Front End Technical Requirements

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Change Record

Version	Date	Author	Affected Section(s)	Reason
01	2018-07-13	W. Grammer	1–4	Initial draft version
02	2018-09-24	W. Grammer	All	Incorporate corrections from R. Selina, add additional content
03	2018-09-27	S. Durand	All	Small Edits
04	2018-10-17	W. Grammer, R. Selina	4.3, 4.4, 8.1	Added req #s in tables 4.41, 4.42; other minor edits.
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06	2018-10-25	W. Grammer, R. Selina	5.4	Added a new section on dynamic range requirements.
07	2018-11-02	W. Grammer	4.2, All	Deleted section on ngVLA project background, as directed. General cleanup and reformatting done.
08	2019-07-23	W. Grammer	All	Incorporated review comments and corrections. Added subsections on feed horns.
A	2019-07-24	A. Lear	All	Prepared document for approvals and release.

Table of Contents

1 Introduction

1.1 Purpose

This document aims to present a set of preliminary technical requirements for the initial design of the ngVLA Front End subsystem.

Many requirements flow down from the preliminary ngVLA System Requirements [AD02], which in turn are derived from the preliminary ngVLA Science Requirements [AD01].

The Science goals are presently being elaborated by the Science Advisory Council (SAC) and Science Working Groups (SWGs), and are captured in a series of use cases. A preliminary analysis of these use cases, and the flow down recursively to the science, system, and subsystem requirements, is reflected in this draft.

1.2 Scope

The scope of this document is the ngVLA Front End work package. This consists of the cryogenically cooled receiver assemblies and their associated support electronics, mounted on the ngVLA antenna. It includes interface requirements that must be defined in detail.

It should be noted that the physical extent of the Front End work package extends into other subsystems in some cases: one example is that it includes the displacer cylinder from the cryocooler as part of the cryostat assembly, but not the displacer and motor subassemblies. Other examples of this are detailed later in this document.

This requirements document establishes the performance, functional, design, and test requirements applicable to the ngVLA Front End work package.

2 Related Documents and Drawings

2.1 Applicable Documents

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

Reference No.	Document Title	Rev/Doc. No.
AD01	Science Requirements	020.10.15.00.00-0001-REQ
AD02	Preliminary System Requirements	020.10.15.10.00-0003-REQ
AD03	Environmental Specifications	020.10.15.10.00-0001-SPE
AD04	Operations Concept	020.10.05.00.00-0002-PLA
AD05	Protection Against Electric Shock – Common Aspects for Installation and Equipment	IEC 61140:2016
AD06	Insulation Coordination for Equipment within Low-Voltage Systems	IEC 60664
AD07	Occupational Safety and Health Standards for General Industry	29 CFR Part 1910
AD08	Military Handbook, Reliability Prediction of Electronic Equipment	MIL-HDBK-217F
AD09	Non-Electronic Parts Reliability Data	NPRD-95
AD10	Electromagnetic Compatibility	IEC 61000-3-5
AD11	Subsystem Reference Design Description for Monitor & Control Hardware Interface Layer	020.30.45.00.00-0004-DSN
AD12	DC Power Supply Reference Design Description	020.30.50.00.00-0002-DSN
AD13	EMC & RFI Mitigation Requirements	020.10.15.10.00-0002-REQ

2.2 Reference Documents

The following references provide supporting context:

Reference No.	Document Title	Rev/Doc. No.
RD01	Front End Reference Design Description	020.30.05.00.00-0003-DSN
RD02	D. Gajewski et. al., "Reliability of GaN/AlGaN HEMT MMIC Technology on 100-mm 4H-SiC", 26th Annual JEDEC ROCS Workshop, Indian Wells, CA, May 2011	
RD03	"Multiple Uses of Model 22C/350C Cryodyne Refrigerators: Installation, Operation and Servicing Instuctions", Helix Technology Corporation, July 2002, page G-3	Doc. # 8040272, Rev. 100 Dwg. # 3695576, Rev. C
RD04	L. Baker, "Analysis of ngVLA Design #6 with Ideal and Actual Feed", 8 January 2018	020.25.01.00.00-0001-REP

3 Overview of the Front End Technical Requirements

3.1 Document Outline

This document presents the technical requirements of the ngVLA Front End work package. These parameters determine the overall form and performance of the Front End work package.

The functional and performance specifications, along with detailed explanatory notes, are found in Section 4. The notes contain elaborations regarding the meaning, intent, and scope of the requirements. These notes form an important part of the definition of the requirements and should guide the verification procedures. In many cases, the notes contain an explanation or an analysis of how the numeric values of requirements were derived.

