specifications for the cable. In cables that move or flex, the minimum bend radius shall be maintained by mechanical means.	ETR1131

13.4.10 Strain Relief and Retention of Wiring and Cables

Parameter	Req. #	Value	Traceability
Strain Relief and Retention of Wiring & Cables	ANT3501	All wiring and cables shall be installed with ample cable retention and strain relief. Unless specifically needed to move, no cables shall be allowed to flex, dangle or present a tripping or entanglement hazard.	ETR1132

13.4.11 Painting of Cables

Wires and cables of all types shall never be painted. Improper painting of wire and cable can have a negative effect on the life expectancy, safety and performance of cables.

Parameter	Req. #	Value	Traceability
Painting of Wires & Cables	ANT3511	Wires and cables shall never be painted due to risk of damage to cable jackets, loss of flexibility and the inability to identify and work on the cable.	ETR1156

13.4.12 Wire Insulation Type and Ratings

Low Voltage DC and signal wiring shall utilize Irradiated PVC type insulation certified to meet the UL 1430 specification. This shall be rated at 300 VDC minimum over a temperature range of –55°C to +105°C. Exceptions may occur where they need to be installed in environments that require a specific type of insulation, i.e. inside of a vacuum Dewar, anywhere exposed to extreme temperatures or in designated air plenum spaces. Exceptions are also allowed for COTS devices.

Parameter	Req. #	Value	Traceability
Wiring Insulation Type	ANT3521	Low-voltage DC and signal wiring shall utilize Irradiated PVC type insulation certified to meet the UL 1430 specification. This shall be rated at 300 VDC minimum over a temperature range of –55° C to +105° C.	ETR1157

13.5 Connectors

The following requirements apply to all connectors in the antenna, electrical or optical.

13.5.1 Labeling of Connectors

Clear and concise labeling of cables is critical to the reliability and maintainability of any electronic system. In the ngVLA system, all connectors shall be labeled in accordance with ANSI Standard TIA-606-C [AD32].

Parameter	Req. #	Value	Traceability
Connector Labeling	ANT3601	All connectors shall be labeled in accordance with ANSI Standard TIA-606-C.	ETR1134

13.5.2 Connector Current Ratings

The maximum current ratings of connectors must be observed! Paralleling of pins for increased current shall not be used.

Parameter	Req. #	Value	Traceability
Connector Current Ratings	ANT3611	All connector pin current limits shall be followed. Use of multiple pins to increase current on a single circuit shall not be permitted.	ETR1135

13.5.3 Connector Environmental Ratings

Parameter	Req. #	Value	Traceability
Connector Environmental Ratings	ANT3621	All connectors shall be utilized in accordance with their designed environment.	ETR1136

13.5.4 Connector Mating Cycles

Parameter	Req. #	Value	Traceability
Cable Mating Cycles	ANT3631	The specified data sheet rating for mating cycles allowed for a connector type shall be less than the projected number of cycles from the maintenance and reliability analysis.	ETR1137

13.5.5 Hot Swapping

Hot swapping (i.e. connection and disconnection of cables with power applied) is permitted, as part of corrective or preventive maintenance when consistent with the procedures outlined in the maintenance manual. However, proper design techniques must be observed to enable this capability. This can include both connectors that allow exchange of an LRU without removing power and connectors that double as power switches. To avoid contact arcing, sequencing issues and abnormal current flow, connectors used in these applications must be designed for this purpose.

Parameter	Req. #	Value	Traceability
Hot Swapping	ANT3641	All connectors utilized in hot swap or live disconnect application shall have pins designed for this application and not allow exposure of dangerous voltages or currents to personnel.	ETR1138

Parameter	Req. #	Value	Traceability
Hot Swap/Live Connection Pin Length	ANT3642	Connectors used in hot swap or live disconnect applications shall be designed to avoid contact arcing, abnormal current flow and sequencing issues.	ETR1139

13.5.6 No Exposed Live Terminals

In applications where hot swap is utilized or where a connector may be left disconnected or unpopulated while the system is powered up, it is critical that no live terminals be exposed. These can pose a safety threat to technicians and can result in damage to the system if shorted to nearby connections or grounded structure. One of the most common methods of accomplishing this is to ensure live voltages or signals are on enclosed female receptacles, not exposed male pins. Other methods may also be utilized.

Parameter	Req. #	Value	Traceability
No Exposed Live Terminals	ANT3651	Live signal or power pins in connectors shall not be exposed while connectors are unmated.	ETR1140

13.5.7 Connector Uniqueness and/or Keying

Connectors that are similar or closely located should be sufficiently unique or keyed to prevent incorrect connectors from being mated. Incorrect connections can result in personal injury and/or severe damage to equipment. If a standard or common type connector is used on multiple assemblies, a common pinout for critical signals such as power supply voltages, high current outputs and grounds should be chosen and standardized among all of those connectors.

