ALMA System Technical Requirements

ALMA-80.04.00.00-005-C-SPE

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**Prof. Koh-Ichiro Morita passed away on 7th May 2012. We could never have achieved this revision without his large contribution. We would like to offer our most sincere sympathy upon this grievous loss and dedicate this revision to him.*

Change Record

Version	Date	Affected Section(s)	Author	Reason/Initiation/Remarks
A	2004-08-13	All	R. Sramek	First Issue
B	2006-09-21	All	Ch. Haupt R. Sramek	Close out AI from System Requirements Review and correct and complete the ALMA System Requirements Document
C1	2012-07-31	All	K. Morita P. Napier M. Miccolis D. Sramek P. Yagoubov N. Whyborn M. Sugimoto	Revised for ALMA System Review
C2	2012-08-30	2.2 6 7 7.1.8 7.2.22 7.2.24 7.2.39	M. Sugimoto M. Miccolis D. Sramek N. Whyborn P. Napier P. Yagoubov	- 2.2 - Added RD 44 ACA science req. - 7.2.39 and 6 - Sub-array (total 4 to 6) - Sec 6 #444 R to T -Description of identification code inserted - BLC to 64-Ant Correlator - #290 updated -RD22 hyperlink added -RD28 link changed -RD29, RD42 document status added -RD14 link was changed to project level approved document -Req#145 updated -Req#273 numbering minor change -Req#311 T* to T -Req#482 T to R -#227 updated
C3	2012-09-04	2.2 7.3.7,7.3.9, 7.2.41, 7.4.17, 7.4.2	M. Sugimoto	-RD19 link Rev. A to C - #541.1, #542 Note modified -RD20 link -RD17 link -section 5.1.3 and the table #425 3% to 5% #619 note added #680 note added #614 note added -Added RD47

C4	2012-09-12	Several chapters	M. Miccolis	Comments received from IPTs and reviewers, in the frame of the document discussion, before the approval from the CCB.
C5	2012-09-25		M. Miccolis	Further comments.
C6	2012-10-01		M. Miccolis	Removal to explicit reference to VLBI except where flowing directly from Science requirements.
C7	2012-11-07		M. Miccolis	Modified according to the comments from EU Corr IPT and NA FE IPT.
C8	2012–12-06	7.2.25	M. Miccolis	Clarifications on the spurious mask plots
C9	2012-12-10	 7.1.3 7.2.17 7.4.14	M. Miccolis	Feedback from the SV workshop. Clarified that the requirement has to be verified at multiple frequencies Removed the categorization of antennas "optimized for total power" Clarification on applicability of requirement to frequency lower than Band7

Table of Contents

1 Document Description

1.1 Purpose

This document is intended to provide the complete list of the ALMA System Technical Requirements.

Many of the requirements contained here flow down from the higher level ALMA Science Requirements therefore this document provides also a tracking indication of the origin and relationship between a given requirement and its source.
Other requirements are generated at the level of this document, therefore they do not refer to a specific higher level requirement or document.

1.2 Scope

The scope of this document includes the entire ALMA array from the reception of the astronomical signal to the generation of the collected data sent to the archive.

Even where the content of these requirements refers to specific features or performance of ALMA subsystems, this document is actually applicable to the technical capabilities of the entire Observatory.

It is included, in the scope of this document:

- All the 66 array elements both 12m and 7m Antennas
- All the technical equipment located in the AOS building that are directly involved in the generation of the output data (Correlators, Central Local Oscillator, Fiber Optic Demultiplexers and Patch Panels)
- The Software necessary to the work of the above subsystems

It is outside the scope of this document:

- All the AOS, OSF and ancillary buildings, including the living quarters.
- All the commodities (water, power supply, roads, canteen, …)
- The Safety and IT infrastructure
- The interfaces to the Array operators and to the Astronomers for the exploitation of the Observatory

2 Related Documents and Drawings

2.1 Applicable Documents

No	Document Title	Reference
AD 01	ALMA Scientific Specifications and Requirements	ALMA-90.00.00.00-001-A-SPE
AD 02	ALMA Coordinate Systems Specification	ALMA-80.05.00.00-009-B-SPE
AD 03	Change Allen Standard Deviation for Gain Stability to ASDg(2,T,tau=T) in Technical Requirements for BEND Subsystem	ALMA-50.00.00.00-583-A-CRE (CRE-274, approved by CCB on 2011-10-25)
AD 04	Use of LO-Offsetting for Spurious Signal Rejection	ALMA-80.04.00.00-022-A-CRE (CRE-78 approved by CCB)
AD 05	Change the Band 3 Receiver Noise Temperature Specification in ALMA System Technical Requirements Document and ALMA Scientific Specifications and Requirements Document	ALMA-40.02.03.00-230-A-CRE (CRE-196 approved by CCB)
AD 06	Change to IF Bandwidth for Band 6 Cartridges	FEND-40.02.06.00-379-A-CRE (CRE-230 approved by CCB)
AD 07	Change Request for the Band 8 Cartridge Polarization Alignment	FEND-40.02.08.00-0158-A-CRE (CRE-272 and FECRE-49 approved by CCB on 2011-10-11)
AD 08	Change Request for the Band 8 Cartridge Polarization Efficiency	FEND-40.02.08.00-273-A-CRE (CRE-291 and FECRE-54 (supersedes CRE-271), approved by CCB on 2012-04-03)
AD 09	Relaxation of the Band 3 polarization efficiency specification	ALMA-40.02.03.00-0662-A-CRE (CRE-260 and FECRE-40 approved by CCB on 2010-10-23)
AD 10	Change to Cross Polarization Isolation Specification for Band 6 Cartridges	FEND-40.02.06.00-424-B-CRE (CRE-244 and FECRE-27 approved by CCB on 2010-07-06)
AD 11	Change to the “absolute” definition for the polarization orientation alignment accuracy in the Front-End and Cold Cartridges Technical Specifications	FEND-40.00.00.00-211-A-CRE (CRE-235 and FECRE-22 approved by CCB on 2010-04-07)
AD 12	Band 7 Cartridges: Polarisation Alignment Accuracy	FEND-40.02.07.00-253-A-CRE (CRE-232 and FECRE-13 approved by CCB on 2010-04-28)
AD 13	Band 9 Cartridge Cross Polarization	ALMA-40.02.09.00-086-A-CRE (CRE-94 approved by CCB on 2008-03-20)
AD 14	Change Request for the Band 4 Cartridge Polarization Efficiency	FEND-40.02.04.00-0236-A-CRE (CRE-300 approved by CCB on

		2012-06-05)
AD 15	Change to the "differential" definition for Saturation in the Front-End Technical Specifications and relaxation for the Bands 3 and 4.	FEND-40.00.00.00-212-A-CRE (CRE-234 approved by CCB)
AD 16	Band 7 cartridges: Image band suppression	ALMA-40.02.07.00-092-A-CRE (CRE-88 approved by CCB)
AD 17	Band 9 Cartridge Sideband Ratio	ALMA-40.02.09.00-083-A-CRE (CRE-66 approved by CCB)
AD 18	Change to IF Bandwidth for Band 6 Cartridges	FEND-40.02.06.00-379-A-CRE (CRE-230 approved by CCB)
AD 19	Band 7 cartridges: IF power variation	FEND-40.02.07.00-093-A-CRE (CRE-87 approved by CCB)
AD 20	Change Request for the Band 8 Cartridge IF variation	FEND-40.02.08.00-0150-A-CRE (CRE-270 approved by CCB)
AD 21	Band 9 Cartridge Output Power Variation versus Intermediate Frequency	ALMA-40.02.09.00-085-A-CRE (CRE-67 approved by CCB)
AD 22	Upgrade of the pre-production DGCK module design	ALMA-53.04.01.00-001-A-CRE (CRE-79 approved by CCB)
AD 23	Change in the IF Switch Operations Mode and Specifications	ALMA-40.08.01.01-017-A-CRE (CRE-221 approved by CCB)
AD 24	Change the Time to Phase Switch (Requirement # 442) specification in ALMA System Technical Requirements Document	ALMA-40.10.00.00-088-A-CRE (CRE-95 approved by CCB)
AD 25	Change Request for Band 1 Phase Noise	ALMA-56.11.00.00-024-A-CRE (CRE-254 approved by CCB)
AD 26	ALMA Operations Plan	ALMA-00.00.00.00-002-D-PLA
AD 27	Change of Amplitude Calibration Device Technical Specification to modify the attenuation values for the Solar Filter	FEND-40.06.02.01-0018-A-CRE (CRE-273 approved by CCB)
AD28	Change Request for the Band 10 Cartridge Noise Performance	FEND-40.02.10.00-0124-A-CRE (CRE-301 approved by CCB)

2.2 Reference Documents

No	Document Title	Reference
RD 01	System Design Description	ALMA-80.04.00.00-002-A-DSN
RD 02	Fringe Tracking, Sideband Separation, and Phase Switching In the ALMA Telescope	ALMA memo 287

RD 03	Notes On Delay Tracking For ALMA: Resolution and Tolerance	BEND-50.00.00.00-002-A-GEN
RD 04	Frequency Band Considerations and Recommendations	ALMA memo 213
RD 05	Gain Stability Testing For Front End and Back End Assemblies	SYSE-80.10.00.00-003-A-SPE
RD 06	Gain Stability: Requirements and Design Considerations	ALMA memo 466
RD 07	Passband Shape Deviation Limits	ALMA memo 452
RD 08	Enhancing the Baseline ALMA Correlator Performances with the Second Generation Correlator Digital Filter System	ALMA memo 476
RD 09	Joint Distribution of Atmospheric Transparency and Phase Fluctuations at Chatnantor	ALMA memo 521
RD 10	Simulation of Atmospheric Phase Correction Combined With Instrumental Phase Calibration Using Fast Switching	ALMA memo 523
RD 11	Front-End Sub-System for the 12 m-Antenna Array Technical Specifications	ALMA-40.00.00.00-001-A-SPE
RD 12	Interferometry and Synthesis in Radio Astronomy	ISBN: 978-0-471-25492-8. Second Addition, John Wiley & Sons Inc, 2001
RD 13	ALMA System Technical Requirements for 12m array	ALMA-80.04.00.00-005-B-SPE (previous revision)
RD 14	Technical Specification for the Design, Manufacturing, Transportation on Site of the 64 ALMA ANTENNAS	ALMA-34.00.00.00-006-A-SPE
RD 15	Technical Specification for the Design, Manufacturing, Transport and Integration on Site of the ACA 12-m Antennas	ALMA-38.00.00.00-001-A-SPE
RD 16	Technical Specification for the Design, Manufacturing, Transport and Integration on Site of the 12 ACA 7-m Antennas	ALMA-39.00.00.00-001-A-SPE
RD 17	Revised ALMA System Technical Requirements - Spurious Signals	ALMA-80.04.00.00-0042-A-SPE
RD 18	Walsh Function Demodulation in the Presence of Timing Errors, leading to Signal Loss and Crosstalk	ALMA memo 537
RD 19	ALMA Use of LO Offsetting for Spurious Signal Suppression and Sideband Rejection	SYSE-80.04.00.00-018-C-DSN
RD 20	Revised ALMA System Technical Requirements – Polarization	ALMA-80.04.00.00-0038-A-SPE
RD 21	Impact of System level polarization requirements update on the Front-End sub-system specifications	SYSE-40.00.00.00-1215-A-GEN
RD 22	Atmospheric Transmission at Microwaves (ATM):	IEEE Trans. on Antennas and

	An Improved Model for mm/submm applications	Propagation, 2001, 49, 1683
RD 23	ALMA Sensitivity, Supra-THz Window and 20 km baselines	ALMA memo 276
RD 24	The Atacama Compact Array (ACA)	PASJ 2009, 61, 1
RD 25	Design of the Cone at the Centre of the Subreflector	ALMA memo 545
RD 26	Design of the central cone for the subreflector of the ACA 7-m antenna	ALMA memo 574
RD 27	Impact of ACA on the Wide-Field Imaging Capabilities of ALMA	ALMA memo 398
RD 28	Calibration Specifications and Requirements	ALMA-90.03.00.00-001-A-SPE (Withdrawn, CAR-13 and DAR-21)
RD 29	ACA Calibration Plan	ALMA-90.03.00.00-009-A-PLA (Draft shown in ACA System PDR)
RD 30	Beam squint specification: elements for a proposal	by Bernard Lazareff, 2005-11-05
RD 31	Illumination Taper Misalignment and Its Calibration	ALMA memo 402
RD 32	Electromagnetic properties and optical analysis of the ALMA antennas and Front Ends	ALMA-80.04.00.00-026-A-REP
RD 33	Spurious Responses From IF Signals Above 12 GHz	11-May-2010 memo by P. Napier attached to JIRA issue AIV-2057
RD 34	Instrumental Delay	ALMA-80.00.00.00-0015-A-SPE
RD 35	Fibre-Optic Link Design of the Atacama IF Data Transfer System	ALMA memo 349
RD 36	Digital Transmission System Signaling Protocol	ALMA memo 420
RD 37	ALMA Back End Electronics Design Description	BEND-50.00.00.00-077-B-DSN
RD 38	ACA Correlator Technical Specifications and Requirements	ALMA-62.00.00.00-001-A-SPE
RD 39	ICD between ACA Correlator and Computing/ACA Correlator Software	ALMA-64.00.00.00-70.42.00.00-A-ICD
RD 40	ALMA Software Science Requirements	ALMA-70.10.00.00-002-L-SPE
RD 41	Calibration Device Technical Specifications	FEND-40.06.00.00-009-C-SPE
RD 42	Change of Amplitude Calibration Device Technical Specification to include Maximum Allowable Path Error for Solar Filter	ALMA-40.06.00-0003-CRE (Withdrawn, CAR-268)
RD 43	ALMA Solar Filter Core Evaluation in Band 9 Cartridge Setup	FEND-40.06.02.01-026-A-REP
RD 44	ACA Scientific Specifications and Requirements	ALMA-90.00.00.00-013-A-SPE (Draft shown in ACA System PDR)
RD 45	Missing Specification on Receiver Alignment	by Richard Hills, 2012-08-05

RD 46	Water Vapour Radiometer Technical Specifications	FEND-40.07.00.00-001-D-SPE
RD 47	ALMA Engineering Data Access Needs –Archive Access Requirements	ALMA-70.50.00.00-0010-A-SPE
RD 48	The new 3-stage, low dissipation digital filter of the ALMA Correlator	ALMA Memo 579
RD 49	64 Antenna Correlator Specifications and Requirements	ALMA-60.00.00.00-001-C-SPE

2.3 Abbreviations and Acronyms

AA	Antenna Article
ABM	Antenna Bus Master
ACA	Atacama Compact Array
ACD	Amplitude Calibration Device
ACRV	Acceptance Review
ACU	Antenna Control Unit
ALMA	Atacama Large Millimeter/submillimeter Array
AMB	Antenna Monitor and Control Bus
AMC	Active Multiplier Chain
AOS	Array Operations Site
ARTM	ALMA Real Time Machine
ASDy	Allan Standard Deviation of variable y
ATM	Atmospheric Transmission at Microwaves
AZ	Azimuth
BE /BEND	Back End
BER	Bit Error Rate
BW	Bandwidth
CCB	Configuration Control Board
CDP	Correlator Data Processor
CLO	Central LO
CLOA	Central LO Article
CORR	Correlator
CRE	Change Request
CW	Continuous Wave
DC	Direct Current
DGCK	Digitizer Clock
DSB	Double Side Band
DTS	Data Transmission System
DTX	Data Transmitter
EL	Elevation
FDM	Frequency Division Multiplexing
FE / FEND	Front End
FESS	Front End Support Structure
FLOOG	First Local Oscillator Offset Generator
FTS	Fine Tuning Synthesizer
FWHM	Full Width at Half Maximum

HFET	Hetero-structure Field Effect Transistor
HPBW	Half Power Beam Width
ICD	Interface Control Document
IF	Intermediate Frequency
IFDC	IF Down Converter
IPT	Integrated Product Team
IT	Information Technology
LLC	Line Length Corrector/Correction
LO	Local Oscillator
LRU	Line Replaceable Unit
LSB	Lower Side Band
M&C	Monitor and Control
OSF	Operations Support Facility
OTF	On-the-fly
PAI	Provisional Acceptance In-house
PAS	Provisional Acceptance at Site
RF	Radio Frequency
RMS	Root-Mean-Squared
RSS	Root Sum Squared
SB	Scheduling Block
SIS	Superconductor Insulator Superconductor
SRR	System Requirement Review
STR	System Technical Requirement
SW	Software
TBD	To Be Determined
TDM	Time Division Mode
TE	Timing Event
TFB	Tunable Filter Bank
TMCDB	Start-up antenna Class Reference
TP	Total Power
USB	Upper Side Band
UTC	Universal Time Coordinated
VLBI	Very Long Baseline Interferometry
WCA	Warm Cartridge Assembly
WVR	Water Vapor Radiometer
YTO	YIG Tuned Oscillator
2SB	2-Side Band

For a complete set of acronyms and abbreviations used in the ALMA project, please go to https://adewiki.alma.cl/bin/view/Main/AcronymFinder

3 Overview of the System Technical Requirements

This document presents the technical requirements of the ALMA telescope at the system level. These are the parameters that determine the overall hardware performance of the telescope.

A quick reference summary of the requirements is given in Section 6. The requirements are repeated along with detailed explanatory notes in Section 7. In some cases there are notes that apply to a group of requirements and not just to a single requirement, e.g., polarization, gain stability and phase stability requirements. These general notes are found Section 5.
The notes attached to most requirements in Section 7 contain elaborations regarding the meaning, intent and scope of the requirements. They form an important part of the definition of the requirement and should guide the verification procedures.

In many cases the notes contain an explanation or an analysis of how the numeric values of requirements were derived. This may be done in the notes using references to other documents. In this way the history of how the ALMA concept arrived at its present state is preserved for the benefit of future scientists and engineers who will guide the evolution of the telescope.

Finally, the Notes also contain any exceptions to the general statement of a requirement. These are usually in the form of references to change requests (CREs).

Changes to the requirements or new requirements introduced in this document are entered in the requirements summary in Sections 6 and in the detailed discussion of each requirement in Section 7. These new or changed requirements may come from a more recent analysis of what is needed to meet the ALMA scientific requirements or from early operational experience. However, this has to be done with care. It is often too late in the project to introduce new requirements when much of the equipment has already been designed and built. Also, some desired specifications may simply not be achievable, especially within budget and schedule constraints.

However, we don't want to lose sight of what is currently considered needed to deliver the ALMA science. Such new requirements or tightening existing requirements will serve as guidelines for future upgrades or modifications to the ALMA system.

Therefore, where it is feasible, changes in the requirements are introduced and justified (in some cases, relaxing existing requirements). Where it is not feasible to change the requirements, the desired performance specifications are presented in the requirement notes for consideration for future development and upgrades.

Both the ALMA 50-element main array and the Atacama Compact Array are covered by these requirements. In the tables, requirements may be applicable to the Main 50-element Array (M), the 4-element Total Power Array (T) and/or to the ACA 7-meter Array (7). A blank in this field indicates the requirement is applicable to all arrays.

3.1 Changing the STR Version B to Version C

This latest version reflects improvements in our understanding of the ALMA system since the System Technical Requirements Version B (STR-B) was released in September 2006.

The major features of STR-C are:

- The scope of the document is largely unchanged, except as noted below. In reality, the STR document contains mostly requirements on the signal processing electronics hardware, from the antennas through to the correlator output.
- The requirements for the ACA are included along with those of the Main Array.
- The explanatory notes are expanded as needed.
- The explanatory notes are embedded with the numbered requirements in the main table of STR-C. In STR-B they are at the end of the document and can easily be missed.
- Although STR-C is consistent with the higher level Science Requirements and will take note of the sub-system requirements, it does not include a full analysis of requirements flow-down. This is done in separate documents (see Section 4. for references).
- The STR-B requirement numbering is not changed except new numbers will be introduced for any new requirements that are added. If a requirement is removed, its number will be retired and not used again.
- Requirements that were uncertain in STR-B and tagged with TBD (To Be Determined) will be resolved.
- System Requirements that are impacted by approved CREs will be updated or noted.

