Atacama
Large
Millimeter
Array

Technical Requirements for the Back End Subsystem

ALMA-50.00.00.00-092-C-SPE

Version: C

Status: Released

2018-12-06

Prepared By:	**Organization**	**Signature**
W. Brundage	NRAO	2011-08-01
IET Leader Approvals:	**Organization**	**Signature**
E. Ford	NRAO	Ephraim Ford Digitally signed by Ephraim Ford Date: 2018.12.17 13:29:03 -07'00'
K. Saini	NRAO	Kamaljeet Saini 2019.01.11 11:13:48 -05'00'
S. Rossi	ESO	Silvio Rossi 2019.01.15 16:17:25 +01'00'
S. Asayama	NAOJ	S. Asayama
System Engineering/Science Approvals:	**Organization**	**Signature**
N. Whyborn	JAO	Digitally signed
J. Carpenter	JAO	John Carpenter 2019.03.01 16:13:08 -04'00'
Configuration Control Board Approval:	**Organization**	**Signature**
Release:	**Organization**	**Signature**
S. Corder	**JAO**	Stuartt Corder Digitally signed by Stuartt Corder DN: cn=Stuartt Corder, o=National Radio Astronomy Observatory, ou=ALMA ADO, email=scorder@alma.cl, c=CL Date: 2019.06.10

Change Record

Version	Date	Affected Section(s)	Change Request #	Reason/Initiation/Remarks
A-2	2005-06-06	All		Second draft with major revisions based on replies in DAR.
A-3	2006-03-01	Many		Third draft with text revisions for typos & clarity (especially delay drift, noise, Allan deviation). Changed values in Table 4, 5.28, 5.31, 5.39. Added 5.6, 5.10.1, 5.49, 5.50, 5.51. Deleted Walsh function.
A-4	2006-06-02	Many		Allocated drift and noise down the 1st LO, 2nd & 3rd LO chains. Simplified & clarified contents of each requirement. Replaced finder table with summary table. Corrected Fig. 1. Deleted excessive quotes from AD1. Revised requirements per Version B of AD1 (2006-05-05) in CRE.
A-5	2006-09-29	Many		Revised requirements per Version B of AD1 (2006-09-20) in CRE and clarified text. Significant changes in 3.3, 100, 164, 227, 261, 262, 264, 273, 425, 431, 432, 435, 450, 451n, 452n, 619, 910. Added 461, 920, 930, 940.
A-6	2006-11-10	3.3, 4, 5.45.n, 5.46.n, 5.71		Corrected inconsistencies and errors. Improved clarity. Added 5.71.
A-7	2007-02-07	Many 2.1.1 2.1.2 5.2 5.25 5.32 5.61 5.64, 5.65 5.69 5.61 5.71		Replaced BE system with BE subsystem. Added AD16. Added RD20. Added references to AD16, RD17, RD18. Added limits IF to BB feed-thru & images. Clarified digitizer variable phase steps. Clarified with deferral to ICDs with CIPT. Clarified. Added placeholders for RFI emission and susceptibility limits of operational racks of equipment. Simplified & clarified. Corrected and clarified. Added Tables 10 and 11.
A-8	2007-02-22	Table 3 5.22 5.46.5 5.61 5.71		Change value of 06190 to <15 min. Add verification comment. Change 0.1 to 1 sec. Clarify. Add two LVDS requirements.

Version	Date	Affected Section(s)	Change Request #	Reason/Initiation/Remarks
A9	2007-03-22	Table 3 5.1 5.2 5.30 #323 5.55 #490 5.64 #618 5.69 #930		Corrected typos & changes. Added BE articles. Clarified header. Corrected req. Corrected req. Added CLO LRUs not in common mode LO. Corrected req.
A10	2007-04-12	3.2, 3.2.1, 3.2.2, Table 3, 5.5, 5.6, 5.70		Corrected per reply 164.35 by Fabio Marchet
B	2008-03-14	Many	ALMA-50.00.00.00-128-A-CRE, ALMA-54.04.01.00-001-A-CRE, ALMA-54.05.00.00-017-A-CRE, [AD1]	Corrections and clarifications prompted by experience with tests of Antenna Article, review of AD1 notes and review of this doc.
B	2009-01-26	Many	2009-01-26-ALMA-50.00.00.00-152-A-CRE	Additional clarifications prompted by more experience and many queries.
B	2009-02-20	2.1.1, 2.1.2, Table 3, 5.60, 5.72	2009-02-20-ALMA-50.00.00.00-152-A-CRE	Add environmental conditions and references.
B	2009-08-24	Table 3, Req. 261, 292, 295, 431, 456, 614, 617, 950; Sec 3.3	2009-08-24-ALMA-50.00.00.00-152-A-CRE	Clarifications, especially settling time of gain changes in band/position switching phase-cal mode. Removed procedure for calculating Allan Std. Dev.(Sec 3.3) to another document.
B	2009-08-27	5.71	2009-08-26-ALMA-50.00.00.00-152-A-CRE	Change RS485 to RS422.
B	2009-11-17	Table 3, Req 263 and Sec 5.16	2009-11-17-ALMA-50.00.00.00-152-A-CRE	Correct and clarify Req. 02630.
C	2011-08-01	Table 3, Req 261, 262, 263, 264; 452 _	ALMA-50.00.00.00-nnn-A-CRE; ALMA-56.11.00.00-024-CRE	Change ASDg(2,T,τ) to ASDg(2,T,τ=T); Change Band 1 phase noise. Minor clarifications.
C	2018-12-06	Cover page		Signature matrix updated, for release of this version

Table of Contents

List of Tables

List of Figures

1 Description

1.1 Purpose

This document gives the technical requirements for the electronics subsystem produced by the Back End (BE) Integrated Product Team (IPT). These technical requirements flow down from the ALMA System Technical Requirements given by **AD1**. This document, together with the BE external Interface Control Documents (ICDs) and BE internal ICDs, defines the specifications of the BE subsystem.

1.2 Scope

This document gives the requirements that flow down directly from **AD1**, ALMA System Technical Requirements for the 12m Array (ALMA-80.04.00.00-005-B-SPE), and shall be met by the BE subsystems for production. It does not include other BE requirements, such as those given in ICDs, nor those of project level or other documents that are not listed in Applicable Documents. These requirements shall assure the required implementation of the BE subsystems and their constituent products.

Requirements are allocated within the BE subsystems, and among the LRUs and the interconnects between LRUs, so that the total performance of all the BE electronics will be as good as or better than the total BE electronics allocations as given here and in **AD1**. In some cases, especially delay/phase errors, the partitioning of the requirements among the various BE subsystems is not well understood. The values stated are based on engineering judgment. The accuracy or appropriateness of the judgments can only be determined by testing in prototype integration by the System Engineering and Integration (SE&I) IPT and the Assembly, Integration and Verification (AIV) group. Future revisions of this document will consolidate the data from the system-level integration tests and will better reflect the actual performance and allocation of requirements.

Herein, BE subsystem electronics are defined as the IF processing subsystem (IFP), the signal data transmission subsystem (DTS), the local oscillator reference and timing subsystem (LOT), the photonic local oscillator reference subsystem (PLO) and the fiber optic transmission (FOT) subsystem, which are all the responsibility of the BE IPT. It does not include the first local oscillator (LO) subsystem, which is part of the Front End (FE) IPT.

The LOT timing subsystem establishes all of the time synchronization in the array. The LOT subsystem also provides the coherent frequencies necessary to convert the received signals at each antenna from RF to IF to baseband and for tuning these signals for frequency and phase. The second LO (LO2) tunes the IFP baseband channels across the IF frequency range from the FE. The DTS digitizes the baseband signals from the IFP, formats the data into serial bit streams, and transmits the data from each antenna to the array correlator. The ALMA System Design Description **[RD1]**, ALMA Back End Electronic Design Description **[RD2],** and

ALMA System Block Diagram **[RD3]** give more detailed descriptions of the ALMA and BE subsystems.

2 Related Documents

2.1 References

2.1.1 Applicable Documents

The documents listed in Table 1 are applicable to the BE technical requirements. The revision level is the most recent at the time this document was submitted for approval.

Table 1 Applicable Documents

Reference	Document Title	Document ID
AD1	ALMA System Technical Requirements for the 12m Array	ALMA-80.04.00.00-005-B-SPE (2006-09-21)
AD2	ALMA Safety Manual	ALMA-10.08.00.00-011-C-SPE
AD3	ALMA Policy Document on the Use of Metric and SI Units	ALMA-80.00.00.00-004-A-SPE
AD4	ALMA Documentation Standards (Sec. 6 Requirement Numbering)	ALMA-80.02.00.00-003-G-STD
AD5	ALMA Power Quality (Compatibility Levels) Specifications	ALMA-80.05.00.00-001-C-SPE
AD6	Standard for AC Plugs, Sockets-outlets and Couplers	ALMA-80.05.00.00-004-B-STD
AD7	ALMA System Electrical Design Requirements	ALMA-80.05.00.00-005-C-SPE
AD8	ALMA System Electromagnetic Compatibility (EMC) Requirements	ALMA-80.05.01.00-001-B-SPE
AD9	Embedded Software Standards	ALMA-70.20.00.00-008-A-STD
AD10	ALMA Monitor and Control Bus AMBSI2 Standard Interface Design Description	ALMA-70.35.10.02-001-D-MAN
AD11	ALMA Monitor and Control Bus Interface Specification	ALMA-70.35.10.03-001-B-SPE
AD12	Back End Product Assurance Requirements	BEND-50.00.00.00-079-B-PRO
AD13	Back End Configuration Item Numbers and Product Tree	BEND-50.00.00.00-084-F-LIS
AD14	Back End Configuration Item and Documentation Numbering	BEND-50.00.00.00-105-C-PLA
AD15	ALMA Environmental Specification	ALMA-80.05.02.00-001-B-SPE
AD16	ICD between Antenna Subsystem and Back End Subsystem	ALMA-34.00.00.00-50.00.00.00-C-ICD

Reference	Document Title	Document ID
AD17	Array Wide Sub-arraying	ALMA-50.00.00.00-128-A-CRE
AD18	Upgrade of the Pre-production DGCK Module Design	ALMA-53.04.01.00-001-A-CRE
AD19	Add 14 EDFA/Demux to Allow Correlation of the ACA Antennas with the ALMA-B Correlator	ALMA-54.05.00.00-017-A-CRE
AD20	Back End Procedure for Calculating Allan Standard Deviation $ASD_y(2,T,\tau)$	BEND-50.00.00.00-324-A-PRO

2.1.2 Reference Documents

Reference documents are listed in Table 2. These are useful references for understanding the requirements for BE subsystems and LRUs. Latest versions apply.

Table 2 Reference Documents

Reference	Document title	Document ID
RD1	ALMA System Design Description	SYSE-80.04.00.00-002-A-DSN
RD2	ALMA Backend Electronics Design Description	BEND-50.00.00.00-077-B-PLA
RD3	ALMA System Block Diagram	ALMA-80.04.01.00-094-P-DWG
RD4	ICD between Front End First Local Oscillator and Back End Photonic First LO Reference	ALMA-40.10.00.00-56.00.00.00-A-ICD
RD5	ICD between Front End / IF and Back End / IF Processor	ALMA-40.08.00.00-52.00.00.00-A-ICD
RD6	ICD from Back End to Correlator	ALMA-50.00.00.00-60.00.00.00-B-ICD
RD7	ICD from Back End to ACA Correlator	ALMA-50.00.00.00-62.00.00.00-A-ICD
RD8	Back End Electronics Design Guidelines	BEND-50.00.00.00-056-A-STD
RD9	RFI Limits for Back End Equipment at the AOSTB	BEND-50.00.00.00-061-B-SPE
RD10	Back End Reliability Plan	BEND-50.00.00.00-069-A-PLA
RD11	Estimated EMI Limits for Back End Equipment in an Antenna Cabin	BEND-50.00.00.00-099-A-REP
RD12	Verification and Acceptance Plan for the Back End Subsystem	ALMA-50.00.00.00-171-A-PLA
RD13	Internal ICD between IF Processor (IFP) LRU and Data Transmitter (DTX) LRU	BEND-52.00.00.00-53.08.00.00-B-ICD
RD14	Internal ICD between IF Processors and Second Local Oscillators	BEND-52.00.00.00-55.05.00.00-B-ICD

Reference	Document title	Document ID
RD15	Internal ICD between LORR/LORRD and LO2	BEND-55.04.00.00-55.05.00.00-B-ICD
RD16	ICD between Back End and AOS Computing Communication Equipment	ALMA-50.00.00.00-70.02.00.20-A-ICD
RD17	ICD between AOS Technical Building and Back End Central Equipment	ALMA-20.01.02.00-50.00.00.00-A-ICD
RD18	ICD between Site and AOS External Fiber System	ALMA-20.07.00.00-54.09.03.00-A-ICD
RD19	ALMA Subsystem Testing and Handover Guidelines	ALMA-80.00.00.00-008-A-PLA
RD20	AMB1 Wiring Description	BEND-57.02.02.05-001-A-DSN
RD21	Verification and Acceptance Procedures for Back End Electromagnetic Compatibility (EMC)	BEND-50.00.00.00-183-A-PRO
RD22	Verification and Acceptance Check List for Safety of BEND Electrical Equipment	BEND-50.00.00.00-182-A-LIS
RD23	Specifications for Shocks and Vibrations Analysis and Testing	ALMA-80.05.02.00.006-A-SPE
RD24	Seismic Design Specifications for ALMA-AOS and ALMA-OSF	SYSE-80.10.00.00-002-B-REP
RD25	Back End IPT North America Procedure for Shipping, Handling and Receiving`	BEND-50.00.00.00-140-A-PRO
RD26	Back End Antenna Article Environmental Specification	BEND-50.00.00.00-144-A-SPE

2.2 Abbreviations and Acronyms

Acronyms used in this document are listed below. Back End LRUs are designated as such along with their CIN/Product Tree (PT) number **AD13**. A set of acronyms used in the ALMA project can be found in EDM (http://edm.alma.cl) via the header tab “Acronyms.”

