Front-End Sub-System for the 12 m-Antenna Array Technical Specifications

ALMA-40.00.00.00-001-A-SPE

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A01	2004-01-13	Many	–	Revised draft with updated document number.
A02	2004-04-12	Many	–	Revised.
A03	2004-08-22	Many	–	Document revamped.
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A05	2005-04-26	Many	–	Saini – Title modified since document no longer describes the 4-antennas optimized for total power. Reconciling specifications with ALMA Project System Level Technical Requirements (ALMA-80.04.00.00-005-A-SPE).
A06	2005-04-27	Many	–	Rudolf - Document revised
A07	2005-05-17	Many	–	Rudolf – several small changes
A08	2005-05-19		–	
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A14	2006-06-08	4.1.3, 6.5.1	-	Saini – Corrections
A15	2006-11-27		-	Rudolf & Saini – changes based on the approved ALMA System Level Technical Requirements draft document version B and the FE teleconference 2006-11-17.
A16	2007-01-23	4.3 4.5 3.3.2	-	Rudolf, Saini, Tan: Changes based on the discussion with SE&I. Revised optics section.
A17	2007-03-27	.3.3.2 4.1.3 4.1.7 4.3.3.1	-	Rudolf, Tan: Changes based on the final discussion with SE & I.
A18	2007-04-17	4.1.2 4.1.6 5.3	ALMA-40.02.09.00-083-A-CRE ALMA-40.02.09.00-085-A-CRE -	Relaxed side-band ratio requirement for Band 9 receiver Relaxed requirement IF power variations Updated Eigen-frequency after discussion with SE&I IPT

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1 INTRODUCTION

1.1 Purpose

This document summarizes the key design specifications and requirements of the Front-End assembly.

1.2 Scope

This document describes the specifications and requirements that shall be met by the Front-End assemblies for the 50 antenna (interferometer) array that are delivered to the project. The front end assemblies, which will be used for total power measurements or for the ACA, will be described in different documents.

This document applies to all products 40.xx.xx.xx within the ALMA product tree [RD3] with the exception of 40.09.xx.xx (Front End specific test, construction & service equipment) and 40.90.xx.xx (Front End Design Reviews).

1.3 Applicable documents

The following documents are included as part of this document to the extent specified herein. If not explicitly stated differently, the latest issue of the document is valid.

Reference	*Document title*	*Document ID*
[AD1]	ALMA Environmental Specification	ALMA-80.05.02.00-001-B-SPE
[AD2]	ALMA System: Electromagnetic Compatibility (EMC) Requirements	ALMA-80.05.01.00-001-B-SPE
[AD3]	ICD between Antenna and Front-End	ALMA-34.00.00.00- 40.00.00.00-D-ICD
[AD4]	ICD between Front-End/WVR and Back End/LO & Time Reference	ALMA-40.07.00.00 -50.03.00.00-B-ICD
[AD5]	ICD between Front-End/IF and Back End/IF Down-converter	ALMA-40.08.00.00 -52.00.00.00-A-ICD
[AD6]	ICD between Front-End and Computing/Control software	ALMA-40.00.00.00 -70.35.25.00-A-ICD
[AD7]	ICD between Front-End/Compressor and Computing/Control software	ALMA-40.03.00.00 -70.35.25.00-A-ICD
[AD8]	ICD between Front-End/WVR and Computing/Control software	ALMA-40.07.00.00 -70.35.25.00-A-ICD
[AD9]	ALMA System: Electrical Design Requirements	ALMA-80.05.00.00-005-C-SPE
[AD10]	ALMA Power Quality (Compatibility Levels) Specification	ALMA-80.05.00.00-001-C-SPE
[AD11]	Standards for AC Plugs, Socket-outlets, and Couplers	ALMA-80.05.00.00-004-B-STD
[AD12]	ALMA System: General Safety Design Specification	ALMA-10.08.00.00-003-B-SPE
[AD13]	ALMA Project System-Level Technical Requirements	ALMA-80.04.00.00-005-B-SPE
[AD14]	ICD between Front End – Integrated Calibration & Widgets and Computing – Control Software	ALMA-40.06.00.00-70.35.25.00-A-ICD
[AD15]	ICD between Front End - power supply unit and Computing – control software	ALMA-40.04.01.00-70.35.25.00-A-ICD
[AD16]	ICD between Front End First Local Oscillator and Back End LO and Time Reference	ALMA-40.10.00.00-50.00.00.00-A-ICD

Table 1

In the event of a conflict between one of the above referenced applicable documents and the contents of this document, the contents of this document shall be considered as a superseding requirement.

1.4 Reference documents

The following documents contain additional information and are referenced in this document.

Reference	*Document title*	*Document ID*
[RD1]	ALMA Acronyms and Abbreviations	ALMA-80.02.00.00-004-A-LIS
[RD2]	ALMA Front-end Optics Design Report	FEND-40.02.00.00-035-B-REP
[RD3]	ALMA Product Tree	ALMA-80.03.00.00-001-N-LIS
[RD4]	ALMA Scientific Specifications and Requirements	ALMA-90.00.00.00-001-A-SPE

Table 2

1.5 Acronyms

A limited set of basic acronyms used in this document is given below. A complete set of acronyms used in the ALMA project can be found in reference [RD1].

