Front End Sub-System Technical Specification

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Change Record

Version	Date	Affected Section(s)	Change request #	Reason/remarks
A		All	-	First document release

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1. INTRODUCTION

1.1. Purpose

This document summarizes the key design specifications and requirements for the Front End.

1.2. Scope

The information given in this document provides a complete summary of all the requirements and specifications that must be met by the front ends delivered to the project.

The following table shows a partial view of the ALMA product tree [AD1] at "module" and "unit" level for the ALMA Front End sub-system products that are covered by this document. Those products belonging to the FE sub-system that are not specified by this document are clearly identified in table 1.

PT level 1 / "sub-system"		***PT level 2 / "module"***		***PT level 3 / "unit"***		
Product No.	***Product Name***	***Product No.***	***Product Name***	***Product No.***	***Product Name***	***Remarks***
40.00.00.00	Front end					
		40.01.00.00	Warm optics			
		40.02.00.00	Cartridges			
				40.02.01.00	Frequency band 1 cartridge	Not in baseline
				40.02.02.00	Frequency band 2 cartridge	Not in baseline
				40.02.03.00	Frequency band 3 cartridge	
				40.02.04.00	Frequency band 4 cartridge	Not in baseline
				40.02.05.00	Frequency band 5 cartridge	Not in baseline
				40.02.06.00	Frequency band 6 cartridge	
				40.02.07.00	Frequency band 7 cartridge	
				40.02.08.00	Frequency band 8 cartridge	Not in baseline
				40.02.09.00	Frequency band 9 cartridge	
				40.02.10.00	Frequency band 10 cartridge	Not in baseline
		40.03.00.00	Cryostat			
				40.03.01.00	Dewar	
				40.03.02.00	Cryo-cooler	
				40.03.03.00	Vacuum pumps	
				40.03.04.00	Cryostat electrical infrastructure	
		40.04.00.00	Front end auxiliary sub-systems			
				40.04.01.00	Front end power supply sub-system	
				40.04.02.00	Bias electronics sub-system	
				40.04.03.00	Front end M&C sub-system	

PT level 1 / "sub-system"		***PT level 2 / "module"***		***PT level 3 / "unit"***		
Product No.	***Product Name***	***Product No.***	***Product Name***	***Product No.***	***Product Name***	***Remarks***
		40.05.00.00	Front end chassis			
				40.05.01.00	Front end mechanical structure	
				40.05.02.00	Front end cabling	
		40.06.00.00	Front end integrated calibration & widgets			
				40.06.01.00	Vane calibration sub-system	
				40.06.02.00	Solar protection	
				40.06.03.00	Polarisation widgets	
		40.07.00.00	Water vapour radiometer			
		40.08.00.00	Front end IF			
				40.08.01.00	IF switch sub-system	
		40.09.00.00	Front end specific test, construction & service equipment			Not covered in this document
				40.09.01.00	SIS mixer fabrication equipment	Not covered in this document
				40.09.02.00	SIS mixer test equipment	Not covered in this document
				40.09.03.00	Front end test fixture	Not covered in this document
				40.09.04.00	Cartridge test dewars	Not covered in this document
				40.09.05.00	Cartridge RF test fixtures	Not covered in this document
				40.09.06.00	Front end service vehicle	Not covered in this document
		40.10.00.00	First local oscillator			
				40.10.01.00	First LO frequency sources	
				40.10.02.00	Warm frequency multipliers	
				40.10.03.00	First LO PLL unit	
				40.10.04.00	Band selection	
				40.10.05.00	First LO interconnects	