Where numbers are not well substantiated, this is also documented in the notes. In this way, the required analysis and trade-space available is apparent to scientists and engineers who will guide the evolution of the ngVLA Front End concept.

Requirements pertinent to interfacing systems are described in Section 5. Initial requirements are noted by interface, along with identified parameters for Interface Control Documents (ICDs) that will fully define the interfaces as the design progresses.

Safety requirements applicable to both the design phase and the functional Front End are described in Section 7. Additional requirements for the design phase are described in Section 8. Documentation requirements for both technical design documentation and software are provided in Section 9.

Requirements for the Verification and Test, from the conceptual design through to prototype, are described in Section 10. Section 11 identifies Key Performance Parameters (KPP) that should be estimated and monitored throughout the design phase. These are metrics to assist in the trade-off analysis of various concepts, and help identify and resolve tensions between requirements as the design progresses.

3.2 General Front End Description

The ngVLA will provide near-continuous frequency coverage from 1.2–116 GHz in multiple bands, with a gap at the atmospheric absorption band between ~50–70 GHz. The primary design goals are maximizing sensitivity for each band while also minimizing the overall operating cost. Therefore, receivers and feeds will be cryogenically cooled, with multiple bands integrated into a common cryostat to the greatest extent possible. Using feed designs that yield broad bandwidths and high aperture efficiencies are key to meeting these goals.

The proposed receiver configuration [RD01] will be implemented as six independent bands, each with its own feed. The upper five bands will be integrated into a single compact cryostat, while the lowest-frequency band occupies a second cryostat of similar volume and mass. Components within the cryostats are cryogenically cooled for optimum noise performance.

3.3 Summary of Front End Requirements

The following table provides a summary of the major subsystem requirements, in order to provide the reader with a high-level view of the Front End. Should there be a conflict between the requirements listed here and the descriptions in Sections 4 through 10, the latter shall take precedence.

3.3.1 General Functional Specifications

Parameter	Req. #	Summary of Requirement	Traceability
Frequency Coverage	FE0001	1.2–116 GHz continuous, with a gap between 50.5–70 GHz	SYS0801
Frequency Band Overlap	FE0002	1% minimum, at band edges	SYS0806
Output Polarization Type	FE0003	Dual orthogonal	SYS0102
Number of Pixels/Receiver Band	FE0004	One	(TBD)
Number of Receiver Bands	FE0005	Maximum of 6	(TBD)
Number of Cryostats/Cryocoolers	FE0006	Maximum of 2	(TBD)

3.3.2 Other General Requirements

Parameter		Summary of Requirement	Traceability
Mass, Cryostat A	FE0007	74 kg max., including cryocooler	(TBD)
Mass, Cryostat B	FE0008	89 kg max., including cryocooler	(TBD)
Total Mass (Service Limit)	FE0009	163 kg, max.	(TBD)

4 Front End Functional and Performance Requirements

These requirements apply to a properly functioning system under the normal operating environmental conditions unless otherwise stated.

4.1 RF Frequency Ranges

The specified frequency range is the minimum over which the sensitivity and gain requirements defined for that band are met. Bandpass shape and precisely defined band edges are not critical for the Front End; bands may overlap.

Parameter	Req. #	Value	Traceability
Band 1 Frequency Range	FE0101	1.2–3.5 GHz	IRD0711
Band 2 Frequency Range	FE0102	3.5–12.3 GHz	SYS0801–0806
Band 3 Frequency Range	FE0103	12.3–20.5 GHz	SYS0801–0806
Band 4 Frequency Range	FE0104	20.5–34 GHz	SYS0801–0806
Band 5 Frequency Range	FE0105	30.5–50.5 GHz	SYS0801–0806
Band 6 Frequency Range	FE0106	70–116 GHz	SYS0801–0806

4.2 Sensitivity Requirements

Receiver noise temperatures shall be measured using the Y-factor method, taken at the frequency intervals specified in the table for each band. The average given is an overall unweighted average of all values, across the full band. Maximum limit is typically at the band edges, over a single interval.