4 The Flow Down of Technical Requirements

The source of the requirements contained here are the documents describing the "use of ALMA for science" [AD 01].
An analysis of the Science cases that generate this System Technical Requirements document is not contained in a specific document, rather most of the requirement listed here are associated to a sort of "justification discussion" that clarify the background and the rationale that led to the definition of the requirement as it is now.

Several more detailed technical specifications are derived from this document and provide requirements to specific sub-systems. Those requirements need to be clearly referred to their parent requirements (where applicable) in this System Technical Requirement Document.

4.1 Flow Down from Science Reqs

At chapter 6 of this document, in the table containing the summary of the ALMA Technical Requirements, it is reported also the reference of their origin, when coming from the ALMA Scientific Requirements document [AD 01].

Moreover, in several cases the rationale of the flow down is described in the note associated to the detailed requirements reported in chapter 7.

4.2 Flow Down to Software Reqs

Some of the requirements contained in this document have relevance in the definition of ALMA SW expected capabilities and performances. For example Req #520 that asks for the implementation of Tunable Filter Banks (TFB), is mapped into CORR-10 within the SW Feature Spreadsheet.

Since there wasn't a formal requirement flow down process, for SW, the links between the requirements in this document and the list of SW features have been only recently tied starting from release B of the System Technical Requirement document.
Any further modification of the requirement contained here should maintain the consistency with lower tier document and the CCB, with in the process of document change, should guarantee that the links are not broken.

Notice that, some times (e,g, for some SW requirements), the requirements flow down process goes from Observatory top level requirements directly to SW requirements. Some other times the "end user" Science Requirements flow down to the SW requirements through the System Technical Requirements.

4.3 Flow Down to Other Sub-System Reqs

The requirements contained here are flown down into the sub-system specifications. Nevertheless the relevant version of the sub-systems Technical Specification remains that which was applicable at the time of the sub-system relevant PAI, PAS or ACRV.
New sub-system requirements derived from this document become only applicable after the acceptance of a CRE for the update of the Technical Specification of the relevant sub-system

The System Technical Requirements that flow into Front End requirements are indicated in the text of the individual relevant requirements in the FE Specifications.

For what concerns the Specifications of the Back End the flow down of the requirements is obtained including the "original" System Technical Requirement number in the numbering convention of the Back End requirements as described below.

BEND-XXXXX-YY/ZZZ

Where: BEND stands for "BackEnd";
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 this System Technical Requirement Document;
YY describes the requirement revision and starts with 00;
ZZZ describes one or more verification methods.

The Antenna Specification, on the other hand doesn't contain any reference to the System Technical Requirement Document.

4.4 Links to Operations, Maintenance, Availability Safety Reqs

Operations and Maintenance Plans do not contain any reference to this System Technical Requirements document.

Rather these requirements are already embedded into the lower tier hardware requirements such that they flow down as Construction requirements rather than Operation ones.

5 General Notes for Groups of Requirements

Hardware system requirements apply to performance before operational calibration is done. The accuracy of calibration that is needed to meet the higher level science requirement is included in the system requirements notes and may be reflected in other system requirements.

The hardware requirements apply to a properly functioning system and assume that all parts of the system that would normally be in place during observations are working properly (e.g., LLC, antenna metrology).

5.1 Delay and Phase Stability: Req #151, 152 and 450 through 459

Delay and phase stability are closely related. A delay change produces a signal phase change that is proportional to frequency, arising for example, from a change in cable length. Alternatively, all frequencies in a bandpass range can be shifted by the same phase if the phase of a local oscillator experiences a phase shift.

In these requirements, the expression "delay stability" or "delay/phase" will be used for both situations, path length or LO change. The units of time will be used to express delay/phase stability, typically in femto-seconds (fsec), which is 10^{-15} seconds. The resulting phase change can always be found by multiplying the delay by the appropriate frequency.

5.1.1 Introduction

Variations in the instrumental delay/phase cause two effects:

- loss of coherence and thus loss of sensitivity due to fluctuations faster than the elementary integrating time (**delay noise**), and,
- errors in the phase of the calibrated visibility measurements due to fluctuations on longer time scales (**delay drift**), up to the length of a full calibration cycle.

For the requirements given here, the time scale division between delay/phase **noise** and delay/phase **drift** is defined as one second.

Variations in instrumental delay/phase (both noise and drift) arise from changes in the electronics equipment signal path and in various mechanical structures; these can be separated into two types:

- variations which are a function of time, usually thermally or wind induced (see Req #151, 152, 451, 452), and,

- variations which are a function of antenna pointing angle, usually due to cable movement or twisting, structural deformations under changing gravity vector or equipment deformation (see Req #456, 457, 458 and 459).

Delay/phase variations as a function of antenna pointing angle are separated into systematic and random changes. By definition, random changes will tend to average towards zero with repeated observations, while systematic changes do not decrease, are more damaging and should have a different level of constraint. Different requirements are given for small angle changes which impact phase calibration and large angle changes which impact antenna position determination and astrometric observations.

The large angle variations can be estimated from the residual phases after an antenna position determination; however some systematic instrumental errors may be subsumed into any single antenna position solution.

It is assumed that the temporal and antenna pointing angle phase error contributions are independent and RSS additive.

For both delay/phase changes with angle and with time, the quantity that is measured is the delay/phase difference of the signals processed through two antenna systems. Making the assumption that the phase variations in the two antennas are uncorrelated, $1/\sqrt{2}$ of the measured delay/phase difference will be taken as the delay/phase variation of each antenna system.

In these requirements, the limits on delay/phase variations always refer to the per antenna variations.

5.1.2 Establishing the Temporal Delay/Phase Stability Requirements

The requirements on temporal delay/phase noise and drift, on time scales up to 300 sec, are based on the idea that the delay variations caused by the instrument should be smaller than those caused by the natural environment for at least 95% of the time. These natural limits are those imposed by the residual delay fluctuations of the troposphere after all available corrections have been applied.

More specifically, the system requirement on the total permitted temporal instrumental delay/phase variation is set to be less than the tropospheric delay error under the best 5th percentile atmospheric conditions after WVR and fast switching corrections are applied.

(n.b. fast switching is an observing technique involving switching the antenna pointing between the target and a reference source with a cycle time of 10 or 20 seconds for the purpose of phase calibration. It is distinct from frequency switching which involves LO switching with a cycle time of tens of milli-seconds.)

Statistics of the tropospheric fluctuations at the Chajnantor site are available from more than six years of site testing [RD 09]. Simulations, using a range of atmospheric conditions, were done to estimate the effects of various calibration techniques, including rapid phase referencing to a nearby calibrator (fast switching) and inter-band instrumental phase calibration (see [RD 01] and [RD 10]).

Three observing and calibration techniques were considered for use in the simulations. Consider these three Cases:

1. Two-frequency fast switching. A phase calibrator is observed at a different frequency from the target source, with the calibrator observations rapidly interspersed between target source observations. This is repeated with a cycle time T_1 of about 10 to 20 sec. A separate observation of a calibrator at both frequencies is then made to determine the difference of instrumental phases between the two frequencies. This is done less often, with cycle time $T_2 \sim 300$ seconds $> T_1$.

   This sequence would typically be used when observing in the high frequency bands where suitable nearby phase calibrators are rare and delay/phase calibration must be done at a lower frequency where the density of suitable calibrators is higher [RD 10].

2. Single frequency fast switching. Again, phase calibrator observations are rapidly interspersed with target source observations at cycle time T_1, but with both at the same frequency.

3. No fast switching. A phase calibrator is observed at interval T_2, and at the same frequency as the target.

These different Cases lead to different delay/phase stability requirements; the more stringent requirements were then selected to define the system level requirements.

In Case 1, the requirements are based primarily on simulations with $T_1 \cong 20$ sec and $T_2=300$ sec [RD 10]. The fast switching calibrator observation simultaneously removes the tropospheric delay fluctuations and the instrumental phase. However, the instrumental drift requirement is on a time scale of 300 seconds and is determined by the need to constrain the instrumental phase between the slow calibrations, T_2, which link the phase at the two bands.

Some parts of the electronics are common to both frequency band observations. Any drift in the IF system which is common to both calibrator and target observations would not be significant if it were not for the fact that the low frequency phase data needs to be scaled up to correspond to the high frequency data. This scaling factor is the ratio of the observing frequencies, and for Bands 3 and 10 equals 8.7. Multiplying one data stream by this factor destroys the common mode cancellation.

For fast fluctuations on time scales $\gtrsim$ 1 second, it is likely that corrections based on water vapor radiometry alone will produce residuals about the same as with fast switching alone. In practice, a combination of the two techniques will probably be used.

In Case 2 both the tropospheric correction and the instrumental calibration are performed at one frequency and the delay/phase drift is important only for intervals ~T_1 ~ 20 seconds. There is one less calibration step in Case 2 compared to Case 1, and thus the instrumental stability requirement at 20 seconds could be relaxed. Since the phase stability at 20 seconds will certainly be equal or better than the stability at 300 seconds, it is the **Case 1** requirements, which use the longer time scales of 20 to 300 seconds, which are more demanding and should define the delay/phase drift requirements.

In Case 3 the calibrator observation cannot effectively remove the tropospheric fluctuations and serves mainly to calibrate the instrumental phase. It applies for example if the tropospheric effects are negligible or have been corrected by other means (e.g., WVR measurements). Then the instrumental phase drift at the single frequency is important at interval T_2 and is set equal to the anticipated accuracy of the WVR. Again, **Case 1** offers the stricter requirement.

Therefore, **Case 1** forms the basis of the system delay/phase requirements which are given as the bottom line of Table 1, the "Total Instrumental Error".

These values were determined as follows. The rms residual atmospheric phase after fast switching phase calibration is given by Eq (1) of RD10,

$$\sigma_\phi = \sqrt{D_\phi\left(\frac{v_{atmos} * t_{cycle}}{2} + d\right)}$$

where D_ϕ is the structure function of the atmospheric phase variations, v_{atmos} is the velocity of the atmosphere at the height of the turbulent layer, t_{cycle} is the fast switching cycle time, and d is the linear distance between the lines of sight to the target source and the calibrator at the altitude of the turbulent layer. Typical values are v_{atmos} = 12 m/s and t_{cycle} = 20 sec; with the target and calibrator separated by 1 deg and the height of the turbulent layer 500 m above ground, d is about equal to 10 meters. This means that the residual atmospheric phase

is the phase structure function evaluated at 130 meters. For baselines longer than this, atmospheric phase errors will be reduced to this level. For shorter baselines, fast switching will offer no improvement and should be avoided.
Based on simulations, Section 7.1 and Table 6 of RD10 present the rms atmospheric residual phase for an antenna pair, observing at bands 9 and 10 under 5th percentile atmospheric conditions. These values are divided by $\sqrt{2}$ to give the rms contribution for a single antenna. What is called "phase jitter" in RD10 is called "phase noise" in this document.
It follows that for baselines shorter than 130 meters, under the very best atmospheric conditions, the instrumental phase variations will exceed those due to the atmosphere.

5.1.3 Allocation of Temporal Delay/Phase Stability Requirements

The allocation of temporal delay/phase requirements among the electronics sub-systems and the mechanical structure is given in Table 1. The various quantities are combined in an RSS sense.

Component	**Noise**	**Drift** 20 to 300 seconds
First LO - FE	38	13
First LO - BE	38	13
Signal Path FE - RF	22	10
2nd LO & Digitizer clock	17	4
Signal Path BE (IF common)	24	4
Subtotal for Electronics	**65**	**22**
Structure	38	13
Total Instrumental Error	**75**	**25**

Table 1: Allocation of Temporal Instrumental Delay/Phase Errors
(per antenna errors, in fsec)

Notes:

1. The two entries: "2nd LO & Digitizer clock" and "Signal Path BE (IF common)", are actually fixed values in phase which do not scale with frequency. However they are expressed in fsec and should be understood to apply at 950 GHz. Expressing these errors in fsec allows them to be combined with the other terms which do scale with frequency.

2. For the First LO, the phase error expressed as time (fsec) is the phase error expressed as angle divided by the LO frequency. The qualifiers -BE and -FE refer to those parts of the First LO system assigned to the Front End and Back End IPTs.

3. The temporal delay/phase error allocation to "Structure" refers to the mechanical structure of the antenna, and arises from wind or thermal distortions of the antenna. The delay error is a function of the direction of the incident wave front and direction of the antenna distortion. These errors are addressed in Requirements #151 and #152.

   Rapid movement of the antenna on time scales less than an integration period (e.g., buffeting by the wind), is constrained by the **Structure-Noise** requirement. Slower movement of the antenna on time scales longer than a fast switching cycle, ~ 20 seconds (e.g., quasi-steady wind or thermal distortion) is constrained by the **Structure-Drift** requirement. This is like a phase change due to an error in antenna location and is therefore differential over angle. The Structure-Drift requirement is defined as the difference in delay/phase as the antenna is switched over 2.0 degrees in the fast switching phase calibration process. (n.b., this is changed from 1.5 degrees in [RD 13] to be compatible with the antenna non-repeatable residual delay error requirement, Section 5.6.2, RD 14)

   Note that this **Structure-Drift** term is different from phase errors arising from shifting or twisting of electronic cables or flexing of the Front End structure as the antenna pointing angle is changed. These errors are addressed in Requirements #456 through #459.

   The allocation of errors in Table 1 between the "Structure" and the "Electronics" is somewhat arbitrary, with 25% of the squared error allowed for the structure.

4. The Antenna Technical Specification [RD 14] calls for 15u (50 fsec) non-repeatable residual delay error on time scales of < 180 seconds (Section 5.6.2). The RSS of System Technical Req #151 and #152 is 40 fsec. There is thus a discrepancy between these two requirements that is noted here but not resolved since there should be little impact on array performance. See additional notes to Req #151.

5. The temporal delay/phase error allocations that are summed as "Subtotal for Electronics" are addressed in Requirements #451 and #452.

6. The delay/phase drift requirements in Table 1 apply on a time scale up to 300 sec, which is taken to be the length of a complete instrumental calibration cycle. It is desirable to meet this requirement over longer intervals so as to allow longer

calibration cycles; a goal is to meet the delay/phase drift requirement on time scales of 1000 sec.

7. It is recognized that the allocated delay errors produce a significant loss of coherence in Bands 9 and 10 and therefore it is considered a goal that the system should provide delays errors that are smaller that allocations, in order to reduce these losses.

If the Total Instrumental Error delay/phase noise requirement is met, the expected coherence of an interferometer pair is given below at various ALMA observing bands.

Band	Coherence	Frequency
Band 1	0.9997	at mid frequency
Band 2	0.9986	at mid frequency
Band 3	0.9978	at mid-frequency
Band 4	0.9954	at mid frequency
Band 5	0.9923	at mid frequency
Band 6	0.9870	at mid-frequency
Band 7	0.9770	at mid-frequency
Band 8	0.9574	at mid frequency
Band 9	0.9075	at mid-frequency
Band 10	0.8184	at max. freq. 950GHz

The coherence is given by $C = e^{-\sigma^2/2}$ where σ is the rms phase error, in radians, of a pair of antennas, i.e., $\sqrt{2}$ times the error contribution of a single antenna.

5.1.4 Calculating Delay/Phase Noise and Drift

The short period delay/phase **noise** requirement refers to the RMS deviation delay/phase from a 10-sec average. The requirement applies to the integrated phase noise from the highest significant frequency (~1 MHz) down to 1Hz.

The delay/phase **drift** requirement refers to the 2-point Allan Standard Deviation with a fixed averaging time, τ, of 10 seconds and intervals, T, between 20 and 300 seconds.

$$\sigma^2(2,T,\tau) = 0.5 * <[\varphi_\tau(t+T) - \varphi_\tau(t)]^2>$$

φ_τ is the average of the absolute or differential phase over time τ = 10 seconds;
< … > means the average over the data sample which should extend to 10 or 20 times the largest value of the sampling interval T that is used.

Note that this usage of the name "Allan variance" and other related terms is somewhat non-standard.
Strictly speaking, the Allan variance refers to the 2-sample variance of fractional frequency and was introduced by David Allan in his studies of oscillator stability. Here the same formalism is used and the name Allan variance extended to mean the 2-sample variance of phase and of gain.

5.2 Gain Stability: Req #261, 262 and 263

The noise power delivered to the correlator is the product of the system gain and the sytem temperature, G * T_{sys}, where $T_{sys} = T_{atmos} + T_{rcvr} + T_{spillover} + T_{3K} + T_{astro}$. In the requirements discussed here, only the variations in G, as a function of time and the pointing angle of the antenna are considered.

There are currently no system requirements on the stability of T_{rcvr} or $T_{spillover}$ in time or angle.

Requirements on system gain stability flow down from the science requirements for the accuracy of total power observations and interferometric observations.

5.2.1 Total Power Observations

Total power observations are based on the difference of auto correlation spectral power (or perhaps analogue total power detector output) between two switched states. For example, these two switched states might be two beam pointing positions using nutator beam switching. They also might be the on-source measurements during an OTF scan versus the off-source measurements at the end of the scan. Frequency switching is another example. The time scale of the switching is typically between 0.1 second and 1.0 second.

Gain variations on time scales shorter than the switching period limit the extent to which the measurement accuracy decreases as $1/\sqrt{T}$ and lead to Req #263 and partially to Req #261.

Gain variations on time scales longer than the switching period but shorter than the interval between external ACD calibration impact the accuracy of the calibration of the total power observation and/or add noise when integrating for longer periods. This leads to Req #262 and partially to Req #261.
The value of the total power gain stability requirements are based primarily on the studies reported in [RD 06] and the testing method in [RD 05], and they are stated in terms of the 2-point Allan standard deviation of the fractional gain variation $\Delta G/G$.

With a CRE [AD 03] it was established that variations of system gain will be defined in terms of $\sigma^2(2,T,\tau=T)$, i.e., τ is not a fixed quantity, unlike that used for phase. In [RD 13] the details of the ASD were given for the delay/phase variations but were not specified for the gain variations.

Tentatively, and somewhat arbitrarily, the four requirements on system gain stability are allocated equally to the Front End components and the "back end" components (down converter, baseband processor, 2nd LO, digitizer) of the signal path. On the assumption that gain fluctuations in FE and BE are independent, 0.707 of the standard deviation is allocated to each.

5.2.2 Interferometric Observations

The original intent of Req #261 and #262 was to constrain the system gain variations that would limit the accuracy of interferometry observations and calibration. However, the current practice in ALMA is that the cross-correlation products are normalized by the auto-correlations in the correlator,

$$V'_{ij} = \hat{g}_i\ \hat{g}_j^* < v_i\ v_j^* > \Big/ \sqrt{\hat{g}_i\ \hat{g}_i^* < v_i\ v_i^* > \hat{g}_j\ \hat{g}_j^* < v_j\ v_j^* >}$$

$$= g_i g_j e^{-i(\theta_i - \theta_j)} < v_i\ v_j^* > \Big/ g_i g_j \sqrt{< v_i\ v_i^* >< v_j\ v_j^* >}$$

$$= e^{-i(\theta_i - \theta_j)} < v_i\ v_j^* > \Big/ \sqrt{< v_i\ v_i^* >< v_j\ v_j^* >}$$

Where v_i is the equivalent voltage at the input to an antenna, $\hat{g}_i = g_i e^{-i\theta_i}$ is the complex voltage gain of that antenna and V'_{ij} is the normalized visibility or correlation coefficient of the noise input signals of antennas *i* and *j*. V'_{ij} is zero for completely uncorrelated noise signals and varies between +/- 1 for correlated noise.

V'_{ij} is the ratio of correlated power to the mean uncorrelated power in the two antenna signals and therefore is independent of system gain.

$$V'_{ij} \propto {P_{ij}} \Big/ {\sqrt{P_{sys,i}\, P_{sys,j}}}$$

However, V'_{ij} does depend on the square root of the total power in each antenna signal, i.e., it depends on T_{sys}. Therefore V'_{ij} is multiplied by $\sqrt{T_{sys,i}\, T_{sys,j}}$ to put the cross-correlation in physical units related to power. T_{sys} is measured using the ACD at each source change and periodically in time as the atmospheric contribution to T_{sys} changes. Also, atmospheric ATM models and water vapor contributions measured by the WVRs are used to estimate atmospheric variations in $T_{sys.}$ Note that these measurements also do not depend on system gain.

