ALMA SPECIFICATION

Specifications for the

ALMA Front End Assembly

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Distribution:
(to team managers, division heads, WP managers and chairpersons of the following groups for further distribution as appropriate):

ALMA Executive Committee

ALMA Joint Receiver Design Group

ALMA Receiver Optics Group

ALMA Dewar Group

ALMA Cryocooler Group

ALMA Mixer Groups

ALMA Local Oscillator Group

ALMA Science Groups

ALMA System Groups

ALMA Scientific Advisory Committee

Change record

Issue	Date	By	Affected paragraphs	Reason/remarks
N/A	21 Apr 2000	D'Addario	All	Specifications adopted by US Division Heads
draft 1.1	11 May 2000	Wild/Payne	All	First document release
draft 1.4	31 Aug 2000	Wild/Payne	1.2 3.1	Definition of FE subsystem Band 3 down to 84 GHz proposed
1.0	18 Oct 2000	Wild/Payne		Approved by AEC
1.0	11 Dec 2000	Wild/Payne	3.13	No cold load calibration, added appendix with TBD items
2.0	25 Apr 2001	Lamb/Payne/ Wild + JRDG	3.1 3.1 3.2.1 3.2.2 3.5 3.7 3.14 4.9 4.10 4.11	Band 3 down to 84 GHz Moved input device type to 4.9 Nominal polarization is linear Changed max non-orthogonality to cross-polarization, added measurement method Simplified mixer options to DSB and 2SB WVR simultaneously with all bands Added reference to WVR specs New: Band device type (from 3.1) New: Operational aspects New: Bias electronics

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1 Introduction

1.2 General

This document describes the specifications for the ALMA front end subsystem. Its first version is based on the document *ALMA Receivers: Specifications adopted* (by U.S. Division Heads), written by L. D'Addario. We distinguish between science driven specifications and engineering specifications as follows:

- **Science driven specifications**: these are the specifications which have immediate influence on the scientific capabilities of ALMA, such as frequency bands, IF b/w, noise temp, stability etc. These specifications are of concern to the future scientific users of ALMA, and a change would affect the scientific goals of ALMA.
- **Engineering specifications**: they describe details of the front end subsystem which have no direct influence on the scientific capabilities but are important engineering specs. Examples are IF interface specs (e.g. power level), breakdown of noise contributions, cool down time etc. A necessary change would not affect the scientific capabilities of ALMA. In any case, changes with an influence on interfaces will be discussed with and must be approved by the relevant groups.

1.2 Definition of the front end assembly

The front end (FE) assembly accepts the focused beam from the antenna's secondary reflector over a selected band of frequencies. It amplifies and converts this band to an intermediate frequency band in several channels (typically differing in polarization and/or sideband), and delivers the IF signals as outputs. It accepts as inputs local oscillator reference signals at the appropriate frequencies and levels to generate the local oscillator signal for conversion. The front end assembly includes:

- RF optics as required to couple the subreflector beam to its first electronic element.
- Mixers and amplifiers of the RF-IF signal path (separately for each band required to cover the overall frequency range), including any components needed to couple the LO signal to each mixer.
- Local oscillator components within the cryostat and associated hardware. The interface between the LO subsystem and the Front End subsystem is at the waveguide input to the warm multiplier assembly at a frequency of around 100 GHz. Each cartridge will have its own interface to the LO sub system. The interface will be specified in detail in a corresponding ICD.
- Vacuum system and cryocoolers needed to achieve the appropriate operating temperatures for certain components, along with related thermal insulation and mechanical supports.
- Bias and control circuits to support the RF-IF amplifiers and mixers.
- Devices to select the desired frequency, including IF band switching and any required tuning or adjustment of amplifiers and mixers as a function of frequency.
- A monitor/control system allowing remote control of all functions and providing extensive remote diagnosis capability, with an appropriate interface to the general ALMA monitor and control bus. The implementation of such a system will be decided between the front-end, systems and software groups and corresponding ICDs developed.
- A water-vapor monitoring radiometer.
- Devices that are placed directly in the input beam of the receiver and which include (but are not limited to) calibration systems, insertable components such as quarter wave plates for circular polarisation, and attenuators for solar observations.

