Band 6 Cartridge Technical Specifications

FEND-40.02.06.00-001-A-SPE

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Change Record

Version	Date	Affected Section(s)	Reason/remarks
A	2004-08-24	All	First document release
A.01	2005-02-10	Many	Jee: Comments from Kerr and Effland, originally made to pdf file in 08-2004 but now updated here. Also compared to Band 9 Specification, which is a RELEASED document.
A.02	2005-03-14	Many	• Jee: Added AD8, Vac Requirements • Added shock test requirements from Darren Erickson's "Concerns Regarding Shock and Vibration Testing in the ALMA Front-End Sub-systems, 2005-03-03, Revision: 1.0 • Changed LO sections to reference AD's • Removed +/- from IF power variations.
A.03	2005-03-24	Many	Jee: Made changes recommended by Saini: • Returned IF bandwidth to 8 GHz per sideband • Added 100 MHz resolution to IF power variation section • Added [AD9] - "ICD Band 6 cartridge – Warm Cartridge Assembly"
A 04	2005-03-28	5.3.1	• KSS: Changed total output power in IF frequency range to -25 ± 2 dBm • KSS: Changed total output power in 10 MHz to 18 GHz range to -22 dBm
A.05	2006-09-26	4.3.2, 4.3.3, 5.1, 5.3.1, 5.3.3	Saini – Updated LO frequency range, changed IF bandwidth per polarization from 16 GHz to 8 GHz, corrected T_{SSB} any RF frequency, updated output IF power range, deleted the requirement of gain matching amongst cartridges [FEND-40.02.06.00-00220-00 / T] as per email from Gie Han. Updated signature block.
A.06	2006-09-26	5.7.1	Saini – Added 10.5 dB edge taper requirement to RF Beam Efficiency section. Fixed broken section header numbering.

TABLE OF CONTENTS

1. INTRODUCTION

1.1. TBD Items

Section 7.2: Rate of temperature increase needed for cartridge to survive warm-up to 20 C

1.2. Purpose

This document details the specifications and requirements for the ALMA Band 6 cartridge.

1.3. Scope

The information given in this document provides a complete summary of all the specifications and requirements to be met by the ALMA Band 6 cartridges.

The following table details the ALMA product tree (AD1) at the "unit" and "item" level for the Band 6 cartridge and its components.

PT level 3 / "unit"		*PT level 4 / "item"*		
Product No.	*Product Name*	*Product No.*	*Product Name*	*Remarks*
40.02.06.00	Band 6 cartridge			
		40.02.06.01	Band 6 cold optics	
		40.02.06.02	Band 6 LO injection	
		40.02.06.03	OMT	
		40.02.06.04	Band 6 SIS mixers	
		40.02.06.05	Band 6 quadrature hybrids	
		40.02.06.06	Band 6 IF amplifiers	
		40.02.06.07	Band 6 bias circuits	Not part of this requirements document
		40.02.06.08	Band 6 mechanical structure	Not part of this requirements document
		40.02.06.09	Band 6 cartridge wiring	Includes sensors for monitoring
		40.02.06.10	Band 6 cartridge hermetic electrical feed-throughs	Includes waveguide feedthroughs
		40.02.06.11	Cold Frequency Multipliers	Not part of this requirements document
		40.02.06.12	Temperature sensors	

1.4. Applicable documents

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

Reference	*Document title*	*Document ID*
[AD1]	ALMA Product Tree	ALMA-80.03.00.00-001-L-LIS
[AD2]	ICD Band 6 cartridge – Cryostat	FEND-40.02.06.00-40.03.01.00-A-ICD
[AD3]	ICD Band 6 cartridge – Band 6 bias circuits	FEND-40.02.06.00-40.02.06.06-A-ICD
[AD4]	ICD Band 6 cartridge – IF switch sub-system	FEND-40.02.06.00-40.08.01.00-A-ICD
[AD5]	ICD Band 6 cartridge – Band 6 first LO	FEND-40.02.06.00-40.10.06.00-A-ICD
[AD6]	ALMA System: Electromagnetic Compatibility Requirements	ALMA-80.05.01.00-001-A-SPE
[AD7]	ALMA Environmental Specification	ALMA-80.05.02.00-001-B-SPE
[AD8]	Vacuum requirements for receiver components inside the ALMA Front End cryostat	ALMA-40.03.00.00-015-A-SPE
[AD9]	ICD Band 6 cartridge – Warm Cartridge Assembly	FEND-40.02.00.00-40.11.00.00-A-ICD

In the event of a conflict between the applicable documents mentioned above and the contents of this specifications and requirements document, the contents of this document shall take precedence.

