

Draft only

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Band 4 Cartridge Technical Specifications

FEND-40.02.04.00-001-A-SPE

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1 Introduction

1.1 Purpose

This document summarizes the design specifications and requirements for the ALMA Band 4 cartridge.

1.2 Scope

The information given in this document provides a complete summary of all the specifications and requirements that must be met by the ALMA Band 4 cartridges delivered to the project. This document was drafted with reference to [RD3] and [RD4].

The following table shows a partial view of the ALMA product tree [RD1] at "unit" and "item" level for the Band 4 cartridge and its components.

PT level 3 / "unit"		PT level 4 / "item"		Remarks
Product No.	Product Name	Product No.	Product Name	
40.02.04.00	Band 4 cartridge	40.02.04.01	Band 4 cold optics	Not part of this technical specifications Not part of this technical specifications Includes sensors for monitoring Not part of this technical specifications
		40.02.04.02	Band 4 LO injection	
		40.02.04.03	Band 4 Ortho mode transducer	
		40.02.04.04	Band 4 SIS mixers	
		40.02.04.05	Band 4 IF amplifiers	
		40.02.04.06	Band 4 bias circuit	
		40.02.04.07	Band 4 mechanical structure	
		40.02.04.08	Band 4 cartridge wiring	
		40.02.04.09	Band 4 cartridge electrical feedthroughs	
		40.02.04.10	Band4 Cryo frequency multiplier	

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1.3 Applicable documents

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

	Document title	Document ID
[AD1]	ICD between Band 4 cartridge and Dewar	FEND-40.02.04.00-40.03.01.00-A-ICD
[AD2]	ICD between Band 4 cartridge and FE bias module	FEND-40.02.04.00-40.02.04.06-A-ICD
[AD3]	ICD between Band 4 cartridge and IF switch sub-system	FEND-40.02.04.00-40.08.01.00-A-ICD
[AD4]	ICD between Band 4 cartridge and Band 4 First Local Oscillator	FEND-40.02.04.00-40.02.04.13-A-ICD
[AD5]	ALMA System: Electromagnetic Compatibility (EMC) Requirements	ALMA-80.05.01.00-001-A-SPE
[AD6]	ALMA Environmental Specification	ALMA-80.05.02.00-001-B-SPE

In the event of a conflict between one of the before mentioned 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.

	Document title	Document ID
[RD1]	ALMA Product Tree	ALMA-80.03.00.00-001-M-LIS
[RD2]	ALMA Front End Sub-System Technical Specification	FEND-40.00.00.00-001-A-SPE
[RD3]	ALMA band 3 technical specifications	FEND-40.02.03.00-012-A-SPE
[RD4]	ALMA band 9 technical specifications	FEND-40.02.09.00-002-A-SPE

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1.5 Acronyms

A limited set of basic acronyms used in this document is given below.

AD	Applicable Document
ALMA	Atacama Large Millimeter/Submillimeter Array
FE	Front End
ICD	Interface Control Document
IF	Intermediate Frequency
IPT	Integrated Product Team
LO	Local Oscillator
MTBF	Mean Time Between Failures
NAOJ	National Astronomical Observatory of Japan
OMT	Ortho-Mode Transducer
PDR	Preliminary Design Review
RF	Radio Frequency
SIS	Superconductor-insulator-Superconductor
SSB	Single-SideBand
2SB	SideBand 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-40.02.04.00-XXXXX-YY / Z(ZZ)]

Where:

FEND-40.02.04.00 identifies the 'Frontend -Band 4 Cartridge' as based on [RD1];

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;

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

2 Description

2.1 Equipment Definition

The Band 4 cartridge is one of the receiver cartridges which populate the front end cryostat. It receives radiation in the 125 - 163 GHz range in two orthogonal polarizations and down-converts the signals to intermediate frequencies between 4 and 8 GHz. The Band 4 cartridge work-package includes the cold optics (feed horn), two sideband separating SIS mixers, components required to couple the LO into the mixers, IF amplifiers, temperature sensors and component interconnects. Other ALMA work-packages will supply the warm optics, the first LO subsystem, the cryostat window and IR-blocking filters and the DC support electronics. These deliverable elements shall be integrated into the Band 4 cartridge and the assembly tested as a whole. All vacuum and cryogenic services are provided by the front end cryostat.