Parameter	Req. #	Value	Traceability
Connector Uniqueness & Keying	ANT3661	Connectors that are similar or closely located shall be sufficiently unique or keyed to prevent incorrect connectors from being mated.	ETR1141
Common Connectors	ANT3662	Connectors used repeatedly across multiple devices shall have critical signal pinouts standardized.	ETR1142

13.5.8 Connector Alignment Guides

Connectors used in blind mate or back plane applications shall utilize some mechanism to ensure alignment of the connector during installation to avoid damage to the connector. The most common examples of this are tapered guide pins used for blind mate applications and tapered keys on some "Hardmetric" backplane connectors.

Parameter	Req. #	Value	Traceability
Connector Alignment Guides	ANT3671	Connectors used in blind mate or back plane applications shall utilize some mechanism to ensure alignment of the connector during installation to avoid damage to the connector.	ETR1158

13.5.9 Connectors and Devices Requiring High Insertion/Removal Force

Many connectors with large pin counts and/or high current rating can require considerable physical force to insert and remove. The same applies to high power devices such as voltage regulator modules, relays, switches and high power semiconductors. When using connectors of these types, the designer shall provide hardware such as ejectors or provide for the use of external insertion/removal tools to aid in mating and un-mating of these connectors. The design shall not depend on the use of a screwdriver, pry bar, hammer, or other such tool for assembly and disassembly.

Parameter	Req. #	Value	Traceability
High Insertion Force Connector & Device Support	ANT3681	Connectors & devices requiring high insertion force shall be supported to prevent damage to the device, connector, cable, chassis or PCB during insertion and removal.	ETR1159
High Insertion Force Connector & Device Ejectors and Tooling	ANT3682	Assemblies, cables, devices and PCBs utilizing high insertion force components or connectors shall be equipped with ejectors or other tooling to aid in installation and removal. The design shall not depend on tools such as screwdrivers, pry bars or hammers for assembly and disassembly.	ETR1160

13.6 Lighting – Colors and Type

Light Emitting Diodes (LEDs) and Organic Light Emitting Diodes (OLEDs) are available in a large variety of single and multiple colors in numerous package and brightness configurations. These, when incorporated in the design, are a compact and low power means to immediately determine the operating status of electronics hardware and systems. Certain colors of LEDs will be reserved for specific functions across all electronics in the Array.

These requirements are applicable to custom electronics developed for the project. For COTS equipment these requirements are amended to be goals.

Parameter	Req. #	Value	Traceability
Type of Light Sources	ANT3720	All light sources shall be long-life LED or OLED type devices. Incandescent or neon/gas type light sources shall not be used.	ETR1148
Color of LEDs Indicating the Presence of Power	ANT3721	All LEDs Indicating the presence of power supply voltages should be Blue. Blue LEDs should not be used for other purposes unless part of a multicolor RGB or RGBW type LED used to display many colors. When seen by operators or maintenance personnel, BLUE should immediately be only interpretable as "power is applied to this hardware."	ETR1149
Color of LEDs Indicating Fault, Warning or Abnormal Operation	ANT3722	All LEDs indicating Faults, Warnings, or Abnormal Operation should be Red. Red LEDs should not be used for other purposes unless part of a multicolor RGB or RGBW type LED used to display many colors. When seen by operators or maintenance personnel, RED should immediately be interpretable only as "something is not right with this equipment."	ETR1150
Color of LEDs Used for Purposes of Illuminating a Space	ANT3723	LEDs used to physically illuminate a workspace or physical hardware for purposes of maintenance and repair should be White. White LEDs should not be used for other purposes unless part of a multicolor RGB or RGBW type LED used to display many colors.	ETR1151

Parameter	Req. #	Value	Traceability
Color of LEDs Used to Indicate General Status	ANT3724	LEDs used to indicate general status other than those indicated above should not be blue, red or white. All other colors are useable and left to the discretion of the designer.	ETR1152
LED Brightness	ANT3725	LEDs should be operated at the minimum current required to perform their function and should not be set at a brightness level that causes safety concerns or discomfort to individuals.	ETR1153

14 Subsystem Requirements

Derivation of subsystem requirements shall be included as part of the antenna design effort and updated throughout the design. Post the Critical Design Review (CDR), subsystem requirements shall only be updated through formal project change control processes that will include the designer, manufacturer, and NRAO.