ALMA Atacama Large Millimeter Array
DSB Double-SideBand
EMC Electro-Magnetic Compatibility
FESS Front-End Support Structure
FLOOG First LO Offset Generator
FWHM Full Width Half Maximum
ICD Interface Control Document
LO Local Oscillator
MTBF Mean Time Between Failures
MTTR Mean Time To Repair
MTTS Mean Time To Service
PDR Preliminary Design Review
RF Radio Frequency
RFI Radio Frequency Interference
RMS Root Mean Square
SSB Single-SideBand
WVR Water Vapour Radiometer
2SB Dual Side Band separating

1.6 Verb Convention

"Shall" is used whenever a specification expresses a provision that is binding. The verbs "should" and "may" express non-mandatory provisions.
"Will" is used to express a declaration of purpose on the part of the design activity.

1.7 Requirements Numbering

The requirements within the present document are numbered according to the following code:

[FEND-40.00.00.00-XXXXX-YY / Z(ZZ)]

Where:

FEND-40.00.00.00 identifies the 'Front-End Sub-System' as based on [RD3];

XXXXX is a consecutive number 00010, 00020, … (the nine intermediate numbers remaining available for future revisions of this document);

YY describes the requirement revision. It starts with 00 and is incremented by one with every requirement revision;

Z(ZZ) describes the requirement verification method(s). Where T stands for Test, I for Inspection, R for Review of design and A for Analysis. Multiple verification methods are allowed.

2 DESCRIPTION

2.1 Equipment Definition

The ALMA Front-End assembly is a low-noise cryogenically cooled ten-band receiver that converts radio frequencies ranging from 31.3 GHz to 950 GHz to intermediate frequencies in the range from 4 to 12 GHz. The Front-End sub-system includes:

Cryostat

This accommodates ten band-specific cartridge assemblies and provides vacuum and cryogenic services. It includes a built-in cooler and its associated compressor and controller.

Front-End chassis

This is attached to the cryostat and accommodates and protects the Front-End electronic and support equipment.

Tertiary optics

These are attached to the top of the cryostat and couple the beam from the sub-reflector into the ten cartridge assemblies. Includes vacuum windows mounted on the top of the cryostat and infrared blocking filters that are attached to the radiation shields.

Calibration assembly and other optics

This is a stand-alone unit that is attached to the FESS and comprises devices that are placed directly in the input radio beam of the Front-End assembly. These include (but are not limited to) a calibration system and an attenuator for solar observations.

Water vapour radiometer

This is a stand-alone unit that is attached to the FESS and used to monitor the atmospheric water vapour.

Cartridge assemblies

Ten assemblies, each covering a single band. These assemblies are partially mounted within the cryostat. They receive the RF signals for their respective bands and contain all of the components required to convert the RF signals (corresponding to two orthogonal linear polarisations) to the intermediate frequency (optics, IF amplifiers, LO components). For further details see section 2.2

IF switch assembly

This assembly select/routes and conditions the output (IF) signals from one of the ten cartridges to the four Front-End IF output connectors.

Monitor and control assembly

A local monitor and control system enabling remote control of all Front-End functions and providing extensive remote diagnosis capability. It has an appropriate interface to the general ALMA Monitor and Control bus.

Photonic LO reference receiver assembly (supplied by the BE-IPT [AD15])

Provides the microwave reference signal to the First LO assembly in each cartridge. Includes an optical switch, the necessary optical fibres and photomixers. .

A first local-oscillator offset generator splitter assembly

Routes and conditions the First LO Offset Generator signal to the first local-oscillator chains in each of the cartridge assemblies.

Power supplies

Converts main power supplied by the antenna to regulated DC power used in the Front-End.

Front-End support structure (FESS)

This is a support plate that is permanently bolted to the antenna interface flange. The Front-End assembly together with the Water Vapour Radiometer and Calibration assembly are attached to it.

The Front-End assembly does not include calibration devices located outside the receiver cabin (including any built into the sub-reflector).

This document does not cover the following elements although they are a Front-End IPT responsibility:

- The service and exchange vehicles that are used to transport and facilitate the installation of the Front-End.
- Front-End test and construction equipment.

2.2 Definition of terms

- Band:
  The ALMA Front-End covers the frequency range from 31.3 GHz to 950 GHz in ten discrete bands. Each band receives signals in both orthogonal linear polarisations.

- Frequency channel:
  An individual band contains two parallel receiver chains (channels), each receiving one linear polarisation.

- Cartridge assembly:
  This is an assembly that is partially mounted within the cryostat. It receives the RF signal for a particular band in dual polarisation. It contains all of the components required to convert the RF signal to the intermediate frequency (optics, mixers, IF amplifiers, First LO components).