3 General Requirements

3.1 Operation modes

The Band 4 cartridge will be used in the following modes.

3.1.1 Operational

[FEND-40.02.04.00-00010-00 / I]

This mode is applicable during normal observations with the front end sub-system. For this mode, all specifications and requirements in this document shall apply.

3.1.2 Non-Operational

[FEND-40.02.04.00-00020-00 / I]

This mode is applicable when the Band 4 cartridge is switched off. In this mode, the specifications and requirements, with the exception of section 5, apply.

3.1.3 Stand-by

[FEND-40.02.04.00-00025-00 / I]

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This mode applies when operational power is applied to the Band 4 cartridge but signal levels are not at their nominal values. In this mode, the specifications and requirements, with the exception of section 5, apply.

3.1.4 Transport with the antenna

[FEND-40.02.04.00-00030-00 / I]

This mode applies when the Band 4 cartridge, integrated into the front end sub-system, is transported with the antenna on the antenna transport vehicle. In this mode, the specifications and requirements, with the exception of section 5, apply

3.1.5 Transport in the front end service vehicle

[FEND-40.02.04.00-00040-00 / I]

This mode is applicable, when the Band 4 cartridge as part of the front end sub-system is transported on the front end service vehicle. In this mode, the specifications and requirements, with the exception of section 5, apply.

3.2 Compatibility with ALMA front end sub-system

[FEND-40.02.04.00-00050-00 / I]

The Band 4 cartridge design shall be compatible with other products within the ALMA front end sub-system, especially the receiver optics and cryostat design. Details as given in the applicable ICDs.

3.3 Design for production

3.3.1 Technology

[FEND-40.02.04.00-00060-00 / R]

The Band 4 cartridge design should use mature technologies whenever possible.

3.3.2 Series production

[FEND-40.02.04.00-00070-00 / R]

The Band 4 cartridge design should be compatible with low production and assembly costs. The design should be as simple as possible.

3.3.3 Standard parts

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[FEND-40.02.04.00-00080-00 / R]

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

3.4 Mechanical tuning

[FEND-40.02.04.00-00090-00 / R]

No mechanical tuning shall be employed during operation.

3.5 Metric dimensioning

[FEND-40.02.04.00-00110-00 / R]

All hardware used in the Band 4 cartridge, including but not limited to fasteners, tapped holes, etc., shall be metric. Standard waveguide flanges using imperial dimensions may be used.

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4 FUNCTIONAL REQUIREMENTS

4.1 Mixer type

[FEND-40.02.04.00-00120-00 / R]

The Band 4 cartridge shall employ SIS mixers as the frequency translating device.

4.2 Mixing scheme

[FEND-40.02.04.00-00130-00 / R]

The Band 4 mixers shall be of the sideband separating type (2SB), in which both upper and lower sidebands are available.

4.3 Frequency Coverage

4.3.1 RF input port

[FEND-40.02.04.00-00140-00 / R]

The RF input frequency range shall be 125 GHz to 163 GHz. In the range 125 - 163 GHz the performance specifications need not be met but every effort should be made to retain reasonable performance.

4.3.2 LO input port

[FEND-40.02.04.00-00150-00 / R]

The LO input port frequency range shall be 133 GHz to 155 GHz.

137-151, #4-12

assumes 4-8 GHz.

Driver?

4.3.3 IF output port bandwidth and center frequency

[FEND-40.02.04.00-00160-00 / R]

Each polarization shall provide 8 GHz of IF bandwidth. Each 8 GHz of bandwidth shall be evenly split into upper and lower sidebands and these shall be centered at 6 GHz.