125RD	125 MHz Reference distributor, LRU, 55.09 in LOT subsystem
5RD	5 MHz Reference Distributor, LRU, 55.08 in LOT subsystem
AA	BE Antenna Article (analog and digital racks with LRUs, interconnects, FOW)
ABM	Antenna Bus Master computer in each antenna
AC	Alternating Current (as in electrical power)
ACA	ALMA Compact Array (Japanese array)
AIV	Assembly, Integration and Verification
ALMA	Atacama Large Millimeter Array
AMB	Antenna Monitor/control Bus
AMBSI	ALMA Monitor/control Bus Standard Interface

AOS	Array Operation Site
AOSTB	Array Operation Site Technical Building
A-RACK	Analog Rack, 57.02.02
ARTM	Array Real Time Machine (computer in AOSTB)
ASD	Allan Standard Deviation
ASD_y	Allan Standard Deviation of variable y
BB	Base Band or baseband
BE	Back End
BEND	Back End IPT
CCS	Computing Control Software
CIN	Configuration Item Number
CLOA	BE Central LO Article (MFS, CRG, CRD, PLO LRUs, interconnects & racks)
CRD	Central Reference Distributor, LRU, 55.02 in LO & Time subsystem
CRE	Change Request
CRG	Central Reference Generator, LRU, 55.03 in LO & Time subsystem
CVR	Central Variable Reference, LRU, 56.04 in PLO subsystem
DC	Direct Current
DGCK	Digitizer Clock, LRU, 53.04 in DTS subsystem
D-RACK	Digital Rack, 57.02.01
DRX	Data Receiver, LRU, 53.06 in DTS subsystem
DRXA	BE Data Receiver Article (DRX LRUs)
DTS	Data Transmission Subsystem
DTX	Data Transmitter, LRU, 53.08 in DTS subsystem
DWDM	Dense Wavelength-Division Multiplexer
EDFA	Erbium Doped Fiber Amplifier (optical amplifier)
EDM	Electronic Document Management (accessible via an ALMA server)
EMC	Electromagnetic Compatibility
EU	Europe
FE	Front End
FEND	Front End IPT
FLOOG	First LO Offset Generator, LRU, 55.07 in LOT subsystem
FOAD	Fiber Optic Amplifier & Demultiplexer, LRU, 54.05 in FOT subsystem
FOM	Fiber Optic DWDM Multiplexer, LRU, 54.02 in FOT subsystem
FOMA	BE Fiber Optic Management Article (external fiber, internal fiber, patch panel, FOAD and racks)
FOT	Fiber Optic Transmission Subsystem
FOW	Fiber On-axis Wraps, azimuth and elevation, LRU, 54.09.02
FTS	Fine Tuning Synthesizer assembly embedded in LO2 and in FLOOG LRUs
GPS	Global Positioning Satellite
GSa/sec	Giga samples per second
HVAC	Heating, Ventilating and Air Conditioning
ICD	Interface Control Document
IEEE	(was Institution of Electrical and Electronic Engineers)

IF	Intermediate Frequency
IFP	IF Processor, downconverter and total power digitizer & MC, LRU, 52.00 within IFPS
IFPS	IF Processor Subsystem, includes IFP and coax connecting to FE and DTX
IPT	Integrated Product Team
LFRD	Photonic Low Frequency Distributor, LRU, 56.06 in PLO subsystem
LLC	Line Length Corrector, LRU, 56.03 in PLO subsystem
LO	Local Oscillator
LO2	Second Local Oscillator, LRU, 55.05 in LOT subsystem
LORR	LO Reference Receiver, LRU, 55.04 in LOT subsystem
LORRD	LORR Reference Distributor, LRU, 55.10 in LOT subsystem
LOT	LO & Time Reference ($\leq$ 2 GHz) subsystem
LPR	Photonic Reference Receiver, LRU, 56.05 in PLO subsystem
LPRA	BE LO Photonic Receiver Article (LPR LRUs and photomixers)
LRU	Line Replaceable Unit, a module that, in the field, can be removed for repair
LS	Laser Synthesizer, production, LRU, 56.11 in PLO subsystem
LVDS	Low Voltage Differential Signal
M&C	Monitor and Control by Computing IPT
MFS	Master Frequency Standard, LRU, 55.01 in LOT subsystem
ML	Master Laser, production, LRU, 56.13 in PLO subsystem
MLD	Master Laser Distributor, LRU, 56.07 in PLO subsystem
MTBF	Mean Time Between Failures
NA	North America
NIST	National Institute of Standards and Technology
ODF	Optical Diplexer Filter, 1532/1557 nm
OSF	Operations Support Facility
PCB	Printed Circuit Board
PLL	Phase Lock Loop
PLO	Photonic LO 1st LO reference (> 2 GHz) subsystem
pps	pulse per second
PRD	Photonic Reference Distributor, LRU, 56.08 in PLO subsystem
PSA	Power Supply Analog rack 230 VAC / penta-voltage DC, LRU, 57.03.03
PSAD	Power Supply Analog Distributor, penta-voltage DC, LRU, 57.03.04
PSD	Power Supply Digital rack 230 VAC / 48VDC, LRU, 57.03.01
PT	Product Tree
RFI	Radio Frequency Interference
rms	root mean square
RSS	square Root of Sum of Squares
SAS	Subarray Switch, LRU, 56.09 in PLO subsystem
SE	System Engineering
SE&I	Systems Engineering and Integration
SNR	Signal to Noise Ratio
TBC	To Be Confirmed
TBD	To Be Determined

TE	Timing Event (leading edge of the 48 millisec timing pulse)
THD	Total Harmonic Distortion
VCO	Voltage Controlled Oscillator
VLBI	Very Long Baseline Interferometry

2.3 Requirements Numbering

The requirements within this document are numbered according to the following code per **AD4 Section 6**, Requirement Numbering:

BEND-XXXXX-YY/ZZZ

Where:

BEND stands for "Back End";

XXXXX is the consecutive number 00010, 00020,… (the nine intermediate numbers remaining available for future revisions of this document), where xyz > 100 of 0xyz0 corresponds to the requirement number of **AD1**;

YY describes the requirement revision and starts with 00;

ZZZ describes one or more verification methods, where:

1. A stands for analysis of subsystem or product
2. I stands for inspection of subsystem or product
3. R stands for review of design of subsystem or product
4. T stands for test of subsystem or product according to **AD12 and RD12**.

2.4 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.

2.5 Order of Precedence

In the event of conflict between the text of this document and applicable documents, the following order of precedence shall apply:

1. This document,
2. Applicable documents.

3 Definitions

3.1 Operational and Test (On) Modes

The Operational Mode identifies the state in which an antenna is actively engaged in observation. In the Operational Mode, all specifications and requirements in this document shall apply, unless otherwise stated. Test Mode is the same as Operational Mode, except the antenna may not be observing and valid data may not be available. The Operational or Test Modes are also termed "On" modes. **AD15** gives environmental conditions for this "On" mode.

3.2 Non-Operational (Off) Modes

The Non-Operational Mode for BE electronics identifies the state in which an antenna is not in an "On" mode. The Non-Operational Mode is also termed "Off" mode. The "Off" mode results in loss of data from one antenna or possibly the entire array. Operational requirements do not apply to the Non-Operational Modes. However, the electronics shall, without subsequent degradation of performance, survive environmental conditions such as vibration, shock, humidity, water, dust, temperature and earthquake **[AD15]**.

3.2.1 Transport Mode (Off) with the antenna or in a service vehicle

Transport Off Mode identifies the state in which the BE equipment is transported in an antenna on the antenna transport vehicle or by other service vehicle. Electrical power may or may not be available to the BE electronic equipment. **AD15** gives environmental conditions for this mode.

3.2.2 Shipping Mode (Off)

Shipping Off Mode identifies the state in which the BE equipment is shipped between the Operations Support Facility (OSF) and North America (NA) or Europe (EU) production or repair centers. During shipment, equipment is expected to experience environmental conditions as outlined in **AD15**. **AD12** gives general shipping, handling and storage information.

3.2.3 Storage Mode (Off)

In Storage "Off" Mode, the ALMA BE electronic modules may be stored completely assembled. **AD12** gives general shipping, handling and storage information.

3.3 Allan Standard Deviation $ASD_y(2,T)$and $ASD_y(2,T,\tau)$

The **AD1** and Back End definition, based on IEEE and NIST, for **2-point Allan Standard Deviation (ASD) of y (2,T) and (2,T,τ)** of a set of time domain measures of stability of y is given in **[AD20].**

4 Summary of Requirements and LRU Finder

Table 3 summarizes the BE technical requirements flowed down from **AD1** by number and value. It also lists the applicable LRUs by acronym to aid finding the requirements applicable to each LRU.

Table 3 Summary of Requirements and Applicable LRU(s)

Req. No.	Parameter	Value	Applicable LRU(s)
00010	Verification & acceptance	Compliance with applicable requirements of **AD12**	All
00020	On / Off modes in environmental conditions of **AD15**	Meet req. in ON mode in operational environment; survive OFF mode in non-operational conditions	All
00030	Electrical & electronic design requirements	Compliance with applicable requirements of **AD7**	All
01000	Number of antennas & modules	Equip 50 antennas in 12m array plus 16 ACA antennas [*design for future expansion to original 64 antennas in 12m array*]	5RD, DGCK, DTX, DRX, FLOOG, FOAD, FOT, FOW, IFPS, LFRD, LLC, LORR, LORRD, LO2, LPR, MLD, ODF, PRD, PSD, PSA, SAS
01640	Number of antenna stations for ACA	22 total: 18 for 7m antennas, 4 for total power 12m antennas	FOT
01650	Number of antenna stations for 12m array	175	FOT
02100	Frequency coverage of PLO tuning	Table 2 in **AD1** and Table 12 in **RD4**	CVR, LS, ML, LPR
02200	Signal path noise contribution	Add less than 1% to system noise temp; equivalent to SNR > 20dB	IFPS
02260	Cross coupling between polarization channels	< -60 dB coupling between polarization channels	DTX
02270	Signal and baseband total power dynamic range and gain compression	> 11 dB with less than 1 dB gain compression	IFP
02340	IF outputs from 2SB front end bands	USB and LSB FE outputs simultaneously	IFP
02400	IF frequency range	4 – 12 GHz	IFP
02500	Total IF bandwidth each of 2 polarizations	Tuning over 8 GHz of bandwidth in each polarization	IFP, LO2
02610	Gain stability $\Delta G/G$ from 1 to 100 sec, both signal path & baseband total power	$ASD_g(2,T) < 0.707E-3$ total for T = 1 to 100 sec	DTX, IFPS
02620	Gain stability $\Delta G/G$ at 300 sec, both signal path & baseband total power	$ASD_g(2,T) < 2.12E-3$ total for T = 300 sec	DTX, IFPS

Req. No.	Parameter	Value	Applicable LRU(s)
02630	Gain stability ΔG/G from 0.05 to 1.0 sec of baseband total power path in 4 antennas optimized for total power observations (ACA 12m)	$ASD_g(2,T) < 2.83E-4$ total for T = 0.05 to 1 sec	IFPS
02640	Differential gain & phase stability between polarization pairs	$ASD_g(2,T) < 0.707E-3$ for T = 0.05 to 300 sec and $ASD_\Phi(2,T,\tau) < 0.042$ deg phase total for T = 0.05 to 100 sec, τ = 0.05 sec and for T = 300 sec, τ = 10 sec	DTX, IFPS
02700	Shape of passband, each baseband channel	Anti-alias filter -20 dB at >1850 MHz and at < 4150 MHz; -40 dB at all freq < 1600 MHz and > 4400 MHz	IFP
02710	Effective passband bandwidth	Each baseband channel >1800 MHz	IFP
02720	Gain variation across baseband effective passband	≤ 3 dB peak-peak	DTX, IFPS
02730	Temporal change in effective passband shape	<-43 dB w.r.t. mean power within any 2 MHz bandwidth at 60 sec intervals, <-33 dB w.r.t. mean power within effective passband at 3600 sec intervals. See 5.21	DTX, IFPS
02750	Shape of baseband narrow passband	Differential variation between two antennas across any 31 MHz section of the operational baseband passband, under any tuning: <1.4 dB (p-p) gain and <6.4 degree phase (rms)	DTX, IFP
02900	Spurious signals, 1st & 2nd LO	Each <-43dBc from 380 Hz to 8 GHz offset from carrier	FLOOG, LO2
02920	Incoherent broad band spurious signals at IF & baseband	Total <-13 dB relative to system noise power in any 2 GHz bandwidth; note baseband harmonics aliased by DG	DTX, IFPS, LO2
02950	IF & baseband narrow band spurious signals	Total <-43 dB relative to system noise power in any 1 MHz bandwidth; note baseband harmonics aliased by DG	DTX, IFPS, LO2
03110	Digital signal transmission latency	Repeatable latency with no loss of samples	DRX, DTX, FOT
03120	Digital signal transmission errors	<1E-6 bit error rate	DRX, DTX, FOT
03210	Digitization bandwidth	Each DTX digitizes a polarization pair of baseband channels each 2 – 4 GHz	DTX