Therefore, interferometric observations do not impose a requirement on variations of system gain with time.

One way this might change is if T_{sys} had to be measured on time scales shorter than is practical with the ACD (about once every few minutes). If the analogue total power detectors or the correlator auto-correlation are used to estimate T_{sys}, the accuracy of these measurements does then depend on system gain stability.

Although the above argument ignores complications that arise from the fact that these measurements are actually done as spectral observations and that image sideband contributes to the signal power, these complications do not change the basic conclusion.

5.2.3 Gain variation with Antenna Pointing Angle

If the current practices remain in place where:

1) total power observations are calibrated with the ACD for each target source, and the calibrations interval is kept sufficiently small that the antenna pointing angle does not significantly change, and

2) interferometric observation are normalized by the auto-correlations, the T_{sys} correction is done using the ACD, and no T_{sys} correction is needed between ACD measurements,

It follows that there is no constraint on system gain changes with antenna pointing angle.

5.2.4 Possible Changes in Requirements Relating to Gain

- There may be a need for a requirement on the stability of Trcvr with time and/or antenna pointing angle if it is found that variations in Trcvr limit the accuracy of the ACD calibration of total power or interferometric observations.
  - An example of this might be Trcvr variations in time and/or angle across a large, several degree, total power raster scan.
  - Another example could be Trcvr variation on time scales short compared to the time between ACD calibrations of an interferometric observation.
- There may be a need for a requirement on the stability of system gain with time if the analogue total power detectors or auto-correlation data are needed to calibrate Tsys on time scales shorter than the ACD calibration period (see Section 5.2.2).

5.3 Spurious Signals: Req #290, 292, 293, 295.1, 295.2 and 297

An extensive discussion of the flow down of requirements regarding the permitted level of spurious signals is given in [RD 17]. The analysis in that document forms the basis for the updates to the system requirements given here.

In the earlier Version B of the System Technical Requirements [RD 13], the requirements on spurious signals are found in #290, 292, 293 and 295. In the revised version given here, these requirements retain their basic content, but # 295 has been explicitly divided into two parts, 295.1, relating to the intensity of narrow band coherent signals, and a new requirement 295.2 relating to the amplitude stability in time of narrow band coherent and incoherent signals. Also a new requirement #297 is introduced here constraining the stability of the power in spurious signals integrated the 2 GHz bandwidth of the Total Power Detectors.

Below are some general notes on spurious signals, taken from section 6.2.1 of [RD 17].

1. These requirements apply to self generated spurious signals within the array and do not address external Radio Frequency Interference.

2. These requirements give limits to spurious signals that appear in the spectral auto-correlation and cross-correlation outputs of the correlator, and which impact the 2GHz Total Power Detector output.

3. In these requirements, the term "coherent spurious signals" refers to signals that are coherent between antennas. Constraints on coherent spurious signals that are coherent between polarization channels are covered in the system polarization requirements #224 #225 and #226.

4. Spurious signals are divided into two classes, narrowband and broadband. In both cases the requirements will include an integration bandwidth to define the integrated power in the spurious signal. A pure sine wave or CW signal, such as an LO signal, would be a limiting case of a narrowband coherent signal.

5. Incoherent and coherent spurious signals could limit the spectral dynamic range. There is a scientific requirement, SCIE 70, on spectral dynamic range of 10,000:1, for weak spectral lines in the presence of stronger spectral lines, and 1000:1, weak spectral lines in the presence of strong continuum emission.

   Flowing down from this are two main technical requirements: (i) Sys Req 273, that the bandpass be sufficiently stable in time that it does not give false appearance of weak lines, and (ii) Sys Req #290 to 295, that there should not be self generated spurious features in the output spectra.

6. Single dish spectral observation will generally be performed using nutator switching, frequency switching, or On-The-Fly (OTF) scanning. A common technique is to difference the spectra, (signal - reference)/(reference), which effectively calibrates the bandpass every switching period or OTF subscan duration. The quality of the calibration then depends on the stability of the spectra for the duration of the switching cycle or the OTF subscan. Besides the spectral stability, other issues include spurs on local oscillators, alias response and other spurious responses within the receiver chain.

7. Pulsar and other time domain observations are another area where instrumental effects may impact the data quality. Such issues are beyond the scope of these spurious signal system requirements.

8. In interferometry mode, spurious signals coherent between antennas can lead to a) spurious spectral features, b) closure errors which limit calibration accuracy and thus image dynamic range, and c) image defects, usually broad stripes and ripples throughout the field, which limit the continuum sensitivity.

   LO-offsetting and 180º phase switching (Walsh switching) can be used to reduce the impact of spurious signal introduced after the 1st LO by ~30dB. [see RD 18, AD 04 and RD 19]

9. Suppression due to the natural fringe rate in interferometry mode is not considered since it can be near zero on short baselines or when the baseline vector u component is near zero.

The limits on the intensity of spurious signals given in these requirements are before a) 180º phase switching or LO Offsetting suppression in interferometry mode, or b) nutator switching, OTF differencing, or frequency switching in single dish mode.

5.4 Polarization: Req #205, 224, 225, 226 and 264

In this section, comments that apply collectively to several polarization requirements are presented. See Section 7 for comments on individual requirements.

In the earlier Version B of the System Technical Requirements [RD 13], the requirements on polarization are found in #205, 224, 225, 226 and 264. In the revised version given here, these requirements retain their basic meaning, but the numerical values of some requirements are changed.

An extensive discussion of the flow down of the polarization requirements is given in [RD 20]. In this document the values of system level technical parameters regarding cross-coupling between polarizations and gain stability are established in order to meet the top level scientific requirement, which states that the errors in polarization measurements should be less than 0.1% of the total intensity. In doing this, some assumptions are made about calibration accuracy and the degree to which antenna based errors are independent.

Accepting the analysis in [RD 20] doesn't mean that the system technical requirements should be tightened. As discussed in Section 3, it is too late in the project to introduce changes in the requirements when much of the equipment is already designed and built. Also, some desired specifications may simply not be achievable, especially with budget and schedule constraints. However, we don't want to lose sight of the impact of not tightening the requirements on the scientific performance of the telescope.

Therefore, where it is feasible, changes in the requirements are introduced and justified (in some cases, relaxing existing requirements). Where it is not feasible to change the requirements, the desired performance levels are presented in the requirement notes for consideration for future development and upgrades.

In particular, the impact of the polarization requirements suggested in [RD 20] on the Front End sub-system are discussed in a note by P.Yagoubov [RD 21]. These will be discussed in the specific notes to requirements #205, 224, 225 and 226.

5.4.1 The D-Terms

Below is an extract from [RD 20].

The D terms (amplitude and phase) represent the fraction of the input signal voltage in one polarization channel, $\mathcal{V}_Y$, that leaks into the output of the other polarization channel $\mathcal{V}_X'$.

$$\mathcal{V}_X' = \mathcal{V}_X + \mathcal{V}_Y * D_X$$

The D terms are dimensionless complex numbers, typically with a magnitude of a few percent in radio telescopes. If $\mathcal{V}_X = 0$, the amount of power that is leaked to the opposite polarization output is

$$< \mathcal{V}_X' \mathcal{V}_X' > = < \mathcal{V}_Y \mathcal{V}_Y > * D_X^2$$

This ratio is used in hardware specifications for cross-polarization power. It is often used in presenting total power cross-polarization of antenna feeds.

When a polarization cross product is taken in a cross-correlator for example, the D terms represent the fraction of the power in one polarization channel that appears as cross-polarization power.

$$< \mathcal{V}_X' \mathcal{V}_Y' > = < \mathcal{V}_X \mathcal{V}_Y > + < \mathcal{V}_Y \mathcal{V}_Y > * D_X$$

This ratio is used in discussing the instrumental cross-polarization found in a synthesis array image.

Slightly more complicated, the D-terms are actually a function of the position of the source in the antenna primary beam, $D(\theta)$. The co-polar and cross-polar power levels as a function of beam position are the primary beam response and the polarization beam response. Three of the System Technical Requirements discuss different aspects of the D-terms.

Requirements #224 (on-axis polarization) constrains the value of $D_{RF}(0)$, the polarization cross-coupling measured on-axis of the primary beam, which arises from RF components such as the antenna geometry and optics, Front End optics and the Front End polarizer.

Requirements #225 (off-axis polarization) constrains the value of $D_{RF}(\theta)$ off-axis of the primary beam, typically arising from the same RF components as $D_{RF}(0)$. Typically the magnitude of the cross-polarization is several time larger off-axis than on-axis. This is difficult to predict from Front End patterns and antenna geometry and is best verified by observations using the full antenna plus Front End system.

Requirements #226 (cross coupled IF) constrains the value of $D_{IF}(0)$ the cross-coupling power between polarization channels in the IF system after the RF mixer. By definition, it does not depend on the location of the source in the primary beam.

5.5 Band Dependent Performance Requirements

Band No.	Frequency Range, GHz	Max. Rcvr. Temperature (100% of band), K	Max. Rcvr. Temperature (80% of band), K	Bandwidth	Front End Type	IF Range, GHz
1	31.3-45.0	26	17	8 GHz per polarization in IF range	HFET, USB	4-12
2	67—90	47	30	"	HFET, LSB	4-12
3	84—116	43[a]	39[a,b]	"	SIS, 2SB	4-8
4	125—163	82	51	"	SIS, 2SB	4-8
5	163—211	105	65	"	SIS, 2SB	4-8
6	211—275	136	83	"	SIS, 2SB	5-10[c]
7	275—373	219[d]	147	"	SIS, 2SB	4-8
8	385—500	292	196	"	SIS, 2SB	4-8
9	602—720	261[e]	175[e]	"	SIS, DSB	4-12
10	787—950	344[e]	230[f]	"	SIS, DSB	4-12

Table 2: Band-Dependent Requirements

Notes:

[a] Noise temperature averaged over all four IFs 4 GHz bandwidth.

[b] Noise temperature at LO = 104 GHz. LO = 104 GHz corresponds to RF frequencies in the range of 96 – 100 GHz and 108 – 112 GHz, which excludes the CO J = 0→1 transition line [AD 05].

[c] IF range with all guarantied performances is 6-10 GHz. Expanded 5-10 GHz IF range allows to observe 12CO and 13CO simultaneously, however Req.220 (Receiver Noise Temperature) does not apply to this expanded IF range and Req.272 (Bandpass Shape: gain vrs freq; wide band) relaxed over 5-6 GHz [AD 06].

[d] Relaxed noise temperature ,< 300 K, for the RF frequency range 370 - 373 GHz.

[e] DSB noise temperatures.

[f] 230 K over 80% of a reduced frequency range (787-905 GHz) [AD 28]

6 Summary Table of System Technical Requirements

In the identification code for the requirements "M" refers to the EU and NA Antennas and/or to the 64-Antennas Correlator. "T" refers to Total Power PM antennas or any other 12 m antenna used as a TP antenna. "7" refers to the 7 m Antennas. "T/7" refers to the ACA Correlator and relevant array.

Parameters	Req #	.#	Value	Sci #
Antenna				
Ant: Number (R)	100	M	>= 50	100
	100	T	4	
	100	7	12	
Ant: Diameter (R)	120	M	12 m	100
	120	T	12 m	
	120	7	7 m	
Ant: Aperture Efficiency (T)	130	M	> 0.45 at 675 GHz.	150
	130	T	> 0.45 at 675 GHz.	
	130	7	> 0.5 at 675 GHz	
Ant: Surface Accuracy (T*)	131	M	< 25 microns rms	110
	131	T	< 25 microns rms	
	131	7	< 20 micron rms	
Ant: Forward Efficiency (T)	132		> 0.95 for elevation angles greater than 15 degrees	80
Ant: Geometric blockage (R)	134	M	< 3 %	
	134	T	< 3 %	
	134	7	< 5 %	
Ant: Offset Pointing Accuracy (T)	140	M	0.6 arcsec, relative to reference source within 2 deg.	260
	140	T	0.6 arcsec, relative to reference source within 4 deg.	
	140	7	0.6 arcsec, relative to reference source within 4 deg.	
Ant: Fast Switching (T)	145	M	The antenna shall perform steps of 1.5 degrees on the sky and settle to within 3 arcsec peak pointing error, in 1.5 seconds of time and 0.6 arcsec, within 2.0 seconds (total).	260

Parameters	Req #	.#	Value	Sci #
	145	T	The antenna shall perform steps of 1.5 degrees on the sky and settle to within 3 arcsec peak pointing error, in 1.8 seconds of time *and* 0.6 arcsec, within 2.3 seconds (total).	
	145	7	The antenna shall perform steps of 1.5 degrees on the sky and settle to within 3 arcsec peak pointing error, in 1.9 seconds of time *and* 0.6 arcsec, within 2.4 seconds (total).	
Ant: Delay error; structure, time, drift (R)	151		< 13 fsec, Allan SD with T = 10 to 300 seconds (drift)	
Ant: Delay error; structure, time, noise (R)	152		< 38 fsec, RMS about 10 seconds average (noise)	
Ant: Phase Center long term stability (T)	154		Long term Allan SD at 0.1 to 14 days < 217 fsec (65 micro m)	280
Ant: nutator, number (R)	161	T	For the 4 total power antennas only	235
Ant: Nutator, performance (T or T*)	162	T	1.5 arcmin (on the sky) throw in 10 msec (switching freq up to 10 Hz)	235
Ant: Number Stations (R)	165	M	175	
	165	T	4	
	165	7	18	
Receiving Signal Path				
Optics: Beam Squint (T*)	205		< 1/10 of the beam FWHM	
Optics: Aperture Illumination Alignment (T)	207		a) Centroid of the aperture amplitude illumination distribution to be within 4% of the antenna diameter (0.48 m for 12-m and 0.28 m for 7-m) of the main reflector axis. b) Stability < 0.8 % of the antenna diameter (0.1 m for 12-m, 0.06 m for 7-m) for overall antenna elevation angles and with a calibration interval of 180 days.	
Freq Coverage: Front End (T*)	210		31.3−950 GHz, all atmospheric windows (see Table 2)	10

Parameters	Req #	.#	Value	Sci #
Optics: Beam shape stability (T)	215		Beam shape stable to: < 1% of the peak at -10dB point for <400GHz and < 2% of the peak at -10dB point for >400GHz under all operating conditions. This applies over a time period equal to the expected calibration interval of 180 days.	270
Receiver Noise Temperature (T*)	220		See Table 2	160
Optics: ON-axis cross polarization (T)	224		a) for the Antenna plus Front End the cross-polarization shall be < -20 dB before calibration, and b) < -40 dB after calibration c) this applies over 30 degrees of antenna motion in azimuth or elevation and with a calibration interval of 4 hours.	320
Optics: OFF-axis cross polarization (T)	225		a) for the Antenna plus Front End, the cross-polarization shall be < -20 dB before calibration but after the ON-AXIS cross polarization discussed in Req #224 has been subtracted. This applies out to the -6dB contour of the primary beam; b) assuming a 10% calibration accuracy, this allows a cross-polarization of < -34 dB after calibration and after ON-AXIS cross-polarization has been removed; c) this applies over a range of antenna elevation of 5 to 80 degrees and with a calibration interval of 20 days.	
Polarization: IF coupling (T*)	226		< -60 dB coupling between the IF channels of a baseband pair for all angles of antenna pointing.	
Signal Dynamic range (T*)	227		The differential large signal gain compression should be less than 8% (7%) for Bands 3-4 (for Bands 5-10), for the input signal level range 30 K to 373 K.	

Parameters	Req #	.#	Value	Sci #
1st Mixer Sideband Ratio (T)	231		>10dB suppression over 90% of the IF frequency range, SSB and 2SB >7dB suppression over 100% of the IF frequency range[a], SSB and 2SB <3 dB difference across 80% of the combined IF and LO frequency ranges, DSB	
Front End: Conversion (R)	233		HFET = SSB, SIS = 2SB or DSB	
Front End: IF output (R)	234		All 2SB FE systems shall output to the BE both sidebands simultaneously	
Freq range, 1st IF (T*)	240		See Table 2	
Total Instantaneous Bandwidth (T*)	250		8 GHz (minimum) in each of 2 polarizations	
Gain Stability: .05-100 sec (T*)	261		ASD < $1.0 * 10^{-3}$ on time scales of 0.05 to 100 seconds; applies to all antennas	300
Gain Stability 100 to 300 seconds (T*)	262		ASD < $3.0 * 10^{-3}$ on time scales of 100 to 300 seconds; applies to all antennas	300
Total Power Gain Stability (T*)	263	M	NA	
	263	T	ASD < $4.0 * 10^{-4}$ at time scales of 0.05 to 1.0 sec for the 4 antennas used for total power observations	305
	263	7	NA	
Polarization: Complex gain Stability (T)	264		a) < 0.01 in amplitude and b) <0.4 degrees of phase for ASD time periods 0.05 to 300 sec	320
Baseband filter: stopband response (T*)	270		The -20dB points of the 2-4 GHz baseband filter shall be no more than 150 MHz beyond the nominal band edges. The filter rejection shall be at least -40dB at all frequencies beyond 400 MHz from the nominal band edges.	
Baseband filter: passband response (T*)	271		Effective bandwidth of the Back End IFDC antialiasing filter shall be > 90% of nominal.	
Bandpass Shape: gain vrs freq; wide band (T)	272		Gain variation (p-p) across a baseband channel, due to all system components, under any tuning: < 8dB[a,b,c]	

Parameters	Req #	.#	Value	Sci #
Bandpass Stability: spectral gain vrs time (T)	273.1		1 sec: Temporal change in bandpass gain or shape of auto correlation. < -40 dB over 1 second	70
Bandpass Stability: spectral gain vrs time (T)	273.2		1 hr: Temporal change in bandpass gain or shape of cross correlation < -30 dB over 3600 seconds	70
Bandpass Shape: gain vrs freq; high resolution (T)	275		The differential variation across any 32 MHz section of the operational baseband bandpass between two antennas, due to all system components, under any tuning shall be: <2.7 dB (p-p) gain and <9 degree phase (rms)	75
Spurious signals on the Local Oscillators (T)	290		a) see Tables 290-1, 290-1A and the notes for the maximum permitted spur power for LO1; b) see Table 290-2 and its notes for the maximum permitted spur power for LO2;	70
Broad-band Spurious Signal – Incoherent among antennas (T)	292		a) IF power in incoherent spurious signals shall be < - 10 dB per unit bandwidth relative to the nominal system noise power per unit bandwidth. b) stability of the incoherent spurious signals shall be < - 20 dB per unit bandwidth relative to the nominal system noise power per unit bandwidth.	
Broad-band Spurious Signal – Coherent among antennas (T)	293		< -17 dB averaged over the continuum bandwidth, before suppression by LO-offsetting or phase switching; In those cases where spur suppression is not effective, the requirement is < -47 dB	80
Narrow-band Spurious Signal – Coherent among all antennas (T)	295.1		< -28 dB before interferometric spur suppression (spur signal power relative to the system noise power in a 1 MHz bandwidth) In those cases where spur suppression is not effective, the requirement is < -58 dB	70

