Integrated Receivers and Downconverters: Preliminary Technical Requirements

020.30.15.00.00-0001-REQ-A-INTEGR_RECVR_DOWNCONVERTER_TECH_REQS

Status: **RELEASED**

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Change Record

Version	Date	Author	Affected Section(s)	Reason
1	201801-10	M. Morgan	All	First draft. Used ngVLA Antenna Specs as a template, and took some data from ngVLA memo #29, "An Integrated Receiver Concept for the ngVLA."
2	2018-03-29	M. Morgan	4.1, 4.2	Modified Band 5 LO frequencies.
3	2018-04-16	M. Morgan	5.4	Removed reference to TEC supply.
4	2018-04-26	M. Morgan	many	Increased Bands 4 and 5 to 8 bits, added two Band 4 modules for WVR, added 3.3 V digital supply.
5	2018-05-03	M. Morgan	4.6.3	Changed spurious spec to –43 dBm/MHz.
6	2018-05-16	M. Morgan	many	Re-harmonized with updated system requirements.
7	2018-06-24	M. Morgan	header	Corrected file number.
8	2018-07-03	M. Morgan	Fig. 1	Corrected Band 2 edge frequency.
9	2018-07-31	M. Morgan	4.10, 6	Added mass and physical dimension specs.
9.9	2018-09-06	S. Durand	All	Minor changes, number of antennas.
10	2018-10-01	M. Morgan	All	Updates from Internal Pre-Decadal Submission Review.
11	2018-10-19	M. Morgan	5.6, 2.1	Clarified number of fibers. Removed rev numbers in AD reference table.
12	2018-10-31	M. Morgan	header	Changed title block to show author/owner. Also deleted ngVLA project background.
A	2019-07-25	A. Lear	All	Prepared PDF for approvals and release.

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1 Introduction

1.1 Purpose

This document presents a preliminary set of technical specifications for the ngVLA Integrated Receiver and Downconverter (IRD) modules.

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

The integrated receiver packages further amplify the signals provided by the cryogenic stage, down convert them where necessary, digitize them, and deliver the resultant data streams by optical fiber to a moderately remote collection point from the focal plane (but possibly still inside the antenna base).

From there, they are time-stamped and launched onto a conventional network for transmission back to the array correlator and central processing facility. Hooks are needed to provide for synchronization of local oscillators (LOs) and sample clocks, power leveling, command and control, health and performance monitoring, and diagnostics for troubleshooting in the event of component failure.

1.2 Scope

The scope of this document is the set of ngVLA Integrated Receiver and Downconverter modules. This consists of direct-sampled and sideband-separating modules for all telescope bands, which include warm amplification, filtering, power leveling, analog-to-digital conversion, and fiber-optic transmission. It also covers external splitters and combiners as needed to feed them from the cryogenic signal paths.

Cryogenic systems and thermal transitions, as well as front-end cabling, waveguide runs, and fiber-optic signal paths outside the IRD modules themselves are outside the scope of this work package, though interfaces must be considered. This specification establishes the performance, functional, design, and test requirements applicable to the ngVLA IRD modules.

2 Related Documents and Drawings

2.1 Applicable Documents

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

Reference No.	Document Title	Rev / Doc. No.
AD01	ngVLA Preliminary System Requirements	020.10.15.10.00-0003-REQ
AD02	ngVLA System Environmental Specifications	020.10.15.10.00-0001-SPE

2.2 Reference Documents

The following references provide supporting context:

Reference No.	Document Title	Rev / Doc. No.
RD01	An Integrated Receiver Concept for the ngVLA	ngVLA Memo #29, Nov. 2017
RD02	Unformatted Digital Fiber-Optic Data Transmission for Radio Astronomy Front-Ends	PASP, vol. 125, no. 928, June 2013

3 Overview of Technical Specifications

3.1 Document Outline

This document presents the technical specifications of the ngVLA Integrated Downconverters. These parameters determine the overall form and performance of the downconverter modules.

The functional and performance specifications, along with detailed explanatory notes, are found in Section 4. The notes contain elaborations regarding the meaning, intent, and scope of the requirements. These notes form an important part of the definition of the requirements and should guide the verification procedures.

In many cases the notes contain an explanation or an analysis of how the numeric values of requirements were derived. Where numbers are not well substantiated, this is also documented in the notes. In this way, the required analysis and trade-space available is apparent to scientists and engineers who will guide the evolution of the ngVLA Integrated Downconverter concept.