Req. No.	Parameter	Value	Applicable LRU(s)
03220	Digitization rate and levels	Each baseband signal digitized at 4 GSa/sec with 8 levels (3 bits) uniformly spaced	DGCK, DTX,
03230	Sampling clock fine delay	Variable phase for fine delay steps 1/16 sample	DGCK
03240	Sampling clock commonality	Common to all channels at an antenna	DGCK, DTX,
03250	Sampling clock synchronization	Synchronized with correlator to within 10 µsec	125RD, CRG, CRD, DGCK, DRX, DTX, FOT, FOW, LFRD, LLC, LORR, LORRD, ODF
04110	Tuning sky frequency to baseband	Place any sky frequency at any baseband frequency within ±200 MHz	LO2
04120	Tuning sky frequency to IF	Place any sky freq at any IF frequency ±400 MHz	CVR, FLOOG, LS
04200	Tunable subarrays	6 sub-arrays fully interchangeable between ACA and 12m array	125RD, 5RD, CRG, CVR, FOAD, LFRD, LS, MLD, PRD, SAS, fiber patch panel
04250	Switching time between subarrays	Limited by time to tune, reset, or reconfigure equipment	CVR, LS, SAS
04300	Intraband frequency tuning time	<1.5 sec over whole band	CVR, FLOOG, IFP, LO2, LPR, LS
04310	Interband frequency tuning time	<1.5 sec switching to any frequency in either of 2 FE bands in standby mode; note ΔG and ΔΦ in band/position switching phase-cal mode	CVR, FLOOG, IFP, LO2, LPR, LS
04320	Small frequency-shift switching	Within same FE band, <10 msec rise & fall up to 10 Hz rate for freq shift up to 25 MHz at FLOOG, spectral line total power mode only	FLOOG
04350	Band 3	Band 3 is always either in use or in standby. Note #04310.	CVR, LPR, LS
04410	Phase switching shifts in 1st LO	180 deg sign reversal after digitization. Switching rates 180 deg at 0.016 sec (TE/3), 90 deg at 2.048 sec (128*16msec)	DTX, FLOOG
04420	Rate of change of phase switching	1st LO phase change of 25 deg in < 1 µsec	FLOOG
04440	Phase switching synchronization	< 0.1 µsec between antennas, < 0.1 µsec within antenna, < 20 nsec relative delay among 8 baseband channels of antenna, < 1.0 µsec 180 deg sign reversal relative to correlator dump	CRD, CRG, DTX, FLOOG, LORR

Req. No.	Parameter	Value	Applicable LRU(s)
04500	Unambiguous phase of all frequency synthesis	Return to original phase & no change with tuning of LO phase difference between antennas (except non-VLBI LS & CVR)	FLOOG, LO2
04510	Delay and phase drift, $ASD_{\Phi}(2, T = 20 \text{ to } 300 \text{ sec}, \tau = 10 \text{ sec})$	ASD <4 fsec total through signal path, applied at 950 GHz, ASD <4 fsec total of 2nd LO and 3rd LO, applied at 950 GHz, ASD <13 fsec total BE contribution to 1st LO	See below.
04511	Delay & phase drift in BE signal path	ASD <1.37 deg from IF input to baseband output	IFPS
04512	Delay and phase drift in 2nd LO chain	See Table 4	FOT, FOW, LLC, LO2, LORR, LORRD, ODF
04513	Delay and phase drift in the 3rd LO chain	See Table 5	DGCK, FOT, FOW, LLC, LORR, LORRD, LPR, ODF
04514	Delay and phase drift in BE 1st LO chain	See Table 6	5RD, FLOOG, FOT, FOW, LFRD, LLC, LORR, LORRD, LPR, MLD, ODF, PRD, SAS
04515	Measurement of delay and phase drift	See BEND-04515-00/RT	5RD, DTX, FLOOG, FOT, FOW, IFP, LFRD, LLC, LO2, LORR, LORRD, LPR, LS, MLD, ODF, PRD, SAS
04516	Common mode drift in BE LO chains	See BEND-04516-00/RT	125RD, CRD, CRG, CVR, LS, MFS, ML
04520	Delay and phase noise at $\Delta f > 1$ Hz	<24 fsec rms total through signal path, applied at 950 GHz, <17 fsec rms total of 2nd LO and 3rd LO, applied at 950 GHz, <38 fsec rms total BE contribution to 1st LO, except 80 fsec for Band 1	See below.
04521	Delay and phase noise in BE signal path	<8.2 deg rms integrated 1 Hz to 1 MHz	IFPS, LO2, LORR
04522	Delay and phase noise in 2nd LO chain	See Table 7	FOT, FOW, LLC, LO2, LORR, LORRD, LPR, ODF
04523	Delay and phase noise in 3rd LO chain	See Table 8	DGCK, FOT, FOW, LLC, LORR, LORRD, ODF
04524	Delay and phase noise in BE 1st LO chain	See Table 9	5RD, FLOOG, FOT, FOW, LFRD, LLC, LORR, LORRD, LPR, MLD, ODF, PRD, SAS

Req. No.	Parameter	Value	Applicable LRU(s)
04525	Measurement of delay and phase noise in BE LO chains	See BEND-04525	5RD, FLOOG, FOT, FOW, LFRD, LLC, LO2, LORR, LORRD, LPR, MLD, ODF, PRD, SAS
04526	Common mode noise in BE LO chains	See BEND-04526	125RD, CRD, CRG, CVR, ML, MFS, ML
04540	System delay discontinuities	Operate > 1 hour without step discontinuities in system delay >10 fsec	FOT, LLC, LPR
04560	Antenna small angle motion, systematic delay errors	<4.6 fsec for az & el change of 2.0 deg; note Δdelay in band/position switching phase-cal mode	A-RACK, DGCK, D-RACK, DTX, FLOOG, FOM, FOW, IFPS, LLC, LO2, LORR, LORRD, LPR, ODF
04570	Antenna small angle motion, random delay errors	<8.6 fsec for az & el change of 2.0 deg	A-RACK, DGCK, D-RACK, DTX, FLOOG, FOM, FOW, IFPS, LLC, LO2, LORR, LORRD, LPR, ODF
04580	Antenna large angle motion, systematic delay error	<57 fsec rms for az change ± 180 deg, <29 fsec rms for el change ± 40 deg	A-RACK, DGCK, D-RACK, DTX, FLOOG, FOM, FOW, IFPS, LLC, LO2, LORR, LORRD, LPR, ODF
04590	Antenna large angle motion, random delay error	<18 fsec rms for full range of az & el	A-RACK, DGCK, D-RACK, DTX, FLOOG, FOM, FOW, IFPS, LLC, LO2, LORR, LORRD, LPR, ODF
04600	Common mode fractional frequency fluctuations for VLBI	$ASD_f(2, T = \tau = 1$ sec) < 1.4E-13, $ASD_f(2, T = \tau = 100$ sec) < 9.2E-15, $ASD_f(2, T = \tau = 1000$ sec) < 2.1E-15	125RD, 5RD, CRD, CRG, CVR, LS, ML
04610	Sub-array for VLBI	Minimum 1 sub-array for VLBI	125RD, 5RD, CRD, CRG, CVR, LS, ML
04700	Absolute frequency accuracy	< 1E-11	MFS
04900	RFI protection	Shielding effectiveness >20 dB to 12 GHz	All LRU containing frequencies ≥2 GHz at levels ≥ -20 dBm
04920	Fiber optic cable	Achieve all requirements with external fiber lengths up to 15 km	DRX, DTX, FOAD, FOT, FOW, LLC, LORR, LPR
05110	Baseband total power accuracy	<1 % of full scale after linearity correction	IFP
05120	Baseband total power sampling	Output data word interval 500 μsec at > 495 μsec effective integration time	IFP

Req. No.	Parameter	Value	Applicable LRU(s)
05130	IF total power	Used for FE IF gain setting and engineering, not for astronomy	IFP
06140	Monitor points	Sufficient monitor points to identify failures as quickly as possible	All LRUs containing an AMB node
06150	Monitor control of LRUs	Self identify at each AMB node	All LRUs containing an AMB node
06160	Monitor control availability	Available at all times during observations	All LRUs containing an AMB node
06170	Reliability of BE equipment	MTBF > 5 years for each LRU	All
06180	Restart without re-calibration	LRUs & subsystems restart without re-calibration beyond a simple phase calibration	5RD, DGCK, DRX, DTX, FLOOG, FOT, LFRD, LLC LO2, LORR, MLD, PRD
06190	Time to restart	<15 min to restart any LRU or subsystem	All LRUs
09000	Interchangeability of identical LRUs	Full functionality without manual intervention	All
09100	Power supplies and quality of 230VAC	Not susceptible to certain levels of conducted disturbances; **RD21**	PSD, PSA and any LRU using 230VAC
09200	Power distribution	Peak-peak noise to 20 MHz on DC power distributed to LRUs < 1% VDC	PSA, PSAD PSD, PSLLC, PSLLCD, PSSAS, PSSASD
09300	Electromagnetic compatibility	**AD8** to the extent practicable, **RD21**	Each rack
09400	Safety	Failsafe rack power shut-down on over-temperature; laser safety; **RD22**	Each rack, FOT
09500	TE distribution	Leading edge of pulse with 48 msec period	CRD and all LRUs using TE

5 Performance Requirements for Operational (On) Mode

5.1 Verification and acceptance of LRUs and articles [BEND-00010-00/AIRT]

The BE IPT, with assistance by the System Engineering (SE) IPT, shall verify during review and test that the delivered articles or products have complied with the requirements in this document. Production of all LRUs and articles shall comply with **AD12 and RD12**. Before transfer from BE to Systems Engineering AIV in Chile, and for acceptance by AIV, each BE article shall be verified or accepted at a BE center, or at the Operations Support Facility (OSF) or at the Array Operations Site (AOS). BE articles are defined as:

AA – antenna racks (analog and digital) with interconnects, LRUs and fiber on-axis wraps,
LPRA – deliverables to FEND: photo mixers (PM) and LO photonic receiver LRUs (LPRs),
DRXA – deliverables to correlator: data receiver LRUs (DRXs),

CLOA – central LO reference and central photonic LO racks with LRUs; installed at AOS,
FOMA – fiber optic management equipment; installed at AOS.

5.2 On / Off modes and environmental conditions [BEND-00020-00/ART]

All BE LRUs shall meet all performance requirements when in the Operational (On) Mode and for the applicable operational environmental conditions given in **AD15, AD16 and RD17**. Also see section 3.1 above. The most critical environmental factor for BE performance is temperature range and temporal stability of the air entering the BE equipment racks and surrounding certain inter-rack signal cables. Back End interprets relevant documentation to mean that the temporal rate of change of such air temperatures will be < 0.17 Kelvin / 300sec in both antenna receiver cabins and in the AOS Technical Building (AOSTB). Also, the in-ground fiber cable temperature environment will have a temporal rate of change < [TBD] Kelvin / 300 sec, although it will be greater for the optical fiber between the antenna pad fiber vault and its termination in the antenna cabin.

All BE LRUs shall survive the test (On) mode and all Off modes for the applicable environmental conditions given in **AD15**. Also see section 3 above.

5.3 Electrical and electronic design requirements [BEND-00030-00/RT]

All BE LRUs and other equipment will conform to **AD7**.

5.4 Number of antennas and modules [BEND-01000-00/R]

There shall be sufficient number of **LRUs in the IFPS, LOT, PLO and FOT subsystems** which operate in antennas and which supply LO and TE reference signals to each antenna to operate 50 antennas in the 12m array plus 16 antennas in the ACA **[AD1 Req. 100]**.

The **LOT, PLO and FOT subsystems** should design for future expansion to 80 antennas (64 in 12m array plus 16 ACA) with minimum cost in funds, personnel, time and disruption.

5.5 Number of antenna stations for ACA [BEND-01640-00/R]

The **FOT external and internal subsystems** shall provide for 22 antenna stations in the ALMA Compact Array (ACA); 18 stations for the 7 m antennas and 4 stations for the 4 total power 12m antennas **[AD1 Req. 164]**.

5.6 Number of antenna stations for 12m array [BEND-01650-00/R]

The **FOT external and internal fiber subsystems** shall provide for 175 antenna stations in the baseline 12m antenna array **[AD1 Req. 165]**. This number of stations may increase in the future.

The **FOT sub-subsystem (FOMA)** should design for future extension to 216 original antenna stations with minimum cost in funds, personnel, time and disruption.

5.7 Frequency coverage of PLO tuning [BEND-02100-00/RT]

LRUs **CVR, LS, ML and LPR** shall provide PLO 1st LO reference tuning as given in Table 2 in **AD1** and Table 12 in **RD4**. This requirement flows down from **AD1 Req. 210**. See also **BEND-04120-**.