Parameters	Req #	.#	Value	Sci #
Narrow-band Spurious Signal –Spur amplitude stability- Incoherent or coherent among antennas (T)	295.2		< -32 dB rms of a random component, and < - 56 dB constant difference component (the difference of the spur signal power in two switching states, relative to the system noise power, both in a 1 MHz bandwidth)	70
Spurious Signal: Stability of spur amplitude integrated over 2GHz bandwidth of Total Power Detector (T)	297		< -48 dB rms of a random component, and < - 72 dB constant difference component (the difference in two switching states of the aggregate spur signal power over the 2 GHz baseband, relative to the system noise power)	70, 80
Digital Signal Transmission (T)	311		The cable delay in each DTS should remain constant within ±8ns for at least 2 weeks.	
Digital Signal Transmission – Bit Error Rate (T*)	312		The Bit Error Rate (BER) for each DTS should be better than 10^{-6}.	
Digitization: 2 GHz nom ch bandwidth (R)	321		2 GHz nominal channel bandwidth	
Digitization: 3 bits, 4 GHz (R)	322		8 levels (3 bits), uniformly spaced, at 4 GSample/second	
Sampling clock: fine delay steps (R)	323		Variable phase for fine delay, < 1/16 sample accuracy.	
Sampling clock: common to all ant IFP (R)	324		Common to all channels at an antenna.	
Sampling clock: synchronization to correlator (T)	325		The synchronization between the DGCK sampling clock fine delay adjustment, that requires a transition from 15/16 of the period back to zero or viceversa, and the corresponding coarse timing adjustment in the correlator, that changes by 1 unit the coarse delay, shall be better than ±500us	
Tuning range and resolution: Baseband (R)	411		Any sky frequency may be placed at any: baseband frequency within ±10% of digitized BW	20
Tuning range and resolution: FE IF (R)	412		1st IF frequency within ±10% of the 1st IF bandwidth.	20
Independently Tunable sub-arrays (R)	420	M	It shall be possible to run at least 4 independent arrays (sub-arrays). Each of them can be pointed in different times to different sources and tuned to different frequency.	390

Parameters	Req #	.#	Value	Sci #
	420	T/7	It shall be possible to run at least 2 independent arrays (sub-arrays). Each of them can be pointed in different times to different sources and tuned to different frequency.	01010
Sub-arrays switching time (T)	425		The generation of a sub-array, for a 300s observation, shall not increase the duration of execution of the relevant SB by more than 3% or 1 sigma, whichever larger.	
Frequency tuning: within FE band, time (T)	430		< 1.5 sec for intraband tuning over whole band.	40
Frequency tuning: between FE bands, time (T)	431		< 1.5 sec interband, switching to a FE band in standby mode.	50
Freq Switching: time & range (T)	432		Up to 10Hz rate with a < 10 msec (rise and fall time) (Frequency throw up to of 25 MHz sky frequency; Spectral line total power mode only & within the same FE band)	
FE & LO1: number of bands in standby (R)	433		Up to two bands may be in standby mode while one band is in operational mode, or up to three bands in stand-by mode and none in operational mode.	50
	435		*Deleted*	
Phase Switching: LO1 180d & 90d (R)	441		180° and 90° phase switching inserted in the 1st LO	
Phase Switching: Settling time (T*)	442		1st LO PLL effective time constant to achieve the desired phase shall be < 1 µs.	
Phase Switching: Walsh functions (R)	443		Walsh functions, with maximum 128 sequence for 180° series; maximum 64 sequence for 90° series; orthogonal by antenna;	

Parameters	Req #	.#	Value	Sci #
Phase Switching: Synchronization (T)	444		Phase Switching synchronization between FLOOG (that applies the switch) and DTX (that removes it) in the same antenna shall be better than 100 ns Switching delay difference, among the 4 DTXs in each antenna shall be better than 100 ns After the delay correction applied in the Correlator, for antennas receiving the incoming signal in different times, the synchronization shall be better than 100 ns. Sign reversal relative to correlator dump, < 10 μs	
LO Offsetting (T)	446		Offset LO1, LO2 or TFB LO from their nominal values by integer increments of $125MHz/2^{12}$ (30.5176 KHz)	
LO Return to Phase: No phase ambiguity (T)	450		All frequency synthesis unambiguous	
Delay Errors: Time, phase drift (T)	451		< 22 fsec, Allan SD with T = 10 to 300 seconds (drift)	
Delay Errors: Time, phase noise (T)	452		< 65 fsec, RMS about 10 sec average (noise)	290
Delay Errors: Continuous operation (T)	454		System shall typically operate for at least one hour with no step discontinuities in system delay > 10 fsec	
Delay Errors: Ant, small angle, systematic (T)	456	M	Systematic, for (az,el) change of 2.0deg, < 8 fsec	
	456	T	Systematic, for (az,el) change of 4.0deg, < 8 fsec	
	456	7	Systematic, for (az,el) change of 4.0deg, < 8 fsec	
Delay Errors: Ant, small angle, random (T)	457	M	Random, for (az,el) change of 2.0deg: < 15 fsec	
	457	T	Random, for (az,el) change of 4.0deg: < 15 fsec	
	457	7	Random, for (az,el) change of 4.0deg: < 15 fsec	
Delay Errors: Ant, large angle, systematic (T)	458		az ± 180 ° rms < 100 fsec el ± 40 ° rms < 50 fsec	280
Delay Errors: Ant, large angle, random (T)	459		for full range of permitted az,el : < 32 fsec	

Parameters	Req #	.#	Value	Sci #
Frequency stability (T*)	460		Allan std dev, frequency < 2e-11 for T = 20-300 sec.	
VLBI: Array number (R)	461		VLBI Support shall be provided to minimum one Array	380
Absolute frequency accuracy (T)	470		<5e-10	
Array time: accuracy (R)	481		Maintained within 10 micro sec of UTC.	
Array time: knowledge (R)	482		Difference from UTC known to within 100 nsec.	
Shielding effectiveness receiver cabin (T*)	490		The shielding effectiveness of the antenna receiver cabin shall be at least 20 dB up to 12 GHz	
Max fiber optic cable length (CLO) (R)	492		The fiber optic cable (LO, DTS & M/C) length from the AOS Technical Building to an antenna station shall be < 15 km	
Detection and Correlation				
Analog power detectors: accuracy (T*)	511		Analog power detectors, baseband channel (2 GHz): Accuracy 1% of full scale (after linearity correction).	
Analog power detectors: sampling interval (R)	512		0.5 msec at >99 % efficiency	
Analog power detectors: 8 GHz (R)	513		Not used for astronomy; for engineering monitoring only. Requirements are in BE sub-system requirements	
Tunable Filter Bank to 64-Ant Correlator (R)	520		32-subchannel tunable filter bank	
Quantization resolution (R)	521		At antenna, first quantization, 8-level (3b); At 64-Ant Correlator, 4level (2b) and 16 levels (4b); At ACA Correlator, the second requantization >= 16 levels (4bit)	190
Spectral resolution, minimum for 64-Ant Correlator and ACA Correlator (T)	530		< 5 kHz	30
Correlator output rate: cross-correlation (T)	541.1		16 msec integrations and readout interval, all baselines.	240
Correlator output rate: auto-correlation (T)	541.2		1 msec integrations and readout interval, all antennas	240
Correlator output rate (T)	542	M	128M complex correlations per second.	
	542	T/7	300M complex correlations per second.	

Parameters	Req #	.#	Value	Sci #
General				
Archive writing rate (T)	610	M	>= 60 MB/sec.	
	610	T/7	>=3.6 MB/sec.	
Monitor points (R)	614		It shall be possible to access to the monitor points of each LRU, assembly, sub-system, as defined in the ICDs, for normal Observatory operations, contingency operations, maintenance or troubleshooting.	
LRU self identifying (R)	615		All Line Replaceable Units (LRU) with an AMB or ARTM node shall be self identifying to the ABM.	
Control Points (R)	616		It shall be possible to access to the control points of each LRU, assembly, sub-system, etc for normal Observatory operations, contingency operations, maintenance or troubleshooting This is valid unless the asynchronous control access is forbidden by the case-by-case ongoing activities.	
Availability (T*)	617		The availability of the Array shall be larger than 85% with a goal of 95% for steady ALMA Operations.	
System Restart: calibration (T)	618		It shall be possible to perform warm restart (soft resets) or power cycles of equipment at the module, sub-system and system level, including the Full System Restart, without recalibrating the telescope beyond those calibrations carried out during normal observation activities.	
System Restart: time (T)	619		It shall be possible to restart any part of the system, including the full system, in less than 15 minutes	
WVR: Installed on all antennas (R)	621	M	Installed on all antennas	
	621	T	Installed on all antennas	
	621	7	NA	
WVR: Correction error & rate (T)	622	M	Path length correction error (rms) $\delta L <$ (0.01w + 10) μm, with a sampling rate <1 Hz.	290
	622	T	Path length correction error (rms) $\delta L <$ (0.01w + 10) μm, with a sampling rate <1 Hz.	290

Parameters	Req #	.#	Value	Sci #
	622	7	NA	
WVR: Beam direction (T)	623	M	Divergence from observing beam < 10 arcmin.	
	623	T	Divergence from observing beam < 10 arcmin.	
	623	7	NA	
Phased array (R)	631		Array shall be usable as a single station (phased up)	370
Real-time phased array (R)	632		Real-time phasing up is required.	370
Phase sub-array possible (R)	633		Sum output available for any subset of antennas.	370
Mosaic Image Dynamic Range (T)	650		Mosaic Image Dynamic Range > 1000 at band 7 and lower frequency Bands under atmospheric condition which does not dominate the image dynamic range.	220
Solar Filter: RF attenuation (T*)	660		The nominal RF attenuation in dB shall be $A = 4 + 2\lambda$, where λ is the wavelength millimeters, in a RF frequency range 84 GHz to 950 GHz. The actual attenuation shall be no more than 2 dB below the nominal value and no more than 4 dB above the nominal the value at all frequencies.	360
	665		*Deleted*	
	666		*Deleted*	

Parameters	Req #	.#	Value	Sci #
Solar Filter: System performance specifications (R for a, T* for c, T for b)	667		a) Gain stability a-1) ASD < $2.0*10^{-3}$ on time scales of 0.05 to 100 seconds; applies to all antennas a-2) ASD < $4.0*10^{-3}$ on time scales of 100 to 300 seconds; applies to all antennas b) Phase stability b-1) < 150 fsec, RMS about 10 sec average (noise) b-2) < 50 fsec, Allan SD with T = 10 to 300 sec (drift) c) Polarization c-1) ON-AXIS: for the Antenna plus Front End the cross-polarization shall be < -13 dB before calibration c-2) OFF-AXIS: for the Antenna plus Front End, the cross-polarization shall be < -13 dB before calibration This applies out to the -6dB contour of the primary beam	360
Receiver protection from CloudSat. (T*)	680		Receivers shall be protected from the overflight of a radar satellite, such as CloudSat.	
ACD frequency coverage (T*)	1222		Ambient RF Load - cover RF frequency range corresponding to Bands 1-10; Hot RF Load – cover RF frequency range corresponding to Bands 3-10	
ACD Calibration Loads temperatures (T*)	1223		Ambient RF Load – receiver cabin temperature; Hot RF Load – 60-90 degrees Celsius	
ACD Calibration Loads accuracy (T*)	1224		Total calibration uncertainty: Ambient RF Load +/-0.3 K; Hot RF Load +/- 1 K[a];	

7 Requirements in Detail

In the identification code for the requirements "M" refers to the EU and NA Antennas and/or to the 64-Antennas Correlator. "T" refers to Total Power PM antennas or any other 12 m antenna used as a TP antenna. "7" refers to the 7 m Antennas. "T/7" refers to the ACA Correlator and relevant array.

7.1 Antennas

7.1.1 Requirement # 100 - Number of Antennas

Parameters	**Req #**	**.#**	**Value**	**Sci #**
Ant: Number	100	M	≥ 50	100
		T	4	
		7	12	
Allocation				

7.1.2 Requirement # 120 - Antenna Diameter

Parameters	**Req #**	**.#**	**Value**	**Sci #**
Ant: Diameter	120	M	12m	100
		T	12 m	
		7	7m	
Allocation				

7.1.3 Requirement # 130 - Antenna Aperture Efficiency

Parameters	**Req #**	**.#**	**Value**	**Sci #**
Ant: Aperture Efficiency	130	M	> 0.45 at 675 GHz.	150
		T	> 0.45 at 675 GHz.	
		7	> 0.5 at 675 GHz	
Allocation				

Values for 12 m antennas (M & T) correspond to a Ruze efficiency of 0.61 (the theoretical value for a surface error of 25 microns rms at 675 GHz), along with a value of 0.75 for all other contributions. Value for 7 m antennas corresponds to a Ruze efficiency of 0.73 (the theoretical value for a surface error of 20 microns rms surface at 675 GHz), along with the same feed and spillover efficiency and additional blockage.
Contibutors to the aperture efficiency are:
- Ruze Loss
This is an antenna requirement and defined through the antenna surface accuracy.

- Spillover Efficiency
This is mainly a Front End specification.

- Edge Taper
Between -10dB and -12dB depending on the frequency and the main contributor is the Front End

- Polarisation Efficiency
This mainly defined through the feed system. Minor antenna contribution might come through the off axis configuration of the feeds.

- Ohmic Loss
Mainly an antenna requirement and also specified in the antenna requirement documentation.

- Blockage Efficiency
This is purely an antenna requirement and is specified in the antenna requirement document.

- Defocus (Phase) loss
Defocus loss can be neglected as the moveable subreflector will refocus the beam.

It is envisaged that the verification of the actual efficiency is done also at frequencies lower than 675GHz to confirm the theoretical behaviour of the efficiency in function of frequency.

7.1.4 Requirement # 131 - Antenna Surface Accuracy

Parameters	**Req #**	**.#**	**Value**	**Sci #**
Ant: Surface Accuracy	131	M	< 25 microns rms	110
		T	< 25 microns rms	
		7	< 20 microns rms	
Allocation				

7.1.5 Requirement # 132 - Forward Efficiency

Parameters	Req #	.#	Value	Sci #
Forward Efficiency	132		> 0.95 for elevation angles greater than 15 degrees	80
Allocation				

This is equivalent to the contribution of the antenna on system noise temperature, i.e. that the integrated response of the antenna to the ground shall be less than 5% when the antenna is pointing at zenith.

The Science Requirement [AD 01] defines: Sub-millijansky (millijansky for ACA) point source sensitivity at all observing frequencies, within ten minutes of integreation time, under median atmospheric conditions (tau=0.082) in Interferometric Mode. Under the 50 percentile atmospheric conditions (ATM mode [RD 22] with pwv=1.3 was adopted) and receiver noise temperatures specified in #220, the sensitivity with ten minutes integration time can be estimated [RD 23] to be 0.01 mJy at band 3, 0.03 mJy at band 6, 0.52 mJy at band 9, and 1.0 mJy at band 10 for the 12-m array (50 antennas assumed, see [RD 23] for assumed aperture efficiency), and 0.17 mJy at band 3, 0.38 mJy at band 6, 5.7 mJy at band 9, and 10 mJy at band 10 for the 7m array (12 antennas assumed, see [RD 24] for assumed aperture efficiency), where the forward efficiency of 0.95.

This requirement should have been allocated to the ANT and FE subsystems, for the following contributions:

(1) Ground spillover due to the diffraction from the edge of the subreflector going past the edge of the primary: This depends on the taper level at the subreflector, which is defined by illumination pattern from FE and the shape of the edge of the subreflector.

(2) Spillover going into the vertex hole: This is related with the design of the subreflector central cone [RD 25][RD 26].

(3) Quadripod legs equipping a wedge shape profile to minimize ground noise pickup: This is specified in the section 6.8.4 of the Antenna Requirement.

(4) Ohmic loss at the primary and the subreflector: This is specified in the section 5.8 of the Antenna Requirement (<1% for each reflector).

(5) The size and shape of the gaps between the surface panels, the holes for e.g. the adjusters and the OPT, etc.

(6) Effective power reflected from the membrane and terminated at the ambient temperature.

Although no quantitative allocation is reflected to the as-built specifications of ANT and FE, the most of the items listed above were designed in both the 12-m and the 7-m antenna to minimize the noise contribution or maximize the efficiency.
Measurement should be made by sky dips over the elevation angles for typical astronomical observations.

7.1.6 Requirement #134 – Antenna Geometric Blockage

Parameters	Req #	.#	Value	Sci #
Ant: Geometric blockage	134	M	< 3 %	
	134	T	< 3 %	
	134	7	< 5 %	
Allocation				

7.1.7 Requirement #140 – Antenna Offset Pointing Accuracy

Parameters	Req #	.#	Value	Sci #
Ant: Offset Pointing Accuracy	140	M	0.6 arcsec, relative to reference source within 2 deg and for an observation of at least 15 minutes	260
	140	T	0.6 arcsec, relative to reference source within 4 deg and for an observation of at least 15 minutes	
	140	7	0.6 arcsec, relative to reference source within 4 deg and for an observation of at least 15 minutes	
Allocation				

The ALMA antennas shall point to 0.6 arcseconds rms radial with the aid of reference pointing [RD 27]. Angular distance between target source and reference source is expected 2 deg for 12 m Array [RD 28] and 4 deg for ACA [RD 29].
The requirement shall be met during the tracking of a source for at least 15 minutes.

7.1.8 Requirement #145 – Antenna Fast Switching

Parameters	Req #	.#	Value	Sci #
Ant: Fast Switching	145	M	The antenna shall perform steps of 1.5 degrees	260

Parameters	Req #	.#	Value	Sci #
			on the sky and settle to within 3 arcsec peak pointing error, in 1.5 seconds of time *and* 0.6 arcsec, within 2.0 sec (total).	
	145	T	The antenna shall perform steps of 1.5 degrees on the sky and settle to within 3 arcsec peak pointing error, in 1.8 seconds of time *and* 0.6 arcsec, within 2.3 sec (total).	
	145	7	The antenna shall perform steps of 1.5 degrees on the sky and settle to within 3 arcsec peak pointing error, in 1.9 seconds of time *and* 0.6 arcsec, within 2.4 sec (total).	
Allocation				

This is a new requirement that is not in the previous version of the STR [RD 13].

Requirement #140 gives the antenna pointing accuracy needed for offset pointing and this new requirement gives the time scale in which this must be achieved. This requirement reflects the existing requirements on the antennas regarding FAST SWITCHING PHASE CALIBRATION and STEP RESPONSE for the 12-meter array [RD 14], the Total Power array [RD 15] and the 7-meter array [RD 16]. Therefore, it should impose no new burden on the project.

For offset pointing, Req #140, requires that the ALMA antennas shall point with an error less than 0.6 arcseconds rms radial with the aid of reference pointing [RD 27] and the angular distance between target source and reference source is expected to be 2 deg for the 12- meter Array [RD 28] and 4 deg for the ACA [RD 29]. Note that these angular offsets are different than those used in the step response requirement given here.

7.1.9 Requirement # 151 - Ant: Delay Error; Structure, Time, Drift

Parameters	Req #	.#	Value	Sci #
Ant: Delay error; structure, time, drift	151		< 13 fsec, Allan SD with T = 10 to 300 sec (drift)	
Allocation	N/A			

This temporal delay/phase drift error mainly arises from temperature changes in the antenna structure and from quasi-static wind loading. This is a requirement on the design stiffness and thermal insulation of the antenna and foundation. The antenna design can use active metrology to help meet this requirement if so desired.

The requirement is a component of the total instrumental delay/phase drift. This requirement is differential over the change in the angle of the incident wave front when switching to a phase calibrator, taken to be 2 degrees away.

Historically, this Req #151 and the antenna requirement on non-repeatable residual delay (Section 5.6.2 of RD 14) call for time scales of <300 seconds and < 180 seconds respectively. This is not strictly correct since variations on any time scale up to the baseline recalibration time scale can contribute to this error. However, it is impractical to introduce more strict requirements on the antenna at this late date in the project.

See Req #451 for the requirement on temporal delay/phase drift in the electronics system.

7.1.10 Requirement # 152 - Ant: Delay Error; Structure, Time, Noise

Parameters	Req #	.#	Value	Sci #
Ant: Delay error; structure, time, noise	152		< 38 fsec, RMS about 10 sec average (noise)	
Allocation	N/A			

This temporal delay noise error mainly arises from wind gust loading on the structure. This is a requirement on the design stiffness of the antenna and foundation. The antenna design can use active metrology to help meet this requirement if so desired.

Unlike Req #151 on temporal delay/phase drift, this requirement on delay/phase noise is not differential over angle since the time scales are shorter than the phase calibration cycle.

See Req #452 for the requirement on temporal delay/phase noise in the electronics system.