The expected main elements of the antenna include, at a minimum:

- Antenna Mount
- Main Reflector / Main Reflector Panels
- Panel/Reflector Adjusters
- Main Reflector Backup Structure
- Subreflector
- Subreflector Support Arm/Structure
- Receiver Selection Mechanism / Feed Indexer
- Cables & Cable Wraps
- Antenna Control System & Drives

The detailed decomposition of the antenna shall be developed by the antenna designer as a product breakdown structure (or equivalent) which shall be reviewed and approved by NRAO.

15 Documentation Requirements

15.1 Technical Documentation and Platforms

All documentation related to the antenna shall meet the following requirements:

- The language used for written documentation shall be English.
- Drawings shall use metric units.
- Layouts of custom (non-COTS) electronic circuits and printed circuit boards shall be provided in an electronically-readable form. The preferred software is Altium Designer.
- The electronic document formats are Microsoft Word and Adobe PDF.
- The preferred Computer Aided Design (CAD) system used is AutoDesk Inventor and/or AutoCAD.
- The preferred FEA modeling software is Siemens FeMAP NASTRAN.

The FEA and CAD models and any other specially developed model are deliverables. Any deviation from the above shall be submitted to NRAO for review and approval.

15.2 Software and Software Documentation

The ACU software and any other specially developed software (SW) are deliverables. The SW shall be delivered in source and object form, together with all procedures and tests necessary for compilation, installation, testing, upgrades, and maintenance.

- Software must be tagged with suitable version numbers that allow identification (also online remotely) of a Release.
- User manuals of software developed under this specification and of any other commercial software used (controllers embedded software, special tools, etc.) shall be provided.
- Software maintenance and installation upgrade documentation shall be provided.
- Full Test and Acceptance procedures shall be documented.

16 Verification and Quality Assurance

The design may be verified to meet the requirements by design (D), analysis (A), inspection (I), a factory acceptance test (FAT), or a site acceptance test (SAT). The definitions of each are given below.

Verification by Inspection: The performance shall be demonstrated by an inspection or review of the design documentation or item/assembly/unit.

Verification by Analysis: The fulfillment of the specified performance shall be demonstrated by appropriate analysis (hand calculations, finite element analysis, thermal modeling, etc.), which will be checked by the ngVLA project office during the design phase.

Verification by Demonstration: The compliance of the developed item is determined by a demonstration or measurement of the item/assembly/unit.

Verification by Factory Acceptance Test: The compliance of the developed item/assembly/unit with the specified performance shall be demonstrated by tests. A FAT is performed w/o integration with interfacing systems.

Verification by Site Acceptance Test: The compliance of the developed item/assembly/unit with the specified performance shall be demonstrated by tests. SAT is performed on-site with the equipment as installed.

Table 10 summarizes the expected final verification method for each requirement. Multiple verification methods are allowed and expected over the design phase. E.g., requirements which undergo final verification at SAT may also undergo a provisional FAT test. All requirements that are subject to a FAT or SAT test shall have a supporting analysis for preliminary verification at each design review. This degree of verification applies to the prototype antenna(s) only. Separate verification procedures should be developed as part of the verification plan to ensure the production antennas conform to the design specification (manufacturing to print).

Req. #	Parameter/Requirement	I	A	D	FAT	SAT
ANT0101	Upper Operating Frequency	*				
ANT0102	Lower Operating Frequency	*				
ANT0103	Optimized Operating Frequencies	*				

Req. #	Parameter/Requirement	I	A	D	FAT	SAT
ANT0201	Optical Configuration Type	*				
ANT0202	Primary Aperture Diameter and Shape	*				
ANT0203	Mount Geometry	*				
ANT0204	Optical Specification	*				
ANT0205	El-Boresight Axis Offset	*				
ANT0206	Az-El Axis Offset	*				
ANT0207	Az-Boresight Axis Offset	*				
ANT0301	Minimum Spacing			*		
ANT0302	Height			*		
ANT0401	Number of Antennas	*				
ANT0501	Surface Accuracy, Precision					*
ANT0502	Surface Accuracy, Normal					*
ANT0503	Reflector Construction		*			
ANT0611	Absolute Pointing Error, Precision					*
ANT0612	Referenced Pointing Error, Precision					*
ANT0621	Absolute Pointing Error, Normal					*
ANT0622	Referenced Pointing Error, Normal					*
ANT2501	Optical Path Length Drift					*
ANT0702	Focus Stability, Normal					*
ANT0703	Focus Rotation, Normal					*
ANT0704	Feed Selection Travel Rate			*		
ANT0801	Azimuth Tracking Range			*		
ANT0802	Elevation Tracking Range			*		
ANT0901	Slew: Azimuth					*
ANT0902	Slew: Elevation					*
ANT0903	Acceleration: Azimuth					*
ANT0904	Acceleration: Elevation					*
ANT0905	Slew + Settle Time					*
ANT0906	Tracking: Azimuth					*
ANT0907	Tracking: Elevation					*
ANT1001	Stow Position - Survival		*	*		
ANT1002	Stow Position - Maintenance	*		*		
ANT1101	Resistive Losses	*				
ANT1201	Solar Observations					*
ANT1301	Spurious Signal Level				*	
ANT1411	Precision Env.: Solar Thermal Load		*			
ANT1412	Precision Env.: Wind		*			
ANT1413	Precision Env.: Temperature		*			
ANT1414	Precision Env.: Temp. Rate of Change		*			
ANT1415	Precision Env.: Precipitation	*				
ANT1421	Normal Env.: Solar Thermal Load		*			
ANT1422	Normal Env.: Wind		*			
ANT1423	Normal Env.: Temperature		*			
ANT1424	Normal Env.: Temp. Rate of Change		*			
ANT1425	Normal Env.: Precipitation	*				
ANT1430	Ops. Limit: Solar Thermal Load		*			

