ngVLA Antenna Time and Frequency Technical Requirements

020.30.35.00.00-0004 REQ

Status: **RELEASED**

PREPARED BY	ORGANIZATION	DATE
B. Shillue, J. Muehlberg	Central Development Laboratory, NRAO	2024-07-10

APPROVALS	ORGANIZATION	SIGNATURES
B. Shillue, Central Electronics IPT	ngVLA, NRAO	B. Shillue (Aug 19, 2024 10:25 EDT)
P. Kotzé, Systems Engineer	ngVLA, NRAO	Pieter Kotzé (Aug 19, 2024 12:55 MDT)
R. Selina, Project Engineer	ngVLA, NRAO	Rob Selina (Aug 22, 2024 09:00 MDT)
W. Esterhuyse, Project Manager	ngVLA, NRAO	

RELEASED BY	ORGANIZATION	SIGNATURE
W. Esterhuyse, Project Manager	ngVLA, NRAO	

Change Record

Version	Date	Author	Affected Section(s)	Reason
1	2021-10-27	B. Shillue	All	Initial Draft
2	2022-03-25	B. Shillue	All	Incorporated comments from formal internal review.
3	2022-03-28	J. Muehlberg	All	Review and revisions.
A	2022-04-01	A. Lear	All	Formatting, minor copy edits. Prepared PDF for signatures and release.
A.1	2024-01-23	B. Shillue	many	Expanded Section 3.4, Added Requirements ATF1208, ATF1215, ATF1290. Other minor updates throughout
A.2	2024-02-23	B. Shillue	Many	Major revisions to 7.3, 7.5, 9 Minor revisions throughout
B	2024-02-29	M. Archuleta	All	Minor formatting and edits; prepared for release.
C	2024-07-10	B. Shillue		ATF1215, ATF0210, ATF4210, ATF4220 clarified.

Table of Contents

1 Introduction

1.1 Purpose

This document presents the complete set of Level 2 subsystem requirements that should guide the design and development of the Antenna Time and Frequency (ATF) subsystem. 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 overall requirements hierarchy and management strategy are outlined in [AD01] and [AD02].

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 Antenna Time and Frequency (ATF) subsystem, as delivered for ngVLA integration. This includes the following:

- Assumptions upon which the requirements are based
- Definition of environmental requirements to be used as applicable conditions in the definition of the 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.
- Nonfunctional requirements unique to this subsystem (e.g., safety, quality, reliability, maintainability).
- List of Interface Requirements (I/F) and link to Interface Control Documents necessary to integrate with other Systems and Subsystems.
- Numbering of all requirement and establishment of traceability to higher level requirements.
- Technical Performance Measures (TPMs) at the subsystem level, which support the Measures of Performance (MOPs) at the system level.
- Requirements specified for the complete lifecycle of the subsystem, including any requirements that are applicable for operations, maintenance, decommissioning, and disposal.

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	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 System Electronics Specifications	020.10.15.10.00-0008 REQ
AD10	Calibration Requirements	020.22.00.00.00-0001 REQ
AD11	System Technical Budgets	020.10.25.00.00-0002 DSN

2.2 Applicable Interface Control Documents

Ref. No.	Document Title	Doc. No.
AD20	Interface Control Document Between: Antenna Electronics Integrated Receiver and Downconverters (IRD) *and* Antenna Time and Frequency (ATF)	020.10.40.05.00-0005
AD21	Interface Control Document Between: Antenna Electronics DC Power Supply (PSU) *and* Antenna Time and Frequency (ATF)	020.10.40.05.00-0059
AD22	Interface Control Document Between: Digital Backend (DBE) *and* Antenna Time and Frequency (ATF)	020.10.40.05.00-0152
AD23	Interface Control Document Between: Water Vapor Radiometer (WVR) *and* Antenna Time and Frequency (ATF)	020.10.40.05.00-0028
AD24	Interface Control Document Between Antenna Electronics: Bins, Modules, Racks (BMR) *and* Antenna Time and Frequency	020.10.40.05.00-0040
AD25	Interface Control Document Between Antenna Electronics: Antenna Fiber Distribution (AFD) and Antenna Time and Frequency (ATF)	020.10.40.05.00-0041
AD26	Interface Control Document Between Antenna Time and Frequency (ATF) *and* Antenna Electronics Environmental Control System (EEC)	020.10.40.05.00-0070

Ref. No.	Document Title	Doc. No.
AD27	Interface Control Document Between: Antenna Electronics Monitor and Control Hardware Interface Layer (HIL) *and* Antenna Time and Frequency (ATF)	020.10.40.05.00-0078
AD28	Interface Control Document Between: LO Reference and Timing – Distribution (RTD) *and* Antenna Time and Frequency (ATF)	020.10.40.05.00-0125

2.3 Reference Documents

The following documents are referenced within this text or provide supporting context:

Ref. No.	Document Title	Doc. No.
RD01	Science Requirements	020.10.15.05.00-0001 REQ
RD02	ANSI Z136 Standards for Implementing a Safe Laser Program	ANSI Z136.1 through .9
RD03	Safety of Laser Products – Part 1: Equipment Classification and Requirements	IEC 60825-1:2014
RD04	R. Selina, B. Shillue, O. Ojeda, M. Schiller, "Timing Requirements & Considerations"	ngVLA Electronic Memo #15, July 2023
RD05	M. Morgan "Downconversion and Digitization Methodology for the ngVLA"	ngVLA Electronic Memo #1, Jan 2020
RD06	R. Selina, B. Shillue, O. Yeste, Ojeda, M. Schiller, "Supporting Spectral Dynamic Range Requirements"	*ngVLA Electronics Memo, in prep*
RD07	Integrated Receivers and Digitizers: Technical Requirements	020.30.15.00.00-0003 REQ
RD08	Integrated Receivers and Digitizers: Design Description	020.30.15.00.00-0004 DSN
RD09	JESD204C Standard	https://www.jedec.org/standards-documents/docs/jesd-204a
RD10	ngVLA Digitizer Trade Study	020.10.25.00.00-0007 REP
RD11	IRD design risk reduction	020.10.60.10.00-0003 ECR

3 Overview of Subsystem Requirements

3.1 Document Outline

This document presents the technical requirements for the Antenna Time and Frequency subsystem. These parameters determine the overall performance of the subsystem and the functional requirements necessary to enable its operation and maintenance.

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 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 have a degree of ambiguity or are insufficiently substantiated, this is also documented in the notes. In this way, the trade-space available is apparent to scientists and engineers who will guide the evolution of the ngVLA concept.

In certain cases, parameters are simply noted with a TBD or TBC value. The goal in such cases is to identify parameters that will require definition in future releases of the Antenna Time and Frequency Subsystem Requirements as the associated technical issues are understood.

Section 11 identifies performance metrics that will be monitored throughout the conceptual design phase. These are metrics to assist in the trade-off analysis of various concepts, should tensions be identified between requirements.

3.2 Subsystem General Description

The Antenna Time and Frequency Subsystem compromises a set of modules that perform a function of hardware timekeeping: generation and routing of an electronic signal, pulse, or digital rising or falling edge from a common reference input to another module or subsystem. These can include for instance local oscillators or digital clocks.

3.3 Subsystem Boundary and External Interfaces

Figure 1 (on the next page) shows the Antenna Time and Frequency subsystem boundaries, in the context of other systems on the antenna. External systems are shown in boxes with their Configuration Item (CI) number, in accordance with the Product Breakdown Structure (PBS) generated from the system architecture model. The ICD document number corresponding to each interface is displayed above the interconnect, where it exists.

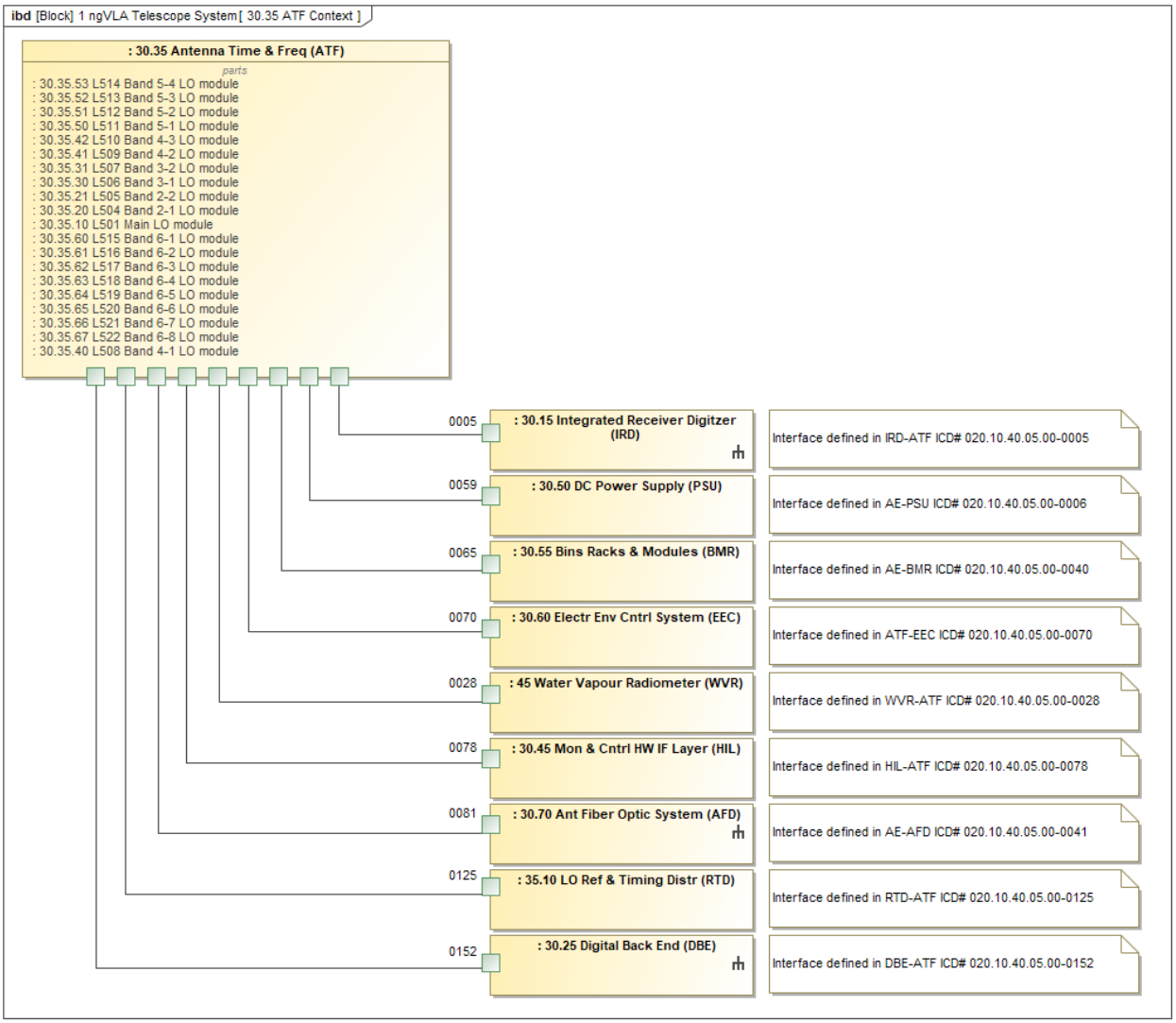

Figure 1: Antenna Time and Frequency subsystem product breakdown, interfaces with other antenna subsystems.

3.4 Key Requirements Summary

The following table extracts a subset of the requirements from Section 7that are considered driving requirements for the ATF subsystem design.

Table 1 - Key Requirements for Antenna Time and Frequency

Parameter	Value	Requirement #
LO Phase Noise	< 76 fsec integrated from 1 Hz to maximum IF frequency offset Goal < 50 fsec	ATF1240
This is the phase noise requirement directly flowed down from Systems Requirements. The phase noise is most important at the antenna local oscillator and digitizer clock. References provided by RTD subsystem and		

transferred to ATF subsystem shall be consistent with ultimately meeting the antenna LO phase noise requirement. In most cases the design of a distributed LO or clocking system will utilize phase lock loops or jitter cleaners in the distribution that make parts of the original central source phase noise spectrum irrelevant. So the interpretation of this requirement is:

(a) The RTD phase noise spectrum provided as input to ATF subsystem shall be consistent with ultimately meeting the overall system phase noise requirement at the antenna.

