ngVLA System Electronics Specifications

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Change Record

Version	Date	Author	Affected Section(s)	Reason
1	2019-11-18	Durand	All	Initial Draft
2	2019-11-20	Lenox	1 and 2	Reformatting
3	2019-11-26	Jackson	All	Text Editing
4	2019-12-04	Durand	All	Text Editing
5	2019-12-05	Jackson	All	Text Editing
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8	2020-05-18	Jackson	All + SysML Model	Extensive text & requirement editing, reformatting. Assigned IDs & verification methods to requirements, added many ADs and RDs. Work on incorporating and synchronizing requirements with ngVLA Cameo SysML model.
9	2020-07-17	Jackson	All + SysML Model	Extensive text & requirement editing, reformatting. All requirements are in the ngVLA Cameo SysML model (except section 11.5).
10	2020-07-23	Jackson	4.5, 9.2.2, 11.2.9, 11.2.10, 11.5 + SysML Model	Added and/or edited requirements and text in these sections. Also included changes in SysML model. Also renamed SysML model of his doc from L2 to L1.1 (per Rob S.)
11	2020-08-03	Jackson	All + SysML Model	Added and/or edited requirements and text in all sections. Also included changes in SysML model.
12	2020-08-31	Lear	All	Formatting, copy edits to prepare document for review; added Acronyms & Abbreviations table
13	2020-12-09	Jackson	All + SysML Model	Implement many changes & updates from major document review on 2020-09-30. All changes also reflected in ngVLA SysML model.
14	2021-01-12	Kusel	14	Added phasing of verification methods
15	2021-01-14	Durand	All	Minor edits
A	2021-01-14	Lear	All	Minor copy edits and formatting; removed notes; prepared PDF for release as v.A.

Table of Contents

1 Introduction

1.1 Purpose

The purpose of this ngVLA Engineering Specification Document is to provide requirements and guidelines for ngVLA electronics designers to be applied to all electronic subsystems in the telescope. The designs shall consider manufacturability, reliability, maintainability, operability, extensibility, fault tolerance, interoperability, resilience, robustness, testability, and stability as nonfunctional requirements relevant to the ngVLA system design.

1.2 Scope

The requirements, and the applicable discussions, included in this document shall apply to all electronic subsystems and equipment designed and built for the ngVLA telescope by NRAO, national and international program partners, vendors, and contractors. It is recognized that some of these requirements may not be practical in the case of commercial-off-the-shelf (COTS) equipment. In this case, the subsystem designer(s) and/or contracts and procurements staff shall make a "best attempt" to ensure as many of these requirements as possible are met.

1.3 Considerations

A primary consideration for both the design and the estimated maintenance costs is array availability. Since maintenance costs are primarily determined by the staffing level, the maintenance efficiency must be improved over current observatory standards. For the ngVLA, the array maintenance efficiency will be improved (at a *minimum)* by a factor of three compared to the VLA through a reduction in the frequency of maintenance visits. Achieving these efficiency improvements requires careful planning and forward-looking design decisions long before the array is constructed and operational. The decision process includes a thorough understanding of expected equipment performance, system design life, and maintainability.

The design life and system Mean Time Between Failure (MTBF) estimates of the electronics shall be consistent with the requirement that the antenna hardware is expected to operate for a year or more between PM and/or maintenance visits. In other words, the limited number of maintenance staff hours will drive the overall system quality requirements.

2 Related Documents and Drawings

2.1 Applicable Documents

The following documents are applicable to this Requirements Specification to the extent specified. An understanding of these documents is necessary to fully comprehend the scope of this Requirements Specification. In the event of conflict between the documents referenced herein and the content of this Requirements Specification, the content of the highest-level specification (in the requirements flow-down) shall be considered the superseding requirement.

Ref. No.	Document Title	Rev./Doc. No.
AD01	ngVLA System Requirements	020.10.15.10.00-0003-REQ
AD02	ngVLA Configuration Management Plan	020.10.10.15.00-0001-PLA
AD03	ngVLA Operations Concept	020.10.05.00.00-0002-PLA

Ref. No.	Document Title	Rev./Doc. No.
AD04	ngVLA Documentation Management Plan	020.10.10.10.00-0001-PLA
AD05	ngVLA System Electromagnetic Compatibility and Radio Frequency Interference Mitigation Requirements	020.10.15.10.00-0002-REQ
AD06	Level 0 Safety Requirements	020.10.15.00.00-0004-REQ
AD07	System Environmental Specifications	020.10.15.10.00-0001-SPE
AD08	ngVLA Assembly, Integration and Verification (AIV) Concept	020.10.05.00.00-0005-PLA
AD09	Level 1 Security Requirements	020.80.00.00.00-0003-REQ
AD10	Level 1 Safety Requirements	020.80.00.00.00-0001-REQ

2.2 *Reference Documents*

The following references, specifications and standards provide supporting context. The revision or edition in effect at the start of the design is the version in force.

Ref. No.	Document Title	Rev./Doc. No.
RD01	RFI Emission Limits for Equipment at the EVLA Site	EVLA Memo #106. Perley, Brundage, Mertely.
RD02	Attenuation of Radio Frequency Interference by Interferometric Fringe Rotation	EVLA Memo #49. Perley.
RD03	Protection Criteria Used for Radio Astronomical Measurements	Recommendation ITU-R RA.769-2
RD04	Department of Defense Standard Practice: Marking of Electronic Items (02 Nov 1999)	MIL-STD-13231
RD05	Detail Specification: Plates, Tags, and Bands for Identification of Equipment, General Specification for (28 Nov 1997)	MIL-DTL-15024
RD06	Detail Specification: Plates, Identification or Instruction, Metal Foil, Adhesive Backed General Specification for (06-Jul-2006)	MIL-P-19834
RD07	G. T. Dangelmayer, *AT&T ESD Program Management*, Chapman & Hall, 1990	ISBN-13: 978-1-4612-8500-7
RD08	Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices) (25 Oct 1995)	Mil-Std-1686c
RD09	Electrostatic Discharge (ESD) Control Handbook for Protection of Electrical and Electronic Parts, Assemblies, and Equipment (Excluding Electrically Initiated Explosive Devices) (31 Jul 1994)	MIL-HDBK-263B
RD10	IPC Specification for Acceptability of Printed Boards	IPC-A-600K
RD11	IPC Standard Generic Performance Specification for Printed Boards	IPC-6011
RD12	IPC Standard for Qualification and Performance Specification for Rigid Printed Boards	IPC-6012D
RD13	IPC Qualification and Performance Specification for Flexible/Rigid-Flexible Printed Boards	IPC-6013D
RD14	IPC Qualification and Performance Specification for High Frequency (Microwave) Printed Boards	IPC-6018C

Ref. No.	Document Title	Rev./Doc. No.
RD15	IPC Specification for Base Materials for Rigid and Multilayer Printed Boards	IPC-4101E
RD16	IPC Specification for Flexible Base Dielectrics for Use in Flexible Printed Boards	IPC-4202B
RD17	IPC Requirements and Acceptance for Cable and Wire Harness Assemblies	IPC/WHMA-A-620D
RD18	IPC Acceptability of Electronic Assemblies	IPC-A-610G
RD19	IPC Requirements for Soldered Electrical and Electronic Assemblies	IPC J-STD-001G
RD20	IPC Rework, Modification, and Repair of Electronic Assemblies	IPC-7711/21C
RD21	IPC Acceptability Standard for Manufacture, Inspection, and Testing of Electronic Enclosures	IPC-A-630
RD22	ANSI Standard Protection of Electrical and Electronic Parts, Assemblies and Equipment	ANSI/ESD S20.20-2014
RD23	US National Electrical Code (NEC)	NFPA 70
RD24	US Military Handbook: Reliability Prediction of Electronic Equipment	MIL-HDBK-217F(2)
RD25	US Military Handbook: Reliability/Design Thermal Applications	MIL-HDBK-251
RD26	US Military Handbook: Electronic Reliability Design	MIL-HDBK-338B
RD27	Electronic Components – Reliability – Reference Conditions for Failure Rates and Stress Models for Conversion	IEC 61709 Ed.3.0 b:2017
RD28	Cable Labeling Standards	ANSI / TIA 606-C
RD29	NEMA Standard – Industrial Laminating Thermosetting Products	NEMA LI 1-1998
RD30	IPC Specification for Electroless Nickel/Immersion Gold (ENIG) Plating for Printed Circuit Boards and associated docs	IPC-4552, IPC-4552 Amendment 1, IPC-4552 A
RD31	IPC Specification, "Qualification and Performance Specification of Permanent Solder Mask"	IPC-SM-840E
RD32	IPC Specification, "Qualification and Performance Specification of Permanent, Semi-Permanent and Temporary Legend and/or Marking Inks"	IPC-4781
RD33	Military Specification, Chemical Conversion Coatings on Aluminum and Aluminum Alloys	MIL-DTL-5541E
RD34	ESD Association Standard for the Protection of Electrostatic Discharge Susceptible Items – Packaging Materials for ESD Sensitive Items	ANSI/ESD S541-2003
RD34	Electromagnetic Compatibility (EMC) Part 3–5: Limits – Limitation of voltage fluctuations and flicker in low-voltage power supply systems for equipment with rated current greater than 75 A	IEC 61000-3-5:2009
RD35	ISO General Purpose Screw Threads – Basic Profile – Part 1: Metric Screw Threads	ISO 68-1:1998
RD36	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)

Ref. No.	Document Title	Rev./Doc. No.
RD37	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)
RD38	Non-Electronic Parts Reliability Data	NPRD-95
RD39	Machinery's Handbook, 31st Edition; Erik Oberg, et al; March 2020	ISBN-13 : 978-0831141318
RD40	Fastener Black Book, 1st Edition, May 2014	ASIN : B00KC58Z3M
RD41	Electromagnetic compatibility (EMC) – Part 4-2: Testing and measurement techniques – Electrostatic discharge immunity test	IEC 6100-4-2:2008
RD42	US General Services Administration Federal Acquisition Regulation (FAR)	Federal Acquisition Regulation 2019
RD43	ANSI Z136 Standards for Implementing a Safe Laser Program	ANSI Z136.1 through .9
RD44	Safety of Laser Products – Part 1: Equipment Classification and Requirements	IEC 60825-1:2014
RD45	International Standard: Protection Against Lightning	IEC 62305:2010

2.3 Driving Requirements

The following ngVLA key system requirements are fundamental to many of the requirements and guidelines covered in this document and are listed here for reference:

- **Array Element MTBF – SYS2402:** The antenna, antenna electronics, array infrastructure, and signal processing system shall be designed with an expected number of failures to be less than four per array element per year. (Traceability – STK1802, STK0101)
- **Safety Specification – SYS2700:** All designs shall comply with the Level-1 System Safety Specification 020.80.00.00.00-0001-REQ
- **Design Life – SYS2801:** The system shall be designed for an expected operational life of no less than 20 years, where the operational life is defined to start at the full operations milestone and close-out of the construction project. (Traceability – STK0303)
- **Optimization for Maintenance – SYS3202**: Tools shall be provided for the organization of the maintenance and repair teams in order to maximize the efficiency of time spent on antenna visits and repair of equipment. (Traceability – STK5003, STK5005)

3 Line Replaceable Units

Consistent with the goal of efficient maintenance, most of the ngVLA electronics will be packaged as Line Replaceable Units (LRU), where LRU modules are interchanged at the antenna or in the equipment rooms. When installed and connected to the Monitor and Control (M&C) System, the individual LRUs will electronically self-identify providing status, configuration information, hardware and firmware versions, and location in the array. [AD03]

The ngVLA will employ a scheduled maintenance program for the antennas with a goal of minimizing repeat and unscheduled visits to each antenna. The program will be structured to incorporate both reliability data on critical components and actual performance of equipment. For example, cryogenic refrigerators and other components with a known service life will be replaced at a regularly scheduled maintenance intervals, regardless of their current operating condition. Components may also be replaced if analysis of their performance predicts an imminent failure.

Parameter	Req. #	Value	Traceability
LRU Designation	ETR0301	An item replaceable at the operational location shall be designated as a Line Replaceable Unit (LRU).	SYS2403

4 Physical and Online Identification

4.1 Marking

References for Sections 4.1 and 4.2:

- MIL-STD-13231: Department of Defense Standard Practice: Marking of Electronic Items (02 Nov 1999) [RD04] – 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) [RD05] – 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) [RD06] – 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):

1. The model number/name of the LRU – as defined in MIL-STD-13231 [RD04]
2. The serial number of the LRU – as defined in MIL-STD-13231 [RD04]
3. The hardware revision level – as defined in MIL-STD-13231 [RD04]
4. The unique part number or a fully qualified CID number – as defined in Section 3, ngVLA Documentation Management Plan (020.10.10.10.00-0001-PLA). This provides a reference to all documentation of the associated LRU.

