First Local Oscillator Driver for Band 10 Technical Specifications

FEND-40.10.10.00-001-A-SPE

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1 Introduction

The Atacama Large Millimeter/submillimeter Array (ALMA), an international astronomy facility, is a partnership of East Asia, Europe and North America in cooperation with the Republic of Chile. ALMA is funded in East Asia by the National Institutes of Natural Sciences (NINS) of Japan in cooperation with the Academia Sinica (AS) in Taiwan, in Europe by the European Organization for Astronomical Research in the Southern Hemisphere (ESO) and in North America by the U.S. National Science Foundation (NSF) in cooperation with the National Research Council of Canada (NRC) and the National Science Council of Taiwan (NSC). ALMA construction and operations are led on behalf of East Asia by the National Astronomical Observatory of Japan (NAOJ), on behalf of Europe by ESO and on behalf of North America by the National Radio Astronomy Observatory (NRAO), which is managed by Associated Universities, Inc. (AUI).

ALMA will be located in the Altiplano of northern Chile at an elevation of 5000 meters above sea level. The ALMA site is the highest, permanent, astronomical observing site in the world. On this remote site super-conducting receivers that are cryogenically cooled to less than 4 degrees above absolute zero will operate on each the sixty-four 12-meter diameter antennas.

The Band 10 local oscillator driver provides local oscillator power for the Band 10 cartridge and is comprised of the following components integrated into an assembly: YIG tuned oscillator, integrated active multiplier chain, phase lock module, monitor and control/power module, support structure, waveguides and wiring harness.

The North American ALMA Project Office (NAAPO) is responsible for the delivery of North American work-packages to the ALMA project. Within the NRAO, the North American Front-end Group (NAFEG) is responsible for the delivery of the Band 10 local oscillator driver to the NAAPO.

1.1 Purpose

This document details the specifications and requirements for the ALMA Band 10 first local oscillator driver.

1.2 Scope

The following product tree items are covered by this document:
40.11.10.00 Band 10 Warm Cartridge Assembly (WCA)
40.10.10.00 Band 10 First Local Oscillator Driver (LO)
The product tree is described in [RD2].

Note that the scope of this document does not extend to the local oscillator reference photo-mixer or its bias supply, or to the cold frequency multiplier.

1.3 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	ALMA Doc. Number
[AD1]	ICD: Band 10 cartridge – Band 10 local oscillator driver	FEND-40.02.10.00-40.10.10.00-A-ICD
[AD2]	ICD: WCA connector plate and FE-WCA Harness Plate	FEND-40.11.00.00-40.04.00.00-A-ICD
[AD3]	ICD: Front-end assembly monitor and control – First local oscillator	FEND-40.04.03.03-007-A-DSN
[AD4]	ICD: Front-end first local oscillator – Back End LO and time reference	ALMA-40.10.00.00-56.03.00.00-A-ICD
[AD5]	ICD: Cartridges – Warm cartridge assembly	FEND-40.02.00.00-40.11.00.00-A-ICD
[AD6]	ALMA System: Electromagnetic Compatibility Requirements	ALMA-80.05.01.00-001-B-SPE
[AD7]	ALMA Environmental Specification	ALMA-80.05.02.00-001-B-SPE

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.

1.4 Reference documents

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

Reference	Document Title	ALMA Doc. Number
[RD1]	Statement of Work for the Band 10 Cartridge Support Equipment (NRAO)	ALMAJ-FE-B10-08013-C-SOW
[RD2]	ALMA Product Tree	ALMA-80.03.00.00-001-M-LIS

1.5 Acronyms

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

ALMA Atacama Large Millimeter Array
AM Amplitude Modulation
AMC Active Multiplier Chain
EMC Electromagnetic Compatibility
ESO European Southern Observatory
FE Front-End
FLOOG First Local Oscillator Offset Generator
ICD Interface Control Document
IF Intermediate Frequency

IPT	Integrated Product Team
LO	Local Oscillator
M&C	Monitor & Control
MMIC	Monolithic Microwave Integrated Circuit
MTTF	Mean Time To Failures
NAAPO	North American ALMA Project Office
NAFEG	North American Front-end Group
NAOJ	National Astronomical Observatory of Japan
NRAO	National Radio Astronomy Observatory
PA	Power Amplifier
PDR	Preliminary Design Review
PLL	Phase Locked Loop
RF	Radio Frequency
WCA	Warm Cartridge Assembly
YTO	YIG Tuned Oscillator

1.6 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 discretionary.