Parameter	Req. #	Value	Traceability
Band 1 Noise Temperatures	FE0201	10.9 K average, 13.8 K maximum, 25 MHz meas. interval	SYS1011
Band 2 Noise Temperatures	FE0202	14.2 K, average, 15.5 K maximum, 100 MHz meas. interval	SYS1011–1012
Band 3 Noise Temperatures	FE0203	15.8 K, average, 18.6 K maximum 100 MHz meas. interval	SYS1012
Band 4 Noise Temperatures	FE0204	16.6 K, average, 19.5 K maximum 100 MHz meas. interval	SYS1012
Band 5 Noise Temperatures	FE0205	22.4 K, average, 26.5 K maximum 200 MHz meas. interval	SYS1012
Band 6 Noise Temperatures	FE0206	52.4 K, average, 72.6 K maximum 500 MHz meas. interval	SYS1013

4.3 Feed Horn Performance Requirements

Feed horn specifications are derived from electromagnetic and physical optics simulations. For calculation of overall aperture efficiency, the antenna optics are included in the simulation [RD04]. The Band 1 and 2 feeds are wideband ridged types, while the Band 3–6 feeds are axially corrugated types.

Parameter	Req. #	Value	Traceability
Beam Subtended Angle, Bands 1–6	FE0301	55 degrees, nom., @ –16 dB edge taper, all planes	ANT0204
Band 1–2 Aperture Efficiency	FE0311	0.80 avg. total, excluding Ruze (surface)	(TBD)
Band 1–2 Side Lobe Levels	FE0312	–20 dB max., all planes	(TBD)

Parameter	Req. #	Value	Traceability
Band 1–2 Cross Polarization	FE0313	–20 dB max., all planes	(TBD)
Band 1–2 Return Loss	FE0314	–15 dB max.	(TBD)
Band 3–6 Aperture Efficiency	FE0321	0.85 avg. total, excluding Ruze (surface)	(TBD)
Band 3–6 Side Lobe Levels	FE0322	–30 dB max., all planes	(TBD)
Band 3–6 Cross Polarization	FE0323	–30 dB max., all planes	(TBD)
Band 3–6 Return Loss	FE0324	–20 dB max.	(TBD)

4.4 Gain Requirements

The minimum Front End gain requirement stems from a need to reduce noise contributions from subsequent signal amplification and down-conversion stages to <1K of total system noise temperature.

Gain is specified as between the input of the feed horn and the output connector on the cryostat bulkhead. The gain ripple and slope requirements are derived from the system-level requirement of 3 dB for each. The system requirement includes contributions from both the Front End and IRD subsystems, but no budget for sharing this allowance across them has been established.

Tentatively, therefore, 20% of the overall budget (0.6 dB) has been allocated to the Front End. The remaining 80% (2.4 dB) is allocated to the IRD subsystem, given it has twice as much analog gain and several added lossy signal-conditioning components in its cascade.

Parameter	Req. #	Value	Traceability
Gain, Bands 1–6	FE0401	30 dB, minimum	SYS1011–1013
Gain Stability, Bands 1–6	FE0402	Maximum change < 0.01 dB, over 1 hour	SYS1701, SYS4901–4902
Gain Ripple, Bands 1–6	FE0403	<0.6 dB peak-to-peak (TBC)	SYS1702
Gain Slope, Bands 1–6	FE0404	<0.6 dB, over 80% BW (TBC)	SYS1703

4.5 Dynamic Range Requirements

Parameter	Req. #	Value	Traceability
Input Dynamic Range	FE0501	30 dB min., 50 dB goal	SYS1201
Gain Calibrator Dynamic Range	FE0502	30 dB	SYS1202
Input Power Damage Threshold	FE0503	+10 dBm, avg. (TBC)	SYS1204

4.6 Cryogenic Cooling Requirements

Parameter	Req. #	Value	Traceability
Cryostat A 1st Stage Loading	FE0601	20W max., 80 K stage temp	
Cryostat A 2st Stage Loading	FE0602	5W max., 20 K stage temp	
Cryostat B 1st Stage Loading	FE0611	20W max., 80 K stage temp	
Cryostat B 2nd Stage Loading	FE0612	5W max., 20 K stage temp	

4.7 Spurious Signals/Radio Frequency Interference Generation

The Front End subsystem shall conform to the system EMC and RFI requirements outlined in [AD13].

4.8 Environmental Conditions

4.8.1 Normal Operating Conditions

Parameter	Req. #	Value	Traceability
Temperature (outside)	FE0801	–15 C ≤ T ≤ +35 C	ENV0323
Temperature Rate of Change	FE0802	< 3.6 °C per hour	ENV0324
Altitude	FE0803	Max. 2500 meters	ENV0351

4.8.2 Specific Environmental Requirements

Except for the exposed radome/vacuum window on Cryostat A, the Front End subsystem components will be located entirely within a weather-tight enclosure with temperature regulation. Other than the requirements below, details about this enclosure are beyond the scope of this document.