Table 1

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*	*Date*	*Document ID*
[AD1]	ALMA Product Tree	2002-11-01	SYSE-80.03.00.00-001L-LIS
[AD2]	ALMA Environmental Specification	2003-03-21	ALMA-80.05.02.00-001-A-SPE
[AD3]	ALMA system: Electromagnetic Compatibility (EMC) Requirements	2003-04-04	ALMA-80.05.00.00-001-A-SPE
[AD4]	ICD Antenna - Front End	2003-08-29	ALMA-34.00.00.00- 40.00.00.00-A-ICD
[AD5]	ICD Front End / WVR - Back End / LO & Time Reference	2003-08-28	ALMA-40.07.00.00 -50.03.00.00-A-ICD
[AD6]	ICD Front End / IF - Back End / IF Downconverter	2003-07-24	ALMA-40.08.00.00 -50.01.01.00-A-ICD
[AD7]	ICD Front End – Computing / Control software	2003-09-01	ALMA-40.00.00.00 -75.35.25.00-A-ICD
[AD8]	ICD Front End / Cryostat – Computing / Control software	2003-09-01	ALMA-40.03.00.00 -75.35.25.00-A-ICD
[AD9]	ICD Front End / WVR	2003-09-01	ALMA-40.07.00.00 -40.09.06.00-A-ICD
[AD10]	ALMA Electronic Design Specification and Guidelines	2003-04-25	ALMA-80.05.00.00-005-A-SPE
[AD11]	ALMA Power Quality (Compatibility Levels) Specification	2003-02-14	SYSE-80.05.00.00-001A-SPE
[AD12]	Standard for AC Plugs, Socket-outlets, and Couplers	2003-07-18	ALMA-80.05.00.00-004-B-STD

Table 2

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*	*Date*	*Document ID*
[RD1]	List of acronyms and glossary for the ALMA project	2003-04-23	ALMA-80.02.00.00-004-B-LIS
[RD2]	ALMA Project Book	2002-02-20	Version 5.5
[RD3]	ALMA Receiver Optics Design	2001-04-11	ALMA Memo #362

Table 3

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 Millimetre Array
CDR Critical Design Review

DSB	Double-SideBand
FESS	Front End Support Structure
FTS	Fine Tuning Synthesizer
ICD	Interface Control Document
LO	Local Oscillator
MTBF	Mean Time Between Failures
MTTR	Mean Time To Repair
PDR	Preliminary Design Review
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 [AD1];

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 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

Accomodates ten band-specific cartridge assemblies and provides cryogenic services. Includes a built-in cooler and the coolers associated compressor and controller. It also provides vacuum services

Front end chassis

Attached to the cryostat this structure accommodates and protects the front end electronic and support equipment.

Tertiary optics

Attached to the top of the cryostat, these couple the beam from the sub-reflector beam into each of the ten cartridge assemblies. Includes vacuum windows and infrared blocking filters.

Calibration and other optics

Devices that are placed directly in the input radio beam of the receiver and which include (but are not limited to) a calibration system, components that can be inserted into the beam such as quarter wave plates for the reception of circular polarisation, and attenuators for solar observations.

Water vapour radiometer

Attached to the FESS this is a stand-alone unit used to monitor the atmospheric water vapour.

Cartridge assemblies

Ten assemblies, each covering a single band. The assemblies contain all the components need for the low-noise conversion of the RF signal to the intermediate frequency.

IF switch assembly

Routes and conditions the IF output signals from all the cartridges to the four front end IF output connectors.

Monitor and control assembly

A local monitor and control system permitting remote control of all front end functions and providing extensive remote diagnosis capability, with an appropriate interface to the general ALMA Monitor and Control bus.

A local oscillator reference switch assembly

Routes and conditions the optical local-oscillator reference signal to the first local-oscillator chains in each of the cartridge assemblies.

An FTS splitter assembly

Routes and conditions the fine-tuning synthesizer signal to the first local-oscillator chains in each of the cartridge assemblies.

Power supplies

Converts mains power supplied by the antenna to clean DC power used in the front end.

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

This specification also 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.

