Environmental Control Requirements Specification

020.30.60.00.00-0001-REQ

Status: **RELEASED**

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Change Record

Version	Date	Author	Affected Section(s)	Reason
A	2022-05-19	S. Sturgis, J. Allison, D. Urbain	All	Release for the Reference Design, following an internal review
B	2022-06-10	S. Sturgis	All	Release for the System CDR, incorporating changes according to the RIDS from a formal internal review

Table of Contents

1 Introduction

1.1 Purpose

This document presents the complete set of Level 2 subsystem requirements that guide the design and development of the Electronics Environmental Control (EEC) subsystem for the 18m antenna. Requirements described in this document are derived from applicable ngVLA System Requirements and System-Level Specification documents as listed in the Applicable Documents table. The engineering process and requirements hierarchy that govern this specification are defined in [AD01] and [AD02] respectively.

The content of these requirements is at the subsystem level, conforming to the system architecture [AD06], but aims to be implementation agnostic within the subsystem boundaries. Some assumptions about the subsystem may be given, but only to the degree necessary to unambiguously define the subsystem requirements.

1.2 Scope

The scope of this document is the specification of the Environmental Control Subsystem, configuration item number 020.30.60, of the ngVLA system. This includes:

- Assumptions on which the requirements are based.
- Environmental conditions to be used in the definition of requirements.
- A complete set of requirements for the subsystem needed for the development, operation and maintenance of the subsystem, including interface requirements that are derived from the applicable list of ICDs.
- Numbering of all requirement and establishment of traceability to higher level requirements.
- Verification requirements and their traceability to the subsystem main requirements.
- Identification of Key Performance Parameters (KPPs) at the subsystem level.

The Level 2 Subsystem Requirements, along with detailed explanatory notes, are found in Section 7. The notes contain elaborations regarding the meaning, intent, and scope of the requirements. These notes form an important part of the definition of the requirement. In many cases, the notes contain an analysis of how the numeric values of requirements were derived to ensure correct interpretation of the requirements and to resolve ambiguity.

In cases where the requirements analysis is incomplete, such values are marked with TBD or TBC, which need to be resolved before the final requirements are published.

2 Related Documents and Drawings

2.1 Applicable Documents

The following documents apply to this Requirements Specification to the extent specified. In the event of a 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 for design elaboration and verification.

Ref. No.	Document Title	Rev./Doc. No.
AD01	ngVLA Systems Engineering Management Plan	020.10.00.00.00-0001-PLA
AD02	ngVLA Requirements Management Plan	020.10.15.00.00-0001-PLA
AD03	ngVLA System Requirements	020.10.15.10.00-0003-REQ
AD04	L1 System Environmental Specifications	020.10.15.10.00-0001-SPE
AD05	L1 System EMI/RFI Requirements	020.10.15.10.00-0002-REQ
AD06	System-Level Architecture Model	020.10.20.00.00-0002-DWG
AD07	L1 Safety Specification	020.80.00.00.00-0001-REQ
AD08	L1 Security Specification	020.80.00.00.00-0003-REQ
AD09	ngVLA Electronics Specifications	020.10.15.10.00-0008-REQ
AD10	BMR Conceptual Design Description	020.30.55.00.00-0002-DSN
AD11	ngVLA Antenna and Equipment HVAC Specification	1021006-SPE-21-00000-001
AD12	Combined Antenna Power Budget Analysis	1021006-ANA-21-00000-005

2.2 Applicable ICDs

The following ICDs define the external boundary of this subsystem and are applicable to its specification:

Ref. No.	Document Title	Rev./Doc. No.
AD20	ICD: Integrated Receiver Digitizer (IRD) to Environmental Control (EEC)	020.10.40.05.00-0003
AD21	ICD: Power Supply (PSU) to Antenna Electronics	020.10.40.05.00-0006
AD22	ICD: Antenna Electronics (ANTELEC) to Main Antenna (ANT)	020.10.40.05.00-0011
AD23	ICD: Antenna Electronics (ANTELEC) to Short Baseline Array (SBA)	020.10.40.05.00-0032
AD24	ICD: Front End (FED) to Environmental Control (EEC)	020.10.40.05.00-0017
AD25	ICD: Water Vapor Radiometer (WVR) to Environmental Control (EEC)	020.10.40.05.00-0024
AD26	ICD: Antenna Electronics (ANTELEC) and Bins Modules and Racks (BMR)	020.10.40.05.00-0040
AD27	ICD: Antenna Electronics (ANTELEC) and Antenna Fiber Distribution (AFD)	020.10.40.05.00-0041
AD28	ICD: Cryogenics (CRY) to Environmental Control (EEC)	020.10.40.05.00-0045
AD29	ICD: Hardware Control and Interface Layer (HIL/MCL) to Environmental Control (EEC)	020.10.40.05.00-0066
AD30	ICD: LO Reference & Timing Distribution (RTD) to Environmental Control (EEC)	020.10.40.05.00-0069

AD31	ICD: Antenna Timing and Frequency (ATF) and Environmental Control (EEC)	020.10.40.05.00-0070
AD32	ICD: DBE to EEC	020.10.40.05.00-0127

3 Overview of Subsystem

3.1 Subsystem boundary, context, external interfaces, and product breakdown

The EEC subsystem provides temperature and humidity regulation of the antenna electronics at the different locations on the antenna. The various components are shown in the decomposition in Figure 3.

The purpose of the ECC is to control the temperature of the various active components across the antenna, and regulate the air temperature inside the pedestal. A chiller will feed propylene glycol to a series of heat exchangers (evaporators) to control the air temperature in various locations inside the antenna structure, while cold plates will be used to cool cryogenic equipment and various electronics modules on the antenna feed-arm. Because the antenna is a moving structure, the pump that circulates the glycol to the cold plates on the feed-arm will have to be able to change speed to maintain a steady pressure in the supply lines. The variations in environmental conditions (ambient temperature, sun exposure and wind for example) will change the heat load on the antenna structure and consequently the total heat load seen by the chiller. To account for a variable heat load, the compressor will have to modify its speed to maintain a constant glycol temperature. At the subassembly level (cold plate), if the thermal load varies the flow of glycol will have to be adjusted to maintain the required temperature. However, the electronics modules that can tolerate a broad range of operating temperatures will see a fixed flow of glycol. The flow will be set to absorb the highest thermal load seen by the module and maintain the temperature below the upper limit of the operating range.

The second subsystem encompassed by EEC is the Front End enclosure dry-air that will be used to reduce the humidity level of the inside air to prevent formation of condensation on the cryostats vacuum windows and the enclosure radome. The presence of even a very thin layer of water on those surfaces would attenuate the astronomical signal and degrade the Front End.

Note: While not always specified in the text, the EEC will use exclusively a mixture of water and propylene glycol as the cooling liquid due to its non-toxicity.

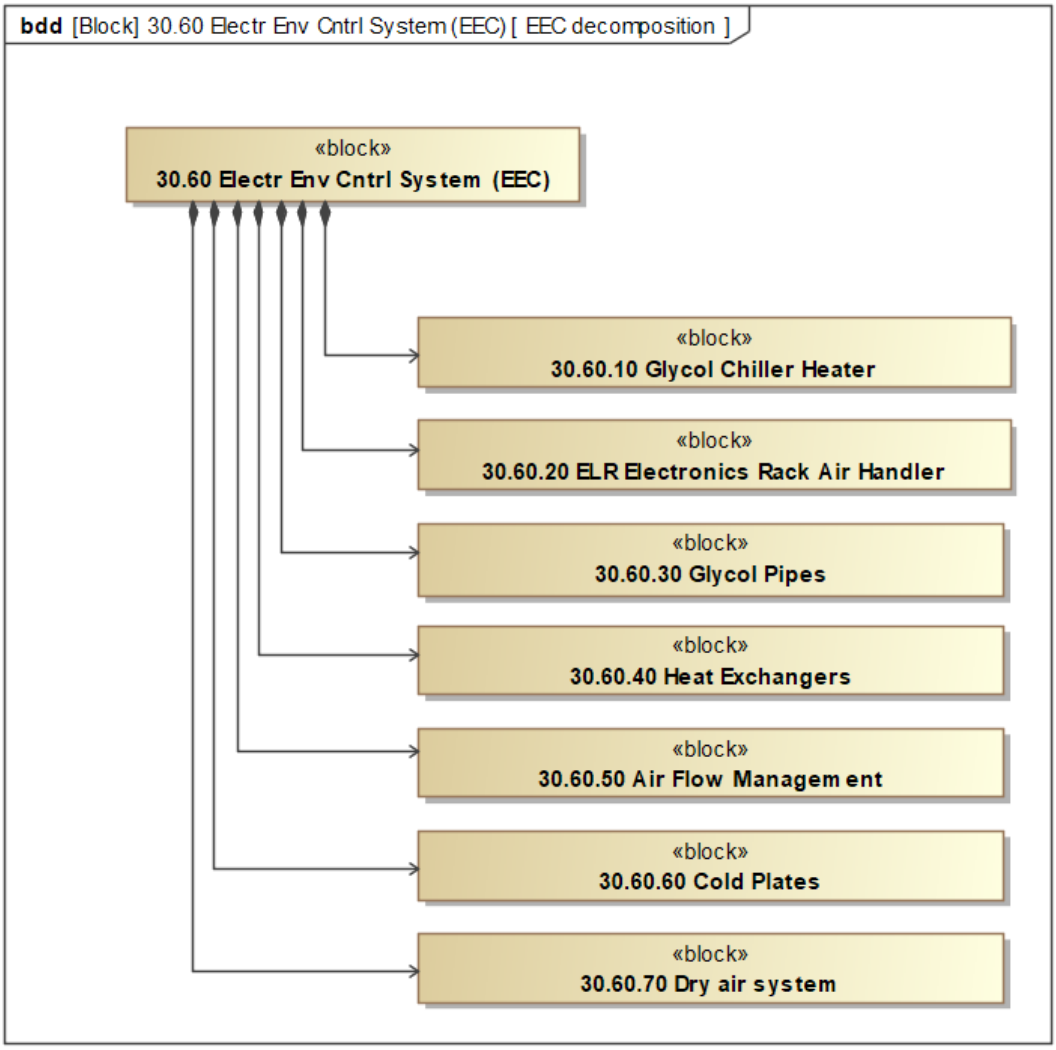

Figure 1. Electronics Environmental Control decomposition diagram

The external interfaces of EEC are shown in Figure 2 below. The EEC interfaces with:

a) Antenna Electronics that are housed inside the modules/enclosures.
b) Antenna: including mechanical interfaces for the glycol piping and AC power connections, and space for glycol hoses in Azimuth and Elevation Wraps.
c) Antenna: shared use of the glycol chiller.