7.1.11 Requirement #154 – Phase Center long term stability

Parameters	Req #	.#	Value	Sci #
Ant: Phase Center long term stability	154		Long term Allan SD at 0.1 to 14 days < 217 fsec (65 micro m)	280
Allocation				

The purpose of this requirement is to limit the variation of the antenna to antenna vector separation, i.e., the interferometric baseline error.

The maximum permitted baseline error flows down from Science Req #280. The resulting phase error after phase calibration is equal to the baseline error times the sine of the target-to-calibrator angular separation. For fast switching phase calibration with a target-to-calibrator separation to be 2 deg this equals 7.6 fs, which small compared to the permitted temporal phase drift error of the electronics of 22 fs given in Req #451. For a target-to-calibrator separation to be 6 deg the phase error is equal to 22 fs. This brackets a reasonable range of calibrator separation.

The baseline vector is defined as the vector between the phase centers of the two antennas in an antenna pair and its components are established through astronomical baseline calibration.

The minimum of the time range for this requirement assumes that it will take about an hour of observing to derive a highly accurate baseline calibration. The maximum of the time range assumes that regular array baseline re-calibration (not including cases of antenna moves) will not happen more often than every two weeks.

Medium to long period antenna phase center movements, baseline changes, might arise from antenna thermal distortion, steady wind loading, antenna station structural changes, or antenna station settling and other station movements.

On shorter time scales, phase errors that arise from structural changes in the antenna which move the phase center (baseline variations) are covered in Req #151 and #152. Changes in the phase center owing to quadrupod movement would be covered here.

Phase changes arising in the FE and BE electronic systems that are caused by antenna pointing changes are constrained by Req. #456, 457, 458 and 459.

Requirement #154 shall apply to all ALMA antennas and shall be applicable under all environmental and operational conditions.

More detail:
Although the baseline vector is defined as the vector between the phase centers of two antennas, it can be thought of as the vector between the alt-az axis intersection points in the two antennas. To this should be added the vector difference of any alt-az axis offsets; however, for ALMA, by design, this is small and variations are even smaller.

Another vector must be added to get from the alt-az axis intersection point to the antenna phase center. However this vector points in the direction of the incoming wave front and is largely constant in length over time and antenna pointing. Therefore it only contributes a constant in phase and is calibrated out by the normal interferometric phase calibration.

7.1.12 Requirement # 161 – Antenna Nutator, Number

Parameters	Req #	.#	Value	Sci #
Ant: Nutator, Number	161	M	NA	
		T	For the 4 total power antennas only	235
		7	NA	
Allocation				

7.1.13 Requirement # 162 – Nutator, Performance

Parameters	Req		Value	Sci #
Ant: Nutator, performance	162	M	NA	
		T	1.5 arcmin (on the sky) throw in 10 msec (switching freq up to 10 Hz)	235
		7	NA	
Allocation				

Nutator throw shall be ±1.5arcmin on sky (±20.5arcmin of the nutator) with respect to nutator neutral position, when the subreflector axis is parallel to Z_N [AD 02].

7.1.14 Requirement # 165 – Number Stations

Parameters	Req		Value	Sci #
Ant: Number Stations	165	M	175	
		T	4	
		7	18	
Allocation				

The requirement is aimed to specify the number of Antenna Stations and not their position. The indicative distribution of the 175 Antenna stations is given here for reference:

- 78 in the central cluster.
- 73 within 5 km diameter (without central cluster)
- 24 outside the 5 km diameter

7.2 Receiving Signal Path

7.2.1 Requirement # 205 - Optics: Beam Squint

Parameters	Req #	.#	Value	Sci #
Optics: Beam Squint	205		$\Delta < 1/10$ of the beam FWHM	
Allocation	N/A			

The original requirement on the offset of the antenna power beams in the two polarizations (beam squint) is $\Delta < 1/10$ of the beam FWHM. This comes from a calculation by B. Lazareff [RD 30]. It is based on the desire to keep the amplitude error in the primary beam correction in large field imaging that is due to beam squint less than the error due to random pointing errors.

However, beam squint also leads to errors in the difference of the co-polarized correlation products (see Section 4.9 of RD 20) and thus leads to errors in polarization measurements. In order to meet the science polarization requirements, that analysis suggests that the beam squint requirements should be tightened and there should be separate requirements for the systematic, $\Delta < 0.025$, and the random (among antennas), $\Delta < 0.004$, allocations for beam squint.

In more detail taken from [RD 20], for systematic beam squint common to all antennas, the error introduced into the visibility measurements of polarization, **after calibration**, has to be kept at the same level as the permitted error in the measurement of the polarization.

$$\sigma_{U_V}(after\ calibration)/_I \approx \sigma_U/_I = 10^{-3}$$

Assuming that post processing software is available and that the beam squint is stable enough over many weeks that it can be calibrated out at the 98% level, then

$$\sigma_{U_V}(before\ calibration)/_I \approx \frac{1}{.02}\sigma_{U_V}(after\ calibration)/_I = .05$$

Next, the distance from the primary beam center over which the science requirement on polarization accuracy should apply must be considered; the 3 dB or 6 dB or 10 dB points of the beam might be used. The most challenging case will be high dynamic range polarization mosaic imaging. The beam positions in the mosaic would usually be spaced at the 3 dB point, but there may be spurious polarization features introduced by strong sources much further out. The above limits on polarization errors should apply (at least) out to the 6 dB point of the beam.

To achieve this before calibration error out to the 6 dB point of the primary beam, the intrinsic systematic beam squint should be $\Delta < 0.025$.

Likewise, if beam-squint among the antennas of a 50 element array is random and uncorrelated, to meet the science requirement for polarization error while making a large scale polarization image the limit on the visibilities associated with an antenna is:

$$\frac{\sigma_{Q_V}}{I'_V} < \sqrt{50} * 0.001 = 0.007$$

Here we assume that calibration of the random beam offsets will not be of much use but just make use of the many random errors.

To achieve this error level out to the 6 dB point of the primary beam, the random beam squint among the antennas should be $\Delta < 0.004$.

Pavel Yagoubov points out in [RD 21] that this new beam squint requirement tightens the requirement on the allowed off-axis D-Term beyond that which is given in Req #225.

For reason cited in Section 5.3, it is not practical to alter system requirement #205 at this late date in the project, so this note is added here simply for information and the old spec is retained.

7.2.2 Requirement # 207 – Optics: Aperture Illumination Alignment

Parameters	Req		Value	Sci #
Ant: Aperture Illumination Alignment	207		a) Centroid of the aperture amplitude illumination distribution to be within 4% of the antenna diameter (0.48 m for 12-m and 0.28 m for 7-m) of the main reflector axis. b) Stability < 0.8 % of the antenna diameter (0.1 m for 12-m, 0.06 m for 7-m) for overall antenna elevation angles and with a calibration interval of 180 days.	
Allocation				

This requirement places a limit on the displacement of the centroid of the antenna aperture illumination distribution from the center of the aperture. Such a displacement causes a phase gradient across the antenna primary beam which will cause phase errors for sources located in the outer parts of the beam. Such displacements are caused by installation alignment tolerances of feeds, cartridges, dewars and subreflectors. The specified limit of 0.04D comes from simulations reported in [RD 31, RD 45] and is an rms over all the antennas in the array. From the relation between illumination offsets and imaging fidelity degradation (clipping at 1% case in figure 6 of RD 31), the stability <0.8 % of the antenna diameter is defined to assure the 5 % degradation of image fidelity during the expected calibration interval (180 days), as well as consistency with beam stability requirement #215 [RD 45]. Astro-holography technique or the phase information available from interferometric pointing can evaluate this requirement. If it is found that a particular band on a particular antenna significantly exceeds these requirements the situation should be investigated to determine if it is feasible to realign a feed, cartridge or receiver to reduce the misalignment. Periodic calibration of the centroid alignment of all bands on all antennas should be performed by the ALMA Operations group.

This is a new requirement implemented in Rev.C. Not considered for Bands 3, 4, 6, 7, 8, 9, and 10, and design of the FESS and ALMA cryostat. In particular the stability requirement, for antenna elevation changes, may become difficult to meet, especially for the Bands with warm optics installed on top of cryostat.

7.2.3 Requirement # 210 – Front End Frequency Coverage

Parameters	**Req**		**Value**	**Sci #**
Front End: Frequency Coverage	210		31.3−950 GHz, all atmospheric windows (see Table 2)	10
Allocation				

Band edge frequency choices are explained in [RD 01], section 2.2, and in [RD 04].

7.2.4 Requirement # 215 - Optics: Beam shape stability

Parameters	**Req #**	**.#**	**Value**	**Sci #**
Optics: Beam shape stability	215		Beam shape stable to: < 1% of the peak at -10dB point for <400GHz and < 2% of the peak at -10dB point for >400GHz	270

Parameters	Req #	.#	Value	Sci #
			under all operating conditions. This applies over a time period equal to the expected calibration interval of 180 days.	
Allocation				

7.2.5 Requirement # 220 – Receiver Noise Temperature

Parameters	Req #	.#	Value	Sci #
Receiver Noise Temperature	220		See **Error! Reference source not found.**	160
Allocation	Front End			

Maximum receiver temperatures are set equal to $T_{SSB}=Nhf/k$ + 4K, where f is the maximum frequency in the band, h and k are the usual constants, and N=6 (80% of bands) / 10 (100% of band) for bands 1..6, N=8 / 12 for bands 7 and 8, and N=10 / 15 for bands 9 and 10. Regarding bands 9 and 10, $T_{SSB}/2$ is adopted because of DSB noise temperature. See Table 2 and its notes for more details.
Back End contribution to the total system noise shall be <1% of the total for all bands under all observing and all calibration conditions.

7.2.6 Requirement # 224 - Optics: ON-AXIS Cross Polarization

Parameters	Req #	.#	Value	Sci #
Optics: ON-AXIS cross polarization	224		a) for the Antenna plus Front End the cross-polarization shall be < -20 dB before calibration, and b) < -40 dB after calibration c) this applies over 30 degrees of antenna motion in azimuth or elevation and with a calibration interval of 4 hours.	320
Allocation	Equally between the Front End (-26 dB) and the antenna optics (-26 dB); this is worst case where cross-polarizations simply add.			

This requirement flows down directly from the Science requirement #320 limiting the allowable error in the measured polarization at beam center. The flow down is analyzed in [RD 20].

This requirement constrains the on-axis D-Term arising from the RF sub-system of antenna, feed and polarizer. This is a D Term component that is *constant* across the beam and measured at beam center. This D-Term will be less than the primary beam off-axis D-Term (Req #225) that usually peaks near the 3 dB point of the co-polar beam pattern.

The current system requirement #224 in [RD 13] constrains the on-axis D Term to be < 0.10 before calibration (the requirement is written in terms of the fraction of power in one polarization channel that is transferred to the other; this corresponds to D^2 and equals a cross polarization less < -20 dB).

This requirement needs to be clarified and changed is several ways. Although the allowable level of instrumental cross-polarization is unchanged (existing CREs are discussed below), the calibration cycle is better defined and a requirement on the stability of the on-axis D-Term with antenna motion is introduced.

The allowable on-axis *after* calibration cross-polarization error derived in [RD 20] is $\sigma_D < 0.01$, this requires *after* calibration instrumental cross-polarization be < -40 dB. However, this is not an important change from the < -30 dB in [RD 13], since what is needed is the instrumental cross-polarization *before* calibration. It is this quantity and it's stability in time and with antenna motion impacts the feed and optics design.

From experience, it should not be difficult to calibrate the D-Terms to about 10%. Thus to achieve $\sigma_D < 0.01$, the value of the on-axis D-Term should be < 0.1 and equivalently the cross polarization D^2 < - 20 dB; this the same as the old value in [RD 13].

To achieve $\sigma_D < 0.01$, the on-axis cross-polarization power *before* calibration must be stable over a calibration cycle. The stability of the cross-polarized power should be better than -20dB relative to the co-polarized on-axis power. The typical calibration cycle for measuring on-axis D-terms is taken to have a time scale of 4 hours and require moving the antenna over an angle between target and calibrator of about 30 degrees. This should allow observing a strong calibrator at various parallactic angles. If a polarized beacon signal is used, the time scale could be shorter.

This requirement will be allocated between the Front End and the antenna optics. Although the antenna optics contribution may be small, [RD 32], its variability may be large owing to gravitational and/or thermal deformations. Until the situation is better understood, the requirement, before and after calibration, should be allocated equally between Front End optics and the Antenna optics.

This ON-AXIS cross-polarization requirement includes cross-polarization arising from misalignment of the polarization orientation within a FE cartridge and misalignment between cartridges in different antennas. The 4 deg inter-antenna alignment (-23 dB) allowed for the FE is a large fraction of the total permitted -20dB cross-pol spec. There is a possible additional alignment error arising from the mounting of the FE in the antenna, but it is probably much less than 4 degrees. This misalignment alone would exceed the -26 dB permitted cross-polarization allocation to FE.

Also, the antenna membrane can contribute significantly to the on-axis cross-polarization term. [RD 32] cites a -27 dB measured value for a 0.5 mm think membrane. This should be part of the antenna optics allocation.

CREs:

Several Change Requests (CREs) have been submitted to the ALMA Configuration Control Board (CCB) regarding the flow down of System Requirement Req #224 to specific sub-systems. Details may be found on EDM at http://edm.alma.cl/tiny/nmzun.html.

Band 8 - CRE "Change Request for the Band 8 Cartridge Polarization Alignment" FEND-40.02.08.00-0158-A-CRE (see CRE-272 and FECRE-49) was approved by the CCB on 11-Oct-2011 [AD 07].

Band 8 - CRE "Change Request for the Band 8 Cartridge Polarization Efficiency" FEND-40.02.08.00-273-A-CRE (see CRE-291 and FECRE-54 (supersedes CRE-271)) was approved (with action items) by the CCB on 03-Apr-2012 [AD 08].

Band 3 - CRE "Relaxation of the Band 3 polarization efficiency specification" ALMA-40.02.03.00-0662-A-CRE (see CRE-260 and FECRE-40) was approved by the CCB on 23-Nov-2010 [AD 09].

Band 6 - CRE "Change to Cross Polarization Isolation Specification for Band 6 Cartridges" FEND-40.02.06.00-424-B-CRE (see CRE-244 and FECRE-27) was approved by the CCB on 06-Jul-2010 [AD 10].

Front End Technical Requirements – CRE "Change to the "absolute" definition for the polarization orientation alignment accuracy in the Front-End and Cold Cartridges Technical Specifications" FEND-40.00.00.00-211-A-CRE (see CRE-235 and FECRE-22) was approved by the CCB on 07-Apr-2010 [AD 11].

Band 7 – CRE "Band 7 Cartridges: Polarisation Alignment Accuracy" FEND-40.02.07.00-253-A-CRE (see CRE-232 and FECRE-13) was approved by the CCB on 28 April 2010 [AD 12].

Band 9 - CRE "Band 9 Cartridge Cross Polarization" ALMA-40.02.09.00-086-A-CRE (see Approved CRE-94 (earlier was CRE-164, then transferred)). This CRE was approved by the CCB on approximately 20-Mar-2008 [AD 13].

Band 4 – "Change Request for the Band 4 Cartridge Polarization Efficiency" FEND-40.02.04.00-0236-A-CRE (see CRE-300) approved by the CCB on 05-June-2012 [AD 14].

7.2.7 Requirement # 225 - Optics: OFF-AXIS Cross Polarization

Parameters	Req #	.#	Value	Sci #
Optics: OFF-AXIS cross polarization	225		a) for the Antenna plus Front End, the cross-polarization shall be < -20 dB before calibration but after the ON-AXIS cross polarization discussed in Req #224 has been subtracted. This applies out to the -6dB contour of the primary beam; b) assuming a 10% calibration accuracy, this allows a cross-polarization of < -34 dB after calibration and after ON-AXIS cross-polarization has been removed; c) this applies over a range of antenna elevation of 5 to 80 degrees and with a calibration interval of 20 days.	
Allocation				

There is no scientific constraint on the off-axis cross-polarization, but since ALMA will typically image objects that fill much of the primary beam, or even larger objects for mosaic observations, it is reasonable to want some constraint on the polarization accuracy off-axis.

After the on-axis cross-polarization, which can be as large as D = 0.1, is removed, the remaining instrumental off-axis cross-polarization should be no larger than an additional D = 0.1 (i.e., cross-polarized power < -20 dB). This permits a total off-axis instrumental polarization up to D=0.2 (cross-polarized power < -14 dB). As with Req# 224, assuming that a calibration accuracy of 10% can be achieved over time and changing antenna pointing angle, the residual off-axis D-term of an antenna should be < 0.02 (i.e., residual cross-polarized power < -34 dB).

Note that $D^2(\theta)$ is the ratio cross-polarized power to co-polarized power for a source located off-axis in the beam and therefore reduced by the beam profile. With this definition, when both the measured polarized intensity and its error are corrected for the beam shape, the limit on the polarization error OFF-AXIS will be constant across the beam.

Concerning the distance from the primary beam center over which this constraint on $D(\theta)$ applies, as with Req #205, accurate polarization calibration out to the 6 dB beam radius is a reasonable limit both for single field imaging of large objects and for mosaic imaging with 3 dB beam off-sets. This is a relaxed specification compared to the 10 dB beam radius in [RD 13].

Calibrating off-axis polarization will require mapping the beam polarization. This could be done with a raster scan of a strong and unpolarized compact source or by using a terrestrial beacon. These D Terms might change with elevation angle, temperature and frequency within a band. As a minimum, we specify that the off-axis D-Term calibration must be stable over a range of antenna elevation of 5 to 80 degrees. This will allow one beam calibration to be used for target sources all over the sky and will also allow the use of a terrestrial beacon for calibration.

Mapping the beam polarization at all bands will likely require many hours of observing. Therefore $D(\theta)$ should not change by more than +/- 0.01 over a reasonable beam polarization re-calibration interval of 20 days.

The Requirement #225 is the same for all ALMA bands except where changed by a CRE. If a CRE changes the on-axis polarization requirements (Req #224), this modified value also impacts the expected error in the off-axis polarization measurement.

7.2.8 Requirement # 226 - Polarization: IF Coupling

Parameters	Req #	.#	Value	Sci #
Polarization: IF coupling	226		< -60 dB coupling between the IF channels of a baseband pair for all angles of antenna pointing.	
Allocation				

Contributions to the D-Term arising from cross coupling between the IF channels of a baseband pair may vary on time scales of minutes, far shorter than the on-axis D-Term calibration period of 4 hours. Therefore Requirement #226 constrains this $D_{IF}(0)$ to be < 0.001 (i.e., cross-polarized power < -60 dB) and thus is unlikely to be a significant contributor to the total error. Even if the variation in $D_{IF}(0)$ are equal to the value of $D_{IF}(0)$, its contribution to the total error only $\sigma_{D-IF} < 0.1\ \sigma_{D-Total}$.

D-Term contributions arising before the RF mixer are covered in Sys Reqs #224 and #225 and are assumed stable and able to be calibrated out with a residual error of $\sigma_{D-Total} < 0.01$.

Requirement #226 should apply at all antenna pointing angles.

7.2.9 Requirement # 227 – Signal Dynamic range

Parameters	Req #	.#	Value	Sci #
Signal Dynamic range	227		The differential large signal gain compression should be less than 8% (7%) for Bands 3-4 (for Bands 5-10), for the input signal level range 30 K to 373 K.	
Allocation	Front End and Back End			

Gain compression allocation for the FE is 6% for Bands 3 and 4, according to [AD 15], and 5% for Bands 5-10

HEMT amplifiers will be used in Bands 1 and 2, instead of SIS mixers. It is not yet known how solar observations will be conducted in bands 1 & 2. Note that the solar filter is not designed to be used with band 1 and has significant vignetting in band 2. Therefore, the required dynamic range in bands 1 & 2 is not yet defined but the required level of compression is likely to be similar to that required in band 3, i.e. 8%.

FE compression is defined by differential metric, between the 77K and 373 K inputs [AD 15]. This extrapolates to 7% (Bands 3-4) for the 11dB input dynamic range, 30K-373K, and 30K receiver noise temperature. <6% for Bands 5-10. Metric remains differential.