1.5. Reference documents

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

Reference	*Document title*	*Document ID*
[RD1]	ALMA Front-End Design Specifications & Requirements	FEND-40.00.00.00-001-A-SPE
[RD2]	ALMA Band 6 cartridge Statement of Work	FEND-40.02.06.00-002-A-SOW

1.6. Acronyms

A list of the acronyms used in this document is given below.

ALMA	Atacama Large Millimeter Array
CDR	Critical Design Review
DSB	Double side-band
EMC	Electromagnetic compatibility
FE	Front-End
ICD	Interface Control Document
IF	Intermediate Frequency
IPT	Integrated Product Team
LO	Local Oscillator
MTBF	Mean time between failures
NAAPO	North American ALMA Project Office
NRAO	National Radio Astronomy Observatory
PDR	Preliminary design review
RF	Radio frequency
SIS	Superconductor-Insulator-Superconductor
SSB	Single side-band
2SB	Side-band separating

1.7. Verb Convention

"Shall" and “must” are used when a specification or provision is mandatory. The verbs "should" and "may" indicate a specification or provision that is not mandatory.

1.8. Requirements numbering

The requirements are numbered according to the following code:
[FEND-40.02.06.00-XXXXX-YY / Z]

Where:

FEND-40.02.06.00 identifies the ‘Front-End – Band 6 cartridge’ as in [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 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 Band 6 cartridge is one of the ten receiver cartridges that populate the Front-End cryostat. It receives radiation in the 211 – 275 GHz frequency range in two orthogonal polarizations and down-converts the signals to intermediate frequencies between 4 and 12 GHz.
The band 6 cartridge work-package includes the cold optics (mirrors and feed horn), SIS mixers, components required to couple the LO into the mixers, IF amplifiers (cold and warm), temperature sensors and component interconnects. Other ALMA work-packages will supply the cartridge body, the ortho-mode transducer, cold optics design, the LO subsystem including cold multipliers, cryostat window/infrared blocking filters and the DC support electronics. These deliverable items shall be integrated into the band 6 cartridge and the assembly tested as a whole. All vacuum and cryogenic services are provided by the Front-End cryostat.

Although the cartridge body itself is not part of this Work Element, this Work Element includes the mechanical mounting of all components forming the Band 6 Cartridge so that the requirements mentioned in this document are met.

3. GENERAL REQUIREMENTS

3.1. Operation modes

The band 6 cartridge will be used in the following modes.

3.1.1. Operational

[FEND-40.02.06.00-00010-00 / I]
This mode applies during normal observations with the Front-End sub-system. In this mode, all the specifications and requirements described in this document apply.

3.1.2. Non-Operational

[FEND-40.02.06.00-00020-00 / I]
This mode applies when the Band 6 cartridge is switched off. In this mode, the specifications and requirements, with the exception of Section **Error! Reference source not found.**, apply.

3.1.3. Stand-By

[FEND-40.02.06.00-00025-00 / I]
This mode applies when operational power is applied to the Band 6 cartridge but signal levels are not at their nominal values. In this mode, the specifications and requirements, with the exception of section 5, apply unless otherwise noted.

3.1.4. Transport with Antenna Transporter

[FEND-40.02.06.00-00030-00 / I]
This mode applies when the Band 6 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 unless otherwise noted.