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

Requirements for the Verification and Test of the integrated modules, from the conceptual design through to prototype, are described in Section 6.

3.2 General Description

The integrated downconverters will take cryogenically amplified RF inputs ranging from 1.2 to 116 GHz in bands and perform all necessary conversions from RF to baseband, from analog to digital, and from copper to fiber in compact, integrated, line-replaceable units (LRUs). The lower bands may be digitized directly (without down conversion) in the first-, second-, and/or third-Nyquist zones, while the higher bands may be down converted with in-phase and quadrature (I and Q) baseband outputs. Final sideband-separation will be performed numerically by the backend (outside the scope of this work package) with calibrated amplitude and phase coefficients. The initial concept and frequency plan for this subsystem (now somewhat modified, and still evolving) was presented in [RD01].

Due to instantaneous digital bandwidth limitations, more than one downconverter module may be required to service a single RF feed band. Where needed, passive splitters/combiners will be provided within this scope to divide the RF band into more manageable chunks for the integrated modules.

The digitized I and Q or direct-sampled data streams will be transmitted by optical fiber as unformatted serial data. The mathematical basis of operation and methodology for parsing the bit stream at the receive end is described in detail in [RD02].

Auxiliary inputs to the integrated downconverters will include LOs, sample clocks, power supplies, and the monitor and control (M&C) serial bus. Sufficient on-board monitoring will be provided to isolate most failures to a single LRU.

3.3 Summary of Integrated Downconverter Requirements

The following table provides a summary of the major integrated downconverter requirements in order to provide the reader with a high-level view of the desired subsystem. Should there be a conflict between the requirements listed here and the descriptions in Sections 4 through 6, the latter shall take precedence.

Parameter	**Summary of Requirement**	**Reference Reqs.**
RF Input Frequency Bands	1.2–3.5 GHz 3.5–10.5 GHz 10.5–20.5 GHz 20.5–34 GHz 30.5–50.5 GHz 70–116 GHz	IRD0101 IRD0102 IRD0103 IRD0104 IRD0105 IRD0106
IF Bandwidth	3.5 GHz (RF < 10.5 GHz) 3.5 GHz per sideband, 2SB (10.5 < RF < 50.5 GHz) 7 GHz per sideband, 2SB (70 < RF < 116 GHz)	IRD0301–0302 IRD0303–0305 IRD0306
Image Rejection	>30 dB (calibrated)	IRD0611–0614
Gain (nominal)	60 dB (TBC)	IRD0411–0416
Gain Flatness	<2.7 dB slope, plus <2dB peak-to-peak ripple	IRD0421–0422
Gain Adjust	±12 dB min. (from nominal)	IRD0431
Noise Temperature	<1000 K	IRD0501–0506
Bit Resolution	8 bits (RF < 50.5 GHz) 4 bits (70 < RF < 116 GHz)	IRD0721–0725 IRD0726

4 Functional and Performance Requirements

All function and performance requirements apply to a properly functioning system, with nominal inputs and control settings (e.g., attenuator states), under normal operating environmental conditions (temperature, power, etc.), and with normal operational calibrations applied, unless otherwise stated.

4.1 RF Frequency Ranges

Parameter	Req. #	Value	Traceability
Band 1 RF Frequency	IRD0101	1.2–3.5 GHz	SYS0801–0806
Band 2 RF Frequency	IRD0102	3.5–10.5 GHz	SYS0801–0806
Band 3 RF Frequency	IRD0103	10.5–20.5 GHz	SYS0801–0806
Band 4 RF Frequency	IRD0104	20.5–34 GHz	SYS0801–0806
Band 5 RF Frequency	IRD0105	30.5–50.5 GHz	SYS0801–0806
Band 6 RF Frequency	IRD0106	70–116 GHz	SYS0801–0806