The ATF subsystem shall provide frequency sources and frequency references such that the total LO integrated phase noise requirement ATF1240 is met.

LO Phase Drift	< 59 fsec at 300 s for output of ATF including the RTD distribution < 42 fsec for ATF subsystem alone (linear term removed) < 250 fsec absolute	ATF1250

This requirement is applicable to the entire distributed LO system for ngVLA. Most significant sources of LO phase drift may be expected to be incurred in the RTD and ATF subsystems. In particular, in the RTD subsystem it is necessary to compensate for phase drift associated with the fiber link. The requirements noted above are applicable after any round trip compensation is applied.

These requirements come from SYS1504, 1505, 5001 in "ngVLA System Requirements," NRAO Doc# 020.10.15.10.00-0003-REQ:
SYS1504 The (relative) system phase drift residual shall not exceed 95 fsec rms per antenna over 300 seconds. Goal to meet this specification over a period of 1000 seconds.
SYS1505 The absolute phase drift per antenna over 300 seconds shall not exceed 4 psec. Goal to meet this specification over 1000 seconds.
SYS5001 takes the relative (95 fsec) and absolute (4000 fsec) drifts and allocates them to different subsystems. The Antenna Time and Frequency subsystem is allocated 1/5th of the total rms noise (i.e. 95/$\sqrt{5}$ = 42 fsec) for residual noise. The requirement ATF 1250 takes into account the need to verify the phase drift with and without the RTD frequency drift subsystem. For phase drift between two LO units measured without fiber optic distribution, the phase drift requirement is 42 fsec. Including the fiber optic distribution (and compensation) the requirement is 42 fsec *$\sqrt{2}$ = 59 fsec.
For absolute drift over 1000 seconds, $\tau = 250$ fsec is equivalent to 0.17 rad of phase scaled to the maximum LO frequency of 113.1 GHz.

Spurious Narrowband Tones	Spurious narrowband tones introduced in the LO spectrum may be expected to pass directly to the receive path. These tones shall contribute no more than -43 dB/MHz relative to the system noise level in the IF receive path. ***Derived requirement (see below)*** Within 3.5 GHz of carrier < –103 dBc Beyond 3.5 GHz from carrier < –48 dBc	ATF1500

- Assume that the LO power is + 10 dBm.
- Further assume that the receive signal path noise floor is low ~ –80 dBm/Mhz. The requirement sets the spurious at –43 dB relative to this level, or –123 dBm/MHz.

If the conversion efficiency of spurious inputs at the LO port was about the same as inputs at the RF port, then we would need to suppress those spurious inputs by 10 + 123 = 133 dBc. Direct port-to-port leakage of the tone is likely to be less significant than downconversion, and in any case the spurs we are currently concerned with lie well outside the IF baseband frequency range, and will be significantly attenuated by the baseband signal path if not downconverted first.

This downconverted LO path can be mitigated by the use of balanced mixers, anti-alias filtering, and the use of saturated amplification in the receiver LO path. These details may be different depending on the LO frequency and receiver or downconverter band.

For instance, the anti-aliasing filters will suppress signals more than ~3.5 GHz away from the primary LO by at least 55 dB (IRD062x). Second, the mixers will likely all be balanced, which should suppress LO noise and inputs by another 15 dB or so. Finally, LO buffer amps inside the IRD modules will likely be run in compression, which would tend to suppress weak signals which are present on top of the primary LO. We can conjecture an additional 15 dB (TBC) for this effect. So, with these effects we can relax our spurious LO tone suppression spec (for signal beyond 3.5 GHz) to 133–55–15–15 = –48 dBc. Or, for tones close (within 3.5 GHz) to the carrier –103 dBc.

LO Frequency Ranges	LO frequencies shall be provided to support downconversion (except instances of direct conversion).	ATF1200
These shall fall in or near to the range of sky frequencies required for ngVLA: 1.2–8 GHz, 8–50 GHz, and 70–116 GHz. Fixed or tunable LOs shall allow for continuous frequency coverage across these spans. Additionally, the design plan shall allow for simultaneously multiple LOs in a given receiver band so that the full available instantaneous downstream processing bandwidth can be achieved, and so that discontinuous portions of a band may be selected.		
LO Frequency Table	Given the overall frequency ranges covered by ngVLA, the detailed design of the Front End receiver and downconverter spanning this range will determine the specific LO tunings for each downconverter (IRD module) and receiver band.	ATF1205
A tuning plan, or table, with required amplitudes and frequencies will be specified in the ICD between the ATF and the IRD. The current working version of this frequency table is shown below:		

RF Band	Module	RF start (GHz)	stop (GHz)	LO harmonic	(GHz)
2	a	3.5	12.3	2	5.8
	b			4	11.6
3	a	12.3	20.5	5	14.5
	b			7	20.3
4	a	20.5	34	8	23.2
	b			10	29
	c			12	34.8
5	a	30.5	50.5	11	31.9
	b			13	37.7
	c			15	43.5
	d			17	49.3
6	a	70	116	25	72.5
	b			27	78.3
	c			29	84.1
	d			31	89.9
	e			33	95.7
	f			35	101.5
	g			37	107.3
	h			39	113.1

LO Frequency Offsets	Nominal LO frequencies shall be capable of frequency offsetting on a per antenna basis.	ATF1210

The considerations around the implementation of this requirement are detailed in [RD06]. Each antenna station will incorporate a fixed frequency offset that is a multiple of a small fixed offset. The current design value of this fundamental offset is 15.68 kHz. Thus, an antenna will have its LO offset by an amount of m*15.68 kHz, where m is an index representing the antenna station and can take on values m= –131, –130,…, –1,0,1,…130,131 for an overall offset range of +/-131*15.68 kHz equals +/- 2.054 MHz. Similarly, the digitizer clock shall offset by the same amount.

Since bands 2–6 all have more than one LO, it is noted that the fixed offset attached to each LO in a particular band results in a different ratio between the offset and the LO frequency. This has implications for the LO design and is not a requirement but rather a system design choice subject to review and/or change.

Also, it is noted that the incremental assignment of offsets to stations applies only within a single science subarray. Thus, only when all antennas are in a single subarray would the full +/- 2.054 MHz tuning range be used. This, and the fact that subarrays can be re-assigned amongst sets of antenna stations, means that the fixed offset is tunable across m= –131, –130,…, –1,0,1,…130,131.

Digitizer/ Sampler Frequency	The Digitizer, or Sampler, implementation depends on the Front End design. The ATF shall supply a digitizer frequency, or a reference frequency, as necessary, to support the Front End implementation.	ATF1208

Specific frequency (-ies) required for support of digitizers will be communicated to ATF via Antenna Electronics IRD group by means of ICD between ATF and IRD [AD20].

Digitizer/ Frequency Offsets	The reference clock supplied to the digitizer shall be capable of frequency offsetting on a per antenna basis.	ATF1215

Digitizer/Sampler Frequency Offsets: not a strict requirement but per [SYS2015] a desirable feature. See especially the discussion in [RD06]. The implementation of offsets will be detailed in the ICD between ATF and IRD [AD20], as well as the ICD between ATF and DBE [AD22]. A potential implementation is as follows:

Each antenna station will incorporate a fixed frequency offset to the digitizer (or digitizer reference) that is a multiple of a small fixed offset. The current design value of this fundamental offset is 15.68 kHz. If the offset is to be applied to a reference to the digitizer that is fractionally related to the digitizer clock frequency, then the offset shall be applied as the same fraction multiplied by 15.68 kHz. Thus, an antenna will have its digitizer offset by an amount of m*15.68 kHz, where m is an index representing the antenna station and can take on values m= –131, –130,…, –1,0,1,…130,131 for an overall offset range of +/-131*15.68 kHz equals +/- 2.054 MHz.

Also, it is noted that the incremental assignment of offsets to stations applies only within a single science subarray. Thus, only when all antennas are in a single subarray would the full +/- 2.054 MHz tuning range be used. This, and the fact that subarrays can be re-assigned amongst sets of antenna stations, means that the fixed offset to applicable to a particular station shall be tunable to any of the values for m= –131, –130,…, –1,0,1,…130,131.

Timing to CSP-DBE	Timing accuracy to CSP-DBE shall be within 2 nsec (goal of 1 nsec) Relative to the central system clock on short timescales and relative to the absolute timing standard over 1-day averaging	ATF1300

Note: DBE subsystem is located at antenna pedestal. This requirement includes RTD correction for fiber link delay, and accurate transmission of the corrected timing signal to the DBE subsystem at the antenna

Digitizer JESD Clocking	LO and Timing requirements for support of commercial digitizer chosen for implementation in IRD modules shall support the relevant JESD technical standard	ATF1290

JESD204D is expected to be the standard of the eventual ngVLA digitizer. This standard is not published yet. However, clock and timing requirements are expected to be similar to the published JESD204C standard [RD09]

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 expressed in technical functional or performance terms, but still implementation agnostic (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

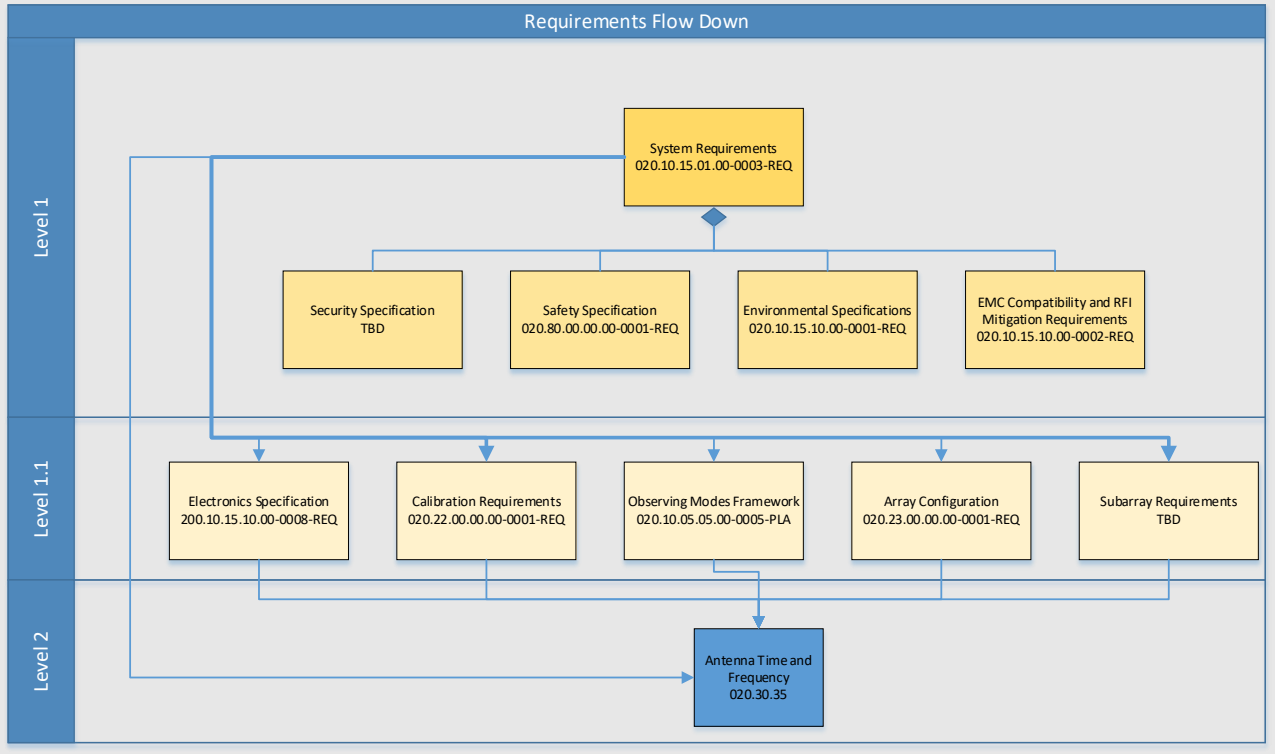

Figure 2 – Requirements flow-down to the Antenna Time and Frequency Subsystem Requirements.