It does not include the following elements, which belong to other subsystems:

- the local oscillator subsystem up to the agreed interface (see ICD),
- general power supplies (which are part of the common infrastructure), and
- calibration devices located outside the receiver cabin (including any built into the subreflector).

1.3 Definition of terms

- **Front end assembly**: this is the front end subsystem as defined in 1.2 . It provides space for 10 cartridges (see below).
- **Band**: this is the range of RF frequencies which is received in dual linear polarization and defined in Table 1.
- **Frequency channel**: this is one receiving chain which receives one polarization within the specified band. A band has two channels.
- **Cartridge**: a device insertable into the main dewar, receiving RF frequencies within one specified band in dual polarization, containing optics, mixers, IF amplifiers, LO components. Receives the RF from external optics, accepts an LO signal at TBD frequency and power, and delivers IF signals.
- **ICD:** Interface Control Document. The document which specifies interfaces between subsystems and parts within a subsystem.

2 Document references

2.1 Applicable documents

The following documents form part of this specification document to the extent specified herein. In the case of conflict between documents referenced herein and the contents of this specification, the content of the specification shall be considered a superseding requirement.

- ALMA Construction Project Book
- Antenna/Receiver ICD No. 1
- Antenna/Receiver Cabin Equipment Rack ICD No. 10
- ALMA Front End Optics Design: ALMA Memo no. 362 (see http://www.alma.nrao.edu/memos/html-memos/alma362/memo362.pdf).
- WVR specs: ALMA Memo no. 352 (see *http://www.alma.nrao.edu/memos/html-memos/alma352/memo352.pdf*).
- System PDR report
- Front End/Local Oscillator ICD (to be written)
- Front End/IF system ICD (to be written)

2.2 Reference documents

- ALMA memos, see *http://www.alma.nrao.edu/memos/* or *http://www.eso.org:8082/memos/*
- Reports of the Joint Receiver Design Group (JRDG), see *http://www.eso.org:8082/committees/jrdg/index.html* or *http://www.alma.nrao.edu/committees/jrdg/*

- Reports of the ALMA Scientific Advisory Committee (ASAC), see *http://www.eso.org:8082/committees/ASAC/index.html* or *http://www.alma.nrao.edu/committees/ASAC/*
- Review Reports: Antenna PDR, Antenna CDR, Multiplier LO PDR, Photonic System PDR (available at *http://www.alma.nrao.edu/administration/index.html*)

3 Science driven specifications

3.1 Frequency coverage

The ALMA front end subsystem will cover frequencies between 30 GHz and 950 GHz as given in Table 1.

Table 1: Frequency bands for ALMA

Band	from (GHz)	to (GHz)
1	31.3	45
2	67	90
3	84	116
4	125	163
5	163	211
6	211	275
7	275	370
8	385	500
9	602	720
10	787	950

3.2 Polarization

3.2.1 Polarization states

Simultaneous reception of two orthogonal polarizations is required, with each converted to (one or more) separate IF output(s). The nominal polarization states shall be linear.

Detailed specifications on polarization performance are under study and TBD.

3.2.2 Maximum cross-polarization

At any frequency within the front end's tuning range, the polarization states of the two channels should conform to a maximum cross-polarization of -20 dB, measured at the optical entrance to the front end subsystem. The cross-polarization shall be determined using hot and cold loads with a grid (or a series of grids).

3.2.3 Maximum polarization mismatch

The front end contribution to the maximum polarization mismatch between any pair of antennas in the array shall not exceed -20 dB.

3.3 Optical coupling to the telescope

The optical coupling of each front end channel to the telescope shall be maximized. Details can be found in ALMA memo no. 362.

3.4 Receiver noise performance

[Note: The noise temperatures in this section need to be revised in view of the noise contribution of the optics, see ALMA memo no. 362.]