2.3 Block diagram

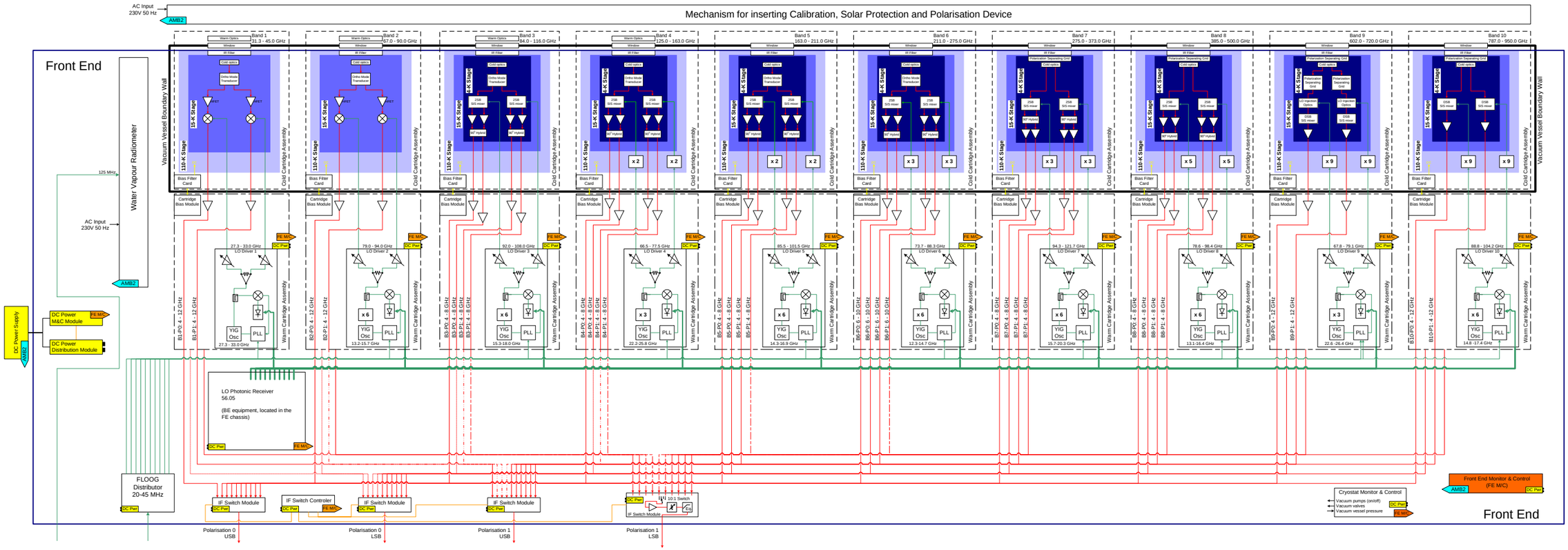

Figure 1: Block diagram of the Front-End sub-system. It is based on the overall ALMA system block diagram (ALMA-80.04.01.00-004-L-DWG).

3 FUNCTIONAL REQUIREMENTS

3.1 Operation modes

The ALMA Front-End can exist in the following states.

3.1.1 Operational

In this mode electrical power is applied to the ALMA Front-End with all active signal levels at nominal values. One frequency band cartridge is powered and operational while a maximum of two other cartridges are on stand-by (see section 3.1.3). All specifications and requirements in this document apply, unless otherwise stated.

3.1.2 Non-Operational

In this mode electrical power is not applied and signal levels are not at nominal values.

3.1.3 Stand-by

In this mode operational power is applied to a cartridge but signal levels are not at nominal values. The stand-by mode only applies to cartridges within the Front-End and not to the Front-End assembly as a whole.

3.1.4 Transport with the antenna or in the service vehicle

In this mode the Front-End is being transported with the antenna on the antenna transport vehicle or in the Front-End service vehicle. This mode differs from the non-operational mode in the environmental operating conditions [AD1]. For this mode, the same specifications and requirements as for the non-operational mode apply, unless otherwise stated.

3.1.5 Storage

In this mode the ALMA Front-End is stored completely assembled. This mode differs from the non-operational mode in the environmental conditions and the lack of monitoring and control signals. For storage, the same specifications and requirements as for the non-operational mode apply, unless otherwise stated.

3.2 General

3.2.1 Pre-selection of observation bands

[FEND-40.00.00.00-00010-00 / R]

Means shall be provided for the application of nominal power and signals to the desired cartridge and the associated warm cartridge assembly. The local oscillator of the pre-selected cartridge does not need to be phase locked. Specifications and requirements of this document do not apply.

3.2.2 Mechanical tuning

[FEND-40.00.00.00-00020-00 / R]

The operation of the Front-End shall not require the use of mechanical tuners.

3.2.3 Standard parts

[FEND-40.00.00.00-00030-00 / R]

Standard, unmodified commercially available components shall be used where possible.

3.2.4 Cables and connectors

[FEND-40.00.00.00-00040-00 / IR]

All power cables and connectors shall comply with [AD10] and [AD11].

3.2.5 Solar observing and safety

[FEND-40.00.00.00-00050-00 / AT]

This follows from requirement number 666 of [AD13].

This specification applies only to the operational and non-operational modes. During solar observation no cartridges are required to be in the stand-by mode.

The application of 0.03 W/cm^2 of solar radiation shall not result in damage to a Front-End assembly. Provisions shall be taken to allow observations of the sun. The performance specifications for solar observation are TBD.

3.3 Frequency Coverage

This section only applies to the operational mode.

3.3.1 RF input port

[FEND-40.00.00.00-00060-00 / R]

This follows from requirement number 210 in [AD13]. The RF input frequency ranges shall comply with the following values:

Band	*Lower frequency*	*Upper frequency*	*Remarks*
1	31.3 GHz	45 GHz	
2	67 GHz	90 GHz	
3	84 GHz	116 GHz	
4	125 GHz	163 GHz	
5	163 GHz	211 GHz	
6	211 GHz	275 GHz	
7	275 GHz	373 GHz	
8	385 GHz	500 GHz	
9	602 GHz	720 GHz	
10	787 GHz	950 GHz	

Table 3

3.3.2 LO input port

[FEND-40.00.00.00-00070-00 / R]

This is derived from requirement numbers 210, 233, 240 and 250 in [AD13]. The first LO frequency ranges shall comply with the following values:

Band	*Lower frequency*	*Upper frequency*	*Mixing scheme*	*Remarks*
1	27.3 GHz	33 GHz	USB	
2	79 GHz	94 GHz	LSB	
3	92 GHz	108 GHz	2SB	
4	133 GHz	155 GHz	2SB	
5	171 GHz	203 GHz	2SB	
6	221 GHz	265 GHz	2SB	Band 6 uses a 2SB mixing scheme, but provides an IF at 4-12 GHz. All specifications met over 4.5-10 GHz (TBC – John Webber), usable with slight degradation over the remainder of the 4-12 GHz range
7	283 GHz	365 GHz	2SB	
8	393 GHz	492 GHz	2SB	
9	610 GHz	712 GHz	DSB	This allows for a possible 2SB option.
10	795 GHz	942 GHz	DSB	This allows for a possible 2SB option.

