Independent Phase Calibration System: Preliminary Requirements

020.45.00.00.00-0001-REQ-A-INDEP_PHASE_CALIBRATION_PRELIM_REQS

Status: **RELEASED**

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Change Record

Version	Date	Author	Affected Section(s)	Reason
01	2018-09-27	Erickson	All	Final 01
02	2018-12-20	Erickson	All	Address RIDs
03	2019-04-30	Erickson	All	Final review
04	2019-05-30	Selina	2.1, 4, 11	Minor edits for release. Updated traceability.
A	2019-07-26	Lear	All	Prepared PDF for signatures and release

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1 Introduction

1.1 Purpose

This document aims to present a set of technical requirements for the reference design of the ngVLA Independent Phase Calibration system.

Many requirements flow down from the preliminary ngVLA System Requirements [AD02], which in turn flow-down 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 draft use cases. This document represents a preliminary analysis of these use cases, and the flow down recursively to the science, system and subsystem requirements.

1.2 Scope

The scope of this document is the ngVLA Independent Phase Calibration system. It includes interface requirements that must be defined.

This requirements document establishes the performance, functional, design, and test requirements applicable to the ngVLA Independent Phase Calibration system.

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.

Ref. No.	Document Title	Rev/Doc. No.
AD01	ngVLA Science Requirements	020.10.15.00.00-0001-REQ
AD02	Preliminary System Requirements	020.10.15.10.00-0003-REQ
AD03	Operations Concept	020.10.05.00.00-0002-PLA
AD04	Protection Against Electric Shock—Common Aspects for Installation and Equipment	IEC 61140:2016
AD07	Insulation Coordination for Equipment within Low-Voltage Systems	IEC 60664
AD08	Occupational Safety and Health Standards for General Industry	29 CFR Part 1910
AD10	Military Handbook, Reliability Prediction of Electronic Equipment	MIL-HDBK-217F
AD11	Non-Electronic Parts Reliability Data	NPRD-95
AD12	Electromagnetic Compatibility	IEC 61000-3-5
AD13	Monitor & Control Hardware Interface Layer: Preliminary Requirements	020.30.45.00.00-0002-REQ

2.2 Reference Documents

The following references provide supporting context:

Ref. No.	Document Title	Rev/Doc. No.
RD01	Fast Switching Calibration at the ngVLA Site	ngVLA Memo No. 1
RD02	Calibration Strategies for the ngVLA	ngVLA Memo No. 2
RD03	The Concept of a Reference Array for the ngVLA	ngVLA Memo No. 4
RD04	Considerations for a Water Vapor Radiometer System	ngVLA Memo No. 10
RD05	Results of Water Vapor Radiometry Tests at the VLA	EVLA Memo No. 73
RD06	A Study of the Compact Water Vapor Radiometer for Phase Calibration of the Karl G. Jansky Very Large Array	EVLA Memo No. 203

3 Overview of the Independent Phase Calibration System Technical Requirements

3.1 Document Outline

This document presents the technical requirements of the ngVLA Independent Phase Calibration system. These parameters determine this system's overall form and performance.

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 Independent Phase Calibration system 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 Independent Phase Calibration system 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 Project Background

The Next Generation Very Large Array (ngVLA) is a project of the National Radio Astronomy Observatory (NRAO) to design and build an astronomical observatory that will operate at centimeter wavelengths (25 to 0.26 centimeters, corresponding to a frequency range extending from 1.2 GHz to 116 GHz). The ngVLA will be a synthesis radio telescope composed of approximately 244 reflector antennas each of 18 meters diameter, and 19 reflector antennas each of 6 meters diameter, operating in a phased or interferometric mode.

The facility will operate as a proposal-driven instrument with Principal Investigator (PI)-led proposals determining the science program. Data will generally be delivered to PIs and the broader scientific community as Science Ready Data Products; automated pipelines will calibrate raw data and create higher-level data products (typically image cubes). Data and quality assured data products will be available through an Observatory science archive. Data exploration tools will allow users to analyze the data directly from the archive, reducing the need for data transmission and reprocessing at the user's institution.

The array's signal processing center will be located at the Very Large Array site on the Plains of San Agustin, New Mexico. The array will include stations in other locations throughout New Mexico, west Texas, eastern Arizona, and northern Mexico. Long baseline stations are located in Hawaii, Washington, California, Iowa, Massachusetts, New Hampshire, Puerto Rico, the US Virgin Islands, and Canada.

Array operations will be conducted from both the VLA site and the Array Operations and Repair Centers in Socorro, NM. A Science Operations Center and Data Center will likely be located in a metropolitan area and will serve as the base for science operations and support staff, software operations, and related administration. Research and development activities will be split among these centers as appropriate.