The noise temperature measured at the dewar input window to the cartridge shall not exceed the values of T(SSB) for SSB response and 0.5 x T(SSB) for DSB response as given in Table 2. Specifications and goals are given. The first number of the specifications and goals, respectively, refers to T(SSB) that must not be exceeded over the 80% range of the nominal bandwidth that has the best performance, whereas the second value may not be exceeded at any frequency within the nominal bandwidth.

Table 2: Specifications and goals for receiver noise temperatures

Band	Freq (GHz)	Specification		Goal	
		T(SSB) over 80%	T(SSB) at any freq	T(SSB) over 80%	T(SSB) at any freq
1	31.3 – 45	15 K	23 K	10 K	14 K
2	67 – 90	28 K	43 K	16 K	24 K
3	84 – 116	34 K	54 K	19 K	29 K
4	125 – 163	47 K	76 K	26 K	40 K
5	163 – 211	60 K	98 K	32 K	51 K
6	211 – 275	77 K	126 K	40 K	65 K
7	275 –370	133 K	198 K	69 K	133 K
8	385 – 500	181 K	270 K	93 K	181 K
9	602 – 720	335 K	500 K	202 K	301 K
10	787 – 950	438 K	655 K	351 K	525 K

Following an ASAC recommendation the values in Table 2 were calculated with 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 center frequency of a particular band. The frequency dependent quantity A has the following specification and values (over 80% / at any freq):

Bands 1-6 (below 275 GHz)	Spec: A = 6 / 10	Goal: A = 3 / 5
Bands 7-8 (275-500 GHz)	Spec: A = 8 / 12	Goal: A = 4 / 8
Band 9 (602-720 GHz)	Spec: A = 10 / 15	Goal: A = 6 / 9
Band 10 (787-950 GHz)	Spec: A = 10 / 15	Goal: A = 8 / 12

[detailed break down of noise contributions within cartridge (optics, mixer, IF amps, LO): TBD]
[how to measure the noise temperature: TBD]

3.5 Sidebands

Each frequency channel may be double sideband (DSB), or sideband separating (2SB) with one sideband supplied per polarization. An attempt shall be made to optimize the overall sensitivity for both spectral line and continuum observations. 2SB channels shall provide at least 10 dB image band suppression.

3.6 IF bandwidth

The ALMA IF system and IF transport from each antenna to the correlator are designed for an IF bandwidth of 8 GHz per polarization and two polarizations (i.e. a maximum of 16 GHz IF per antenna). Each frequency channel shall provide 8 GHz total IF bandwidth (per polarization) using one of the following alternatives:

- 8 GHz single-sideband (SSB), upper or lower sideband, or
- 8 GHz double-sideband (DSB), or
- 4 GHz dual-sideband (2SB), upper and lower sideband.

Sideband separation in the correlator for DSB mode will be possible for integration times in multiples of 1 sec. Detailed IF interface specifications are contained in the corresponding ICD.

3.7 Simultaneous operation of bands

Astronomical observations will be done in only one frequency band at any one time (no dual frequency observations). The water-vapor monitoring radiometer shall operate simultaneously with any of the observing bands.

In order to allow fast phase switching, band 3 shall be ready for operation at all times.

3.8 Selection of a (pre-set) observing band

Selection and operation of a pre-set (i.e. switched on and tuned) observing band shall be possible in less than 1.5 sec. This provides support for fast phase-switching and switching to another (pre-set) observing band. The reselection of a particular frequency band at a particular antenna shall result in pointing errors not to exceed 0.2" and in phase changes not to exceed (TBD).

3.9 Selection of new observing band

Switching to a new observing band shall be possible in less than 1.5 sec if the electronics of this particular observing band has been switched on the time t_{warmup} before using the band. t_{warmup} shall not exceed 15 min, and a much shorter time is desirable. This is to reach thermal equilibrium and maximum stability. In practice, t_{warmup} may be much shorter, but is not known at this time.

(Note: Since due to cryogenic limitations not all bands can be switched on at all times. This spec was introduced to minimize the impact on scheduling. It is intended to have at least three bands (two observing bands and band 3) plus the WVR switched on at any one time.)