This label will be placed on an accessible external surface of the LRU. These permanent markings must be impervious to the hardware's operational, storage, transport, and maintenance environments as defined in US DoD Standards MIL-DTL-15024 [RD05] and MIL-P-19834 [RD06]. 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	ETR0401	Each LRU shall be marked with the model number/name, serial number and hardware revision level as defined in MIL-STD-13231 [RD04] and the unique part number (as defined in Section 3, ngVLA Documentation Management Plan (020.10.10.10.00-0001-PLA).	SYS2406, SYS3900, SYS3910, SYS3404, SYS3600
LRU Physical Marking Label Ruggedness	ETR0409	The attached LRU Physical Marking Label shall comply with MIL-DTL-15024 [RD05] to ensure durability and longevity of the label.	ENV0341, ENV0342, ENV0343, ENV0344, ENV0562, ENV0591, SAF0059, SYS2700, SYS2801, SYS3202

4.2 Physical Tracking

Electronic 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 electronic device at the start of each unit's construction and can be used as the assembly, testing, and installation traveler. Examples include a printed bar code or electronic RFID tags that 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 United States Department of Defense (DoD) as defined in [RD04], [RD05], and [RD06] (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. UID, UII, and IUID data used in the ngVLA project will be generated by NRAO.

Parameter	Req. #	Value	Traceability
LRU Physical Tracking Device	ETR0402	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 [RD06]. UID and IUID data used in the ngVLA project will be generated by NRAO.	SYS3900, SYS3910, SYS3902, SYS2406, SYS3700, SYS3600
LRU Tracking Label & Tag Specifications	ETR0405	The physical tracking label and/or device attached to each LRU shall conform to the specifications outlined in US DoD Standards MIL-DTL-15024 [RD05] and MIL-P-19834 [RD06].	SYS2801, SYS3900, SYS3910, SYS3600

4.3 Remote Monitor and Control Identification

To aid in configuration control, maintenance tracking, and planning of maintenance visits, all devices (electronic equipment and subsystems) with any connectivity to the M&C System shall identify itself when polled via the M&C network. At a minimum, information reported shall include

1. Module/Model Number
2. Serial Number
3. CID Number which leads to all documentation
4. Hardware Revision Level
5. Software Revision Levels (if applicable)
6. Firmware Revision Levels (if applicable)
7. 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 may also be reported when polled.

Parameter	Req. #	Value	Traceability
Remote Identification	ETR0403	Any device with any connectivity to the M&C system shall identify itself when polled via the M&C network. Minimum information to be reported includes 1. Module/Model Number 2. Serial Number 3. CID Number which leads to all documentation 4. Hardware Revision Level 5. Software Revision Levels (if applicable) 6. Firmware Revision Levels (if applicable) 7. UID and IUID from Physical tracking tag or device	SYS2406, SYS3202, SYS3600, SYS3602, SYS3603

4.4 Non M&C LRU Identification

Devices declared as LRUs that would not ordinarily be connected to the M&C system shall provide a mechanism of identification readable by a nearby M&C connected device. An example of a device that would need this feature is a cryogenic refrigerator. The readable ID shall be implemented as a serial non-volatile memory.

Parameter	Req. #	Value	Traceability
LRU Remote ID for devices with no direct M&C connection	ETR0404	LRUs that would not ordinarily be connected to the M&C system shall provide unique identification via a non-volatile memory readable by a nearby M&C connected device. Information to be provided includes (but is not limited to): 1. Module/Model Number 2. Serial Number 3. CID Number which leads to all documentation 4. Hardware Revision Level 5. Software Revision Levels (if applicable) 6. Firmware Revision Levels (if applicable) 7. UID and IUID from the physical tracking device	SYS2406, SYS3202

4.5 Labels for Physical Safety

All LRUs shall include at least one clearly visible label indicating the weight of the LRU in pounds. The weight in kilograms can also be added at the designer's discretion. If the LRU weighs in excess of 50 lbs (22.68 Kg), a clearly visible label indicating "Multiple Person Lift Required" along with the number of persons required shall be included. Additionally, clearly visible labels shall be included identifying the presence and location of all lift or hoist points on the LRU.

Parameter	Req. #	Value	Traceability
LRU Weight Labels	ETR0406	All LRUs shall include at least one clearly visible label indicating the weight of the LRU in pounds. The label shall be compliant with applicable standards at the time of installation.	SYS2700, SYS3202, SAF1050

Parameter	Req. #	Value	Traceability
LRU Multiple Person Lift Labels	ETR0407	If the LRU weighs in excess of 50 lbs (22.68 Kg), a clearly visible label indicating "Multiple Person Lift Required" along with the number of persons required shall be included. The label shall be compliant with applicable standards at the time of installation.	SYS2700, SYS3202, SAF1050
Lift and Hoist Points	ETR0408	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.	SYS2700, SYS3202, SAF1050
Hot Connect & Disconnect Warning Labels	ETR0410	In situations where disconnecting cables or pulling of equipment with power on can cause damage, clearly visible labels shall be applied to warn on this condition.	SYS2700, SYS3202, SAF0059

5 Electrostatic Discharge Protection

5.1 LRU and Sub-Assembly Requirements

Each LRU will be evaluated to determine the susceptibility to damage from Electrostatic Discharge (ESD). The ESD sensitive components classification (ESD Class) shall be determined for each LRU design. This susceptibility classification can help to identify:

- ESD vulnerabilities of the hardware that may require design changes or additions to the hardware which harden the resistance to ESD.
- The ESD protection precautions necessary during assembly, testing, maintenance, and handling, i.e. when the enclosure is open and internal hardware is exposed.
- The ESD protection necessary during storage, transport and installation of the hardware, i.e. when the enclosure is sealed and the hardware is protected within.

Testing and evaluation shall be performed on a few sacrificial qualification units built for testing purposes. Production units destined to be installed in the array as operational hardware will not be subject to ESD testing due to potential degradation of performance and life expectancy.

Testing shall be in accordance with IEC 61000-4-2:2008 (RD41), "Electromagnetic compatibility (EMC) – Part 4-2: Testing and measurement techniques – Electrostatic discharge immunity test".

Parameter	Req. #	Value	Traceability
ESD Low Air Discharge Susceptibility Testing	ETR0501	Qualification units of all enclosed ngVLA electronic LRUs shall be tested to 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. Specific exceptions will be considered where components or sub-assemblies are present that are very high value or are known to be vulnerable. In these cases, evaluation will be through analysis of the design and a "best attempt" should be made in design to protect these vulnerable components in the LRUs.	SYS2402, EMC0471

Parameter	Req. #	Value	Traceability
ESD High Air Discharge Susceptibility Testing	ETR0505	Qualification units of all enclosed ngVLA electronic LRUs shall be tested to 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. Specific exceptions will be considered where components or sub-assemblies are present that are very high value or are known to be vulnerable. In these cases, evaluation will be through analysis of the design and a "best attempt" should be made in design to protect these vulnerable components in the LRUs.	SYS2402, EMC0472
ESD Direct Contact Discharge Susceptibility Testing	ETR0506	Qualification units of all enclosed ngVLA electronic LRUs shall be tested to 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. Specific exceptions will be considered where components or sub-assemblies are present that are very high value or are known to be vulnerable. In these cases, evaluation will be through analysis of the design and a "best attempt" should be made in design to protect these vulnerable components in the LRUs.	SYS2402, EMC0473

5.2 Protection of Workspaces and Operational Environments

Ultimately, standards for ESD protection are applied to the environments and procedures utilized where the equipment is built, serviced, stored and installed vs being applied to the equipment itself. This is where the maximum vulnerability occurs. For these purposes ngVLA Electronics will be built in facilities meeting one of two standards. It is understood existing facilities could be designed to meet one or the other of these and that the guidelines provided by either meet the needs of the ngVLA project.

- Mil-STD-1686C (RD08), Military Standard: Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies, and Equipment (excluding electrically initiated explosive devices) (25-Oct-1995) [supersedes DoD-std-1686]
- Mil-HDBK-263b (RD09), Military Handbook: Electrostatic Discharge (ESD) Control Handbook for Protection of Electrical and Electronic Parts, Assemblies, and Equipment (excluding electrically initiated explosive devices) (31 Jul 1994)
- ANSI/ESD S20.20-2014 (RD22): Protection of Electrical and Electronic Parts, Assemblies, and Equipment (excluding Electrically Initiated Explosive Devices)

Parameter	Req. #	Value	Traceability
ESD Protection	ETR0502	ESD protection of equipment and workspaces shall be based on USDOD MIL-STD-1686C (RD08) and MIL-HDBK-263B (RD09) or ANSI/ESD S20.20-2014 (RD22)	SYS2402

5.3 Storage and Shipping of ESD Sensitive Hardware

Equipment and components sensitive to damage from ESD must be packaged, shipped, and stored in ESD protective packaging. These materials act as a Faraday cage keeping the packaging and everything else enclosed at the same potential. LRUs that consist of metal enclosures with external connectors may use shorting plugs or conductive caps in lieu of an outer wrapping or package. The items shall be closed and opened at ESD safe workstations as described in Section 5.2.

Parameter	Req. #	Value	Traceability
ESD Packaging and Storage	ETR0503	Equipment and components sensitive to damage from Electrostatic Discharge (ESD) shall be packaged, shipped and stored in ESD protective packaging and/or equipped with shorting plugs and conductive caps on all external connections. These items shall only be sealed and opened at ESD safe workstations.	SYS3904

5.4 Buildup of Static Charge

Equipment and assemblies made using dielectric materials or coated with nonconductive coatings can build up a static charge due to interaction with the atmosphere, as a result of mechanical movement, or due to electrical flow in and out of the device. These charges can ultimately be damaging to the system or, in extreme conditions, represent a hazard or startling event to an individual operating or servicing the equipment.

Parameter	Req. #	Value	Traceability
Prevention and Discharge of Electrostatic Charge Build-Up	ETR0504	Equipment and assemblies made using dielectric materials or coated with nonconductive coatings shall be designed to prevent build up or to dissipate excessive electrostatic charge.	SYS2402, SYS2801, SYS2700, SAF0710

6 Radio Frequency Interference/Electro-Magnetic Compatibility

In a radio telescope such as the ngVLA, Radio Frequency Interference (RFI) and Electro-Magnetic Compatibility (EMC) have a major impact on the performance of the telescope. The RFI/EMC requirements for the ngVLA are spelled out in [AD05], "System EMC and RFI Mitigation Requirements." There are multiple categories to this puzzle which have different implications, level of harm, and solutions:

- Coherent Self-Generated RFI: Hardware that is part of the array can generate coherent noise that is coupled into the astronomical data either directly through the Front Ends or coupled in by secondary paths such as power supplies, grounds, reference signals, or M&C signals. These noise sources are coherent between antennas and are usually synchronized either to the array LO/Reference system or to the power grid. These signals can be very destructive to the astronomy even at very low levels.
- Incoherent Self-Generated RFI: Hardware that is part of the array can also generate incoherent noise that is coupled into the astronomical data either directly through the Front Ends or coupled in by secondary paths such as power supplies, grounds, reference signals, or M&C signals. These signals are not coherent between antennas and are usually generated by independent clocks in microprocessors, COTS products, the antenna drive system, standalone computers, and phones. These signals mainly cause problems when they are strong enough to affect the linearity of the system. They can be tolerated at much higher levels than coherent signals.

- External RFI sources: This category essentially covers everything else, including signals produced outside of our hardware and not under ngVLA control. The most common sources are terrestrial and satellite communications, the power grid, automobiles, aircraft, etc. These can be very strong and can be coherent across many antennas to the entire array.

To minimize RFI and EMC at the ngVLA, it is required that designers follow the Requirements spelled out in "ngVLA System EMC and RFI Mitigation Requirements" [AD05].

Parameter	Req. #	Value	Traceability
EMC/RFI Mitigation in Designs	ETR0601	RFI/EMC Requirements shall be in compliance with and tested per the ngVLA System Electromagnetic Compatibility and Radio Frequency Interference Mitigation Requirements	EMC0310, EMC0321, EMC0322, EMC0323, EMC0326, EMC0327, EMC0328, SYS2104, SYS2106, SAF0800

7 Printed Circuit Boards

The ngVLA Electronics systems will contain numerous Printed Circuit Boards (PCBs). For reliability, maintainability, and documentation purposes, it is critical that these PCBs all be designed to a consistent set of standards. For the ngVLA project, PCBs will adhere to the current version of IPC standard, IPC-A-600K: Acceptability of Printed Circuits Boards [RD10].

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).
- 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).

Exemptions from IPC and RoHS requirements will be considered where lifecycle, manufacturability, and/or reliability issues are a concern. Requests for exemptions must be submitted by the Responsible Engineer with justifications to the ngVLA project Engineering Change Control Board (ECCB).