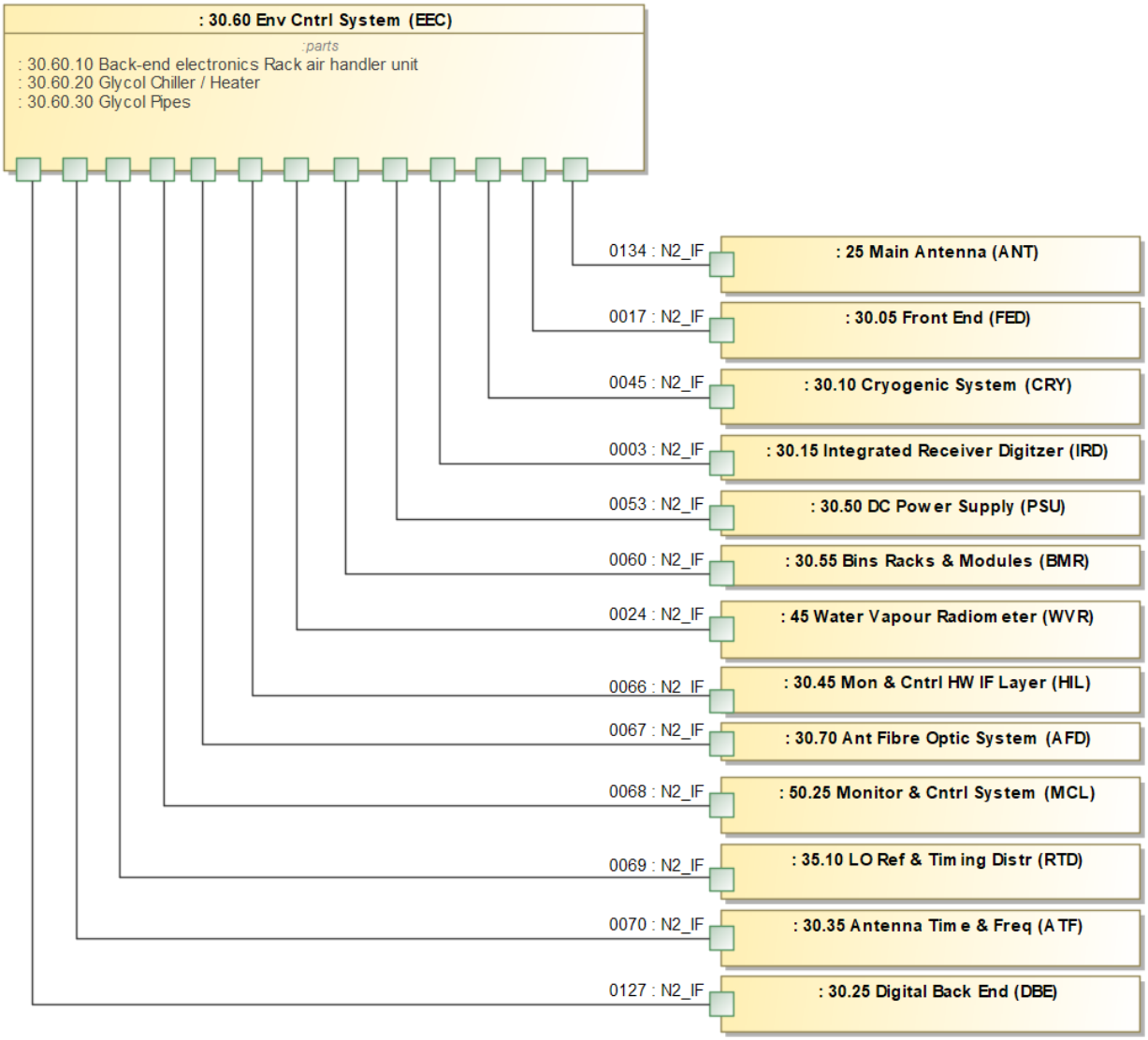

Figure 2. EEC External Interfaces

3.2 *Subsystem functional overview*

The Antenna Electronics is comprised of various subassemblies located in a number of places on the antenna, primary equipment being the Front End Enclosure, the Auxiliary Enclosure, the Electronics Rack, the Cryogenics enclosure, and the Water Vapor Radiometer (Figure 3). The Electronics Environmental Control is responsible for the regulation of the air temperature within the antenna structure (pedestal and turn head), air cooling of the Electronics Rack contents, and direct glycol cooling of the Antenna Electronics on the feed-arm.

The primary temperature control system is a chilled (or heated as necessary) glycol loop which runs from the chiller unit to each of the components on the antenna that require cooling. Antenna electronics modules located above the azimuth bearing will be cooled via glycol passing through cold

plates. The air within the antenna structure and the electronics located below the azimuth bearing will be cooled via forced air, which is in turn chilled by the liquid glycol loop.

The EEC subsystem shall provide the complete glycol cooling system for the antenna. An overview of the products EEC will supply for each Antenna Electronics location is listed below.

3.2.1 EEC Equipment in the Antenna Pedestal

In the antenna pedestal, the ECC shall control the temperature of the air that is circulated within the structure to cool the drive motors and electronics and absorb the heat generated by the sun radiating on the structure. Inside the pedestal EMI cabinet, the ECC shall produce the cold air flow used to cool NRAO electronics rack, the battery enclosure and the antenna servo system.

- Pedestal air conditioner
- Pedestal air ducts
- Blowers to circulate the air
- EMI cabinet room Air Handler
- Electronics Rack air ducting
- Electronics Rack internal air flow baffles
- Glycol pipes to Air Handler
- Glycol pipes to distribution manifold in the turn head

3.2.2 EEC Equipment in the Antenna Turn Head

In the antenna turn head, the ECC shall provide the distribution manifold that will split the incoming supply and return lines to feed the antenna feed-arm and the cryogenic equipment. ECC will also supply the flow control valves and the required control electronics if proven necessary. Adjusting the flow of glycol is common practice to keep the electronics temperature constant when if the heat load is changing.

- Turn head air ducts
- Blowers to circulate the air
- Distribution manifold
- Flow control valves
- Glycol lines
- Drive electronics for the flow control valves
- Dry air controller

3.2.3 EEC equipment in the Front End Enclosure

The Front End Enclosure resides on the feed-arm at the secondary focus. The EEC subsystem shall provide the cold plates needed to cool the various electronics modules and the dry air system that will control the inside humidity level. The temperature stability requirement of some electronics modules or subassemblies might require the flow to be adjusted, proportional solenoid valves with control loops will then be required

- Glycol lines internal to Front End Enclosure
- Liquid to air heat exchanger with fan
- Cold plate, SA501 Bands 5-6 IRD/LO Module
- Cold plate, SA502 Bands 1-4 IRD/LO Module
- Cold plate, L501 Main LO Module
- Cold plate, M507 Utility Module

- Dry air system to control humidity
- Flow control valves
- Flow control valve drive electronics

3.2.4 EEC Equipment in the Auxiliary Enclosure

The Auxiliary Enclosure resides behind the Front End enclosure on the feed-arm. At this location the EEC subsystem shall provide:

- Glycol lines internal to Auxiliary Enclosure
- Liquid to air heat exchanger with fan
- Cold plate, M506 Utility Module
- Cold plate, F521 Cold Head VFD Driver Module
- Cold plate, F523 VFD Control Module
- Flow control valves
- Drive electronics for the flow control valves
- Cold plate for Vacuum pump (TBD)

3.2.5 EEC Equipment for the Water Vapor Radiometer

The Water Vapor Radiometer (WVR) is located on the edge of the primary reflector and consists of a reflective dish with a dedicated Front End receiver module at the focus, and a utility module located behind the dish (or another suitable location close by). Each module will be within an environmental enclosure to protect it from the weather. The WVR has a very tight requirement for temperature stability that will required the flow of the glycol loop to be controlled. The WVR subsystem shall provide:

- Glycol piping internal to the WVR subsystem
- Cold plate, F507 WVR Receiver Module
- Cold plate, M508 WVR Utility Module
- Flow control valve
- Drive electronics for the flow control valve

3.2.6 EEC Equipment for the Cryogenic Equipment Located in the Turn Head

The Cryogenics Equipment located in the Antenna Turn Head is composed of the Helium Compressor and the Cryogenics RFI Enclosure. The EEC subsystem shall provide:

- Glycol piping to Helium Compressor and Cryogenics RFI Enclosure
- Cold plate, M505 Utility Module
- Cold plate, Helium Compressor VFD Module
- Cold plate, Helium Pressure Regulator Electronics Module (TBD)
- Flow control Valve (TBD)
- Drive electronics for the flow control valve

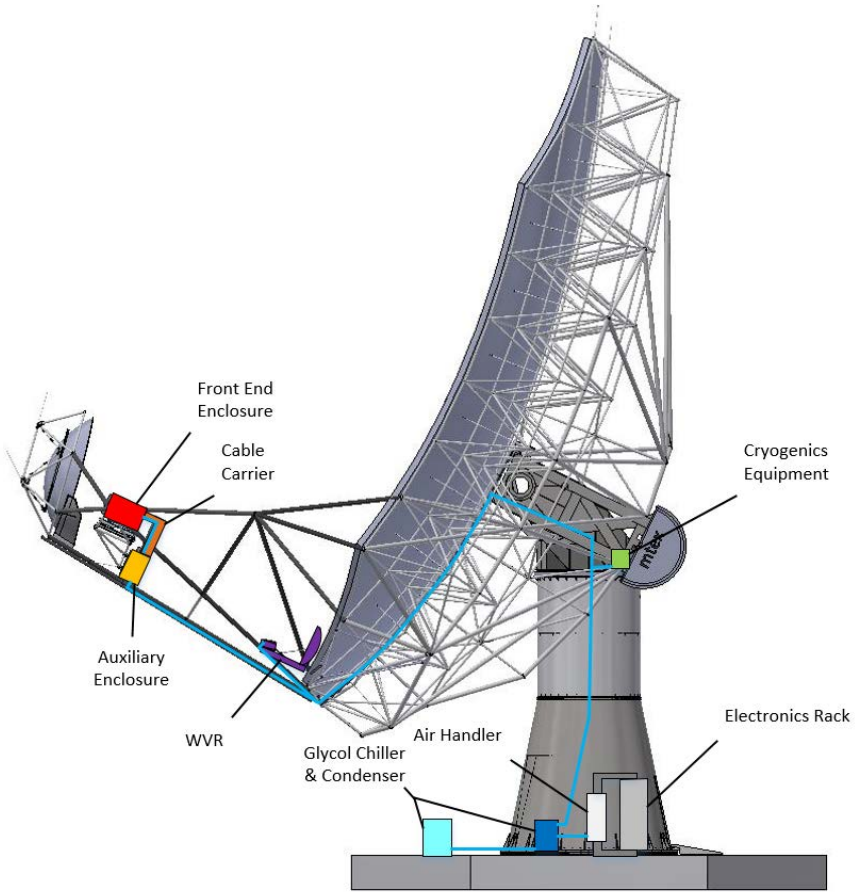

Figure 3. Locations of Various Components of the Environmental Control Subsystem

3.3 Design driving requirements

The following tables provide a summary of the major design-driving subsystem requirements. Should there be a conflict between the requirements listed here and the descriptions in Section 7, the latter shall take precedence. The driving requirements for the EEC subsystem originate primarily from the System Environmental Specifications (AD02), Antenna to Antenna Electronics ICD, and all of the ICD's between EEC and the other Antenna Electronics Subsystems (AD20-AD32).

Parameter	Summary of Requirement	Reference
Cooling Capacity	The EEC chiller shall have a minimum cooling capacity of 17.5kW	EEC0001
Temperature Stability	The EEC subsystem shall maintain a glycol temperature stability of +/-1°C/hour (TBC) at each of the Antenna Electronics locations	EEC0002

Glycol temperature	The EEC subsystem shall maintain the glycol supply between 5°C and 10°C at the inlet of each Antenna Electronics Enclosure	EEC0003
Glycol pump flow capacity	The EEC subsystem shall be capable of achieving the required flow rates and required pressure differentials to all components, for antenna pointing elevations from 12 degrees to 88 degrees	EEC0004
Chiller Power Consumption	The Chiller power consumption while operating at full capacity shall not exceed TBD kW	EEC0007
Chiller Operating Voltage	The chiller shall operate on 480VAC 3 phase	EEC0008
Glycol mixture	The EEC subsystem shall use a mixture of propylene glycol and water that will ensure no damage occurs to any EEC components under the survival conditions, see Table 3	EEC0009
Life of the cooling system	The cooling system shall have a life expectancy of 30 year	EEC0010
MTBM for the glycol cooler	The mean time between maintenance (MTBM) shall be at least 11905 hours	EEC0011

Table 1: Key EEC Subsystem Requirements.