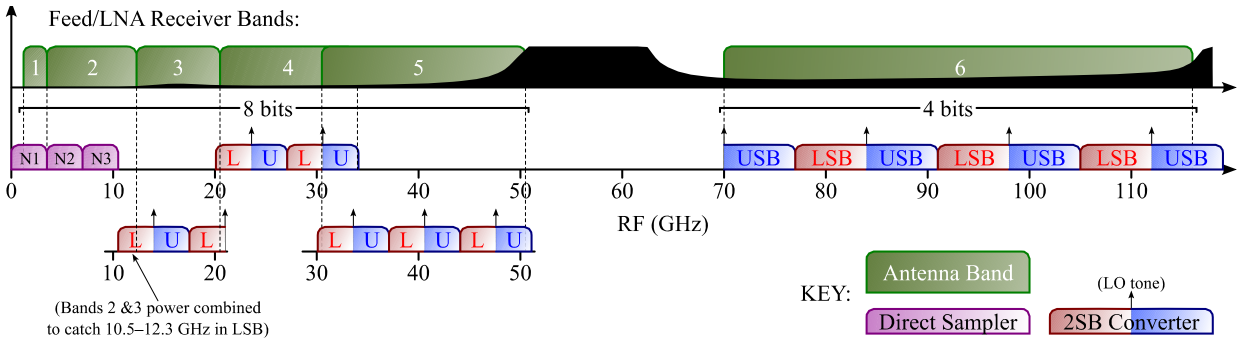
The total RF frequency range flows down from the system requirements, and the selection of band edges stem from a combination of engineering feasibility, hardware efficiency, and the system requirement that the band edges do not coincide with important spectral features.

It should be noted that the Band 2/3 transition at 10.5 GHz for the IRD modules do not coincide with those of the planned feed and cryogenic amplifier bands. This is because 10.5 GHz marks the transition from one type of integrated module (direct-sampled) and another (sideband-separating), which in turn is driven by the expected analog bandwidth of the digitizers.

A general frequency plan for the integrated receivers is shown in Figure 1 (next page). Unless otherwise noted, all references to RF bands within this document shall refer to the integrated module band ranges, not the cryogenic front-end band ranges.

The RF signal path will include a set of passive splitters and combiners to feed the correct bandwidth to each module. Note that the wider RF bands will require more than one module for complete frequency coverage. Although the reference design anticipates that all modules within a given RF band will be identical, this is not a requirement.

A subset of antennas (their number as yet undetermined) will require additional Band 4 modules to service the water vapor radiometer (WVR).



Band	Frequency	Receiver Type	# bits	Sample Rate
1	1.2–3.5 GHz	DS	8	7 GS/s
2	3.5–7.0 GHz	DS	8	7 GS/s
	7.0–10.5 GHz	DS	8	7 GS/s
3	10.5–20.5 GHz	2SB	8	7 GS/s
		2SB	8	7 GS/s
4	20.5–34 GHz	2SB	8	7 GS/s
		2SB	8	7 GS/s
WVR (4)	20.5–34 GHz	2SB	8	7 GS/s
		2SB	8	7 GS/s
5	30.5–50.5 GHz	2SB	8	7 GS/s
		2SB	8	7 GS/s
		2SB	8	7 GS/s
6	70–116 GHz	2SB	4	14 GS/s
		2SB	4	14 GS/s
		2SB	4	14 GS/s
		2SB	4	14 GS/s

Figure 1 - Integrated downconverter frequency plan. DS refers to direct-sampled receivers, while 2SB refers to sideband-separating receivers.

4.2 *LO Frequencies*

Parameter	Req. #	Value	Traceability
Band 3 LO Frequencies	IRD0201	14 and 21 GHz	SYS0906
Band 4 LO Frequency	IRD0202	23.6 and 30.6 GHz	SYS0906
Band 5 LO Frequencies	IRD0203	33.6, 40.6, and 47.6 GHz	SYS0906
Band 6 LO Frequencies	IRD0204	70, 84, 98, and 112 GHz	SYS0906
LO Frequency Tunability	IRD0205	±2 GHz	SYS0806

The LO frequencies above were selected to allow complete coverage of the RF bands in Section 4.1 with only minimal gaps at near-DC IF frequencies and at the edges between sidebands of adjacent downconverters. LOs were also selected, where reasonable, to be harmonically related to the sample clock frequencies to minimize the chance of spurious mixing products between the two. For simplicity, we do not require the LOs to tune over very wide ranges, but a minimal LO tuning requirement (IRD0205) permits access to these nominal gap frequencies at the discretion of the telescope operator (with the exception of the gaps at 3.5 GHz and 7 GHz between Nyquist zones of the direct-sampled receivers).