Table 4

3.3.3 IF output port bandwidth and centre frequency

[FEND-40.00.00.00-00080-00 / R]

This is related to requirement numbers 233, 240 and 250 of [AD13]. Each signal channel shall provide 8 GHz total IF bandwidth per polarisation using one of the following alternatives, depending on the mixing scheme selected:

- 8 GHz bandwidth single-sideband (SSB), upper or lower sideband centred at 8.0 GHz
- 8 GHz bandwidth double-sideband (DSB), centred at 8.0 GHz
- 4 GHz bandwidth dual-sideband, (2SB) upper and lower sideband, centred between 6.0 GHz and 10 GHz. This shall be compatible with the LO tuning range of section 3.3.2.

4 PERFORMANCE REQUIREMENTS

4.1 General requirements

4.1.1 Front-End Noise Performance

[FEND-40.00.00.00-00090-00 / T]
This follows from requirement number 220 of [AD13]. This section only applies to the operational mode.
The following table indicates the required noise temperature performance of the ALMA Front-End. The noise performance includes all contributions from warm optics, cryostat windows, and IR filters. It shall include all noise contributions through to the Front-End assembly IF output ports.
Depending on the selected mixer scheme the cartridge noise temperature shall not exceed the values as follows:

Specifications for maximum receiver noise temperatures

Band	*SSB*		*DSB*		*Requirement Number*
	T_{SSB} over 80% of the RF band	*T_{SSB} at any RF frequency*	*T_{DSB} over 80% of the RF band*	*T_{DSB} at any RF frequency*	
1	17 K	26 K	NA	NA	[FEND-40.00.00.00-00810-00 / T]
2	30 K	47 K	NA	NA	[FEND-40.00.00.00-00820-00 / T]
3	37 K	60 K	NA	NA	[FEND-40.00.00.00-00830-00 / T]
4	51 K	82 K	NA	NA	[FEND-40.00.00.00-00840-00 / T]
5	65 K	105 K	NA	NA	[FEND-40.00.00.00-00850-00 / T]
6	83 K	136 K	NA	NA	[FEND-40.00.00.00-00860-00 / T]
7	147 K	219 K	NA	NA	[FEND-40.00.00.00-00870-00 / T]
8	196 K	292 K	NA	NA	[FEND-40.00.00.00-00880-00 / T]
9	NA	NA	175 K	261 K	[FEND-40.00.00.00-00890-00 / T]
10	NA	NA	230 K	344 K	[FEND-40.00.00.00-00900-00 / T]

Table 5

Remarks:

- In the frequency range 370 – 373 GHz a relaxed receiver noise temperature of less than 300 K (SSB) is allowed.
- The frequency ranges of the bands in the table above are specified in section 3.3.1 of this document.
- In interpreting measurements the Rayleigh-Jeans law shall be used to calculate noise temperatures.
- SSB noise temperatures shall be corrected for true single side band response, i.e. corrected for the residual image response
- Note that the values in Table 5 were calculated using the following formula:

  $T_{SSB} = A * (h*freq/k) + 4\ K$

  where h and k are the usual physical constants, and freq was taken as the upper frequency of a particular band. The frequency dependent quantity A has the following specification and values (over 80% of the RF band / at any freq):

  Bands 1-6 (below 275 GHz) Spec: A = 6 / 10
  Bands 7-8 (275-500 GHz) Spec: A = 8 / 12
  Band 9 (602-720 GHz) Spec: A = 10 / 15
  Band 10 (787-950 GHz) Spec: A = 10 / 15

4.1.2 Image Band Suppression / sideband mismatch

[FEND-40.00.00.00-00100-00 / T]
This follows from requirement number 231 of [AD13]. This section only applies to the operational mode.

For a SSB or 2SB mixing scheme the image band suppression (for any LO frequency) shall be ≥ 10 dB over 90% of IF frequency range. Image-band suppression (for any LO frequency) shall be > 7 dB over entire IF frequency range

For all receiver bands using the DSB mixing scheme the side-band ratio shall be less than 3 dB averaged across all IF frequencies. This with the exception of that for the ALMA Band 9 the side-band ratio shall be 3 dB or better across 80% of the combined IF and LO frequency ranges specified under sections 3.3.1 and 3.3.2.

For each band, an approved measurement test plan shall define the precise RF and IF frequencies at which image suppression shall be measured to verify compliance.

4.1.3 Spurious response of the Front-End

[FEND-40.00.00.00-00120-00 / T]
This follows from requirement number 290, 292, and 295 of [AD13]. This section only applies to the operational mode.

At any LO frequency (within the specified range of a band) the IF power due to incoherent spurious signals shall be at least 10 dB below the nominal noise power in any 2 GHz bandwidth. Spurious signals shall occupy less than 0.1% of the nominal IF bandwidth.

The level of any spurious (coherent or incoherent) LO CW signals shall be < -40 dBc over the frequency range from 500 Hz to 12 GHz offset from the carrier signal.

This applies to both interference between cartridges as well as interference between the cartridges and the water vapour radiometer.