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 and traceable science requirements, system requirements, and subsystem specifications ensures this trade-off process is complete and well understood by the project team. The effect of a change in a subsystem specification can be analyzed at the system level, and thereafter the impact on a specific scientific program can be ascertained.

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.
- Notwithstanding the desire that these requirements be implementation agnostic, a set of subsystems is assumed that interfaces with the ATF subsystem on the antenna. These are defined and an overview of the interface requirements included in Section 9.
- A receiver and water vapor radiometer are located on the elevated moving structure of the antenna
- A digital backend is located in the antenna pedestal

6 Environmental Conditions

The Antenna Time and Frequency subsystem components will be located in or on the Antenna Stations. The ATF equipment can be located either: inside the antenna pedestal, or on the elevated (and moving) structure of the antenna.
Local oscillators need to be provided to the receiver downconverters, close to the secondary focus of the antenna. Therefore, the applicable environmental conditions for a given subsystem, assembly, line-replaceable unit, or shop replaceable unit depends on its location and local conditions.
All ATF equipment shall be installed in environmentally controlled facilities or racks. As such, the normal operating conditions are defined by the applicable ICD:

- [AD24] 020.10.40.05.00-0040 (Interface 0065): Interface Control Document Between Antenna Electronics: Bins, Modules, Racks (BMR) *and* Antenna Time and Frequency
- [AD26] 020.10.40.05.00-0070: Interface Control Document Between Antenna Time and Frequency (ATF) *and* Antenna Electronics Environmental Control System (EEC)

6.1 Survival Conditions

The ATF subsystem when installed on the antenna shall survive without sustaining residual damage the following conditions:

Parameter	Req. #	Value	Traceability
Temperature	ATF0110	–30 C ≤ T ≤ +50 C This is the range of ambient temperature to which the modules may be exposed, thus internal temperatures may rise above that	ENV0342
Thermal Shutdown	ATF0115	The ATF equipment will shutdown when temperatures exceeding a safe level have been detected	ATF0110

All ATF equipment is expected to be housed in a temperature-controlled environment. However, in case of power outage, the survival temperature range is applicable.

6.2 Transportation Conditions

Parameter	Req. #	Value	Traceability
Packaging for Transportation	ATF0160	All ATF LRUs shall be transported using ESD, thermal and vibration protective packaging in accordance with the System Environmental and Electronics Specifications	ETR0503 ENV0381 ENV0382 ENV0531
Solar Thermal Load	ATF0170	Exposed to full sun, 1200W/m^2 (within transport cases)	ENV0381
Transportation Temperature	ATF0180	–30 C ≤ T ≤ +60 C (within transport cases)	ENV0382
General Vibration	ATF0190	Vibration on all three axes, for 60 minutes.	ENV0531
Mechanical Shock	ATF0200	LRUs packaged for shipping shall survive a mechanical shock level defined in [AD04]. In case of shop replaceable units (SRU), these shall be designed to withstand the drop requirement when they are packaged for shipment within the LRU.	ENV0582

The ATF subsystem is expected to consist of some products that are LRUs and some that are SRUs. The former, for instance, could be a module located in a rack in the antenna pedestal. The latter would be an LO SRU packaged into the Front End enclosure which is an LRU. The drop test is applicable to the LRU with testing conducted on the LRU in its shipping container.

6.3 Storage Conditions

Parameter	Req. #	Value	Traceability
Packaging for Storage	ATF0210	All ATF LRUs shall be stored using ESD and thermal protective packaging in accordance with the System Environmental and Electronics Specifications. Storage temperature range is 0 to 30 deg C with controlled humidity.	ETR0503 ENV0372 ENV0373

6.4 Site Elevation

Parameter	Req. #	Value	Traceability
Altitude Range	ATF0220	All ATF elements shall be designed for operation and survival at altitudes ranging from sea level to 2500 m.	ENV0351, [AD26]

Equipment using air flow as a means of temperature regulation shall account for reduced air pressure at 2500 m.

6.5 Environmental Protection Requirements

6.5.1 Seismic

Parameter	Req. #	Value	Traceability
Seismic Protection	ATF0230	The ATF 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. Units shall not sustain residual damage under these conditions while in the installed and operational state.	ENV0521

6.5.2 Lightning, Dust, Fauna, Rain/Water Infiltration and Corrosion Protection

Parameter	Req. #	Value	Traceability
Equipment Protection	ATF0240	Protection against lightning, dust, fauna, solar radiation, rain/water infiltration and corrosion shall be provided by the environmentally controlled facilities or racks in which the ATF elements are installed, as defined by the applicable ICD [AD24], [AD26]. No ATF element shall be installed outside these facilities or racks.	ENV0541, ENV0542, ENV0571, ENV0591

6.6 Precision Operating Conditions (POC)

The ATF subsystem shall have precision performance as defined in [AD04] under the following conditions:

Parameter	Req. #	Value	Traceability
Temperature POC	ATF0320	+17.5 C ≤ T ≤ +22.5 C	ENV0313, [AD22], [AD26]
Temperature Rate of Change POC	ATF0330	< 0.1 °C per hour	ENV0314, [AD22], [AD26]

[AD24] and [AD26] specify in further detail the temperature and humidity ranges which will surround the ATF subsystem LRUs and subassemblies during precision operating conditions. This temperature range shall be maintained while external temperatures are present in the range -15 C ≤ T ≤ +25 C, at night-time only, with temperature rate of change less than 1.8 C/hr, and during quieter wind and water vapor conditions specified in [AD04], Section 3.1.

6.7 Normal Operating Conditions (NOC)

The ATF subsystem shall have normal performance as defined in [AD04] under the following outside ambient conditions:

Parameter	Req. #	Value	Traceability
Temperature NOC	ATF0390	+15 C ≤ T ≤ +25 C	ENV0323, [AD22], [AD26]
Temperature Rate of Change NOC	ATF0400	< 0.25 °C per hour	ENV0324, [AD22], [AD26]

[4] and [AD26] specify in further detail the temperature and humidity ranges which will surround the ATF subsystem LRUs and subassemblies during normal operating conditions. This temperature range shall be maintained while external temperatures are present in the range -15 C ≤ T ≤ +35 C, in full sun, with temperature rate of change less than 3.6 C/hr, and with wind, and water vapor conditions as specified in [AD04], Section 3.2.

6.8 Limits to Operating Conditions (LOC)

The ATF subsystem shall be able to operate for extended periods without sustaining residual damage under the following outside ambient conditions:

Parameter	Req. #	Value	Traceability
Temperature LOC	ATF0410	+5 C ≤ T ≤ +30 C	ENV0313, [AD22], [AD26]
Temperature Rate of Change LOC	ATF0420	< 0.5 °C per minute	ENV0314, [AD22], [AD26]

Per [AD04], external temperature range -20 C ≤ T ≤ +45 C is applicable. [AD22] and [AD26] specify in further detail the temperature and humidity ranges which will surround the ATF subsystem LRUs and subassemblies during precision operating conditions.

7 Subsystem Requirements

7.1 Size and Weight

Parameter	Req. #	Value	Traceability
Size, ATF Equipment in Secondary Focus Front End Enclosure	ATF1100	ATF equipment shall be housed in NRAO designed RFI-shielded ARCs modules within the 1800mm wide X 1150mm deep X 600mm enclosure Allowable space within the enclosure will be detailed in [AD24]	SYS1001, SYS1101, SYS2403, CAL0201, CAL0205, CAL0206
Weight, ATF Equipment in Secondary Focus Front End Enclosure	ATF1110	ATF equipment shall be housed in NRAO designed RFI-shielded ARCs modules within enclosure, which itself shall have a maximum mass of 522kg Allocation of weight for ATF equipment within the enclosure will be detailed in [AD24]	SYS1001, SYS1101, SYS2403, CAL0201, CAL0205, CAL0206

The size and weight limitations of the front end enclosure flow down from the design choice of an offset dual reflector antenna geometry. The antenna design choice in turn flows down from SYS1001 and SYS1101 which set the antenna effective area to noise temperature ratio and the Field-of-view requirements. SYS2403 requires that equipment be modularized into line replaceable units. Once this design choice is in place, several calibration requirements conspire to limit the size and weight of the enclosure:
CAL0201 – blind pointing performance of the antenna. Since the enclosure is on the offset feed arm, the antenna pointing is sensitive to the weight
CAL0205 – Primary beam power pattern is influenced by accuracy of feed positioning, sensitive to enclosure size and weight
CAL0206, CAL0207- Calibration requirements for Band switching and antenna motion. Antennas dynamic response depends on the enclosure weight on the feed arm.

7.2 Frequency

Parameter	Req. #	Value	Traceability
LO Frequency Ranges	ATF1200	LO frequencies shall be provided to support downconversion (except instances of direct conversion). These shall fall in or near to the range of sky frequencies required for ngVLA: 1.2—8 GHz, 8-50 GHz, and 70-116 GHz. Fixed or tunable LOs shall allow for continuous frequency coverage across these spans. Additionally, the design plan shall allow for simultaneously multiple LOs in a given receiver band so that the full available instantaneous downstream processing bandwidth can be achieved, and so that discontinuous portions of a band may be selected.	SYS0801, SYS0803, SYS0804, SYS0805, SYS0806, SYS0903, SYS0905
LO Frequency Table	ATF1205	Given the overall frequency ranges covered by ngVLA, the detailed design of the Front End	[AD20], SYS0801,

Parameter	Req. #	Value	Traceability
		receiver and downconverter spanning this range will determine the specific LO tunings for each downconverter (IRD module) and receiver band. A tuning plan, or table, with required amplitudes and frequencies will be specified in the ICD between the ATF and the IRD.	SYS0803, SYS0804, SYS0805, SYS0806, SYS0903, SYS0905
Digitizer/Sampler Frequency	ATF1208	The Digitizer, or Sampler, implementation depends on the Front End design. The ATF shall supply a digitizer frequency, or a reference frequency, as necessary, to support the Front End implementation. Specific frequency (-ies) required for support of digitizers will be communicated to ATF via Antenna Electronics IRD group by means of ICD between ATF and IRD [AD20]. Following completion of ICD this requirement will be updated and finalized.	[AD20], SYS0801-0806, SYS0903-0906
LO Frequency Offsets	ATF1210	Nominal LO frequencies shall be capable of frequency offsetting on a per antenna basis.	SYS2105, SYS0603, SYS2217, [RD06]
Digitizer/Sampler Offsets	ATF1215	The Digitizer shall be capable of frequency offsetting on a per antenna basis.	SYS2105, SYS0603, SYS2217, [RD06]
Tuning Resolution	ATF1220	The LO shall be tunable if necessary to cover the required full frequency spans. If tuning is required, the resolution shall be 250 MHz or less.	SYS0906, SYS0907,
Switching Speed	ATF1225	Frequency switching between or within a band shall be accomplished in < 10 s. The switching time is defined as time to reach full performance.	SYS0908

The LO Frequency Table: arises from the design of the receiver and downconverters, and thus the specific frequencies and number of frequencies required to support ngVLA are detailed in the ICD between ATF and IRD [AD20].
A representation of the current version of the frequency table is shown in Table 2 (on the next page).

Table 2: LO Frequency Table

RF Band	Module	RF start (GHz)	stop (GHz)	LO harmonic	(GHz)
2	a	3.5	12.3	2	5.8
	b			4	11.6
3	a	12.3	20.5	5	14.5
	b			7	20.3
4	a	20.5	34	8	23.2
	b			10	29
	c			12	34.8
5	a	30.5	50.5	11	31.9
	b			13	37.7
	c			15	43.5
	d			17	49.3
6	a	70	116	25	72.5
	b			27	78.3
	c			29	84.1
	d			31	89.9
	e			33	95.7
	f			35	101.5
	g			37	107.3
	h			39	113.1

LO Frequency Offsets: The role of the per antenna small frequency offset is to provide a mechanism for image suppression and self-generated spurious that would otherwise be coherent antenna-to-antenna. This is discussed extensively in [RD06]. The implementation of offsets will be detailed in the ICD between ATF and IRD [AD20], as well as the ICD between ATF and DBE [AD22]. A potential implementation is as follows:

Each antenna station will incorporate a fixed frequency LO offset that is a multiple of a small fixed offset. The current design value of this fundamental offset is 15.68 kHz. Thus, an antenna will have its LO offset by an amount of m*15.68 kHz, where m is an index representing the antenna station and can take on values m= –131, –130,…, –1,0,1,…130,131 for an overall offset range of +/-131*15.68 kHz equals +/- 2.054 MHz.