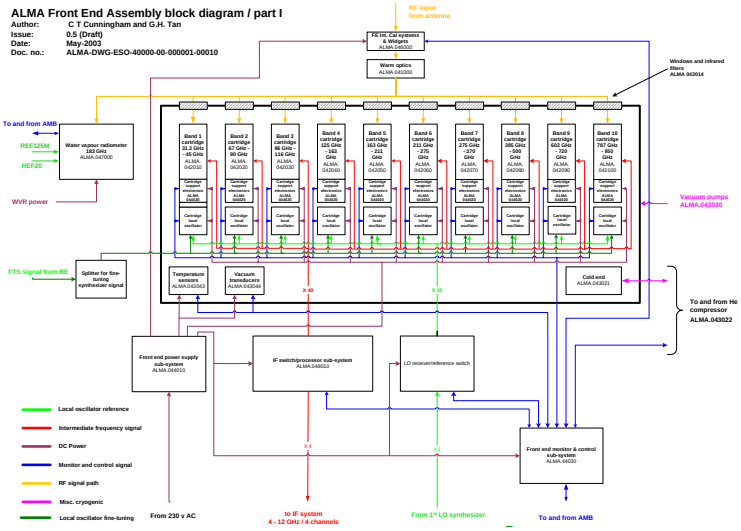
2.2. Definition of terms

- Band:
  The ALMA Font-End covers the frequency range from 31.3 GHz to 950 GHz in ten discrete bands. Each band receives signals in orthogonal linear polarisation (defined in 3.3.1.)

- Frequency channel:
  Within a particular band there are two parallel receiver chains. Each receives one linear polarisation.

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

2.3. Block diagram



The overall system design drawing (current revision G) is located in the system engineering section (80.04) of the ALMA EDM.

3. FUNCTIONAL REQUIREMENTS

Comment: SE should define the operating modes!

3.1. Operation modes

The ALMA Front End can exist in the following states.

3.1.1. Operational

In this mode operational power is applied with all active signal levels at nominal values. All specifications and requirements in this document apply, unless otherwise stated.

3.1.2. Non-Operational

In this mode operational 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. This mode differs from the non-operational mode in the environmental operating conditions. 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. Specifications and requirements of this document do not apply.

3.2.2. Mechanical tuning

[FEND-40.00.00.00-00020-00 / R]
No mechanical tuning shall be employed during operation.

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 cables and connectors shall be in compliance with [AD10] and [AD12].

3.2.5. Solar observing and safety

[FEND-40.00.00.00-0050-00 / AT]
No components shall be damaged with 0.3 W/cm^2 of solar radiation incident anywhere on a Front End assembly. This specification applies for all modes. Provisions shall be taken to allow observations of the sun.

3.3. Frequency Coverage

This section applies only to the operational mode.

3.3.1. RF input port

[FEND-40.00.00.00-00060-00 / R]

Band	Start frequency	Stop frequency	Remarks
1	31.3 GHz	45 GHz	
2	67 GHz	90 GHz	
3	86 GHz	116 GHz	operation to 84 GHz
4	125 GHz	163 GHz	
5	163 GHz	211 GHz	
6	211 GHz	275 GHz	
7	275 GHz	370 GHz	operation to 372 GHz
8	385 GHz	500 GHz	
9	602 GHz	720 GHz	
10	787 GHz	950 GHz	

Table 4

Specifications and requirements do not apply for operation outside nominal frequency limits.

3.3.2. LO input port

[FEND-40.00.00.00-00070-00 / R]

Band	Bottom frequency	Top frequency	Remarks
1	27.3 GHz	33 GHz	USB mixing scheme
2	79 GHz	94 GHz	LSB mixing scheme
3	94 GHz	108 GHz	operation to 92 GHz
4	133 GHz	155 GHz	
5	171 GHz	203 GHz	
6	223 GHz	263 GHz	
7	283 GHz	362 GHz	operation to 364 GHz
8	393 GHz	492 GHz	
9	614 GHz	708 GHz	
10	795 GHz	942 GHz	

Table 5

Full specifications and requirements do not apply for operation outside nominal frequency limits. Assumed IF bandwidths reflect current plans (September 2003).

3.3.3. IF output port bandwidth and centre frequency

[FEND-40.00.00.00-00080-00 / R]
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 at 6.0 GHz

4. PERFORMANCE REQUIREMENTS

4.1. Cryogenics, Dewar, and Vacuum

4.1.1. Evacuation and cool-down time

[FEND-40.00.00.00-00090-00 / T]
The period required to evacuate the cryostat 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.

4.1.2. Warm-up time

[FEND-40.00.00.00-00100-00 / T]
The warm-up of the dewar from operating to ambient temperature shall take a maximum of 12 hours.