4.4 Polarization States

[FEND-40.02.04.00-00170-00 / R]

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The cartridge shall receive two orthogonal polarizations, designated "polarization 0" and "polarization 1", with each being converted to two separate IF output. The nominal polarization states shall be linear.

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5 PERFORMANCE REQUIREMENTS

5.1 Cartridge Noise Performance

[FEND-40.02.04.00-00180-00 / T]

The following table shows the required noise temperature performance of the Band 4 cartridge. The cartridge noise performance is referred to its quasi optical RF input port. It includes the noise contributions from cryostat windows and IR filters, either as fabricated for the test cryostat, or standard issue ALMA windows and filters. It must take into account all the noise contributions up to the cartridge IF output ports. The cartridge noise temperature shall not exceed the values of T as follows:

Requirement	
T _{SSB} over 80% of the frequency range	T _{SSB} at any frequency within the RF band
47 K	76 K

Remarks:

- Frequency and frequency range in the table above as specified in section 4.3.1 of this document.
- The required noise temperatures shall be met when averaging over the full IF band, (as defined in section 4.3.3). At no point within the IF bandwidth shall the noise-temperature exceed the average by more than 25% when measured in a bandwidth of not more than 100 MHz.
- The noise temperature shall be calculated from measurements according to the Rayleigh-Jeans law.
- SSB noise temperatures must be corrected for residual image response.
- The noise performance shall be measured for an operating temperature of 4 ± 0.25 K, measured at the mixer block.

5.2 Image Band Suppression / sideband mismatch

[FEND-40.02.04.00-00190-00 / T]

The side-band ratio shall be 10 dB or better across the full IF band.

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5.3 Cartridge IF output

5.3.1 IF output power

[FEND-40.02.04.00-00200-00 / T]

This section only applies to the operational mode.

With a 300 K load at the RF input of the cartridge, the output power for each of the cartridge IF outputs shall comply with the following requirements:

- Total power in the IF frequency range as specified under section 4.3.3:
-37 dBm to -24 dBm
- Total power in the frequency range from 10 MHz to 18 GHz: < -22 dBm

Remarks:

These power levels must be measured at the IF outputs of the warm cartridge assembly that houses the second-stage IF amplifier and the first local oscillator chain.

5.3.2 IF power variations

[FEND-40.02.04.00-00210-00 / T]

Within the IF band (as specified in section 4.3.3), variations from the average IF power over the whole IF band as specified in section 5.3.1 shall be less than:

- 4dB peak to peak in any 2 GHz portion of the IF band
- 6 dB peak to peak across the whole IF band

5.4 Gain compression

[FEND-40.02.04.00-00230-00 / T]

This section only applies to the operational mode.

The large signal gain compression shall be less than 5 % between the situation that a 77 K load is placed at the RF input port and the situation that a 300 K load is placed at the same RF input port.

5.5 Amplitude stability

[FEND-40.02.04.00-00240-00 / T]

The IF amplitude stability, measured at the IF connectors on the output flange of the warm cartridge assembly that houses the second-stage IF amplifier and the local oscillator chain, shall comply with the following requirement:

- The Allan variance, $\sigma^2(2, T, 0,9 \cdot T)$, of the IF output power in the IF band must be less

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than $4.0 \cdot 10^{-7}$ for timescales between 0.1 and one second.

Remarks: This stability must be achieved when using the ALMA first local oscillator chain.

5.6 Signal path phase stability

[FEND-40.02.04.00-00250-00 / T]

For all frequencies within the IF pass-band the signal path transfer function shall maintain a phase stability of better than 0.6 degrees on timescales up to 300 seconds. The phase being the average value measured in 16 msec. The signal path shall include all components between the RF window and the IF outputs of the warm assembly that houses the second-stage amplifier and the local oscillator chain. The required phase stability excludes any contribution from the local oscillator chain. The phase stability must be maintained as the gravity vector is varied within a solid angle of 3 degrees.