4 Requirements Management

4.1 Requirements Definitions

Consistent with the Requirements Management Plan [AD02], the following definitions of requirement "levels" are used in the ngVLA program. The requirements in this document are at the L2 subsystem level.

Requirement Level	Definition
L0	User requirements expressed in terms applicable to their needs or use cases (Science Requirements or Stakeholder Requirements)
L1	Requirements of the System, expressed in technical functional or performance terms (System Level Requirements)
L2	Requirements that define a specification for an element of the system, presuming a system architecture (Subsystem Requirements)

4.2 Requirements Flow Down

Figure 4 shows the relationships between the Subsystem (L2) requirements and the System (L1) requirements from which they are derived.

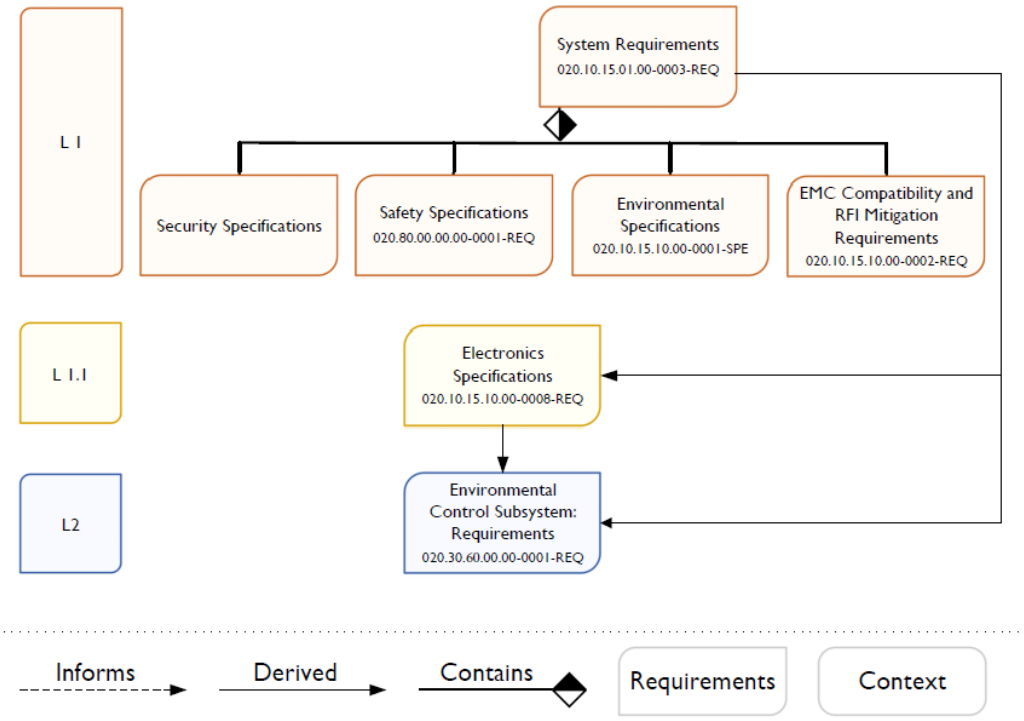

Figure 4 Requirements flow-down to the EEC Subsystem Requirements.

Individual subsystem specifications (Level 2) flow from the Level 1 requirements, and may not always be directly attributable to a single system requirement. For example, phase drift specifications at the system level may be apportioned to multiple subsystems, or a subsystem spec may be in support of multiple higher-level requirements. Completeness of the Level 2 requirements is assessed at the requirements review of each subsystem.

While this is a top-down design process, the process is still iterative rather than a "waterfall" or linear process. The feasibility and cost of requirements implementation lead to trade-offs that feedback to higher-level requirements. The end goal is to build the most generally capable system that will support the Key Science Goals within the programmatic constraints of cost and schedule. Maintaining enumerated traceability between system requirements and subsystem requirements ensures that this trade-off process can be managed in a controlled way.

4.3 Verb Convention

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

5 Assumptions

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

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

6 Environmental Conditions

The chilled glycol system required for the operation of the antenna is complex and physically distributed over the entire antenna structure from the pedestal to the end of the feed-arm. The chiller, or at least its condenser assembly, will be located in a shelter annex to the antenna pedestal to avoid having hot air exhausted too close to the antenna structure. Any subassembly that requires active cooling depends on the continuous supply of glycol, therefore, the EEC subsystem has to meet or exceed the environmental requirements adopted for the other subsystems and the antenna.

- If the glycol chiller is an integrated unit, it will be inside the annex shelter
- If the glycol chiller is a split unit the compressor, condenser coil, and fan will be located in the annex shelter with the remaining components located in the pedestal
- cold plates will always be inside protective enclosures
- piping and hoses will be both inside and outside of environmental enclosures

Most of the EEC components will be offered environmental protection by other subsystems' equipment, and therefore do not need to be designed to conform to the environmental specifications outlined in [AD04]. If the glycol chiller is in the pedestal, it will be protected from the elements and fauna by the antenna structure. All of the cold plates supplied by the EEC subsystem will be shielded from such hazards by the Front End, Auxiliary, and WVR environmental enclosures. At this time the extent of environmental exposure the glycol supply and return lines will be subjected to is unknown. Although we know the antenna will provide some means of cable, piping, and tubing management between the antenna turn head and the subsystems located on the exterior of the antenna, it is unclear what level of protection the management system will offer from weather, dust, and solar loading. At this time, the only EEC product that will be located outdoors but protected by an annex shelter is the condenser for the glycol chiller, which will almost certainly be an outdoor-rated COTS unit requiring little-to-no modifications.

6.1 Limits to Operating Conditions.

The chilled glycol system shall remain operational when other systems on the antenna are placed in Stand-by. Therefore, the operational conditions are the following:

Parameter	Req. #	Value	Traceability
Solar Thermal Load	EEC0100	Exposed to full sun, 1200W/m^2	ENV0360
Wind	EEC0101	0 m/s ≤ W ≤ 30 m/s average	ENV0361
Temperature	EEC0102	–25 C ≤ T ≤ 45 C	ENV0362
Precipitation	EEC0103	Up to 5 cm/hour over 10 mins	ENV0363
Ice	EEC0104	Equivalent to radial ice of 2.5 mm	ENV0364
Relative Humidity	EEC0105	0 ≤ RH ≤ 100%; condensation permitted	ENV0365

Table 2. Limits to Operating Environmental Conditions

6.2 Survival Conditions.

The chilled glycol system has to survive the same environmental conditions as the antenna.

Parameter	Req. #	Value	Traceability
Wind	EEC0110	0 m/s ≤ W ≤ 50 m/s average	ENV0341
Temperature	EEC0111	–30 C ≤ T ≤ 52.5 C	ENV0342
Radial Ice	EEC0112	2.5 cm	ENV0343
Rain Rate	EEC0113	16 cm/hour over 10 mins	ENV0344
Snow Load, Antenna	EEC0114	25 cm	ENV0345
Snow Load, Equipment & Buildings	EEC0115	100 kg/m^2 on horizontal surfaces	ENV0346
Hail Stones	EEC0116	2.0 cm	ENV0347
Antenna Orientation	EEC0117	Stow-survival, as defined by antenna designer	ENV0348

Table 3. Survival Environmental Conditions

The survival conditions describe the environment that the antenna and all outside structures should be able to withstand without damage when placed in its least-vulnerable state. For the antenna, the designer will specify the orientation that will result in minimum stress to the structure at the maximum wind speed and maximum snow and ice loading. Systems housed within or on the antenna (including the environmental control system) shall assume this orientation.

The temperature limits, radial ice, snow load and hail stone requirements are based on experience at the VLA site and a survey of conditions throughout the extent of the array.

6.3 Additional Environmental Requirements

The coolant selected for the chiller is a mixture of propylene glycol and water. The water has higher heat capacity but to keep from freezing under survival conditions it is mixed with propylene glycol. Propylene glycol was selected over ethylene glycol for its non-toxicity.

Parameter	Req. #	Value	Traceability
Altitude range	EEC0200	The EEC subsystem shall operate normally at altitude ranging from sea level up to 2500m	ENV0351

Parameter	Req. #	Value	Traceability
UV radiation	EEC0201	The components of the EEC subsystem exposed to UV shall be designed to handle a maximum diurnal UV radiation flux of 100W/m^2 from 280-400nm	ENV0562 ETR1125
Corrosion Resistance	EEC0203	The chilled glycol subsystem shall use corrosion resistant materials and/or highly corrosion resistant coating and finish on surfaces to prevent corrosion that may impact the performance or structural integrity of the equipment over the system design life.	SYS2801 SAF0490 ENV0591
Dust Protection	EEC0204	The chilled glycol subsystem shall be protected against windblown dust, ashes, and grit.	ENV0541
Cleaning of Heat Exchanger	EEC0205	The condenser shall be designed so that the cleaning of the heat exchanger coil can be done easily with no or minimal disassembly and at a required time interval to be no less than one year.	SAF0960 ETR1180 ETR1181
Rodent Protection	EEC0206	The EEC subsystem shall be designed to prevent rodent intrusion and possible damage to the wiring and electrical system.	ENV0551 ETR1127
Seismic Protection	EEC0207	The EEC subsystem shall be designed to withstand a low probability earthquake with up to 0.2g peak acceleration in either the vertical or the horizontal axis	ENV0521
Condensation protection	EEC0209	All components of the EEC susceptible to see formation of condensation shall be insulated to prevent dripping and corrosion	TBD
Glycol Mixture	EEC0009	The EEC subsystem shall use a mixture of propylene glycol and water that will ensure no damage occurs to any EEC components under the survival conditions, see Table 3	TBD
Sound Level	EEC0012	EEC equipment installed inside the Antenna (i.e. in the pedestal or the turn head) shall not generate audible noise >TBD dB	TBD

Table 4. Additional Environmental Requirements

7 Subsystem Requirements

7.1 Cooling Requirements

The chilled glycol is used to cool many modules and subsystems on the antenna. Figure 5 shows a block diagram of the various heat loads present in the antenna.