Parameter	Req. #	Value	Traceability
Temperature (inside)	FE0811	+20 C ≤ T ≤ +30 C	
Temperature Rate of Change	FE0812	< 1 °C per hour	

4.9 Maintenance and Reliability Requirements

The maintenance and reliability requirements support high-level requirements that limit the array's total operating cost. For the antenna electronics system as a whole, approximately half of the MTBF budget for the antenna itself (~17,500 hrs.) is assumed.

The dominant maintenance driver for the antenna electronics is likely to be the cryocooler, as on the VLA. It is estimated to have an MTBF of ~six years, assuming a continuous, average running speed of 40 Hz. Given there will be two basically identical cryocoolers per antenna, the net MTBF is therefore three years, which is actually less than what is currently specified for the entire antenna electronic system. However, the actual MTBF in practice will depend on how often the cryocoolers are exchanged during scheduled periodic maintenance. If this is less than three years, the effective MTBF will be longer. This in turn will determine what fraction of the overall antenna electronic system MTBF can be allocated for the Front End and other antenna electronic subsystems.

The intrinsic reliability of the Front End is difficult to estimate due to a lack of reliability data for the cryogenic LNAs under controlled conditions. Life tests of comparable MMIC technology [RD02] indicate the MTBF should be well into the tens of millions of hours. Given the low power and low temperatures inherent in our receivers, intrinsic device reliability would likely be even higher. However, overall LNA reliability will be drastically reduced due to the temperature cycling they are subject to, when a cryocooler needs to be exchanged, or due to a power failure or vacuum loss that causes a warmup. The failure mechanism here is mechanical, usually a broken or loosened bond wire to the MMIC chip. Reliability is again hard to predict, but from the observed failure rate of VLA LNAs, and accounting for a ~3.5-fold reduction in the number of bonds for an equivalent MMIC, the MTBF of the ngVLA Front End with 14 MMIC LNAs works out to roughly 100,000 hours. See the Appendix for details of this analysis.

Monitor points or sensors should be included in the MTBF/MTTR analysis, but sensors and other components that can be reasonably deemed to be ancillary to operation may be removed from the determination of compliance with the MTBF requirement.

"Failure" will be defined as a condition that places the system outside of its performance specifications or into an unsafe state, requiring repair.

Parameter	Req. #	Value	Traceability
Antenna Electronics MTBF	(TBD)	≥35,000 hrs. (4 years)	SYS2402
Front End Subsystem MTBF	FE0901	≥100,000 hrs. (~12 years)	

4.10 Monitor and Control Requirements

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

Other features of the M&C interface are to be specified in the Monitor and Control ICD.

Parameter	Req. #	Value	Traceability
Self-Monitoring	FE1001	The Front End shall measure, report and monitor a set of parameters that allow for determination of its status and may help predict or respond to failures.	SYS2601

4.11 Lifecycle Requirements

Lifecycle costs include manufacturing, transportation, construction/assembly, operation and decommissioning.

Parameter	Req. #	Value	Traceability
Design Life	FE1101	The Front End shall be designed to be operated and supported for a period of 20 years.	SYS2801
Lifecycle Optimization	FE1102	The Front End design shall minimize its lifecycle cost for 20 years of operation.	SYS2802

5 Interface Requirements

This section describes Front End interfaces. Interface Control Documents (ICDs) are required between the Front End and all connecting systems. In many cases, specifications for the interfaces are not yet available, but the broad scope of the ICDs can be defined.

These interfaces shall be developed and documented by the Front End Designer and approved by ngVLA as part of the Front End reference and conceptual design efforts, and updated throughout the design. Post CoDR, the ICD shall only be updated through formal project change control processes.

5.1 Interface to the Power Supply Subsystem

The Power Supply Subsystem provides DC voltages required by the Front End electronics, packaged in modules F512 and F522 [AD05]. Voltages and currents supplied are: +32.5V @0.5A, +17.5V @6A, +7.5V @0.5A, and –7.5V @0.1A, from the P501 power supply module [AD12].

The electromechanical interface details are presently undefined. However, it will likely consist of a single multi-pin round, twist-lock, or threaded connector interface, like those widely used by the US military (e.g., MIL-DTL-26482, MIL-DTL-38999, MIL-DTL-22992). These are highly rugged, weather-tight, and reliable, with a multitude of pin sizes and counts available at moderate cost. Location is likely to be on the rear panel of the F521 and F522 electronics modules.