The IF band as specified in section 3.3.3 shall not contain any coherent or incoherent self generated spurious signals larger than -40 dB per 1 MHz (TBC) relative to the receiver noise spectral density at the IF output.

4.1.4 Saturation

[FEND-40.00.00.00-00130-00 / AT]
This is related to requirement number 227 of [AD13]. This section only applies to the operational mode.

The large signal gain compression resulting from an RF load of 100°C shall be less than 5%.

4.1.5 IF output power

[FEND-40.00.00.00-00140-00 / AT]
This follows from the requirements of [AD5]. This section only applies to the operational mode.

For load temperature between 10 and 800 K at the RF input of the cartridge, the IF output power of the Front-End (measured at the Front-End IF outputs) shall comply with the following requirements:

- Total power in the IF frequency range specified in section 3.3.3: -31 dBm to -18 dBm
- Total power in the frequency range 10 MHz to 18 GHz: < -12 dBm (SSB, DSB)
- Total power in the frequency range 10 MHz to 18 GHz: < -15 dBm (2SB)

4.1.6 IF power variations

[FEND-40.00.00.00-00150-00 / A, T]
This follows from requirements number 272 and 275 of [AD13].

Within the IF band, variations from the average IF power over the whole IF band, specified in section 3.3.3, shall be less than:

- 1.35 dB (TBC) peak-to-peak in any 31 MHz portion of the IF band specified in section 3.3.3
- 6 dB (7 dB for Band 9 only) peak-to-peak in any 2 GHz portion of the IF band specified in section 3.3.3
- 10 dB (11 dB for Band 9 only) peak-to-peak across the complete IF band specified in section 3.3.3

4.1.7 Amplitude stability

[FEND-40.00.00.00-00170-00 / T]
This follows from requirement numbers 261 and 262 of [AD13]. This section only applies to the operational mode.
The IF amplitude stability, measured at each of the IF outputs of the Front-End, shall comply with the following requirement:

- The Allan variance, $\sigma^2(T)$, of the IF output power in the IF band (specified in section 3.3.3) shall be less than 5.0×10^{-7} for T in the range of $0.05\ s \leq T \leq 100\ s$ and 4.0×10^{-6} for T = 300 seconds.
  This corresponds to an Allan standard deviation of 7.07×10^{-4} and 2.0×10^{-3}, respectively.

4.1.8 Signal path phase stability

[FEND-40.00.00.00-00180-00 / T]
This follows from requirement numbers 451 and 454 of [AD13].
For all frequencies within the IF pass-band the signal path transfer function shall maintain the following phase stabilities:

- Long term (delay drift) $20\ s \leq T < 300\ s$ - 10 fs

The signal path shall include all Front-End components and be measured at the IF outputs of the Front-End. The required phase stability excludes any contribution from the first local oscillator. The delay drift requirement refers to the 2-point standard deviation with a fixed averaging time, τ, of 10 seconds and intervals, T, between 20 and 300 seconds.
The system shall typically operate for at least one hour with no step discontinuities in the system delay exceeding 10 fs.

4.1.9 IF phase variations

[FEND-40.00.00.00-00185-00 / A, T]
This follows from requirement number 275 of [AD13].
Within the IF band, variations from the average IF phase shall be less than:
6.4^{o} rms in any 31 MHz portion of the IF band specified in section 3.3.3

4.2 Cryogenics and vacuum requirements

4.2.1 Evacuation and cool-down time

[FEND-40.00.00.00-00190-00 / T]
The period required to evacuate the vacuum parts of the Front End from atmospheric pressure and to cool to operating temperatures (with all cartridges installed) shall be a maximum of 48 hours. Note that this may be achieved with the aid of a high-throughput external backing pump.

4.2.2 Warm-up time

[FEND-40.00.00.00-00200-00 / T]

The warm-up of the cooled parts of the Front End from operating to ambient temperature shall take a maximum of 40 hours.

4.2.3 Vacuum integrity

[FEND-40.00.00.00-00210-00 / AT]
The vacuum parts of the Front End shall have a sufficient vacuum integrity to enable continuous operation without mechanical pumping for at least one year.

4.3 Optics Requirements

This section applies only to the operational mode.

4.3.1 Beam performance

4.3.1.1 Aperture efficiency FE assembly contribution

[FEND-40.00.00.00-00220-00 / A]
The aperture efficiency factor due to the optics of the FE assembly shall exceed 80 % (TBC) for all ten bands, with frequency ranges as defined by requirement [FEND-40.00.00.00-00060-00 / R].

The contribution to the aperture efficiency within the FE assembly is split into the following components:

- Taper efficiency η_t: factor expressing the signal power loss due to 1) non-uniform amplitude distribution over the secondary reflector and 2) the field across the secondary reflector not being in phase everywhere;
- Spillover efficiency η_s: fraction of the total power that is radiated by the tertiary optics, intercepted and collimated by the secondary reflector;
- Polarization efficiency η_p: factor expressing the signal power lost in cross-polarized fields over the antenna aperture plane;
- Focus efficiency η_f: factor expressing the signal power loss due to focus errors, both radial as well as axial, of the tertiary optics relative to the secondary reflector.

The requirement can be summarized by the following expression:

$$\eta_t \cdot \eta_s \cdot \eta_p \cdot \eta_f = \eta_{ap\_FE} > 80\ \%$$

The ohmic losses of all tertiary optics and feeds are included in the T_{rx} as specified in section 4.1.1 and do not contribute to an aperture efficiency degradation.