It is unlikely that COTS PCBs will meet all of these requirements. In the case of COTS PCBs, these requirements become recommendations. The subsystem 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	ETR0701	PCBs shall be designed and manufactured to meet IPC Standard IPC-A-600K: Acceptability of Printed Circuits boards (RD10)	SYS2402, SYS2805
Printed Circuit Board RoHS Compliance	ETR0712	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)	SYS2803

7.1 Printed Circuit Board Types

There are three major types of printed circuit board that could likely be used in ngVLA Electronics:

1. **Rigid Printed Circuit Boards** are the most common type and will cover the majority of the electronics in the system. These are made of one to many layers of a rigid material such as fiberglass (FR-4), other composites, and in some cases, exotic material such as ceramic or glass.
2. **Flexible Printed Circuit Boards** are mostly used for interconnect between boards where high reliability, ease of assembly, and/or motion are required. These may be single or multilayer and are usually made from a polyimide such as Kapton. A few small surface mount components can be included on these but that can result in a delicate assembly.
3. The third option is a **Rigid/Flex Hybrid** that uses rigid PCBs interconnected by a flex layer that is part of the PCB stackup of the rigid boards. This can result in a reliable, easy to assemble design.

7.2 Materials

7.2.1 PCB Substrate

Rigid PCBs shall be made from materials covered in IPC Specification IPC-4101E [RD11]. Most rigid PCBs will be FR-4 type materials. FR-4 (or **FR4**) is a NEMA-grade designation for glass-reinforced epoxy laminate material. FR-4 is a composite material composed of woven fiberglass cloth with an epoxy resin binder that is flame resistant (self-extinguishing). FR-4 does not specify specific material, but instead a grade of material, as defined by NEMA LI 1-1998 specification [RD29]. Materials meeting this specification are suitable for most ngVLA PCBs in the ngVLA System. Numerous manufacturers make materials to this specification, many with specific properties emphasized. It is left to the discretion of the designer to decide which of these materials best fits a particular design from the perspective of performance and/or cost.

Flexible PCBs shall be made from a polyimide material. These materials are covered in IPC Standard IPC-4202 [RD12].

Specialized high-performance microwave, optical, or extremely high-speed digital circuits frequently require more exotic dielectric materials. Numerous examples of these exist and it is left to the discretion of the designer to select a material that best fits their application in these special cases.

Parameter	Req. #	Value	Traceability
Rigid Printed Circuit Board Material	ETR0702	Rigid PCBs shall be manufactured from materials specified in and meeting IPC Specification IPC-4101E (RD11). The default material is an FR-4 type material defined by NEMA LI 1-1998 (RD29).	SYS2402, SYS2805
Flexible Printed Circuit Board Material	ETR0703	Flexible PCBs shall be manufactured from materials specified in and meeting IPC Specification IPC-4202 (RD12).	SYS2402, SYS2805

7.2.2 PCB Plating

Electroless Nickel Immersion Gold (**ENIG**) is a type of surface plating used on printed circuit boards. ENIG consists of an electroless nickel plating covered with a thin layer of immersion gold, which protects the nickel from oxidation. ENIG has several advantages over more conventional (and cheaper) surface plating such as HASL (solder), including excellent surface planarity (particularly helpful for PCBs with large BGA packages), good oxidation resistance, RoHS compliance, and usability for untreated contact surfaces such as membrane switches and contact points. Printed Circuit Boards in the ngVLA electronics system shall use ENIG plating.

Specialized high-performance microwave or extremely high-speed digital circuits frequently require more exotic materials. Numerous examples of these exist and it is left to the discretion of the designer to select a material that best fits their application in these special cases.

Parameter	Req. #	Value	Traceability
Printed Circuit Board Plating/ Surface Finish Material	ETR0704	Rigid PCBs shall utilize an Electroless Nickel/Immersion Gold (ENIG) surface finish specified in and meeting IPC Specification IPC-4552 [RD30]. Specialized high performance designs which require specific or advanced plating materials are exempt from this requirement.	SYS2402, SYS2805

7.2.3 Solder Mask Material

Parameter	Req. #	Value	Traceability
Printed Circuit Board Solder Mask Material	ETR0705	Rigid PCBs shall utilize solder mask specified in and meeting IPC Specification IPC-SM-840E "Qualification and Performance Specification of Permanent Solder Mask" [RD31].	SYS2402, SYS2805

7.3 Markings

7.3.1 Solder Mask Color

Printed circuit boards that utilize a solder mask can be made using numerous colors for the solder mask. This technique can be used to quickly identify which revision of a board is in a particular piece of equipment. In the ngVLA, it is required that when a major revision is made to a production circuit board, the new version shall be manufactured using a different color solder mask not previously used for this particular PCB. The sequence chosen for these colors shall be:

Version/Rev	Solder Mask Color
A	Green
B	Blue
C	Red
D	Orange
E	White
F	Black

COTS PCBs and PCBs not using a solder mask are excluded from this requirement.

If a PCB goes beyond Revision F, the sequence repeats.

Parameter	Req. #	Value	Traceability
Printed Circuit Board Solder Mask Color	ETR0707	Rigid Production PCBs using a solder mask shall utilize a solder mask color in the following sequence: Version/Rev: Solder Mask Color A: Green B: Blue C: Red D: Orange E: White F: Black For PCBs beyond Revision F, the sequence repeats.	SYS2805, SYS3202

7.3.2 PCB Overlay Legend and Marking Ink Material and Color

Every PCB should contain a silk screen text overlay on the board. This text will be printed in white, yellow, or black silk screen epoxy that is impervious to any possible cleaning solution the board may be subject to. The ideal selection of color is determined by the visibility of the printing on the solder mask color chosen.

Text portions of this overlay shall be in a simple font, large enough to be clearly printed utilizing the vendor's design rules and readable by assemblers and technicians that may be handling the PCB.

For all components that must be installed in a particular orientation, markings clearly showing this shall be printed on the PCB for use by assemblers and service technicians. Large complex components like Ball Grid Arrays (BGAs) and Quad Flat Packs (QFPs) shall contain fiducial markings necessary for alignment of assembly equipment.

COTS PCBs are excluded from this requirement. PCBs too small or dense to permit inclusion of useful or readable markings, or where inks may interfere with RF properties of the board, are exempt from this requirement.

Parameter	Req. #	Value	Traceability
Printed Circuit Board Marking Material	ETR0706	Rigid PCBs shall utilize legend and marking inks specified in and meeting IPC Specification IPC-4781 "Qualification and Performance Specification of Permanent, Semi-Permanent and Temporary Legend and/or Marking Inks" (RD32). PCBs too small or dense to permit inclusion of useful or readable markings, or where inks may interfere with RF properties of the board, are exempt.	SYS2402, SYS2805
Printed Circuit Board Fiducials & Alignment Markings	ETR0716	Rigid PCBs shall include fiducials and other alignment markings necessary for machine installation of alignment critical components such as Ball Grid Array (BGA) packages.	SYS2402, SYS3202

7.3.3 Identification Information

All ngVLA PCBs shall be clearly labeled with the CID number to find all associated documents for the board, including manuals, schematics, and artwork and production files. The information shall also include the revision level and the date the design or revision was completed. Additional information useful to the

designer, assembler, or service technician is allowed and encouraged. An approved NRAO logo shall be on the board. Additional identifying logo(s) for the project, individual designer(s), group, or organization responsible for the PCB are also allowed providing space is available. However, at least one dimension must be the same size as or smaller than the NRAO logo. Provision for a permanent serial number shall be provided. This can be a sequential number applied by the PCB vendor during fabrication or a block allowing for permanent marking or engraving of a board serial number during initial assembly.

Exemptions to identification markings will be considered in cases where board size or physical restrictions exist. Requests for exemptions must be submitted by the designer with justifications to the ngVLA project ECCB.

COTS PCBs are excluded from this requirement.

Parameter	Req. #	Value	Traceability
PCB Identification Markings	ETR0708	PCBs shall be marked with the PCB name/function, CID number (to find all associated documents for the board), the revision level and the date the design or revision was completed. Additional information useful to the designer, assembler, or service technician is allowed and encouraged.	SYS3600
PCB Logos	ETR0713	All ngVLA project PCBs shall include the NRAO logo that is approved at the time the PCB is designed. PCB designers are also permitted to include additional logo(s) identifying the project and/or their organization, however, at least one dimension must be the same size or smaller than the NRAO logo.	SYS3600, IP protection

7.4 High Frequency/Low Emission Design Requirements for PCBs

Given the high emphasis on RFI and EMC in the ngVLA system, it is critical that PCBs be designed for the best high-frequency performance, lowest RFI emission, and best immunity to electromagnetic interference possible. While it is true that the vast majority of PCBs in the ngVLA Electronics System will be packaged in RFI-shielded enclosures, those enclosures should not be considered the primary line of defense. To meet the extremely stringent system requirements and specifications, a layered approach is absolutely necessary. This starts with the design of the PCBs and selection of components on them. Careful attention shall be applied to the detailed design of the boards. Excellent references and analysis tools exist to ensure that the PCBs are designed for minimum emission and susceptibility, and these usually also result in maximum performance.

Given the wide range of possibilities, it is not practical to require a specific standard for these design parameters. The PCB designer shall analyze their designs and take steps to optimize PCB performance and minimize RF emission. They shall be prepared to discuss their analyses and the techniques used to address the results in the design reviews for their PCBs and subsystems.

PCBs designed for use in the central shielded chamber(s) are exempted. However, bear in mind that design for low emission and design for good RF/high-speed performance usually go hand in hand, therefore this analysis is still recommended.

Parameter	Req. #	Value	Traceability
PCB Optimum High-Frequency Performance and Low Emission	ETR0714	The PCB designer shall analyze their designs and take steps to optimize PCB performance and minimize RF emission. They shall be prepared to discuss their analysis and the techniques used to address the results in the design reviews for their PCBs and subsystems. PCBs designed to operate in the central shielded chambers are exempt from this requirement but the analysis is still recommended.	EMC0310, EMC0322, SYS2402

7.5 Test and Maintainability of PCBs

Due to the long design life of the ngVLA, PCBs need to be designed with service and maintainability in mind. The use of adequate test points, proper labeling, indicator LEDs, boundary scan technologies like JTAG, etc., is key to serviceability.

On PCBs utilizing BGA Integrated Circuit (IC) packages or similar components, designers and production teams shall procure sufficient extra PCBs and components to allow for creation of BGA assembly and rework station soldering profiles. These are essential for reliable production and to support long-term maintenance.

Many PCBs designed for the ngVLA project will be produced in sufficient quantity where automated assembly and test will be required in manufacturing. If more than 50 of a specific PCB type will be produced or if it is known automated assembly and/or test capability is required, then the PCB shall be designed with the features needed to support these processes. Features that may be needed include, but are not limited to:

- Fiducials and other markings to assist with optical alignment of the board and components
- Clearances around the board perimeter to allow for machine handling of the PCB
- Minimized use of through hole components or other parts that will require manual installation
- Use of well-placed test connections for JTAG, boundary scan testing, device programming, etc.

Parameter	Req. #	Value	Traceability
PCB Power Supply Test Points	ETR0709	PCBs shall include labeled and accessible Test Points to be used during development, maintenance and upgrades to verify and/or adjust on-board produced supply voltages.	SYS3202
PCB FPGA Test Points and/or Indicators	ETR0710	PCBs utilizing FPGAs shall incorporate test points and/or LED indicators connected to spare pins of the FPGA. These are needed, during development, maintenance and upgrades to verify and debug operation of FPGA firmware.	SYS3202
PCB Critical Signal Test Points	ETR0711	Signals on PCBs critical for verifying proper operation of the board or calibrating the board shall be made available on labeled test points.	SYS3202
Solder Profiles for BGA Packages	ETR0715	For PCBs containing BGA or similar packages, sufficient spare PCBs and components shall be procured to be used for building soldering profiles for both assembly and long-term maintenance use.	SYS3202, SYS2801, SYS2805

Parameter	Req. #	Value	Traceability
PCB Design for Automated Assembly & Test	ETR0717	If more than 50 of a specific PCB type will be produced or if it is known automated assembly and/or test capability is required, then the PCB shall be designed with the features needed to support these processes.	SYS2402, SYS3202

8 Power, Grounding, and Circuit Protection

8.1 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	ETR0801	Design and installation of all AC Power and Grounding wiring shall conform to US National Electrical Code NFPA 70 (RD23).	SYS2700, SYS2402, SAF1170
AC Voltages Available	ETR0819	All equipment in the ngVLA powered from AC voltages shall utilize 480V/277V or 208V/120V 60 Hz AC Power.	Local Interface Requirement
AC Voltage Tolerance	ETR0820	All equipment in the ngVLA powered from the AC line shall tolerate variations of +/– 10%.	Local Interface Requirement

8.2 DC Power and Grounding Physical Connection Design

Proper power and grounding connections are required to maintain safety, provide for low noise levels, and ensure good reliability.

Most LRUs will be provided DC power supply voltages from a separate isolated DC–DC converter based power supply running from either the AC line or a battery backed –48 VDC Power supply system. Remaining LRUs will be powered directly from the battery backed –48 VDC Power supply system and generate all needed voltages internally. These external DC voltages are not well regulated and should be considered as raw power. Each LRU will need to provide final internal regulation to all required voltages.

The LRU chassis or housing shall be electrically connected to the antenna structure. This should be accomplished using a proper grounding wire and not simply dependent on the mounting structure and hardware and/or the power supply returns for proper grounding. This wire can be a separate ground connection or included in the connectorized harness carrying power to the device.