4.3 IF Bandwidth

Parameter	Req. #	Value	Traceability
Band 1 IF Bandwidth	IRD0301	3.5 GHz	
Band 2 IF Bandwidth	IRD0302	3.5 GHz	
Band 3 IF Bandwidth	IRD0303	3.5 GHz	
Band 4 IF Bandwidth	IRD0304	3.5 GHz	
Band 5 IF Bandwidth	IRD0305	3.5 GHz	
Band 6 IF Bandwidth	IRD0306	7 GHz	

Note that these bandwidths correspond to the maximum theoretical bandwidths sampled by the digitizers, and do not necessarily represent *alias-free* bandwidth. Bands 3 and above are sideband-separating, while the Band 2 module is expected to utilize two Nyquist zones with 3.5 GHz bandwidth each. Further, all modules are dual polarization. Finally, as noted earlier, some bands will be populated with more than one module. Consequently, the numbers above represent the IF bandwidth *per sideband or Nyquist zone*, *per polarization*, and *per module*, as applicable for each band.

4.4 Analog Gain

The net warm electronic gain is required to amplify the weak output spectra of the cryogenic system to a level at the digitizers that balances quantization efficiency and dynamic range. It is specified in terms of nominal (average) value, flatness, and adjustment range. The final values of these specs will depend on the gain specification of the cryogenic amplifiers and the full-scale range of the samplers.

4.4.1 Nominal Gain

Parameter	Req. #	Value	Traceability
Band 1 Nominal Gain	IRD0411	60 dB (TBC)	
Band 2 Nominal Gain	IRD0412	60 dB (TBC)	
Band 3 Nominal Conversion Gain	IRD0413	60 dB (TBC)	
Band 4 Nominal Conversion Gain	IRD0414	60 dB (TBC)	
Band 5 Nominal Conversion Gain	IRD0415	60 dB (TBC)	
Band 6 Nominal Conversion Gain	IRD0416	60 dB (TBC)	

Nominal gain is defined as the average analog signal gain between the RF inputs of the IRD modules and the inputs to the samplers over the RF operating frequency for each band defined in Section 4.1. The nominal setting of the internal step attenuators are determined post-fabrication as that setting which most closely achieves the desired gain. The modules will further be required to have enough attenuator control range leftover to meet the gain adjustability requirements in Section 4.4.3.

4.4.2 Gain Flatness

Parameter	Req. #	Value	Traceability
Gain Slope	IRD0421	<2.4 dB (80% BW) TBC	SYS1703
Gain Ripple	IRD0422	<2.4 dB peak-to-peak TBC	SYS1702

Gain slope is measured as the best fit line over that 80% of each IF band (defined in Section 4.3) which minimizes its value. Gain ripple is defined as the residual variation over the same 80% bandwidth after the slope is removed from the data. The system requirements for gain slope and ripple are 3 dB each. No budget for sharing this allowance across subsystems has been completed, but it can be assumed 80% of that can be allocated to the IRD system and 20% to the cryogenic front-ends, for two reasons. First, IRD comprises roughly two-thirds of the net analog gain (60 dB out of roughly 90 dB). Second, several lossy signal-conditioning components such as mixers, filters, and variable attenuators, must be further compensated by gain stages in the IRD.

4.4.3 Gain Adjustment

Parameter	Req. #	Value	Traceability
Gain Adjustment Range	IRD0431	±12 dB	
Gain Adjustment Step Size	IRD0432	≤1 dB	
Solar Mode Adjustment	IRD0433	+30 dB up to 10.5 GHz (TBC)	SYS1203

Analog gain shall be adjustable in discrete steps via integrated step attenuators. The nominal setting of these attenuators shall be determined on a per module basis to most closely meet the nominal gain targets, with enough range left over to meet the requirements above. An additional 30 dB attenuator shall be available in the lower frequency bands to support solar observations. At present, it is assumed the extra attenuation is not needed for the higher frequency bands.

4.4.4 Gain Stability

Parameter	Req. #	Value	Traceability
Gain Amplitude Stability	IRD0441	<0.01 dB per hour	SYS1701
Gain Phase Stability	IRD0442	<0.01 degrees over 300 sec	SYS1504
Allan Variance	IRD0443	TBD	

Gain amplitude and phase stability is required to reach the ngVLA's ultimate sensitivity goals, as well as to enable a low-overhead calibration policy in which bandpass and gain solutions for each antenna and receiver are stored for use in subsequent observations. The stability of gain amplitude and phase shall apply at any point in the pass-band, and shall be met under nominal environmental conditions (especially temperature gradient) given in Section 4.8.1. Allan variance is measured on amplitude only. As described in the system-level requirements, the phase drift specification is an rms residual, after subtraction of any linear trend over the specified time period.