Req. #	Parameter/Requirement	I	A	D	FAT	SAT
ANT1431	Ops. Limit: Wind		*			
ANT1432	Ops. Limit: Temperature		*			
ANT1433	Ops. Limit: Precipitation		*			
ANT1434	Ops. Limit: Ice		*			
ANT1435	Relative Humidity		*			
ANT1441	Survival: Wind		*			
ANT1442	Survival: Temperature		*			
ANT1443	Survival: Radial Ice		*			
ANT1444	Survival: Rain Rate				*	
ANT1445	Survival: Snow Load - Antenna		*			
ANT1446	Survival: Hail Stones		*			
ANT1447	Antenna Orientation	*				
ANT1451	Lightning Protection: Structure		*			
ANT1452	Lightning Protection: Electronics Systems		*			
ANT1453	Lightning Protection: Personnel		*			
ANT1461	Seismic Protection		*			
ANT1471	Site Elevation		*			
ANT1481	Wind Vibration		*			
ANT1490	Dust: Ext. Equipment Protection			*		
ANT1491	Dust: Int. Equipment Protection			*		
ANT1492	Rodent Protection			*		
ANT1493	Large Mammal Protection			*		
ANT1494	Maximum Solar Flux		*			
ANT1495	Maximum UV Radiation		*			
ANT1496	Rain/Water Infiltration				*	
ANT1497	Corrosion Protection			*		
ANT1498	Mechanical Shock				*	
ANT1501	Preventive Maintenance Cycle		*			
ANT1502	Preventive Maintenance Effort		*			
ANT1503	Mean Time Between Failure		*			
ANT1601	Antenna Control Unit	*				
ANT1602	Servo Loops		*			
ANT1603	Self-Monitoring			*		
ANT1604	Weather Monitoring			*		
ANT1605	Network Hardening/Authentication			*		
ANT1606	Remote Reset			*		
ANT1607	M&C Commanded Reset			*		
ANT1608	On-Site Reset / Start-up Sequence			*		
ANT1609	Periodic Self-Tests			*		
ANT1701	Software Limits				*	
ANT1702	Hardware Limits				*	
ANT1703	Elevation Hard Stops	*				
ANT1704	Safety Lock-Out			*		
ANT1705	Fire Alarm			*		
ANT1706	Fail Safe Brakes			*		

Req. #	Parameter/Requirement	I	A	D	FAT	SAT
ANT1801	Design Life		*			
ANT1802	Lifecycle Optimization		*			
ANT1803	Country of Origin	*				
ANT2001	Standby: Solar Thermal Load		*			
ANT2002	Standby: Wind		*			
ANT2003	Standby: Temperature		*			
ANT2004	Standby: Precipitation		*			
ANT2005	Standby: Radial Ice		*			
ANT2006	Standby: Relative Humidity		*			
ANT2320	Drive System Shielding	*				
ANT2321	Relay Contact Arcing	*				
ANT2322	Amplifiers & Oscillators	*				
ANT2323	Silicone Controlled Rectifiers	*				
ANT2324	Gaseous Discharge Devices	*				
ANT2325	Static Discharge Mitigation	*				
ANT2326	Display Shielding	*				
ANT2327	Digital Equipment Shielding	*				
ANT2401	COTS Immunity Standards	*				
ANT2402	COTS Certification	*				
ANT2411	AC Supply Step Fluctuation				*	
ANT2412	DC Supply Step Fluctuation				*	
ANT2421	AC Supply Short Voltage Dip				*	
ANT2422	AC Supply Long Voltage Dip				*	
ANT2423	DC Supply Short Voltage Dip				*	
ANT2424	DC Supply Long Voltage Dip				*	
ANT2431	AC Supply Voltage Interruptions				*	
ANT2432	DC Supply Voltage Interruptions				*	
ANT2451	AC Supply Burst Immunity				*	
ANT2452	DC Supply Burst Immunity				*	
ANT2461	AC Supply Conducted Noise Immunity				*	
ANT2462	DC Supply Conducted Noise Immunity				*	
ANT2471	ESD Low Air Discharge				*	
ANT2472	ESD High Air Discharge				*	
ANT2473	ESD Direct Contact Discharge				*	
ANT3001	LRU Designation	*				
ANT3011	LRU Physical Marking Label Contents	*				
ANT3012	LRU Physical Marking Label Ruggedness	*				
ANT3021	LRU Physical Tracking Device			*		
ANT3022	LRU Tracking Label & Tag Specifications	*				
ANT3031	Remote Identification	*				
ANT3051	LRU Weight Labels	*				
ANT3052	LRU Multiple Person Lift Labels	*				
ANT3053	Lift and Hoist Points	*				
ANT3101	Printed Circuit Board IPC Standard Compliance	*				