1.7 Requirements numbering

The requirements are numbered according to the following code:
[FEND-40.10.10.00-XXXXX-YY / Z]

Where:

FEND-40.10.10.00 identifies the ‘Front-end /Local oscillator/Band 10’ 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.

Details of the verification methods are contained in the Band 10 local oscillator driver acceptance test plan.

2 Description

2.1 Equipment Definition

The Band 10 first local oscillator driver components that were mentioned in the introduction are located within the Band 10 warm cartridge assembly (WCA) that bolts directly onto the bottom of the Band 10 cartridge. The Band 10 first LO driver consists of a YIG tuned oscillator (YTO) operating at 14.7–17.4 GHz followed by an integrated multi-chip assembly of frequency

multipliers, amplifiers, filters, and mixers. This active multiplier chain (AMC) produces a millimeter-wave output at the desired frequency which is then split into two channels and further amplified by the power amplifier (PA). The power available at the two outputs is controlled by varying the bias voltage on the MMICs in the PA. To phase lock the local oscillator chain a fraction of the LO power is split off within the AMC and mixed with a millimeter-wave reference provided by a photo-mixer. The resulting IF signal and a 20-45 MHz signal from the FLOOG are compared in a digital PLL. The PLL correction signal is sent to the YTO, closing the phase-locked loop. The control and power signals to the YTO, PLL, AMC, and photo-mixer come from, or are routed through the LO controller module which also resides in the WCA. The desired frequency is set by applying the appropriate reference signal (via the photomixer) and then sweeping the YTO under software control unit phase-lock is acquired to the desired sideband above or below the reference by a frequency offset controlled by the FLOOG setting.