Parameter	Req. #	Value	Traceability
DC Power & Grounding Design	ETR0802	Design and installation of all DC power distribution and grounding wiring shall conform to ngVLA System and RFI/EMC requirements.	SYS2700, SYS2402, SYS2104, SYS2106, SYS1503, SAF0070, SAF0080, SAF1170,
LRU Power Input	ETR0803	Input power to all LRUs shall be considered raw power. Internal regulation and filtering is required.	SYS2700, SYS2402, SYS2104

Parameter	Req. #	Value	Traceability
LRU Physical Ground	ETR0804	LRU chassis or housing shall be electrically connected to the antenna structure using a proper grounding wire. This wire can be a separate ground connection or included in the connectorized harness carrying power to the device.	STK2700, SYS2402, SYS2104, SYS2106, SAF0070, SAF0080
Power Supply Dedicated Returns	ETR0813	All power supplies shall have dedicated current return paths.	SYS2700, SYS2104, SYS2106, EMC0310, EMC0322, SAF0070, SAF0080
Power Supply Returns Separate from Ground	ETR0814	Structural/Chassis components and signal grounds shall never be used as a power supply return path.	SYS2700, SYS2104, SYS2106, EMC0310, EMC0322, SAF0070
Connections in Hot Swap Configuration	ETR0815	In hardware designed to be hot swapped (i.e. installed or removed with power applied) interconnect shall be designed such that safety grounds, structural grounds, and power returns are connected first on installation and disconnected last on removal.	SYS2700, SYS2402, SYS1601, SYS1504, SYS1505, SYS4601, SAF0070, SAF0080
DC Voltages available	ETR0821	All equipment in the ngVLA powered from DC voltages shall utilize either the Main -48 VDC power system or voltages produced by the PSU modules, currently + 4.5 VDC, +/– 7.5 VDC and +/– 17.5 VDC. Equipment.	Local Interface Requirement
– 48 VDC Tolerance	ETR0822	Devices on the –48 VDC system shall tolerate voltages from –42.0 VDC to –60.0 VDC.	Local Interface Requirement
PSU Voltage Tolerance	ETR0823	Devices powered from the PSU modules shall tolerate +/– 10% of the rated voltages.	Local Interface Requirement

8.3 Fusing and Protection

8.3.1 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, connector, or wiring in the equipment or causing a fire.
- Minimize nuisance tripping or blowing of the protective device.
- Minimize long term degradation of the protection device and/or other components.

Bear in mind also that:

- Polysilicon 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 or continuous operation too close to the trip point.

- Data sheets of protection devices frequently contain subtle details that, if not followed, can adversely affect protection capabilities and life expectancy of the device.

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. do not use a circuit breaker as a switch unless it is specifically designed for that purpose).

Due to the requirement to remotely diagnose failures in 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	ETR0805	All ngVLA Electronics systems shall implement overcurrent protection on LRUs.	SYS2402, SYS2700, SAF0150
Overcurrent Protection Device Monitoring	ETR0806	The ngVLA M&C system shall be able to monitor the state of overcurrent protection devices in an LRU. An exception is if the circuit protection device activated disables the LRUs M&C interface. In this situation, the LRU ceases to communicate and should be presumed as bad by the responding technician (i.e. they take a spare with them and swap the LRU after evaluating M&C connections).	SYS2402, SYS2700, SYS2701

8.3.2 Thermal Protection and Analysis

All 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 array operations 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.

The designer shall analyze their designs and take steps to optimize thermal performance with a focus on proper cooling, thermal stability, and the elimination of hot spots. They shall publish these results in a memo and be prepared to discuss their analysis and the techniques used to address the results in the design reviews for their equipment and subsystems.

Parameter	Req. #	Value	Traceability
Thermal Protection	ETR0807	ngVLA LRUs shall be thermally protected.	SYS2402, SYS2700, SAF0100, SAF0770
Thermal Protection Monitoring	ETR0808	The LRU shall be able to monitor the state of thermal protection features. An exception is if the thermal protection activated disables the LRUs M&C interface. In this situation the LRU ceases to communicate and should be presumed as bad by the responding technician (i.e. they take a spare with them and swap the LRU after evaluating M&C connections).	SYS2402, SYS2700, SYS2701

Parameter	Req. #	Value	Traceability
Thermal Analysis	ETR0816	The designer shall analyze their designs and take steps to optimize thermal performance with a focus on proper cooling, thermal stability and the elimination of hot spots. They shall publish these results in a memo and be prepared to discuss their analysis and the techniques used to address the results in the design reviews for their equipment and subsystems.	SYS2402, SYS2801, SYS2700, SYS1601, SYS4601, SAF0100, SAF0770

8.4 Power System Operational Design

The operational design of the power system is critical to the reliability, safety, and autonomous functionality of the system. With 263 antennas, the ability of the system to survive and recover after power related incidents is of crucial importance. With this in mind, the electronics system in each antenna shall be able to be fully started up and shut down by technicians at the local site without interaction with operations or the central M&C System.

Additionally, after an unscheduled local power outage, the antenna's electronics system shall recover autonomously to a state suitable for normal operation on resumption of commercial power. If, after power is restored, a problem exists preventing the normal operation of the antenna, the system shall at least be at a state that is safe for the antenna, electronics, and any array or emergency personnel that arrive.

During a power outage, much of the electronics will continue to be powered by battery backup as described in Section 8.5. Over-current and thermal protection shall remain in full effect during the outage. During power outages, electronics may be placed into a low-power mode to minimize overheating and extend battery life. This low-power safe mode may be commanded via the local M&C system or, in the event of lost communications, enacted automatically within the LRU based on the combination of no commands received and monitored local conditions such as temperature or supply voltage. Battery condition shall be monitored and the backup system shut down before reaching a state of discharge that could permanently degrade the batteries.

All power supplies and LRUs shall contain power on indicators visible on the exterior surface of the unit. Indicators shall be blue LED(s). In RFI shielded enclosures, these may be implemented with small LEDs or light pipes.

Parameter	Req. #	Value	Traceability
On-Site Reset/Start-Up Sequence	ETR0809	All ngVLA antenna electronics shall be able to be started up and shut down locally at the antenna site with no intervention from operations, even in the event of no M&C and/or audio communications between the antenna and array operations.	SYS2700, SYS2402, SYS3202, SYS3220, SAF1060

Parameter	Req. #	Value	Traceability
Power Outage Behavior	ETR0810	All system electronics shall enact a sequential managed shutdown procedure in response to power outages, placing the system in a safe standby state in order to avoid damage to hardware and minimize recovery time. This low power safe mode may be commanded via the local M&C system or, in the event of lost communications, enacted automatically within the LRU based on the combination of no commands received and monitored local conditions such as temperature or supply voltage.	SYS2700, SYS2701, SYS2402, SYS2601, SYS2602, SAF1060
Automated Recovery Sequence	ETR0811	All ngVLA antenna electronics shall enact procedures to autonomously recover from a power outage in a state suitable for normal operations, or at least to a safe state.	SYS2700, SYS2701, SYS2402, SYS2601, SYS2602, SAF1060
Power On Indicators	ETR0812	LRUs and power supplies shall contain externally visible LED power indicators with "steady blue" indicating "nominal operation" and "blinking blue" indicating "power is on but not meeting nominal conditions." In RFI shielded enclosures, these may be implemented with small LEDs or light pipes.	SYS2700, SYS3220

8.5 Batteries

Batteries typically represent a reliability concern, require regular maintenance or replacement and can be a safety concern. With the exception of the Antenna –48 VDC power system, which will contain battery backup, and a commercial Uninterruptible Power Supply (UPS) that may be required for AC powered equipment, batteries shall not be used in the ngVLA system. Non-volatile memory should be used where possible. Real-time clocks should not be needed in the system since time is available via the M&C network.

Exemptions will be considered on a case by case basis. Requests for exemptions must be submitted by the designer with justifications to the ngVLA Project ECCB.

Parameter	Req. #	Value	Traceability
Battery Use	ETR0817	Batteries shall not be used in the ngVLA system except in the case of the antenna –48 VDC power system and a commercial UPS device for critical AC line powered equipment.	SYS2700, SYS2402, SYS2801

8.6 Transient Protection

Based on past experiences with JVLA and ALMA, there is a need for transient protection on sensitive digital and analog I/O lines as well as power supply inputs on electronics. Transient Voltage Surge Suppression (TVSS) devices shall be used on sensitive analog and digital I/O signals and power supplies entering or exiting a LRU. RF and other signals that will be adversely affected by the inclusion of these devices are exempt from this requirement.

Parameter	Req. #	Value	Traceability
Transient Protection of LRU I/O & Power Connections	ETR0818	Transient Voltage Suppression devices shall be used on sensitive analog and digital I/O signals and power supplies entering or exiting a LRU. RF and other signals that will be adversely affected by the inclusion of these devices are exempt from this requirement.	SYS2402, SYS2403

8.7 Lightning and EMP Protection

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 electronics system design. The antenna and housed equipment shall be protected in any antenna orientation. 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 IEC 62305-1—Protection against Lightning [RD45]. This level assures protection against 99% of strikes, with a residual risk of damage for strikes with parameters outside the defined range.

Parameter	Req. #	Value	Traceability
Lightning Protection– Structure & Housings	ETR0824	The antenna, buildings, and housed equipment shall be protected from both direct and nearby lightning strikes, achieving Protection Level I as defined in IEC 62305-1/3. [RD45]	SYS2402, ENV0511
Lighting Protection of Electronics Systems	ETR0825	Antenna and central electronics systems shall be protected against Lightning Electromagnetic Impulse (LEMP) in accordance with IEC 62305-4. [RD45]	SYS2402, ENV0512

9 Electronics Reliability and Maintainability

One of the key general design goals of the ngVLA is to have a system that is over 10 times the size of the VLA operated at about 3x the annual operating cost of the VLA. This goal places a large focus on the design of the system. The ngVLA system requirements have an overall MTBF specification calling for the system to be designed with an expected number of failures to be less than four (4) per array element per year. An even tighter requirement exists for the central electronics. Reliability and ease of maintenance is paramount and must be a key focus of the ngVLA system design from the beginning. Spending the additional time and resources up front may increase development time and cost, but it will ultimately lead to lower long-term operating costs.

9.1 Design for Reliability

While there are no published standards for reliability of this type of electronic system, there are a number of handbooks and guidelines covering various design aspects and reliability analysis techniques:

- MIL-HDBK-217F(2), US Military Handbook: Reliability Prediction of Electronic Equipment [RD24]
- MIL-HDBK-251, US Military Handbook: Reliability/Design Thermal Applications [RD25]
- MIL-HDBK-338B, US Military Handbook: Electronic Reliability Design [RD26]

- NPRD-95 [RD38]
- IEC 61709 Ed.3.0 b:2017, Electronic Components – Reliability – Reference Conditions for Failure Rates and Stress Models for Conversion [RD27]

There are a number of key areas to consider, which will be covered in the following sections.

9.2 *Component Selection*

The selection of components used in the design is key to a reliable system.

9.2.1 Reputable Manufacturers and Proven Suppliers

Utilize components from known reputable manufacturers and proven suppliers. This reduces the possibility of substandard or counterfeit parts that are rampant in the electronics industry. It also simplifies procurement strategies and long-term component availability. Also, research components to determine if they are a likely risk for near-term obsolescence.

Parameter	Req. #	Value	Traceability
Component Sources	ETR0901	Components shall be sourced from reputable, proven manufacturers, vendors, and/or distributors as determined in the purchase requisition process. The US Government GSA Federal Acquisition Regulations (FAR) [RD42] in effect at the time of purchase shall be followed where applicable.	SYS2402, SYS2601, SYS2602, SYS2801, SYS2805, SYS3702

9.2.2 Standard ngVLA Libraries of Parts

Wherever possible, components shall be from standard project libraries of parts. If a component is required that is not in these libraries, that component shall be added to a standard library along with any pertinent data. This is especially critical if the component can be used in multiple places in the system.

Using common parts libraries enables the ngVLA project to keep track of a standard set of components used across the system. This has multiple benefits: reduced manufacturing and spare parts inventories, simplified procurement strategies, a database of component reliability data to be used in reliability analysis, and a well understood library of tested and proven simulation models, schematic symbols, PCB footprints, and 3D CAD models.

Parameter	Req. #	Value	Traceability
Standard Component Libraries	ETR0902	Managed libraries shall be kept of commonly used electronic components and hardware.	SYS2402, SYS2601, SYS2602, SYS2801, SYS2805

9.2.3 Utilize Components Designed and Specified for Their Environment

Some ngVLA components will have to operate or be stored under very harsh environmental conditions (temperature, humidity, etc.), and others will operate or be stored in very benign, environmentally controlled conditions. Components shall be chosen based on these conditions.