3.1.5. Transport with Front-End Service Vehicle

[FEND-40.02.06.00-00040-00 / I]
This mode applies when the Band 6 cartridge, integrated into 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 the ALMA Front-End sub-system

[FEND-40.02.06.00-00050-00 / I]
The Band 6 cartridge design shall be compatible with other parts of the ALMA Front-End sub-system, especially the receiver optics and cryostat. Details are given in the applicable ICDs.

3.3. Design for production

3.3.1. Technology

[FEND-40.02.06.00-00060-00 / R]
The Band 6 cartridge design should use mature technologies whenever possible.

3.3.2. Series Production

[FEND-40.02.06.00-00070-00 / R]
The Band 6 cartridge design should be compatible with low production and assembly costs. Complexity of the design and mechanical structures should be simplified wherever possible..

3.3.3. Standard Parts

[FEND-40.02.06.00-00080-00 / R]
Standard, unmodified commercially available components should be used whenever possible.

3.4. Mechanical tuning

[FEND-40.02.06.00-00090-00 / R]
Operation of the band 6 cartridge shall not require the use of mechanical tuners.

3.5. Metric dimensioning

[FEND-40.02.06.00-00110-00 / R]
In general, metric dimensioning shall be used in the Band 6 cartridge. This includes items such as fasteners and tapped holes. However the internal details of components may use imperial dimensioning and fasteners. Standard wave-guide flanges (using imperial dimensions) may be used.

4. FUNCTIONAL REQUIREMENTS

4.1. Mixer type

[FEND-40.02.06.00-00120-00 / R]
The Band 6 cartridge shall employ SIS mixers as the frequency-translating devices.

4.2. Mixing scheme

[FEND-40.02.06.00-00130-00 / R]
The band 6 mixers shall be of the sideband separating type, in which both upper and lower sidebands are available.

4.3. Frequency Coverage

(Note that this section applies to the operational mode.)

4.3.1. RF input port

[FEND-40.02.06.00-00140-00 / R]
The RF input frequency range shall be from 211 GHz to 275 GHz.

4.3.2. LO input port

[FEND-40.02.06.00-00150-00 / R]
The LO input port frequency range shall be from 221 GHz to 265 GHz.

4.3.3. IF output ports

[FEND-40.02.06.00-00160-00 / 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 8 GHz.

4.4. Polarization States

[FEND-40.02.06.00-00170-00 / R]
The cartridge shall receive two orthogonal polarizations, designated “polarization 0” and “polarization 1”, with each being converted to two separate IF outputs. The nominal polarization states shall be linear.

5. PERFORMANCE REQUIREMENTS

5.1. Cartridge Noise-Temperature

[FEND-40.02.06.00-00180-00 / T]
The following table details the required noise temperature performance for the Band 6 cartridge. The cartridge noise performance is referenced to the atmospheric side of the vacuum window. The noise performance includes the contributions from the IF chain (up to the cartridge IF output connectors), cryostat vacuum window and IR filters (either as provided by the Project for the test cryostat, or standard issue ALMA windows and filters).

Requirement	
T_{SSB} *over 80% of the frequency. range*	T_{SSB} *at any frequency within The RF band*
83 K	136 K

Remarks:

- The frequency ranges of the bands in the table above are 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 and sideband mismatch

[FEND-40.02.06.00-00190-00 / T]
The image-band suppression shall be 10 dB or better across the full IF band.

5.3. Cartridge IF power

5.3.1. IF output power

[FEND-40.02.06.00-00200-00 / T]
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:

- The total power in the IF frequency range (specified in Section 4.3.3) must fall between -25 dBm to -31 dBm.
- The total power in the frequency range from 10 MHz to 18 GHz must be less than -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-40.02.06.00-00210-00 / T]
Within the IF band (as specified in Section 4.3.3), variations from the average IF power must be less than:

- 4.0 dB peak to peak in any 2 GHz portion of the IF band, as specified under Section 4.3.3 of this document.
- 6.0 dB peak to peak across the whole IF band. as specified under Section 4.3.3 of this document.

Measurements of the IF power variations shall use 100 MHz resolution.

5.4 Gain compression

[FEND-40.02.06.00-00230-00 / T]
The large signal gain compression caused by the exchange of RF load temperatures of 78 and 300K must be less than 5 %.