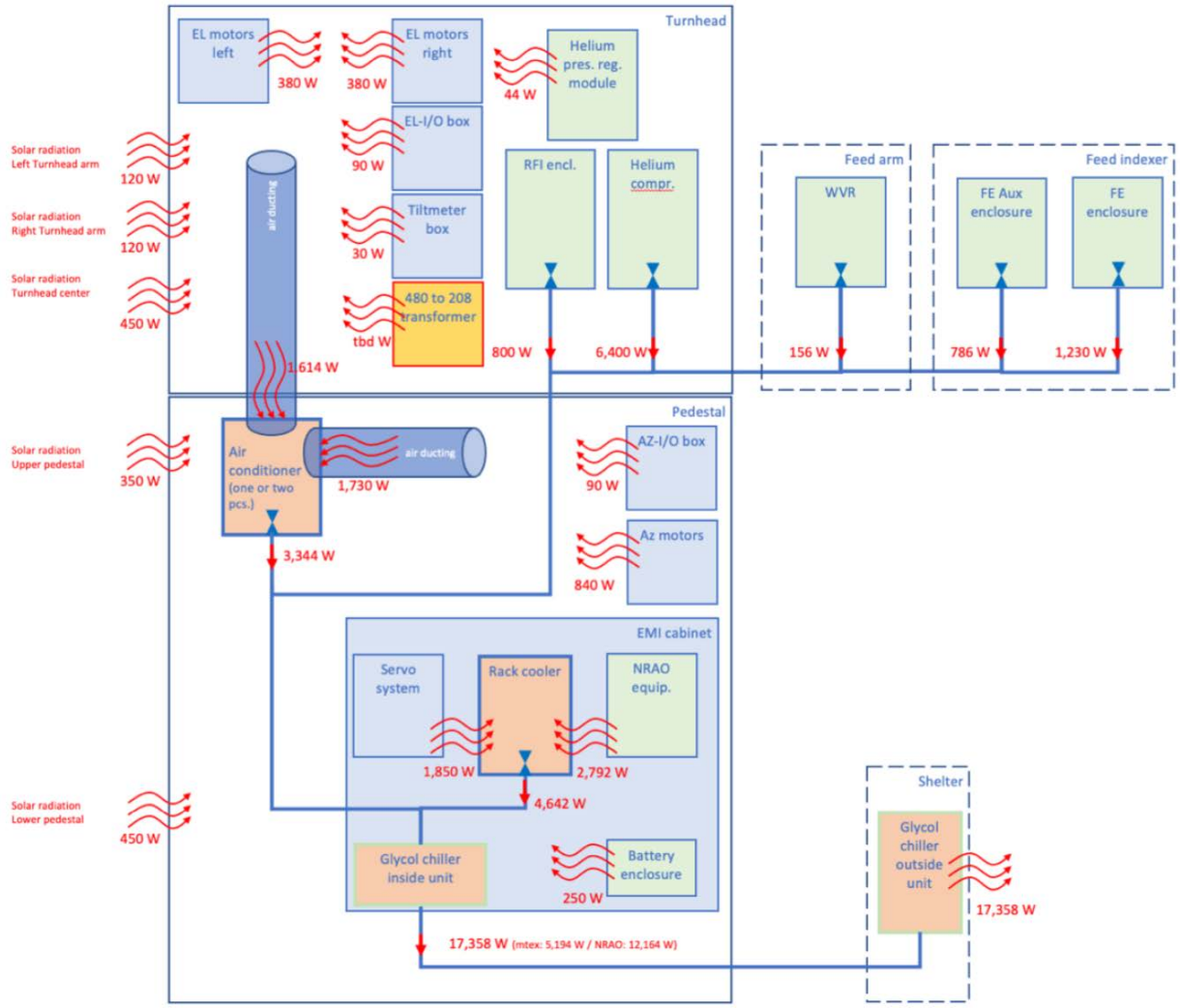

Figure 5. Block Diagram of the Chilled Glycol System

Parameter	Req. #	Value	Traceability
Cooling capacity	EEC0001	The EEC chiller shall have a minimum cooling capacity of 17.5kW	TBD
Temperature Stability	EEC0002	The EEC subsystem shall maintain a glycol temperature stability of +/-1°C/hour (TBC) at each of the Antenna Electronics locations	TBD
Glycol temperature	EEC0003	The EEC subsystem shall maintain the glycol supply between 5°C and 10°C at the inlet of each Antenna Electronics Enclosure	TBD
Glycol pump flow capacity	EEC0004	The EEC subsystem shall be capable of achieving the required flow rates and required pressure differentials to all components, for antenna pointing elevations from 12 degrees to 88 degrees	TBD

Parameter	Req. #	Value	Traceability
Refrigerant Type	EEC0013	Refrigerant used in the EEC subsystem shall meet all United States regulations	TBD

Table 5 Chiller Cooling Requirements

7.1.1 Front End enclosure cooling requirements

Parameter	Req. #	Value	Traceability
Heat load at Front End	EEC0020	The heat dissipated by the electronics at the Front End enclosure shall be ≤1230W	TBD
Glycol flow rate at Front End	EEC0021	The flow rate of glycol required at the Front End enclosure shall be ≤9.5 liter/min	TBD
Pressure drop at Front End	EEC0022	The static pressure drop at the maximum glycol flow rate at the Front End is ≤211.9 KPa	TBD
Dry Air System	EEC0024	The EEC shall supply dry air to the Front End enclosure to maintain a dew point in the enclosure of ≤ -5°C TBC	TBD

Table 6. Front End Enclosure Cooling Requirements

7.1.2 Auxiliary enclosure cooling requirements

Parameter	Req. #	Value	Traceability
Heat load at Auxiliary	EEC0030	The heat dissipated by the electronics at the Auxiliary enclosure shall be ≤786W	TBD
Glycol flow rate at Auxiliary	EEC0031	The flow rate of glycol required at the Auxiliary enclosure shall be ≤6.25 liter/min	TBD
Pressure drop at Auxiliary	EEC0032	The static pressure drop at the maximum glycol flow rate at the Auxiliary enclosure is ≤121.6 KPa	TBD

Table 7. Auxiliary Enclosure Cooling Requirements

7.1.3 WaterVapor Radiometer cooling requirements

Parameter	Req. #	Value	Traceability
Heat load at WVR	EEC0040	The heat dissipated by the electronics at the WVR shall be ≤156W	TBD
Glycol flow rate at WVR	EEC0041	The flow rate of glycol required at the WVR shall be ≤2.75 liter/min	TBD
Pressure drop at WVR	EEC0042	The static pressure drop at the maximum glycol flow rate at the WVR is ≤60.8 KPa	TBD

Table 8. WVR Cooling Requirements

7.1.4 Turn head cryogenic equipment cooling requirements

Parameter	Req. #	Value	Traceability
Heat load at Cryogenics RFI enclosure	EEC0050	The heat load at the Cryogenics RFI shall be ≤800W	TBD
Glycol flow rate at Cryogenics RFI enclosure	EEC0051	The flow rate of glycol required at the Cryogenics RFI shall be ≤4.0 L/min	TBD
Pressure drop at Cryogenics RFI enclosure	EEC0052	The static pressure drop at the maximum glycol flow rate at the Cryogenics RFI Enclosure is ≤91.3 KPa	TBD
Minimum Glycol temperature at Cryogenics RFI enclosure	EEC0054	The glycol supplied to the Cryogenics RFI enclosure shall have a minimum temperature of 5°C	TBD
Heat loads at Helium Compressor	EEC0055	The heat load at the Helium Compressor shall be ≤6,400W	TBD
Glycol flow rate at Helium Compressor	EEC0056	The flow rate of glycol required at the Helium Compressor shall be ≤10 L/min	TBD
Pressure drop at Helium Compressor	EEC0057	The static pressure drop at the maximum glycol flow rate at the Helium Compressor is ≤100 KPa	TBD
Helium compressor maximum Supply pressure	EEC0059	The maximum glycol supply pressure to the Helium Compressor shall be ≤903 KPa	TBD
Helium pressure regulation enclosure maximum heat dissipation	EEC0060	The maximum heat dissipated in the turn head ambient air by the helium pressure regulation enclosure is ≤44W	TBD

Table 9. Turn Head Cryogenic Equipment Cooling Requirements

7.1.5 Pedestal EMI cabinet

Parameter	Req. #	Value	Traceability
Heat load at NRAO Electronics Rack	EEC0070	The heat load at the Electronics Rack shall be ≤2,792W	TBD

Parameter	Req. #	Value	Traceability
Air flow rate at Electronics Rack	EEC0071	The flow rate of air required at the Electronics Rack shall be ≤0.24 M^3/s	TBD
Pressure drop at Electronics Rack	EEC0072	The static pressure drop at maximum airflow at the Electronics Rack is ≤500 Pa	TBD
Minimum Air Temperature	EEC0073	The air supplied to the Electronics Rack shall have a minimum temperature of TBD °C at the inlet to the rack	TBD
Heat load from the antenna servo electronics	EEC0074	The maximum heat load from the antenna servo electronics shall be ≤1,850W	TBD
Heat load from battery cabinet	EEC0075	The maximum heat load from the battery cabinet shall be ≤250W	TBD

Table 10. Pedestal EMI Cabinet Cooling Requirements

7.1.6 Pedestal air conditioner

Parameter	Req. #	Value	Traceability
Heat load from the pedestal air conditioner	EEC0080	The maximum heat load from the antenna pedestal air conditioner shall be ≤3,344W	TBD
Diameter of the air duct feeding the turn head	EEC0081	The air duct feeding the cold air to the turn head shall have a diameter of TBD cm to accommodate the estimated 1,624W of heat dissipation	TBD
Diameter of the air duct feeding the pedestal	EEC0082	The air duct feeding the cold air to the pedestal shall have a diameter of TBD cm to accommodate the estimated 1,730W of heat dissipation	TBD

Table 11. Pedestal Air Conditioner Cooling Requirements

7.2 Maintenance and Reliability Requirements

The glycol cooling circuit represents a single point of failure for the antenna, the reliability of the subsystem is critical and unscheduled down time should be avoided. The minimum interval between maintenance shall match or exceed the antenna MTBM and failure prediction algorithms shall be implemented to identify and replace LRUs before breakdown.

Parameter	Req. #	Value	Traceability
Mean Time Between Failures (MTBF)	EEC0550	The EEC equipment shall be designed to have an MTBF ≥ TBD hrs.	SYS2302, SYS3200
MTBM for the glycol cooler	EEC0011	The mean time between maintenance (MTBM) shall be at least 11905 hours	SYS2610
Modularization	EEC0551	The EEC system shall be modularized into LRUs whenever possible to facilitate site maintenance	SYS2403
Failure Prediction	EEC0552	The EEC equipment shall provide sufficient monitoring sensors to enable failure prediction	SYS3221

Table 12 Reliability Requirements

The maintenance and reliability requirements are in support of high-level requirements that limit the total operating cost of the array.

Monitor points/sensors should be included in the MTBF/MTTR analysis, but sensors and other components that can be reasonably deemed to be ancillary to operation may be removed from the determination of compliance with the MTBF requirement. "Failure" will be defined as a condition which places the system outside of its performance specifications or into an unsafe state, requiring repair.

7.3 Monitor and Control Requirements

7.3.1 M&C sensors

The EEC equipment will include sensors for temperature of the glycol in several locations, sensors for pressure and flow will also be used. In the Front End enclosure, an humidity sensor will be required to control the dry air system and report the value to the antenna M&C.

Parameter	Req. #	Value	Traceability
Self-Monitoring	EEC0600	The EEC shall measure, report, and monitor a set of parameters that allow for determination of its status	SYS2701

Table 13. 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 Antenna Electronics Environmental 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.

7.3.2 LRU identification

The LRU shall be uniquely identified to track and locate them and keep an up-to-date inventory. Whenever possible, the EEC equipment shall be remotely accessible for identification and provided maintenance information like the date of commissioning, the running hours and date of the next service.

Parameter	Req. #	Value	Traceability
LRU Identification	EEC0610	Each LRU shall be equipped with a standardized physical tracking label or device (e.g. bar code or RFID tags) to facilitate status and location across the observatory. Whenever possible these unique identification codes must be remotely accessible and visible.	SYS3600 SYS3900 SYS3902 SYS2406 SYS3700 ETR0402
LRU Tracking Label and Tag Specifications	EEC0611	The physical tracking label and/or device attached to each LRU shall conform to the specifications outlined in US DOD standards MIL-DTL-15024 [RD07] and MIL-P-19834 [RD08].	ETR0405 SYS2801 SYS3900 SYS3910 SYS3600
Remote Identification	EEC0612	Any device with any connectivity to the Monitor & Control System shall identify itself when polled via the Monitor and Control Network. Minimum information to be reported is: 1. Module/Model Number 1. Serial Number 2. CID Number which leads to all documentation 3. Hardware Revision Level 4. Software Revision Levels (if applicable) 5. Firmware Revision Levels (if applicable) UID and IUID from physical tracking tag or device	ETR0403 SYS2406 SYS3600 SYS3602 SYS3603

Table 14 LRU Requirements

7.4 Lifecycle Requirements

The EEC equipment shall be designed and built to last the 20 years of operation and the 10 years of construction.

Parameter	Req. #	Value	Traceability
Design Life	EEC0010	The EEC equipment shall be designed to be operated and supported for a period of 30 years.	SYS2801
Lifecycle Optimization	EEC0651	The EEC subsystem design shall minimize its lifecycle cost for 30 years of operation.	SYS2802

Table 15 Lifecycle Requirements

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

7.5 Safety and Security

Personnel and equipment safety are the primary concern for ngVLA and every measure that will reduce the risk of injury or damage must be implemented. This can be as simple as warning labels or installation of protections on exposed sharp edges or corners.