4.1.3. Vacuum integrity

[FEND-40.00.00.00-00110-00 / AT]
The cryostat shall have a sufficient vacuum integrity to enable operation for at least one year.

4.2. Optics

This section only applies to the operational mode.

4.2.1. Polarisation

4.2.1.1. Polarisation Optimisation

[FEND-40.00.00.00-00120-00 / R]
The polarisation performance of the optical design shall be optimised for band 7.

4.2.1.2. Polarisation States

[FEND-40.00.00.00-00130-00 / R]
Each of the bands in the Front End shall simultaneously receive two orthogonal polarisations. The nominal polarisation states shall be linear.

4.2.1.3. Polarisation alignment accuracy

[FEND-40.00.00.00-00140-00 / T]
The variation in relative orientation of the E-vector (from cartridge to cartridge) shall be less than +- 2 degrees

4.2.1.4. Cross-Polarisation

[FEND-40.00.00.00-00150-00 / T]
At any frequency within the Front End's tuning range, the cross-polarised contribution within a signal channel shall be at least 20 dB below the desired polarization at any direction within the main beam.

4.2.1.5. Polarisation mismatch

Comment: I suggest to remove this. The polarization ellipse is defined for the FE, anything else is out of the FE influence.

[FEND-40.00.00.00-00160-00 / AT]
The Front End contribution to the maximum polarisation mismatch between any pair of antennas in the array shall not exceed -20 dB.

4.2.2. Beam pattern / Beam efficiency

[FEND-40.00.00.00-00170-00 / T]
The beam pattern of all the bands shall couple to the antenna secondary with an efficiency exceeding 90 % (TBC).

4.2.3. Insertion Loss

[FEND-40.00.00.00-00180-00 / A]
The tertiary optics shall be designed to efficiently couple each of the Front End bands to the telescope. Details can be found in [RD3].

4.2.4. Pointing stability

[FEND-40.00.00.00-00190-00 / T]
Tipping of the Front End assembly from the zenith to the horizon shall result in an RF pointing change of less than 0.1 arc-seconds and a telescope coupling efficiency change of less than 2 %.

4.2.5. Solar Filter

[FEND-40.00.00.00-00200-00 / T]
A solar filter shall be provided to allow solar observations. The filter shall be inserted into the any of the ALMA bands under remote control. It shall attenuate the 10 micron radiation by at least 20 dB while not attenuating the RF signal by more than 13 dB.

4.2.6. Quarter-Wave-Plate

[FEND-40.00.00.00-00210-00 / T]
A quarter wave plate that can be inserted into the beam of band 7 shall be provided. The centre frequency of the quarter wave plate shall be 345 GHz. The combined absorptive and reflective losses shall be less than 0.5 dB (TBC). The induced cross-polar component shall be less than 10 % (TBC). These specifications shall apply over a 10 % (TBC) fractional bandwidth at 345 GHz.

4.2.7. Amplitude Calibration

[FEND-40.00.00.00-00220-00 / R]
Means for periodic amplitude calibration of all the Front end bands shall be provided. A complete calibration cycle for a particular band, involving the presentation of loads of differing effective temperature, shall not take longer than two seconds.

4.3. Water Vapour Radiometer

This subsection only applies to the operational mode.

The Front End assembly shall include a radiometer to allow the measurement of the amount of water vapour along the signal path, using the 183 GHz line. This instrument shall operate simultaneously with the selected astronomy band and shall illuminate the sub-reflector. It must include all necessary LO sources, coupling optics, signal processing, power supplies and monitoring and control electronics.

4.3.1. WVR beam position

[FEND-40.00.00.00-00230-00 / AT]
The beam of the WVR shall be within 10 arc-minutes of the observing beam.

4.3.2. WVR sensitivity

[FEND-40.00.00.00-00240-00 / T]
The computed RMS path error of the WVR shall be less than $10*(1+w_v)$ µm , with w_v being the water vapour along the line of sight in millimetres. This sensitivity shall be achieved with a time resolution of 1 second.

4.3.3. WVR stability

[FEND-40.00.00.00-00250-00 / T]
The sensitivity of the WVR shall be maintained over time periods of 5 minutes and for changes in zenith angle of up to 1 degree.