This requirement simultaneously applies to both orthogonally polarized beams of a cartridge.

Individual requirements are defined for the following efficiency contributions:

4.3.1.2 Taper efficiency

[FEND-40.00.00.00-00222-00 / AT]
The taper efficiency of the tertiary optics inside the FE assembly shall exceed 80 % for all ten bands. This requirement simultaneously applies to both orthogonally polarized beams of a cartridge.

4.3.1.3 Spillover efficiency

[FEND-40.00.00.00-00224-00 / AT]
The spillover efficiency of the tertiary optics inside the FE assembly shall exceed 80 % for all ten bands. This requirement simultaneously applies to both orthogonally polarized beams of a cartridge.

4.3.1.4 Polarization efficiency

[FEND-40.00.00.00-00226-00 / AT]
The polarization efficiency of the tertiary optics system shall exceed 99.5 % for all ten bands.
This requirement simultaneously applies to both orthogonally polarized beams of a cartridge.

4.3.1.5 Focus efficiency

[FEND-40.00.00.00-00228-00 / AT]
The focus efficiency of the tertiary optics system shall comply with the following expression for all ten bands:

$$\eta_f > 80\ \% / \eta_t \,.\, \eta_s \,.\, \eta_p$$

This requirement simultaneously applies to both orthogonally polarized beams of a cartridge.

4.3.2 Polarization requirements

4.3.2.1 Polarization State

[FEND-40.00.00.00-00250-00 / R]
The nominal polarization state of the front end optics shall be linear.

4.3.2.2 Polarization Configuration

[FEND-40.00.00.00-00255-00 / RI]
For all frequency bands the Front End shall receive two orthogonal polarizations, designated “Polarization 0” and “Polarization 1”, with each one converted to one or more separate IF outputs depending on mixing scheme.

4.3.2.3 Absolute Polarization Alignment Accuracy

[FEND-40.00.00.00-00260-00 / T]
The E vector of the polarization channel designated “Polarization 0” shall be aligned to within 2 degrees of the radial direction of the cryostat.

4.3.2.4 Relative Polarization Alignment Accuracy

[FEND-40.00.00.00-00265-00 / T]
The E vector of the polarization channel designated “Polarization 0” and the E vector of the polarization channel designated “Polarization 1” shall be orthogonal to within 2 degrees.

4.3.2.5 Cross talk between orthogonal polarization receiver channels

[FEND-40.00.00.00-00271-00 / AT]
The, uncorrected, cross talk between orthogonal receiver channels, RF and IF, inside the front end shall be less than -60 dB. The receiver channel is defined as the signal path starting at the RF waveguide input of either the low-noise amplifier (Bands 1 and 2) or SIS mixer (Bands 3-10) and ending at the IF output of the FE assembly.

4.3.2.6 Beam squint

[FEND-40.00.00.00-00272-00 / AT]
The co-alignment, on sky, between the beams of the orthogonal polarization channels of one cartridge shall be less than 1/10 of the Full Width at Half Maximum (FWHM) of the primary beam. This requirement is applicable for Bands 1 through 10.

4.3.3 Widgets

4.3.3.1 Solar Attenuator

[FEND-40.00.00.00-00290-00 / R]
A solar attenuator shall be provided to allow solar observations. The attenuator shall be inserted into the signal path of any of the ALMA bands under remote control.

4.3.3.1.1 IR attenuation

[FEND-40.00.00.00-00300-00 / T]
This follows from requirement number 665 of [AD13].

If the solar attenuator is inserted into the RF beam of a cartridge, it shall attenuate the 10 micron (TBC) radiation by at least 20 dB.

4.3.3.1.2 RF attenuation

[FEND-40.00.00.00-00320-00 / T]
This follows from requirement number 660 of [AD13].
The solar attenuator shall attenuate the RF signal, over the frequency range as defined by requirement [FEND-40.00.00.00-00060-00 / R], by 13 - 16 dB.

4.4 Amplitude Calibration

[FEND-40.00.00.00-00330-00 / R]
Means for periodic amplitude calibration of all the Front-End bands shall be provided. The calibration assembly is stand-alone and as such shall include all necessary power supplies and monitor and control electronics.

4.4.1 Calibration cycle

[FEND-40.00.00.00-00340-00 / RT]
A complete calibration cycle for a particular band, involving the presentation of loads of differing effective temperature, shall not take longer than 9 seconds.

4.4.2 Calibration repeatability

[FEND-40.00.00.00-00350-00 / RT]
The repeatability of the amplitude calibration shall be better then 1 % for frequencies below 300 GHz and better then 3 % for all other frequencies covered by the ALMA Front-End.

4.5 Water Vapour Radiometer

[FEND-40.00.00.00-00360-00 / RI]
This subsection only applies to the operational mode.
The Front-End assembly shall include a radiometer to allow the measurement of the amount of precipitable water vapour along the signal path, using the 183 GHz water line. This instrument shall operate simultaneously with the selected cartridge and shall illuminate the sub-reflector. It is a stand-alone assembly and as such must include all necessary LO sources, coupling optics, signal processing, power supplies and monitor and control electronics.

4.5.1 WVR beam position

[FEND-40.00.00.00-00370-00 / AT]
The centre of the WVR beam shall be within 10 arc-minutes of the centre of the beam for any cartridge.

4.5.2 WVR sensitivity

[FEND-40.00.00.00-00380-00 / T]
The computed RMS path error of the WVR shall be less than $10*(1+w_v)$ μm, with w_v being the precipitable water vapour along the line of sight in millimetres and w_v is in the range from 0,3 to 5 mm. This sensitivity shall be achieved with a time resolution of 1 second.