Parameter	Req. #	Value	Traceability
Component Environmental Specifications	ETR0903	Electronic and mechanical components used in the ngVLA system shall always be used in accordance with their specified environmental specifications (storage/operation temperature, humidity, altitude derating, corrosion resistance, etc.)	SYS2402, SYS2801, SYS2805, ENV0332, ENV0333, ENV0581, ENV0582, ENV0571, ENV0521, ENV0531, ENV0342, ENV0344, ENV0532

9.3 Reliability Analysis

The ngVLA project will be utilizing reliability analysis software to analyze the expected reliability of electronics systems designed and built for the project. All designs shall be subject to this process. This analysis will be used to determine if a design meets the MTBF requirements of the project and to identify weaknesses in the design that could ultimately lead to increased maintenance costs. Weaknesses identified by this analysis shall be investigated by the lead designer of the hardware with two possible outcomes:

- Alternative components or design changes can be implemented to correct the shortcoming in the hardware.
- No suitable alternative exists and a waiver will need to be approved via an engineering change process.

Organizations external to NRAO can choose to implement this on their own or submit their design to NRAO for analysis.

A Reliability, Availability, Maintainability analysis shall be performed by each designer at the LRU level 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 [RD24], but the designer may propose to use other methods. For non-electronic parts, the values of NPRD-95 [RD38] 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 [RD24]. 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.

The results of this analysis are a required part of the Design Review Process.

Parameter	Req. #	Value	Traceability
Reliability Analysis	ETR0904	A Reliability, Availability, Maintainability analysis shall be performed by each designer at the LRU level 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 [RD24], but the designer may propose to use other methods. For non-electronic parts, the values of NPRD-95 [RD38] or data from manufacturers or other databases may be used. They shall publish these results in a memo and be prepared to discuss their analysis and the techniques used to address the results in the design reviews for their equipment and subsystems.	SYS2402, SYS2801, SYS2802, SYS2805

9.4 Design Robustness

Electronic systems for the ngVLA shall be operationally reliable and robust.

Designers shall take steps to ensure that the hardware behaves consistently and reliably under any conditions that may be realistically expected. This includes proving operation and/or survivability:

- At all expected temperature and humidity conditions (storage, transport, and operational)
- At any expected vibration condition (storage, transport, and operational)
- Over expected tolerances of DC power supply, analog, and digital input voltages
- Over expected variations of input signal timing
- In response to noise present on DC power supply, analog, and digital inputs
- Through component tolerances and expected variation in component specifications over their design life
- In the event of failure of any other connected equipment

Many tools are available to the designer to accomplish this task including (but not limited to):

- Mathematical analysis of the design by hand
- Simulation of the design by modeling, analog, digital, or mixed signal simulation
- Laboratory testing

Parameter	Req. #	Value	Traceability
Robustness Analysis	ETR0905	All ngVLA electronics designs shall be subject to a robustness analysis. Results of this analysis are a required part of the design review process.	SYS2402, SYS2601, SYS2602, SYS2801, SYS2802, SYS2805

9.5 Programmable Devices

The ngVLA will contain many programmable devices such as FPGAs, PSOCs, micro-controllers, and other programmable logic. Such components come with their own set of robustness and upgradability concerns.

9.5.1 Firmware Field Upgradability and Storage Location

Firmware for all devices shall be stored locally at the antenna. This may be in flash memory within the LRU or on an M&C host device located at the antenna. No hardware in the antenna shall be dependent

on a connection to the central M&C system to boot up and become operational in a basic configuration. Devices with dynamically configurable firmware (likely to occur in DSP hardware) could have a default configuration stored locally but operational firmware provided remotely.

All devices with firmware shall be remotely upgradeable without visiting the antenna. A firmware upgrade requiring a visit to all ngVLA antennas would be operationally and cost prohibitive. The designer may request a case-by-case waiver to this from the Project Engineer but this should be avoided.

Parameter	Req. #	Value	Traceability
Local Firmware	ETR0906	All programmable devices shall have a local copy of the firmware at the antenna site. Firmware for basic functional and diagnostic purposes but that may be configured remotely for normal operation satisfies this requirement.	SYS2601, SYS3202
Firmware Updates	ETR0907	All devices containing firmware shall be upgradeable remotely, i.e. without visiting the antenna.	SYS2304, SYS2601, SYS2602, SYS3202

9.5.2 Watchdog Timers and Recovery

Complex programmable devices such as FPGAs, PSOCs, and microcontrollers will inevitably experience a lockup or other unrecoverable failure. To guard against this, all programmable devices shall utilize watchdog timers and power supervisors to detect and attempt to recover from such a failure. Additionally, reset connections shall be provided via a local M&C device to allow remote commanded resets to be sent to these devices.

Parameter	Req. #	Value	Traceability
Watchdogs	ETR0908	All complex programmable devices shall utilize watchdog timers and power supervisors to detect lockups and attempt self-recovery.	SYS2402, SYS2601, SYS2602
M&C Commanded Reset for DC Powered Devices	ETR0909	All DC powered LRUs and complex programmable devices shall be provided with a physical reset line connected to a local M&C device to allow remote reset commands to be sent. This could be implemented as a ganged reset to all devices in an LRU or as individual lines to each device (or group of devices) as determined by the designer.	SYS2601, SYS2602
M&C Commanded Reset for AC Powered Devices	ETR0912	All AC powered LRUs shall be connected to a remotely controllable Power Distribution Unit (PDU) or similar device which can be remotely commanded via the M&C system to power cycle each individual device.	SYS2601, SYS2602

9.6 Periodic Self-Tests and Advanced Diagnostics

Parameter	Req. #	Value	Traceability
Periodic Self-Tests	ETR0910	Any device with internal M&C capability or connected to an external M&C module shall perform self-tests at power on and on a periodic basis. Selection of the appropriate time the period is left to the designer. Results shall be reported back to the M&C system.	SYS2402, SYS2801, SYS3202, SYS3205, SYS3220
Advanced Diagnostics	ETR0911	Any device with internal M&C capability or connected to an external M&C module shall have the capability to perform advanced diagnostics on a request received via the M&C system.	SYS2402, SYS2801, SYS3202, SYS3205, SYS3220

9.7 Electronic Test Equipment

Parameter	Req. #	Value	Traceability
Electronic Test and Measurement Equipment – Maintenance & Calibration	ETR0913	All electronic test equipment used in the development and maintenance of ngVLA electronics shall be maintained and calibrated to traceable external standards on an annual basis or as recommended by the equipment manufacturer (whichever is shorter)	SYS2402, SYS3202, SAF1060

10 Electrical, Electronics, and Optical Safety

10.1 US National Electric Code 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	ETR1001	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.	SYS2700, SAF1170
Grounding Conflict Resolution	ETR1002	Conflicts between safety grounding being compliant with the NEC and grounding designed for low noise shall be documented and brought to the attention of the Project Engineer and ECCB for analysis and resolution.	SYS2700, SYS4601, SYS1601, SYS2104, SYS2106, EMC0310

10.2 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	ETR1003	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.	SYS2700, SAF0070, SAF0090
Contact with High Voltage during Diagnosis & Repair	ETR1004	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.	SYS2700, SAF0070, SAF0090
Safety Interlocks	ETR1017	Safety interlocks shall be used in situations where high voltages (i.e. >= 50 Volts) could be exposed.	SYS2700, SAF0690, SAF0070, SAF0090, SAF0930

10.3 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	ETR1005	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.	SYS2700, SAF0940
Contact with Terminals of Storage Devices	ETR1006	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.	SYS2700, SAF0070, SAF0090
Contact with Terminals of Storage Devices During Diagnosis and Repair	ETR1007	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.	SYS2700, SAF0070, SAF0090

10.4 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 OSHA requirements.

Parameter	Req. #	Value	Traceability
High Voltage Labels	ETR1008	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.	SYS2700, SAF0059
Battery Labels	ETR1009	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 and contain space allowing for permanent marking of the battery install date.	SYS2700, SAF0059
Power Switch Labels	ETR1010	Any equipment containing a power switch shall contain at least one clearly visible label indicating the existence and location of that switch.	SYS2700, SAF0059
Emergency Cutoff Switch Labels	ETR1011	Any equipment containing an Emergency Cutoff Switch shall contain at least one clearly visible label indicating the existence and location of that switch.	SYS2700, SAF0059
Safety Ground Labels	ETR1012	Any equipment containing a critical safety ground connection shall contain at least one clearly visible label indicating the existence and location of that connection.	SYS2700, SAF0059
Hazardous Condition or Operation Labels	ETR1013	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.	SYS2700, SAF1010, SAF1040
Safety Instruction Labels	ETR1014	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.	SYS2700, SAF1010, SAF1040
Arc Flash Hazard Warning Labels	ETR1015	In any situation where there exists the possibility of generating an arc-flash, clearly visible label(s) shall be affixed stating this hazard. This can include, but is not limited to: connection or disconnection of cables & connectors, installing or removing hot pluggable equipment, or actuating switches & circuit breakers.	SYS2700, SAF0059, SAF0200
Electrical and Optical Label Safety Standards	ETR1016	All electrical and optical safety labels shall be compliant with applicable standards at the time of installation.	SYS2700, SAF0059

10.5 Optical and Laser Safety

Proper labeling of any equipment where potential exposure to optical hazards exists is critical to prevent Injury to personnel and compliance with codes and OSHA requirements.

Parameter	Req. #	Value	Traceability
Design for Optical Safety	ETR1018	All LRUs using Lasers or high intensity LEDs at levels defined as dangerous in the ANSI Z136 series of standards (RD43) shall be designed to minimize or prevent human exposure.	SYS2700, SAF0840
Optical Safety Labels	ETR1019	In all LRUs containing lasers, clearly visible labels in accordance with the IEC 60825-1:2014 Standard (RD44) shall be applied.	SYS2700, SAF0840

11 Mechanical and Wiring

11.1 Electrical Wiring and Cables

The ngVLA system will include numerous types of electrical cable and wiring. It is critical that the correct types be specified and utilized throughout the system, and that those wires and cables be installed and documented in a proper and consistent manner. The following requirements should be applied to all electrical wiring and cables in the system as well as optical fiber cables where applicable.

11.1.1 Documentation

Drawings will follow the Drafting and Documentation Standards established for ngVLA in a separate document. BOM (Bill of Materials) will be in a format specified in that document.

Parameter	Req. #	Value	Traceability
Cable Documentation	ETR1101	All wiring, cables, and harnesses installed in the ngVLA system shall be documented in accordance to ngVLA Drafting and Documentation Standards.	SYS2402, SYS2700, SYS3202

11.1.2 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	ETR1102	Wiring, cables, and harnesses shall be labeled in accordance with ANSI Standard TIA-606-C (RD28).	SYS2402, SYS2700, SYS3202

11.1.3 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 shall be of a consistent color across all ngVLA electronics systems. Those signal types and colors are defined in the table below. Multi-conductor cables can be exempted from these requirements.

Parameter	Req. #	Value	Traceability
+3.3 VDC Wire Color	ETR1103	+3.3 VDC Wiring shall be Solid Pink in color.	SYS3202
+5.0 VDC Wire Color	ETR1104	+5.0 VDC (+4.7 to +5.3 VDC) Wiring shall be Orange in color	SYS3202

Parameter	Req. #	Value	Traceability
+7.5 VDC Wire Color	ETR1105	+7.5 VDC (>+5.3 to <+10.0 VDC) Wiring shall be White w/Orange stripe.	SYS3202
–5.0 VDC Wire Color	ETR1106	–5.0 VDC (–4.7 to –5.3 VDC) Wiring shall be Solid Brown in Color	SYS3202
–7.5 VDC Wire Color	ETR1107	–7.5 VDC (>–5.3 to <–10.0 VDC) Wiring shall be White w/Brown stripe.	SYS3202
+12 VDC Wire Color	ETR1108	+12 VDC (+10.0 to +12.5 VDC) Wiring shall be Solid Blue in color.	SYS3202
+13.5 VDC Wire Color	ETR1154	+13.5 VDC (>+12.5 to <+14.7 VDC) Wiring shall be White w/Blue Stripe.	SYS3202
–12 VDC Wire Color	ETR1109	–12 VDC (–10.0 to –12.5 VDC) Wiring shall be Solid Tan in color	SYS3202
–13.5 VDC Wire Color	ETR1155	–13.5 VDC (>–12.5 to <–14.7 VDC) Wiring shall be White w/Tan Stripe	SYS3202
+15 VDC Wire Color	ETR1110	+15 VDC (+14.7 to <+15.5 VDC) Wiring shall be Solid Red in color.	SYS3202
+17.5 VDC Wire Color	ETR1111	+17.5 VDC (>+15.5 to <+20.0 VDC) Wiring shall be White w/Red stripe.	SYS3202
–15 VDC Wire Color	ETR1112	–15 VDC (–14.7 to <–15.5 VDC) Wiring shall be Solid Yellow in color	SYS3202
–17.5 VDC Wire Color	ETR1113	–17.5 VDC (>–15.5 to <–20.0 VDC) Wiring shall be White w/Yellow stripe.	SYS3202
+20 to <+30 VDC Wire Color	ETR1114	+20 to <+30 VDC Wiring shall be Solid Grey or Slate in color.	SYS3202
+30> VDC Wire Color	ETR1115	>+30 VDC Wiring shall be White w/ Grey or Slate	SYS3202
–48 to –54 VDC Wire Color	ETR1116	–48 to –54 VDC Wiring shall be Solid Purple or Violet in color.	SYS3202
DC Power & Signal Return Wire Color	ETR1117	All return wiring for DC voltages and low voltage signals shall be Solid Black in color.	SYS2700, SYS3202, SAF0070
Earth, Chassis, Safety Ground Wire Color	ETR1118	All Earth, Chassis (structure), and Safety Grounds shall be Solid Green or Green w/a Yellow Stripe.	SYS2700, SYS3202, SAF0070
TTL Digital Signal (+5V based) Wire Color	ETR1119	Standard TTL level Digital Signal wiring shall be Solid White w/Black and Orange Stripes.	SYS3202
LVTTL Digital Signal (+3.3V) Wire Color	ETR1120	Standard LVTTL level Digital Signal wiring shall be Solid White w/Black and Violet stripes.	SYS3202
LVDS Digital Signal Wire Color	ETR1121	Standard LVDS digital signal wiring pairs will be Yellow w/a Blue stripe (+ signal) and Blue w/a Yellow stripe (– signal).	SYS3202
RS422/485 Digital Signal Wire Color	ETR1122	Standard RS422/485 digital signal wiring pairs will be Orange w/a Blue stripe (+ signal) and Blue w/an Orange stripe (– signal).	SYS3202