3.10 Narrow-band frequency switching

Changing between two frequencies within .03% of each other (30 MHz at 100 GHz, 285 MHz at 950 GHz) and in the same band shall require no more than 10 msec (goal of 1 msec). This provides support for narrow-band frequency switching.

3.11 Frequency changes within a band

Changing between frequencies more than .03% apart and in the same band shall not require more than 5 sec.

3.12 Receiver stability

Specifications on receiver phase stability and total power gain stability (including 1/f noise) are under study and TBD. These are in addition to, and independent of, stability specifications imposed on the LO and on the antenna structure. Preliminary suggestions for gain fluctuation limits are: 1e-4 rms over a 1 sec interval (ASAC report, March 2000), and 1e-4 rms over a 0.1 sec interval (Wright, ALMA memo # 289). A complete specification should give the limit as a function of time interval over a wide range.

3.13 Receiver calibration

The front end shall not include a cold load for calibration.

Further specifications on overall calibration concepts are under study by several groups and TBD (U.S. Calibration & Imaging group, European Observational Concept & Calibration group, receiver WBS 4.8.1: Receiver calibration system). The specifications for the front end calibration accuracy (as part of the overall calibration requirements) need to be seen in the context of a system wide calibration concept and strategy. In any case, front end calibration will be supplied in terms of Volts output per degree input and is for the front end assembly only (not including atmospheric calibration).

In any case, an effort shall be made to reach the best receiver calibration accuracy possible.

3.14 Water vapour radiometer

The front end shall include a radiometer for measurement of water vapor along the signal path, using the 183 GHz line. This instrument shall operate simultaneously with the selected astronomy band illuminating the subreflector so as to produce a beam on the sky that is offset from that of an astronomy channel by no more than 10 arcmin. It must include all necessary LO sources and signal processing.

Detailed specifications and a technical description for the water vapour radiometer can be found in ALMA Memo no. 352, (http://www.alma.nrao.edu/memos/html-memos/alma352/memo352.pdf).

3.15 Solar observing and safety

No components shall be damaged if the receiver input is illuminated by 0.3 W/cm^2 of solar optical and infrared radiation. Provisions shall be taken to allow observations of the sun.

4 Engineering specifications

4.1 IF system

4.1.1 IF interface

The IF shall be delivered in the range from 4 to 12 GHz, at a nominal power spectral density of [TBD, tentatively -30] dBm/GHz when the antenna temperature at the receiver input is 290 K. There will be four such signals to support 2SB, dual-polarization receivers; SSB or DSB receivers will use only two of them. If the instantaneous bandwidth B of one IF channel is 4GHz<B<=8 GHz, the center frequency should be 8.0 GHz; if B=4.0 GHz, then the center frequency should be 6.0 or 10.0 GHz. More detailed specs will be part of an ICD.

4.1.2 IF passband ripple

TBD, FE-IF ICD

4.1.3 IF selection switch

- to be written -

[4.2 – Not used]

4.3 Local oscillator

4.3.1 Interface front end subsystem - LO subsystem

The interface between the local oscillator subsystem and the front end subsystem is at the waveguide input to the warm multiplier assembly. Details are to be specified in a corresponding ICD.

4.3.2 LO range and power

LO tuning range, min. output power vs. frequency

[4.4 – Not used]

4.5 Optics

See ALMA Memo no. 362.

4.6 Dewar size and mass

The maximum size and mass of the dewar as well as mechanical interfaces with the antenna are specified in ICD #1 Antenna/Receiver interface.

4.7 Cryocooling

- temp stages: 4 K, 12-15 K, and 70 K
- stability for each stage: 4K: <2 mK in 1 min (TBC), 12-15 K: under study and TBD
  70 K: <0.5 K in 1 min (TBC)
- max thermal load for each stage: under study and TBD
- max thermal load for each cartridge: under study and TBD
- operational requirements:
  - # of bands switched on: min 3 + WVR
  - what mounted where:
    4K: cartridge optics, SIS mixers, first IF amps
    12-15K: second IF amps, HFETs (bands 1 and 2, possibly 3)
    70K: LO multipliers or photomixer
  - dewar cooldown time: max 24 h. goal of 6 to 12 h]

4.8 Packaging

All components specific to one band shall be packaged into an assembly (called "cartridge") that can be removed and tested separately from the others, except that it may be broken into two assemblies, one for the cryogenically cooled components and one for the room temperature components. Components common to several or all bands, or similar among bands (e.g., bias circuits), shall be packaged in their own removable assemblies.