4.3.4. WVR tuning range and step size

[FEND-40.00.00.00-00260-00 / R]
The tuning range of the WVR shall be no less than 25 MHz (TBC), with tuning steps no larger than 25 kHz (TBC).

4.3.5. WVR calibration interval

[FEND-40.00.00.00-00270-00 / R]
The calibration interval of the WVR shall be 5 minutes.

4.4. Front End Noise Performance

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 is referred to the RF input port and includes all contributions from warm optics, dewar windows, and IR filters. It must 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 of either T_{SSB} for SSB and 2SB response or $T_{DSB} = 0.5.T_{SSB}$ for DSB responses as follows:

Specifications for maximum receiver noise temperatures

Band	SSB(corrected for sideband ratio)		DSB		
	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	15 K	23 K	8 K	12 K	[FEND-40.00.00.00-00280-00 / T]
2	28 K	43 K	14 K	22 K	[FEND-40.00.00.00-00290-00 / T]
3	34 K	54 K	17 K	27 K	[FEND-40.00.00.00-00300-00 / T]
4	47 K	76 K	24 K	38 K	[FEND-40.00.00.00-00310-00 / T]
5	60 K	98 K	30 K	49 K	[FEND-40.00.00.00-00320-00 / T]
6	77 K	126 K	39 K	63 K	[FEND-40.00.00.00-00330-00 / T]
7	133 K	198 K	67 K	99 K	[FEND-40.00.00.00-00340-00 / T]
8	181 K	270 K	91 K	135 K	[FEND-40.00.00.00-00350-00 / T]
9	335 K	500 K	168 K	250 K	[FEND-40.00.00.00-00360-00 / T]
10	438 K	655 K	219 K	328 K	[FEND-40.00.00.00-00370-00 / T]

Table 6

Remarks:

- The frequency ranges of the bands in the table above are specified in section 3.3.1 of this document.

- The noise temperatures measured at each point across the RF band shall be averaged over the full IF band, (as defined in section 3.3.3). At no point within the IF bandwidth shall the noise-temperature exceed the average by more than 30%

- The noise temperature shall be calculated from measurements according to the Callen and Welton radiation law. The cold load used in these measurements shall be calibrated assuming that radiation temperature of the microwave absorber AN72 (Emerson and Cuming), when immersed in liquid air and viewed through the air/liquid interface, is 80K

- SSB noise temperatures should be corrected for side-band ratios

- Note that the values in table 6 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 centre 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

4.5. Image Band Suppression / sideband mismatch

[FEND-40.00.00.00-00380-00 / T]
This section only applies to the operational mode.

For a SSB or 2SB mixing scheme the image band suppression shall be at least 10 dB at all frequencies. For a DSB mixing scheme the side-band ratio shall be less than 1.5 dB (TBC) averaged across the IF band.

4.6. Spurious response of the Front end

[FEND-40.00.00.00-00390-00 / T]
This section only applies to the operational mode.

In any 60 MHz portion of a band's RF range, the power received in spurious signals shall be at least 3 dB (TBC) below that band's nominal noise power. This specification applies to both interference amongst cartridges and interference between the cartridges and the water vapour radiometer.

4.7. Out-of band response

[FEND-40.00.00.00-00400-00 / T]
This section only applies to the operational mode.

For a 2SB mixing scheme, the total output power in the 8-12 GHz IF frequency range shall be at least 10 dB below the total in-band (4-8 GHz) power.

4.8. Saturation

[FEND-40.00.00.00-00410-00 / T]
This section only applies to the operational mode.

For an increase in RF input power of not less than 300 K above T_{rx}, the gain compression shall be less than 1 % for bands 1-6 and less than 3 % for bands 7-10.

Define the type of gain compression (whether incremental or large-signal, and if measured using CW or noise

4.9. Gain

[FEND-40.00.00.00-00420-00 / T]
This section only applies to the operational mode.