5.2 Interface to the Cryogenic Subsystem

The cryocooler unit consists of two parts: a drive motor/valve/displacer assembly, and a polished steel cylinder that slides over the displacers. The cylinder is the mechanical interface for both cold stages, and is an integral part of the cryostat assembly. The displacer assembly is external to the cryostat and removable, and is considered part of the cryogenic subsystem. The interface between these parts is an interface plate or flange pattern that allows a gas-tight seal and properly aligns the two parts. Figure 1 presents a mechanical drawing of this interface pattern [RD03].

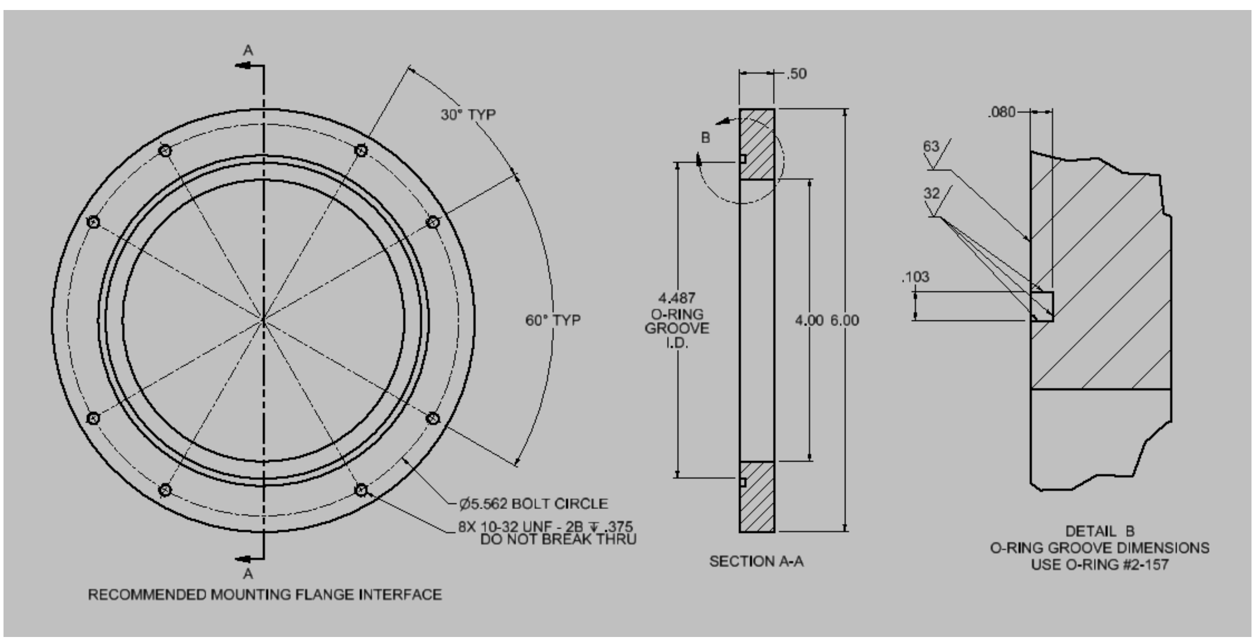

Figure 1 - Cryocooler displacer mechanical interface.

5.3 Interface to the Integrated Receivers and Downconverters (IRD) Subsystem

The IRD subsystem module will be mounted in close proximity to Cryostat B to keep the RF interconnects to it as short as possible. It might even be feasible to bolt them directly together, using blind-mate connectors instead of cables/waveguides, but this will be decided later on. Longer armored cables will be used to connect the Band 1RF outputs of the Cryostat A to the IRD module.

The table below shows the type and number of RF interconnects with the Front End subsystem. The physical locations and outlines of the connectors are still TBD.

Signal at Interface	Type	Parameter	Value
Band 1 RF	Output	Connector	SMA (F)
		Impedance	50 Ω
		Number	2 (one per pol.)
Band 2 RF	Output	Connector	SMA (F)
		Impedance	50 Ω
		Number	2 (one per pol.)
Band 3 RF	Output	Connector	2.92 mm (F)
		Impedance	50 Ω
		Number	2 (one per pol.)
Band 4 RF	Output	Connector	2.92 mm (F)
		Impedance	50 Ω
		Number	2 (one per pol.)
Band 5 RF	Output	Waveguide size	WR-22 (UG599)
		Number	2 (one per pol.)
Band 6 RF	Output	Waveguide size	WR-10 (UG387)
		Number	2 (one per pol.)