5.8 Signal path noise contribution [BEND-02200-00/RT]

IFPS in the signal path shall contribute noise less than 1% of that delivered from the FE to the **IFPS** as given in **RD5** under any observing and calibration cycle **[AD1 Req. 220]**. See cycle in requirement **BEND-02270-**.

In other words, the signal to noise ratio (SNR) from **IFPS** inputs to the baseband outputs to the Data Transmitter (DTX) shall be > 20 dB, where the **IFPS** input IF signal levels are given in **RD5** and the output levels to the DTX are given in **RD13**. Here, the **IFP**S baseband output noise level is that with 50 ohm terminations at ~300K substituted for the IF input from the FE. Signal is the normal baseband output level to the DTX with the minimum IF input level from the FE **RD5**. Both noise and signal are measured with the same **IFP** gain. This also applies to the IFP baseband total power data.

5.9 Cross coupling between polarization channels [BEND-02260-00/RT]

The **DTX** shall provide <-60 dB coupling between polarization channels **[AD1 Req. 226]**.

5.10 Signal Dynamic range and gain compression [BEND-02270-00/RT]

LRU **IFP** shall provide throughput dynamic range > 11 dB with less than 1 dB gain compression **[AD1 Req. 227]** for any constant gain setting during an observing–calibration cycle. Such a cycle shall include and be constrained by:

- the two-temperature thermal calibration device,
- antenna position switching to calibration sources,
- FE output signal power range (13 dB) given in ICD **RD5,**
- IFP output power range to the DTX given in ICD **RD13** for interferometric observing.

Throughput is from IF outputs from the FE to baseband outputs to the DTX inputs and to the baseband total power detector output data to the ABM. Note that the SNR requirement **[BEND-02200-]** also applies to the above cycle.

5.11 IF outputs from 2SB FE bands [BEND-02340-00/RT]

The two LRU **IFPs** and four LRU **LO2s** in each antenna shall process both IF sidebands (USB and LSB) simultaneously **[AD1 Req. 234]** and in accordance with ICD **RD5** and with **AD1 Req. 233**.

As commanded by an antenna bus master (ABM) computer, each **IFP** shall be able to connect each of two baseband pairs to either IF sideband without blocking the other pair.

5.12 IF frequency range [BEND-02400-00/RT]

The LRUs **IFP** and **LO2** shall process the 4 – 12 GHz IF frequency range to baseband, nominally 2 – 4 GHz **[AD1 Req. 240]**.

5.13 Total IF bandwidth in each of two polarizations [BEND-02500-00/RT]

Each of the two LRU **IFP** and the four LRU **LO2** in each antenna shall provide tuning over 8 GHz of bandwidth in each of two polarizations **[AD1 Req. 250]**. One **IFP** shall process one polarization and the other **IFP** shall process the other polarization. Each **IFP** shall output 4 baseband channels of nominally 2-4 GHz each (8 GHz total bandwidth). Each **LO2** shall simultaneously tune corresponding **IFP** baseband channels of both polarizations across the 4-12 GHz IF range (**LO2** outputs nominally 8-14 GHz). All astronomical data paths (baseband channels) shall be in pairs of both polarizations with identical sky frequencies. See **RD1, RD2 and RD3**.

5.14 Gain stability ΔG/G from 1 to 100 second [BEND-02610-00/RT]

The **IFPS** shall contribute fractional gain stability **ΔG/G** as 2-point Allan standard deviation **$\mathbf{ASD_g(2,T)}$** < 6.1E-4, where T = range from 1 to 100 sec. Gain is that *from IF input to baseband digital output* <u>*and from IF input*</u> *to the baseband total power data* delivered by **IFP** to the ABM. Note that the **LO2** output power stability contributes to part of the **IFPS** requirement of **RD14**.

The **DTX** LRU shall contribute gain stability ΔG/G as 2-point Allan standard deviation **$\mathbf{ASD_g(2,T)}$** < 3.6E-4, where T = range from 1 to 100 sec.

See section 3.3 for the definition of **$\mathbf{ASD_g}$.**

Total BE requirement is < 0.707E-3 **[AD1 Req. 261]**. By RSS, 75% is allocated to **IFPS** and 25% to **DTX**. The total applies on each antenna to the combination of **IFPS** and **DTX** from the signal outputs of the front end **[RD5]** to the baseband digital data delivered to the correlator **[RD6]**.

Note that Req. 04310 and 04560 imply that this Req. should apply to ΔG/G settling time <1.5 sec in band/position switching phase-cal mode. Tests indicate that the IFP implementation achieves this within 1.5 sec only for single bit (0.5, 1, 2, 4, 16 dB) switching of the baseband attenuator. Analysis indicates that gain switching for this mode by single bits in both front end and IFP can be achieved via Computer Control Software (CCS) [TBC at AOS].

5.15 Gain stability ΔG/G at 300 seconds [BEND-02620-00/RT]

The **IFPS** shall contribute fractional gain stability ΔG/G as 2-point Allan standard deviation **$\mathbf{ASD_g(2,T)}$** < 1.84E-3, where T = 300 sec. Gain is that *from IF input to baseband digital* *output and from IF input to the baseband total power data* delivered by **IFP** to the ABM. Note that the **LO2** output power stability contributes to part of the **IFPS** requirement **[RD14].**

The **DTX** LRU shall contribute gain stability ΔG/G as 2-point Allan standard deviation **ASD_g(2,T,τ)** < 1.06E-4, where T = 300 sec and τ = 10sec.

See section 3.3 for the definition of **ASD_g**.

Total BE requirement is < 2.12E-3 **[AD1 Req. 262]**. By RSS, 75% is allocated to **IFPS** and 25% to **DTX**. The total applies on each antenna to the combination of **IFPS** and **DTX** from the signal outputs of the front end **[RD5]** to the baseband digital data delivered to the correlator **[RD6]**.

5.16 Gain stability ΔG/G for dedicated total power antennas (ACA 12m) [BEND-02630-00/RT]

The **IFPS** in the 4 total power antennas having nutating subreflectors (ACA 12m) shall contribute fractional gain stability ΔG/G as 2-point Allan standard deviation **ASD_g(2,T)** < 2.83E-4, where T = range 0.05 to 1 sec **[AD1 Req. 263]**. See section 3.3 for the definition of **ASD_g**. Gain is that *from IF output of the front end to the baseband total power data* delivered by **IFPS** to the ABM over Ethernet. Note that the **LO2** output power stability contributes to part of the **IFPS** requirement **[RD14]**.

AD1 Req. 263 applies this stringent **ASD_g(2,T)** value to the instrumental gain stability of the 4 dedicated total power antennas having nutating subreflectors. Therefore this requirement applies only to the limited set of IFP LRUs (8) and IF coaxial cables used in the 4 total power antennas.

5.17 Differential gain and phase stability between channels of a polarization pair [BEND-02640-00/RT]

Polarization pairs of **IFPS** shall contribute residual differential fractional gain stability $\Delta G(t)/G_{av}$, averaged over 2 GHz, between channels of a polarization pair, as 2-point Allan standard deviation **ASD_g(2,T)** < 0.612E-3, where T = range from 0.05 sec to 300 sec.

Gain is that from IF input to baseband output and to the baseband analog total power data delivered by **IFP** to the ABM. Note that the **LO2** output power stability contributes to part of the **IFPS** requirement **[RD14]**.

The **DTX** LRU shall contribute differential gain stability ΔG/G, averaged over 2 GHz, between channels of a polarization pair, as 2-point Allan standard deviation **ASD_g(2,T,τ)** < 0.354E-3, where T = range from 0.05 sec to 300 sec.

See section 3.3 for the definition of **ASD_g**.

Total BE differential gain requirement is < 0.707E-3 **[AD1 Req. 264]**. By RSS, 75% is allocated to **IFPS** and 25% to **DTX**. The total applies on each antenna to the combination of **IFPS** and **DTX** from the signal outputs of the front end **[RD5]** to the baseband digital data delivered to the correlator **[RD6]**.

Polarization pairs of **IFPS** shall contribute differential phase stability, averaged over 2 GHz, between channels of a polarization pair, as 2-point Allan standard deviation

$ASD_\Phi(2,T,\tau)$ < 0.037 deg at baseband 2-4 GHz, where T = range from 0.05 sec to 100 sec and τ = 0.05 sec, and where T = 300 sec and τ = 10 sec.

See section 3.3 for the definition of **$ASD_\Phi(2,T,\tau)$**.

The **DTX** LRU shall contribute differential phase stability, averaged over 2 GHz, between channels of a polarization pair, as 2-point Allan standard deviation

$ASD_\Phi(2,T,\tau)$ < 0.021 deg, where T = range from 0.05 sec to 100 sec and τ = 0.05 sec, and where T = 300 sec and τ = 10 sec.

Total BE differential phase requirement is < 0.042 deg **[AD1 Req. 264]**. By RSS, 75% is allocated to **IFPS** and 25% to **DTX**. The total applies on each antenna to the combination of **IFPS** and **DTX** from the signal outputs of the front end **[RD5]** to the baseband digital data delivered to the correlator **[RD6]**.

5.18 Shape of passband, each baseband channel [BEND-02700-00/RT]

Each **IFP** baseband anti-alias filter passband shall be -20 dB at > 1850 MHz and at < 4150 MHz; stop band shall be < -40 dB at all frequencies < 1600 MHz and > 4400 MHz **[AD1 Req. 270]**.

5.19 Baseband effective bandwidth [BEND-02710-00/RT]

Each baseband anti-alias filter of the **IFPS** (in **IFP** LRU**)** shall have an effective passband bandwidth > 90% of 2 GHz nominal, i.e. > 1800 MHz **[AD1 Req. 271]**. Effective bandwidth is the "equivalent rectangular bandwidth that produces the same continuum signal-to-noise ratio as the actual filter **[AD1 note 271]**". In other words, it is the integral of G(f) from 2000 MHz to 4000 MHz divided by G_{max} within that band.

5.20 Gain variation across baseband effective passband [BEND-02720-00/RT]

Peak-to-peak gain variation across the signal path effective passband and across frequency scales less than 62 MHz, from FE IF output to DTX data output, including interconnects, shall be ≤3 dB. By RSS, this is allocated ≤ 2.7 dB for the **IFPS** and ≤1.2 dB for the **DTX** conversion to digital data **[AD1 Req. 272, note 272]**. Tests of the DTX alone and the combination of DTX and IFPS will be via autocorrelation passband spectra.

5.21 Temporal change in effective passband shape [BEND-02730-00/RT]

From **[AD1 note 273],** the **IFPS and the DTX** shall each have temporal change (fractional instability) in the effective passband shape (profile) across the effective passband < -43 dB (0.5E-4) with respect to mean power within any 2 MHz bandwidth, at 60 sec intervals,

< -33 dB (0.5E-3) with respect to mean power within effective passband, at 3600 sec (1 hour) intervals.
BE assumes 1/2 (-3 dB) of the totals in **[AD1 Req. 273]**.

5.22 Shape of narrow passband [BEND-02750-00/RT]

The **combined IFPS and DTX** throughput differential gain and phase variation between two antennas across any 31 MHz section of the operational (effective) passband at baseband, under any LO tuning, shall be:
< 1.4 dB pk-pk gain and
< 6.4 degree rms phase **[AD1 Req. 275]**.

Verification tests may require the ALMA correlator and astronomical tests.

AD1 Req. 275 allocates total 2.7 dB equally between FE and BE, and total 9 deg phase equally by RSS between FE and BE.

5.23 Spurious signals, 1st & 2nd LO [BEND-02900-00/RT]

The First LO Offset Generator (**FLOOG)** and **LO2** shall each generate spurious signals < -43 dBc from 380 Hz to 8 GHZ offset from carrier **[AD1 Req. 290]**.

5.24 Incoherent broad band spurious signals [BEND-02920-00/RT]

The combination of **IFPS and LO2** shall generate baseband power due to incoherent broadband spurious signals < -16 dB relative to the total noise power in the 2 GHz baseband bandwidth **[AD1 Req. 292]**. The **DTX** shall generate less than the same level as measured by autocorrelation spectra.

Note that baseband harmonics generated in the **IFP** can be aliased into the digitized data.

5.25 Narrow band spurious signals [BEND-02950-00/RT]

The combination of **IFPS and LO2** shall generate IF and baseband power due to coherent and incoherent spurious signals < -43 dB relative to system noise power in a bandwidth of 1 MHz **[AD1 Req. 295]**. The **DTX** shall generate less than the same level as measured by autocorrelation spectra.

Furthermore, because of IF feed-through and imaging (aliasing) of strong spectral lines and the impact on observing in spectral line, total power and calibration modes, the combination of **IFPS and LO2** shall limit
a) IF to base-band feed-through (P_{BB}/P_{IF}) < -30 dB at IF = 4 GHz and < -40 dB at IF ≤ 3.9 GHz,
b) spurious response $P_{BB}/P(2*f_{LO2} - f_{IF})$ < -40 dB, and
c) spurious response $P_{BB}/P(f_{LO2} – 2* f_{IF})$ < -40 dB.

Note that baseband harmonics generated in the **IFP** can be aliased into the digitized data.

5.26 Digital signal transmission latency [BEND-03110-00/RT]

The combination of LRUs **DTX** and **DRX**, and the fiber optic transmission subsystem **FOT**, shall provide repeatable latency with no loss of samples for all antennas in all array configurations **[AD1 Req. 311]**.