7.5.1 Personnel safety

The safety of the personnel is the priority for the observatory. The EEC equipment present risk to the people doing installation or maintenance because of the high voltage, the pressurized liquid, some moving parts and high or cold surface temperatures. The technical staff working on the EEC equipment must be well trained and be aware of the potential dangers, and work procedures should be developed and approved by the safety committee to prevent accidents.

Parameter	Req. #	Value	Traceability
Follow Safe Design Priorities	EEC0700	The EEC subsystem shall address safety of personnel first followed by safety of equipment. The information needed to control the equipment must be unambiguous and easily understood.	SAF0031, SAF0190 SAF0200, SAF0750 SAF0970, SAF1060 SAF1130
Warning Labels	EEC0701	Warning labels shall be applied on the EEC equipment to inform the personnel of possible hazard or special handling information (electrical shock hazard, high temperature hazard, etc.).	SYS2700, SYS2704 SAF0100, SAF0050 SAF0170, SAF0750 SAF1010, ETR1008 ETR1010, ETR1011 ETR1012, ETR1015
Labeling Quality	EEC0702	Labels shall withstand environmental conditions, be waterproof, and not detach or become unreadable with repeated handling or UV exposure.	ETR0409
Mass and Center of Gravity Marking	EEC0703	All LRUs shall include at least one clearly visible label indicating the weight of the LRU in pounds (lbs.) and kilograms (kg). Location of the center of mass shall be clearly indicated on equipment that will need to be handled with a lifting device. The label shall be compliant with the standards at the time of installation.	SAF1050, ETR0406 SYS2700

Parameter	Req. #	Value	Traceability
Lifting Handles	EEC0704	Any EEC subsystem LRU with a mass 5 kg ≤ W ≤ 40 kg shall be equipped with handles for handling. The number of persons required for handling shall be clearly indicated. The label shall be compliant with applicable standards at the time of installation.	SAF0160, SAF0210 SAF0240, SAF0260 ETR0406, ETR0407 ETR0408, ETR1178
LRU Multiple Person Lift Label	EEC0705	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 SAF1050, ETR0407
Lifting Points	EEC0706	Any EEC LRU or part with a mass > 40 kg shall have lifting point(s) (eye bolts or slots) allowing handling with an overhead crane or a forklift. The lifting point location shall be clearly identified and the label shall be compliant with applicable standard at the time of installation.	SAF0160, SAF0210 SAF0240, SAF0250 ETR0406, ETR0407 ETR0408, ETR1178
Sharp Edges Protection	EEC0707	The EEC subsystem shall protect sharp edges that cannot be eliminated from the design with covers or coatings	SAF0540, ETR1172
Cold Plate Pressure testing	EEC0708	Any cold plate shall be pressure tested to x1.5 times the maximum operating pressure.	SAF0034, SAF0036
Protection from Risk of Overpressure	EEC0709	The EEC equipment shall comply with the pressurized equipment safety requirements. The EEC system shall be equipped with overpressure relief valves to eliminate the risk of explosion or a large pressure burst that could harm personnel or damage equipment.	SAF0720, SAF0780 SAF0850
Flexible Glycol Line Working Pressure	EEC0710	The flexible glycol line shall have a working pressure >TBD.	SAF0520
Rigid and Flexible Lines Mechanical Attachment	EEC0711	Both rigid and flexible lines shall be firmly attached and/or protected against all external stresses and strains to ensure that no risk to personnel or equipment is posed by a rupture.	SAF0520

Parameter	Req. #	Value	Traceability
High Voltage Safety Protection	EEC0712	The EEC equipment shall comply with the electrical safety protection requirements. 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, or routine maintenance.	SAF0050, SAF0070 SAF0080, SAF0090 SAF0120, SAF0690 ETR1001, ETR1002 ETR1003, ETR1004 ETR1005
Contact with High Voltage during Diagnosis & Repair	EEC0713	In situations where exposure to high voltages (i.e. at or above 50 Volts DC or 50 Volts RMS AC) may be possible during in-depth diagnosis and repair, procedures for minimizing risk of contact shall be provided in a maintenance manual for the subsystem or equipment under repair.	ETR1004 SYS2700 SAF0070 SAF0090
Safety Interlocks	EEC0714	Safety interlocks shall be used in situations where high voltages (i.e. ≥ 50 Volts) could be exposed.	ETR1017 SAF0690,SAF0070 SAF0090,SAF0930
Equipment Stability	EEC0715	Any EEC equipment or assembly shall be stable under foreseen operating conditions or shall be anchored to the antenna structure to provide the required stability.	SAF0470
Protection from Moving Parts	EEC0716	Any moving part that presents a risk for personnel shall be equipped with a grid, a screen, or a mesh to avoid any possible contact and prevent any risk of personnel injury.	SAF0640
Leak protection	EEC0717	Any EEC equipment that can develop a leak of glycol shall have a way to collect or evacuate the liquid to prevent personnel injury or damage to other equipment	TBD

Table 16 Personnel Safety Requirements

7.5.2 Equipment Safety

Parameter	Req. #	Value	Traceability
Subsystem Self-Monitoring	EEC0750	The EEC shall monitor its system health and prohibit actions likely to cause damage. The monitor may also shut down the system to prevent damage.	SYS2701 SAF0037 ETR0807
Hardware Failsafe Implementation	EEC0751	The EEC subsystem shall be designed with hardware fail-safe in specific LRUs, where an M&C failure or malfunction could potentially damage that system.	SAF0042
Initial Safe State Power-Up	EEC0752	The EEC subsystem shall initialize in a safe state for personnel and equipment without human intervention when powered up.	SAF0041

Glycol Level	EEC0754	The EEC chiller shall monitor the glycol level and generate an alarm when the level drops below a warning level and shall shut down if the level drops below the minimum level	TBD

Table 17 Equipment Safety Requirements

7.5.3 Electrostatic Discharge Protection and Lightning Protection

The dry environment of New Mexico makes electrostatic discharge a problem that should be addressed during the design and the maintenance of the equipment. The thunder storms common during the summer months could have catastrophic consequences for the equipment. Proper grounding is absolutely essential for the safety and operation of the equipment. Glycol being electrically conductive, the glycol lines should be treated as electrical lines for grounding protection.

Parameter	Req. #	Value	Traceability
ESD Susceptibility Testing	EEC0800	Qualification units of all enclosed ngVLA LRUs shall be tested for susceptibility to ESD damage and an ESD class determined. See [AD09] for more details on testing requirements.	ETR0501 ETR0505 ETR0506 EMC0471 EMC0472 EMC0473
ESD Protection	EEC0801	ESD protection of equipment and workspaces shall be based on USDOD MIL-STD-1686C [RD10] and MIL-HDBK-263B [RD11] or ANSI/ESD S20.20-2014 [RD12].	SAF0710 ETR0502
ESD Packaging and Storage	EEC0802	Equipment and components sensitive to damage from ESD shall be packaged, shipped, and stored in ESD protective packaging. This packaging shall only be sealed and opened at ESD-safe workstations.	ETR0503 SYS3904
Prevention & Discharge of Electrostatic Charge Build-Up	EEC0803	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.	ETR0504 SYS2801 SYS2700 SAF0710
Lightning Protection	EEC0804	The EEC subsystem shall be protected against lightning electromagnetic impulse (LEMP) in accordance with IEC 62305-4.	ENV0512 ETR0825
Metallic Braid on Flexible Glycol Lines	EEC0805	For grounding and RFI protection the flexible glycol lines shall have an outer metallic braid	ENV0512 ETR0825
Glycol Line Routing	EEC0806	Wherever possible, glycol lines shall be routed as close as possible to grounded conductive surfaces in order to reduce the risk of lightning induced currents in the lines	ENV0512 ETR0825

Table 18 EDS and Lightning Protection Requirements

7.6 Power Requirements

7.6.1 AC Power

The EEC equipment will use 3-phase AC power and DC power. The power to the chiller compressor shall be frequency controlled by a VFD to minimize power consumption. An independent VFD power source for the glycol pump should be considered to reduce power consumption and improve reliability.

Parameter	Req. #	Value	Traceability
Chiller Operating Voltage	EEC0008	The Chiller shall operate on 480VAC 3 phase	TBD
Chiller Power Consumption	EEC0007	The Chiller power consumption while operating at full capacity shall not exceed TBD kW	CON002
AC Power and Grounding Design	EEC0900	Design and installation of all AC power and grounding wiring shall conform to US National Electrical Code NFPA 70 [RD13].	ETR0801
Chiller Power Factor	EEC0902	The chiller shall have a power factor larger than 0.82 (TBC) at any operating frequency.	TBD
Start-Up Power Consumption	EEC0903	The chiller start-up power consumption shall not exceed TBD kVA.	ETR0805
Harmonic Distortion	EEC0904	The chiller shall not induce total harmonic distortion (current) onto the electrical supply that exceeds TBD level.	SYS2802
Phase Imbalance	EEC0905	The EEC equipment shall not induce phase imbalance (current) onto the electrical supply that exceeds TBD level.	SYS2802
Chiller Operating Frequency	EEC0906	The chiller shall be able to operate at variable speed to reduce power consumption. The range of operating frequency is 30 Hz ≤ F ≤ 60 Hz (TBC).	SYS2802
Glycol Pump Operating Frequency	EEC0907	The glycol pump shall be able to operate at variable speed to reduce glycol flow. The range of operating frequency is 30 Hz ≤ F ≤ 60 Hz (TBC).	SYS2802
Switches and Controls Labeling	EEC0908	The EEC equipment shall have labels on switches and controls used by technical personnel marking their function clearly.	ETR1010 ETR1011
AC Voltages Available	EEC0909	All equipment in the ngVLA powered from AC voltages shall utilize 480 V or 208 V/120 V 60 Hz AC Power.	ETR0819
AC Voltage Tolerance	EEC0910	All equipment in the ngVLA powered from the AC line shall tolerate variations of +/– 10%.	ETR0820

Table 19 AC Power Requirements

7.6.2 DC Power

The proportional solenoid valves used to control the glycol flow to the Antenna Electronics enclosure will be operated by DC voltage (12, 24VDC).

Parameter	Req. #	Value	Traceability
DC Power & Grounding Design	EEC0950	Design and installation of all DC power distribution and grounding wiring shall conform to ngVLA system and RFI/EMC requirements.	ETR0802
DC LRU Power Input	EEC0951	Input power to all LRUs shall be considered raw power. Internal regulation and filtering is required.	ETR0803
Power Supply Dedicated Returns	EEC0952	All power supplies shall have dedicated current return paths.	ETR0813
Power Supply Returns Separate from Ground	EEC0953	Structural/chassis components and signal grounds shall never be used as a power supply return path.	ETR0815
DC Voltages Available	EEC0954	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.	ETR0821
-48VDC Tolerance	EEC0955	Devices on the -48 VDC system shall tolerate voltages from -42.0 VDC to -60.0 VDC.	ETR0822
PSU Voltage Tolerance	EEC0956	Devices powered from the PSU modules shall tolerate +/- 10% of the rated voltages.	ETR0823

Table 20 DC Power Requirements

7.6.3 Grounding

The EEC equipment shall be grounded to the antenna structure using dedicated grounding straps or wires.

Parameter	Req. #	Value	Traceability
Grounding	EEC1000	EEC equipment shall have a grounding point easily identifiable and each connection path to the antenna ground shall have a resistance of less than 10 mΩ.	SAF0710 ETR0804

Table 21 Grounding Requirements

7.6.4 Thermal protection

All EEC subsystem LRUs shall have a protection circuit able to detect over temperature conditions and power down modules or send them into low-power mode.