This requirement applies to the input signal (30-373 K), and not Tsys variations.

BE IFDC specifications are:

a. 1% compression;
b. ±5% deviation from square-low over a 13dB range, for the baseband detectors, with a goal of ±1%. This specification is covered by SYS Req.511

Based on above, and assuming BB detectors do not contribute to the total budget as their performance is covered separately by Req.511, the signal dynamic range requirement can be changed to 8% instead of 1dB, for Bands 3-4. 7% will be allocated to the FE, and 1% to the BE. Bands 5-10 will be required 7% total, of which 6% allocated to FE and 1% to BE.

This compression requirement is not a direct flow down from Sci.350, and not satisfactory to obtain the required accuracy flux scale with two temperature calibrators (ambient and hot). Special calibration techniques will be using known flux calibrators, cold sky calibration etc, to obtain the required calibration accuracy. Other system components, e.g. ACD accuracy, antenna efficiency, correlator linearity etc will actually contribute to the calibration accuracy as well, so the flow down need to be addressed elsewhere.

This requirement as stated is intended for the case that the solar filter is not in use. With the solar filter (really an attenuator) in the signal path, stated gain compression would occur at much higher signal level.

7.2.10 Requirement # 231 – 1st Mixer Sideband Ratio

Parameters	**Req #**	**.#**	**Value**	**Sci #**
1st Mixer Sideband Ratio	231		>10dB suppression over 90% of the IF frequency range, SSB and 2SB >7dB suppression over 100% of the IF frequency range[a], SSB and 2SB <3 dB difference across 80% of the combined IF and LO frequency ranges[b], DSB	
Allocation	Front End			

[a] Band 7 requires >7dB suppression over 99% of the IF frequency range [AD 16].
[b] See [AD 17] for more details regarding the DSB case.

7.2.11 Requirement # 233 – Front End Conversion

Parameters	**Req**		**Value**	**Sci #**

Parameters	Req		Value	Sci #
Front End: Conversion	233		HFET-SSB, SIS - 2SB or DSB	
Allocation				

7.2.12 Requirement # 234 – Front End IF Output

Parameters	Req		Value	Sci #
Front End: IF Output	234		All 2SB FE systems shall output to the BE both sidebands simultaneously	
Allocation				

7.2.13 Requirement # 240 – Freq range, 1st IF

Parameters	Req #	.#	Value	Sci #
Freq range, 1st IF	240		See Table 2	
Allocation	Front End and Back End			

7.2.14 Requirement # 250 – Total Instantaneous Bandwidth

Parameters	Req		Value	Sci #
Total Instantaneous Bandwidth	250		8 GHz (minimum) in each of 2 polarizations	
Allocation				

8 GHz is achieved when using the 64-Antennas Correlator in TDM mode or when using the ACA correlator. When using the 64-Antennas Correlator in FDM mode 7.5 GHz is achieved due to the need to have overlapping channels between adjacent sub-bands.

7.2.15 Requirement # 261 - Gain Stability: .05-100 sec

Parameters	Req #	.#	Value	Sci #
Gain Stability: .05-100 sec	261		ASD < 1.0* 10^{-3} on time scales of 0.05 to 100 seconds; applies to all antennas	300
Allocation	0.707 of the gain stability requirement is allocated BE and FE sub-systems respectively			

This requirement on gain variations on the 0.05 to 1.0 second time scale is needed to limit amplitude measurement errors during OTF analogue total power and spectral auto-correlation observations. It applies to all antennas of the array and to both the main signal path averaged over 2 GHz and to the 2-4 GHz analogue total power detectors.

On the 1.0 to 100 second time scale, this instrumental gain stability requirement is set by the need to maintain accurate total power calibration between ACD measurements.

It is also assumed that the variable attenuators are not changed in the time between the ACD system gain calibrations. Also, that the requantization levels in TFB are not changed on this same time scale.

This requirement applies to the 2-4 GHz baseband detectors, but not 4-12 GHz IF detectors).

On all time scales, 0.707 of each of the gain stability requirements are allocated BE and FE sub-systems respectively.

See section 5.2 for the definition of Allan Standard Deviation (ASD).

7.2.16 Requirement # 262 - Gain Stability 100 to 300 sec

Parameters	Req #	.#	Value	Sci #
Gain Stability 100 to 300 seconds	262		ASD < 3.0* 10^{-3} on time scales of 100 to 300 seconds; applies to all antennas	300
Allocation	0.707 of the gain stability requirement is allocated BE and FE sub-systems respectively			

This requirement on gain stability on the 100 to 300 second time scale is set by the need to maintain accurate total power calibration between ACD measurements. Changes in gain will be a small contributor to overall calibration accuracy and this requirement can be relaxed to 5*10^-3 in case it becomes a cost driver.

See section 5.2 for the definition of Allan Standard Deviation (ASD).

7.2.17 Requirement # 263 - Total Power Gain Stability

Parameters	Req #	.#	Value	Sci #
Total Power Gain Stability	263	M	NA	
	263	T	ASD < 4.0 * 10^{-4} at time scales of 0.05 to 1.0 sec for the 4 antennas used for total power observations	305
	263	7	NA	
Allocation	0.707 of the gain stability requirement is allocated BE and FE sub-systems respectively			

The four antennas used for total power observations will have nutating sub-reflectors. The stated requirement represents a compromise to the 1.0*10^{-4} desired for the Science Requirement and what is thought achievable. However recent test results suggest that $\Delta G/G$ of close to 1.0*10^{-4} could be achievable

The $\Delta G/G$ value is allocated equally to BE and FE sub-systems respectively. See section 5.2 for the definition of Allan Standard Deviation.

The FE requirement for the 12-m array, [RD 11], does not cover this requirement and there is no plan to install special FEs into 4 total power antennas.

7.2.18 Requirement # 264 - Polarization: Complex Gain Stability

Parameters	Req #	.#	Value	Sci #
Polarization: Complex gain Stability	264		a) < 0.01 in amplitude and b) <0.4 degrees of phase for ASD time periods 0.05 to 300 sec	320
Allocation	Equally between the Front End and Back End sub-systems; RSS			

This requirement constrains the differential gain and phase stability for an interferometer pair is derived as shown in Section 4.4 of [RD 20]:

$$\frac{\sigma(G_{Y1Y2}-G_{X1X2})}{\bar{G}_{12}} \leq 10^{-2} \quad \text{and} \quad \frac{\sigma(\emptyset_{Y1Y2}-\emptyset_{X1X2})}{\bar{G}_{12}} \leq 0.4 \text{ degrees}$$

This is more relaxed than the existing Requirement #264 in [RD 13].

The requirement on differential gain variations is calculated using the Allan Standard Deviation, ASD(2,T,τ=T) for T = 0.05 sec to 300 sec. ASD(2,T,τ=T) is also used to calculate the single channel interferometric gain stability in Req #261 and #262.

The requirement on differential phase variations is calculated using the Allan Standard Deviation, ASD(2,T,τ) T = 0.05 sec to 300 seconds and τ = 10 seconds as defined for Requirement #451.

A requirement on the stability of individual interferometer gains, G_{XX} and G_{YY}, time is given in Requirements #261 and #262. These are more stringent than what is needed for polarization given here. Therefore, this requirement should not be difficult to meet.

This requirement applies to the main signal path averaged over the 2GHz baseband.

The differential gain and phase stability between channels of a polarization pair are allocated equally to BE and FE sub-systems respectively with an RSS calculation.

7.2.19 Requirement # 270 – Baseband filter: stopband response

Parameters	Req		Value	Sci #
Baseband filter: stopband response	270		The -20dB points of the 2-4 GHz baseband filter shall be no more than 150 MHz beyond the nominal band edges. The filter rejection shall be at least -40dB at all frequencies beyond 400 MHz from the nominal band edges.	
Allocation				

The -40 dB requirement is to achieve the required Spectral dynamic range.

7.2.20 Requirement # 271 – Baseband filter: passband response

Parameters	Req		Value	Sci #
Baseband filter: passband response	271		Effective bandwidth of the Back End IFDC antialiasing filter shall be > 90% of nominal.	
Allocation				

The effective bandwidth is the equivalent rectangular bandwidth that produces the same continuum signal-to-noise ratio as the actual filter. See Eq. 7.36 of [RD 12].

7.2.21 Requirement # 272 – Bandpass Shape: gain vrs freq; wide band

Parameters	Req #	.#	Value	Sci #
Bandpass Shape: gain vrs freq; wide band	272		Gain variation (p-p) across a baseband channel, due to all system components, under any tuning: < 8dB[a,b,c]	
Allocation	Front End and Back End			

Notes:
[a] This requirement was originally allocated: 5 dB to Front End, 3 dB to Back End
[b] Front End allocation for Band 6 is <7 dB across any 2 GHz baseband in the 6-10 GHz IF range. This corresponds to <9dB system gain variations requirement. Additional Front End relaxation applies to the expanded IF range 5-6 GHz, <6 dB p-p gain variation across this 1 GHz bandwidth
[c] <9 dB for Bands 7, 8 and 9

1. Need to update the note, page 28 of Rev.B, - remove first paragraph
2. Band 6 relaxed performance, according to [AD 18]
3. Relaxed specification, 5 dB instead of 4 dB, for cold cartridges:
    a. Band 6, according to [AD 18]
    b. Band 7, according to [AD 19]
    c. Band 8, according to [AD 20]
    d. Band 9, according to [AD 21]

This results in the relaxation of the FE budget (cold cartridges + IF switch + interconnects) from 6dB to 7dB. Total system bandpass gain variation will be <9dB instead of <8dB.

4. Special relief for Band 6 expanded 5-6 GHz IF range, according to [AD 18]

This requirement is set by the Science Requirement on uniformity of s/n ratio across the correlator spectral channels (1.5 dB TBC, SRR-2005 AcIt #65). Since quantization noise is distributed approximately evenly across the IF bandpass, the s/n ratio is low where the IF gain is low. The worst case occurs when observing is done using the TFB by-pass mode; in that case the 2-bit digitization noise is applied across the full 2 GHz bandpass. This leads to the requirement that the gain variation across the operational bandpass be <8 dB p-p.

When the TFB is in use, 3-bit digitization noise is applied across the 2 GHz bandpass, and, in the presence of IF gain variations, would lead to variations of s/n ratio. If the bandpass variations in the power output of the TFB are adjusted to be small, there will be no further variations in s/n ratio due to the 2-bit re-quantization on frequency scales greater than 62 MHz. The 3-bit quantization leads to the requirement that the gain variation across the operational bandpass be <13 dB p-p. Variations in IF gain on frequency scales less than 62 MHz will be impacted by 2-bit digitization and should be <8 dB p-p.

7.2.22 Requirement # 273.1 – Bandpass Stability: spectral gain vrs time

Parameters	**Req**		**Value**	**Sci #**
Bandpass Stability: spectral gain vrs time	273.1		1 sec: Temporal change in bandpass gain or shape of auto correlation. < -40 dB over 1 second	70
Allocation				

See the note of Req #273.2 Case (a) in the section 7.2.23.

7.2.23 Requirement # 273.2 – Bandpass Stability: spectral gain vrs time

Parameters	**Req**		**Value**	**Sci #**
Bandpass Stability: spectral gain vrs time	273.2		1 hr: Temporal change in bandpass gain or shape of cross correlation. < -30 dB over 3600 second	70
Allocation				

There are two Science Requirements on spectral dynamic range:

(a) 10000:1 spectral dynamic range for looking at weak spectral lines in presence of stronger ones, and
(b) 1000:1 for looking for weak lines in presence of strong continuum emission.

From this flows the technical requirement that the passband shape should be sufficiently stable such that it does not give a false appearance of weak lines. This leads to different requirements on the passband shape stability for single dish and interferometric observations.

Case (a) determines the passband stability for single dish spectral observations. They will typically be performed using some form of frequency switching. A common technique is to use (signal - reference)/(reference), which effectively calibrates the passband every switching period. What counts is the stability for the duration of the switching cycle. The spectral baseline, after switching, should be adequately flat. Taking representative values of 100 K for a very strong line and 100 K for the system noise, the baseline variation after 60 seconds switching should be less than (100/10^4) = 0.01 K.
The difference in the passband over 2GHz shape should be taken at 60sec intervals and compared to the mean power in the passband. This shall be smaller than -40 dB at resolution bandwidth of 2MHz,

Case (b) determines the bandpass stability for interferometric observations. The stability of the continuum within the passband has to be adequate and over long timescales. Assume that a bandpass calibration is done every 60 minutes and that spectra are sufficiently over-sampled that ringing is not a problem and that thermal noise is not significant. Then thermal changes which alter reflections and/or bandpass ripple in the analogue system may limit the spectral dynamic range. Therefore, the stability of the passband profile, with respect to the mean signal strength within the total IF, has to be better than -30 dB for a time of ~3600 seconds at a resolution bandwidth of 2 MHz.

7.2.24 Requirement # 275 – Bandpass Shape: gain vrs freq; high resolution

Parameters	Req		Value	Sci #
Bandpass Shape: gain vrs freq; high resolution	275		The differential variation across any 32 MHz section of the operational baseband bandpass between two antennas, due to all system components, under any tuning shall be: <2.7 dB (p-p) gain and <9 degree phase (rms)	75
Allocation	Equally in gain (dB) and rss in phase, among the BE and FE			

The image dynamic range Science Requirement limits the permitted gain/phase closure errors, which in turn constrain the bandpass match between antennas. Since all imaging will be done using a spectral correlator, gain/phase variations on frequency scales greater than a correlator spectral channel can be largely eliminated with bandpass calibration. To calculate the worst case, the widest correlator spectral channel occurs in the TFB bypass mode with full polarization products; there the 2 GHz IF bandpass is divided into sixty-four 31 MHz channels.

If the image in each 31 MHz channel is to meet the image dynamic range requirement of 50,000:1, the visibilities should be calibrated to within rms 2.5% (assuming ~400 independent snapshots). A reasonable allocation is that the error contribution arising from closure errors should be held to < 1%. To achieve this, the gain variation over any 31 MHz in the operational bandpass of a baseband channel must be < 2.7 dB p-p, and the phase variation about the mean in 31 MHz, after the removal of the slope across the operational bandpass, must be <9d rms (see Table 7.2 of RD 12). The phase requirement is differential between two IF channels.

This requirement is allocated equally in gain (dB) and rss in phase, among the BE and FE sub-systems. This is not a tightly constrained requirement but tests on a significant number of antennas show that it is usually satisfied (see JIRA CSV-1543).

7.2.25 Requirement # 290 - Spurious Signals: Local Oscillators

Parameters	**Req #**	**.#**	**Value**	**Sci #**
Spurious signals on the Local Oscillators	290		A) see Tables 290-1, 290-1A and the notes for the maximum permitted spur power for LO1; B) see Table 290-2 and its notes for the maximum permitted spur power for LO2;	70
Allocation	N/A			

See Section 5.2 of this document and [RD 17] for further discussion of spurious signals.

ALMA Science Requirement #70, applied to both auto-correlation and cross-correlation, states "the required spectral dynamic range is 10,000:1 for measurement of weak spectral lines in the presence of stronger ones".

Regarding spurs on the LO reference signals, it is assumed that the signal-to-spur ratio in the output spectrum is the same as the LO-to-spur ratio. This may not always be true depending on the nature of mixer design (single-ended vrs balanced mixers which suppress the LO spur products at the IF) and the type of modulation causing the spurs. This correspondence may also vary with the offset frequency owing to, e.g., mixer efficiency.

However, accepting the assumption, the principal System Technical Requirement is therefore that local oscillator signals shall not contain spurs greater than -40 dBc, but other considerations discussed below add to the complexity of this requirement.

These requirements are a constraint on the final LO spurs at the interface to the appropriate mixer. Unless stated otherwise in the notes, these limits apply to spurs both coherent and incoherent among antennas.

The limits to spurious signals on the LO references are given in the Tables below. Table 290-1 and 290-1A refer to the LO1 and 290-2 refers to the LO2 and DGCK. $IF1_{Low}$ and $IF1_{High}$ refer to the lower and upper IF1 frequencies of a FE cartridge; RFBW is the full RF bandwidth of a FE cartridge.

Table 290-1		**LO1 - Maximum Amplitude of Spurious Signals**				
Offset Freq Low	0.003 Hz	1.0 Hz	380 Hz	5.0 kHz	$IF1_{Low}$	$IF1_{High}$
Offset Freq High	1.0 Hz	63.0 Hz	5000 Hz	$IF1_{Low}$	$IF1_{High}$	RFBW – $IF1_{High}$
Spur Level (Max)	-32 dBc	-20 dBc	-20 dBc at low offset, decreasing to -40 dBc at high offset	-40 dBc	See Table 290-1A	-20 dBc
	Note a)	Note b)	Note c)	Note d)	Note e)	Note f)

Table 290-1A	**IF In-Band LO1 Spurious Signals**			
Band	$IF1_{Low}$ GHz	$IF1_{High}$ GHz	RFBW GHz	Spur Level (Max) dBc
1	4	12	14	TBD
2	4	12	23	TBD
3	4	8	32	-54
4	4	8	38	-52
5	4	8	48	-47
6	5	10	64	-57
7	4	8	98	-51
8	4	8	115	-49
9	4	12	118	-45
10	4	12	163	-45

Table 290-2	LO2 and DGCK - Maximum Amplitude of Spurious Signals			
Offset Freq Low	0.003 Hz	1.0 Hz	380 Hz	5.0 kHz
Offset Freq High	1.0 Hz	63.0 Hz	5000 Hz	+4 GHz and -6 GHz
Spur Level - Max	-42 dBc	-20 dBc	-20 dBc decreasing to -40 dBc	-40 dBc
	Note a)	Note b)	Note c)	Note d)

Notes to the Tables:

a) Spurs that are very close to the LO and that are coherent between antennas can lead to modulation of the fringe rotation in interferometry.
With offset frequencies between 0.003 Hz and 1.0 Hz (time scales between 300 sec, a typical calibration interval, and 1.0 sec), LO spurs will produce LO phase errors that are quasi sinusoidal in time, of the kind studied in JIRA issue CSV-292. To keep such phase errors at 1/3 of the phase drift requirement in Table 1 in Section 5.1.3, the spurs should be < -32 dBc for LO1 and < -42 dBc total for LO2 and the DGCK. These levels are calculated by equating the spur to carrier voltage ratio to the permitted phase error in radians.

This requirement applies only to LO spurs that are coherent among antennas. However, since the LOs are phase locked between antennas and the offset frequencies considered here are within the PLL bandwidths of the LOs, all such close in spurs should be considered coherent among antennas.

Spurs in this offset frequency range readily appear as a phase rotation on the astronomical visibility which cannot be due to source structure or other known errors. After a few one-off problems were resolved, this does not, at this time, appear to be a problem with the system design.

b) With offset frequencies of 1 Hz to 63 Hz (time scales between 1 sec and 16 msec, the shortest possible cross-correlation integration period) spurs will typically undergo several phase rotations and produce an amplitude error rather than a phase error. Keeping this amplitude error below 1% leads to a requirement of -20 dBc on such a spur.

This requirement applies only to LO spurs that are coherent among antennas. However, since the LOs are phase locked between antennas and the offset frequencies considered here are within the PLL bandwidths of the LOs, all such close in spurs should be considered coherent among antennas.

c) This requirement is driven by the need to prevent measureable broadening of a very narrow astronomical line by mixing with a close-in LO spur. The low end offset frequency is taken to be a fraction of the highest resolution spectral channel bandwidth which is 3.8 kHz (correlator mode #25). This bandwidth requires running the TFB with a 31.25 MHz bandwidth to achieve the highest possible resolution. The low end frequency offset is taken to be 0.1 * 3.8 kHz = 380 Hz.

The high end offset frequency is taken to be about a spectral channel width and is where the appearance of a ghost line in the astronomical spectrum becomes the major concern. The permitted level of the LO spur is taken to match the requirements above and below this offset frequency range.