Since bands 2–6 all have more than one LO, it is noted that the fixed offset attached to each LO in a particular band results in a different ratio between the offset and the LO frequency. This has implications for the LO design and is not a requirement but rather a system design choice subject to review and/or change.

Also, it is noted that the incremental assignment of offsets to stations applies only within a single science subarray. Thus, only when all antennas are in a single subarray would the full +/- 2.054 MHz tuning range be used. This, and the fact that subarrays can be re-assigned amongst sets of antenna stations, means that the fixed offset to applicable to a particular station shall be tunable to any of the values for m= –131,–130,…, –1,0,1,…130,131.-

Digitizer/Sampler Frequency Offsets: not a strict requirement but per [SYS2015] a desirable feature. See especially the discussion in [RD06]. The implementation of offsets will be detailed in the ICD between ATF and IRD [AD20], as well as the ICD between ATF and DBE [AD22]. A potential implementation is as follows:
Each antenna station will incorporate a fixed frequency offset to the digitizer (or digitizer reference) that is a multiple of a small fixed offset. The current design value of this fundamental offset is 15.68 kHz. If the offset is to be applied to a reference to the digitizer that is fractionally related to the digitizer clock frequency, then the offset shall be applied as the same fraction multiplied by 15.68 kHz. Thus, an antenna will have its digitizer offset by an amount of m*15.68 kHz, where m is an index representing the antenna station and can take on values m= –131, –130,…, –1,0,1,…130,131 for an overall offset range of +/- 131*15.68 kHz equals +/- 2.054 MHz.
Also, it is noted that the incremental assignment of offsets to stations applies only within a single science subarray. Thus, only when all antennas are in a single subarray would the full +/- 2.054 MHz tuning range be used. This, and the fact that subarrays can be re-assigned amongst sets of antenna stations, means that the fixed offset to applicable to a particular station shall be tunable to any of the values for m= –131, –130,…, –1,0,1,…130,131.

7.3 Amplitude

Parameter	Req. #	Value	Traceability
LO Amplitude	ATF1230	Given the overall frequency ranges covered by ngVLA, the detailed design of the front end receiver and downconverter spanning this range will determine the specific LO levels required needed for each downconverter (IRD module) and receiver band. A tuning plan, or table, with required amplitudes and frequencies will be specified in the ICD between the ATF and the IRD.	[AD20], SYS1011, SYS1012, SYS1013, SYS1033, SYS1034, SYS1035
LO Amplitude Stability	ATF1235	LO amplitude change shall not contribute to the receive signal path amplitude change so as to cause fractional gain stability to exceed: > 1e-3 at 60 s (goal 1e-4) > 4e-3 at 200 s (1 MHz bandwidth)* > 8e-3 at 200 s (1 MHz bandwidth)** > 1e-2 for 4° change in elevation (8 GHz)*** > 1e-2 per deg K *Precision Operating Conditions (see Sec 6.6, [AD04]) **Normal Operating Conditions (see Sec 6.7, [AD04]) ***scaled with frequency	SYS1601 SYS4601 SYS4604 SYS1603 SYS4603 SYS4902

LO Amplitude: Final requirements will be in the ICD between IRD and ATF [AD20]. A preliminary version of this ICD has the following placeholders, which are subject to change:

Band 2 LO Power	The Band 2 LO nominal power shall be +7 dBm (CW).
Band 3 LO Power	The Band 3 LO nominal power shall be +7 dBm (CW).

Band 4 LO Power	The Band 4 LO nominal power shall be +3 dBm (CW).
Band 5 LO Power	The Band 5 LO nominal power shall be +13 dBm (CW).
Band 6 LO Power	The Band 6 LO nominal power shall be +13 dBm (CW).

LO Amplitude Stability: The levels appearing in the table above refer to the maximum acceptable level for gain (or power) level change in linear units, of the *receive chain signal path*. The specific acceptable level for LO amplitude changes versus time, temperature, or tilt depend on the LO design and its interface with the integrated receiver modules. ***This is a derived requirement that will be confirmed (TBC) following the ICD between ATF and IRD [***AD20***].***

- The sixty second accuracy of 1e-3 is equivalent to .004 dB.
- The sixty second goal accuracy of 1e-4 is equivalent to .0004 dB.
- The 200s accuracy of 4e-3 is equivalent to .017 dB

Assuming that the IRD buffer amplifiers are designed to operate in compression so that 90% of incident fluctuations are suppressed, then the LO amplitude stability requirement would be:

Local Oscillator Stability		Linear gain	dB
60 s	Required	1e-2	0.04
60 s	Goal	1e-3	0.004
200 s	Required, Precision Conditions	4e-2	0.17
200 s	Required, Normal Conditions	8e-2	0.36
Per deg K	Required	1e-1	0.45
Per 4° change in elevation	Required (at 8 GHz), scaling with frequency	1e-1	0.45

7.4 Phase

Parameter	Req. #	Value	Traceability
LO Phase Noise	ATF1240	< 76 fs integrated from 1 Hz to maximum IF frequency offset Goal is < 50 fs	SYS5001, SYS1503, CAL0314
LO Phase Drift	ATF1250	< 59 fs at 300 s (linear term removed) < 1500 fs (absolute)	SYS5001, SYS1504, SYS1505, CAL0314
Digitizer Clock Phase Noise	ATF1260	< 76 fs integrated from 1 Hz to maximum IF frequency offset Goal < 50 fs	SYS5001, SYS1503, CAL0314
Digitizer Clock Phase Drift	ATF1270	< 59 fs at 300 s (linear term removed) < 1500 fs (absolute)	SYS5001, SYS1504, SYS1505, CAL0314
Return to Phase	ATF1280	Any derived LO or timing signal shall return to phase upon change in frequency from F_1 to F_2 to F_1	SYS0602

These system level phase critical requirements must be fulfilled by elements of the Antenna Time and Frequency subsystem (ATF). The ATF is in turn relies upon receiving accurately phased reference signals from the RTD subsystem. The drift and noise stability that is required at the RTD-ATF interface will be carefully detailed in the ICD [AD28].

Note 1: ATF1250 specifies phase drift performance of the main array out to maximum baseline length of 350 km. The requirement is stricter than the equivalent phase drift between two physically separated hydrogen masers. Consistent with SYS5001 and discussion in [AD03] the requirement beyond 350 km is relaxed to account for the need to have H-masers as independent frequency references at each site.

Note 2: ATF1240 specifies the rms phase noise integrated up to the maximum IF frequency. In practice, it is seldom the case for an oscillator to have significant phase noise contribution above ~ 10 or 20 MHz, whereas in the most recent design the IF frequency goes to 2.9 GHz. Therefore it is sufficient to measure only up to the maximum offset frequency at which non-negligible contribution to phase noise occurs, for the particular oscillator type used in the design.

Note 3: ATF1280 shall be verified by implementing a frequency switching test set, with repeated switch cycles frequency from F1 to F2 to F1 over a long period (one hour or more). The phase measurement at F2 is then thrown out, and the phase samples measured at F1 are kept. The linear drift may be removed from these samples and then the resulting concatenated phase time series shall meet the ATF1250 requirement of 42 fsec RMS averaged at 300 seconds.

7.4.1 Phase Noise and Phase Drift Performance Budget

For each of these requirements (ATF 1240, ATF1250, ATF1260, ATF1270, ATF1280) the design of the antenna time and frequency (ATF) subsystem contains the output LO or clock that defines the performance requirement. The RTD subsystem design must support the ATF requirements and design by supplying adequately clean and accurate references.
The overall system phase noise and drift requirements from [AD03] are shown below.

Table 3 - Overall System Phase Noise and Phase Drift Allocations

Parameter	System Req. #		
Allocation of Phase Noise & Drift	SYS5001		
Component	**Noise**	**Drift Residual**	**Absolute Drift**
	(fsec, rms)	**300 sec fsec, rms**	**300 sec psec**
System	**132**	**95**	**4.3**
Sub-System Allocations:			
ANT	76	42	2
ATF (LO)	76	42	0.25
ATF (DTS Clock)	76	42	0.25
ATF (RTP)	0	42	0.25
RTD	0	42	1.25
Estimated System Total	**132**	**94**	**4**

- The 76 fsec from ATF1240 appears in the second row under sub-system allocations
- The 59 fsec drift residual from ATF1250 is the root sum of the 2nd and 5th row
- The 1500 fsec from ATF1240 absolute drift is the sum of the 2nd and 5th row
- The 76 fsec from ATF1260 appears in the third row under sub-system allocations
- The 59 fsec drift residual from ATF1270 is the root sum of the 3rd and 5th row

We also allocate a phase drift at the output of the RTD (i.e. the RTD/ATF interface). At this interface the antenna subsystem will perform cleanup phase lock loop and frequency multiplication. Nevertheless, the low frequency phase noise from the RTD output will be "copied" to the antenna system. Therefore, the relevant integration limits for verification of the RTD/ATF interface is in the low frequency regime, which we choose to be 1 Hz to 1 KHz (this can be revisited as the design matures).

Table 4 – Phase noise allocation breakdown for 1st LO

Phase Noise source	Frequency offset limits	Phase noise allocation rms	RSS contribution
RTD output integrated from 1 Hz to 1 kHz	1 Hz to 1 kHz	44 fsec	33 %
Contribution from Cleanup loop 2.9 GHz oscillator	1 Hz to 2.9 GHz	31 fsec	16.6 %
Output of Cleanup Loop Oscillator	1 Hz to 2.9 GHz	54 fsec	50 %
Higher frequency multiplication and synthesis	1 Hz to 2.9 GHz	53.7 fsec	50 %
LO Output	1 Hz to 2.9 GHz	76 fsec	100 %

7.5 Clock and Timing of Commercial Digitizer

Parameter	Req. #	Value	Traceability
JEDEC Standard Clock and Timing	ATF1290	LO and Timing requirements for support of commercial digitizer chosen for implementation in IRD modules shall support the relevant JESD technical standard	SYS0302, SYS0745, SYS0903, SYS2002, [AD20], [AD22], [RD07], [RD08]

JEDEC standard: JEDEC publishes a set of standards called JESD. JESD204, which specifically focuses on the electrical and mechanical specifications for high-speed serial interfaces used in data converters, particularly Analog-to-Digital Converters (ADCs) and Digital-to-Analog Converters (DACs). JESD204 standards define the communication protocols and physical layer requirements for transferring digital data

between data converters and other components within a system, such as FPGAs, DSPs, or microcontrollers. The most recent update is JESD204C [RD09]. At present, ngVLA expects to implement a device with the forthcoming JESD204D standard [RD10, RD11]. Generally, commercial manufacturers of LO and timing devices concurrently develop devices to support the signal requirements of the ADC standards. With this requirement, LO Reference and Timing will implement the required circuitry to provide the ADC, or digitizer, with the correct reference clock and timing signals. Likewise, for the DBE which will receive the data stream and which will also require specialized clock and timing meeting JESD204D (or whatever standard is chosen).

7.6 Timing

Parameter	Req. #	Value	Traceability
Timing at RTD output	ATF1300	Timing accuracy to RTD output shall be within 2 nsec (goal of 1 nsec) Relative to the central system clock on short timescales and relative to the absolute timing standard over 1-day averaging Note: DBE subsystem is located at antenna pedestal. This requirement includes RTD correction for fiber link delay, and accurate transmission of the corrected timing signal to the DBE subsystem at the antenna	SYS2002, SYS2003, SYS0404, [RD04]
Time Accuracy – Antenna Station Functions	ATF1355	The relative difference between local antenna time and the system clock shall not exceed ±5 μs. This requirement is for relative accuracy of antenna tracking, switched power, and fringe search functions. (all antenna functions except DBE-timestamping)	SYS2002, SYS2003, SYS0404, [RD04]
Antenna Timing	ATF1357	The antenna clock domain shall be stable relative to the antenna LO reference to within 2 ns. This requirement supports synchronization of LO, digitizer and antenna timing signal.	SYS2002, SYS2003, SYS0404, [RD04]
Timing to DBE	ATF1380	From the output of the RTD, 1 PPS timing accuracy to digitizer and DBE using JESD protocols shall result in not more than 1 nsec residual timing error	SYS2002, SYS2003

System requirement for Temporal Accuracy (SYS2002): Data Product timestamps shall be referred to an absolute time standard (e.g., GPS or TAI) with an error of less than 10 ns (goal of 1 ns).