2.2 Block Diagram

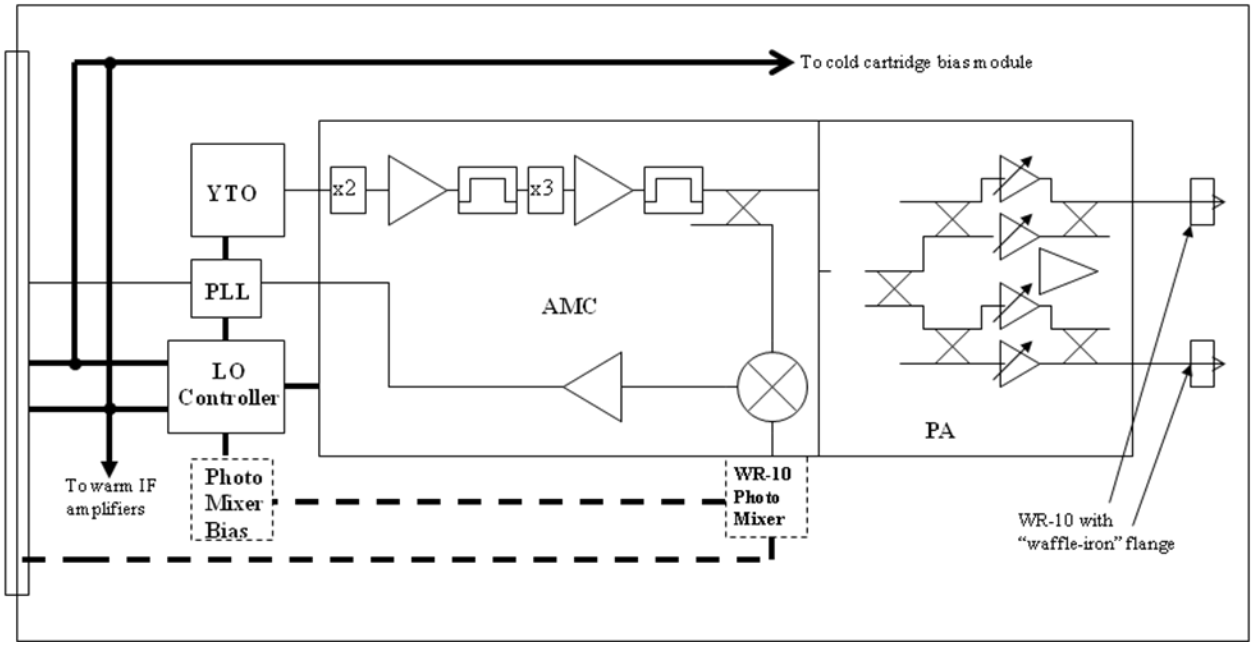

Figure 1 - Block diagram for the Band 10 First LO driver assembly[1].

3 General Requirements

3.1 Operation modes

The Band 10 local oscillator driver will be used in the following modes.

[1] Back-end components essential to the operation of the ALMA system but not covered by this document are shown with dashed lines.

3.1.1 Operational

[FEND-40.10.10.00-00010-00 / 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-40.10.10.00-00020-00 / I]
This mode applies when electrical power is not applied to the Band 10 local oscillator driver.

3.1.3 Stand-by

[FEND-40.10.10.00-00030-00 / I]
This mode applies when electrical power is applied to the Band 10 local oscillator driver but the optical and FLOOG reference signal levels are not at their nominal values.

3.1.4 Transport with the antenna or service vehicle

[FEND-40.10.10.00-00040-00 / I]
This mode applies when the Band 10 local oscillator driver, integrated into the front-end sub-system, is transported with the antenna on the antenna transport vehicle or in the front-end service vehicle.

3.2 Compatibility with the ALMA front-end sub-system

[FEND-40.10.10.00-00050-00 / I]
The Band 10 local oscillator driver design shall be compatible with other parts of the ALMA front-end sub-system. Details are given in the applicable ICDs [AD1 – AD5].

3.3 Design for production

3.3.1 Technology

[FEND-40.10.10.00-00060-00 / R]
The Band 10 local oscillator driver design should use mature technologies whenever possible.

3.3.2 Series production

[FEND-40.10.10.00-00070-00 / R]
The Band 10 local oscillator driver design should be compatible with low production and assembly costs. The design should be as simple as possible.

3.3.3 Standard parts

[FEND-40.10.10.00-00080-00 / R]
Standard, unmodified commercially available components should be used in the Band 10 local oscillator driver whenever possible.

3.4 Mechanical tuning

[FEND-40.10.10.00-0090-00 / R]
Operation of the Band 10 local oscillator driver shall not require the use of mechanical tuners.

3.5 Metric dimensioning

[FEND-40.10.10.00-00100-00 / R]
In general, metric dimensioning shall be used in the Band 10 local oscillator driver. 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.

3.6 Monitor and control

3.6.1 Remotely controlled functions

It shall be possible to control the following functions of the Band 10 local oscillator driver via the front-end local oscillator monitor and control system:

3.6.1.1 Set frequency

[FEND-40.10.10.00-00110-00 / T]
This control shall be executed via digital control bits to set the coarse tune coil on the YTO. See [AD3].

3.6.1.2 Sweep to acquire lock

[FEND-40.10.10.00-00120-00 / T]
This shall be a software function based on other remotely executable functions as described in [AD3].

3.6.1.3 Set Loop Gain

[FEND-40.10.10.00-00132-00 / T]
This control shall be executed via digital control bits to set the appropriate loop gain depending on the multiplication factor in the AMC of the band selected. See [AD3]. This is only applicable to the LO drivers incorporating the “digital” PLL circuitry as well as the integrated M&C and “digital” PLL circuitry.