This requirement applies to spurs both coherent and incoherent among antennas.

d) Spurs on local oscillator signals can mix with astronomical spectral lines to produce weak ghost lines within the IF band. This will be a problem for both spurs that are coherent among antennas (interferometry) and incoherent (single dish autocorrelation) and will be a problem with all LOs. The limit on the spur intensity, -40 dB, is determined by the requirement on spectral dynamic range discussed at the beginning of these notes.

For the LO1, the offset frequency of this requirement extends from the frequency of a small spectral channel bandwidth up to the low end of the cartridge IF bandwidth, where saturation considerations become important.

For the LO2 the situation of a ghost line arising from mixing of an LO2 spur with an strong spectral line somewhere in the IF1 bandpass, requires a limit on any LO2 spur out to + 4 GHz above the LO2 frequency and -6 GHz below the LO2 frequency. There are similar limits on the DGCK.

e) Spurs on the LO1 with offset frequencies in the IF1 range can mix with the LO1 signal to produce powerful spectral lines in the IF1 bandpass. A limit is placed on spurs that fall in this frequency range to prevent saturation of the IF system. The requirement is that the power in the LO spur should be less than the noise power integrated over the IF1 bandwidth at the first mixer.

The requirements for Band 1 and Band 2 are TBD since the analysis uses Trcvr (at the feed input) to determine the noise power at the mixer. These bands have an LNA before the mixer and until a cartridge design is accepted and this LNA is specified, the noise power at the mixer is unknown.

These requirements are more stringent than the previous -40dBc spur power limits reported in [RD 13]. However they are adopted here since this type of spur is not seen in early operations and the requirement is probably met.
In no case this tightened requirement is retroactively applicable to the acceptance of HW already designed or delivered at the time of issuing of this document.

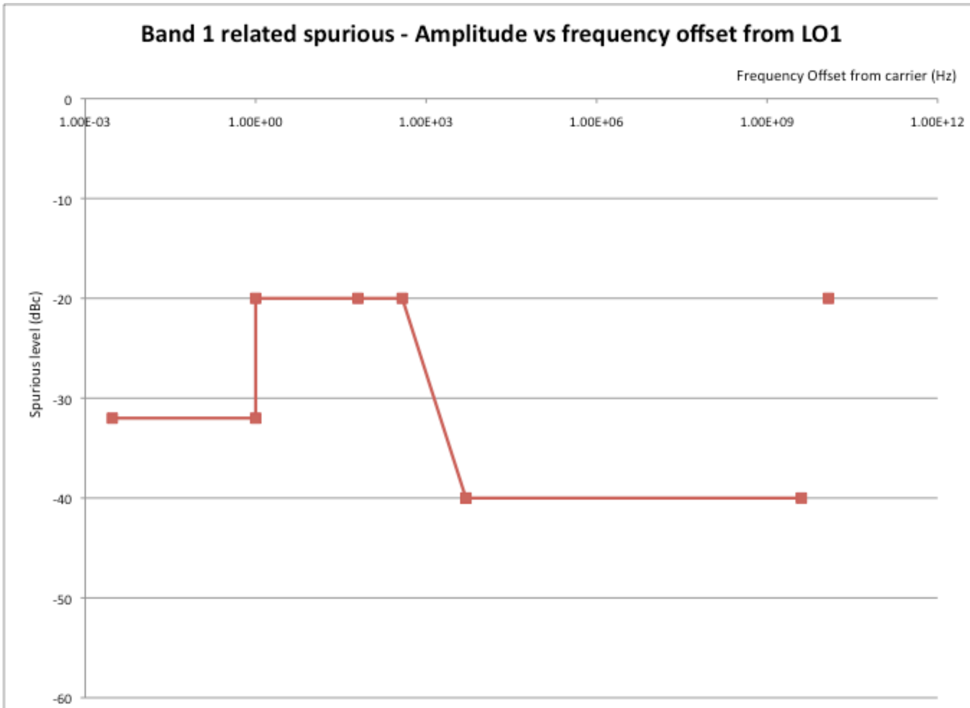
LO1 spurs directly converted to spurs in the IF1 bandpass may also be subject to Req 295.1 and 295.2 which are stricter than the requirement given here to prevent IF1 saturation.

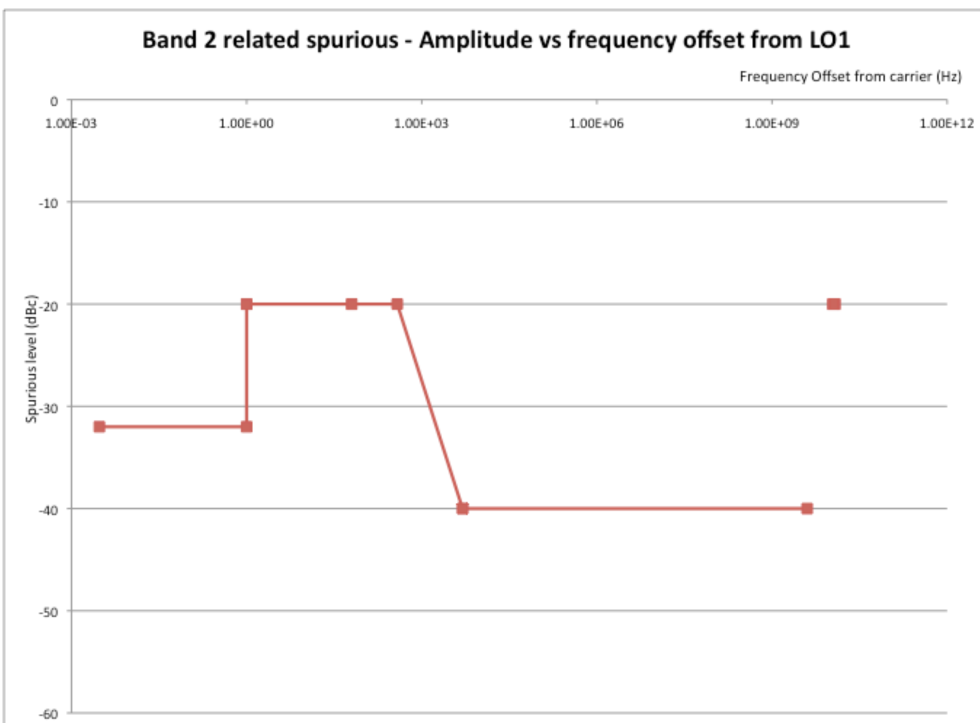
f) This is a new system requirement on LO1 spurs with offset frequencies that are beyond the high end of IF1. These can arise as harmonics of the Front End WCA-YTO and can be generated in the YTO itself, in the WCA-AMC and/or in the cold multipliers. These spurs can mix with astronomical spectral signals anywhere in the FE RF bandpass to produce ghost signals in the IF1. Therefore, the LO offset frequency range of this requirement should be such that an astronomical line anywhere in the RF range of the appropriate cartridge will not be shifted into the IF1 bandpass of that cartridge.

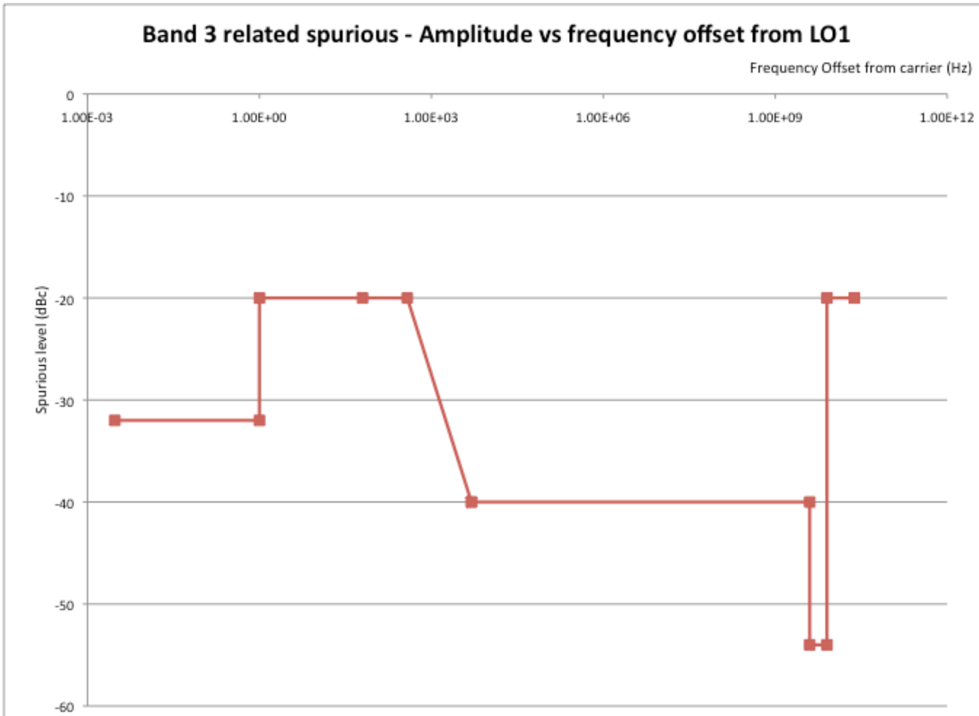
The requirement for harmonically related spurs already exist in most, if not all, LO ICDs to the cold cartridges, and sets a limit of < -20 dBc. This is also about a level of what is obtained in production. Assuming that the amplitude of the astronomical line producing the ghost spectral line is about equal to that of the strongest astronomical line in the desired bandpass, and since the ghost line conversion efficiency is, to a first order, proportional to the strength of such LO spurs, the existing subsystem LO requirement is ~20 dB above the -40 dBc needed to meet the science requirement #70 on spectral dynamic range.

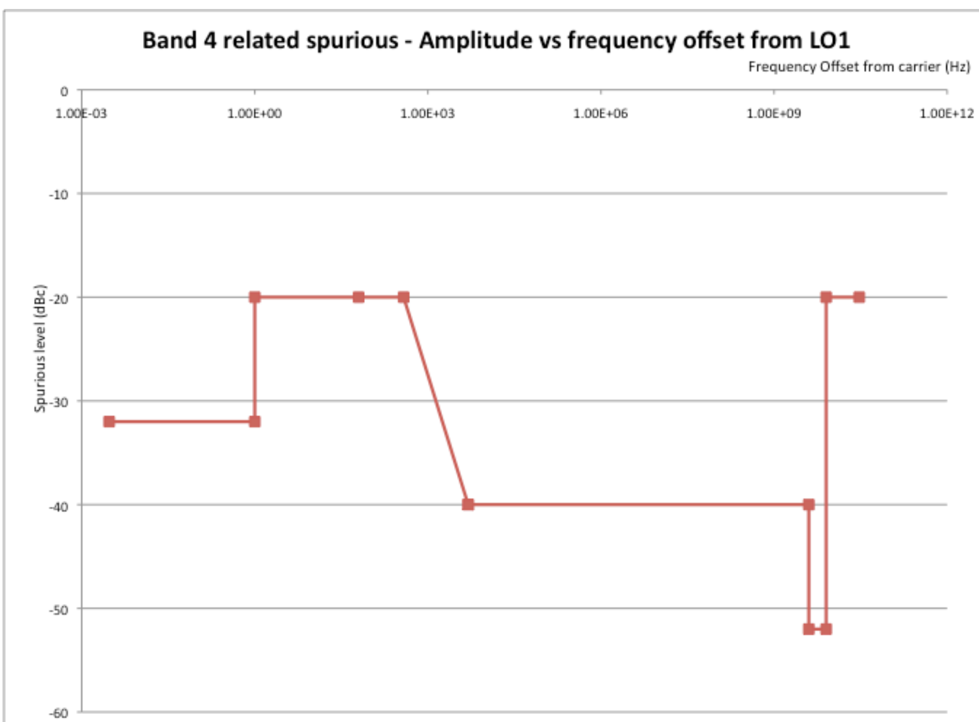
In interferometry mode, LO-offsetting could significantly suppress such ghost lines and Walsh switching could be somewhat effective. Fringe rotation will not be effective at all in suppressing the ghost lines since the LO spur will carry the fringe rotation appropriate for that spur LO frequency. However, LO-offsetting cannot be used where full DSB observations are needed in Band 9 and 10. Also, none of these mitigations help in total power, auto-correlation observations.

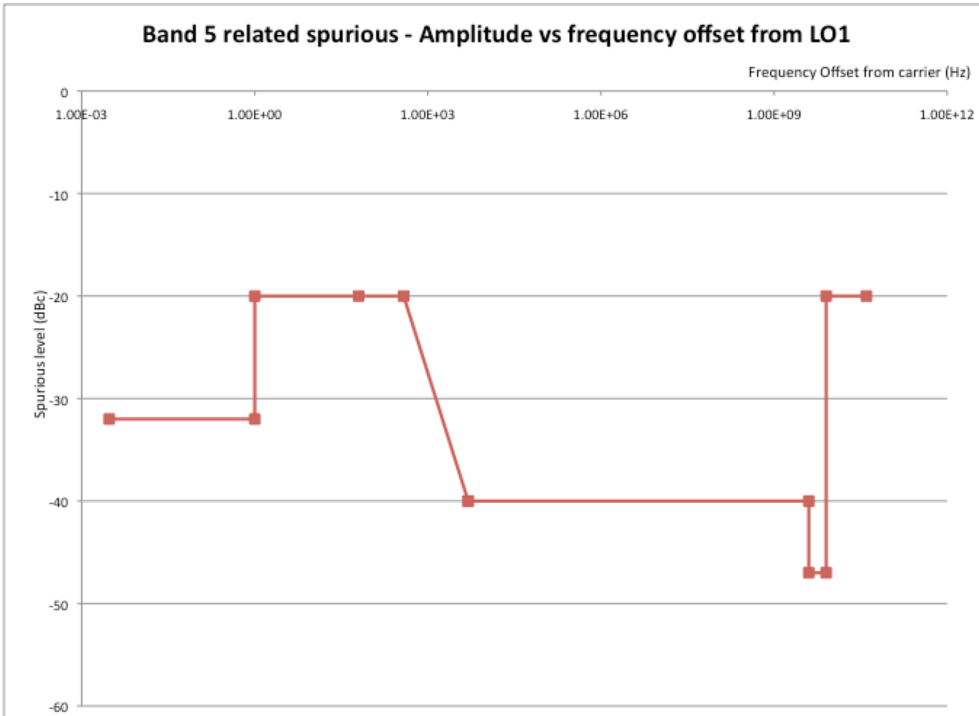
Here are reported the plots of the masks, for each Band, limiting the spurious, as defined in Table 290-1 and 290-1A.
Notice that these plots show only the "positive offset" from the LO1 frequency, whereas the specification is referred to the absolute value of the offset.

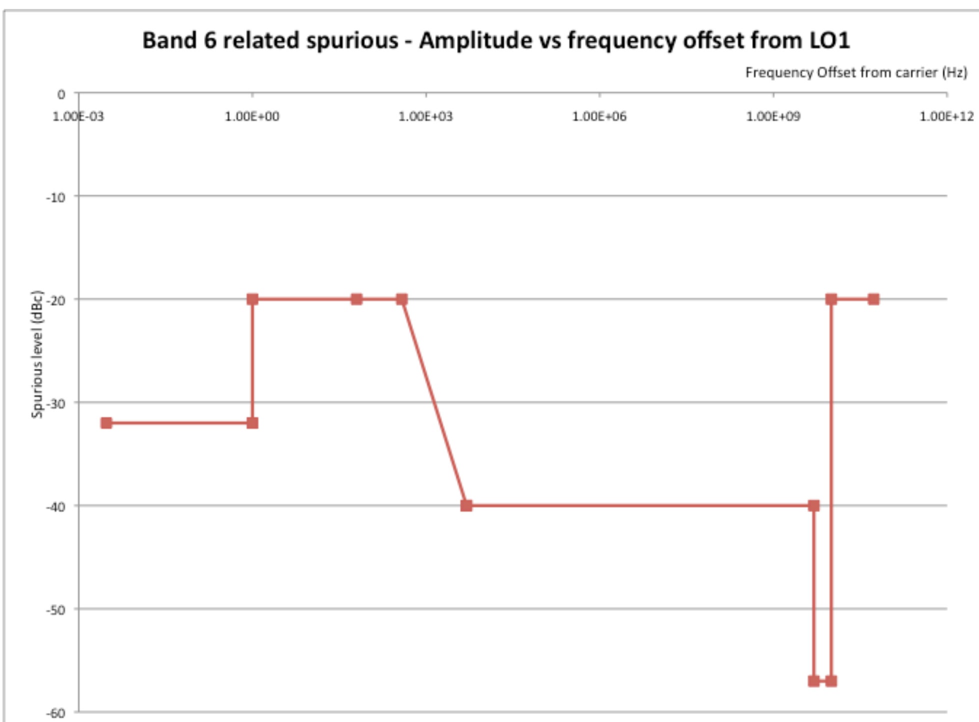

Band 1 related spurious - Amplitude vs frequency offset from LO1
Frequency Offset from carrier (Hz)
Spurious level (dBc)
0
-10
-20
-30
-40
-50
-60
1.00E-03
1.00E+00
1.00E+03
1.00E+06
1.00E+09
1.00E+12

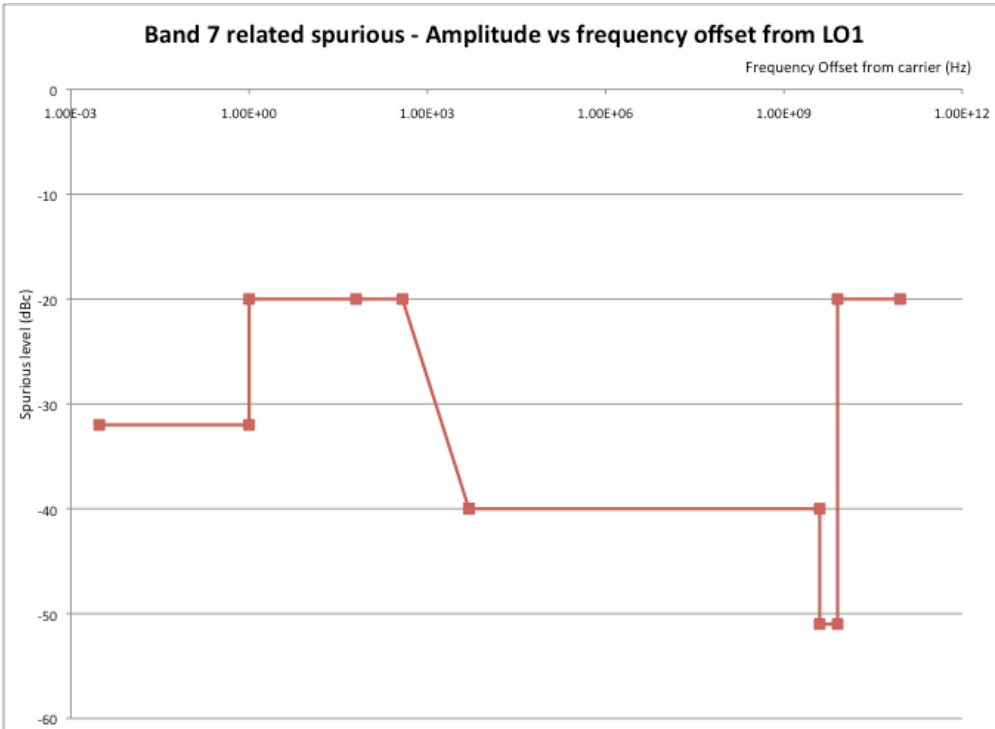

Band 2 related spurious - Amplitude vs frequency offset from LO1
Frequency Offset from carrier (Hz)
Spurious level (dBc)
0
-10
-20
-30
-40
-50
-60
1.00E-03
1.00E+00
1.00E+03
1.00E+06
1.00E+09
1.00E+12


Band 3 related spurious - Amplitude vs frequency offset from LO1
Frequency Offset from carrier (Hz)
Spurious level (dBc)
0
-10
-20
-30
-40
-50
-60
1.00E-03
1.00E+00
1.00E+03
1.00E+06
1.00E+09
1.00E+12