A two level approach is recommended: when the temperature reaches the first level an alarm is sent to the array operator to evaluate the situation and make possible corrections. When the temperature reaches the second level, the LRU goes into over temperature protection mode with no external intervention required.

During the design phase, designers shall take into consideration the ambient temperature range and the maximum elevation to optimize the thermal performance of the LRU, and use that information for the thermal analysis and/or the test.

Parameter	Req. #	Value	Traceability
Thermal Protection	EEC1050	The EEC subsystem shall issue an alarm if its internal temperature approaches a near critical level to allow operators to intervene	ETR0807
Thermal Protection Monitoring	EEC1051	Any EEC LRU shall be able to monitor the state of thermal protection features	ETR0808
Over Temperature Protection	EEC1053	The EEC subsystem shall implement automatic over-temperature self-protection if it reaches critical internal temperature	ETR0807

Table 22 Thermal Protection Requirements

7.6.5 Powered System Operational Design

Because of the large number of antennas and the remote locations for some of them, the ability of the EEC system to survive and recover after power outage is essential. Because most of the antenna electronics rely on the EEC for cooling, the equipment shall restart autonomously to allow the other systems to be powered and come online. A basic safety interlock shall prevent the other systems to be powered up if the glycol circuit is not operational and it shall generate an alarm to alert the service center.

Parameter	Req. #	Value	Traceability
EEC Remote Startup and Recovery Sequence	EEC1100	The EEC shall restart autonomously at power up	ETR0809 ETR0811
Power Outage Behavior	EEC1101	In case of a power outage, the pump shall be able to circulate the glycol long enough for the other subsystems to go through their shut down procedure and for drive electronic to move the antenna to a safe position.	ETR0810
EEC Safety Interlock	EEC1102	A hardware interlock shall prevent other systems to be powered up if the glycol circuit is not operational	TBD
DC Powered LRU Power ON Indicator	EEC1103	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.	ETR0812
Cold Start	EEC1104	The EEC subsystem shall be capable of a cold start while under the limits to operating conditions, see Table 2	TBD

Table 23 EEC Power-up Requirements

7.7 Radio Frequency Interference/Electro-Magnetic Compatibility (RFI/EMC)

The EEC equipment susceptible to generate RFI shall be tested and proper protection implemented to reduce the level of emission below the required threshold.

Parameter	Req. #	Value	Traceability
EMC/RFI Mitigation in Designs	EEC1150	RFI/EMC requirements shall be compliant with the ngVLA System EMC/RFI Mitigation Requirements.	ETR0601
RFI Enclosure Glycol Lines	EEC1151	EEC glycol lines penetrating shielded enclosures shall not degrade the enclosure shielding by more than TBD dB	ETR0601

Table 24 RFI/EMC Requirements

7.8 Mechanical Requirements

7.8.1 Mechanical Requirements Driven by the Antenna

The chiller could be an integrated unit and mounted outside of the antenna in a shelter or a split unit with the compressor inside the pedestal and the condenser outside. The glycol lines will be a mix of rigid and flexible sections. The flexible sections will be used for the azimuth and elevation wraps, as well as the cable carrier between the Front End and Auxiliary enclosures. Everywhere there is no motion, rigid sections are preferred for reliability and lower pressure drop.

Parameter	Req. #	Value	Traceability
Chiller Tilt Angle	EEC1200	The chiller shall operate normally with a tilt angle ≤ 5° from the horizontal.	
Physical Orientation	EEC1201	The EEC equipment shall operate normally as the antenna moves through its entire elevation range from 12°–88°.	
Chiller Volume	EEC1202	The chiller including the space around it required for proper ventilation shall fit within a volume of W TBD mm x D TBD mm x H TBD mm.	
Compressor Mass	EEC1203	The mass of the chiller shall not exceed TBD kg.	
Flexible Glycol Line Dynamic Bending Radius	EEC1204	The flexible glycol line shall have a minimum dynamic bending radius of ≤ 250 mm.	

Table 25 Antenna Driven Mechanical Requirements

7.8.2 Coupling and Hardware Requirements

The couplings used to interconnect the various LRUs of the glycol subsystem shall be quick disconnect self-sealing with very low spill and provide a drip free connection. The fasteners used in the assembly of the EEC system shall be metric whenever possible and made of stainless steel for corrosion resistance. TORX and hexagonal heads are preferred for reliability, and captive screws shall be used for panel assembly to avoid dropping screws during service on the antenna.

Parameter	Req. #	Value	Traceability
LRU Couplings	EEC1250	LRUs shall use quick disconnect self-sealing with very low spill and drip free connection	TBD
Coupling Marking	EEC1251	The glycol connections shall be clearly marked in red to identify return connections and blue to identify supply connections.	SAF0740
Metric Fasteners	EEC1252	The EEC subsystem shall use metric fasteners and request a non-compliance agreement where imperial hardware must be used.	ETR1161
Stainless Steel Hardware	EEC1253	The hardware used on the EEC subsystem shall be stainless steel for long lasting life.	SYS2801 SAF0490 ETR1163
Type of Fasteners	EEC1254	Pan head or flat-head screws shall use Textron TORX type 6-point star shaped screw heads driven by TORX type drivers. All cap head screws shall utilize hexagonal Allen type screw heads driven by hex type driver.	ETR1166 ETR1167 ETR1168
Hardware Retention	EEC1255	All nut and bolt type hardware interfaces shall use retention techniques to prevent loosening.	SYS2700 SYS2801 ETR1169
Captive Fasteners	EEC1256	All panels that need to be removed on the antenna for service shall use captive fasteners to prevent loss of hardware during maintenance.	SAF0530

Table 26 Coupling and Hardware Requirements

7.8.3 Shock and Vibration Requirements

The chilled glycol is a large system composed of many parts that will be assembled on-site while the antenna is being built. Some of the parts will be considered LRUs and will be easily swapped on-site. Other components, while not considered LRU's, will still have to be replaced on the antenna because the system is an integrated part of the antenna. The parts that composed the chilled glycol system will have to withstand the vibrations and shocks produced during transportation, maintenance, and operation.

Parameter	Req. #	Value	Traceability
Environmental Vibrations	EEC0500	All EEC equipment shall be designed to withstand persistent vibration with a power spectral density defined in Figure 1. Line Replaceable Units shall be tested to this vibration specification, as packaged for shipping, along all three axes as defined in the MIL-STD-810H Method 514.8 Procedure I for General Vibration, for a period of 60 minutes.	ENV0531
Mechanical Shocks	EEC0501	EEC Line Replaceable Units packaged for transportation shall survive mechanical shock levels from handling as defined in the MIL-STD-810H Method 516.8 Logistic	ENV0582

Parameter	Req. #	Value	Traceability
		Transit Drop Test, modified to use the drop heights specified in Table 28.	
Generated Vibrations	EEC0502	The EEC system shall not generate vibration and shock that could affect other systems on the antenna	SAF0810

Table 27 Shock and Vibration Requirements

The table below lists the height and the number of drops that an LRU packaged for transportation shall survive with no damage based on the total mass of the assembly.

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

Table 28. Drop heights for logistic transit drop test

7.8.4 Surface Finish Requirements

The various components composing the EEC could be made of steel, aluminum, stainless steel, plastic, or composite materials. The surface finish shall provide adequate protection based on the environmental requirements and electrical conduction requirements.

Anodization shall not be used on structural component made of aluminum because this type of finish could hide cracks, rather a chromate finish is recommended.

Parameter	Req. #	Value	Traceability
Chromate Converted Surfaces	EEC1300	Aluminum surfaces where electrical conduction is required (RFI/EMI or safety grounding) shall be treated using a Chromate Conversion process as outlined in MIL-DTL-5541E. Either Class 1A or Class 3 can be used based on requirements determined by the designer.	ETR1143
Stainless Steel Surfaces	EEC1301	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.	ETR1144

Parameter	Req. #	Value	Traceability
Anodized Surfaces	EEC1302	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. Anodizing shall not be used on structure components	ETR1145
Painted Surfaces	EEC1303	Surfaces requiring paint shall be painted with white or light color paint suitable for the surface material and environmental conditions the surface will experience.	ETR1146
Colored Paint Marking	EEC1304	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.	ETR1147
Surface Preparation for Painting	EEC1305	Before painting, all surfaces shall undergo proper surface preparation suitable for the material and paint that is used.	ETR1188

Table 29 Surface Finish Requirements

7.9 Wiring and Cables

The glycol circuit will have pressure, flow and temperature sensors to give feedback information to the electronics modules controlling the compressor VFD, the pump VFD and the proportional solenoid valves. Interconnecting cables will be used to provide power, send commands and route sensor information. In order to minimize noise pickup, shielded cables are required and robust military type connectors shall be selected for reliability.

Custom electronics assemblies shall respect the wire color code to provide consistency across the antenna electronics and simplify maintenance.

Different connector size or sex and colored labels shall be used on the cables assemblies to avoid mistakes and prevent damage to the electronics during construction and maintenance.

7.9.1 Documentation

Parameter	Req. #	Value	Traceability
Cable Documentation	EEC1350	All wiring, cables, and harnesses installed in the ngVLA system shall be documented in accordance to ngVLA Drafting and Documentation Standards.	ETR1101 SYS2700

Table 30 Wiring Documentation Requirement

7.9.2 Labeling of wiring and cables

Parameter	Req. #	Value	Traceability
Cables and Harnesses Labeling	EEC1360	The EEC subsystem shall use labels on all cables, harnesses, and connectors to allow identification while cables and harnesses are installed. The labels shall comply with the ANSI standard TIA-606-C [RD14].	ETR1102 SYS2700
Switches and Controls Labeling	EEC1361	The EEC subsystem shall have labels on switches and controls used by technical personnel marking their function clearly.	ETR1010 ETR1011

Table 31 Wires and Cables Labeling Requirements

7.9.3 Wiring Color Standard

Parameter	Req. #	Value	Traceability
DC Wire Color Standard	EEC1370	The wiring of custom EEC equipment for ngVLA shall comply with the approved color standard. +3.3 VDC Pink +5.0 VDC Orange +7.5 VDC White with Orange stripe -5.0 VDC Brown -7.5 VDC White with Brown stripe +12 VDC Blue +13.5 VDC White with Blue stripe -12 VDC Tan -13.5 VDC White with Tan stripe +15 VDC Red +17.5 VDC White with Red stripe -15 VDC Yellow -17.5 VDC White with Yellow stripe +20 to <+30 VDC Grey or Slate >+30 VDC White with Grey or Slate stripe -48 to -54 VDC Purple or Violet All return for DC voltages and LVS Black All Earth, chassis and safety grounds Green or Green with Yellow stripe Standard TTL White with Black and Orange stripes Standard LVTTL White with Black and Violet Standard LVDS Yellow with Blue stripe (+signal) Blue with Yellow stripe (-signal) Standard RS422/485 Orange with Blue stripe (+signal) Blue with Orange stripe (-signal) LVAS White	ETR1105, ETR1106 ETR1107,ETR1108 ETR1154,ETR1109 ETR1155,ETR1110 ETR1111,ETR1112 ETR1113,ETR1114 ETR1115,ETR1116 ETR1117,ETR1118 ETR1119,ETR1120 ETR1121,ETR1122 ETR1123, SYS2700 SAF0070
AC Wiring Color	EEC1371	All AC wiring colors shall conform to US NEC requirements.	ETR1124 SYS2700 SAF1000,SAF1170

Table 32 Wiring Color Standard Requirement

7.9.4 Wire Insulation Type

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.