5.4 Interface to the Antenna Subsystem

A dual offset-Gregorian optical configuration for the antenna is assumed. The key interface specification is the subtended angle of the subreflector at the secondary focal point, which drives the design of all feed horns, and the physical size of the cryostats as well.

The Front End cryostat assemblies will be mounted at the secondary focus of the antenna, on a platform attached to the feed arm structure. The platform will include an X-Y axis motorized positioner for focusing and band selection and the temperature-controlled enclosure.

Figure 2 shows a rendering of the mounting concept, which will be the same for both the 18-meter and 6-meter antennas. Detailed mechanical interface drawings are pending completion of the antenna design.

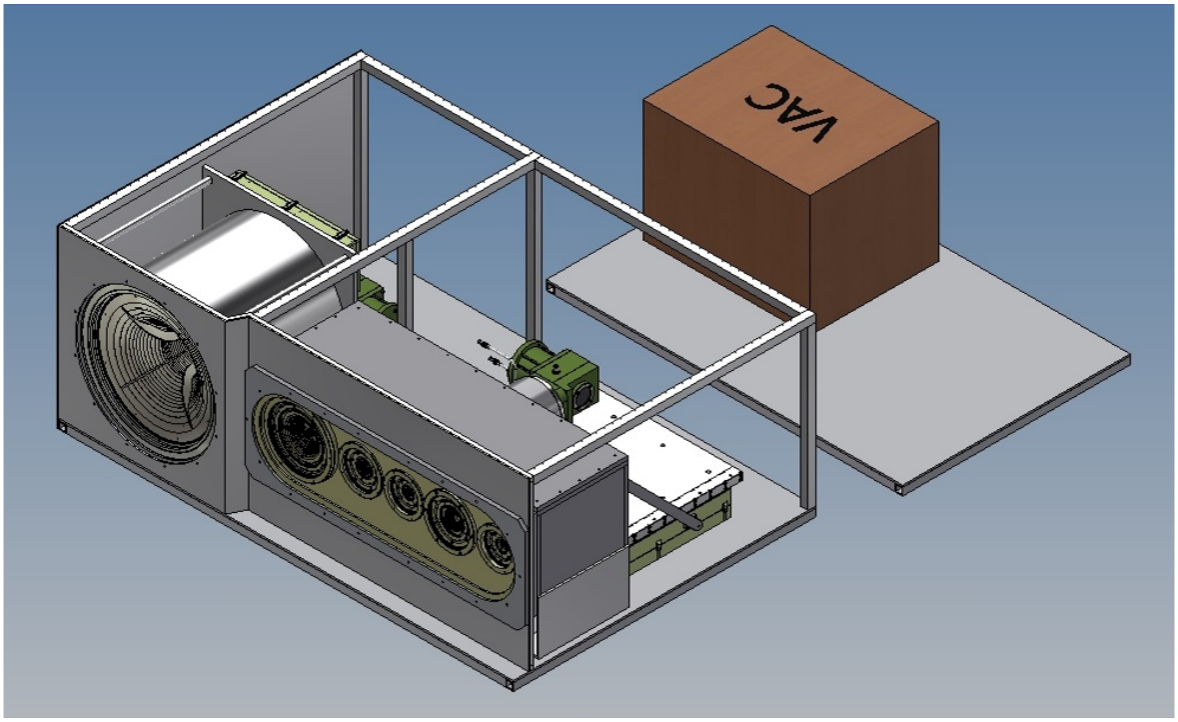

Figure 2 - Front End subsystem enclosure, opened to show cryostats and IRD assembly.

Parameter	Req. #	Value	Traceability
Feed Subtended Half Angle	FE0301	55° between the optical axis and edge of the subreflector, at the secondary focus	ANT0204

5.5 Interface to the Monitor and Control Subsystem

The two Front End cryostat assemblies presently contain only RF electronics. All the analog support electronics for Cryostats A and B are packaged within two external modules, referred to as F521A and F521B, respectively. These will be located inside the platform enclosure on the antenna feed arm, in close proximity to the cryostats. The support electronics provide the following functions:

- DC bias/driver circuitry for LNAs, noise calibrator sources, and other active components,
- RF output control/leveling for the noise calibrator sources,
- Input signal conditioning from the cryostat vacuum and temperature sensors, and
- Driver circuitry and current monitoring for the cryostat vacuum solenoid valve.