Req. #	Parameter/Requirement	I	A	D	FAT	SAT
ANT3102	Printed Circuit Board RoHS Compliance	*				
ANT3103	Soldering and Electrical Connections	*				
ANT3201	AC Power and Grounding Design	*				
ANT3211	Overcurrent Protection	*				
ANT3212	Overcurrent Protection Device Monitoring			*		
ANT3221	Thermal Protection					
ANT3222	Thermal Protection Monitoring					
ANT3231	Battery Use	*				
ANT3241	Local Firmware	*				
ANT3242	Firmware Updates			*		
ANT3301	US National Electric Code Compliance	*				
ANT3311	Contact with High Voltages	*				
ANT3312	Contact with HV During Repair	*				
ANT3313	Safety Interlocks			*		
ANT3321	Discharge of Capacitors	*				
ANT3322	Contact with Terminals	*				
ANT3323	Contact with Terminals During Repair	*				
ANT3331	High Voltage Labels	*				
ANT3332	Battery Labels	*				
ANT3333	Power Switch Labels	*				
ANT3334	Emergency Cutoff Switch Labels	*				
ANT3335	Safety Ground Labels	*				
ANT3336	Hazardous Condition or Operation Labels	*				
ANT3337	Safety Instruction Labels	*				
ANT3401	Cable Labeling	*				
ANT3402	+3.3 VDC Wire Color	*				
ANT3402	+5.0 VDC Wire Color	*				
ANT3403	+7.5 VDC Wire Color	*				
ANT3404	–5.0 VDC Wire Color	*				
ANT3405	–7.5 VDC Wire Color	*				
ANT3406	+12 VDC Wire Color	*				
ANT3407	+13.5 VDC Wire Color	*				
ANT3408	–12 VDC Wire Color	*				
ANT3409	–13.5 VDC Wire Color	*				
ANT3410	+15 VDC Wire Color	*				
ANT3411	+17.5 VDC Wire Color	*				
ANT3412	–15 VDC Wire Color	*				
ANT3413	–17.5 VDC Wire Color	*				
ANT3414	+20 to <+30 VDC Wire Color	*				
ANT3415	+30> VDC Wire Color	*				
ANT3416	–48 to –54 VDC Wire Color	*				
ANT3417	DC Power & Signal Return Wire Color	*				

Req. #	Parameter/Requirement	I	A	D	FAT	SAT
ANT3418	Earth, Chassis, Safety Ground Wire Color	*				
ANT3419	TTL Digital Signal (+5V based) Wire Color	*				
ANT3420	LVTTL Digital Signal (+3.3V) Wire Color	*				
ANT3421	LVDS Digital Signal Wire Color	*				
ANT3422	RS422/485 Digital Signal Wire Color	*				
ANT3423	Low Voltage Analog Signal Wire Color	*				
ANT3431	AC Wiring Colors	*				
ANT3441	UV Protection of Wire & Cables	*				
ANT3451	Moisture Protection of Wire & Cables	*				
ANT3461	Rodent Protection of Wire & Cables	*				
ANT3471	Plenum Cable Specifications	*				
ANT3481	Riser Grade Cables	*				
ANT3491	Flexible Cables	*				
ANT3492	Bend Radius	*				
ANT3501	Strain Relief and Retention of Wiring & Cables	*				
ANT3511	Painting of Wires & Cables	*				
ANT3521	Wiring Insulation Type	*				
ANT3601	Connector Labeling	*				
ANT3611	Connector Current Ratings	*				
ANT3621	Connector Environmental Ratings	*				
ANT3631	Cable Mating Cycles	*				
ANT3641	Hot Swapping	*				
ANT3642	Hot Swap/Live Connection Pin Length	*				
ANT3651	No Exposed Live Terminals	*				
ANT3661	Connector Uniqueness & Keying	*				
ANT3662	Common Connectors	*				
ANT3671	Connector Alignment Guides	*				
ANT3681	High Insertion Force Connector & Device Support	*				
ANT3682	High Insertion Force Connector & Device Ejectors and Tooling	*				
ANT3720	Type of Light Sources	*				
ANT3721	Color of LEDs Indicating the Presence of Power	*				
ANT3722	Color of LEDs Indicating Fault, Warning or Abnormal Operation	*				
ANT3723	Color of LEDs Used for Purposes of Illuminating a Space	*				
ANT3724	Color of LEDs Used to Indicate General Status	*				
ANT3725	LED Brightness	*				
ANT3701	Chromate Converted Surfaces	*				