3.3 General Description

The independent phase calibration system consists of a water vapor radiometer (WVR) that measures atmospheric water vapor concentration in the antenna main beam. This data can be used to provide continuous phase calibration between calibrator source measurements.

The WVR has its own antenna: a fixed dish one meter in diameter mounted below the main dish. A WVR receiver module sits at the offset Gregorian focus of this antenna, and receives, amplifies, downconverts, and digitizes a band from 18–30 GHz. The receiver is temperature stabilized by a thermally regulated plate on which the electronics are mounted. The whole unit is thermally stabilized by the antenna liquid cooling system with a Peltier thermoelectric device for fine temperature regulation. Power is delivered to the receiver module and to a feed heater located in front of the module from the –48V antenna power supply via a junction box near the receiver module.

Digitized data is sent over dedicated fiber to a high-speed FPGA-based processing module in the pedestal room electronics rack. The low-speed processed data is injected onto the antenna monitor and control data stream for inclusion in the science data package. The processing module is powered and cooled by standard rack power and cooling air.

3.4 Summary of WVR System Requirements

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

3.4.1 General Technical Requirements

Parameter	Summary of Requirement	Reference Reqs.
Precipitable water vapor relative measurement	35µm	WVR0001
Measurement interval	≤1s	WVR0002
Beam diameter	≤18m at 2km	WVR0003
Pointing offset from main beam	≤0.7deg	WVR0004
Digitized bandwidth	18–26GHz	WVR0005
Receiver temperature stability	≤2.5mK over 20 minutes	WVR0006
Receiver components temperature	30C +/– 2C	WVR0007
Channel count (minimum)	32	WVR0008

- **Precipitable water vapor relative measurement**: See VLA Memo 203 [RD06] for derivation.
- **Measurement interval**: Expected wind speeds at the altitude at which most precipitable water vapor (PWV) is expected from the relationship between WVR spacing and frequency of measurement. For 100m WVR antenna spacing, 10m/s wind speeds imply a 10s integration time. A factor of ten is incorporated to allow averaging and to give buffer room for faster wind speeds.
- **Beam diameter**: The WVR beam should sample the main beam at all altitudes where PWVR is present, but must sample the main beam accurately where the primary region of turbulent PWVR is known to exist at 2km above ground level (AGL).

- **Pointing offset from main beam**: As above, the WVR beam must sample the main beam. The pointing offset limits the beam offset to a reasonable amount at 2km AGL.
- **Digitized bandwidth**: The broad water vapor spectral line centered near 22GHz must be sampled entirely. Additionally, one must separate it from the superimposed liquid water emission and the O_2 line emission.
- **Receiver temperature stability**: The PWVR measurement forces a very tight gain stability specification, which in turn requires that the components be held to a very tight temperature range.
- **Receiver components temperature**: The absolute temperature of the components—more specifically, the connecting wires—is chosen to minimize the effects on the RF signal from thermally-induced changes in the properties of Teflon and related insulation materials.
- **Channel count**: High channel count allows excision of expected RFI to be performed without significantly impacting measurement accuracy.

3.4.2 Other General Requirements

Parameter	Req. #	Summary of Requirement	Reference Reqs.
Design Life	WVR1001	Design for an expected operational life no less than 20 years, excluding the batteries	SYS2701
Maintenance Interval	WVR1002	Preventive maintenance interval of no shorter than 2 years, with a goal of 4 years.	SYS2401
Mean Time Between Failures (MTBF)	WVR1003	Antenna electronics has MTBF of 35,040 hours each.	SYS2402
Modularization	WVR1004	Line Replaceable Units (LRU) to facilitate site maintenance	SYS2403
Altitude Range	WVR1005	Sea level to 2500 meters	ENV0351
Lightning Protection	WVR1006	Protect against Lightning Electromagnetic Impulse	ENV0512
Equipment Protection Against Dust	WVR1007	Exposed equipment shall be protected against windblown dust, ashes, and grit	ENV0541
Rodent Protection	WVR1008	Exposed equipment shall be designed to prevent rodent damage	ENV0551
Transportation Environment	WVR1009	Designed to withstand typical loads and environments encountered during transportation	ENV0581
Mechanical Shock	WVR1010	Designed to survive mechanical shock levels	ENV0582
Equipment Shielding	WVR1011	All equipment shall be shielded and have it AC power line and communication lines filtered at the chassis	ENC0327
EMC Test Frequencies	WVR1012	RFI suppression shall extend from 50 MHz to 12 GHz	EMC0328
Hazzard Analysis	WVR1013	Hazard analysis shall be performed for all high-power systems. Include lock-outs for service by technicians	SYS2703