With a 300 K RF noise input the IF output power spectral density (over the full IF band from 4-12 GHz) shall be within a range of -40 dBm/GHz to -27 dBm/GHz. When the selected band is such that the useful bandwidth is less than 4-12 GHz, the power within 4--12 GHz but outside the useful bandwidth shall be less than -44 dBm (10 dB below the minimum in-band power). The total IF output power shall be more than -18 dBm. and less than -15 dBm over the 10 MHz to 18 GHz frequency range.

Over the full IF bandwidth (4 GHz or 8 GHz), and with any LO frequency within the specified range for that band:

a) the gain slope shall be < 5 dB
b) the gain ripple shall be < 4 dB peak to peak.

Over any 2 GHz segment within the useful IF range of the selected band, and with any LO frequency within the specified range for that band:

a) the gain slope shall be < 3 dB
b) the gain ripple shall be < 2 dB peak to peak

Here "gain slope" is defined to be the edge-to-edge range of the best straight line fit to log[G(f)] where G(f) is the power gain from the front end's input (window) to its IF output as a function of frequency; and "gain ripple" is defined as the peak-to-peak deviation of log[G(f)] from this line.

Note that the difference in the full-band gain slope between any two front end assemblies operating at the same LO frequency shall be < 3 dB.

4.10. Gain stability

[FEND-40.00.00.00-00430-00 / T]
This section only applies to the operational mode.

The amplitude stability of the Front end should be better than a linear extrapolation between values of 1×10^{-2} (at a time-scale of 100 seconds) and 3×10^{-4} (at a time-scale of 0.1 seconds). At time-scales between 1 and 0.25 seconds (where the stability is dominated by the refrigerator) this specification is relaxed to 1.5×10^{-3}.

Note - this specification is based on measurements of a representative system by NRAO staff.

4.11. Signal path phase stability

[FEND-40.00.00.00-00440-00 / T]

The signal path transfer function should maintain a phase stability of better than 1° (TBC) for any 5 minute period for all frequencies within the passband.

5. MECHANICAL AND ELECTRICAL REQUIREMENTS

Comment: Include mass of FESS eventually.
Only mass attached on the FESS.

5.1. Mass

[FEND-40.00.00.00-00460-00 / T]
The mass of all the Front End components attached to the FESS shall not exceed 750 kg.
Details can be found in ICD [AD4].

5.2. Centre of Gravity

[FEND-40.00.00.00-00470-00 / T]
The centre of gravity of all the Front End components attached to the FESS shall be at 400 +/- 40 mm below the FESS and within a 250 mm radius of the FESS centre.

5.3. Eigen-frequency

[FEND-40.00.00.00-00480-00 / A]
The lowest Eigen-frequency of any Front End subassembly that is directly attached to the antenna shall be at least 10 Hz.

5.4. Volume

[FEND-40.00.00.00-00490-00 / R]
Details can be found in the ICD [AD4].

5.5. Orientation

[FEND-40.00.00.00-00500-00 / T]
The Front End 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 [AD4]. The compressor shall meet its performance requirements at tilt angles up to 10^{o} in any orientation.

5.6. Thermal Load

[FEND-40.00.00.00-00510-00 / T]
The maximum thermal load presented by all the Front End components installed in the receiver cabin during operation shall not exceed 4 kW. Details can be found in the ICD [AD4].

5.7. Power requirements

[FEND-40.00.00.00-00520-00 / T]
The Front End components within the receiver cabin shall not consume more than 4 kW in the operational mode. The Front End components outside the receiver cabin (compressor/controller) shall not consume more than 10 kW. Details can be found in the ICD [AD4].

The mains power shall be single-phase 230 VAC/50 Hz and three-phase 400 VAC/50 Hz. Details can be found in [AD11].

6. OPERATING CONDITIONS

6.1. Stabilisation time

[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. Within 100 ms (TBC) 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 of duration at least 5 minutes the Front end shall exhibit a gain change of less than $2x10^{-3}$ (TBC) RMS 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 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) will 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 (pre-set) observing band

[FEND-40.00.00.00-00560-00 / T]
Selection and operation of a band that has been in standby mode shall take less than 1.5 sec.

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

[FEND-40.00.00.00-00580-00 / T]
Switching between two frequencies within .03% of each other shall take no more than 10 ms. Note that this only applies to switching within a band

6.4.4. Frequency changes within a band

[FEND-40.00.00.00-00590-00 / T]
Changing between frequencies more than .03% apart and in the same band shall take no more than 5 s.