3.6.1.4 Zero Integrator

[FEND-40.10.10.00-00134-00 / T]
This control shall be executed via digital control bit to open the loop and dump/zero the loop filter. See [AD3]. This is only applicable to the LO drivers incorporating the "digital" PLL circuitry as well as the integrated M&C and "digital" PLL circuitry.

3.6.1.5 Set power level

[FEND-40.10.10.00-00140-00 / T]
This output power level shall be adjusted by programming the driver amplifier drain bias voltages in the power amplifier sub-assembly.

3.6.2 Operating parameters to be monitored

The following operating parameters of the Band 10 local oscillator driver shall be monitored via the front-end local oscillator monitor and control system:

3.6.2.1 PLL IF power

[FEND-40.10.10.00-00150-00 / T]
This shall be derived from the output voltage level of the IF total power detector. The detected voltage, suitably amplified and buffered, shall be available to the front-end first local oscillator monitor and control system as an analog monitor point. See [AD3]. This monitored value will be used in conjunction with the quadrature phase detector voltage to assess whether the PLL is locked to the reference signals.

3.6.2.2 PLL reference signal power

[FEND-40.10.10.00-00160-00 / T]
This shall be derived from the output voltage level of the FLOOG total power detector. The detected voltage, suitably amplified and buffered, shall be available to the front-end first local oscillator monitor and control system as an analog monitor point. See [AD3].

3.6.2.3 PLL +5 V power

[FEND-40.10.10.00-00170-00 / T]
This voltage shall be monitored as an analog monitor point. See [AD3]. This monitor point is not applicable to the LO drivers incorporating the integrated M&C and "digital" PLL circuitry.

3.6.2.4 PLL temperature

[FEND-40.10.10.00-00180-00 / T]
The buffered sensor voltage shall be monitored as an analog monitor point. See [AD3].

3.6.2.5 AMC amplifier gate and drain voltages

[FEND-40.10.10.00-00190-00 / T]
This voltage shall be monitored as an analog monitor point. See [AD3].

3.6.2.6 AMC amplifier drain currents

[FEND-40.10.10.00-00200-00 / T]
This shall be calculated from measurements of the voltage drop across a known resistor inserted in series. The voltage shall be monitored as an analog monitor point.

3.6.2.7 AMC tripler bias voltage

[FEND-40.10.10.00-00210-00 / T]
This voltage shall be monitored as an analog monitor point. See [AD3].

3.6.2.8 AMC +5 V

[FEND-40.10.10.00-00220-00 / T]
This voltage shall be monitored as an analog monitor point. See [AD3].

3.6.2.9 AMC -3 V

[FEND-40.10.10.00-00225-00 / T]
This voltage shall be monitored as an analog monitor point. See [AD3]. This monitor point is not applicable to the LO drivers incorporating the integrated M&C and "digital" PLL circuitry.

3.6.2.10 PLL correction voltage

[FEND-40.10.10.00-00230-00 / T]
This voltage shall be monitored as an analog monitor point. See [AD3].

3.6.2.11 Quadrature phase detector voltage

[FEND-40.10.10.00-00240-00 / T]
This voltage shall be monitored as an analog monitor point. See [AD3]. This monitor point is not applicable to the LO drivers incorporating the "digital" PLL circuitry.

3.6.2.12 PA -3 V

[FEND-40.10.10.00-00250-00 / T]
This voltage shall be monitored as an analog monitor point. See [AD3].

3.6.2.13 PA +5 V

[FEND-40.10.10.00-00260-00 / T]
This voltage shall be monitored as an analog monitor point. See [AD3].

3.6.2.14 PA gate and drain voltages

[FEND-40.10.10.00-00270-00 / T]
This voltage shall be monitored as an analog monitor point. See [AD3].

3.6.2.15 PA drain currents

[FEND-40.10.10.00-00280-00 / T]

This shall be calculated from measurements of the voltage drop across a known resistor inserted in series. The voltage shall be monitored as an analog monitor point.

3.7 Channels

[FEND-40.10.10.00-00290-00 / R]

The Band 10 local oscillator driver shall service both Band 10 channels.