Parameter	Req. #	Summary of Requirement	Reference Reqs.
Precision Operation Temperature Conditions	WVR1014	–15°C ≤ T ≤ 25° C	ENV0313
Precision Operation Temperature Rate of Change Conditions	WVR1015	1.8°C/Hour	ENV0314
Limits to Operating Conditions	WVR1016	–20°C ≤ T ≤ 45°C	ENV0332
Survival Temperature Conditions	WVR1017	–30°C ≤ T ≤ 50°C	ENV0342
Storage Requirements	WVR1018	–65°C ≤ T ≤ 125°C	

4 Functional and Performance Requirements

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

4.1 Performance Requirements

Parameter	Req. #	Summary of Requirement	Traceability
System temperature (T_{sys})	WVR0009	300 K	SYS1504
T_{sys} measurement accuracy	WVR0010	20 mK	SYS1504
T_{sys} drift over 1 minute	WVR0011	5 K	SYS1504
T_{cal}/T_{sys}	WVR0012	10 %	SYS1504
Gain drift with temperature	WVR0013	0.66 %/C	SYS1504

- **T_{sys}**: The WVR is non-cryogenic; ambient T_{sys} allows WVR data recovery.
- **T_{sys} measurement accuracy**: Calibration requires accurate measurement of T_{sys}.
- **T_{sys} 1-minute drift**: Between calibrator fixes, T_{sys} must be held to close tolerance to allow accurate measurement of changes in PWVR signal.
- **T_{cal}/T_{sys}**: Lab calibration must be maintained at or below a fixed fraction of T_{sys}.
- **Gain drift with temperature**: Highly accurate temperature control of amplifiers reduces variations in amplitude with temperature. As temperature variation can never be reduced to zero, amplifiers must meet a requirement for gain drift with temperature to maintain adequate SNR.

4.2 Spurious Signals/Radio Frequency Interference Generation

Processor, receiver, and other WVR-specific modules shall be verified to comply with ngVLA RFI emissions standards as specified in 020.10.15.10.00-0002-REQ.

4.3 Environmental Conditions

The WVR receiver component must meet both Normal and Precision Environmental conditions as defined in 020.10.15.10.00-0001-SPE.

4.4 Maintenance and Reliability Requirements

Parameter	Req. #	Value	Traceability
Mean Time Between Failures	WVR0101	MTBF ≥ 2000 hrs.	SYS2302

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.

4.5 Monitor and Control Requirements

Parameter	Req. #	Value	Traceability
Self-Monitoring	WVR0201	The Independent Phase Calibration system 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

All WVR modules will provide monitor points per the ngVLA Monitor and Control protocol [AD13] at the necessary intervals. Control points will be documented and tested to comply with the ngVLA Monitor and Control protocol.

4.6 Lifecycle Requirements

Parameter	Req. #	Value	Traceability
Design Life	WVR0301	The Independent Phase Calibration system shall be designed to be operated and supported for a period of 20 years.	SYS2801
Lifecycle Optimization	WVR0302	The Independent Phase Calibration system design shall minimize its lifecycle cost for 20 years of operation.	SYS2802

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

5 Interface Requirements

This section provides information about the interfaces of the Independent Phase Calibration system. Interface Control Documents (ICDs) are required between the Independent Phase Calibration system and all connecting systems. In many cases, specifications for the interfaces are not yet available, but the broad scope of the ICD can be defined.

These interfaces shall be developed and documented by the Independent Phase Calibration system Designer, and approved by ngVLA, as part of the Independent Phase Calibration system 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 Antenna Liquid Cooling System

The Receiver Cooling Plate shall interface with the antenna liquid cooling system via standard fittings as specified by the ALC specification. Protection to the liquid cooling lines shall be applied per the same specification.

5.2 Interface to the Monitor and Control Network

Interface to the Monitor and Control system shall be per the ngVLA M&C specification for each WVR component. It should be noted that WVR output data will also be transmitted on the M&C network as a standard monitor point.

5.3 Interface to the Antenna Mechanical Structure

Mechanical connection of the WVR components to the antenna structure shall be evaluated under the auspices of antenna designers and engineers to ensure that safety and performance specifications are met for both the mounted module and the structure to which it is attached. Preventive maintenance and inspection items shall be specified for each mounting structure.

5.4 Interface to the Pedestal Room Rack Cooling System

WVR processor module cooling requirements shall be compatible with pedestal room rack cooling systems.