Req. #	Parameter/Requirement	I	A	D	FAT	SAT
ANT3702	Stainless Steel Surfaces	*				
ANT3703	Anodized Surfaces	*				
ANT3704	Painted Surfaces	*				
ANT3705	Colored Paint Marking	*				
ANT3731	Metric Hardware	*				
ANT3732	Hardware Labeling	*				
ANT3733	Assembly Hardware: Galvanic/ Corrosion Properties	*				
ANT3734	Assembly Hardware: Electrical Properties	*				
ANT3735	Assembly Hardware: Strength Properties	*				
ANT3736	Heads and Drivers for Pan Head Screws	*				
ANT3737	Heads and Drivers for Flat Head Screws	*				
ANT3738	Heads and Drivers for Cap Head Screws	*				
ANT3739	Hardware Retention	*				
ANT3740	Fastener Torque Specifications	*				
ANT3741	Fasteners in Electrically Conductive Applications	*				
ANT7001	Code Compliance	*				
ANT7002	Safety of Personnel	*				
ANT7003	Hazard Analysis		*			
ANT7004	Residual Risks	*				
ANT7005	Ergonomic Principles	*				
ANT7006	Use of Personal Protective Equipment	*				
ANT7007	Lighting for Safe Operation	*				
ANT7011	Reduce Risk of Fire	*				
ANT7012	Smoke Detectors			*		
ANT7021	Machinery – Sharp Edges	*				
ANT7022	Machinery – Noise Control			*		
ANT7031	Non-Electric Energy Sources	*				
ANT7041	Safe Lifting / Rigging	*				
ANT7042	Moveable Machinery	*				
ANT7043	Errors of Fit	*				
ANT7051	Prevent Enclosed Entrapment	*				
ANT7061	Ensure Safe Access	*				
ANT7062	Monitor Doors			*		
ANT7063	Door Locks	*				
ANT7064	Access Restriction	*				

Table 10 – Expected requirements verification method.

Any requirements for design listed in the text but not included in this tabulation would be verified by inspection of the design documentation. Requirements listed in the referenced ICDs shall be verified according to the verification method established in the ICD.

17 Technical Metrics

Technical Metrics are used throughout the project and should be monitored throughout project design and development. These parameters strongly influence the eventual effectiveness of the facility and are useful high-level metrics for trade-off decisions. Technical Performance Measures are a category of technical metrics defined at the subsystem level.

17.1 Definitions

The technical metrics below are further described in the Systems Engineering Management Plan [AD01]:

Key Performance Parameters (KPPs): The essential parameters to achieving the key science goals. These are capabilities or characteristics so significant that failure to reach the threshold value of performance can cause the system concept to be reevaluated, or even the program to be reassessed or terminated. A KPP must have a threshold and an objective value. In a trade-off study, everything can be traded off except a KPP. The ngVLA KPPs are tied to a subset of the ngVLA Level-0 Science Requirements. An example of a KPP may be continuum sensitivity.

Measures of Effectiveness (MoEs): These are measures closely related to operational achievement and overall success criteria for the project. MOEs reflect overall Observatory and user satisfaction (e.g., performance, safety, reliability, availability, affordability, operability, and maintainability). These metrics can be expressed on a scale with no fixed threshold. The ngVLA MoEs are tied to a subset of the Level-0 Stakeholder Requirements. An example of an MoE might be calibration efficiency.

Measures of Performance (MoPs): Measures that are components of, or contribute to, MoEs or KPPs. that characterize physical or functional attributes relating to system operation. MoPs measure attributes considered essential to system capability and capacity to perform its operational objectives. The ngVLA MoPs are tied to a subset of the Level-1 System Requirements [AD04]. An example of an MoP might be the Effective Area to System Temperature Ratio of the system, supporting the continuum sensitivity KPP.

Technical Performance Measures (TPMs): These are lower level measures, typically aligned with Level-2 subsystem requirements (such as these Antenna Technical Requirements), that support the MoPs. An example might be Aperture Efficiency, contributing to the system-level Effective Area to System Temperature ratio MoP.