5.7 Optics

5.7.1 RF beam efficiency

[FEND-40.02.04.00-00260-00 / T]

The fraction of the cartridge radiation diagram coupled to the secondary reflector shall exceed 90 %.

5.7.2 Polarization alignment

[FEND-40.02.04.00-00270-00 / T]

At the RF input of the cartridge the E vector of polarization channel 0 must be aligned with the radial direction of the cryostat. Channel 1 shall be orthogonal to channel 0.

5.7.3 Polarization alignment accuracy

[FEND-40.02.04.00-00280-00 / T]

At the RF input of the cartridge the alignment between the orientation of the E vector of either of the polarization channels and the ideal polarization alignment (as specified in 5.7.2.) must be better than two degrees.

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5.7.4 Cross-Polarization

[FEND-40.02.04.00-00290-00 / T]

At any frequency within the RF tuning range and for either of the two polarization channels, the cross-polarized signal shall be at least 20 dB below the co-polar signal.

5.8 Stabilization time

5.8.1 Stabilization time from non-operational mode

[FEND-40.02.04.00-00300-00 / T]

Starting from the non-operational mode, the front end shall reach the operational mode within 15 minutes.

5.8.2 Stabilization time from stand-by mode

[FEND-40.02.04.00-00305-00 / T]

From the stand-by mode, the operational mode shall be reached within 1.5 seconds.

6 MECHANICAL AND ELECTRICAL REQUIREMENTS

6.1 Mass

[FEND-40.02.04.00-00310-00 / T]

The mass of all Band 4 cartridge components (including the cartridge body itself but excluding the local oscillator assembly) must not exceed 10 kg. Details can be found in the applicable Interface Control Document [AD1].

6.2 Eigen-frequency

[FEND-40.02.04.00-00320-00 / A, R]

The Band 4 cartridge shall have a first eigen-frequency of 70 Hz or greater.

6.3 Volume

[FEND-40.02.04.00-00330-00 / I]

The Band 4 cartridge components described in section 2.1 shall be contained within a

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volume of Ø140 mm x 475 mm, measured from the cartridge-mounting flange. Details can be found in the applicable Interface Control Document [AD1].

6.4 Orientation

[FEND-40.02.04.00-00340-00 / A,R,T]

The cartridge shall meet all performance requirements over a range of gravity vectors from 0 to 90 degrees. This rotation occurs about the axis of the antenna elevation-bearing.

6.5 Thermal Load

[FEND-40.02.04.00-00350-00 / A]

The maximum thermal load presented by the cartridge during operation or stand-by is given in [AD1].

6.6 Bias requirements

[FEND-40.02.04.00-00360-00 / R]

Details can be found in the applicable Interface Control Documents [AD2].

6.7 Connectors and RF ports

6.7.1 RF input port interface

[FEND-40.02.04.00-00370-00 / R]

The RF input port of the cartridge shall comply with the requirement as described in section 4.2.3 of [RD2].

6.7.2 LO input port interface

[FEND-40.02.04.00-00380-00 / R, I]

The LO input ports shall comply with the applicable Interface Control Document [AD4].

6.7.3 IF output port interface

[FEND-40.02.04.00-00390-00 / R, I]

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All IF output ports shall be coaxial, details can be found in the applicable Interface Control Document [AD3].

6.7.4 Bias connectors

[FEND-40.02.04.00-00400-00 / R, I]

Details for the bias connector(s) can be found in the applicable Interface Control Documents [AD2].

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7 OPERATING CONDITIONS

7.1 Local Oscillator

7.1.1 LO input frequency

[FEND-40.02.04.00-00420-00 / T]

The LO frequency signal range shall be 133 GHz to 155 GHz.

7.1.2 LO power requirement

[FEND-40.02.04.00-00430-00 / A, T]

(Note that this subsection only applies to the operational mode.)