5.27 Digital signal transmission bit error rate [BEND-03120-00/RT]

The combination of **DTX** and **DRX**, and the fiber optic transmission subsystem **FOT**, shall provide bit error rate < 1E-6 for all antennas in all array configurations **[AD1 Req. 312]**.

5.28 Digitization bandwidth [BEND-03210-00/RT]

Each of the 4 **DTX** in each antenna shall digitize a polarization pair of baseband channels for a total of 8 baseband channels, each of 2 GHz nominal bandwidth of 2 GHz to 4 GHz **[AD1 Req. 321]**.

5.29 Digitization rate and levels [BEND-03220-00/RT]

The **DTX** and its sub assemblies, in combination with its reference clock **DGCK**, shall digitize each baseband channel at 4 GSa/sec with 8 levels (3 bits), uniformly spaced **[AD1 Req. 322]**.

5.30 Sampling clock fine delay [BEND-03230-00/RT]

The **DGCK** shall provide variable phase for fine delay with 1/16 sample intervals (15.625 psec) and accuracy **[AD1 Req. 323 and AD18]**. Timing of the **DGCK** fine delay steps shall be data-synchronized to within 10 μsec to the 1 msec boundaries of coarse delay steps at the correlator **[BEND-03250-]**.

Up to 10 delay steps per timing event (TE) will be available. Insertion of the delay steps will be performed as follows. Generate a local TE in the DGCK that is delayed by L*10 microsec with respect to the antenna TE. L (an integer less than 100) will be provided by the Monitor and Control (M&C) ABM and will be constant over long periods of time (weeks). With respect to this local TE, insert a delay of N(i)*15.625 ps at T(i) ms, where N(i)is the size of the ith delay step and T(i) is the insertion time of the ith delay step. N is an integer in the range 0 to 15, T is an integer in the range 0 to 47 and i is an integer in the range 1 to M where M is the number of delay steps during the TE period. The maximum value of M is 10. The values for M and the M values for N(i) and T(i) will be provided by the M&C ABM for each TE period.

5.31 Sampling clock commonality [BEND-03240-00/R]

The **DGCK** in each antenna shall be common to all 8 baseband channel digitizers, which are contained in the 4 **DTX** LRUs **[AD1 Req. 324]**.

5.32 Sampling clock synchronization [BEND-03250-00/RT]

The **combination of LRUs listed in Table 3 requirement -03250-** shall synchronize the sampling clock with the correlator to within 10 µsec **[AD1 Req. 325 and AD18]**. This includes the propagation delays of the TE (48 msec) from the Central Reference Generator (CRG) to the correlator, antenna and DGCK, and the data propagation delay from the DTX to the correlator, which will be calibrated by M&C and corrected in the digital delays. Relative stability < 1 µsec of timing events (48 msec TE) at all BE LRUs in all antennas and in the AOSTB will satisfy this requirement, according to **RD1 section 4.5**.

5.33 Tuning sky frequency to baseband [BEND-04110-00/RT]

The **LO2** shall provide placement of any sky frequency at any baseband frequency ± 200 MHz, where the baseband frequency range (digitized bandwidth) is 2 GHz - 4 GHz **[AD1 Req. 411]**. Given the requirement **BEND-04120-** for tuning sky frequency to IF ± 400 MHz by the combination of LPR, FLOOG, Laser Synthesizer (LS) and Central Variable Reference (CVR), the **LO2** shall tune in steps < 110 MHz = (200-90) MHz, which will provide the requirement <u>without</u> step tuning the LPR, FLOOG, LS and CVR. The **LO2** shall tune by frequencies and by timing relative to TE according to commands from the M&C ABM.

As designed, the LO2 produces nearly continuous tuning frequencies, except for a ± 20 MHz hole around harmonics of 125 MHz and a ± 20.5 MHz hole around the mid-frequency between harmonics of 125 MHz. Thus it will set any IF frequency to any baseband frequency ± 20.5 MHz. Note that Doppler corrections will fail if an LO2 is commanded into one of its tuning holes.

5.34 Tuning sky frequency to IF [BEND-04120-00/R]

From **AD1 Req. 412**, the combination of the LRUs **FLOOG, CVR and LS** shall provide tuning step and range of the 1st LO so that any accessible sky frequency can be placed

a) within ±800 MHz of any point in a 4-12 GHz 1st IF and
b) within ±400 MHz of any point in a 4-8 GHz 1st IF.

An exception is a sky frequency located

a) within 7.2 GHz of an RF band edge with a 4-12 GHz 1st IF and
b) within 3.6 GHz of an RF band edge with a 4-8 GHz 1st IF.

See **RD4** for band frequency ranges, 1st LO frequency ranges, (ML – LS) 1st LO reference frequency ranges and corresponding IF frequency ranges. The **FLOOG**, which provides 1st LO frequency tuning offset, shall tune from 20 to 45 MHz. These **LRUs** shall tune frequency according to commands from the M&C by the ABM and ARTM.

5.35 Six tunable subarrays [BEND-04200-00/RT]

Six each of LRUs **CVR**, **LS** and Photonic Reference Distributor (**PRD)**, plus sufficient reference frequency distribution in the Master Laser Distributor (**MLD),** photonic Low

Frequency Distributor **(LFRD), 5RD, 125RD and CRG**, plus sufficient Fiber Optic Amplifier & Demultiplexers (FOADs) and fiber patch panel capacity **[AD19]** and sufficient switching in the Subarray Switch **(SAS)**, shall connect any antenna (12m array or ACA) to any of six independently tunable subarrays **[AD1 Req. 420 and AD17]**. A single subarray shall be capable of including antennas from both the 12m array and the ACA. These LRUs shall connect subarrays according to commands from the M&C computer. Initial construction may provide only 4 operational subarrays.

The independent tuning of a subarray is provided by an independent 1st LO Reference frequency, and thus requires independent **CVR, LS and PRD** for each subarray. **AD1 Req. 420** does not specify the maximum or minimum number of antennas in a subarray, nor whether the mapping of subarrays to antenna pads must be flexible or can be fixed. The BE chooses to interpret this in terms of maximum flexibility, where an independent subarray shall contain any number from 1 to 64 of antennas. Normal operation of the full 12-meter array will be as one subarray so that the 1st LO Reference will be common to all antennas.

5.36 Switching time between subarrays [BEND-04250-00/RT]

LRUs **CVR, LS and SAS** switching time between subarrays shall be limited by the time to tune, reset or reconfigure the equipment **[AD1 Req. 425]**.

5.37 Intraband frequency tuning time [BEND-04300-00/RT]

LRUs **CVR, FLOOG, IFP, LO2, LPR and LS** shall provide intraband frequency tuning time < 1.5 sec over the whole band **[AD1 Req. 430]**. These LRUs shall tune frequency according to commands from the ABM and Array Real Time Machine (ARTM).

Note that Req. 02610 and 04560 imply that this Req. should apply to $\Delta G/G$ and $\Delta\Phi$ settling time in band/position switching phase-cal mode. Tests indicate that the **IFP** implementation achieves this Req. within <<1.5 sec for $\Delta\Phi$, but $\Delta G/G$ only for single bit (0.5, 1, 2, 4, 16 dB) switching of the baseband attenuator (settled within 1% in 1 sec). Analysis indicates that gain switching for this mode by single bits of both FE and **IFP** can be achieved via CCS software [TBC at AOS]. See ALMA-40.08.01.01-017-A-CRE.

5.38 Interband frequency tuning time [BEND-04310-00/RT]

LRUs **CVR, FLOOG, IFP, LO2, LPR and LS** shall provide interband frequency tuning time <1.5 sec (<0.1 sec goal), switching to either of two FE bands in standby mode **[AD1 Req. 431, 433]**. See related requirements **BEND-04350-** and **BEND-04500-**.

Note that Req. 02610 and 04560 imply that this Req. should apply to $\Delta G/G$ and $\Delta\Phi$ settling time in band/position switching phase-cal mode. Tests indicate that the **IFP** implementation achieves this Req. within <<1.5 sec for $\Delta\Phi$, but $\Delta G/G$ only for single bit (0.5, 1, 2, 4, 16 dB) switching of the baseband attenuator (settled within 1% in 1 sec). Analysis indicates that gain switching for this mode by single bits of both FE and **IFP** can be achieved via Computing Control Software (CCS) [TBC at AOS]. See ALMA-40.08.01.01-017-A-CRE.

5.39 Small frequency-shift switching [BEND-04320-00/RT]

Within the same FE band, the **FLOOG, in combination with the FE 1st LO driver [RD5],** shall provide < 10 msec rise & fall time up to 10 Hz rate for frequency shift up to 25 MHz at the FLOOG, only in spectral line total power mode, within the same band and without unambiguous phase **[AD1 Req. 432]**. The **FLOOG** shall tune from 20 MHz to 45 MHz and switch frequency by amounts, and timing relative to TE, according to commands from the M&C ABM.

5.40 Band 3 in use or in standby [BEND-04350-00/R]

Band 3 is always either in use or in standby mode **[AD1 Req. 435]**. **CVR, LPR and LS** shall note this requirement in connection with requirement **[BEND-04310-]** on interband switching.

5.41 Phase switching 180 deg and 90 deg in 1st LO [BEND-04410-00/RT]

The **FLOOG** shall provide 180 degree fast phase switching and 90 degree slow phase switching at the 1st LO by offsetting the PLO reference frequency and phase in the 1st LO driver **[AD1 Req. 441]**. **FLOOG** 180 deg switching shall be at rate 0.016 sec (TE/3) and 90 deg switching rate shall be at 2.048 sec (128*16 msec). Note that the **FLOOG** phase shift is multiplied by the frequency multiplication from the driver to the 1st mixer **[RD5]**. The **FLOOG** shall switch phase by amounts, and by timing relative to TE, according to commands from the M&C ABM.

The **DTX** shall remove the 180 degree fast phase switching by sign-bit reversal after digitization, with synchronization to the FLOOG switching and to signal propagation delay from the FLOOG to the 1st mixer to the sign reversal logic **[AD1 Req. 441]**. The **DTX** shall switch sign to value, and at times relative to TE, according to commands from the M&C ABM. The M&C ABM will account for the propagation delays relative to local TEs, if significant.

5.42 Rate of change of 180 deg phase switching [BEND-04420-00/RT]

Rate of change of 180 deg phase changing in 1st LO by **FLOOG** shall be 25 deg in < 1 µsec **[AD1 Req. 442]** and per **RD4**.

5.43 Phase switching synchronization [BEND-04440-00/RT]

From **AD1 Req. 444**, the Central Reference Distributor (**CRD),** Central Reference Generator **(CRG), DTX, FLOOG and** LO Reference Receiver **(LORR)** shall provide phase switching stability adequate to enable switching synchronization to
< 0.1 µsec between antennas,
< 0.1 µsec within antenna,
< 20 nsec relative delay among 8 baseband channels of antenna.
< 1.0 µsec 180 deg sign reversal relative to correlator dump.

Timing shall be relative to TE according to commands from the M&C ABM and ARTM, which command timing according to delay calibrations.

AD1 Req. 444: "Between antennas" refers to the relative timing of the digital sign reversed signal from two antennas at the input to the cross-correlator multiplier stage. The timing of the 1st LO phase switch and the sign reversal must correct for all propagation delays in both timing and signal transmission, including the variable delay introduced in the correlator as an astronomical source is tracked.

"Within antenna" refers to the relative timing of the 1st LO phase switch and the digital sign reversal within an antenna.

"Relative delay" refers to the relative timing among the eight baseband signals from 1st LO phase switch to the correlator multiplier. An offset delay is available in the DTS Formatter independently for each of four baseband pairs. However, the relative delay cannot be allowed to be too large because the phase switch event at the DTS Formatter has to synchronize with both the phase switch at the 1st LO and the sign reversed signal from other antennas at the input to the cross-correlator multiplier stage.

5.44 Unambiguous phase of all frequency synthesis [BEND-04500-00/RT]

Phase differences between two antennas shall not change with tuning of LRUs **FLOOG** and **LO2 [AD1 Req. 450]**. Back End interprets this to mean that these synthesizers shall return to the phase they would have had without the frequency change. **FLOOG** and **LO2** frequencies, phases and timing relative to local TE shall be set according to commands from the M&C ABM.

This requirement does not apply to the combined **LS and CVR** for general interferometry because they are common mode to all antennas. However, this requirement is necessary for future Very Long Baseline Interferometry (VLBI) **[BEND-04610-],** and at that time may be required for only one CVR in only one VLBI subarray.

This requirement does not apply to single dish spectral line mode. See **BEND-04320-**.

5.45 Delay & phase <u>drift</u> [BEND-04510-00/RT]

These requirements flow down from **[AD1 Req. 451, Table 1 and Table 3]**. Also see **RD4**.

Residual delay and phase **drift** contributions by the BE subsystems shall be:

- < 4 fsec rms total through the signal path of **IFP and DTX**, applied at 950 GHz.
- < 4 fsec rms total of **LO2 and DGCK**, applied at 950 GHz,
- < 13 fsec rms total **BE contribution to 1st LO**.

<u>**Drift** is the 2-point Allan Standard Deviation **ASD_{Φ}(2, T, τ)** (see section 3.3) of residual delay and phase drift with differencing interval **T = range 20 to 300 sec** and a fixed averaging time **τ = 10 sec**</u>. See section 3.3.