4.5 Sensitivity

Parameter	Req. #	Value	Traceability
Band 1 Noise Temperature	IRD0501	<1000 K	SYS1011
Band 2 Noise Temperature	IRD0502	<1000 K	SYS1011, SYS1012
Band 3 Noise Temperature	IRD0503	<1000 K	SYS1012
Band 4 Noise Temperature	IRD0504	<1000 K	SYS1012
Band 5 Noise Temperature	IRD0505	<1000 K	SYS1012
Band 6 Noise Temperature	IRD0506	<1000 K	SYS1013

These noise temperatures ensure that the warm electronics contribute less than 1K to the system noise temperature, assuming the cryogenic input stage has 30 dB gain. Noise temperature shall be measured by Y-factor over the integrated noise of the IF bandwidth with the internal step attenuators at nominal setting.

4.6 Spurious Signals

Spurious signals in this document may include any unwanted signal power (aside from in-band noise) that leak into the signal path. These may include image bands, alias bands, and spurious CW or narrowband tones.

4.6.1 Image Rejection

Parameter	Req. #	Value	Traceability
Band 3 Image Rejection	IRD0611	>30 dB	SYS1704
Band 4 Image Rejection	IRD0612	>30 dB	SYS1704
Band 5 Image Rejection	IRD0613	>30 dB	SYS1704
Band 6 Image Rejection	IRD0614	>30 dB	SYS1704

Image rejection shall be measured with calibrated corrections applied and all internal attenuators and LOs at nominal settings.

4.6.2 Alias Rejection

Parameter	Req. #	Value	Traceability
Band 1 Alias-Free IF FBW	IRD0621	80%	SYS1703
Band 2 Alias-Free IF FBW	IRD0622	80%	SYS1703
Band 3 Alias-Free IF FBW	IRD0623	80%	SYS1703
Bands 4–6 Alias-Free IF FBW	IRD0624	80%	SYS1703
Band 1 Alias Rejection	IRD0625	>55 dB	
Band 2 Alias Rejection	IRD0626	>55 dB	
Band 3 Alias Rejection	IRD0627	>55 dB	
Bands 4–6 Alias Rejection	IRD0628	>55 dB	

"Alias-free" IF fractional bandwidth (FBW) is the percentage of the theoretical IF band defined in Section 4.3 in which the aliased signals are attenuated by the given alias rejection levels. The rejection, in turn, is measured relative to the corresponding in-band gain. It is inevitable that anti-aliasing filters will introduce gain slope at the edges of the IF band. The 80% fractional bandwidth specifications above flow down from the System Requirement SYS1703 that the IF slope shall be restricted over 80% of the band.

Note that at the broadest IF bandwidth (7 GHz), an 80% FBW specification allows for a gap of 0.2 x 7 GHz = 1.4 GHz, which is not "alias-free." The LO tuning requirement (IRD0205) ensures that all frequencies within the instrument's RF range (except for the Nyquist zone boundaries at 3.5 GHz and 7 GHz) are accessible with "alias-free" levels of rejection.

4.6.3 Spurious Narrowband Tones

Parameter	Req. #	Value	Traceability
Spurious Tone Power	IRD0631	<–43 dB/MHz above noise floor	SYS2104

Spurious tones in this context refers to any narrowband spurious signal, regardless of its source (e.g., mixing products, clock harmonics, switching transients, oscillations). The relative "spurious power" in a given spectral bin will be calculated as (P–N)/N, where P is the total power in the bin and N is the average power in the adjacent two bins. The bin size will be chosen as large as possible to include broad spurs, while narrow enough to exclude microscale baseband ripples to >10 dB below the spec limit.