5.5 Amplitude stability

[FEND-40.02.06.00-00240-00 / T]

The IF amplitude stability, measured at the IF output connectors 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, $\sigma^2(2, T, 0.9*T)$, of the IF output power in the IF band (specified in sections 5.3.1 and 4.3.3) must be less than 4.0×10^{-7} for timescales between 0.1 and one second and 8.0 × 10-5 at 100 seconds.
- The Allan variance of the difference of the output IF powers of the two polarization channels (differential polarization variance) shall be less than 5.5×10^{-7} for T in the range from 0.1 to 1.0 second and 1.1×10^{-4} at 100 seconds.

Note that this amplitude stability must be achieved when using the first local oscillator chain as supplied by the ALMA project.

5.6 Signal path phase stability

[FEND-40.02.06.00-00250-00 / T]
For all frequencies within the IF pass-band the signal path transfer function shall maintain a phase stability of better than 0.5 degrees on timescales up to 300 seconds. 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 three degrees.

5.7 Optics

5.7.1 RF beam efficiency

[FEND-40.02.06.00-00260-00 / T]
The fraction of the cartridge radiation pattern that is coupled to the sub-reflector must be 90% or greater. The edge taper should be 10.5 dB.

5.7.2 Polarization alignment

[FEND-40.02.06.00-00270-00 / 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-40.02.06.00-00280-00 / T]
At the RF input of the cartridge the alignment between the orientation of the E vector of both of the polarization channels and the ideal polarization alignment (as specified in 5.7.2) must be better than two degrees.

5.7.4 Cross-Polarization

[FEND-40.02.06.00-00290-00 / 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. This requirement must be met for any orientation of the E-vector of the incident radiation and any angle within the solid angle of the main beam towards the secondary reflector.

5.8 Stabilization time

5.8.1 Stabilization time from non-operational mode

[FEND-40.02.06.00-00300-00 / T]
The transition from the non-operational to the operational mode shall take no more than 15 minutes.

5.8.2 Stabilization time from stand-by mode

[FEND-40.02.06.00-00305-00 / T]
The transition from the stand-by mode to the operational mode shall take no more than 1.5 seconds.

6. MECHANICAL AND ELECTRICAL REQUIREMENTS

6.1. Mass

[FEND-40.02.06.00-00310-00 / T]
The mass of all band 6 cartridge components (but excluding the cartridge body itself and the warm cartridge assembly) must not exceed 2 kg. Details can be found in the applicable Interface Control Document [AD2].

6.2. Eigen-frequency

[FEND-40.02.06.00-00320-00 / A,R]
The band 6 cartridge shall have a first eigen-frequency of 70 Hz or greater.

6.3. Volume

[FEND-40.02.06.00-00330-00 / I]
The band 6 cartridge components described in section 2.1 shall be contained within a volume of ∅140 mm x 475 mm, measured from the cartridge-mounting flange. Details can be found in the applicable Interface Control Document [AD2]

6.4. Orientation

[FEND-40.02.06.00-00340-00 / 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. Flexure of components mounted on the cartridge-body shall not cause the cartridge beam coupling efficiency to vary by more than 2 % over the same range.

6.5. Thermal Load

[FEND-40.02.06.00-00350-00 / A]

During operation or start-up the maximum allowable thermal load to be imposed on the cryostat by the cartridge is given in [AD2].

6.6. Bias requirements

[FEND-40.02.06.00-00360-00 / R]

Details can be found in the applicable Interface Control Document [AD3].

6.7. Connectors and RF ports

6.7.1. RF Input port interface

[FEND-40.02.06.00-00370-00 / R]

The RF input port of the cartridge shall comply with the requirements as described in section 4.2.3. of [RD1]

6.7.2. LO Input port interface

[FEND-40.02.06.00-00380-00 / R, I]

The mixer LO input ports shall comply with the applicable Interface Control Document [AD5].