Parameter	Req. #	Value	Traceability
Low Voltage Analog Signal Wire Color	ETR1123	Low Voltage Analog Signal Wiring shall be Solid White in color.	SYS3202

11.1.4 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	ETR1124	All AC wiring colors shall conform to US NEC requirements.	SYS2402, SYS2700, SYS3202, SAF1000 SAF1170

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

Parameter	Req. #	Value	Traceability
UV Protection of Wire & Cables	ETR1125	Wiring and cables exposed to sunlight and UV shall be either UL rated for "Sunlight Resistance" or enclosed to prevent exposure.	SYS2402, SYS2700, SAF0080, SAF0120, SAF0140, SAF1170

11.1.6 Protection of Wiring and Cables Exposed to Moisture

Parameter	Req. #	Value	Traceability
Moisture Protection of Wire & Cables	ETR1126	Wiring and cables exposed to moisture shall be either UL rated "Wet" or enclosed to prevent exposure.	SYS2402, SYS2700, ENV0591, SAF0080, SAF0120, SAF0140, SAF1170

11.1.7 Protection of Wiring and Cables Vulnerable to Rodents

Parameter	Req. #	Value	Traceability
Rodent Protection of Wire & Cables	ETR1127	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.	SYS2402, SYS2700, SAF0080, SAF0120, SAF0140, SAF1170

11.1.8 Specifications of Cables Installed into Plenums

Parameter	Req. #	Value	Traceability
Plenum Cable Specifications	ETR1128	Wiring and cables installed in designated air plenums shall comply with the plenum cable specifications in the US National Electrical Code [RD23].	SYS2402, SYS2700, SAF0080, SAF0120, SAF0140, SAF1170

11.1.9 Use of Riser Grade Cables

Parameter	Req. #	Value	Traceability
Riser Grade Cables	ETR1129	Wiring and cables installed in significant vertical runs shall utilize riser grade cables designed for this application.	SYS2402, SYS2700, SAF0120, SAF1170, SAF0080

11.1.10 Flexibility, Ruggedness, and Protection of Cables Subject to Repeated Bending or Motion and Bend Radius Control

Parameter	Req. #	Value	Traceability
Flexible Cables	ETR1130	Wiring and cables installed in applications where repeated bending and/or small bend radii shall utilize materials specifically designed for this purpose.	SYS2402, SYS2700, SAF0080, SAF0120, SAF0480, SAF0490
Bend Radius	ETR1131	The minimum bend radius of all cables shall be limited by the factory specifications for the cable.	SYS2402, SYS2700, SAF0080, SAF0480, SAF0490
Bend Radius Control of Moving Cables	ETR1189	In cables that move or flex, the minimum bend radius shall be maintained by mechanical means.	SYS2402, SYS2700, SAF0080 SAF0480, SAF0490

11.1.11 Strain Relief and Retention of Wiring and Cables

Parameter	Req. #	Value	Traceability
Strain Relief and Retention of Wiring & Cables	ETR1132	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.	SYS2402, SYS2700, SAF0110, SAF0480, SAF0490, SAF0880, SAF0540

11.1.12 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	ETR1156	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.	SYS2402, SYS2700, SYS3202, SAF0490

11.1.13 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.

Parameter	Req. #	Value	Traceability
Wiring Insulation Type	ETR1157	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.	SYS2402, SYS2700, SAF0120, SAF0480, SAF0490

11.2 Connectors

Connectors represent one of the most critical aspects of any electronic system. The use of proper connectors is key to the reliability of any system, as connector typically represent the highest failure item in most electronic systems. The following requirements apply to all connectors in the ngVLA system, electrical or optical.

A key design philosophy of the ngVLA is to minimize the use of individual interconnect cables and complex wiring wherever possible. This is considered key to achieving the high reliability required by the system.

11.2.1 Documentation

Drawings will follow the Drafting and Documentation Standards established for ngVLA. BOM (Bill of Materials) will be in a format specified with a Bill of Material Management Software package.

Parameter	Req. #	Value	Traceability
Connector Documentation	ETR1133	All connectors installed in the ngVLA system shall be documented in accordance to ngVLA Drafting and Documentation Standards.	SYS2402, SYS2700, SYS3202

11.2.2 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 (RD28).

Parameter	Req. #	Value	Traceability
Connector Labeling	ETR1134	All connectors shall be labeled in accordance with ANSI Standard TIA-606-C (RD28)	SYS2402, SYS2700, SYS3202

11.2.3 Connector Current Ratings

The maximum current ratings of connectors must be observed. Paralleling of pins to gain an increased current rating shall not be used. Paralleling pins for performance purposes is allowed as long as each pin is rated to handle the total current load.

Parameter	Req. #	Value	Traceability
Connector Current Ratings	ETR1135	All connector pin current limits shall be followed. Use of multiple pins to gain an increased current rating shall not be permitted. Where the use of multiple pins is required for signal performance, each pin shall be rated to handle the total current load.	SYS2402, SYS2700, SAF0070, SAF0080, SAF0100, SAF0150

11.2.4 Connector Environmental Ratings

Parameter	Req. #	Value	Traceability
Connector Environmental Ratings	ETR1136	All connectors shall be utilized in accordance with their designed environment.	SYS2402, SYS2700, ENV0591, SAF0080, SAF0140, SAF0480, SAF0490

11.2.5 Connector Mating Cycles

Parameter	Req. #	Value	Traceability
Cable Mating Cycles	ETR1137	The specified data sheet rating for mating cycles allowed for a connector type shall be followed.	SYS2402, SYS2700, SAF0080, SAF0480

11.2.6 Hot Swapping

Hot swapping (i.e. connection and disconnection of cables with power applied) is permitted in the ngVLA system. However, proper design techniques must be observed. 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. Designers will be required to show that these factors have been considered as part of the design review process.

Parameter	Req. #	Value	Traceability
Hot Swapping	ETR1138	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.	SYS2402, SYS2700, SYS3111, SAF0070, SAF0080, SAF0100
Hot Swap/Live Connection Pin Length	ETR1139	Connectors used in hot swap or live disconnect applications shall be designed to avoid contact arcing, abnormal current flow and sequencing issues.	SYS2402, SYS2700, SYS3111, SAF0070, SAF0080, SAF0100

11.2.7 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 humans 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. Of course, there are also other methods that can be utilized.

Parameter	Req. #	Value	Traceability
No Exposed Live Terminals	ETR1140	Live signal or power pins in connectors shall not be exposed while connectors are unmated.	SYS2402, SYS2700, SAF0070, SAF0090

11.2.8 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, severe damage and/or repeated maintenance visits 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
Non-RF Connector Uniqueness & Keying	ETR1141	Non-RF Connectors that are similar or closely located shall be sufficiently unique or keyed to prevent incorrect connectors from being mated.	SYS2402, SYS2700, SYS3202, SAF0070, SAF0130, SAF0730
RF Connector Uniqueness & Identification	ETR1185	RF Connectors are typically are difficult or impossible to physically key. Connectors of this type that are similar or closely located shall be visually unique and identifiable to minimize the possibility of incorrect connectors being mated. For example, this could be accomplished using clear labeling and/or color coding of connector pairs.	SYS2402, SYS2700, SYS3202, SAF0070, SAF0130, SAF0730
Common Connectors	ETR1142	Connectors used repeatedly across multiple devices shall have critical signal pinouts standardized.	SYS2402, SYS2700, SYS3202, SAF0070, SAF0130, SAF0730

11.2.9 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	ETR1158	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.	SYS2402, SYS2700, SYS3202, SAF0070, SAF0130

11.2.10 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 & devices where this is a concern, the designer shall integrate ejectors (or other tooling) into the design or provide for the use of external insertion/removal tools to aid in the mating and un-mating of these parts. 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	ETR1159	Connectors & devices requiring high insertion force shall be adequately supported to prevent damage to the device, connector, cable, chassis or PCB during insertion and removal.	SYS2402, SYS2700, SYS3202, SAF0070, SAF0190

Parameter	Req. #	Value	Traceability
High Insertion Force Connector & Device Ejectors and Tooling	ETR1160	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, and hammers for assembly and disassembly.	SYS2402, SYS2700, SYS3202, SAF0070, SAF0190

11.2.11 Connectors with Crimped Pins

Connectors for terminating cables and wires are available in crimped and/or solder cup configurations. Historically, properly crimped wire connections have proven to have superior reliability and conduction properties than solder type connections. For this reason, the ngVLA project is requiring the use of crimped connectors in wiring terminations wherever possible. It is understood that this is not possible for some connector configurations and applications.

The reliability of this type of connection is very dependent on the proper preparation & stripping of the wire or cable as well as the crimping procedure used when attaching the connector. This process is well defined in IPC/WHMA-A-620. "IPC Requirements and Acceptance for Cable and Wire Harness Assemblies" [RD17].

Parameter	Req. #	Value	Traceability
Crimped Connectors	ETR1186	The designer shall use crimped connectors in wiring terminations wherever possible. It is understood that this is not possible for some connector configurations and applications.	SYS2402
Crimped Connector Installation Standard	ETR1187	When using crimped connectors, wire/cable preparation and connector crimping shall be in accordance with the procedures defined in IPC/WHMA-A-620. "IPC Requirements and Acceptance for Cable and Wire Harness Assemblies" [RD17]	SYS2402

11.3 Surface Finish, Plating, and Painting of Electronic Components, Housings, and Assemblies

11.3.1 Surfaces Requiring Electrical Conductivity for RFI/EMC Purposes or Safety 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 [RD33] 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" [RD33], 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 to levels suitable for Radio Astronomy use should not be directly exposed to an exterior environment. An outer environmental protective cover should be provided meeting the requirements outlined in the document "ngVLA System Environmental Specifications," 020.10.15.10.00-0001-SPE [AD07].

11.3.2 Surface Finish of Environmental Shielding for RFI/EMC Enclosures

There are two categories of this situation. They will be covered independently.

11.3.2.1 Housed Electronics Very Sensitive to Thermal Changes

Some electronics that will be mounted on the exterior of ngVLA antennas are extremely sensitive to temperature variations. Prime examples of this are the Front End Enclosure, Water Vapor Radiometer Enclosure, and Antenna Position Encoders. These should be mounted in environmentally sealed, well insulated enclosures that provide minimal absorption (or maximum reflection) of solar radiation.

11.3.2.2 Housed Electronics to Be Kept Cool but Not Sensitive to Temperature Variations

Other electronics which are mounted on the antenna exterior will need to be kept cool for reliability reasons but will not cause performance degradation with temperature variation. Examples of this include cryogenic controls, antenna/feed positioner electronics, HVAC, and power supply equipment. This equipment could be mounted in painted, painted steel or stainless steel housings, or fiberglass housings.

11.3.3 For Surfaces Not Requiring Electrical Conductivity.

Antenna physical 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.