Exception: Large optical components for one band may be mounted separately from that band's removable assembly if necessary to allow easy removal.

The complete front end package, including components for all bands but not necessarily including some mechanical components (cryocooler compressors, vacuum pumps, etc.), shall be removable from the antenna without major disassembly. Its mass, size, center of gravity etc. shall conform to the Antenna/Receiver ICD.

4.9 Band device type

The ALMA front end bands shall use the following input device types:

Band	from (GHz)	to (GHz)	Input device type
1	31.3	45	HFET amplifier
2	67	90	HFET amplifier
3	84	116	SIS mixer
4	125	163	SIS mixer
5	163	211	SIS mixer
6	211	275	SIS mixer
7	275	370	SIS mixer

8	385	500	SIS mixer
9	602	720	SIS mixer
10	787	950	SIS mixer

4.10 Operational aspects

No change of receiver cartridges is foreseen at the antenna.

The time between a power cut to the front end subassembly and resuming normal operation shall not be longer than TBD.

4.11 Bias electronics

The SIS mixer bias and amplifier bias shall employ standard and identical circuitry for all cartridges as much as possible. Details of the bias circuitry are TBD.

Appendix A: TBD items

3.2.1 Polarization states: Detailed specifications on polarization performance are under study and TBD.

3.4 Receiver noise performance: [detailed break down of noise contributions within cartridge (optics, mixer, IF amps, LO): TBD]

3.4 Receiver noise performance: how to measure the noise temperature: TBD

3.8 Selection of a (pre-set) observing band: Reselection of a particular frequency band at a particular antenna shall result in ... phase changes not to exceed (TBD).

3.12 Receiver stability: Specifications on receiver phase stability and total power gain stability (including 1/f noise) are under study and TBD.

3.13 Receiver calibration: Specifications on overall calibration concepts are under study by several groups and TBD.

4.1 IF interface: nominal IF power spectral density of [TBD, tentatively -30] dBm/GHz when the antenna temperature at the receiver input is 290 K.

[4.2 IF passband ripple] TBD, FE-IF ICD

[4.3 LO range, power and noise] LO tuning range TBD, min. output power vs. frequency TBD, max. noise TBD

[4.4 LO interface] At the feed through to dewar at a frequency of (TBD) and a power level of (TBD).

[4.5 Optics] Beam quality, alignment tolerances etc under study and TBD

4.7 Cryocooling:
- stability for each stage: 4K: <2 mK in 1 min (TBC), 12-15 K under study and TBD, 70 K: < 0.5 K in 1 min (TBC)
- max thermal load for each stage: under study and TBD
- max thermal load for each cartridge: under study and TBD

4.10 Operational aspects: time between power cut and normal operation TBD

4.11 Bias electronics: Details of circuitry TBD

Scientific Drivers for SSB/DSB Receiver Operation

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Abstract

The ASAC recommended in the report of its February meeting that "a careful assessment of the cost/performance tradeoff for SSB vs DSB operation of the receivers and their consequences for the IF subsystem and correlator should be undertaken in the next few months." Using assumptions in ALMA Memo no. 304, we show that for any reasonable mix of continuum and interferometer observations with ALMA at a number of receiver bands, SSB operation provides the most cost-effective means of achieving sensitivity.

1 Introduction

The ASAC recommended in the report of its February meeting that "a careful assessment of the cost/performance tradeoff for SSB vs DSB operation of the receivers and their consequences for the IF subsystem and correlator should be undertaken in the next few months."