4.5.3 WVR accuracy

[FEND-40.00.00.00-00385-00 / T]
The WVR shall provide an estimate of w_v to an accuracy of better than 2%.

4.5.4 WVR stability

[FEND-40.00.00.00-00390-00 / T]
The sensitivity of the WVR as defined above shall be achieved with a time resolution of 1 second and be maintained over time periods of up to 10 minutes and for changes in zenith angle, z, of up to 3 degrees, or of 10% in the value of sec(z) when z is greater than 60 degrees.

4.5.5 WVR tuning range and step size

[FEND-40.00.00.00-00400-00 / R]
The tuning range of the LO signal present in the RF mixer shall be from 183.300 to 183.350 GHz, with tuning steps no larger than 10 kHz.

5 MECHANICAL AND ELECTRICAL REQUIREMENTS

5.1 Mass

[FEND-40.00.00.00-00460-00 / T]
The mass of the Front-End components attached to the Antenna Flange shall not exceed 980 kg.. The mass of the auxiliary electronics chassis fixed to the receiver cabin floor shall not exceed 200 kg.
Details can be found in ICD [AD3].

5.2 Centre of Gravity

[FEND-40.00.00.00-00470-00 / T]
The centre of gravity of the Front-End component attached to the FESS shall comply with [AD3].

5.3 Eigen-frequency

[FEND-40.00.00.00-00480-00 / A]
The lowest Eigen-frequency of any Front-End sub-assembly that is directly attached to the antenna shall be at least 18 Hz.

5.4 Volume

[FEND-40.00.00.00-00490-00 / R]
The volume occupied by the Front-End assembly shall comply with [AD3].

5.5 Orientation

[FEND-40.00.00.00-00500-00 / T]
The Front-End components within the antenna cabin shall meet all performance requirements over a range of gravity vectors from 0 to 90 degrees. This rotation occurs about the antenna elevation-bearing axis. Details can be found in the ICD [AD3]. The compressor and its control unit shall meet its performance requirements at tilt angles up to 10º in any orientation.

5.6 Thermal Load

[FEND-40.00.00.00-00510-00 / T]
During normal operation, the power dissipation of the combined Front-End components installed in the receiver cabin shall not exceed 4 kW. Details can be found in the ICD [AD3].

5.7 Power requirements

[FEND-40.00.00.00-00520-00 / T]
The Front-End electrical power requirements shall be in accordance with [AD3]. The main power shall be single-phase 230 VAC/50 Hz and three-phase 400 VAC/50 Hz. Details can be found in [AD10].

6 OPERATING CONDITIONS

6.1 Stabilization time

6.1.1 Stabilization time from non-operational to operational modes

[FEND-40.00.00.00-00530-00 / T]
When starting from the non-operational mode, the Front-End shall be operational (meet all applicable specifications) within 15 minutes.

6.1.2 Stabilization time after fast-slew

[FEND-40.00.00.00-00535-00 / T]
Within 100 ms of a fast-slew, all operational specifications shall be met.

6.2 Repeatability

[FEND-40.00.00.00-00540-00 / T]
Following a full fast switching cycle with a duration of 5 minutes the Front-End shall exhibit an amplitude change of less than $2x10^{-3}$ RMS (TBC) and a phase change of less than 0.7° RMS (TBC).

6.3 Simultaneous operation of bands

[FEND-40.00.00.00-00550-00 / R]
This follows from requirement number 435 of [AD13]. This section only applies to the operational and stand-by modes.
Astronomical observations will involve the use of one frequency band at a time – there will be no dual frequency observations. In addition to the band in operation, band 3 (when it is not being used directly) shall be maintained in the stand-by mode for phase-calibration purposes. One other band may also be in standby mode to prepare for a band-change. The water-vapour monitoring radiometer shall operate simultaneously with any of the observing bands.

6.4 Band Selection

This section only applies to the operational and stand-by modes.

6.4.1 Selection of a standby band

[FEND-40.00.00.00-00560-00 / T]
This follows from requirement number 431 of [AD13].
Selection and operation of a band that has been in standby mode shall take less than 1 second.

6.4.2 Selection of new observing band

[FEND-40.00.00.00-00570-00 / T]
The time to reach the standby mode from the non-operational mode shall not exceed 15 min. (this is to allow thermal equilibrium to be reached).

6.4.3 Narrow-band frequency switching

[FEND-40.00.00.00-00580-00 / T]
This follows from requirement number 432 of [AD13].
Switching between two frequencies less than 25 MHz at the FLOOG apart shall take no more than 10 ms. Note that this applies to switching within (rather than between) bands. The frequency shall stay within the limits of a band as set in Table 3.

6.4.4 Frequency changes within a band

[FEND-40.00.00.00-00590-00 / T]
This follows from requirement number 430 of [AD13].
Moving between frequencies more than 25 MHz at the FLOOG apart within a particular band shall take no more than 1 second. The frequency shall stay within the limits of a band as set in Table 3.

6.5 Local Oscillator

This subsection only applies to the operational mode.

6.5.1 First local oscillator phase stability

[FEND-40.00.00.00-00600-00 / T]
This follows from requirement number 451 and 452 of [AD13]
The phase stability of the portion of the first local oscillator that is located within the Front-End, but excluding the reference signal [AD16], shall be less than:

- Short term (phase noise) T < 1 s - 38 fs

- Long term (delay drift) $20 \text{ s} \leq T < 300 \text{ s}$ - 13 fs

The short term phase noise requirement refers to the rms deviation from a 10-sec average. The requirement is on the integrated phase noise from the highest significant frequency (~1 MHz) down to 1Hz.
The delay drift requirement refers to the 2-point Allan Standard Deviation with a fixed averaging time, τ, of 10 seconds and intervals, T, between 20 and 300 seconds.