Residual drift can be measured as the difference between two antenna systems. Assume that the variations are uncorrelated and assign 1/√2 of the measured phase difference to each antenna subsystem for corresponding signal paths and LO chains. See **[BEND-04515-]**. The boundary between delay and phase drift and noise is 1 sec (1 Hz) with drift times > 1 sec.

The relation between delay and phase at frequency f is

$\Delta\Phi(f) = 360\text{deg}*f*\Delta D(f)$,

where $\Delta\Phi(f)$ is in degrees (in radians by substituting 2π radians for 360 degrees), $\Delta D(f)$ is in sec and frequency f is in Hz.

The following tables give RSS additive residual drift allocations that are estimates of likely performance based on measurements of prototypes of several LRUs. As development and testing proceeds, these allocations will be reviewed and revised. To this end, the SE&I IPT requests copies of LRU test data to add to its comprehensive spreadsheet analysis of the LO chains (lpopken@eso.org).

Testing of a complete subsystem that demonstrates compliance with its corresponding requirements as given above is sufficient in place of testing its individual LRUs.

5.45.1 Delay and phase drift in the BE signal path [BEND-04511-00/RT]

The contribution of residual delay and phase drift **ASD$_\Phi$(2, 20 to 300sec, 10sec)** by BE equipment in the signal path, as defined by **BEND-04510-** above, of **IFPS** shall be

< 4 fsec applied at 950 GHz, or < 1.37 deg at both 950 GHz and at baseband 2 GHz to 4 GHz.

Because the signal path from sky to baseband digitization consists of frequency translations by the 1st and 2nd LOs, phase drifts, rather than delay drifts, accumulate down the signal path. Therefore the phase drift at the baseband output of the **IFPS** is that required at the sky.

This assumes the phase drift of DTX digitization is determined entirely by its clock, the DGCK, and not by its internals.

5.45.2 Delay and phase drift in the 2nd LO chain [BEND-04512-00/RT]

The contribution of residual delay and phase drift **ASD$_\Phi$(2, 20 to 300sec, 10sec)** by BE equipment in the 2nd LO chain, as defined by **BEND-04510-** above, of LRUs **FOT, FOW,** line length converter **(LLC), LO2, LORR,** LORR Reference Distributor **(LORRD), LPR and** Optical Diplexer Filter **(ODF)** will be as allocated in Table 4 below.

Table 4 Allocation of delay and phase drift in the 2nd LO chain

LRU or fiber transmission	% RSS	fsec @ 8 - 14 GHz	deg @ 8 - 14 GHz
LO2 (phase lock to LORR comb ± FTS, 8 to 14 GHz)	40	149	0.75
LORR/D comb to LO2 (phase lock to 2 GHz + 125	60	182	0.91

LRU or fiber transmission	**% RSS**	**fsec @ 8 - 14 GHz**	**deg @ 8 - 14 GHz**
MHz)			
LLC + LPR + FOT +FOW + ODF (fiber length correction)	0.1	7	0.037
TOTAL (RSS)	100	235	1.18

Assume the RSS additive residual drift contribution of the 2nd LO chain is 75% of the 4 fsec rms total for 2nd and 3rd LO,
or < 3.46 fsec applied at 950 GHz,
or < 3.46 fsec*360deg*950GHz = 1.18 deg applied at both 950 GHz and at the LO2 frequency range of 8 GHz to 14 GHz, because frequency translating phase drifts, rather than delay drifts, accumulate down the LO chain.
Then the delay drift requirement is < 1.18deg/(360deg*14GHz) = 235 fsec at 8 - 14 GHz.

Each listed LRU includes interconnects associated with it per ICDs.

Note that **AD1**, Section 1.3, Case 1 states that the *goal* for IF/LO2 phase drift should be 0.73 deg or 2.3 fsec. By equal RSS allocation, phase drift of IFPS = LO2 ≤√0.73 = 0.52 deg @ 4 – 14 GHz.

5.45.3 Delay and phase drift in the 3rd LO chain [BEND-04513-00/RT]

The contribution of residual delay and phase drift **ASD$_\Phi$(2, 300sec, 10sec)** by BE equipment in the 3rd LO chain, as defined by **BEND-04510-** above, of LRUs **DGCK, FOT, FOW, LLC, LORR, LORRD, LPR and ODF**, will be as allocated in Table 5 below.

Table 5 Allocation of delay and phase drift in the 3rd LO chain

LRU or fiber transmission	**% RSS**	**fsec @ 4GHz**	**deg @ 4GHz**	**deg rms @ freq**	
DGCK (phase lock to 32 * LORR 125 MHz)	40	299	0.43		
LORR + LORRD 125 MHz to DGCK	60	366	0.53	0.017	125 MHz
LLC + LPR + FOT + FOW + ODF (fiber length correction)	0.1	15	0.022		
TOTAL (RSS)	100	472	0.68		

Assume the RSS additive residual drift contribution of the 3rd LO chain is 25% of the < 4 fsec rms required total of 2nd and 3rd LOs,
or < 2 fsec applied at 950 GHz,
or < 2 fsec*360deg*950GHz = 0.68 deg applied at both 950 GHz and at the LO3 frequency of 4 GHz.
Then the delay drift is < 0.68deg/(360deg*4GHz) = 472 fsec at 4 GHz.

The 3rd LO chain (Figure 1) consists of a combination of transmissions and frequency multiplications, so delay drifts add through transmissions and multiplications.

Each listed LRU includes interconnects associated with it per ICDs.

5.45.4 Delay and phase drift in BE 1st LO chain [BEND-04514-00/RT]

The contribution of residual delay and phase drift **ASD$_\Phi$(2, 300sec, 10sec)** through the 1st LO chain, as defined by **BEND-04510-** above, of LRUs **5RD, FLOOG, FOT, FOW, LFRD, LLC, LORR, LORRD, LPR, MLD, ODF, PRD and SAS**, will be as allocated in Table 6 below.

Table 6 Allocation of delay and phase drift in the 1st LO chain

LRU or fiber transmission	% RSS	fsec	deg @ freq	
FLOOG 1st LO Offset Generator @ 45 MHz (RD4 requires 0.066 deg rms output to FE 1st LO)			0.047	20 - 45 MHz
LORR/D LO Reference Receiver 125 MHz to FLOOG (equal RSS of FLOOG output)			0.047	125 MHz
LPR & photonic mixer in FE (frequency generated by CVR, LS & ML)	24	6.4		
LLC Line Length Correction including 25 MHz LORR/LPR + antenna fiber + ODF + FOW + FOT interior & exterior fiber	44	8.6		
5RD 5 MHz Reference Distribution + coax (differential among outputs to LLCs)	2	1.9	5.0E-6	5 MHz
MLD Master Laser Distribution + fiber (differential among outputs to LLCs)	14	4.9		
PRD Photonic Reference Distribution + fiber (differential among outputs to SAS)	14	4.9		
SAS Sub Array Switch + fiber (differential among outputs to LLCs)	2	1.9		
Total estimated by PLO group (RSS)		13.1		
TOTAL REQUIREMENT (RSS)	100	13		

The allocations of RSS additive residual drift for the above LRUs, except LORR and LORRD, are the current best estimates of the Photonic LO group.

In an ideal frequency multiplication LO chain, delay drift at each phase lock loop (PLL) and voltage controlled oscillator (VCO) output and frequency multiplier output remain constant from the 1st LO frequency down the chain. Phase drift does not remain constant down the chain, but PLL frequency offsetting LOs RSS add their phase drifts at their frequencies to the output phase errors of the PLL & VCO. Therefore this **delay drift** requirement for the 1st LO chain LRUs **[AD1-451 Table 1]** starts with the total BE **delay drift** of < 13 fsec at any 1st LO frequency of any band. Contributions to this BE total **delay drift** are allocated in Table 6 by RSS to individual LRUs and groups of LRUs down the 1st LO chain. See Figure 1.

Differential refers to LRUs in different antenna paths in the 1st LO chain. LRUs Master Frequency Standard (MFS), CRG, CRD, 125RD, CVR, LS and ML, which are in the common mode paths of the 1st LO chain, do not contribute to these requirements. See Figure 1.

Appendix A of **RD4** lists the various frequencies in the 1st LO chain for each band. Switching to band 3 for array phase calibration at other bands may require more stringent requirements for the LO frequencies used for band 3.

5.45.5 Measurement of delay & phase drift [BEND-04515-00-00/T]

These requirements for LRU contributions to delay and phase drifts are the residual phase drift RSS added by the LRU(s) to that of the signal path or that of the LO chain. Here residual means phase drift independent of the references feeding the LRU or combined LRUs. Thus the requirements apply to the measured residual drift of one unit, which equals 1/√2 times the *measured differential residual drift* between two independent LRUs (or sets of connected LRUs) having common reference inputs and/or a common signal input. This assumes that each of the compared units has equal but independent statistics of drift.

5.45.6 Common mode drift in BE LO chains [BEND-04516-00/R]

Delay/phase drifts are most important for differential antenna-to-antenna coherence, but for the connected element, ALMA array drift is defined for variation frequencies < 1 Hz (time interval > 1 sec), so common mode delay/phase drifts are insignificant for coherence. Phase drift at rates below 1 Hz from LRUs in the common mode portion of the central LO (**MFS, CRG, CRD, 125RD, CVR, LS and ML,** see Figure 1) are common to all antennas and cancel in correlation. Therefore, the total combined phase drift from these central LO LRUs need only meet the phase drift requirements for VLBI **[BEND-04600-]** for drift times > 1 sec.

5.46 Delay & phase noise [BEND-04520-00/RT]

These requirements flow down from **AD1 Req. 452, Table 1 and Table 3**: Residual delay and phase **noise** contributions by the BE equipment shall be:

< 24 fsec rms total of **IFP and DTX** through the signal path, applied at 950 GHz.

< 17 fsec rms total of **LO2 and DGCK**, applied at 950 GHz,

< 38 fsec rms total **BE contribution to 1st LO, except < 80 fsec rms for Band 1 (ALMA-56.11.00.00-0240A-CRE).**

Noise is the rms deviation from the 10 sec average of residual integrated delay and phase noise from 1 MHz down to 1 Hz **[AD1 section 1.3]**.

Residual noise can be measured as the difference between two antenna systems. Assume that the variations are uncorrelated and assign 1/√2 of the measured phase difference to each antenna subsystem for corresponding signal paths and LO chains. See **BEND-04525-**. The boundary between delay and phase noise and drift is 1 Hz (1 sec) with noise deviation frequencies > 1 Hz. However, requirements for common mode phase noise in the range 1 Hz to 1 kHz for VLBI may be developed.

The relation between delay and phase at frequency f is

$\Delta\Phi(f) = 360deg*f*\Delta D(f)$,

where ΔΦ(f) is in degrees (in radians by substituting 2π radians for 360 degrees), ΔD(f) is in sec and frequency f is in Hz.

The following tables give RSS additive residual integrated noise allocations that are estimates of likely performance based on measurements of prototypes of several LRUs. As development and testing proceeds, these allocations will be reviewed and revised. To this end, the SE&I IPT requests copies of LRU test data to add to its comprehensive spreadsheet analysis of the LO chains (lpopken@eso.org).

Testing of a complete subsystem that demonstrates compliance with its corresponding requirements as given above is sufficient in place of testing its individual LRUs.

5.46.1 Delay and phase noise in the BE signal path [BEND-04521-00/RT]

The contribution of integrated residual delay and phase noise, as defined by **BEND-04520-** above, by BE equipment in the signal path of **IFPS** shall be

< 24 fsec rms applied at 950 GHz,
or < 24 fsec*360deg*950GHz = 8.2 deg rms at both 950 GHz and 2 GHz to 4 GHz,
or integrated delay noise < 8.2 deg/(360deg*4 GHz) = 5700 fsec rms at 4 GHz.

Because the signal path from sky to baseband digitization consists of frequency translations by the 1st and 2nd LOs, phase noise, rather than delay noise, accumulates down the signal path.

This assumes the RSS additive residual noise contribution of the DTX digitization is determined entirely by its clock, the DGCK**.**

5.46.2 Delay and phase noise in the 2nd LO chain [BEND-04522-00/RT]

The contribution of residual delay and phase noise, as defined by **BEND-04520-** above, by the 2nd LO chain of LRUs **FOT, FOW, LLC, LO2, LORR, LORRD, LPR and ODF**, will be as allocated in Table 7 below.

Table 7 Allocation of delay and phase noise in the 2nd LO chain

LRU or fiber transmission	% RSS	fsec rms @ 8 - 14GHz	deg rms @ 8 - 14GHz
LO2 (phase lock to LORR comb ± FTS, 8 to 14 GHz)	40	632	3.2
LORR/D comb to LO2 (phase lock to 2 GHz + 125 MHz)	60	775	3.9
LLC + FOT + FOW + ODF (fiber length correction)	0.1	32	0.16
TOTAL (RSS)	100	1000	5.0

Assume the RSS additive residual noise contribution of the 2nd LO chain is 75% of the total 17 fsec for 2nd and 3rd LO,
or < 14.7 fsec applied at 950 GHz,

or < 14.7 fsec*360deg*950GHz = 5.04 deg applied at both 950 GHz and at the LO2 frequency range of 8 GHz to 14 GHz, because frequency translating phase noise, rather than delay noise, accumulates down the LO chain.
Then the delay integrated noise is < 5.04 deg/(360deg*14GHz) = 1000 fsec at 8 - 14 GHz.