In ALMA Memo No. 304, Thompson and D'Addario show that the sensitivity ratio $S_s sb/S_d sb$ with perfect image rejection is the same in total power and interferometer mode for a spectral line source, but a factor of root two greater for a continuum source observed in interferometer mode than in total power mode. This plethora of factors complicates comparison of observational tradeoffs for ALMA.

In general, Thompson and D'Addario found that SSB provides better sensitivity for spectral line observations, particularly at higher frequencies, and that DSB operation provides better sensitivity for continuum observations. They evaluate sensitivity ratios in their Table 4.

2 Advantages of DSB or SSB Operation

At present, the preferred mode of operation of ALMA is 2SB, a single sideband mode whereby both sidebands are recovered. What would be the observational consequences of DSB as a preferred mode? Clearly, if all ALMA observations were continuum, DSB should be the preferred mode. Suppose ALMA is to satisfy N observing proposals. In fact, at a frequency ν we let f represent the fraction of time which ALMA spends doing continuum experiments, so that 1-f is the fraction of time spent doing line experiments. Furthermore, assume purely interferometric observations. We can evaluate what value of f results in equal performance for the 2SB and DSB ALMA using the numbers in ALMA Memo No. 304. For the DSB ALMA, the fN continuum programs will be accomplished faster by an amount $\frac{S_{dsb}}{S_{ssb}}^2 = A_C^2$ where the factor is drawn from the memo. The two arrays are equal when

$$f = \frac{A_C^2 - \frac{A_C^2}{A_L^2}}{1 - \frac{A_C^2}{A_L^2}} \tag{1}$$

and for more than 53% of the time spent satisfying continuum proposals, ALMA observing would be better satisfied by employing DSB receivers. For reference, the VLBA experience shows that fN $\sim$ 0.67 for instance. For most arrays, and for ALMA in particular, we expect f to be much less than 0.53, for the weather conditions cited in the memo, and for Band 6. In the high submillimeter bands 9 and 10, f=0.96; there is a strong preference for these receivers to operate in SSB mode.

For a power gain ratio between sidebands defined as in Memo No. 304 ρ=0.1 these numbers drop to .24 and .76 for bands 6 and 9/10, respectively.

For total power observations, the fractions are 0.36 and 0.62 for the 1.3mm and deep submillimeter bands, respectively. For the case of ρ=0.1 they are 0.17 and 0.52. Thus, as the mix of total power observations increases, the advantage of SSB receivers drops but as long as continuum observations occupy less than 1752

We conclude that for any ALMA operation in which continuum observations comprise more than 95% of observing time, DSB operation might be preferred. However, if line observations dominate, SSB operation is preferred except possibly for the case of ρ=0.1 and observations at millimeter wavelengths. SSB operation is still preferred for these observations unless the continuum fraction is greater than about one quarter of the mix.

We conclude that from a viewpoint of gaining the best sensitivity for ALMA, SSB operation is to be preferred. However, if the expense of obtaining this were prohibitive, one might still prefer to operate ALMA in DSB mode. We next examine the costs of achieving SSB performance on ALMA.

3 Cost Effectiveness of DSB or SSB Operation

ALMA has new numbers for receiver costs, though they have not been blessed by the Front End Division Heads. I estimate the cost of a DSB receiver by using the costing for Band 7 used there. I estimate the cost of a 2SB receiver by using the costing for Band 6. I have estimates of the cost differential for the LO and backend also, which is nil in comparison. This gives the cost advantage per band of 2SB vs DSB in about as accurate a way as I can imagine. ($2M cheaper for DSB, with a hefty error bar on this).

Thus, we have dollars for each case and sensitivity estimates for each case. We can compare for instance the cost of gaining the sensitivity we would need to match DSB line observations to SSB line observations in terms of, for instance, added collecting area. If the mix of continuum observations is, say 5any fraction of total power observations, an SSB ALMA finishes a given project in 33To attain the same sensitivity increase with collecting area would cost roughly $65M at 225 GHz and roughly $163M at 650 GHz. If the mix of continuum observations were say 25$108M, respectively.

I conclude that we are better off gaining the sensitivity through deploying SSB receivers. Building them is another question of course!