4.7 Digitization

4.7.1 Sample Rate

Parameter	Req. #	Value	Traceability
Band 1 Sample Rate	IRD0711	7 GS/s	
Band 2 Sample Rate	IRD0712	7 GS/s	
Band 3 Sample Rate	IRD0713	7 GS/s	
Band 4 Sample Rate	IRD0714	7 GS/s	
Band 5 Sample Rate	IRD0715	7 GS/s	
Band 6 Sample Rate	IRD0716	14 GS/s	

4.7.2 Bit Resolution

Parameter	Req. #	Value	Traceability
Band 1 Bit Resolution	IRD0721	8 bits	SYS1034
Band 2 Bit Resolution	IRD0722	8 bits	SYS1034
Band 3 Bit Resolution	IRD0723	8 bits	SYS1034
Band 4 Bit Resolution	IRD0724	8 bits	SYS1034
Band 5 Bit Resolution	IRD0725	8 bits	SYS1034
Band 6 Bit Resolution	IRD0726	4 bits	SYS1035

Note that these represent the bit resolutions at the front-end. The correlator may requantize these data streams at lower resolution levels (with appropriate care for sensitivity and dynamic range).

4.8 Operating Conditions

All functional and performance specifications given herein are to be met at nominal operating conditions, while basic functionality is required over the limiting operational conditions.

4.8.1 Nominal Operating Conditions

Parameter	Req. #	Value	Traceability
Nominal Temperature	IRD0811	-15 C ≤ T ≤ 35 C	ENV0323
Nominal Temperature Gradient	IRD0812	<3.6°C per hour	ENV0324

Verification tests shall be considered successful if the measurement passes while environmental conditions are within the ranges of the nominal operating conditions, unless otherwise explicitly stated.

4.8.2 Limiting Operational Conditions

Parameter	Req. #	Value	Traceability
Limiting Temperature	IRD0821	-20 C ≤ T ≤ 45 C	ENV0332
Limiting Temperature Gradient	IRD0822	<3.6°C/Hr.	

The limiting operational conditions define the ranges over which basic functionality is assured without necessarily meeting specifications. They are not intended to define safe storage or working limits beyond which permanent damage may occur.

4.9 Monitor & Control Requirements

Parameter	Req. #	Value	Traceability
RF Signal Monitors	IRD0901	The integrated modules shall measure and report total signal power entering each RF input.	
IF Signal Monitors	IRD0902	The integrated modules shall measure and report total IF signal power entering each digitizer channel.	
Electronic Serial Number	IRD0903	The integrated modules shall report a unique electronic identification upon request.	
Standby Mode	IRD0904	The integrated modules shall be capable of entering a low-power standby mode on command. M&C communications shall still be functional in this mode.	
Automatic Initialization	IRD0905	The integrated modules shall automatically boot into a nominal operational mode on power-up, absent any command from M&C.	

The monitor points (IRD0901 and IRD0902) may comprise raw voltages or digital values in arbitrary units, subject to appropriate scaling and translation to recover meaningful values. No specific precision or accuracy is implied in these requirements.

4.10 Mass and Physical Dimensions

Parameter	Req. #	Value	Traceability
Physical Dimensions	IRD1001	Each integrated module shall fit within a physical envelope measuring 40 x 80 x 160 mm in size.	
Mass	IRD1002	Each integrated module shall weigh less than 1.5 kg.	
Connector Orientation	IRD1003	RF input connectors/flanges shall be located at one end of the physical envelope above, while the outputs and LO, clock, bias, and M&C inputs shall be located at the opposite end.	
Mounting Holes	IRD1004	Each integrated module shall include at least four clear holes (sized for #4 screws) oriented to mount against a temperature-controlled surface in contact with the largest face of the above physical envelope.	

5 Interface Requirements

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

These interfaces shall be developed and documented by the Integrated Receivers and Downconverters designer. Post CoDR, the ICD shall only be updated through formal project change control processes.

Unilateral aspects of the connector interfaces (e.g., M or F) shall refer to the connector on the integrated modules. Cables, waveguide, and fiber runs between the integrated modules and other electronic subsystems are not included in this work package.

5.1 Interface to the Cryogenic Front End Subsystem

Signal at Interface	Type	Parameter	Value	Comments
Band 1 RF	Input	Connector Impedance Multiplicity	2.92 mm (F) 50 Ω x2 (one per pol.)	
Band 2 RF	Input	Connector Impedance Multiplicity	2.92 mm (F) 50 Ω x2 (one per pol.)	
Band 3 RF	Input	Connector Impedance Multiplicity	2.92 mm (F) 50 Ω x2 (one per pol.)	
Band 4 RF	Input	Connector Impedance Multiplicity	2.92 mm (F) 50 Ω x2 (one per pol.)	
Band 5 RF	Input	Flange Multiplicity	WR-22 (UG599) x2 (one per pol.)	
Band 6 RF	Input	Flange Multiplicity	WR-10 (UG387) x2 (one per pol.)	