3.8 Mass

[FEND-40.10.10.00-00300-00 / T]

The mass of all Band 10 local oscillator driver components and their support structure shall not exceed 5 kg. Details can be found in the applicable Interface Control Document [AD1].

3.9 Eigen-frequency

[FEND-40.10.10.00-00310-00 / A]

The Band 10 local oscillator driver assembly shall have a first Eigen frequency of 30 Hz or greater.

3.10 Volume

[FEND-40.10.10.00-00320-00 / I]

The Band 10 local oscillator driver components described in section 2.1 shall be contained within a volume of ∅140 mm x 400 mm, measured from the cartridge 300K plate to the top of the WCA assembly. Note that this does not include the harness plate or allowance for cable clearance. Further details can be found in the applicable Interface Control Document [AD5].

3.11 Orientation

[FEND-40.10.10.00-00330-00 / A, R, T]

The Band 10 local oscillator driver 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.

3.12 Thermal Load

[FEND-40.10.10.00-00340-00 / A]

During operation the maximum allowable thermal load imposed on the cryostat by the local oscillator driver during operation or stand-by is detailed in [AD5].

3.13 First local oscillator reference signal requirements

[FEND-40.10.10.00-00350-00 / R]

Details can be found in the applicable Interface Control Document [AD4].

3.14 DC Power requirements

[FEND-40.10.10.00-00360-00 / R]

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

3.15 Connectors and RF ports

3.15.1 First local oscillator reference input port

[FEND-40.10.10.00-00370-00 / R, I]
The LO reference input port shall be rectangular waveguide.
Details can be found in the applicable Interface Control Document [AD4].

3.15.2 First local oscillator driver output RF ports

[FEND-40.10.10.00-00380-00 / R, I]
Both RF output ports shall be waveguide, the flanges being UG-387 modified to include a non-contacting design. Details can be found in the applicable Interface Control Document [AD5].

3.15.3 First local oscillator offset generator input port

[FEND-40.10.10.00-00390-00 / R, I]
Details can be found in the applicable Interface Control Document [AD4].

3.15.3 DC bias connectors

[FEND-40.10.10.00-00400-00 / R, I]
Details for the bias connector(s) can be found in the applicable Interface Control Document [AD2].

4 Performance requirements

4.1 Output tuning range

[FEND-40.02.07.00-00410-00 / T]
The Band 10 local oscillator driver output shall tune from a frequency of 88.3 to 104.7 GHz inclusive.

4.2 Output power

[FEND-40.10.10.00-00420-00 / T]
At all frequencies specified in section 4.1, the output power of either channel shall be adjustable from 20 mW to 60 mW in less than 0.5 dB steps for the frequency range of 88.3 GHz to <98 GHz, and from 20mW to 80 mW in less than 0.5 dB steps from 98 GHz to 104.7 GHz.

4.3 Stability of output power

[FEND-40.10.10.00-00430-00 / T]
The Allan variance, $\sigma^2(2, T, 0.9*T)$, of the Band 10 first local oscillator output power shall be less than 9.0×10^{-8} for $0.05\ s \leq T \leq 100\ s$ and less than 1.0×10^{-6} for $T = 300\ s$.

4.4 Sideband noise

[FEND-40.10.10.00-00440-00 / T]

The AM sideband noise to signal ratio on the output signal of the Band 10 local oscillator driver shall not exceed 20 K/μW at any LO frequency in the specified frequency range when averaged over the full specified IF band (4-12 GHz).

4.5 Phase stability

[FEND-40.10.10.00-00460-00 / A, R, T]

The short term phase stability ($T < 1$ s) of the phase locked Band 10 first local oscillator output signal shall be less than 38 fs. The long-term phase stability ($20 \text{ s} \leq T \leq 300$ s) shall be less than 12.5 fs. The long term phase stability (delay drift) requirement refers to the 2-point standard deviation with a fixed averaging time, τ, of 10 seconds and intervals, T, between 20 and 300 seconds. Note that these specifications apply to the first local oscillator alone and do not include a contribution from the reference signal.