The relationships between these various technical metrics and their associated source requirements is summarized in Figure 2.

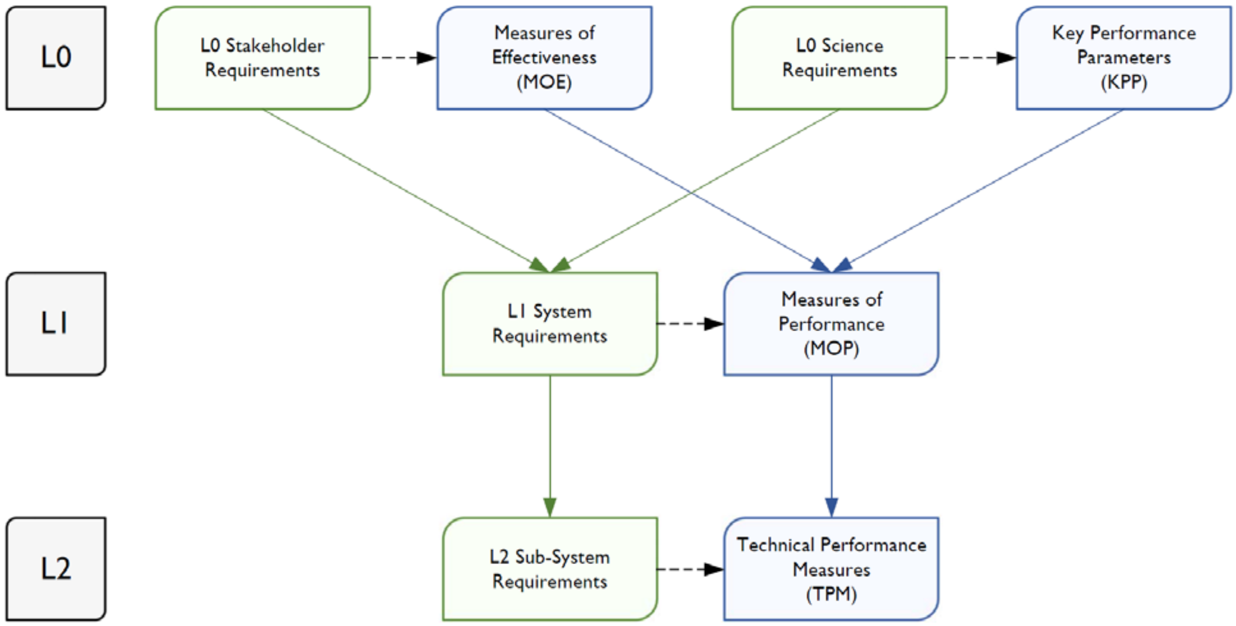

Figure 2 – Relationship of the various technical metrics to the L0 through L2 requirements. The relationships between the various technical metrics is also shown.

17.2 Technical Performance Measures

This section provides the Technical Performance Measures that should be estimated by the designer and monitored by NRAO throughout the design phase of the project. These parameters have a large influence on the eventual effectiveness of the facility, and are useful high-level metrics for trade-off decisions.

These parameters are of higher importance to NRAO. Improved performance above the requirement is desirable on these parameters. The impact on system-level performance is often discussed in the narrative in Section 4.

NRAO's expectation is that the specified technical requirements will not push technical boundaries. Rather, the key challenge of this antenna design is to deliver a design that can be manufactured in volume and delivered affordably. A second challenge is reducing the maintenance burden and total lifecycle cost.

Given these expectations, the technical requirements are generally specified as minimum values. The goal is to give the designer some latitude in optimization for a balanced design. Understanding the anticipated performance of the antenna (not just its specified minimum) on these parameters is of value for system-level analysis and performance estimation.

These parameters may also be useful for determining the relative priority of the requirements documented in Section 4 and can assist in the required analysis should tensions be identified between requirements, or reductions in capability be required to fit within cost constraints.

The Technical Performance Measures that have been identified for monitoring are described in Table 11. Note that the order in the table reflects the order in the document, and is not indicative of relative importance or priority.