System requirement for Timestamp Corrections (SYS2003): Timestamps may be applied or corrected retroactively (i.e., it is not necessary for it to be known in real time.) Any timestamp corrections shall be made through a metadata table that is incorporated into the data model.

Taken together SYS2002 and SYS2003 imply the need for accurate central timing, and the need for – at least—an accurate model of the antenna timing.

The requirement for accurate array timing impacts the Central clocks, the distribution of the clocks to the CSP, and the distribution of the clocks to the antennas. For these (Antenna Time and Frequency) requirements we are concerned only with the latter.
The antenna timing is constrained by at least three functional needs:

- Antenna tracking: Timing accuracy <= 660 us
- Switched Power: Timing accuracy <=50 us
- Fringe search: Timing accuracy <=50 us

These three needs, inclusive of some design margin, lead to a requirement for the timing of the antenna system to not deviate from the system clock by more than about 5 µs. i.e., the relative difference between local antenna time and the system clock **shall not exceed ±5 µs**. This requirement shall be met by the hardware alone, before the application of time corrections (online or offline) derived from astronomical calibration. We note that this is within the capabilities of the IEEE 1588 Precision Time Protocol.
Additionally, there is a need for accurate timing by either model, measurement, or active correction to at least one reference antenna in any given subarray. The accuracy of this timing for support of data timestamping **shall be less than 2 ns**.

7.7 Modes

Parameter	Req. #	Value	Traceability
Standby Mode	ATF1400	A low power standby mode shall be available for all ATF modules. Monitor and Control shall remain operational in this mode.	SYS0010, SYS0011, ETR0809, ETR0810
Automatic Initialization	ATF1410	ATF modules shall automatically boot into standby mode on power-up, absent any command from M&C.	SYS0011, SYS3114, ETR0811
Operating Modes	ATF1420	Any functional operating mode can be reached by command from Standby Mode.	SYS0010

7.8 Spurious/RFI

7.8.1 Signal Path Spurious

Parameter	Req. #	Value	Traceability
Spurious Narrowband Tones	ATF1500	Spurious narrowband tones introduced in the LO spectrum may be expected to pass directly to the receive path. These tones shall contribute no more than -43 dB/MHz relative to the system noise level in the IF receive path. **Derived requirement (see below)** Within 3.5 GHz of carrier < –103 dBc Beyond 3.5 GHz from carrier < –48 dBc ***TBC***	[AD20], SYS2104

Note that the specific acceptable level for spurious with respect to the LO power level LO will be detailed in the ICD between ATF and IRD [AD20].
Derivation of Spurious Requirement:

- Assume that the LO power is + 10 dBm.

- Further assume that the receive signal path noise floor is low ~ –80 dBm/Mhz. The requirement sets the spurious at –43 dB relative to this level, or –123 dBm/MHz.

If the conversion efficiency of spurious inputs at the LO port was about the same as inputs at the RF port, then we would need to suppress those spurious inputs by 10 + 123 = **133 dBc**. Direct port-to-port leakage of the tone is likely to be less significant than downconversion, and in any case the spurs we are currently concerned with lie well outside the IF baseband frequency range, and will be significantly attenuated by the baseband signal path if not downconverted first.

This downconverted LO path can be mitigated by the use of balanced mixers, anti-alias filtering, and the use of saturated amplification in the receiver LO path. These details may be different depending on the LO frequency and receiver or downconverter band.

For instance, the anti-aliasing filters will suppress signals more than ~3.5 GHz away from the primary LO by at least **55 dB** (IRD062x). Second, the mixers will likely all be balanced, which should suppress LO noise and inputs by another **15 dB** or so. Finally, LO buffer amps inside the IRD modules will likely be run in compression, which would tend to suppress weak signals which are present on top of the primary LO. We can conjecture an additional 15 dB (TBC) for this effect. So, with these effects we can relax our spurious LO tone suppression spec (for signal beyond 3.5 GHz) to 133–55–15–15 = **–48 dBc**. Or, for tones close (within 3.5 GHz) to the carrier –**103 dB**c.

7.8.2 Spurious RFI Emission

Parameter	Req. #	Value	Traceability
Spurious Signal Level Emission	ATF1600	Spurious signals generated by the system shall not exceed the equivalent isotropic radiated power limits specified in [AD05] See Table 3	SYS2104, EMC0310
Spurious Emission impacting IRD	ATF1605	Spurious signals generated by the system shall not exceed the equivalent isotropic radiated power limits specified in [AD05] See Table 3and detailed note "Spurious Emission Impacting IRD, ATF1605" below	SYS2104, EMC0310, [AD20]
Emission Verification Frequencies	ATF1610	Spurious signal emission levels shall be verified by test over a minimum range of 1 GHz up to 12 GHz. Modules or devices that may contain frequency content above 12 GHz shall be tested at least up to 50 GHz.	SYS2104, EMC0311
Low Frequency Emission	ATF1620	Spurious signal emission levels shall be quantified by test over an extended frequency range of 5 MHz to 1 GHz. While there is no emission threshold within this range, this information shall be collected to inform future system expansion.	SYS2104, SYS5602, EMC0312
RFI suppressing housings	ATF1630	RFI Suppression housings shall be used to contain and suppress spurious emissions, in order to meet the requirements derived from ATF1600 (see Table 3, column 6, for example)	[AD24]

Spurious Emission ATF1600:
EMC0310 specifies spurious emission level versus frequency for spectral line and continuum emission. For Antenna LO and Timing these are both applicable but spectral line emission is likely to be the greater concern due to LO and digitizer harmonics, subharmonics, and spurious tones. Thus it is elaborated in the text below.
For reference the spectral line emission requirement from [AD05] is shown in Table 5 (reformatted). The columns reflecting 10m distance match [AD05] and would be pertinent for equipment located in the antenna pedestal. For equipment at the secondary focus (nearly co-located with the receiver, the numbers have been reworked to reflect lower acceptable limits (by 20 dB).

Table 5: Spectral Line emission limits from [AD05].

		spectral line 10m		spectral line 1m	
Freq	BW (kHz)	EIRP	dBm/Hz	EIRP	dBm/Hz
1	0.3	-129	-154	-149	-174
3	1	-115	-145	-135	-165
6	2	-106	-139	-126	-159
10	3	-100	-135	-120	-155
30	10	-84	-124	-104	-144
45	15	-78	-120	-98	-140
90	30	-67	-112	-87	-132

For reference the spectral line emission requirement from [AD05] is shown in Table 6 (reformatted; on the next page).
We can then further make a list of the currently projected frequencies for LO and digitizer signals and tabulate the maximum permissible radiation levels, detailed below in Table 6. Note that the sixth column represents the permissible emission for equipment at the secondary focus enclosure after all design mitigations **including RFI suppressing housings**. Shielding levels that may be required to meet the limits detailed here will be included in the ICD with the Antenna Electronics Bins, Modules, and Racks work package [AD24].

Table 6: Maximum permissible spectral line spurious emission levels for select LO and digitizer frequencies.

LOs freq (GHz)	BW (kHz)	spectral line 10m EIRP	dBm/kHz	spectral line 1m EIRP	dBm/kHz
2.9	0.97	-116	-116	-136	-136
5.8	1.93	-106	-109	-126	-129
7.0	2.33	-104.5	-108	-124.5	-128
11.6	3.87	-99	-105	-119	-125
14.5	4.83	-96	-103	-116	-123
20.3	6.77	-92	-100	-112	-120
23.2	7.73	-89	-98	-109	-118
29.0	9.67	-85	-95	-105	-115
34.8	11.6	-82	-93	-102	-113
31.9	10.6	-83	-93	-103	-113
37.7	12.6	-81	-92	-101	-112
43.5	14.5	-79	-91	-99	-111
49.3	16.4	-77	-89	-97	-109
72.5	24.2	-71	-85	-91	-105
78.3	26.1	-70	-84	-90	-104
84.1	28.0	-69	-83	-89	-103
89.9	30.0	-67	-82	-87	-102
95.7	31.9	-66	-81	-86	-101
101.5	33.8	-64	-79	-84	-99
107.3	35.8	-62	-78	-82	-98
113.1	37.7	-61	-77	-81	-97

Note that the permissible limits are lower (i.e. more stringent) at the low end of the frequency range. For frequencies below 1 GHz, such as the digitizer reference frequency, possibly PLL clocks and other timing signals, the ngVLA [AD05] does not expressly limit emissions. For frequencies below 1 GHz, we will consider the 1 GHz emission limit shown in the first line of Table 5 to be a goal.

Spurious Emission Impacting IRD, ATF1605:
Note that the levels shown in Table 6 are applicable as well to the spurious emission from LO modules that could couple to the input of the IRD modules. Meeting this requirement may not have the same mitigation as coupling to the receiver input because both the LO and the IRD modules are expected to be housed in the same RFI suppressing module. However, ATF1500 requires very low level of conducted spurious emission. The level for radiated spurious emission is expected to be lower of course than the conducted emission. However, depending on the final design of the IRD downconverters and the Antenna Time and Frequency LO design, it could be possible for harmonics, subharmonics, or other spurious to present RFI to one or more IRD bands. It is necessary to analyze all possible cases and limit emissions especially that fall close to the LO frequency of a band (within 3.5 GHz). All such requirements arising from the design shall be detailed in the ICD with IRD [AD20].

7.9 Monitor and Control

Parameter	Req. #	Value	Traceability
Self-Monitoring	ATF1630	The ATF subsystem shall measure, report and monitor a set of parameters that allow for determination of its status and may help predict or respond to failures. This shall include but not be limited to on/off status, power levels, frequency lock status, and bias voltages.	SYS2601, SYS3101
LRU Alerts	ATF1640	A subsystem alert shall be generated when an ATF LRU has an abnormal condition or failure.	SYS3102
High-Cadence Monitoring	ATF1650	The M&C interface shall be fast enough to support streaming of diagnostic data. This shall be applicable in operational mode without affecting other performance requirements.	SYS3105, SYS2408
LRU Hot Swapping	ATF1660	ATF LRUs intended for field replacement shall be hot-swappable by design, and recover with minimal intervention by maintenance and operations staff.	SYS3111
Remote Updates	ATF1670	Firmware in embedded processors and configuration data in FPGAs shall be updateable remotely, in-situ.	SYS3223, ETR0907
Automatic Configuration on Restart	ATF1680	The ATF subsystem shall be capable of reaching an operationally-ready Standby state after a full power cycle without human intervention.	SYS3114
Front End Engineering Console	ATF1690	The ATF subsystem shall include an engineering console to display status and aid in real-time problem diagnosis.	SYS2407
M&C Commanded Reset for DC Powered Devices	ATF1700	All DC powered LRUs and complex programmable devices shall be provided with a physical reset line connected to a local M&C device to allow remote reset commands to be sent. This could be implemented as a ganged reset to all devices in an LRU or as individual lines to each device (or group of devices) as determined by the designer.	ETR0909
M&C Commanded Reset for AC Powered Devices	ATF1710	All AC powered LRUs shall be connected to a remotely controllable Power Distribution Unit (PDU) or similar device which can be remotely commanded via the M&C system to power cycle each individual device.	ETR0912

With regard to the self-monitoring, alerts, and high cadence monitoring: these requirements may be satisfied by:

- an ATF LRU alone, in a module which has the onboard intelligence to report status and/or alarms
- by a combination of the ATF modules and the hardware interface layer as specified in [AD27]

7.10 Lifecycle

Parameter	Req. #	Value	Traceability
Design Life	ATF1800	The integrated modules shall be designed to be operated and supported for a period of 30 years.	SYS2801, ETR0903
Lifecycle Optimization	ATF1810	The ATF design shall minimize its lifecycle cost for 30 years of operation.	SYS2802
Parts Selection and Procurement Criteria	ATF1820	Parts selection and procurement criteria shall include: a. Sustainability and environmental impact b. Adequate Supply of critical spares for array lifecycle c. Risk mitigation against parts obsolesce and long term availability	SYS2803, SYS2805, SYS2812, ETR0901, ETR0902

Accounting for product development, integration, and array commissioning, it is reasonable to target a 30-year minimum overall lifetime.
Lifecycle costs include manufacturing, transportation, construction/assembly, operation, and decommissioning.