Parameter	Req. #	Value	Traceability
Wiring Insulation Type	EEC1380	Low-voltage DC and signal wiring shall utilize Irradiated PVC type insulation certified to meet the UL 1430 specification. This shall be rated at 300 VDC minimum over a temperature range of -55°C to +105°C.	ETR1157 SYS2700 SAF0120

Table 33 Low Voltage DC Wiring Insulation Requirement

7.9.5 Connectors

It is a well-established fact that connectors represent a very common source of failure. Connectors shall be selected for their reliability and ease of use. Keyed and tool free with a locking mechanism are the preferred type to simplify interconnection on the antenna and to reduce maintenance time.

Parameter	Req. #	Value	Traceability
Connector Documentation	EEC1390	All connectors installed in the ngVLA system shall be documented in accordance to ngVLA Drafting and Documentation Standards.	ETR1133
Connector labeling	EEC1391	All connectors shall be labeled in accordance with ANSI Standard TIA-606-C [RD14].	ETR1134
Connector Current rating	EEC1392	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.	ETR1135
Connector Environmental Rating	EEC1393	All connectors shall be utilized in accordance with their designed environment.	ETR1136
Cable Mating Cycles	EEC1394	The specified data sheet rating for mating cycles allowed for a connector type shall be followed.	ETR1137
No Exposed Live Terminals	EEC1395	Live signal or power pins in connectors shall not be exposed while connectors are unmated.	ETR1140
Connector Uniqueness & Keying	EEC1396	Connectors that are similar or closely located shall be sufficiently unique or keyed to prevent incorrect connectors from being mated.	ETR1141
Common Connectors	EEC1397	Connectors used repeatedly across multiple devices shall have critical signal pinouts standardized.	ETR1142
Connector Alignment Guides	EEC1398	Connectors used in blind mate or back plane applications shall utilize some mechanism to ensure alignment of the connector during installation to avoid damage to the connector.	ETR1158

Parameter	Req. #	Value	Traceability
Connector Locking or Retaining Mechanism	EEC1399	Connectors that have a locking mechanism are preferred. Connectors that present the risk of unmating during operation shall have a mechanism installed to mitigate the risk.	

Table 34 Connector Requirements

7.10 Interface Requirements

In this section, requirements are derived from the applicable ICDs as listed in Section 2.2. As stated in the SEMP [AD01], ICDs define the interface, but do not contain any requirements. All interface requirements that drive the design and verification of the subsystem shall be listed in this section.

7.10.1 Interface EEC to Antenna

Interface 0134: 30.60 Environmental Control (EEC) to 25 Antenna (ANT)

The EEC subsystem will need to interface with the antenna in multiple locations. The glycol chiller could be located in the antenna pedestal or in a shelter annex with the condenser, for both configurations, glycol lines or refrigerant lines (supply and return) will have to be routed between the shelter and the antenna pedestal. From the chiller, glycol piping and tubing will need to be run to the pedestal air conditioning unit, the EMI cabinet, up through the azimuth axis wrap to the cryogenics equipment in the turn head, and through the elevation axis wrap out to the WVR on the rim of the main dish and Front End and Auxiliary enclosures out at the end of the antenna feed-arm (Figure 3).

Parameter	Req. #	Value	Traceability
Flexible Glycol Line Dynamic Bending Radius	EEC1204	The flexible glycol line shall have a minimum dynamic bending radius of ≤ 250 mm.	AD22

Table 35 EEC to Antenna Requirements

The EEC system shall provide a means of dissipating heat from the electronics inside the pedestal EMI cabinet. Because some of the electronics modules are commercial and designed to be air cooled, it was decided to use air to cool all the electronics in the EMI cabinet. A heat exchanger cooled by glycol and some fans for air circulation will be installed in the EMI cabinet. Because the glycol is electrically conductive, the lines connected to the heat exchanger will have to be metallic or covered with a metallic mesh and grounded at both ends to maintain the required RFI shielding.

Parameter	Req. #	Value	Traceability
Heat load from the antenna servo electronics	EEC0074	The maximum heat load from the antenna servo electronics shall be ≤1,850W	TBD
Heat load from the pedestal air conditioner	EEC0080	The maximum heat load from the antenna pedestal air conditioner shall be ≤3,344W	TBD

Parameter	Req. #	Value	Traceability
Diameter of the air duct feeding the turn head	EEC0081	The air duct feeding the cold air to the turn head shall have a diameter of TBD cm to accommodate the estimated 1,624W of heat dissipation	TBD
Diameter of the air duct feeding the pedestal	EEC0082	The air duct feeding the cold air to the pedestal shall have a diameter of TBD cm to accommodate the estimated 1,730W of heat dissipation	TBD
RFI Enclosure Glycol Lines	EEC1151	EEC glycol lines penetrating shielded enclosures shall not degrade the enclosure shielding by more than TBD dB	ETR0601
Heat load at NRAO Electronics Rack	EEC0070	The heat load at the Electronics Rack shall be ≤2,792W	TBD

Table 36 EEC to EMI Cabinet Requirements

Electronics Rack Modules and Heat loads	
Module Number	**Heat Load**
M500 Antenna Supervisor Computer	550W
M501 Maintenance Computer	20W
M502 Electronics Rack PSU	38W
M503 Antenna Ethernet Switch	466W
M504 EEC Electronics	n/a
D501 Digital Back End	620W
D502 WVR Back End	550W
L502 Reference Distribution Repeater Equipment	300W
L503 Reference Receiver and Timing	50W
P500 -48VDC Power Subsystem	198W
Total	**2792W**

Table 37. Electronics Rack Individual Module Heat Loads

7.10.2 Interface EEC to Front End

Interface 0017: 30.60 Environmental Control (EEC) to 30.05 Front End (FED)

The EEC subsystem shall provide cold plates to dissipate heat from electronics modules and subassemblies inside the Front End enclosure. The EEC shall also provide the dry air system that will control the humidity level inside the enclosure to prevent formation of condensation on cryostat windows and radome.

Parameter	Req. #	Value	Traceability
Dry Air System	EEC0024	The EEC shall supply dry air to the Front End enclosure to maintain a dew point in the enclosure of ≤ -5°C TBC	TBD

Table 38 EEC to Front End Requirement

7.10.3 Interface EEC to Cryogenics

Interface 0045: 30.60 Environmental Control (EEC) to 30.10 Cryogenics (CRY)

The EEC subsystem shall provide liquid cooling for the cryogenic equipment. The selected compressor is designed to be liquid-cooled and comes with its own cold plate to cool the oil and the helium gas.

Parameter	Req. #	Value	Traceability
Heat loads at Helium Compressor	EEC0055	The heat load at the Helium Compressor shall be ≤6,400W	[AD28]
Helium Compressor VFD Cooling	EEC1413	The EEC subsystem shall be able to dissipate at least 750W of heat from the helium compressor VFD	TBD
Vacuum Pump Cooling	EEC1412	The EEC system shall be able to dissipate at least 600W of heat from the vacuum pump	[AD28]
F521 Cooling	EEC1400	The EEC subsystem shall be able to dissipate at least 48W of heat from the F521 module (cold head VFD drive module)	[AD24]
F523 Cooling	EEC1401	The EEC subsystem shall be able to dissipate at least 50W of heat from the F523 module (cold head VFD control module)	[AD24]

Table 39 EEC to Cryogenic Equipment Requirements

7.10.4 Interface EEC to Integrated Receiver Digitizer

Interface 0003: 30.60 Environmental Control (EEC) to 30.15 Integrated Receiver Digitizer (IRD)

The EEC subsystem shall provide cold plates to dissipate heat from the IRD modules in the Front End enclosure.

Parameter	Req. #	Value	Traceability
SA501 Cooling	EEC1420	The EEC subsystem shall be able to dissipate at least 440W of heat from the SA501 Band 5-6 IRD/LO module	[AD20]
SA501 Temperature Stability	EEC1421	The temperature stability of the glycol being delivered to the SA501 module shall not vary more than 2°C/hr (TBC)	[AD20]
SA502 Cooling	EEC1422	The EEC subsystem shall be able to dissipate at least 160W of heat from the SA502 Band 1-4 IRD/LO module	[AD20]
SA502 Temperature Stability	EEC1423	The temperature stability of the glycol being delivered to the SA502 module shall not vary more than 2°C/hr (TBC)	[AD20]

Table 40 EEC to IRD Requirements

7.10.5 Interface ECC to Power Supply and Monitor & Control Interface Layer

Interface 0053: 30.60 Environmental Control (EEC) to 30.50 DC Power Supply (PSU) and 30.45 Monitor & Control Interface Layer (HIL)

The EEC subsystem shall provide cold plates to dissipate heat from the power supply modules throughout the antenna. Since the power supply and M&C electronics will be integrated together in the utility modules, the interface with the EEC is the same for both.

Parameter	Req. #	Value	Traceability
M505 Cooling (Cryogenics RFI Utility Module)	EEC1430	The EEC subsystem shall be able to dissipate at least 55W of heat from the M505 module	[AD21],[AD29]
M506 Cooling (Auxiliary Enclosure Utility Module)	EEC1431	The EEC subsystem shall be able to dissipate at least 88W of heat from the M506 module	[AD21],[AD29]
M507 Cooling (Front End Enclosure Utility Module)	EEC1432	The EEC subsystem shall be able to dissipate at least 147W of heat from the M507 module	[AD21],[AD29]
M508 Cooling (WVR RFI Enclosure Utility Module)	EEC1433	The EEC subsystem shall be able to dissipate at least 71W of heat from the M508 module	[AD21],[AD29]

Table 41 EEC to PSU and HIL Requirements

7.10.6 Interface EEC to Water Vapor Radiometer

Interface 0024: 30.60 Environmental Control (EEC) to 45 Water Vapor Radiometer (WVR)

The EEC subsystem shall provide cold plates to dissipate heat from the WVR receiver electronics and back end module.

Parameter	Req. #	Value	Traceability
F507 WVR Receiver Cooling	EEC1450	The EEC subsystem shall be able to dissipate at least 85W of heat from the WVR Receiver electronics	[AD25]
WVR Receiver Temperature Stability	EEC1451	The temperature stability of the glycol being delivered to the WVR Receiver electronics shall not vary more than 2°C/hr (TBC)	[AD25]

Table 42 EEC to WVR Requirements

7.10.7 Interface EEC to LO Reference Timing Distribution

Interface 0069: 30.60 Environmental Control (EEC) to 35.10 LO Reference Timing Distribution (RTD)

The EEC subsystem shall provide the cold plate to dissipate heat from the LO Reference and Timing Distribution module in the Front End Enclosure. The other module located in the EMI cabinet will be air cooled.

Parameter	Req. #	Value	Traceability
L501 Cooling	EEC1460	The EEC subsystem shall be able to dissipate at least 50W of heat from the L501 module	[AD30]

Table 43 EEC to RTD Requirement

8 Key Performance Parameters (KPPs)

Key Performance Parameters (KPPs) identify critical subsystem capabilities or characteristics that may either have a detrimental impact on the effectiveness of efficiency of the system if not met, or could have a very large positive impact if the specification is exceeded. Subsystem KPPs typically support System KPPs and there should be traceability between them. Each KPP must have a threshold range and objective value. The responsible engineer designs the subsystem to meet the objective value, but performance within the threshold range is considered acceptable. During the design phase, there should be a concerted effort to optimize the KPPs. If the responsible engineer finds that the minimum threshold level of a KPP cannot be achieved the project office shall be notified immediately.

Key Performance Parameter	Req. #	Traceability L1 Req. #
KPP name / description: Cooling Capacity Objective value: 17.5kW Threshold range: TBD	EEC0001	TBD
KPP name / description: Glycol Temperature Stability Objective value: ±1°C/hour Threshold range: TBD	EEC0002	TBD
KPP name / description: Glycol Temperature Objective value: 5-10°C Threshold range: TBD	EEC0003	TBD
KPP name / description: Glycol pump flow capacity Objective value: TBD Threshold range: TBD	EEC0004	TBD
KPP name / description: Chiller Power Consumption Objective value: TBD Threshold range:	EEC0007	TBD

Table 44 Subsystem Key Performance Parameters.