5.5 Interface to the Pedestal Room Rack Power System

WVR processor module power requirements shall be compatible with pedestal rack power systems.

6 Subsystem Requirements

Derivation of any subsystem requirements shall be included as part of the Independent Phase Calibration system 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 Mechanical Safety

Mechanical safety assessment will be based on a Safety Hazard Analysis.

7.2 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 [AD07] while taking into account the altitude of up to 2500 m above sea level.

7.3 Handling, Transport, and Storage Safety

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

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 in order to locate weak design points and to determine whether the design meets the Maintenance and Reliability requirements. ngVLA suggests to apply the Parts Count Method for predicting the reliability of the system as described in the MIL-HDBK-217F, but the designer may propose to use other methods. For non-electronic parts the values of NPRD-95 [AD22] may be used, or data from manufacturers or other databases may be used.

Another, but more time consuming (and considered more accurate) method, the Parts Stress Analysis Prediction, is also described in MIL-HDBK-217F. 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 MIL-HDBK-217F.

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 Independent Phase Calibration system element shall exhibit complete electromagnetic compatibility (EMC) among components (intra-system electromagnetic compatibility). See EMC specification EMC0328.

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 similar system may be used upon approval by ngVLA.

For Line Replaceable Units (LRU, see Section 12.2), it is highly desirable that the serial number of the LRU be ascertainable over the Monitor and Control interface (see Section 5.2).

8.3.5 Labels

All cables and switches, junction boxes, sensors, and similar equipment shall be labeled using a system of marking based on barcodes.

9 Documentation Requirements

9.1 Technical Documentation

All documentation related to the Independent Phase Calibration system 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 Independent Phase Calibration system 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/unit with the specified performance shall be demonstrated by tests. A FAT is performed w/o integration with interfacing systems.

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

Multiple verification methods are allowed.

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

Req. #	Parameter/Requirement	D	A	I	FAT	SAT
WVR001	Precipitable water vapor relative measurement		X			X
WVR002	Measurement interval			X	X	
WVR003	Beam diameter		X			X
WVR004	Pointing offset from main beam					X
WVR005	Digitized bandwidth		X	X	X	
WVR006	Receiver temperature stability		X		X	X
WVR007	Receiver components temperature		X		X	X
WVR008	Channel count	X		X		
WVR009	System temperature (T_{sys})		X		X	X
WVR010	T_{sys} measurement accuracy		X		X	X
WVR011	T_{sys} drift over 1 minute		X		X	X
WVR012	T_{cal}/T_{sys}		X		X	
WVR013	Gain drift with temperature		X		X	

Table 1 - Expected requirements verification method.

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 often 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 Independent Phase Calibration system (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 Table 9. 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. #
Precipitable water vapor relative measurement	WVR001
Pointing offset from main beam	WVR004
Receiver temperature stability	WVR006

Table 2 - Key Performance Parameters for monitoring during design.

12 Appendix

12.1 Abbreviations and Acronyms

Acronym	Description
AD	Applicable Document
CDR	Critical Design Review
CoDR	Conceptual Design Review
CW	Continuous Wave (Sine wave of fixed frequency and amplitude)
EIRP	Equivalent Isotropic Radiated Power
EM	Electro-Magnetic
EMC	Electro-Magnetic Compatibility
EMP	Electro-Magnetic Pulse
FDR	Final Design Review
FEA	Finite Element Analysis
FOV	Field of View
FWHM	Full Width Half Max (of Primary Beam Power)
HVAC	Heating, Ventilation & Air Conditioning
ICD	Interface Control Document
IF	Intermediate Frequency
KPP	Key Performance Parameters
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LO	Local Oscillator
LRU	Line Replaceable Unit
MTBF	Mean Time Between Failure
MTTF	Mean Time To Failure
MTTR	Mean Time To Repair
ngVLA	Next Generation VLA
RD	Reference Document
RFI	Radio Frequency Interference
RMS	Root Mean Square
RSS	Root of Sum of Squares
RTP	Round Trip Phase
SAC	Science Advisory Council
SNR	Signal to Noise Ratio
SRSS	Square Root Sum of the Square
SWG	Science Working Group
TAC	Technical Advisory Council
TBD	To Be Determined
VLA	Jansky Very Large Array

12.2 Maintenance Definitions

12.2.1 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 Independent Phase Calibration system.

A step-by-step procedure for safe exchange of every LRU shall be provided in the Maintenance Manual.

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

12.2.2 Periodic Preventive Maintenance

Preventive maintenance may be performed at planned intervals in order to keep the Independent Phase Calibration system operational and within its specified performance. Any required preventive maintenance should be documented in the Maintenance Manual.