The frequency ranges for these inputs are given in Section 4.1. The RF splitters and combiners are included in the Integrated Receivers and Downconverters subsystem.

5.2 Interface to Water Vapor Radiometer

Signal at Interface	Type	Parameter	Value	Comments
Band 4 RF	Input	Connector Impedance Multiplicity	2.92 mm (F) 50 Ω x2 (one per pol.)	

The Water Vapor Radiometer will be present on all antennas.

5.3 Interface to the Timing Reference/LO Subsystem

Signal at Interface	Type	Parameter	Value	Comments
Sample Clock Reference	Input	Frequency Electrical Format Connector Multiplicity	156.25 MHz LVDS TBD x13 (TBC)	 Coaxial, shielded
Band 3 LO	Input	Power Level Phase Noise Connector Impedance Multiplicity	>+13 dBm (CW) TBD 2.92 mm (F) 50 Ω x2	
Band 4 LO	Input	Power Level Phase Noise Connector Impedance Multiplicity	>+13 dBm (CW) TBD 2.92 mm (F) 50 Ω x4	
Band 5 LO	Input	Power Level Phase Noise Connector Impedance Multiplicity	>+13 dBm (CW) TBD WR-22 (UG599) 50 Ω x3	
Band 6 LO	Input	Power Level Phase Noise Connector Impedance Multiplicity	>+13 dBm (CW) TBD WR-10 (UG387) 50 Ω x4	

The LO nominal frequencies and tuning ranges are given in Section 4.2.

5.4 Interface to the Monitor and Control Subsystem

Signal at Interface	Type	Parameter	Value	Comments
M&C Serial Bus	Input / Output	Protocol Connector Number of Pins Multiplicity	SPI (mode 0) Nano-D (F) TBD x15 (TBC)	May be combined on the same cable harness with power supplies.

5.5 Interface to the Power Supplies

Signal at Interface	Type	Parameter	Value	Comments
Analog Positive Supply	Input	Voltage Current Draw Multiplicity	+5 V <1 A (TBC) x13	Internally regulated for multiple voltages.
Digital Positive Supply	Input	Voltage Current Draw Multiplicity	+3.3 V <1 A (TBC) x15	Internally regulated.
Main Negative Supply	Input	Voltage Current Draw Multiplicity	–5 V <100 mA (TBC) x15	Primarily (exclusively?) for transistor gates.

5.6 Interface to the Data Transmission Subsystem

Signal at Interface	Type	Parameter	Value	Comments
Digital IFs	Output	Data Format Data Content Connector Physical Format Nominal Wavelength Colors/Lanes Baud Rate Effective Bit Rate Modulation Multiplicity	Unformatted I/Q or Nyquist QSFP Single-Mode Fiber 1310 nm 4 28 Gbaud/lane 56 Gbps per lane PAM4 x15	PAM4 modulation carries 2 bits per symbol, so "effective" 56 Gbps per lane is achieved by transmitting 28 billion symbols per second. Number of fibers: 13 Nominal, plus 2 for WVR

6 Verification and Quality Assurance

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

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

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

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

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

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

Multiple verification methods are allowed. The following table summarizes the expected verification method for each requirement.

Req. #	Parameter / Requirement	D	A	I	FAT	SAT
IRD0101	Band 1 RF Frequency	*				
IRD0102	Band 2 RF Frequency	*				
IRD0103	Band 3 RF Frequency	*				
IRD0104	Band 4 RF Frequency	*				
IRD0105	Band 5 RF Frequency	*				
IRD0106	Band 6 RF Frequency	*				
IRD0201	Band 3 LO Frequencies	*				
IRD0202	Band 4 LO Frequency	*				
IRD0203	Band 5 LO Frequencies	*				
IRD0204	Band 6 LO Frequencies	*				
IRD0205	LO Frequency Tunability	*				
IRD0301	Band 1 IF Bandwidth	*				
IRD0302	Band 2 IF Bandwidth	*				
IRD0303	Band 3 IF Bandwidth	*				
IRD0304	Band 4 IF Bandwidth	*				
IRD0305	Band 5 IF Bandwidth	*				
IRD0306	Band 6 IF Bandwidth	*				
IRD0411	Band 1 Nominal Gain	*	*		*	
IRD0412	Band 2 Nominal Gain	*	*		*	
IRD0413	Band 3 Nominal Conversion Gain	*	*		*	
IRD0414	Band 4 Nominal Conversion Gain	*	*		*	
IRD0415	Band 5 Nominal Conversion Gain	*	*		*	
IRD0416	Band 6 Nominal Conversion Gain	*	*		*	
IRD0421	Gain Slope				*	