7.11 Configuration

The following table lists the configuration management requirements applicable to the ATF subsystem equipment.

Parameter	Req. #	Value	Traceability
Serial Numbers	ATF1900	Each LRU shall have both a visible and electronic serial number.	SYS3600
Version Control for Software and Firmware	ATF1910	All custom software and firmware delivered as part of the ATF subsystem shall be version controlled via a configuration management process.	SYS3602
Configuration Retrieval	ATF1920	Any configurable equipment shall retrieve its hardware configuration immediately after installation and power up.	SYS3603
Physical Tracking	ATF1930	Any hardware deliverable or equipment not connected to the M/C subsystem shall be equipped with a physical tracking label or device (bar code or RFID tag), to allow quick and unique identification.	ETR0404

Parameter	Req. #	Value	Traceability
Remote Identification	ATF1940	The ATF modules shall report the following information to the M&C system, to the extent applicable, upon request: 1. Module/Model Number 2. Serial Number 3. CID Number 4. Hardware Revision Level 5. Software Revision Level 6. Firmware Revision Level Note that the software and firmware revision codes together represent a configuration that is tracked under version control from ATF1910 and ATF1920	SYS3600, ETR0403
Documentation	ATF1950	Clear and complete documentation shall be delivered with the ATF LRUs and equipment, meeting project format and standards	SYS6001-SYS6005

7.12 EMC/Immunity

ngVLA standards for Electromagnetic Compatibility and Immunity are developed and described in [AD03], [AD05], and [AD09].

Parameter	Req. #	Value	Traceability
Analog shielding	ATF2200	Analog electronics, especially those containing oscillators and amplifiers, shall be shielded so that emission limits can be met. Careful EMC design shall limit conducted emission between and among subsystems – including by power supply wiring or ground loops.	SYS2106, SYS2107, EMC0322
Digital shielding	ATF2210	All digital equipment shall be shielded and have its AC or DC power line and communication line(s) filtered at the chassis.	SYS2106, SYS2107, EMC0327
Commercial equipment	ATF2220	Any Commercial off-the-shelf (COTS) equipment shall conform to IEC product family standards for immunity standards, or to the generic standard IEC 61000 – Part 6: Generic Standards if no product family standard is given. Additionally, the equipment shall have a CE mark or FCC compliance ID	SYS2016, EMC0401, EMC0402
Conducted Immunity, Testing	ATF2230	LRUs shall be designed and tested for immunity to conducted voltage and noise	SYS2106, EMC0411-0412, EMC0421-0424, EMC0431-0432,

Parameter	Req. #	Value	Traceability
			EMC0451-0452, EMC0461-0462
Electrostatic Discharge, Testing	ATF2240	LRUs shall be designed for and tested to meet ESD discharge requirements	SYS2106, EMC0471-0473, ETR0501, ETR0505, ETR0506
Hi-Speed Design	ATF2250	ATF modules incorporating high speed digital logic shall be designed for low emission, incorporate best EMC practices, and be subject to rigorous review	SYS2016, ETR0714
ESD, Storage and Shipment	ATF2260	ESD sensitive components and modules shall use best practices for storage, shipment, and handling	SYS3904, ETR0503

7.13 Reliability, Availability, and Maintainability

Parameter	Req. #	Value	Traceability
Reliability Analysis	ATF2300	A Reliability, Availability, Maintainability analysis shall be performed and documented as a memo by each designer at the LRU level to locate weak design points and determine whether the design meets the Maintenance and Reliability requirements. [AD09]	ETR0904, SYS2402, SYS2801, SYS2802, SYS2805
Mean Time Between Failure/Mean Time Between Maintenance	ATF2310	The ATF subsystem as a whole shall have a MTBF and MTBM of 18,500 hours (2.11 years) or greater, contributing 9% to the overall antenna electronics budget Here failures are considered in the same category as maintenance, any equipment status that would require a human intervention to address	SYS2610, [AD11]
Array Element MTTR	ATF2330	The Array Elements shall have a Mean Time to Repair (MTTR) of less than 3 hours.	SYS2611
Modularization	ATF2340	The system shall be modularized into Line Replaceable Units (LRUs) to facilitate site maintenance.	SYS2403
Spares Planning	ATF2350	Failure analysis shall be used in the planning of spares inventory. Factors considered shall include the projected availability for spares, the time required to repair the failure, and the viability of critical vendors.	SYS3204
Operations and Maintenance: Transfer of Deliverables	ATF2360	All procedures, test equipment, and test software shall be delivered to the Operations and Maintenance staff prior to full operations.	SYS3211

Parameter	Req. #	Value	Traceability
LRU Interchangeability	ATF2380	LRUs should be interchangeable with no on-site calibration, tuning or alignment.	SYS3232
Identify Failures Physically	ATF2390	All LRUs shall identify a failed state via physical display (e.g., LED).	SYS3234
Report Predicted Failures	ATF2400	All LRUs, where possible, shall report fault prediction sensor data via the M&C system.	SYS3236
Failure Information Source	ATF2410	All LRUs shall report failure information in line with failure isolation as identified in a FMECA analysis.	SYS3237
Robustness Analysis	ATF2420	All ngVLA electronics designs shall be subject to a robustness analysis. Results of this analysis are a required part of the design review process. Robustness shall be demonstrated against environmental, power supply disturbance, vibration, monitor and control, inputs out-of-range.	ETR0905

7.14 Design Requirements

7.14.1 Printed Circuit Boards and Electrical Connections

Parameter	Req. #	Value	Traceability
Printed Circuit Boards-Standards	ATF3200	For printed circuit boards incorporated into ATF subsystem design: a) Design and manufacture shall meet the IPC Standard IPC-A-600K b) Design and manufacture Shall meet RoHS 2 and 3 standards	ETR0701, ETR0712, SYS2402, SYS2803, SYS2805
Printed Circuit Board Design	ATF3210	Requirements for PCB materials, markings, and test and maintainability shall be met by design	ETR0704-07011, ETR0713, ETR0715-0717
Soldered Electrical Connections	ATF3220	Soldered electrical connections shall use Class 2 of the IPC J-STD-001G Requirements for Soldered Electrical and Electronic Assemblies, per [AD09]	ETR1301

Note: For commercial-off-the-shelf PCBs, requirements ATF3200 and ATF3220 are recommendations, with best effort to attempt to procure boards that meet as many of these requirements as possible.

7.14.2 Power and Ground

Parameter	Req. #	Value	Traceability
Power Supply Noise and Stability	ATF3300	ATF shall achieve full performance with power supply voltage stability and rms noise levels specified in ICD	[AD21]
DC Voltages available	ATF3310	All ATF equipment in the ngVLA powered from DC voltages shall voltages produced by the PSU	ETR0821, ETR0803

Parameter	Req. #	Value	Traceability
		modules, currently + 5 VDC, +/– 7.5 VDC and +/– 17.5 VDC.	
PSU Voltage Tolerance	ATF3320	Devices powered from the PSU modules shall tolerate +/– 10% of the rated voltages.	ETR0823
LRU Physical Ground	ATF3330	LRU chassis or housing shall be electrically connected to the antenna structure using a proper grounding wire. This wire can be a separate ground connection or included in the connectorized harness carrying power to the device.	ETR0804
Power Supply Returns Separate from Ground	ATF3340	Structural/Chassis components and signal grounds shall never be used as a power supply return path.	ETR0814
Overcurrent Protection	ATF3350	All ngVLA Electronics systems shall implement overcurrent protection on LRUs.	ETR0805
Overcurrent Protection Device Monitoring	ATF3360	The ngVLA M&C system shall be able to monitor the state of overcurrent protection devices in an LRU. An exception is if the circuit protection device activated disables the LRUs M&C interface.	ETR0806
Thermal Protection	ATF3370	ngVLA LRUs shall be thermally protected.	ETR0807
Thermal Protection Monitoring	ATF3380	The LRU shall be able to monitor the state of thermal protection features. An exception is if the thermal protection activated disables the LRUs M&C interface.	ETR0808
Thermal Analysis	ATF3390	The designer shall analyze their designs and take steps to optimize thermal performance with a focus on proper cooling, thermal stability and the elimination of hot spots. The thermal design shall be published as a report and included in design reviews.	ETR0816
Power On Indicators	ATF3400	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
Battery Use	ATF3410	Batteries shall not be used in the ngVLA system except in the case of the antenna –48 VDC power system and a commercial UPS device for critical AC line powered equipment.	ETR0817
Transient Protection of LRU I/O & Power Connections	ATF3420	Transient Voltage Suppression devices shall be used on sensitive analog and digital I/O signals and power supplies entering or exiting a LRU. RF and other signals that will be adversely affected by the inclusion of these devices are exempt from this requirement.	ETR0818

7.14.3 Electrical Wiring, Cables, Connectors

Parameter	Req. #	Value	Traceability
Wiring Documentation and Labeling	ATF3500	Wiring documentation and labeling shall meet project standards [AD09]	ETR1101, ETR1102
DC voltage Wire Colors	ATF3510	DC voltages shall use a wiring color scheme as specified in [AD09]	ETR1103-ETR1123, ETR1154, ETR1155
AC power wiring colors	ATF3520	All AC wiring colors shall conform to US NEC requirements.	ETR1125
Wire and Cable installation	ATF3530	Wire and cable protection, materials, ruggedness, installation, and insulation shall be implemented according to [AD09]	ETR1125-ETR1132, ETR1156, ETR1157, ETR1189
Connector Documentation and Labeling	ATF3540	Connector documentation and labeling shall meet project standards [AD09]	ETR1133, ETR1134
Connector Selection	ATF3560	Connectors shall be selected for appropriate current rating, environmental rating, and expected number of mating cycles	ETR1135-ETR1137
Connectors for Hot Swap	ATF3570	If hot swapping is used, the design shall be supported by the selection of an appropriate connector to eliminate arcing, abnormal current flow, and sequencing issues	ETR1139
Connector Design for Ease of Operation	ATF3580	Connectors shall be chosen for ease of operational and maintenance use. This includes: a) Use of keying to prevent incorrect mating b) Use of clear labeling and/or color coding c) Use of standardized pinouts for cables/connectors used in multiple places	ETR1141, ETR1185, ETR1142
Crimped Connectors	ATF3590	Crimped wire connections shall be preferred over solder cup, and shall utilize best assembly practice per [AD09]	ETR1186, ETR1187
Connector Type, Retention, and Locking	ATF3600	Connectors shall meet project standards for reliable performance by complying with retention and locking standards. This is applicable to external electronic, RF, and fiber optic connectors, single and multi-pin. Internal to LRUs, PCB board connections and other critical interconnects shall be designed for positive retention. ETR1212 requires a documented analysis for satisfying this requirement.	ETR1197-ETR1212

7.14.4 Materials, Lighting, and Mechanical

Parameter	Req. #	Value	Traceability
Metalwork	ATF3700	Metalwork used for modules, bins, and racks shall use project standard recommendations for use of materials, plating and coating, surface preparation and painting.	ETR1143-ETR1147, ETR1188
Lighting	ATF3710	Status lighting shall be by means of long-life LED or OLED sources. BLUE shall be used solely to indicate presence of power supply. RED shall be used solely to indicate faults or alarms conditions. WHITE shall be used only for illumination. Other colors may be used at the designer's discretion for other conditions or status indication. Brightness shall be set to the minimum necessary for the desired function.	ETR1148-ETR1153
Fasteners	ATF3720	All screws or any type of assembly hardware shall use metric standard, and materials, labeling, and design shall be according to [AD09].	ETR1161-ETR1169, ETR1171, ETR1190, ETR1184
LRUs, Mechanical	ATF3730	LRU shall be designed for ease of installation and removal, be free of rough edges, and follow project recommendations for assembly, installation, and handling per [AD09]	ETR1170, ETR1172, ETR1176-ETR1178, ETR1183
LRU Documentation and Dimensions	ATF3740	LRUs shall be documented with engineering dimensions, units and tolerances per [AD09].	ETR1173-ETR1175

8 Safety

8.1 Safety Requirements

This section defines all design requirements necessary to support the Level-1 Safety, Security, and Cybersecurity requirements.