9 Verification

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

Verification by Analysis: The compliance of the subsystem to the requirement is demonstrated by appropriate analysis (hand calculations, finite element analysis, modeling and simulation, etc.).

Verification by Inspection: The compliance of the subsystem to the requirement is determined by a simple inspection of the subsystem or of its design documentation.

Verification by Demonstration: The compliance of the subsystem to the requirement is determined by a demonstration.

Verification by Test: The compliance of the subsystem to the requirement is determined by means of a test with and associated analysis of test data.

Multiple verification methods are allowed over the course of the design phase. The primary (final) verification method to be used for the product during the qualification phase prior to its Critical Design Review is identified below.

9.1 Verification Methods

Req. #	Parameter/Requirement	A	I	D	T
EEC0001	Cooling Capacity		*		
EEC0002	Temperature Stability				*
EEC0003	Glycol temperature				*
EEC0004	Glycol pump flow capacity				*
EEC0007	Power Consumption				*
EEC0008	Operating voltage			*	
EEC0009	Glycol mixture		*		
EEC0010	Life of the cooling system	*			
EEC0011	The MTBM for the glycol cooler	*			
EEC0012	Sound Level				*
EEC0013	Refrigerant Type	*			
EEC0020	Heat load at Front End	*			
EEC0021	Glycol flow rate at Front End				*
EEC0022	Pressure drop at Front End				*
EEC0024	Dry Air System				*
EEC0030	Heat load at Auxiliary	*			
EEC0031	Glycol flow rate at Auxiliary				*
EEC0032	Pressure drop at Auxiliary				*
EEC0040	Heat load at WVR	*			
EEC0041	Glycol flow rate at WVR				*
EEC0042	Pressure drop at WVR				*
EEC0050	Heat load at Cryogenics RFI enclosure	*			
EEC0051	Glycol flow rate at Cryogenics RFI enclosure				*
EEC0052	Pressure drop at Cryogenics RFI enclosure				*
EEC0054	Minimum Glycol temperature at Cryogenics Enclosure				*
EEC0055	Heat loads at Helium Compressor		*		
EEC0056	Glycol flow rate at Helium Compressor				*

Req. #	Parameter/Requirement	A	I	D	T
EEC0057	Pressure drop at Helium Compressor				*
EEC0059	Helium compressor maximum Supply pressure				*
EEC0060	Helium pressure regulation module maximum heat dissipation	*			
EEC0070	Heat load at NRAO Electronics Rack	*			
EEC0071	Air flow rate at Electronics Rack				*
EEC0072	Pressure drop at Electronics Rack			*	
EEC0074	Heat load from the antenna servo electronics	*			
EEC0075	Heat load from battery cabinet		*		
EEC0080	Heat load from the pedestal air conditioner		*		
EEC0081	Diameter of the air duct feeding the turn head		*		
EEC0082	Diameter of the air duct feeding the pedestal		*		
EEC0100	Operating Condition Solar Thermal Load			*	
EEC0101	Operating Condition Wind			*	
EEC0102	Operating Condition Temperature	*			
EEC0103	Operating Condition Precipitation	*			
EEC0104	Operating Condition Ice	*			
EEC0105	Operating Condition Relative Humidity	*			
EEC0110	Survival Condition Wind	*			
EEC0111	Survival Condition Temperature	*			
EEC0112	Survival Condition Radial Ice	*			
EEC0113	Survival Condition Rain Rate	*			
EEC0114	Survival Condition Snow Load, Antenna	*			
EEC0115	Survival Condition Snow Load, Equipment & Buildings	*			
EEC0116	Survival Condition Hail Stones	*			
EEC0117	Survival Condition Antenna Orientation	*			
EEC0200	Altitude range	*			
EEC0201	UV radiation	*			
EEC0203	Corrosion Resistance	*			
EEC0204	Dust Protection	*			
EEC0205	Cleaning of Heat Exchanger			*	
EEC0206	Rodent Protection	*			
EEC0207	Seismic Protection	*			
EEC0209	Condensation Protection				*
EEC0500	Environmental Vibrations				*
EEC0501	Mechanical Shocks				*
EEC0502	Generated Vibrations				*
EEC0550	Mean Time Between Failures (MTBF)	*			
EEC0011	MTBM for the glycol cooler	*			
EEC0551	Modularization		*		
EEC0552	Failure Prediction	*			
EEC0600	Self-Monitoring		*		
EEC0610	LRU Identification		*		
EEC0611	LRU Tracking Label and Tag Specifications		*		
EEC0612	Remote Identification			*	
EEC0651	Lifecycle Optimization	*			

Req. #	Parameter/Requirement	A	I	D	T
EEC0700	Follow Safe Design Priorities	*			
EEC0701	Warning Labels		*		
EEC0702	Labeling Quality		*		
EEC0703	Mass and Center of Gravity Marking		*		
EEC0704	Lifting Handles		*		
EEC0705	LRU Multiple Person Lift Label		*		
EEC0706	Lifting Points		*		
EEC0707	Sharp Edges Protection		*		
EEC0708	Cold Plate Pressure testing				*
EEC0709	Protection from Risk of Overpressure	*			
EEC0710	Flexible Glycol Line Working Pressure	*			
EEC0711	Rigid and Flexible Lines Mechanical Attachment		*		
EEC0712	High Voltage Safety Protection		*		
EEC0713	Contact with High Voltage during Diagnosis & Repair		*		
EEC0714	Safety Interlocks			*	
EEC0715	Equipment Stability	*			
EEC0716	Protection from Moving Parts		*		
EEC0717	Leak protection		*		
EEC0750	Subsystem Self-Monitoring			*	
EEC0751	Hardware Failsafe Implementation		*		
EEC0752	Initial Safe State Power-Up			*	
EEC0754	Glycol Level			*	
EEC0800	ESD Susceptibility Testing				*
EEC0801	ESD Protection				*
EEC0802	ESD Packaging and Storage		*		
EEC0803	Prevention & Discharge of Electrostatic Charge Build-Up				*
EEC0804	Lightning Protection	*			
EEC0805	Metallic Braid on Flexible Glycol Lines		*		
EEC0900	AC Power and Grounding Design		*		
EEC0902	Compressor Power Factor	*			
EEC0903	Start-Up Power Consumption				*
EEC0904	Harmonic Distortion				*
EEC0905	Phase Imbalance				*
EEC0906	Chiller Operating Frequency				*
EEC0907	Glycol Pump Operating Frequency				*
EEC0908	Switches and Controls Labeling		*		
EEC0909	AC Voltages Available		*		
EEC0910	AC Voltage Tolerance				*
EEC0950	DC Power & Grounding Design		*		
EEC0951	DC LRU Power Input		*		
EEC0952	Power Supply Dedicated Returns		*		
EEC0953	Power Supply Returns Separate from Ground		*		
EEC0954	DC Voltages Available		*		
EEC0955	-48VDC Tolerance				*

Req. #	Parameter/Requirement	A	I	D	T
EEC0956	PSU Voltage Tolerance				*
EEC1000	Grounding				*
EEC1050	Thermal Protection		*		
EEC1051	Thermal Protection Monitoring		*		
EEC1100	EEC Remote Startup and Recovery Sequence				*
EEC1101	Power Outage Behavior				*
EEC1102	EEC Safety Interlock				*
EEC1103	DC Powered LRU Power ON Indicator		*		
EEC1104	Cold Start		*		
EEC1150	EMC/RFI Mitigation in Designs	*			
EEC1151	RFI Enclosure Glycol Lines	*			
EEC1200	Chiller Tilt Angle		*		
EEC1201	Physical Orientation		*		
EEC1202	Chiller Volume		*		
EEC1203	Compressor Mass		*		
EEC1204	Flexible Glycol Line Dynamic Bending Radius				*
EEC1250	LRU Couplings		*		
EEC1251	Coupling Marking		*		
EEC1252	Metric Fasteners		*		
EEC1253	Stainless Steel Hardware		*		
EEC1254	Type of Fasteners		*		
EEC1255	Hardware Retention		*		
EEC1256	Captive Fasteners		*		
EEC1300	Chromate Converted Surfaces		*		
EEC1301	Stainless Steel Surfaces		*		
EEC1302	Anodized Surfaces		*		
EEC1303	Painted Surfaces		*		
EEC1304	Colored Paint Marking		*		
EEC1305	Surface Preparation for Painting		*		
EEC1350	Cable Documentation		*		
EEC1360	Cables and Harnesses Labeling		*		
EEC1361	Switches and Controls Labeling		*		
EEC1370	DC Wire Color Standard		*		
EEC1371	AC Wiring Color		*		
EEC1380	Wiring Insulation Type		*		
EEC1390	Connector Documentation		*		
EEC1391	Connector labeling		*		
EEC1392	Connector Current rating		*		
EEC1393	Connector Environmental Rating		*		
EEC1394	Cable Mating Cycles	*			
EEC1395	No Exposed Live Terminals		*		
EEC1396	Connector Uniqueness & Keying		*		
EEC1397	Common Connectors		*		
EEC1398	Connector Alignment Guides		*		
EEC1399	Connector Locking or Retaining Mechanism		*		

Req. #	Parameter/Requirement	A	I	D	T
EEC1400	F521 Cooling				*
EEC1401	F523 Cooling				*
EEC1413	Helium Compressor VFD Cooling				*
EEC1412	Vacuum Pump Cooling				*
EEC1420	SA501 Cooling (Band 5-6 IRD/LO)				*
EEC1421	SA501 Temperature Stability				*
EEC1422	SA502 Cooling (Band 1-4 IRD/LO)				*
EEC1423	SA502 Temperature Stability				*
EEC1430	M505 Cooling (Cryogenics RFI Utility Module)				*
EEC1431	M506 Cooling (Auxiliary Enclosure Utility Module)				*
EEC1432	M507 Cooling (Front End Enclosure Utility Module)				*
EEC1433	M508 Cooling (WVR RFI Enclosure Utility Module)				*
EEC1450	F507 WVR Receiver Cooling				*
EEC1451	WVR Receiver Temperature Stability				*
EEC1460	L501 Cooling (Main LO module)				*

10 Appendix

10.1 Abbreviations and Acronyms

Acronym	Description
AD	Applicable Document
AFD	Antenna Fiber Distribution
AIV	Acceptance, Integration, and Verification
ALMA	Atacama Large Millimeter Array
ARCS	Advanced RFI Containment System
ATF	Antenna Time and Frequency
BMR	Bins, Modules, and Racks
CDR	Critical Design Review
CoDR	Conceptual Design Review
COTS	Commercial Off the Shelf
CRY	Cryogenics
DBE	Digital Back End
EEC	Electronics Environmental Control
EMI	Electromagnetic Interference
EVLA	Jansky Very Large Array
FDR	Final Design Review
FE	Front End
FED	Front End
HIL	Hardware Interface Layer (Monitor and Control)
I/F	Interface
ICD	Interface Control Document
IPT	Integrated Product Team
IRD	Integrated Receivers and Digitizers
KPP	Key Performance Parameter
LO	Local Oscillator
LRU	Line Replaceable Unit
MCL	Monitor and Control System
MOE	Measure of Effectiveness
MOP	Measure of Performance
MTBF	Mean Time Between Failure
MTBM	Mean Time Between Maintenance
ngVLA	Next Generation Very Large Array
NRAO	National Radio Astronomy Observatory
PE	Project Engineer
RD	Reference Document
RF	Radio Frequency
RFI	Radio Frequency Interference
RTD	LO Reference and Timing - Distribution
TBC	To Be Confirmed
TBD	To Be Determined
TPM	Technical Performance Measure

VFD	Variable Frequency Drive
WVR	Water Vapor Radiometer

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