Electrical connection to the cryostats is assumed to be via multi-conductor shielded cables, with a bulkhead receptacle/cable plug pair at each end. Specific details are undefined at present; however, these will likely consist of single, multi-pin round, twist-locking connector interfaces, with a hermetic glass seal for contacts on the cryostat receptacle side, to maintain vacuum integrity.

It may be feasible, and even desirable, to integrate some or all of the support electronics into their respective cryostats, but for now are they are assumed to be separate assemblies.

The Cryo and LNA Monitor and Control (M&C) module (designated F520) contains the MIB, or Monitor and Control Interface Board, which provides the communications link to the monitor and control subsystem. The F522 is similar to the F521A/B but also provides control electronics for the vacuum pump common to both cryostats [AD11].

6 Subsystem Requirements

Derivation of any subsystem requirements shall be included as part of the Front End reference and conceptual design efforts and updated throughout the design. Post CDR/FDR, the subsystem requirements shall only be updated through formal project change control processes, which will include the designer, manufacturer, and NRAO.

7 Safety

7.1 General

In general, the Front End subsystem is fairly benign from a safety standpoint, posing a low risk of injury to personnel or damage to other equipment.

7.2 Safety Design Requirements

7.2.1 Fire Safety

There are no combustibles, flammable liquids or gases in the Front End subsystem.

7.2.2 Vacuum Safety

Because the cryostats will usually be under vacuum while in storage or transport, there is a potential implosion hazard if one of the large cryostat windows or radomes is breached. The chance of this is low, and will be minimized by proper design, and handling protocols during shipment or installation.

7.2.3 Mechanical Safety

There are no external exposed moving parts, or known pinch points that could cause injury.

7.2.4 Electrical Safety

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

7.2.5 Handling, Transport, and Storage Safety

The design of the Front End shall incorporate all means necessary to preclude or limit hazards to personnel and equipment during assembly, disassembly, test, and operation. These cryostat radomes and windows are fairly robust, but nevertheless must be protected from any impact or abrasion, to minimize the chance of breakage and possible injury to personnel from flying debris.

Moderate care must be exercised when removing or installing the Front End cryostat assemblies, as they are heavy, and can be damaged if dropped more than a few centimeters. A lifting device or small hoist is recommended for installation and removal of the cryostats. As needed, lift points shall be designed into the equipment, and clearly labeled.

8 Requirements for Design

8.1 Analyses and Design Requirements

8.1.1 Reliability Availability Maintainability Analysis

A Reliability Availability Maintainability analysis shall be performed to locate weak design points and determine whether the design meets the Maintenance and Reliability requirements. To this end, the Parts Count Method for predicting reliability of the system can be applied, as described in the MIL-HDBK-217F [AD08], but the designer may propose to use other methods. For non-electronic parts, the values of NPRD-95 [AD09] or data from manufacturers or other databases may be used.

Another, more time consuming (and considered more accurate) method, the Parts Stress Analysis Prediction, is also described in [AD08]. This may be used if the result of the Parts Count Method does not comply with the Maintenance and Reliability requirements.

The ngVLA equipment will typically operate at an elevation of 2200m 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 [AD08]. The analysis shall result in estimates of the Mean Time Between Failures (MTBF), the Mean Time To Repair (MTTR), assuming that any scheduled preventive maintenance is performed.

8.2 Electromagnetic Compatibility Requirements

The ngVLA Front End element shall exhibit complete electromagnetic compatibility (EMC) among components (intra-system electromagnetic compatibility).

8.3 Materials, Parts, and Processes

8.3.1 Fasteners

All fasteners shall be metric except those that are on off-the-shelf units. The use of standard metric cross-sections for construction materials is preferred but not required.

8.3.2 Paints

Any painted coatings shall be chosen to last at least 20 years without repainting.

8.3.3 Surface Treatment

Any unpainted surfaces shall be treated against corrosion.

8.3.4 Name Plates and Product Marking

As a general rule the main parts and all exchangeable units shall be equipped with nameplates which are visible after installation of the part/unit and which contain the following information:

- Part/unit name
- Drawing number including revision
- Serial number
- Manufacturing month and year
- Name of manufacturer

Alternatively, a system of marking based on barcodes or the like may be used upon approval by ngVLA.

For Line Replaceable Units (LRUs), it is highly desirable that the serial number of the unit be ascertainable over the monitor and control interface.

8.3.5 Labels

All cables and switches, junction boxes, sensors, and similar equipment shall be labeled.