Parameter	Req. #	Value	Traceability
Safety Specification	ATF4200	The ATF equipment shall comply with ngVLA L1 Safety Specifications [AD07], including physical security and monitoring	SYS2700, SYS2704
Security Specification	ATF4210	The ATF equipment shall comply with Security Plan and Requirements [AD08] • Includes training, policy, planning in addition to hardware and physical elements	SYS2703

Parameter	Req. #	Value	Traceability
		• Documented hazard analysis with standards approved by Safety and Systems IPT • Established physical security control for each ngVLA location May include access control, entry locks, fire alarms or detectors, key control (equipment and doors), identification of sensitive property	

Cybersecurity Specification	ATF4220	• Compliance with NRAO Master Information Security Policy
		• Compliance with NRAO Cyber Security Incident Response Policy
		• Compliance with Cyber Security Access Control Policy
		• Follows guidelines of NSF19-68 Section 6.3 "Guidelines for Cyber Security of NSF's Major Facilities"
		• Password control, least privilege policy, identity management, strong access authentication
		• Most recommendations, policy, and protocols applicable at level outside or above the hardware IPT, except perhaps:
		  • Apply security updates in timely manner
		  • Embedded device firmware with version control and update features
		  • Use of segregation and firewalls
		  • Reduce software to barest minimum
			SYS2702

Hazard Analysis	ATF4230	The ATF subsystem shall have hazard analysis performed.	SYS2700
LRU Weight Labels	ATF4240	LRUs in the ATF subsystem shall include at least one clearly visible label indicating the weight of the LRU in pounds. The label shall be compliant with applicable standards at the time of installation.	SYS2700, SYS3202, ETR0406
Hot Connect & Disconnect Warning Labels	ATF4250	In situations where, disconnecting cables or pulling of equipment with power on can cause damage, clearly visible labels shall be applied to warn on this condition.	SYS2700, SYS3202, ETR0410
Electrical and Optical Label Safety Standards	ATF4260	All electrical and optical safety labels shall be compliant with applicable standards at the time of installation.	ETR1016, SYS2700

Parameter	Req. #	Value	Traceability
Design for Optical Safety	ATF4270	All LRUs using Lasers or high intensity LEDs at levels defined as dangerous in the ANSI Z136 series of standards (RD02) shall be designed to minimize or prevent human exposure.	ETR1018, SYS2700
Optical Safety Labels	ATF4280	In all LRUs containing lasers, clearly visible labels in accordance with the IEC 60825-1:2014 Standard (RD03) shall be applied.	ETR1019, SYS2700
Connectors for Hot Swap	ATF4290	If hot swapping is used, the design shall be supported by the selection of an appropriate connector for personnel and equipment safety	ETR1138
No Exposed Live Terminals	ATF4300	Live signal or power pins in connectors shall not be exposed while connectors are unmated.	ETR1140

9 Interface Requirements

Antenna Time and Frequency has interfaces with the several major subsystems as detailed in the subsections below.

9.1 Interface to IRD

[AD20] 020.10.40.05.00-0005: Interface Control Document Between: Antenna Electronics Integrated Receiver and Downconverters (IRD) and Antenna Time and Frequency (ATF)

This interface details the requirements for the local oscillator to support the downconversion, and the digitizer and/or digitizer reference signal, as well as any timing signal needed by IRD. Mechanical, thermal, and electronic interfaces are included. Additional interface requirements will be detailed in the ICD for connector types and mechanical and thermal interfaces. A specific subset of these interface requirements (representing critical requirements) have been included in this document for tracking purposes and for completeness, as follows:

Table 7: ATF subsystem requirements tracked in ICD to IRD

Parameter	Req. #	Value	Traceability
LO Frequency Table	ATF1205	See Section 7.1	See Section 7.1
LO Amplitude	ATF1230	See Section 7.3	See Section 7.3
LO Amplitude Stability	ATF1235	See Section 7.3	See Section 7.3
LO Phase Noise	ATF1240	See Section 7.4	See Section 7.4
LO Phase Drift	ATF1250	See Section 7.4	See Section 7.4
Digitizer Clock Phase Noise	ATF1260	See Section 7.4	See Section 7.4
Digitizer Clock Phase Drift	ATF1270	See Section 7.4	See Section 7.4
Return to Phase	ATF1280	See Section 7.4	See Section 7.4
JEDEC Standard Clock and Timing	ATF1290	See Section 7.5	See Section 7.5
Spurious Narrowband Tones	ATF1500	See Section 7.8.1	See Section 7.8.1
Spurious Emission impacting IRD	ATF1605	See Section 7.8.2	See Section 7.8.2

9.2 Interface to PSU

[AD21] 020.10.40.05.00-0006 (Interface 0059): Interface Control Document Between: Antenna Electronics DC Power Supply (PSU) and Antenna Time and Frequency (ATF)

This interface details the requirements for DC power needed to supply ATF equipment. Mechanical, thermal, and electronic interfaces will be included. All of the requirements in Section 7.14.2 are applicable to this ICD.

9.3 Interface to WVR

[AD23] 020.10.40.05.00-0028: Interface Control Document Between: Water Vapor Radiometer (WVR) and Antenna Time and Frequency (ATF)

This interface details the requirements for supply of local oscillator or timing signals from ATF to the WVR. Mechanical, thermal, and electronic interfaces will be included.

9.4 Interface to BMR

[AD24] 020.10.40.05.00-0040 (Interface 0065): Interface Control Document Between Antenna Electronics: Bins, Modules, Racks (BMR) and Antenna Time and Frequency

This interface details the requirements for any bins, modules, or racks needed for ATF equipment. Mechanical, thermal, and electronic interfaces are included. Specific requirements which will be fully defined in the ICD have been included in this document for tracking purposes and for completeness, as follows:

Table 8: ATF subsystem requirements tracked in ICD to BMR

Parameter	Req. #	Value	Traceability
RFI suppressing housings	ATF1630	See Section 7.1	See Section 7.1
Analog shielding	ATF2200	See Section 7.12	See Section 7.12
Digital shielding	ATF2210	See Section 7.12	See Section 7.12

9.5 Interface to AFD

[AD25] 020.10.40.05.00-0041 (Interface 0081): Interface Control Document Between Antenna Electronics: Antenna Fiber Distribution (AFD) and Antenna Time and Frequency (ATF)

This interface details the requirements for fiber optic interfaces to the ATF equipment. Mechanical, thermal, and electronic (optical) interfaces are included.

9.6 Interface to EEC

[AD26] 020.10.40.05.00-0070: Interface Control Document between Antenna Time and Frequency (ATF) and Antenna Electronics Environmental Control System (EEC)

This interface details the requirements for environmental control of the ATF equipment. Mechanical, thermal (air or liquid heat transfer), and electronic interfaces are included. The interface requirement will include specific detailed requirement for the EEC subsystem for thermal control such that the environmental requirements detailed in Sections 6.6, 6.7, and 6.8 are met.

Table 9: RTD subsystem requirements tracked in ICD to EEC.

Parameter	Req. #	Value	Traceability
Precision condition temperature range	LRT0320	See Section 6.6	See Section 6.6
Precision condition temperature stability	LRT0330	See Section 6.6	See Section6.6
Normal condition temperature range	LRT390	See Section 6.7	See Section 6.7
Normal condition temperature stability	LRT400	See Section 6.7	See Section 6.7

9.7 Interface to HIL

[AD27] 020.10.40.05.00-0078: Interface Control Document Between: Antenna Electronics Monitor and Control Hardware Interface Layer (HIL) and Antenna Time and Frequency (ATF)

This interface details the requirements for interface between the ATF equipment hardware layer and the software supervisory layer.

9.8 Interface to RTD

[AD28] 020.10.40.05.00-0125: Interface Control Document Between: LO Reference and Timing – Distribution (RTD) and Antenna Time and Frequency (ATF)

This interface details the requirements for signal, timing, and connection between the ATF and the round-trip distribution equipment that distributes the primary time and frequency references to the antennas.

Table 10: ATF subsystem requirements tracked in ICD to IRD

Parameter	Req. #	Value	Traceability
RTD Reference Frequency	ATF6000	2.9 GHz	ATF1205
RTD Reference Frequency Amplitude	ATF6010	TBD	
RTD Reference Frequency Amplitude Stability	ATF6020	TBD	
RTD Reference Frequency Phase Noise	ATF6030	44 fsec, See Table 4	ATF1240
RTD Reference Frequency Phase Drift	ATF6040	42 fsec, See Table 3	ATF1250
RTD Timing 1 PPS Monitoring Interface	ATF6050	TBD	TBD

9.9 Interface to DBE

[AD22] 020.10.40.05.00-0152: Interface Control Document Between: LO Reference and Timing – Distribution (RTD) and Antenna Time and Frequency (ATF)

This interface details the requirements for signal, timing, and connection between the ATF and the round-trip distribution equipment that distributes the primary time and frequency references to the antennas.

Table 11: ATF subsystem requirements tracked in ICD to IRD

Parameter	Req. #	Value	Traceability
DBE Input Reference Frequency	ATF6100	100 MHz	See Section 7.1
DBE Frequency Input Accuracy	ATF6110	42 fsec at 300s	SYS5001
DBE Frequency Input Phase Noise	ATF6120	Signal requirements per JESD standard. RD09 is latest standard JESD204C	RD09
DBE Frequency Signal Type	ATF6130		RD09
DBE Frequency Signal Level	ATF6140		RD09

Parameter	Req. #	Value	Traceability
		JESD204D JESD204D	
1 PPS Timing Stability	ATF6150	See Section 7.6	ATF1300
Fiber Transmitter	ATF6160	40Gbit/sec multi-mode fiber transceiver	

10 Technical Metrics

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

10.1 Technical Performance Measures

The Technical Performance Measures are requirements that closely impact the overall performance of the ngVLA system and are therefore considered of higher importance. The following Technical Performance Measures are identified for optimization and monitoring throughout the design phase.

Table 12: ngVLA Key Performance Parameters.

Technical Performance Measures	Req. #	Traceability L1 Re#
LO Phase Noise	ATF1240	SYS5001, SYS1503, CAL0314
LO Phase Drift	ATF1250	SYS5001, SYS1504, SYS1505

11 Verification

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

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

Verification by Inspection: The compliance of the developed system is determined by a simple inspection (of the design documentation or deliverables) or measurement.

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

Verification by Test: The compliance of the developed subsystem with the specified performance shall be demonstrated by an acceptance test.

Multiple verification methods are allowed over the course of the design phase, although the primary (final) verification method is identified below.