4.6 Spurious signals

[FEND-40.10.10.00-00470-00 / R, T]

Spurious Signals (coherent or incoherent) on the outputs of the LO drivers in the WCAs shall be < -40 dBc over the range of offset frequencies from the carrier from 500 Hz to 500 kHz and < -50 dBc from 500 kHz to 12 GHz. The components harmonically related to the YTO frequency shall not exceed -20 dBc.

4.7 Stabilization time

4.9.1 Stabilization time from non-operational mode

[FEND-40.10.10.00-00480-00 / T]

The transition from the non-operational to the operational mode shall take no longer than 15 minutes.

4.9.2 Stabilization time from stand-by mode

[FEND-40.10.10.00-00490-00 / T]

The transition from the stand-by mode to the operational mode shall take no longer than 1.5 seconds.

4.8 Phase locking

[FEND-40.10.10.00-00500-00 / T]

The Band 10 first local oscillator driver shall reliably phase lock within 1 second to the first local oscillator reference signal over the tuning range and output power as specified in sections 4.1 and 4.2, and without phase ambiguity in any of the LO outputs.

4.9 Time to phase-switch

[FEND-40.10.10.00-00505-00 / R, T]

The Band 10 first local oscillator hardware shall be designed so that it could be configured to phase-switch (90º or 180º) and reach within 60° of the final phase in 1 μs.

4.10 Time for frequency-switching

[FEND-40.10.10.00-00506-00 / R, T]

The Band 10 first local oscillator driver hardware shall be designed so that it could be configured to track frequency changes resulting from a frequency change of the FLOOG signal or the reference laser signals of 25 MHz within 10 ms.

4.11 Isolation between channels

[FEND-40.10.10.00-00507-00 / R, A]

The isolation between the two channels of the Band 10 first local oscillator driver shall be better than 10 dB.

5 Operating Conditions

5.1 Thermal Environment

[FEND-40.10.10.00-00510-00 / A, R, T]

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

The Band 10 local oscillator driver shall meet its performance requirements with an air flow of 15 l s^{-1} or greater across the unit, in a thermal environment whose temperature is maintained in the 16 – 22 ºC range and in which the maximum temperature variation is 1 ºC in one hour.

5.2 Vibration

[FEND-40.10.10.00-00520-00 /R, T]

The Band 10 local oscillator driver must survive vibration levels as specified in Appendix 1 of [AD7]. The vertical direction is defined as being perpendicular to the 300 K plate at the bottom of the cryostat.

5.3 Acceleration

[FEND-40.10.10.00-00530-00 / R, T]

The Band 10 local oscillator driver must survive the following:

3 g shock load in the vertical direction.

2 g shock load in the horizontal direction.

The vertical direction is defined as being perpendicular to the 300 K plate at the bottom of the cryostat.

5.4 Storage and shipping

[FEND-40.10.10.00-00540-00 / R]

(Note that this section only applies to the storage mode)

The Band 10 local oscillator driver must comply with [AD7].

5.5 Electro-Magnetic Compatibility

[FEND-40.10.10.00-00550-00 / R]

The Band 10 local oscillator driver must comply with [AD6].

6 Reliability Requirements

6.1 Continuous operation

[FEND-40.10.10.00-00560-00 / R]

The Band 10 local oscillator driver shall be designed for continuous use.

6.2 Mean time to failure

[FEND-40.10.10.00-00570-00 / A]

The calculated MTTF of the Band 10 local oscillator driver shall exceed 45 years.

6.3 Mean time to repair

[FEND-40.10.10.00-00580-00 / A]

At the ALMA operational support facility the mean time to repair of the Band 10 local oscillator driver shall be less than eight hours.

6.4 Lifetime

[FEND-40.10.10.00-00590-00 / R]

The Band 10 local oscillator driver shall have a minimum lifetime of 15 years. The Band 10 local oscillator driver shall not need routine maintenance but may be serviced once every 5 years to replace power amplifiers close to the end of their projected lifetime.