9 Documentation Requirements

9.1 Technical Documentation

All documentation related to the Front End shall meet the following requirements:

- The language used for written documentation shall be English.
- Drawings shall be generated according to ISO standards and use metric units.
- Layouts of electronic circuits and printed circuit boards shall also be provided in electronically readable form. The ngVLA preferred formats are Altium Designer files for electronic circuit diagrams and printed circuit board layouts.
- The electronic document formats are Microsoft Word and Adobe PDF.
- The preferred CAD system used is AutoDesk Inventor and/or AutoCAD.

Any deviation from the above shall be agreed to by ngVLA.

9.2 Software and Software Documentation

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

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

10 Verification and Quality Assurance

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

Verification by Design: The performance shall be demonstrated by a proper design, which may be checked by the ngVLA project office during the design phase by review of the design documentation.

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 item is determined by a simple inspection or measurement.

Verification by Factory Acceptance Test: The compliance of the developed item, assembly, or unit with the specified performance shall be demonstrated by tests. A FAT is performed without integration with interfacing systems.

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

Multiple verification methods are allowed.

The following table summarizes the expected verification method for each requirement.

Req. #	Parameter/Requirement	D	A	I	FAT	SAT
FE0101-0106	Frequency Range, Bands 1–6				X	
FE0201-0206	Noise Temperatures, Bands 1–6				X	
FE0311, 0321	Overall Aperture Efficiency	X	X			
FE0312-0313 FE0322-0323	Feed Horn Radiation Pattern	X	X			
FE0314,0324	Feed Horn Return Loss				X	
FE0401	Gain, Bands 1–6				X	
FE0402	Gain Stability, Bands 1–6				X	
FE0601-0612	Cryocooler Thermal Loading	X	X			
FE0901	Front End Subsystem MTBF	X	X			
FE1101	Design Life	X				

11 Key Performance Parameters

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

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

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

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

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

Key Performance Parameter	Req.
Receiver Noise Temperature	FE0201-0206
Overall Aperture Efficiency	FE0311, 0321
Feed Horn Performance (side lobes, cross polarization, return loss)	FE0312-0314 FE0322-0324
Cryostat Masses	FE0007-0009
Cryocooler Thermal Loading	FE0601-0612
Mean Time Between Failures	FE0901

11.1 Maintenance Definitions

11.1.1 Maintenance Approach

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

LRU exchange shall be possible by two trained people within four working hours. It is desirable that LRU replacement be possible using only standard tools identified in a maintenance manual for the Front End. A step-by-step procedure for safe exchange of every LRU shall be provided in the Maintenance Manual.

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

11.1.2 Periodic Preventive Maintenance

Preventive maintenance may be performed at planned intervals to keep the Front End operational and within its specified performance. Any required preventive maintenance should be documented in the Maintenance Manual.

12 Appendix

12.1 Abbreviations and Acronyms

Acronym	Description
AD	Applicable Document
CAD	Computer Aided Design
CDR	Critical Design Review
CoDR	Conceptual Design Review
EMC	Electro-Magnetic Compatibility
FAT	Factory Acceptance Test
FDR	Final Design Review
ICD	Interface Control Document
IRD	Integrated Receiver Downconverter/Digitizer
KPP	Key Performance Parameters
LNA	Low Noise Amplifier
LRU	Line Replaceable Unit
MIB	Monitor/Control Interface Board
MMIC	Monolithic Microwave Integrated Circuit
MTBF	Mean Time Between Failure
MTTR	Mean Time To Repair
M&C, M/C	Monitor and Control
ngVLA	Next Generation VLA
RD	Reference Document
RFI	Radio Frequency Interference
SAT	Site Acceptance Test
TBD	To Be Determined
VLA	Jansky Very Large Array

12.2 MTBF Estimation for ngVLA Front End

1. EVLA LNA Failure Rate, from March 2013 to September 2018 (5.5 years)

Year	# repairs*
2013	10
2014	6
2015	17
2016	6
2017	10
2018	5
TOTAL:	**54**

* Excludes LED failures, upgrades

Active Antennas:	**27**
Cryo LNAs per antenna:	**16**
Total LNAs:	**432**
Duration (yrs):	**5.5**
Duration (hrs):	**48,213**

Failure Rate (/hr-LNA):	**2.593E-06**
MTBF (hrs):	**3.857E+05**

2. Predicted ngVLA MMIC LNA MTBF (1 antenna):

Failure reduction factor:	**3.6**	(relative wire bond count)
MMIC LNAs per antenna:	**14**	(2 ea, Bands 1–5; 4 on Band 6)

Failure Rate (/hr-Ant):	**1.008E-05**
MTBF (hr-Ant):	**9.918E+04**