11.3.4 Paint Colors

Parameter	Req. #	Value	Traceability
Chromate Converted Surfaces	ETR1143	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.	SYS2106, SYS2700, EMC0310, EMC0322, ENV0591, SAF0080, SAF0140, SAF0490
Stainless Steel Surfaces	ETR1144	Stainless steel can 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.	SYS2106, SYS2700, EMC0310, EMC0322, ENV0591, SAF0080, SAF0140, SAF0490

Parameter	Req. #	Value	Traceability
Anodized Surfaces	ETR1145	Aluminum Surfaces where no electrical conductivity is required can be anodized. Anodizing shall be of a color not mistakable for chromate (i.e. 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 off to achieve this.	SYS2106, SYS2700, EMC0310, EMC0322, ENV0591, SAF0080, SAF0140, SAF0490
Painted Surfaces	ETR1146	Surfaces requiring paint shall be painted with white paint suitable for the surface material and environmental conditions the surface will experience.	SYS2106, SYS2700, ENV0591, SAF0140, SAF0490, SAF0880
Colored Paint Marking	ETR1147	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.	SYS2700, SYS3202, ENV0591, SYS2402, SAF0140 SAF0190, SAF0880, SAF0490, SAF1000
Surface Preparation for Painting	ETR1188	Before painting, all surfaces shall undergo proper surface preparation suitable for the material and paint shall be used.	SYS2700, ENV0591, SYS2402, SAF0140, SAF0490, SAF0880

11.4 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 are a compact and low power means of being able 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. Those requirements are outlined here:

Parameter	Req. #	Value	Traceability
Type of Light Sources	ETR1148	All light sources shall be long-life LED or OLED type devices. Incandescent or neon/gas type light sources shall not be used.	SYS2402, SYS2700, SYS2801, EMC0324, SAF0980, SAF0990
Color of LEDs Indicating Presence of Power	ETR1149	All LEDs indicating the presence of power supply voltages shall be Blue. Blue LEDs shall 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."	SYS2700, SYS3202, SYS3220, SAF0980, SAF0990, SAF1100

Parameter	Req. #	Value	Traceability
Color of LEDs Indicating Fault, Warning or Abnormal Operation	ETR1150	All LEDs indicating Faults, Warnings, or Abnormal Operation shall be Red. Red LEDs shall 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."	SYS2700, SYS3202, SYS3220, SAF0980, SAF0990, SAF1100
Color of LEDs Used for Purposes of Illuminating a Space	ETR1151	LEDs used to physically illuminate a workspace or physical hardware for purposes of maintenance and repair shall be White. White LEDs shall not be used for other purposes unless part of a multicolor RGB or RGBW type LED used to display many colors.	SYS2700, SYS3202, SAF0230, SAF1000
Color of LEDs Used to Indicate General Status	ETR1152	LEDs used to indicate general status other than those indicated above shall not be blue, red or white. All other colors are useable and left to the discretion of the designer.	SYS2700, SYS3202, SYS3220, SAF0980, SAF0990, SAF1100
LED Brightness	ETR1153	LEDs shall be operated at the minimum current required to perform their function and shall not be set at a brightness level that causes safety concerns or discomfort to individuals.	SYS2402, SYS2700, SAF0190, SAF0230

11.5 Mechanical Assemblies Engineering Requirements

The ngVLA electronic systems will contain numerous mechanical assemblies designed to operate for 30 years with exceptionally high reliability. It is expected that design, assembly, and maintenance personnel will use the best engineering practices available when designing, building, and maintaining this equipment. The following set of requirements must be applied to assure the performance, maintainability, and life expectancy of the telescope.

Parameter	Req. #	Value	Traceability
Metric Hardware	ETR1161	All ngVLA Electronics will 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. It is understood that this will not always be possible. Exemptions will be considered on a case by case basis. Requests for exemptions must be submitted by the Responsible Engineer with justifications to the ngVLA ECCB. Standard RF waveguide flange screws are a known exception and should be considered automatically exempted.	SYS3202

Parameter	Req. #	Value	Traceability
Hardware Labeling	ETR1162	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.	SYS3202
Assembly Hardware: Galvanic/ Corrosion Properties	ETR1163	All assembly hardware shall be of a material, plating, and/or coating appropriate for its location based on galvanic corrosion properties.	ENV0591, SYS2402, SYS2700, SYS2801, SAF0140, SAF0490
Assembly Hardware: Electrical Properties	ETR1164	All hardware shall be of a material, plating, and/or coating appropriate for its location based on electrical conductivity.	SYS2402, SYS2700, SYS2801, EMC0310, EMC0322, EMC0327, SAF0140, SAF0490
Assembly Hardware: Strength Properties	ETR1165	All hardware shall be of an appropriate grade and material for its location based on strength.	SYS2402, SYS2700, SYS2801, SAF0140, SAF0490
Heads and Drivers for Pan Head Screws	ETR1166	All pan head screws within an LRU shall be of a consistent type drive and utilize a consistent type of maintenance tools.	SYS3202, SAF0190
Heads and Drivers for Flat Head Screws	ETR1167	All flat head screws within an LRU shall be of a consistent type drive and utilize a consistent type of maintenance tools.	SYS3202, SAF0190
Heads and Drivers for Cap Head Screws	ETR1168	All cap head screws within an LRU shall be of a consistent type drive and utilize a consistent type of maintenance tools.	SYS3202, SAF0190
Hardware Retention	ETR1169	All nut and bolt type hardware interfaces shall utilize retention techniques to prevent loosening. Examples include lock washers, adhesives, cotter pins, and safety wiring.	SYS2402, SYS2700, SYS2801, SAF0480, SAF0530
LRU Ease of Replacement	ETR1170	LRUs shall be designed to simplify the installation and removal process.	SYS2700, SYS3202, SAF0070, SAF0190, SAF0240, SAF0260, SAF0730
Fastener Torque Specifications	ETR1171	Torques for all fasteners shall be specified on assembly drawings.	SYS2402, SYS2700, SYS2801, SYS3202, SAF0530
Torque Tooling Calibration	ETR1190	Tools utilized for setting hardware torques shall be shall calibrated to a traceable external source every 5000 uses or 12 months.	SYS2402, SYS3202, SAF1060
LRU Sharp and Rough Edges	ETR1172	LRUs shall be free of sharp and rough edges.	SYS2700, SAF0540
Engineering Dimensions	ETR1173	All engineering dimensions shall be specified on reviewed design documentation.	SYS2402, SYS2801

Parameter	Req. #	Value	Traceability
Engineering Dimension Units	ETR1174	On reviewed manufacturing drawings, engineering dimensions shall be specified in the format of "Metric (Imperial) units" for fabrication expected to occur outside of the US. Alternatively, dimensions shall be specified "Imperial (Metric) units" when expected to be fabricated within the US.	SYS2402, SYS2801
Engineering Tolerances	ETR1175	Engineering tolerances shall be specified on reviewed manufacturing drawings utilizing the same notation as dimensions in ETR1174.	SYS2402, SYS2801
LRU Installation Force	ETR1176	LRU level assemblies shall fit together without applying excessive force.	SYS2402, SYS2700, SYS2801, SYS3202, SAF0190, SAF0260, SAF0730
LRU Installation Damage	ETR1177	LRUs shall be able to be installed easily without damaging cosmetic or conductive surfaces.	SYS2402, SYS2700, SYS2801, SYS3202, SAF0490, SAF0730
LRU Handling	ETR1178	LRUs shall be designed with ease of handling and installation/removal in mind. This includes use of handles, eye hooks, etc. These shall be installed to assure proper balance and safe handling of the LRU.	SYS2700, SYS3202, SAF0190, SAF0490, SAF0730
LRU Hoist Points	ETR1191	Where the weight, size, or shape of LRUs prevents them from being moved by hand or safely removed from the antenna, they must be fitted with attachments for lifting gear, designed so they can be fitted with such attachments (e.g., threaded holes), or shaped so that standard lifting gear can easily be attached.	SAF0250, SYS3202
Design for Transportation	ETR1179	All assemblies shall be designed to survive shipping and transportation. No fragile or insecure assemblies or wiring.	SYS2402, SYS2801, SAF0240, SAF0250, SAF0260, SAF0470
Accessibility for Adjustments & Measurements	ETR1180	Adequate clearances and access shall be provided for adjustments and measurements needed during normal operation and routine maintenance.	SYS3202, SAF0190, SAF0920
Assembly Cleaning	ETR1181	All assemblies shall be fully cleaned after fabrication or repair.	SYS2402, SYS2700, SYS2801, SYS3202, SAF0490, SAF0770, SAF0780, SAF0800
Assembly Inspection	ETR1182	All assemblies shall be fully inspected and tested after fabrication or repair.	SYS2402, SYS2700, SYS2801, SYS3202, SAF0490, SAF0770, SAF0780, SAF0800
LRU Orientation	ETR1183	LRUs shall be marked or keyed to prevent assembly or installation in an incorrect orientation.	SYS2700, SYS3202, SAF0730

Parameter	Req. #	Value	Traceability
Fasteners in Electrically Conductive Applications	ETR1184	Anodized and black oxide fasteners shall not be used at mechanical interfaces requiring electrical conductivity to maintain electrical grounds or RFI/EMC integrity.	SYS2700, EMC0310, EMC0322, EMC0327

12 Surge and Lightning Protection for Cables Entering a Building or Enclosure

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 electronics system design. The antenna and housed equipment shall be protected in any antenna orientation. 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 IEC 62305-1–Protection Against Lightning [RD45]. This level assures protection against 99% of strikes, with a residual risk of damage for strikes with parameters outside the defined range.

Parameter	Req. #	Value	Traceability
Lightning Protection of Structure & Housings	ETR1204	The antenna, buildings, and housed equipment shall be protected from both direct and nearby lightning strikes, achieving Protection Level I as defined in IEC 62305-1/3. [RD45]	SYS2402, ENV0511
Lighting Protection of Electronics Systems	ETR1205	Antenna and central electronics systems shall be protected against Lightning Electromagnetic Impulse (LEMP) in accordance with IEC 62305-4. [RD45]	SYS2402, ENV0512

The design standard shall be that signal lines exposed to large potential gradients, such as those passing via copper lines outside the building or over distances greater than 10 m, shall be protected by silicon avalanche diodes at the circuit board and by gas tubes at building entrances. Note that a low value resistor, such as 10 ohms, is required in line with the signal before the surge protector to ensure sufficient voltage to cause the protector to conduct. Cable sheaths shall be grounded at the building entrance. (See VLA LPS requirements.) Test efficacy of the design with both Surge Arrestor and Ground Resistance test sets.

Parameter	Req. #	Value	Traceability
Surge Protection at Building Entrances	ETR1201	Power/signal lines and metal armored fiber optic cables exposed to large potential gradients shall be protected by gas tubes at building and antenna structure entrances. Protection shall be tested with the appropriate equipment.	ENV0511, ENV0512, SYS2700, SAF0140, SAF1170
Cable Armoring Sheath Termination	ETR1202	Cable armoring sheaths shall terminate at the building or antenna structure entrance and not continue into the building or structure.	ENV0511, ENV0512, SYS2700, SAF0140, SAF1170

Parameter	Req. #	Value	Traceability
Surge Protection at Equipment I/O Entry Points	ETR1203	Power and signal lines exposed to large potential gradients shall be protected by silicon avalanche diodes at I/O entry points to circuit boards and electronics.	ENV0512, SAF0140, SAF1170

13 Soldering and Electrical Connections

All electronic connections will shall follow 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.

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.

Parameter	Req. #	Value	Traceability
Soldering and Electrical Connections	ETR1301	All electronic connections shall follow Class 2 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. Class 3 may be utilized at the discretion of the Responsible Engineer.	SYS2402, SYS2801, SYS3202, SAF0130, SAF0140, SAF0490, SAF0770, SAF0780, SAF0800

14 Verification and Quality Assurance

The design may be verified to meet the requirements by analysis (A), inspection (I), a demonstration (D), or a test (T), each defined below.

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 Inspection: The compliance of the developed system is determined by a simple inspection or measurement.

Verification by Demonstration: The compliance of the developed feature is determined by a demonstration.

Verification by Test: The compliance of the developed system with the specified performance shall be demonstrated by site acceptance tests.

The following table summarizes the expected final design verification methods that will be executed at the product qualification phase in preparation for the Critical Design Review (CDR). Multiple verification methods are allowed and expected over the earlier design phases, e.g. requirements which undergo testing at the CDR stage may be verified by analysis during preliminary design in preparation for the PDR. 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) and electronics only. The verification procedures that will be deployed during the production phase will be defined as part of the production planning documents.