Each listed LRU includes interconnects associated with it per ICDs.

5.46.3 Delay and phase noise in the 3rd LO chain [BEND-04523-00/RT]

The contribution of residual delay and phase noise, as defined by **BEND-04520-** above, in the 3rd LO chain of LRUs **DGCK, FOT, LLC, LORR, LORRD, LPR and ODF**, will be as allocated in Table 8 below.

Table 8 Allocation of delay and phase noise in the 3rd LO chain

LRU or fiber transmission	% RSS	fsec rms @ 4GHz	deg rms @ 4GHz	deg rms @ freq	
DGCK (phase lock to 32 * LORR 125 MHz)	40	1280	1.84		
LORR/D 125 MHz to DGCK	60	1560	2.25	0.070	125MHz
LLC + LPR + FOT + FOW + ODF (fiber length correction)	0.1	64	0.092		
TOTAL (RSS)	100	2020	2.91		

Assume the RSS additive residual noise contribution of the 3rd LO chain is 25% of the < 17 fsec rms total of LO2 and third LO DGCK,
or < 8.5 fsec rms applied at 950 GHz,
or < 8.5fsec*360deg*950GHz = 2.91 degree rms at both 950 GHz and 4 GHz, because frequency translation applies constant phase from 950 GHz to 4 GHz.
Then the integrated delay noise at 4 GHz is < 2.91deg/(360deg*4GHz) = 2020 fsec rms at 4 GHz.

The third LO chain (Figure 1) consists of a combination of transmissions and frequency multiplications, through which delay noise adds.

Each listed LRU includes interconnects associated with it per ICDs.

5.46.4 Delay and phase noise in BE 1st LO chain [BEND-04524-00/RT]

The contribution of residual delay and phase noise, as defined by **BEND-04520-** above, by the differential mode path of the 1st LO chain, LRUs **5RD, FLOOG, FOT, FOW, LFRD, LLC, LORR, LORRD, LPR, MLD, ODF, PRD and SAS**, will be as allocated in Table 9 below.

Table 9 Allocation of delay and phase noise in the 1st LO chain

LRU or fiber transmission	% RSS	fsec rms	deg rms @ freq	
FLOOG 1st LO Offset Generator @ 45 MHz (RD4 requires 0.2 deg total to FE 1st LO allocation)			0.14	20 - 45 MHz
LORR/D LO Reference Receiver 125 MHz to FLOOG (equal to RSS of FLOOG)			0.14	125 MHz
LPR & photonic mixer in FE (frequency generated by LS & ML)	24	19		
LLC Line Length Correction + fiber + antenna fiber + FOW + FOT interior & exterior fiber	44	25		
5RD 5 MHz Reference Distribution + coax (differential among outputs to LLCs)	2	5.4	9.7E-6	5 MHz
MLD Master Laser Distribution + fiber (differential among outputs to LLCs)	14	14		
PRD Photonic Reference Distribution + fiber (differential among outputs to SAS)	14	14		
SAS Sub Array Switch + fiber (differential among outputs to LLCs)	2	5.4		
TOTAL (RSS)	100	38 (80 Band 1)		

In an ideal frequency multiplication LO chain, delay noise at each PLL & VCO output and frequency multiplier output remains constant from the 1st LO frequency down the chain. Phase noise does not remain constant down the chain, but PLL frequency offsetting LOs RSS add their phase noise at their frequencies to the output phase noise of the PLL & VCO. Therefore this **delay noise** requirement for the BE 1st LO chain LRUs **[AD1-452]** starts with the total **delay noise** of < 38 fsec rms at any 1st LO frequency of any band. RSS additive contributions to this BE total residual **delay noise** are allocated in Table 9 to individual LRUs and groups of LRUs down the differential portion of the 1st LO chain. LRUs MFS, CRG, CRD, 125RD, CVR, LS and ML are in the common mode paths of the 1st LO chain and therefore do not contribute to these requirements for noise offset frequencies between 1 Hz and 1 kHz, *but there may be significant noise contribution above 1 kHz*. See Figure 1 and **BEND-04526-**.

Appendix A of **RD4** lists the various frequencies in the 1st LO chain for each band. LPR and photo mixer in Table 9 above lists the band associated frequency which has the smallest required value of phase drift in degrees for the given delay in fsec.

5.46.5 Measurement of delay and phase noise [BEND-04525-00/T]

These requirements for LRU contributions to delay and phase drifts are the residual phase noise RSS added by the LRU(s) to that of the signal path or that of the LO chain. Here residual means phase noise independent of the references feeding the LRU or combined LRUs. Thus the requirements apply to the measured residual noise of one unit, which equals $1/\sqrt{2}$ times the *measured differential residual noise* between two independent LRUs (or sets of connected LRUs) having common reference inputs and/or a common signal input. This assumes that each of the compared units has equal but independent statistics of noise.

Phase noise measurement equipment measures phase noise relative to an internal very low noise reference signal or to an external signal, such as a second identical LRU, as described above. The basic measurement is a ratio of single sideband (SSB) spectral phase noise power SPssb(f_m) in 1 Hz bandwidth to total signal power Psig, as a function of frequency offset (f_m) from the carrier. The displayed SSB spectrum is Lphi(f_m) = 10*log(SPssb(f_m) / Psig) in units of dBc/Hz.

If Lphi(f_m) phase variations are < 1 radian (= 57.3 deg), the rms phase deviation ΔΦ(f)rms, in units of radians, equals the square root of the integral of 2*Lphi(f_m). Linearly scaled Lphi(f_m) (antilog((dBc/Hz)/10)) should be used as the spectrum in the integrand. The integral is over offset frequency f_m from f_1 to f_2. For rms phase noise to 10 sec, the lower integration limit f_1 is 1 Hz. The upper integration limit f2 should be sufficiently large to include sideband noise and spurious spectral spikes, such that spectral noise beyond f2 contributes insignificantly to the integral. Spurious frequency spikes from reference LRUs could contribute to errors such as spurious artifacts.

The integrated rms phase noise is converted to rms delay noise ΔD(f)rms by

$$\Delta D(f)_{rms} = \Delta\Phi(f)_{rms} / (2\pi \text{ radians} * f) = \Delta\Phi(f)_{rms} / (360 \text{degrees} * f).$$

There is no unique conversion of an rms delay variation requirement into an Lphi(f_m) spectrum, so analytic and measured spectra must be integrated and compared to the required rms. Modern phase noise measurement equipment can calculate rms delay in seconds (or fsec) and rms phase in radians or degrees between user-designated limits of f_m, which can range from 1 Hz to 2 MHz in the Agilent E5052A and E5500 series of analyzers. Such equipment calculates and displays rms delay and phase only at the carrier frequency f_c.

5.46.6 Common mode noise in BE LO chains [BEND-04526-00/R]

Delay/phase noise is most important for differential antenna-to-antenna coherence, but common mode delay/phase noise is also important. Delay/phase error fluctuation frequencies below ~1 kHz in the portion of the central LO subsystem that is common to all antennas generally appear equally (i.e. coherent) at all array antennas and cancel in correlation. This limit derives from the difference in transmission times from the central LO to the nearest and most distant antennas (~15 km) plus the flight time of light across the ~15 km of array. Here $T \approx 15km/(c/2) + 15km/c = 150$ µsec, $1/T \approx 6.7$ kHz. But we use 1 kHz to allow for transition effects in phase lock loop bandwidths. LRUs **MFS, CRG, CRD, 125RD, CVR, LS and ML** are in the common mode paths of the 1st LO chain and therefore do not contribute to these requirements for noise offset frequencies between 1 Hz and 1 kHz, *but there is significant noise contribution above 1 kHz*. PLL bandwidths above ~ 1 kHz in the central LO may pass such noise and thus may degrade coherence of the array.

5.47 System delay discontinuities [BEND-04540-00/RT]

The combination of BE equipment **FOT, LLC and LPR** shall operate > 1 hour without step discontinuities in system delay > 10 fsec **[AD1 Req. 454]**. This is particularly important for the fiber stretchers in the **LLC**.

5.48 Antenna small angle motion, systematic delay errors [BEND-04560-00/RT]

The combination of **IFPS** and all **LRUs listed in requirement -04560- of Table 3** shall cause systematic delay errors < 4.6 fsec for antenna small angle motion of azimuth and elevation change of 2.0 deg. Back End assumes 1/3 by RSS of the total of < 8 fsec **[AD1 Req. 456]**.
This will be verified by total system tests in the array.

Note that Req. 02610 and 04310 imply that this Req. should apply to $\Delta\Phi$ settling time <1.5 sec in band/position switching phase-cal mode. Tests indicate that the **IFP** implementation achieves this Req. within <<1.5 sec for $\Delta\Phi$.

5.49 Antenna small angle motion, random delay errors [BEND-04570-00/RT]

The combination of **IFPS** and all **LRUs listed in requirement -04570- of Table 3** shall cause random delay errors < 8.6 fsec for antenna small angle motion of azimuth and elevation change of 2.0 deg. Back End assumes 1/3 by RSS of the total of < 15 fsec **[AD1 Req. 457]**.
This will be verified by total system tests in the array.

5.50 Antenna large angle motion, systematic delay errors [BEND-04580-00/RT]

The combination of **IFPS** and all **LRUs listed in requirement -04580- of Table 3** shall cause systematic delay errors
< 57 fsec rms for antenna azimuth change of ± 180 deg,

< 29 fsec rms for antenna elevation change ± 40 deg.
Back End assumes 1/3 by RSS of the total of < 100 and 50 fsec respectively **[AD1 Req. 458]**.
This will be verified by total system tests in the array.

5.51 Antenna large angle motion, random delay errors [BEND-04590-00/RT]

The combination of **IFPS** and all **LRUs listed in requirement -04590- of Table 3** shall cause random delay errors < 18 fsec rms for antenna motion of full range of azimuth & elevation change. Back End assumes 1/3 by RSS of the total of < 32 fsec **[AD1 Req. 459]**. This will be verified by total system tests in the array.

5.52 Common mode fractional frequency error for VLBI [BEND-04600-00/RT]

From **AD1 Req. 460**, the common mode delay and phase drift contributed by the combination of LOs **CRD, CRG, 125RD, CVR, LS and ML**, and elements of the **PRD** coming before the 1:N splitters (see Figure 1), shall provide Allan standard deviation of $\Delta f/f_{av}$,

$ASD_f(2, T = \tau = 1 \text{ sec}) < 2E\text{-}13$,

$ASD_f(2, T = \tau = 100 \text{ sec}) < 1.3E\text{-}14$,

$ASD_f(2, T = \tau = 1000 \text{ sec}) < 3E\text{-}15$.

5.53 Sub-array for VLBI [BEND-04610-00/R]

CVR and LS shall provide support for VLBI in a minimum of 1 sub-array **[AD1 Req. 461]**. Note the **BEND-04600-** requirements for common mode phase fluctuations and **BEND-0450-** requirement for unambiguous phase.

5.54 Absolute frequency accuracy [BEND-04700-00/RT]

Absolute frequency accuracy of **MFS** shall be 1 part in 1E11 **[AD1 Req. 470]**.

The Change Request (CRE) ALMA-55.01.00.00-002-A-CRE changed LRU **MFS** from a hydrogen maser to any frequency standard, such as a Rubidium, that meets the frequency accuracy requirement. However, the BE subsystem design and implementation shall accommodate later substitution of a hydrogen maser for VLBI.

5.55 Radio Frequency interference (RFI) protection [BEND-04900-00/RT]

BE racks in antennas and each LRU package that contain frequencies ≥ 2 GHz at power levels ≥ -20 dBm shall have shielding effectiveness ≥ 20 dB from 2 GHz to 14 GHz **[AD1 Req. 490]**. Also see **BEND-09300-00/RT**.

5.56 Fiber optic cable [BEND-04920-00/RT]

LRUs **DRX, DTX, FOAD, FOW, LLC, LORR, and LPR**, and fiber subsystem **FOT** shall achieve all of their requirements with fiber lengths up to 15 km **[AD1 Req. 490]**.

5.57 Baseband total power accuracy [BEND-05110-00/RT]

The baseband analog total power detectors and digitizers within the **IFP** shall have accuracy (deviation from square law) < 1% of full scale after linearity correction **[AD1 Req. 511]**.

5.58 Baseband total power sampling [BEND-05120-00/RT]

The **IFP** shall produce astronomical digital data from the baseband analog total power detector on each 2 GHz bandwidth baseband channel with an output data sampling interval of 500 µsec at > 99% efficiency (> 495 µsec effective integration time) **[AD1 Req. 512]**.

5.59 IF total power [BEND-05130-00/RT]

The **IFP** shall produce output from an analog total power detector on each 8 GHz bandwidth IF channel (sideband) for monitoring and also for setting the FE IF switch/attenuator for appropriate power levels at the FE/BE IF interface via M&C ABM software **[AD1 Req. 513]**.

5.60 Monitor points [BEND-06140-00/R]

All LRUs containing an Antenna Monitor and Control Bus (AMB) node shall have sufficient monitor points to identify failures as quickly as possible **[AD1 Req. 614]**. These LRUs will also provide their serial numbers, revision letters, firmware version numbers and/or firmware version dates.