11.1 Environmental Testing

The following environmental test conditions are defined:

Precision Operating Conditions: temperature range and max rate of change (POC): corresponding to requirements ATF0320, ATF0330

- Critical requirements shall be tested at the minimum, median, and maximum temperature
- Stability testing shall be conducted under temperature rate of change defined for POC

Normal Operating Conditions: temperature range and max rate of change (NOC): corresponding to requirements ATF0390, ATF0400

- Critical requirements shall be tested at the minimum, median, and maximum temperature
- Stability testing shall be conducted under temperature rate of change defined for NOC

Limit Operating Conditions (LOC): Components exposed to Limit conditions during operations shall be tested for safe operation and for not incurring residual damage. Test profiles shall include:

- Start-up sequence from off to operational at minimum temperature (ATF0410) (at least 20 cycles).
- Extended operation (60 minutes) at maximum operating temperature (ATF0410)
- Maximum rate of change of temperature (up and down) between minimum and maximum values (at least 20 cycles) (ATF0420)

Transport Conditions (Shock & Vibe) (SV):

- All LRUs that are transported shall be tested for not incurring residual damage at maximum transportation temperature over an extended period (at least 4 hours) (ATF0180)
- Prior to and after conducting SV testing, critical operational performance measures shall be tested (ATF0190, ATF0200)

11.2 Subsystem Verification Table

Req. #	Parameter/Requirement	A	I	D	T
ATF1100	Size of Equipment Enclosures		*		
ATF1110	Weight of Equipment Enclosures		*		
ATF1200	LO Frequency				*** POC, LOC, SV**
ATF1205	LO Frequency Table			*	
ATF1210	LO Frequency Offsets				*** NOC**
ATF1220	Tuning				*** NOC**
ATF1225	LO Switching Speed				*** NOC**
ATF1230	LO Amplitude				*** POC, LOC, SV**
ATF1235	LO Amplitude Stability				*** POC**
ATF1240	LO Phase Noise				*** POC**
ATF1250	LO Phase Drift				*** POC**
ATF1260	Digitizer Clock Phase Noise				*** POC**
ATF1270	Digitizer Clock Phase Drift				*** POC**
ATF1300	Timing at RTD output				*** POC**
ATF1355	Time Accuracy – Antenna Station Functions				*** POC**
ATF1357	Antenna timing				*** POC**
ATF1380	Timing to DBE				*** POC**
ATF1215	LO Return to Phase				*** POC**
ATF1400	Standby Mode			*	
ATF1410	Automatic Initialization			*	
ATF1420	Operating Modes			*	
ATF1500	Spurious Narrowband Tones				*** NOC**
ATF1600	Spurious Signal Level Emission				*** NOC**
ATF1605	Spurious Emission impacting IRD			*	
ATF1610	Emission Verification Frequencies		*		
ATF1620	Low Frequency Emission			*	
ATF1630	Self-Monitoring				*** NOC, LOC, SV**
ATF1640	LRU Alerts				*** NOC, LOC, SV**
ATF1650	High-Cadence Monitoring			*	
ATF1660	LRU Hot Swapping	*		*	
ATF1670	Remote Updates			*	
ATF1680	Automatic Configuration on Restart			*	
ATF1690	Front End Engineering Console		*		
ATF1700	M&C Commanded Reset for DC Powered Devices				*** NOC**
ATF1710	M&C Commanded Reset for AC Powered Devices				*** NOC**
ATF1800	Design Life	*			
ATF1810	Lifecycle Optimization	*			
ATF1820	Parts Selection and Procurement Criteria	*			
ATF1900	Serial Numbers		*		

Req. #	Parameter/Requirement	A	I	D	T
ATF1910	Version Control for Software and Firmware		*		
ATF1920	Configuration Retrieval			*	
ATF1930	Physical Tracking		*		
ATF1940	Remote Identification			*	
ATF1950	Documentation		*		
ATF2200	Analog shielding	*	*		
ATF2210	Digital shielding	*	*		
ATF2220	Commercial equipment		*		
ATF2230	Conducted Immunity, Testing				* **NOC**
ATF2240	Electrostatic Discharge, Testing				* **NOC**
ATF2250	Hi-Speed Design	*			
ATF2260	ESD, Storage and Shipment		*		
ATF2300	Reliability Analysis	*			
ATF2310	Mean Time Between Failures	*			
ATF2320	Mean Time between Maintenance	*			
ATF2330	Array Element MTTR	*			
ATF2340	Modularization		*		
ATF2350	Spares Planning	*			
ATF2360	Transfer of Deliverables		*		
ATF2370	Automated Failure Reporting			*	
ATF2380	LRU Interchangeability		*		
ATF2390	Identify Failures Physically			*	
ATF2400	Report Predicted Failures			*	
ATF2410	Failure Information Source		*		
ATF2420	Robustness Analysis	*			
ATF3200	Printed Circuit Boards- Standards		*		
ATF3210	Printed Circuit Board-Design		*		
ATF3220	Soldered Electrical Connections		*		
ATF3300	LRU Power Input		*		
ATF3310	LRU Physical Ground		*		
ATF3320	Power Supply Returns Separate from Ground		*		
ATF3330	DC Voltages available		*		
ATF3340	PSU Voltage Tolerance: Test Key Performance Parameters over full range of power supply voltages				* **NOC**
ATF3350	Overcurrent Protection		*		
ATF3360	Overcurrent Protection Device Monitoring			*	
ATF3370	Thermal Protection		*		
ATF3380	Thermal Protection Monitoring			*	
ATF3390	Thermal Analysis	*			
ATF3400	Power On Indicators			*	
ATF3410	Battery Use		*		

Req. #	Parameter/Requirement	A	I	D	T
ATF3420	Transient Protection		*		
ATF3500	Wiring Documentation and Labeling		*		
ATF3510	DC voltage Wire Colors		*		
ATF3520	AC power wiring colors		*		
ATF3530	Wire and Cable installation		*		
ATF3540	Connector Documentation and Labeling		*		
ATF3560	Connector Selection		*		
ATF3570	Connectors for Hot Swap		*		
ATF3580	Connector Design for Ease of Operation		*		
ATF3590	Crimped Connectors		*		
ATF3700	Metalwork		*		
ATF3710	Lighting		*		
ATF3720	Fasteners		*		
ATF3730	LRUs, mechanical		*		
ATF3740	LRU documentation and dimensions		*		
ATF4200	Safety Specification	*			
ATF4210	Security Specification	*			
ATF4220	Cybersecurity Specification	*			
ATF4230	Hazard Analysis	*			
ATF4240	LRU Weight Labels		*		
ATF4250	Hot Connect & Disconnect Warning Labels		*		
ATF4260	Electrical and Optical Label Safety Standards		*		
ATF4270	Design for Optical Safety	*			
ATF4280	Optical Safety Labels		*		
ATF4290	Connectors for Hot Swap		*		
ATF4300	No Exposed Live Terminals		*		
ATF5200	As-Built Drawings		*		
ATF5210	Operations & Maintenance Manuals		*		
ATF5220	Units		*		
ATF5230	Language		*		
ATF5240	Electronic Document Format		*		
ATF5250	Compliance Matrix		*		
ATF5260	Test Plan		*		
ATF5270	Design document		*		
ATF5280	RFI/EMC/Immunity Design report		*		
ATF5290	RAM Report		*		
ATF5300	Safety Design Report		*		
ATF5310	Reliability and Robustness Report		*		
ATF5320	LRU Documentation		*		
ATF6000	RTD Reference Frequency			*	
ATF6010	RTD Reference Frequency Amplitude				*

Req. #	Parameter/Requirement	A	I	D	T
ATF6020	RTD Reference Frequency Amplitude Stability				*
ATF6030	RTD Reference Frequency Phase Noise				*
ATF6040	RTD Reference Frequency Phase Drift				*
ATF6050	RTD Timing 1 PPS Monitoring Interface			*	
ATF6100	DBE Input Reference Frequency			*	
ATF6110	DBE Frequency Input Accuracy				*
ATF6120	DBE Frequency Input Phase Noise				*
ATF6130	DBE Frequency Signal Type			*	
ATF6140	DBE Frequency Signal Level			*	
ATF6150	1 PPS Timing Stability				*
ATF6160	Fiber Transmitter		*		

12 Appendix

12.1 Abbreviations and Acronyms

Acronym	Description
AD	Applicable Document
ADC	Analog to Digital Converter
AFD	Antenna Fiber Distribution subsystem
AIV	Acceptance, Integration, and Verification
ANSI	American National Standards Institute
ATF	Antenna Time and Frequency
BMR	Bins, Modules, and Racks subsystem
CDR	Critical Design Review
CE	Conformite Europienne
CI	Configuration Item
CID	Configuration Item Data
CoDR	Conceptual Design Review
COTs	Commercial off the shelf
CSP	Central Signal Processor
DAC	Digital to Analog Converter
DBE	Digital Backend
DC	Direct Current
DSP	Digital Signal Processor
EEC	Antenna Electronics Environmental Control subsystem
EIRP	Emitted Isotropic Radiated Power
EMC	Electromagnetic Compatibility

Acronym	Description
EMI	Electromagnetic Interference
ESD	Electrostatic Discharge
FCC	Federal Communications Corporation
FDR	Final Design Review
FED	Front End subsystem
FMECA	Failure Mode Effects Analysis
FPGA	Field Programmable Gate Array
GHz	GigaHertz
GPS	Global Positioning System
HIL	Hardware Interface Layer
HVAC	Heating, Ventilation, and Air Conditioning
I/F	Interface
I/O	Input-Output
ICD	Interface Control Document
IEC	International Electrotechnical Commission
IPC	Institute for Printed Circuits
IPT	Integrated Product Team
IRD	Integrated Receiver Digitizer
JESD	JEDEC Standards
KPP	Key Performance Parameter
LED	Light Emitting Diode
LO	Local Oscillator
LOC	Limiting Operational Conditions
LRU	Line Replaceable Unit
M/C	Monitor and Control
MCL	Monitor and Control subsystem
MOE	Measure of Effectiveness
MOP	Measure of Performance
MTBF	Mean Time Between Failure
MTTM	Mean Time to Maintenance
MTTR	Mean Time to Repair
NEC	National Electrical Code
ngVLA	Next Generation Very Large Array
NOC	Normal Operating Conditions
NRAO	National Radio Astronomy Observatory
OLED	Organic Light Emitting Diode
PBS	Product Breakdown Structure
PCB	Printed Circuit Board
PDF	Portable Document Format
PDU	Power Distribution Unit

Acronym	Description
PE	Project Engineer
PLL	Phase Lock Loop
POC	Precision Operating Condition
PSU	DC Power Supply subsystem
RD	Reference Document
RF	Radio Frequency
RFI	Radio Frequency Interference
RFID	Radio Frequency Identification
RSS	Root Sum Square
RTD	LO Reference and Timing - Distribution
SRU	Shop Replaceable Unit
TAI	International Atomic time
TBC	To Be Confirmed
TBD	To Be Determined
TPM	Technical Performance Measure
UPS	Uninterruptible Power Supply
WVR	Water Vapor Radiometer

020.30.35.00.00-0004_REQ_Antenna_Time_and_Frequency_Technical_Requirements

Final Audit Report 2024-08-22

Created:	2024-08-16
By:	Pieter Kotzé (pkotze@nrao.edu)
Status:	Signed
Transaction ID:	CBJCHBCAABAAQZZtsVw1rsAT3STN5k_Z9uexVe2ErkmZ

"020.30.35.00.00-0004_REQ_Antenna_Time_and_Frequency_Technical_Requirements" History

Document created by Pieter Kotzé (pkotze@nrao.edu)
2024-08-16 - 10:10:43 PM GMT- IP address: 208.77.77.75

Document emailed to bshillue@nrao.edu for signature
2024-08-16 - 10:11:47 PM GMT

Email viewed by bshillue@nrao.edu
2024-08-19 - 2:24:53 PM GMT- IP address: 192.131.232.128

Signer bshillue@nrao.edu entered name at signing as B. Shillue
2024-08-19 - 2:25:22 PM GMT- IP address: 192.131.232.128

Document e-signed by B. Shillue (bshillue@nrao.edu)
Signature Date: 2024-08-19 - 2:25:24 PM GMT - Time Source: server- IP address: 192.131.232.128

Document emailed to Pieter Kotzé (pkotze@nrao.edu) for signature
2024-08-19 - 2:25:26 PM GMT

Email viewed by Pieter Kotzé (pkotze@nrao.edu)
2024-08-19 - 6:53:27 PM GMT- IP address: 174.56.85.49

Document e-signed by Pieter Kotzé (pkotze@nrao.edu)
Signature Date: 2024-08-19 - 6:55:22 PM GMT - Time Source: server- IP address: 174.56.85.49

Document emailed to Rob Selina (rselina@nrao.edu) for signature
2024-08-19 - 6:55:23 PM GMT

Email viewed by Rob Selina (rselina@nrao.edu)
2024-08-19 - 6:58:04 PM GMT- IP address: 192.92.119.128

Document e-signed by Rob Selina (rselina@nrao.edu)

Signature Date: 2024-08-22 - 3:00:45 PM GMT - Time Source: server- IP address: 66.173.52.81

Document emailed to Willem Esterhuyse (westerhu@nrao.edu) for signature

2024-08-22 - 3:00:47 PM GMT

Email viewed by Willem Esterhuyse (westerhu@nrao.edu)

2024-08-22 - 3:10:28 PM GMT- IP address: 73.31.51.29

Document e-signed by Willem Esterhuyse (westerhu@nrao.edu)

Signature Date: 2024-08-22 - 3:10:42 PM GMT - Time Source: server- IP address: 73.31.51.29

Agreement completed.

2024-08-22 - 3:10:42 PM GMT