Req. ID	Name	Verify Method
ETR0301	LRU Designation	Demonstration
ETR0401	LRU Physical Marking Label Contents	Demonstration
ETR0402	LRU Physical Tracking Device	Demonstration
ETR0403	Remote Identification	Demonstration
ETR0404	LRU Remote ID for devices with no direct M&C connection	Demonstration
ETR0405	LRU Tracking Label & Tag Specifications	Test
ETR0406	LRU Weight Labels	Demonstration
ETR0407	LRU Multiple Person Lift Labels	Demonstration
ETR0408	Lift and Hoist Points	Demonstration
ETR0409	LRU Physical Marking Label Ruggedness	Test
ETR0410	Hot Connect & Disconnect Warning Labels	Demonstration
ETR0501	ESD Low Air Discharge Susceptibility Testing	Test
ETR0502	ESD Protection	Analysis
ETR0503	ESD Packaging & Storage	Test
ETR0504	Prevention & Discharge of Electrostatic Charge Build-up	Test
ETR0505	ESD High Air Discharge Susceptibility Testing	Test
ETR0506	ESD Direct Contact Discharge Susceptibility Testing	Test
ETR0601	EMC/RFI Mitigation in Designs	Test
ETR0701	Printed Circuit Board IPC Standard Compliance	Demonstration
ETR0702	Rigid Printed Circuit Board Material	Demonstration
ETR0703	Flexible Printed Circuit Board Material	Demonstration
ETR0704	Printed Circuit Board Plating / Surface Finish Material	Demonstration
ETR0705	Printed Circuit Board Solder Mask Material	Demonstration
ETR0706	Printed Circuit Board Marking Material	Demonstration
ETR0707	Printed Circuit Board Solder Mask Color	Demonstration
ETR0708	PCB Identification Markings	Inspection
ETR0709	PCB Power Supply Test Points	Demonstration
ETR0710	PCB FPGA Test Points and/or Indicators	Demonstration
ETR0711	PCB Critical Signal Test Points	Demonstration

Req. ID	Name	Verify Method
ETR0712	Printed Circuit Board RoHS Compliance	Demonstration
ETR0713	PCB Logos	Inspection
ETR0714	PCB Optimum HF Performance and Low Emission	Analysis
ETR0715	Solder Profiles for BGA Packages	Demonstration
ETR0716	Printed Circuit Board Fiducials & Alignment Markings	Inspection
ETR0717	PCB Design for Automated Assembly & Test	Demonstration
ETR0801	AC Power & Grounding Design	Analysis
ETR0802	DC Power & Grounding Design	Analysis
ETR0803	LRU Power Input	Analysis
ETR0804	LRU Physical Ground	Inspection
ETR0805	Overcurrent Protection	Test
ETR0806	Overcurrent Protection Device Monitoring	Test
ETR0807	Thermal Protection	Test
ETR0808	Thermal Protection Monitoring	Demonstration
ETR0809	On-Site Reset / Start-Up Sequence	Test
ETR0810	Power Outage Behavior	Demonstration
ETR0811	Automated Recovery Sequence	Demonstration
ETR0812	Power On Indicators	Demonstration
ETR0813	Power Supply Dedicated Returns	Demonstration
ETR0814	Power Supply Returns Separate from Ground	Inspection
ETR0815	Connections in Hot Swap Configuration	Demonstration
ETR0816	Thermal Analysis	Analysis
ETR0817	Battery Use	Demonstration
ETR0818	Transient Protection of LRU I/O & Power Connections	Analysis
ETR0901	Component Sources	Analysis
ETR0902	Standard Component Libraries	Analysis
ETR0903	Component Environmental Specifications	Analysis
ETR0904	Reliability Analysis	Analysis
ETR0905	Robustness Analysis	Analysis
ETR0906	Local Firmware	Demonstration
ETR0907	Firmware Updates	Demonstration
ETR0908	Watchdogs	Test
ETR0909	M&C Commanded Reset for DC Powered Devices	Demonstration
ETR0910	Periodic Self Tests	Demonstration
ETR0911	Advanced Diagnostics	Demonstration
ETR0912	M&C Commanded Reset for AC Powered Devices	Demonstration
ETR0913	Electronic Test and Measurement Equipment – Maintenance & Calibration	Inspection
ETR1001	US National Electric Code Compliance	Analysis
ETR1002	Grounding Conflict Resolution	Analysis

Req. ID	Name	Verify Method
ETR1003	Contact with High Voltages	Analysis
ETR1004	Contact with High Voltage During Diagnosis & Repair	Analysis
ETR1005	Discharge of Capacitors Operating at High Voltages	Analysis
ETR1006	Contact with Terminals of Storage Devices	Analysis
ETR1007	Contact with Terminals of Storage Devices During Diagnosis & Repair	Analysis
ETR1008	High Voltage Labels	Inspection
ETR1009	Battery Labels	Inspection
ETR1010	Power Switch Labels	Inspection
ETR1011	Emergency Cutoff Switch Labels	Inspection
ETR1012	Safety Ground Labels	Inspection
ETR1013	Hazardous Condition or Operation Labels	Inspection
ETR1014	Safety Instruction Labels	Inspection
ETR1015	Arc Flash Hazard Warning Labels	Demonstration
ETR1016	Electrical and Optical Safety Label Standards	Test
ETR1017	Safety Interlocks	Demonstration
ETR1018	Design for Optical Safety	Analysis
ETR1019	Optical Safety Labels	Demonstration
ETR1101	Cable Documentation	Demonstration
ETR1102	Cable Labeling	Demonstration
ETR1103	+3.3 VDC Wire Color	Demonstration
ETR1104	+5.0 VDC Wire Color	Demonstration
ETR1105	+7.5 VDC Wire Color	Demonstration
ETR1106	–5.0 VDC Wire Color	Demonstration
ETR1107	–7.5 VDC Wire Color	Demonstration
ETR1108	+12 VDC Wire Color	Demonstration
ETR1109	–12 VDC Wire Color	Demonstration
ETR1110	+15 VDC Wire Color	Demonstration
ETR1111	+17.5 VDC Wire Color	Demonstration
ETR1112	–15 VDC Wire Color	Demonstration
ETR1113	–17.5 VDC Wire Color	Demonstration
ETR1114	+20 to <+30 VDC Wire Color	Demonstration
ETR1115	+30> VDC Wire Color	Demonstration
ETR1116	–48 to –54 VDC Wire Color	Demonstration
ETR1117	DC Power and Signal Return Wire Color	Demonstration
ETR1118	Earth, Chassis, Safety Ground Wire Color	Demonstration
ETR1119	TTL Digital Signal (+5V based) Wire Color	Demonstration
ETR1120	LVTTL Digital Signal (+3.3V) Wire Color	Demonstration
ETR1121	LVDS Digital Signal Wire Color	Demonstration
ETR1122	RS422/485 Digital Signal Wire Color	Demonstration
ETR1123	Low Voltage Analog Signal Wire Color	Demonstration

Req. ID	Name	Verify Method
ETR1124	AC Wiring Colors	Demonstration
ETR1125	UV Protection of Wire & Cables	Demonstration
ETR1126	Moisture Protection of Wire & Cables	Demonstration
ETR1127	Rodent Protection of Wire & Cables	Demonstration
ETR1128	Plenum Cable Specifications	Demonstration
ETR1129	Riser Grade Cables	Demonstration
ETR1130	Flexible Cables	Analysis
ETR1131	Bend Radius	Analysis
ETR1132	Strain Relief & Retention of Wiring & Cables	Analysis
ETR1133	Connector Documentation	Inspection
ETR1134	Connector Labeling	Inspection
ETR1135	Connector Current Ratings	Analysis
ETR1136	Connector Environmental Ratings	Analysis
ETR1137	Cable Mating Cycles	Analysis
ETR1138	Hot Swapping	Analysis
ETR1139	Hot Swap / Live Connection Pin Length	Analysis
ETR1140	No Exposed Live Terminals	Analysis
ETR1141	Non-RF Connector Uniqueness & Keying	Demonstration
ETR1142	Common Connectors	Analysis
ETR1143	Chromate Converted Surfaces	Demonstration
ETR1144	Stainless Steel Surfaces	Demonstration
ETR1145	Anodized Surfaces	Demonstration
ETR1146	Painted surfaces	Demonstration
ETR1147	Colored Paint Marking	Demonstration
ETR1148	Type of Light Sources	Demonstration
ETR1149	Color of LEDs Indicating the Presence of Power	Demonstration
ETR1150	Color of LEDs Indicating Fault, Warning or Abnormal Operation	Demonstration
ETR1151	Color of LEDs Used for Purposes of Illuminating a Space	Demonstration
ETR1152	Color of LEDs Used to Indicate General Status	Demonstration
ETR1153	LED Brightness	Demonstration
ETR1154	+13.5 VDC Wire Color	Demonstration
ETR1155	–13.5 VDC Wire Color	Demonstration
ETR1156	Painting of Wires & Cables	Inspection
ETR1157	Wiring Insulation Type	Analysis
ETR1158	Connector Alignment Guides	Analysis
ETR1159	High Insertion Force Connector & Device Support	Analysis
ETR1160	High Insertion Force Connector & Device Ejectors and Tooling	Analysis
ETR1161	Metric Hardware	Demonstration
ETR1162	Hardware Labeling	Demonstration
ETR1163	Assembly Hardware – Galvanic / Corrosion Properties	Analysis

Req. ID	Name	Verify Method
ETR1164	Assembly Hardware – Electrical Properties	Analysis
ETR1165	Assembly Hardware – Strength Properties	Analysis
ETR1166	Heads and Drivers for Pan Head Screws	Demonstration
ETR1167	Heads and Drivers for Flat Head Screws	Demonstration
ETR1168	Heads and Drivers for Cap Head Screws	Demonstration
ETR1169	Hardware Retention	Demonstration
ETR1170	LRU Ease of replacement	Demonstration
ETR1171	Fastener Torque Specifications	Demonstration
ETR1172	LRU Sharp and rough edges	Demonstration
ETR1173	Engineering Dimensions	Demonstration
ETR1174	Engineering Dimension Units	Demonstration
ETR1175	Engineering Tolerances	Demonstration
ETR1176	LRU Installation Force	Test
ETR1177	LRU Installation Damage	Demonstration
ETR1178	LRU Handling	Demonstration
ETR1179	Design for Transportation	Test
ETR1180	Accessibility for adjustments & measurements	Demonstration
ETR1181	Assembly Cleaning	Inspection
ETR1182	Assembly Inspection	Inspection
ETR1183	LRU Orientation	Demonstration
ETR1184	Fasteners in Electrically Conductive Applications	Demonstration
ETR1185	RF Connector Uniqueness & Identification	Demonstration
ETR1186	Crimped Connectors	Demonstration
ETR1187	Crimped Connector Installation Standard	Demonstration
ETR1188	Surface Preparation for Painting	Demonstration
ETR1189	Bend Radius Control of Moving Cables	Demonstration
ETR1190	Torque Tooling Calibration	Inspection
ETR1191	LRU Hoist Points	Demonstration
ETR1201	Surge Protection at Building Entrances	Test
ETR1202	Cable Armoring Sheath Termination	Inspection
ETR1203	Surge Protection at Equipment I/O Entry Points	Test
ETR1204	Lightning Protection – Structure & Housings	Analysis
ETR1205	Lighting Protection of Electronics Systems	Analysis
ETR1301	Soldering and Electrical Connections	Demonstration

15 Appendix

15.1 Acronyms and Abbreviations

Acronym	Description
AC	Alternating Current
AD	Applicable Document
AIV	Assembly, Integration, and Verification
ALMA	Atacama Large Millimeter Array
ANSI	American National Standards Institute
BGA	Ball Grid Array IC package type
BOM	Bill of Materials
CAD	Computer Aided Design
CID	Configuration Item Description
COTS	Commercial Off-the-Shelf
DC	Direct Current
DoD	US Department of Defense
DSP	Digital Signal Processing or Digital Signal Processor
ECCB	Engineering Change Control Board
EMC	Electro-Magnetic Compatibility
EMP	Electro-Magnetic Pulse
ENIG	Electroless Nickel/Immersion Gold PCB plating process
ESD	Electro-Static Discharge
EU	European Union
FPGA	Field-Programmable Gate Array
FR-4	Flame Retardant Type 4 Printed Circuit Board Substrate
GFP	Government Furnished Property
HASL	Hot Air Solder Leveling PCB plating process
HVAC	Heating, Ventilation, and Air Conditioning
IC	Integrated Circuit
IEC	International Electrotechnical Commission
IPC	Institute for Interconnecting and Packaging Electronics Circuits (formerly Institute of Printed Circuits)
ISO	International Standards Organization
IUID	Item Unique Identification
JTAG	Boundary Scan test technology developed by the Joint Test Action Group
LED	Light-Emitting Diode
LEMP	Lightning Electro-Magnetic Pulse
LO	Local Oscillator
LPS	Lightning Protection System
LRU	Line Replaceable Unit
LVDS	Low Voltage Differential Signaling
LVTTL	Low Voltage Transistor-Transistor Logic IC technology
MTBF	Mean Time Between Failure
MTTR	Mean Time To Repair
M&C	Monitor and Control
NEC	US National Electrical Code

Acronym	Description
NEMA	US National Electrical Manufacturers Association
NFPA	US National Fire Protection Association
ngVLA	Next Generation VLA
NRAO	National Radio Astronomy Observatory
OLED	Organic Light-Emitting Diodes
OSHA	US Occupational Safety and Health Administration
PCB	Printed Circuit Board
PDU	Power Distribution Unit
PSOC	Programmable System On a Chip
PTC	Positive Temperature Coefficient (a type of thermistor used in circuit protection applications)
PVC	Polyvinyl Chloride
QFP	Quad Flat Pack IC Package type
RD	Reference Document
RF	Radio Frequency
RFI	Radio Frequency Interference
RFID	Radio Frequency Identification
RGB	Red Green Blue (referring to LED configuration)
RGBW	Red Green Blue White (referring to LED configuration)
RMS	Root Mean Square
RoHS	Restriction of Hazardous Substances (EU Directive 2002/95/EC)
TTL	Transistor–Transistor Logic IC technology
TVSS	Transient Voltage Surge Suppression – a semiconductor-based circuit protection device
UID	Unique Identification
UII	Unique Item Identification
UL	Underwriters Laboratories
UPS	Uninterruptible Power Supply
UV	Ultra-Violet
VAC	Volts – Alternating Current (RMS unless otherwise specified)
VDC	Volts – Direct Current
VLA	Jansky Very Large Array