6.5. Local Oscillator

This subsection only applies to the operational mode.

Comment: Front end contribution is to be determined by SE.

6.5.1. LO phase stability

[FEND-40.00.00.00-00600-00 / T]
Phase stability
Short term (jitter) - 63fs
Long term (drift - 29 fs

Note that the final values are awaiting determination by the Systems Engineering IPT

6.5.2. LO phase resolution

[FEND-40.00.00.00-00610-00 / T]
The first LO shall have a frequency resolution no greater than 0.03 Hz (TBC). The LO shall step and settle to a new frequency in less than 10 ms (TBC) with a phase error of less than 0.6 degrees.

6.5.3. LO Phase switch step size

[FEND-40.00.00.00-00620-00 / R]
The LO phase shall be capable of switching from any initial phase (in increments of either plus or minus 90° or 180°) for periods ranging from 256 us to 16 ms. The final phase value shall settle to within 0.5° (TBC) of the desired value.

6.5.4. LO Phase switching time

[FEND-40.00.00.00-00630-00 / T]
The final LO phase shall settle to its final value within 1 us after any phase change of 180 degrees or less.

6.6. Monitoring and Control

[FEND-40.00.00.00-00640-00 / RT]
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 simple troubleshooting. Details can be found in the ICD [AD8].

6.7. Environmental operating conditions

6.7.1. Altitude

[FEND-40.00.00.00-00650-00 / R]
The operating altitude is 0 - 5200 m.

6.7.2. Thermal Environment

[FEND-40.00.00.00-00660-00 / T]
The Front End shall meet all its operational performance for a ambient temperature of 16^{o} C to 22^{o} C. The temperature variation shall not exceed +/- 1^{o} C peak-to-peak.

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 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 [AD2].

6.7.5. Acceleration

[FEND-40.0000.00-00690-00 / AT]
The front end assembly shall comply with [AD2].

6.7.6. Cleanliness

[FEND-40.0000.00-00700-00 / I]
The Front End shall meet its performance under the conditions outlined in [AD2]

6.8. Storage and shipping conditions

[FEND-40.0000.00-00710-00 / IT]
This section applies only to the storage mode.

The front end assembly shall comply with [AD2].

6.9. EMC

[FEND-40.0000.00-00720-00 / T]
The Front End shall comply with [AD3].

6.9.1. RFI

[FEND-40.0000.00-00730-00 / T]
The IF signal isolation between any one 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 RF emission of the WVR shall be at least 10 dB less than the IF cartridge signal level at its maximum frequency resolution.

6.10. Grounding / Isolation

[FEND-40.0000.00-00740-00 / IR]
The Front End shall be grounded in compliance with [AD10].

6.11. Availability, reliability and maintainability

[FEND-40.0000.00-00750-00 / R]
The Front End shall be designed for continuous use.

6.11.1. MTBF

[FEND-40.0000.00-00760-00 / A]
The MTBF of the Front End shall exceed 11.000 hours (TBC).

6.11.2. MTTR

[FEND-40.0000.00-00770-00 / A]
At the OSF, the MTTR of the Front End sub-system shall be less than 24 hours (TBC) once all components have reached room temperature. Note that this does not include post-repair cool-down. Exchanging a Front End assembly at an antenna shall take less than 2 hours (TBC).

6.11.3. Lifetime

[FEND-40.0000.00-00780-00 / A]
The lifetime of the Front End shall be more than 15 years.

6.11.4. Maintenance

[FEND-40.0000.00-00790-00 / R]
In general there shall be no periodic maintenance required for the Front End assembly. Exceptions to this include the cryo cooler, compressor, control unit and vacuum pump. The maintenance interval for the cryo-cooler and associated pumps shall be greater than 10.000 hours. The maintenance interval for the compressor shall be longer greater than 20.000 hours.

6.11.5. Hold times

[FEND-40.0000.00-00800-00 / T]
The cryostat shall be able to allow for 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 specified cryostat hold time shall be achieved at any time in the nominal 1 year of operation between regular service.