Technical Performance Measure	Req. #
Minimum Spacing	ANT0301
Surface Accuracy, Precision Environment	ANT0501

Technical Performance Measure	Req. #
Surface Accuracy, Normal Environment	ANT0502
Reflector Construction	ANT0503
Absolute Pointing Error, Precision Environment	ANT0611
Referenced Pointing Error, Precision Environment	ANT0612
Absolute Pointing Error, Normal Environment	ANT0621
Referenced Pointing Error, Normal Environment	ANT0622
Optical Path Length Drift	ANT2501
Secondary Focus Position Stability, Normal Environment	ANT0702
Secondary Focus Rotation Stability, Normal Environment	ANT0703
Feed Selection Mechanism Travel Rate	ANT0704
Elevation Range (Lower Elevation Limit)	ANT0802
Slew: Azimuth	ANT0901
Slew: Elevation	ANT0902
Acceleration: Azimuth	ANT0903
Acceleration: Elevation	ANT0904
Slew + Settling Time	ANT0905
Tracking: Azimuth	ANT0906
Tracking: Elevation	ANT0907
Preventive Maintenance Cycle	ANT1501
Preventive Maintenance Effort	ANT1502
Mean Time Between Failures	ANT1503
Design Life	ANT1801

Table 11 – Technical Performance Measures identified for monitoring during the design.

18 Appendix

18.1 Abbreviations and Acronyms

Acronym	Description
AC	Alternating Current
ACU	Antenna Control Unit
AD	Applicable Document
AFD	Antenna Fiber Distribution Sub-system
ALMA	Atacama Large Millimeter-submillimeter Array
ANSI	American National Standards Institute
ATF	Antenna Test Facility (at the VLA Site)
AZ	Azimuth
BMR	Bins, Modules and Racks
CAD	Computer Aided Design
CDR	Critical Design Review
CE	Conformité Européenne
CFD	Computational Fluid Dynamics
CFR	Code of Federal Regulations
CFRP	Carbon Fiber Reinforced Plastic
CoDR	Conceptual Design Review
COTS	Commercial Off-The-Shelf (Equipment)
CRT	Cathode Ray Tube
CRY	Cryogenics Sub-system
CW	Continuous Wave (Sine wave of fixed frequency and amplitude)
DC	Direct Current
DoD	Department of Defense
EEC	Electronics Environmental Control Sub-system
EIRP	Equivalent Isotropic Radiated Power
EL	Elevation
EM	Electro-Magnetic
EMC	Electro-Magnetic Compatibility
EMI	Electro-Magnetic Interference
EMP	Electro-Magnetic Pulse
EU	European Union
FCC	Federal Communications Commission
FDR	Final Design Review
FE	Finite Element
FEA	Finite Element Analysis
FED	Front End Sub-System
FOV	Field of View
FPGA	Field Programmable Gate Array
FWHM	Full Width Half Max (of Primary Beam Power)
GFP	Government-Furnished Property
HVAC	Heating, Ventilation & Air Conditioning
ICD	Interface Control Document
IEC	International Electrotechnical Commission

Acronym	Description
IF	Intermediate Frequency
IPC	Institute of Printed Circuits
ISO	International Organization for Standardization
IUID	Item Unique Identification
KPP	Key Performance Parameters
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LEMP	Lightning Electromagnetic Pulse
LO	Local Oscillator
LRU	Line Replaceable Unit
LVDS	Low Voltage Differential Signaling
LVTTL	Low Voltage Transistor-Transistor Logic
M&C	Monitor and Control
MA	Main Array
MoE	Measures of Effectiveness
MoP	Measures of Performance
MTBF	Mean Time Between Failure
MTTF	Mean Time To Failure
MTTR	Mean Time To Repair
NEC	National Electric Code
NFPA	National Fire Protection Association
ngVLA	Next Generation VLA
NPRD	Nonelectronic Parts Reliability Data
NRAO	National Radio Astronomy Observatory
OLED	Organic Light Emitting Diodes
OSHA	Occupational Safety and Health Administration
PC	Personal Computer
PCB	Printed Circuit Board
PCIL	Programmed Check and Intervention List
PSOC	Programmable System-On-Chip
PTC	Positive Temperature Coefficient
RD	Reference Document
RF	Radio Frequency
RFI	Radio Frequency Interference
RFID	Radio Frequency Identification
RGB	Red-Green-Blue
RGBW	Red-Green-Blue-White
RMS	Root Mean Square
RoHS	Restriction of Hazardous Substances
RSS	Root of Sum of Squares
RTP	Round Trip Phase
SAC	Science Advisory Council
SAT	Site Acceptance Test
SNR	Signal to Noise Ratio
SRSS	Square Root Sum of the Square
SPD	Surge Protective Device

Acronym	Description
SW	Software
SWG	Science Working Group
TAC	Technical Advisory Council
TBD	To Be Determined
TPM	Technical Performance Measures
TTL	Transistor-Transistor Logic
UID	Unique Identification
UII	Unique Item Identification
UL	Underwriters Laboratories
UPS	Uninterruptible Power Supply
USGS	United States Geological Survey
UV	Ultra Violet
VAC	Volts, Alternating Current
VDC	Volts, Direct Current
VLA	Jansky Very Large Array
WVR	Water Vapor Radiometer