The Band 4 cartridge shall meet its performance requirements when supplied with a local oscillator signal power that is not less than -6 dBm and not more than 0 dBm. The power levels being measured at each of the local-oscillator input ports on the bottom flange of the cartridge.

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7.1.3 LO sideband/phase noise

[FEND-40.02.04.00-00440-00 / T]

The Band 4 cartridge shall meet its performance requirements when driven by a local oscillator exhibiting sideband noise at a level not exceeding 10 K/ μ W.

Note that sideband noise refers to noise accompanying the LO at frequency offsets within the IF band of the mixer operating in the normal RF frequency range.

7.1.4 LO amplitude stability

[FEND-40.02.04.00-00450-00 / T]

(Note that this subsection only applies to the operational mode.)

The Band 4 cartridge shall meet its performance requirements when pumped by a local oscillator chain with amplitude variations of up to 0.03% per second.

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7.2 Thermal Environment

[FEND-40.02.04.00-00460-00 / T]

The cartridge shall meet its performance requirements in a thermal environment which presents temperature variations, measured at the cartridge side of the thermal interface clamp as follows:

Stage ID	Temperature	Max. variation 1min
4K	< 4 K	2 mK peak-to-peak
15K	10 - 18 K	50 mK peak-to-peak
110K	80 - 130 K	100 mK peak-to-peak

The operating cartridge shall withstand an increase of temperature to ambient temperature of 20° C without damage to the equipment. This subsection does not apply for the transport modes and for the storage mode.

7.3 Vacuum conditions

[FEND-40.02.04.00-00470-00 / R]

All Specifications shall be met a vacuum environment.

The out gassing of the cartridge components shall be compatible with the ALMA cryostat specifications as stated in [AD1].

This subsection does not apply for the transport modes and for the storage mode.

7.4 Environmental operating conditions

7.4.1 Vibration

[FEND-40.02.04.00-00480-00 / R, T]

The Band 4 cartridge shall survive vibration levels as specified in Appendix 1 of [AD6].

The vertical direction is defined as perpendicular to the cartridge base-plate.

7.4.2 Acceleration

[FEND-40.02.04.00-00490-00 / R, T]

The Band 4 cartridge shall comply with the following survival specification:

- 3 g shock load in the vertical direction
- 2 g shock load in any horizontal direction

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The vertical direction is defined as perpendicular to the cartridge base-plate.

7.5 Storage and shipping conditions

[FEND-40.02.04.00-00500-00 / R]

The Band 4 cartridge shall comply with [AD6].

7.6 Electro-Magnetic Compatibility

[FEND-40.02.04.00-00510-00 / T]

The Band 4 cartridge shall comply with [AD5].

7.7 Monitoring and control

This section does not apply to the storage mode.

7.7.1 Mixer voltage and currents

[FEND-40.02.04.00-00520-00 / R]

The mixer voltage and currents shall be monitored as stated in [AD2].

7.7.2 Magnet currents

[FEND-40.02.04.00-00530-00 / R]

Band 4 mixers will not need the suppression magnet.

7.7.3 Temperature

[FEND-40.02.04.00-00540-00 / R]

Temperature sensors shall be provided at critical points of all temperature stages as stated in [AD2].

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7.7.4 Removal of trapped flux

[FEND-40.02.04.00-00550-00 / R]

Means shall be provided to remove flux trapped in the SIS junctions.

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8 RELIABILITY REQUIREMENTS

8.1 Continuous operation

[FEND-40.02.04.00-00560-00 / R]

The cartridge shall be designed for continuous use. It shall not require any periodic maintenance.

8.2 Mean time between failure (MTBF)

[FEND-40.02.04.00-00570-00 / A]

The MTBF of the cartridge shall exceed 20 years.

8.3 Lifetime

[FEND-40.02.04.00-00580-00 / R]

The Band 4 cartridge shall have the same minimum lifetime of 15 years.