6.5.2 First local oscillator phase settling time

[FEND-40.00.00.00-00630-00 / T]
This follows from requirement number 441, 442 and 450 of [AD13].
Following a 180 degree phase change from the first LO offset generator the LO phase shall settle to within 5 degrees of its final value within 1 μs. It shall also be possible to switch the phase (again by changing the phase of the first LO offset generator) by 90 degrees. There shall be no ambiguity in phase.

6.5.3 First local oscillator spurious CW signals

[FEND-40.00.00.00-00631-00 / T]
See section 4.1.3

6.6 Monitoring and Control

[FEND-40.00.00.00-00640-00 / RT]
This follows from requirements number 614, 615, and 616 of [AD13]
All functions of the Front-End assembly shall be remotely controlled and monitored. The monitoring shall be detailed enough to indicate the status of the assembly and to allow troubleshooting. Monitoring and control shall be available at all times during observation. Details can be found in the applicable ICDs [AD6, AD7, AD8, AD14, AD15].
Each unit having a dedicated AMB node shall be self identifying to the AMB.

6.7 Environmental operating condition

6.7.1 Altitude

[FEND-40.00.00.00-00650-00 / R]
The operating altitude of the Front-End assembly shall be 0 - 5200 m.

6.7.2 Thermal Environment

[FEND-40.00.00.00-00660-00 / T]
The Front-End assembly shall meet all of its operational performance requirements at ambient temperatures between 16^{o} C and 22^{o} C. The maximum temperature gradients in the air shall not exceed more than 1 degree C per hour.
In any mode, the Front-End shall survive without damage temperatures excursions of -10^{o} C to 50^{o} C.

6.7.3 Relative Humidity

[FEND-40.00.00.00-00670-00 / R]
The Front-End assembly shall meet its performance with a non-condensing relative humidity between 20 % and 80 %.

6.7.4 Vibration

[FEND-40.00.00.00-00680-00 / AT]
The Front-End assembly shall comply with [AD1].

6.7.5 Acceleration

[FEND-40.00.00.00-00690-00 / AT]
The Front-End assembly shall comply with [AD1].

6.7.6 Cleanliness

[FEND-40.00.00.00-00700-00 / I]
The Front-End assembly shall meet its performance under the conditions outlined in [AD1].

6.8 Storage and shipping conditions

[FEND-40.00.00.00-00710-00 / IT]
This section applies only to the storage mode.
The Front-End assembly shall comply with [AD1].

6.9 EMC

[FEND-40.00.00.00-00720-00 / T]
The Front-End assembly shall comply with [AD2][AD3].

6.8 RFI

[FEND-40.00.00.00-00730-00 / T]
The IF signal isolation between any operational band and all stand-by bands shall be more than 30 dB. The RF emission of any cartridge in the 175-191 GHz range shall be at least 10 dB less than the WVR signal level at its maximum IF frequency resolution. The emission of the WVR shall not exceed 0 dBm at the WVR LO frequency (183 GHz) and -45 dBm at all other frequencies.

6.10 Grounding and Isolation

[FEND-40.0000.00-00740-00 / IR]
The Front-End assembly shall be grounded in compliance with [AD9].

7 RELIABILITY, AVAILABILITY AND MAINTAINABILITY REQUIREMENTS

7.1 Continuous use

[FEND-40.00.00.00-00750-00 / R]
The Front-End assembly shall be designed for continuous use.

7.2 MTBF

[FEND-40.00.00.00-00760-00 / A]
The mean time between failures of a Front-End assembly shall exceed 11.000 hours.

7.3 MTTR

[FEND-40.00.00.00-00770-00 / A]
At the OSF, the mean time to repair the Front-End assembly shall be less than 48 hours. Note that this does not include warm-up or cool-down time.

7.4 MTTS

[FEND-40.00.00.00-00775-00 / A]
At the OSF, the mean time required to service the Front-End assembly shall be less than 48 hours. Note that this does not include warm-up or cool-down time.

7.5 Lifetime

[FEND-40.00.00.00-00780-00 / A]
The lifetime of the Front-End assembly shall be greater than 15 years.

7.6 Front-End assembly exchange time

[FEND-40.00.00.00-00785-00 / A]
The exchange of a Front-End assembly at an antenna shall take less than 2 hours.

7.7 Preventive maintenance

[FEND-40.0000.00-00790-00 / R]
In general there shall be no periodic preventive maintenance required for the Front-End assembly.
Exceptions to this include the calibration device, cryo-cooler, compressor, control unit and vacuum pump.

7.7.1 Preventive maintenance interval cryo-cooler and pumps

[FEND-40.00.00.00-00792-00 / R]
The maintenance interval for the cryo-cooler and associated pumps shall be greater than 10,000 hours.

7.7.2 Preventive maintenance interval cryo compressor

[FEND-40.0000.00-00795-00 / R]
The maintenance interval for the compressor shall be greater than 20,000 hours.

7.8 Hold times

[FEND-40.00.00.00-00800-00 / T]
The cryostat shall be able to accommodate a power interruption of 30 minutes maximum duration and after return of power be able to return to the normal operational mode, fulfilling all applicable specifications in this mode, within 6 hours. This shall be achievable at any time in the nominal 1 year of operation between regular preventive maintenance.