6.7.3. IF Output port interface

[FEND-40.02.06.00-00390-00 / R, I]

All IF output ports shall be coaxial, details can be found in the applicable Interface Control Document [AD4].

6.7.4. Bias Connectors

[FEND-40.02.06.00-00400-00 / R, I]

Details for the bias connector (s) can be found in the applicable Interface Control Document [AD3].

7. OPERATING REQUIREMENTS

7.1. Local Oscillator

For further details see [AD 05]

7.1.1. LO Input Port

[FEND-40.02.06.00-00420-00 / T]

The LO frequency range of the local-oscillator signal is 221 GHz to 265 GHz.

7.1.2. LO Power Requirement

[FEND-40.02.06.00-00430-00 / A,T]
Refer to relevant ICD (Band 6 Cartridge to 1st LO [AD-5])

7.1.3. LO Sideband and Phase Noise

[FEND-40.02.06.00-00440-00 / T]
Refer to relevant ICD (Band 6 Cartridge to 1st LO [AD-5])

7.1.4. LO Amplitude Stability

[FEND-40.02.06.00-00450-00 / T]
Refer to relevant ICD (Band 6 Cartridge to 1st LO [AD-5])

7.2. Thermal Environment

[FEND-40.02.06.00-00460-00 / T]
(Note that this subsection only applies to the operational mode.)

Refer to relevant ICD (Band 6 Cartridge to Cryostat [AD-2])

An operating cartridge must be able to withstand an increase in temperature to ambient (20 C) over a period of TBD minutes without damage.

7.3. Vacuum conditions

[FEND-40.02.06.00-00470-00 / R]
(Note that this subsection does not apply to any of the transport or storage modes)
All specifications shall be met in a vacuum environment. Any out-gassing of cartridge components or leaking of hermetic feed-throughs shall be compatible with the ALMA vacuum requirements for cryostat [AD8].

7.4. Environmental operating conditions

7.4.1. Vibration

[FEND-40.02.06.00-00480-00 /R, T]
The band 6 cartridge must survive vibration levels as specified in Appendix 1 of [AD7]. The vertical direction being defined as perpendicular to the cartridge baseplate.

7.4.2. Acceleration

[FEND-40.02.06.00-00490-00 / R, T]
The band 6 cartridge alone, with no shipping container, must survive the following accelerations:

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

The vertical direction being defined as perpendicular to the cartridge baseplate.

Shock tests using a shaker table should include a half-sine or sawtooth waveform, and an 11 – 23 ms time duration. Tests are repeated 3 times along each principle axis.

7.5. Storage and shipping conditions

[FEND-40.02.06.00-00500-00 / R]
(Note that this section only applies to the storage mode)
The band 6 cartridge must comply with [AD7].

7.6. Electro-Magnetic Compatibility

[FEND-40.02.06.00-00510-00 / T]
The band 6 cartridge must comply with [AD6].

7.7. Monitoring and control

(Note that this section does not apply to the storage mode.)

7.7.1. Mixer Voltages and Currents

[FEND-40.02.06.00-00520-00 / R]
The mixer voltages and currents must be monitored as stated in [AD3]

7.7.2. Magnet Currents

[FEND-40.02.06.00-00530-00 / R]
If required by the mixer design, the currents flowing in the suppression magnet must be monitored, see [AD3]

7.7.3. Temperature

[FEND-40.02.06.00-00540-00 / R]
Temperature sensors must be provided at critical points of all temperature stages, see [AD3].

7.7.4. Removal of Trapped Flux

[FEND-40.02.06.00-00550-00 / R]
Means shall be provided to remove flux trapped in the SIS junctions.

8. RELIABILITY REQUIREMENTS

8.1. Continuous operation

[FEND-40.02.06.00-00560-00 / R]
The cartridge shall be designed for continuous use. It shall not require any periodic maintenance.

8.2. Mean time to failure

[FEND-40.02.06.00-00570-00 / A]
The MTBF of the cartridge shall exceed 20 years.

8.3. Lifetime

[FEND-40.02.06.00-00580-00 / R]
The Band 6 cartridge shall have a minimum lifetime of 15 years.