5.61 Monitor control of equipment [BEND-06150-00/RT]

All BE equipment with an AMB node shall self identify **[AD1-615]** with node address and AMB Standard Interface (AMBSI) serial number in response to the ABM or ARTM initialization command, per ALMA Monitor and Control Bus Interface Specification section 2.2 **[AD11]**. For AMB node address assignments, see ICDs with and documentation by Computing IPT / Control Software.

LRUs having more than one-of-kind location in one antenna or in the AOSTB may need partial disassembly to set location-dependent node address dip-switches prior to installation in the array. Trouble diagnostics sometimes require swapping LRUs between locations. Therefore, to facilitate array operations and maintenance, some BE LRUs will also identify themselves with a plug-in location-dependent node address, per the ICDs with Computing/Control Software. For example, **IFP** in polarization slot 0 or 1; **LO2** in baseband channel BB0, BB1, BB2, or BB3; **DRX** for baseband BBpr0, BBpr1, BBpr2, or

BBpr3 for antenna 1, 2, ... or etc; **LLC** for antenna 1, 2, ... or etc; **PRD, LS and CVR** in sub array 1, ..., or 6). The ALMA system block diagram **[RD3]** shows the multiple LRUs.

All BE equipment with an AMB node, when in On Mode but also in a non-operating state, will report this state to the ABM or ARTM per the ICDs with Computing/Control Software. For example, LO2 reports phase lock failure, DGCK reports phase sync failure, etc.

5.62 Monitor control availability [BEND-06160-00/RT]

All LRUs with an AMB node shall be available for monitor and control at all times during observations **[AD1 Req. 615]**.

5.63 Reliability of BE equipment [BEND-06170-00/A]

By analysis, the mean time between failures (MTBF) reliability of each BE LRU shall be > 5 years **[AD1 Req. 617]**.

5.64 Restart without re-calibration [BEND-06180-00/RT]

LRUs in the signal path and in the non-common mode portion of the LO chains, **5RD, DGCK, DRX, DTX, FLOOG, FOT, LFRD, LLC, LO2, LORR, MLD and PRD,** shall restart without changing system delay (TE-dependent events), which means without recalibrating the telescope beyond a simple phase calibration **[AD1 Req. 618**]. The intent is to avoid lengthy delay recalibration after a routine equipment restart. Restart can mean a reboot of computers, power cycling a LRU or a rack, reset of a LRU or sub-system like the correlator, power cycling an antenna, rebooting the computer network, or a power failure of the array. A phase calibration consisting of observing a single radio source calibrator is permitted. Not permitted are baseline calibrations, delay calibrations, pointing calibration, mechanical alignments and calibration, amplitude scaling, etc. Replacing a piece of hardware may require more extensive calibration. This does not apply to equipment failures.

5.65 Time to restart [BEND-06190-00/RT]

All BE LRUs shall restart in < 15 minutes **[AD1 Req. 619]**. This includes rebooting the complete computing network and the BE subsystem at all antennas and AOSTB. It also includes automatic self-checks and calibrations. It does not include time needed for thermal stabilization after power cycling.

5.66 Interchangeability of identical LRUs [BEND-09000-00/R]

All identical LRUs shall be interchangeable with full functionality of its requirements without manual intervention, such as tuning adjustments, and without downloading firmware or individual special calibration from the AMB or ARTM.

5.67 Power supplies and quality of 230VAC [BEND-09100-00/R]

BE power supplies **PSD** (digital power supply rack)**, PSA** (analog power supply rack) **and any LRU using 230VAC** shall not be susceptible to conducted disturbances on the 230VAC 50 Hz power lines that are equal to or less than:
14 Vrms at harmonic numbers 2 through 10,
8% continuous total harmonic factor THDc,
11% transient total harmonic factor THDt,
0.2% total inter-harmonic factor THDi,
23 V voltage fluctuations, rms and step.
BE power supplies shall not generate conducted disturbances on the 230VAC 50 Hz power lines that exceed 10% of the above susceptibilities. See **AD5**.

5.68 Power distribution [BEND-09200-00/RT]

BE DC power supplies **PSA, PSD and those in PLO**, and their **distribution** to LRUs, shall have operational peak to peak noise < 1% VDC to 20 MHz and shall provide over-voltage protection.

5.69 Electromagnetic compatibility [BEND-09300-00/RT]

Operational racks of BE equipment will conform to the electromagnetic compatibility (EMC) requirements of **AD8** to the extent practicable **and to RD21**. Protection from voltage surges on AC, signal and data lines will be provided where appropriate.

Operational racks of BE equipment in **antennas** will conform, to the extent practicable, to the **RFI emission limit** of $A(f)^{\alpha}$ dBm, where A = [TBD], f = frequency in GHz in the range 1 to 40 GHz and α = [TBD]. Parameters A and α may be determined from measurements according to **RD11** or given by the SE IPT.

Operational racks of BE equipment in **AOSTB** will conform, to the extent practicable, to the **RFI emission limit** of $B(f)^{\beta}$ dBm, where B = [TBD], f = frequency in GHz in the range 1 to 40 GHz and β = [TBD]. Parameters B and β may be determined from measurements according to [**RD9**] or given by Systems Engineering IPT. Also see **RD17**.

Operational racks of BE equipment in **antennas** and in **AOSTB** will conform, to the extent practicable, to the **RFI susceptibility threshold** of $\leq$ PFD(f), where PFD(f) is the power flux density produced at a distance of 1 meter from a dual ridged horn fed with +20 dBm of RF power and f = frequency in the range 1 to 18 GHz. Measurement may be limited to an operational BE article operating in total power and interferometer modes at AOS.

5.70 Safety [BEND-09400-00/RT]

Each BE rack shall shut down power to the rack internal equipment whenever its internal temperature exceeds a safe value, such as when antenna or AOSTB heating, ventilating and air conditioning (HVAC) cooling fails or becomes inadequate. Shut-down sensing and activation shall be fail-safe, without implementation by M&C software. Rack power up recovery shall be commanded via ABM and/or ARTM after adequate cooling is restored. Power supplies shall be self-protecting from internal over-voltages, over-currents and over-temperature. Individual LRUs shall be fused for over-current protection either internally or within a power distributor. See **AD2, AD7, AD15, RD8 and RD22**. Especially see **AD2, section 8.8,** for laser/fiber safety for personnel. Also see Section 3.2 for safety of equipment in off modes.

5.71 Timing event (TE) distribution [BEND-09500-00/RT]

The **CRD** shall generate the master 48 msec timing event **TE**, which is defined as the leading edge of the 6 msec pulse, which is the transition from logic 0 to 1. At M&C command via ARTM, the **CRD** shall synchronize TE with 1 pps from the central GPS receiver. The **CRD** shall distribute TE via low voltage differential signal (LVDS) to the correlators [**RD6**] and data receivers (DRX) and via RS422 transmitter chip [**AD11**] to the ARTM. The **CRD** also shall encode the TE onto the 1532nm optical fiber link to the LORRs in the antennas. The **LORR** in each antenna shall decode the TE from the link. The **LORR** shall distribute the TE to the ABM via RS422 [**AD11**] and via LVDS to **IFPs, LO2s, FLOOG, DGCK and DTXs**. Other LRUs may receive TE via the AMB [**AD11**].

The **TE** distributed from **CRD** and **LORR** via LVDS and RS422 shall have parameters:

event TE = leading edge of pulse (transition from logic 0 to 1 per AMB [**AD11**] and per Table 10 and Table 11),
event rise time ≤ 4 nsec (LVDS), ≤ 40 nsec (RS422),
event jitter ≤ 0.8 nsec rms (LVDS), ≤ 8 nsec rms (RS422),
pulse width = 6 millisec ± 1 millisec,
pulse period = 48 millisec,
termination at end of AMB chain = 120 ohm,
termination at LVDS receiver = 100 ohm,
LVDS transmission on cable and PCB traces of 100 ohm characteristic impedance.

Table 10 Logic for TE = 0 to 1 edge (leading)

LVDS [RD6]	TIMA (Q)	Hi (+) = 1	Low = 0	TIMA ≠ TIMB
	TIMB ($\bar{Q}$)	Low = 0	Hi (+) = 1	TIMA ≠ TIMB
RS422 [AD11]	TIMA (Y)	Low = 1	Hi (+) = 0	TIMA ≠ TIMB
	TIMB (Z)	Hi (+) = 0	Low = 1	TIMA ≠ TIMB

The TE shall be distributed via hardware, cables and connectors according to Table 11.

Table 11 TE distribution hardware

Standard	Driver/Rcvr – TIM	Cable	Connector - Type	Connector Pin
RS422 [AD11]	Y/A - TIMA	Shielded twisted pair Z_0 = 100 ohm	DB9 [AD11]	4
	Z/B - TIMB			8
RS422	Y/A - TIMA	Quadrax pair Z_0 = 100 ohm	Quadrax contact [RD20]	1
	Z/B - TIMB			3
LVDS [RD6]	Q - TIMA	RG108A Twinax pair Z_0 = 78 ohm	BNC Twinax	male pin of cable connector
	$\overline{Q}$ - TIMB			female pin of cable connector
LVDS	Q - TIMA	Quadrax pair Z_0 = 100 ohm	Quadrax contact [RD20]	1
	$\overline{Q}$ - TIMB			3

6 Block diagram of first, second and third LO chains

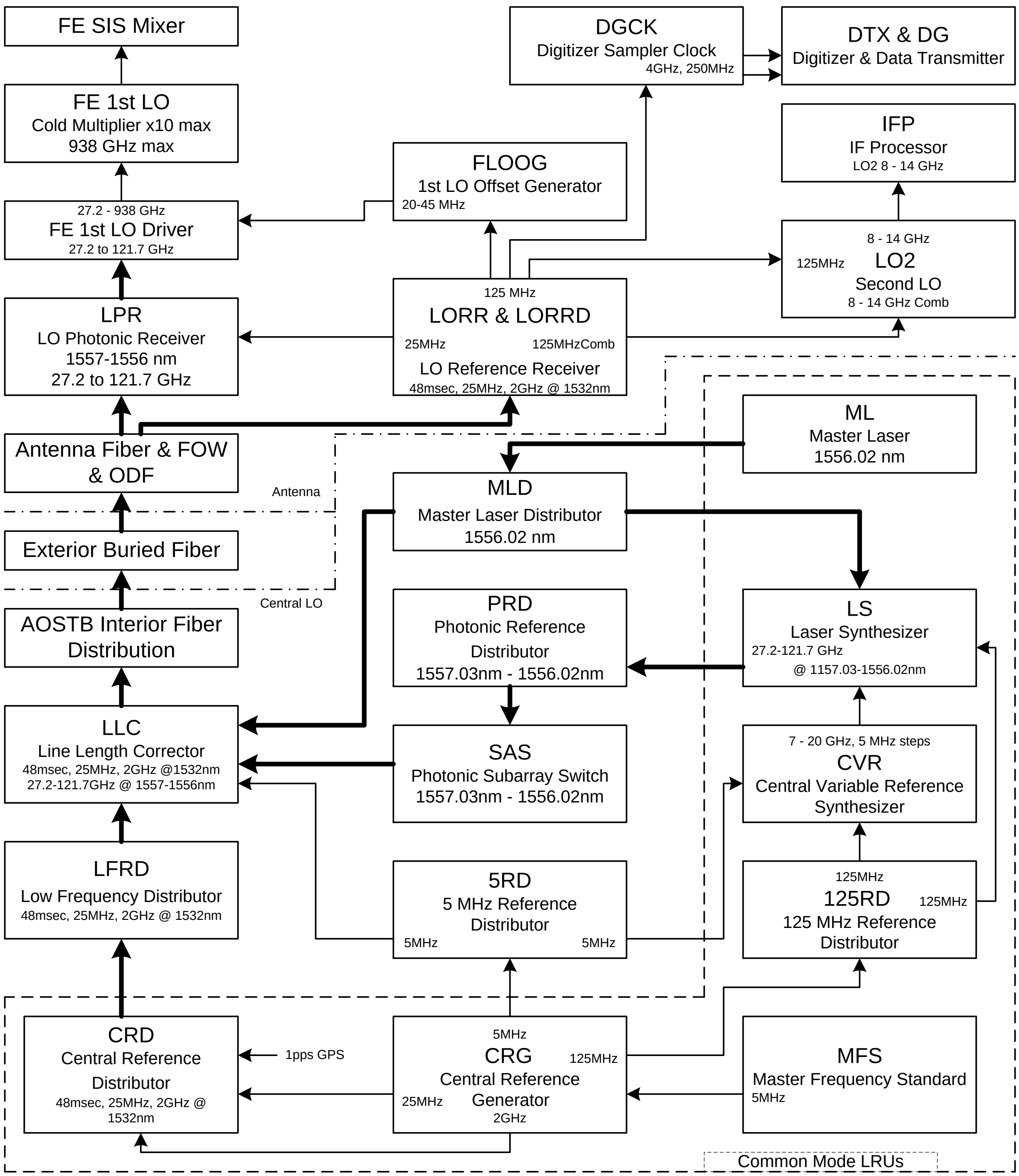

Figure 1: Simplified Block Diagram of ALMA 1st, 2nd & 3rd LO Chains