Req. #	Parameter / Requirement	D	A	I	FAT	SAT
IRD0422	Gain Ripple				*	
IRD0431	Gain Adjustment Range	*	*		*	
IRD0432	Gain Adjustment Step Size	*				
IRD0433	Solar Mode Adjustment	*				
IRD0441	Gain Amplitude Stability				*	
IRD0442	Gain Phase Stability				*	
IRD0443	Allan Variance				*	
IRD0501	Band 1 Noise Temperature	*	*			*
IRD0502	Band 2 Noise Temperature	*	*			*
IRD0503	Band 3 Noise Temperature	*	*			*
IRD0504	Band 4 Noise Temperature	*	*			*
IRD0505	Band 5 Noise Temperature	*	*			*
IRD0506	Band 6 Noise Temperature	*	*			*
IRD0611	Band 3 Image Rejection				*	
IRD0612	Band 4 Image Rejection				*	
IRD0613	Band 5 Image Rejection				*	
IRD0614	Band 6 Image Rejection				*	
IRD0621	Band 1 Alias-Free IF FBW	*			*	
IRD0622	Band 2 Alias-Free IF FBW	*			*	
IRD0623	Band 3 Alias-Free IF FBW	*			*	
IRD0624	Bands 4–6 Alias-Free IF FBW	*			*	
IRD0625	Band 1 Alias Rejection	*			*	
IRD0626	Band 2 Alias Rejection	*			*	
IRD0627	Band 3 Alias Rejection	*			*	
IRD0628	Bands 4–6 Alias Rejection	*			*	
IRD0631	Spurious Tone Power				*	
IRD0711	Band 1 Sample Rate	*				
IRD0712	Band 2 Sample Rate	*				
IRD0713	Band 3 Sample Rate	*				
IRD0714	Band 4 Sample Rate	*				
IRD0715	Band 5 Sample Rate	*				
IRD0716	Band 6 Sample Rate	*				
IRD0721	Band 1 Bit Resolution	*				
IRD0722	Band 2 Bit Resolution	*				
IRD0723	Band 3 Bit Resolution	*				
IRD0724	Band 4 Bit Resolution	*				
IRD0725	Band 5 Bit Resolution	*				
IRD0726	Band 6 Bit Resolution	*				
IRD0811	Nominal Temperature	*				
IRD0812	Nominal Temperature Gradient	*	*			
IRD0821	Limiting Temperature	*				
IRD0822	Limiting Temperature Gradient	*				
IRD0901	RF Signal Monitors	*			*	
IRD0902	IF Signal Monitors	*			*	
IRD0903	Electronic Serial Number	*			*	
IRD0904	Standby Mode	*			*	

Req. #	Parameter / Requirement	D	A	I	FAT	SAT
IRD0905	Automatic Initialization	*			*	
IRD1001	Physical Dimensions	*				
IRD1002	Mass			*		
IRD1003	Connector Orientation	*				
IRD1004	Mounting Holes	*				

7 Appendix

7.1 Abbreviations and Acronyms

Acronym	Description
AD	Applicable Document
CDR	Critical Design Review
CoDR	Conceptual Design Review
CW	Continuous Wave (Sine wave of fixed frequency and amplitude)
FBW	Fractional Bandwidth
FDR	Final Design Review
HVAC	Heating, Ventilation & Air Conditioning
ICD	Interface Control Document
IF	Intermediate Frequency
IRD	Integrated Receivers and Downconverters
KPP	Key Performance Parameters
LO	Local Oscillator
LRU	Line Replaceable Unit
M&C	Monitor and Control
MTBF	Mean Time Between Failure
MTTF	Mean Time To Failure
MTTR	Mean Time To Repair
ngVLA	Next Generation VLA
RD	Reference Document
RF	Radio Frequency
RFI	Radio Frequency Interference
RMS	Root Mean Square
RSS	Root of Sum of Squares
RTP	Round Trip Phase
SNR	Signal to Noise Ratio
TBC	To Be Confirmed
TBD	To Be Determined
VLA	Jansky Very Large Array
WVR	Water Vapor Radiometer