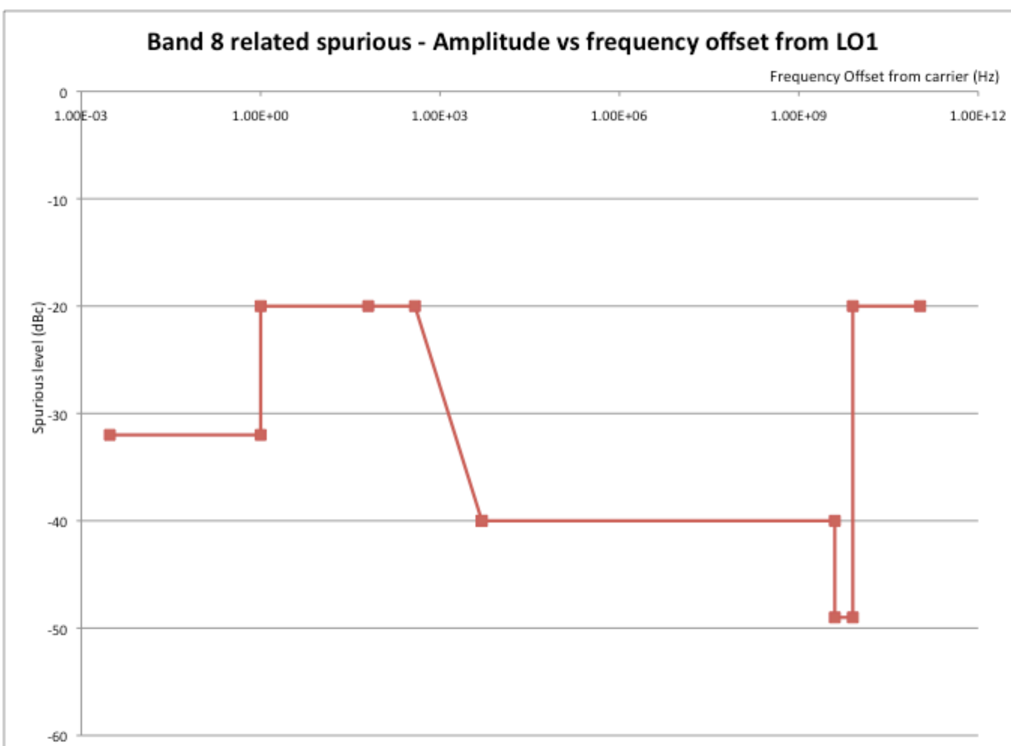

Band 4 related spurious - Amplitude vs frequency offset from LO1
Frequency Offset from carrier (Hz)
Spurious level (dBc)
0
-10
-20
-30
-40
-50
-60
1.00E-03
1.00E+00
1.00E+03
1.00E+06
1.00E+09
1.00E+12


Band 5 related spurious - Amplitude vs frequency offset from LO1
Frequency Offset from carrier (Hz)
1.00E-03
1.00E+00
1.00E+03
1.00E+06
1.00E+09
1.00E+12
Spurious level (dBc)
0
-10
-20
-30
-40
-50
-60

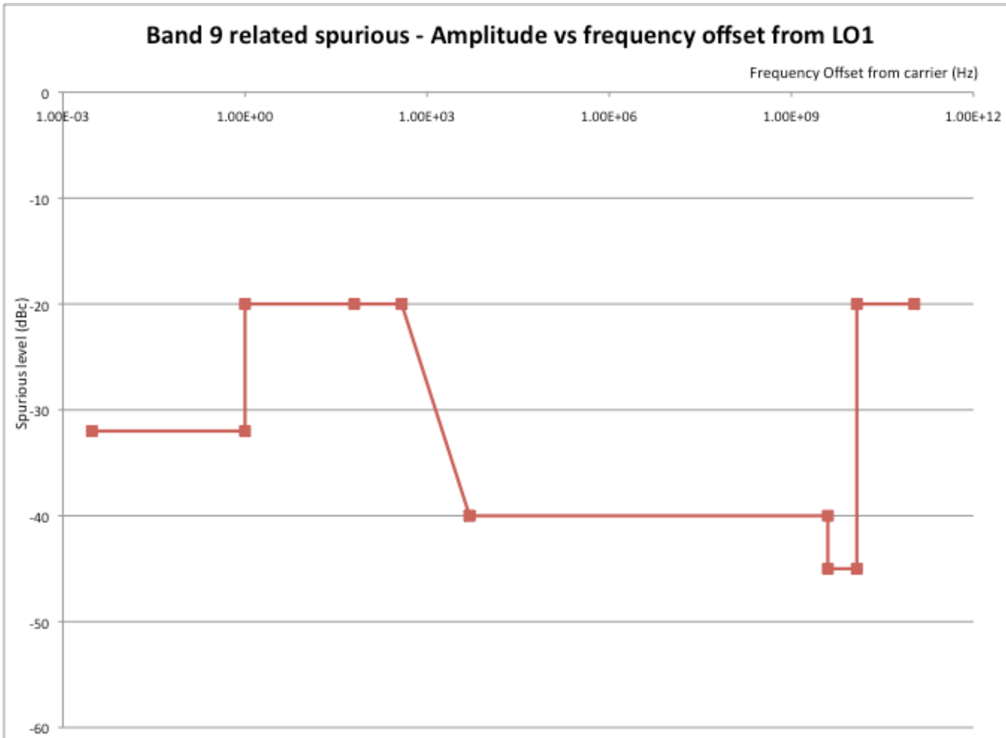

Band 6 related spurious - Amplitude vs frequency offset from LO1
Frequency Offset from carrier (Hz)
1.00E-03
1.00E+00
1.00E+03
1.00E+06
1.00E+09
1.00E+12
Spurious level (dBc)
0
-10
-20
-30
-40
-50
-60

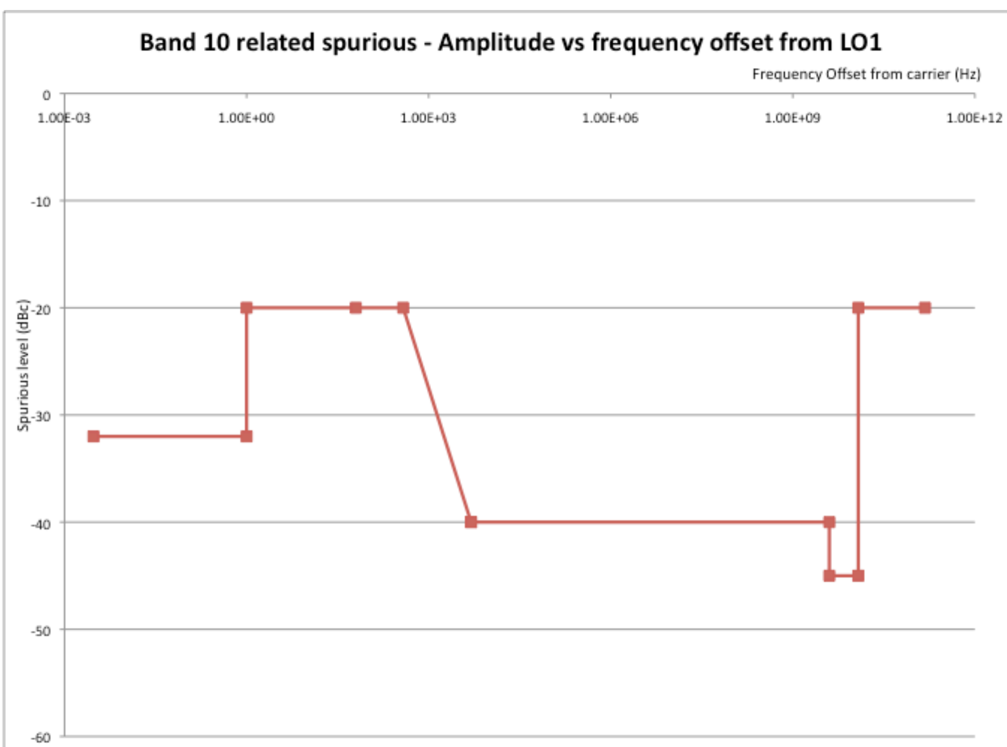


Band 7 related spurious - Amplitude vs frequency offset from LO1
Frequency Offset from carrier (Hz)
Spurious level (dBc)
0
-10
-20
-30
-40
-50
-60
1.00E-03
1.00E+00
1.00E+03
1.00E+06
1.00E+09
1.00E+12



Band 8 related spurious - Amplitude vs frequency offset from LO1
Frequency Offset from carrier (Hz)
Spurious level (dBc)
0
-10
-20
-30
-40
-50
-60
1.00E-03
1.00E+00
1.00E+03
1.00E+06
1.00E+09
1.00E+12


Band 9 related spurious - Amplitude vs frequency offset from LO1
Frequency Offset from carrier (Hz)
1.00E-03
1.00E+00
1.00E+03
1.00E+06
1.00E+09
1.00E+12
Spurious level (dBc)
0
-10
-20
-30
-40
-50
-60


Band 10 related spurious - Amplitude vs frequency offset from LO1
Frequency Offset from carrier (Hz)
1.00E-03
1.00E+00
1.00E+03
1.00E+06
1.00E+09
1.00E+12
Spurious level (dBc)
0
-10
-20
-30
-40
-50
-60

As stated in Section 3, in this Version C of the STR, new requirements will not be introduced that exceed the capabilities of the current implementation. So this requirement is set as -20 dBc, but it is noted here that this might compromise the science requirement #70.

This tightened requirement has not been considered in as built FE hardware and is not retroactively applicable to the acceptance of HW already designed or delivered at the time of issuing of this document.

7.2.26 Requirement # 292 - Spurious Signals: Broad, Incoherent

Parameters	Req #	.#	Value	Sci #
Broad-band Spurious Signal – Incoherent among antennas	292		a) IF power in incoherent spurious signals shall be < - 10 dB per unit bandwidth relative to the nominal system noise power per unit bandwidth. b) stability of the incoherent spurious signals shall be < - 20 dB per unit bandwidth relative to the nominal system noise power per unit bandwidth.	
Allocation	Equally between the Front End and Back End sub-systems			

See [RD 17] for further discussion of spurious signals.

A broad-band spurious signal that is incoherent among antennas is likely to be time variable and can lead to time varying changes in effective system temperature. If the timescale of variations is less than the single dish switching period, the spurious signal will limit the continuum and line detection limits of the observation.
For the purposes of part b (stability) of this requirement, assume that the single dish switching period is equal to one second. The component of a spurious broadband signal that varies on time scales of < 1 second should be constrained to not increase the effective system noise by more than 1% and thus must have a spectral power < -20 dB of the system noise per unit bandwidth.

This requirement is allocated equally in power among the BE and FE sub-systems, i.e., < -23 dB of the total system noise is allocated to each subsystem.

Part b) is a new requirement implemented in Rev.C. It specifically controls the time and antennal elevation varying effects. Stable spurious, e.g. LO excess noise, can have larger magnitude, controlled by a).

This new requirement has not been considered in as built FE hardware and is not retroactively applicable to the acceptance of HW already designed or delivered at the time of issuing of this document.

7.2.27 Requirement # 293 - Spurious Signals: Broad, Coherent

Parameters	Req #	.#	Value	Sci #
Broad-band Spurious Signal – Coherent among antennas	293		< -17 dB averaged over the continuum bandwidth, before suppression by LO-offsetting or phase switching; In those cases where spur suppression is not effective, the requirement is < -47 dB	80
Allocation	N/A			

See [RD 17] for further discussion of spurious signals.

The most likely source of a broad-band spurious signal which is coherent among the antennas is the signal from an astronomical source that is aliased into the IF band owing to inadequate image rejection in the IF filter before the 2nd mixer. See [RD 33].

The impact of such an aliased signal will be negative artifacts in the image plane, mirrored about the phase tracking center. The level of these artifacts are constrained by Science Requirement #75 which calls for an image dynamic range of >50,000. Therefore the power in the aliased band must be 47 dB below the power in the desired continuum band.

Since such a spurious signal follows the same signal path as the desired signal through the first mixer, it is not suppressed by 180 degree Walsh switching nor LO1 offsetting. However, it is suppressed by LO2 offsetting.

Assuming LO2 offsetting will suppress the spurious signal by 30 dB, the requirement on the power from the aliased band is 17 dB below the power in the desired continuum band.

For a broad-band coherent spurious signal where LO-offsetting is not effective, the requirement is that the spurious signal averaged over the continuum bandwidth be 47 dB below the desired signal.

This tightened requirement has not been considered in as built FE hardware and is not retroactively applicable to the acceptance of HW already designed or delivered at the time of issuing of this document.

7.2.28 Requirement # 295.1 - Spurious Signals: Narrow, Coherent

Parameters	Req #	.#	Value	Sci #
Narrow-band Spurious Signal – Coherent among all antennas	295.1		< -28 dB before interferometric spur suppression (spur signal power relative to the system noise power in a 1 MHz bandwidth) In those cases where spur suppression is not effective, the requirement is < -58 dB	70
Allocation	N/A			

See [RD 17] for further discussion of spurious signals.

This is the case for interferometry where the spurious signal is narrow compared to the resolution bandwidth. Sources of such signals, coherent among the antennas, might be LO or other reference signals, their harmonics or sub-harmonics, that find their way into the IF channels. For this requirement, the resolution bandwidth is taken to be B = 1.0 MHz (Doppler broadening of 1.0 km/s at 300 GHz), which is common for an astronomical observation.

The requirement constrains the ratio of the power in a narrow band spurious signal at each antenna, W (in Watts) to the spectral power of the antenna system noise, P_{Sys} (in Watts / Hz) integrated over the resolution bandwidth B. The intent of this requirement is that the error in the radio image due to the spurious signal will be less than 1/3 of the error due to system noise in a very long ALMA integration. The integration time is taken to be T=16 hours.

Assume that the coherent spurious signals at each antenna are of equal power, but that in forming the image, the resulting correlator products of the spurs will combine with random phase. Expressing the spur power as a spectral power over the resolution bandwidth, the normalized spur spectral power in the image is therefore

$$P_{Spur\,Image} = W * {}^{1}\Big/_{\sqrt{N*(N-1)/2}} * {}^{1}/_{B}$$

where N= the number of antennas in the array.

The error in the image due to system thermal noise is

$$\sigma_{P_{Image}} = P_{Sys} * {}^{1}\Big/_{\sqrt{N*(N-1)/2}} * {}^{1}\Big/_{\sqrt{B*T}}$$

If we want the error due to spurs to be < 1/3 of the error due to system thermal noise,

$$P_{Spur\ Image} < {}^{1}/_{3} * \sigma_{P_{Image}}$$

Therefore, the strength of a narrow-band spurious signal in an antenna, relative to the system noise power integrated over the resolution bandwidth must be

$$ {}^{W}/_{B} * {}^{1}/_{P_{Sys}} < {}^{1}/_{3} * {}^{1}\Big/_{\sqrt{B*T}}$$

Using the values given above and converting to dB,

$$ {}^{W}/_{B} * {}^{1}/_{P_{Sys}} < \text{-58 dB}$$

This is the level needed after suppression of spurious signal correlation products due to, for example, LO-Offsetting and 180d Walsh phase switching. The effectiveness of such suppression will depend on where the spurious signals originate. Typically we can expect 30 dB of spur suppression, so the requirement with interferometric suppression turned off is

$$ {}^{W}/_{B} * {}^{1}/_{P_{Sys}} < \text{-28 dB.}$$

There might be additional spur suppression due to fringe rotation if the spur is introduced before the LO1. Since this will often not be the case for internally generated spurs, and since the fringe rate goes to zero when U=0 for the various array baselines, this additional suppression is not considered.

In those cases where spur suppression is ineffective, e.g., when the spur is introduced after the phase switching has been reversed, the requirement remains at

$$ {}^{W}/_{B} * {}^{1}/_{P_{Sys}} < \text{-58 dB.}$$

Verification of the spur level after suppression can be done by observing blank sky at the South Pole with a two element interferometer. This can be accomplished in a reasonable observing time by testing with a very small correlator bandwidth, assuming that the spur remains unresolved. If the test bandwidth B_0 = 7 kHz and the desired measurement error due to noise in the test observation is 1/3 of the maximum spur level, the necessary test observing time T_0 is given by

$$P_{Sys} * 1/\sqrt{B_0 * T_0} = 1/3 \; W/B_0$$

Substituting the maximum value for W shown above, results in

$$T_0/T = 9^2 * B_0/B$$

Using the assumed values, the integration time for the test observation would be

T_0 = 9 hours.

Since the spectral power of the spur in the test bandwidth increases inversely as the bandwidth (while the noise increases inversely as the root bandwidth), the requirement level, with spur suppression turned on, increases to

$$W/B_0 * 1/P_{Sys} = B/B_0 * 1/3 * 1/\sqrt{B * T} =$$ -58 dB + 21 dB = -37 dB.

This test need only be done on a few strong spurious lines to verify the effectiveness of spur suppression.

This tightened requirement has not been considered in as built FE hardware and is not retroactively applicable to the acceptance of HW already designed or delivered at the time of issuing of this document.

7.2.29 Requirement # 295.2 - Spurious Signals: Narrow, Amplitude Stability

Parameters	**Req #**	**.#**	**Value**	**Sci #**
Narrow-band Spurious Signal – Spur amplitude stability-Incoherent or coherent among antennas	295.2		< -32 dB rms of a random component, and < - 56 dB constant difference component (the difference of the spur signal power in two switching states, relative to the system noise power, both in a 1 MHz bandwidth)	70
Allocation	N/A			

See [RD 17] for further discussion of spurious signals.

For single dish autocorrelation observations, it is the amplitude stability in time of both coherent and incoherent spurious signals that will limit the accuracy of beam switching, frequency switching or OTF observations. This requirement limiting narrow-band spurious emission can be derived in a manner similar to Requirement #295.1. The relevant quantity is

$$\Delta P = P_2 - P_1$$

where P_1 and P_2 are the spectral power density levels in the two switching states.

As before, the mean error due to system noise after one switching cycle is

$$\sigma_{\Delta\mathrm{P}}(1) = \sqrt{2} * P_{Sys} * {}^{1}\!\big/\!\sqrt{B * T_s/2}$$

where P_{Sys} is the spectral power due to system noise, T_s is the period of a switching cycle, and B is the resolution bandwidth. For simplicity it is assumed ½ of the period Ts is spent in each state.

If M switching cycles are averaged, the mean error of the average differential power measurement is

$$\sigma_{\Delta\mathrm{P}}(\mathrm{M}) = {}^{1}\!\big/\!\sqrt{M} * \sigma_{\Delta\mathrm{P}}(1)$$

A narrow spurious line with power W (Watts) will have a spectral power density of

$$L = W/B \quad \text{(W/Hz)}$$

The difference of the spurious spectral power density in the two switching states is

$$\Delta L = L_2 - L_1$$

Let $\sigma_{\Delta\mathrm{L}}(1)$ be the RMS value of ΔL for one switching cycle,

$$\sigma_{\Delta\mathrm{L}}(1) = \sqrt{< \Delta L^2 >}$$

Note that $\sigma_{\Delta\mathrm{L}}(1)$ is the RMS of ΔL, not the RMS about its mean value.

Now, we define the requirement on a narrow spurious line in single dish autocorrelation observations to be that after M switching cycles the signature of the spurious line should be less than 1/3 of the error due to system noise,

$$\sigma_{\Delta L}(M) < {}^{1}/_{3} * \sigma_{\Delta P}(M)$$

$$\sigma_{\Delta L}(M) / P_{Sys} = {}^{1}/_{3} \sqrt{2} * 1 / \sqrt{M * B * T_s/2}$$

Using B = 1.0 MHz, a 16 hour integration and a one second switching cycle (Ts = 1.0 and M=16*3600), our requirement on the spurious line with switching in use is

$$\sigma_{\Delta L}(M) / P_{Sys} < -55.6 \text{ dB}$$

Consider two limiting cases, 1) ΔL having a zero mean but random variations from one cycle to the next, and 2) ΔL having a non-zero mean but no random variations.

In the first case, where ΔL is changing randomly,

$$\sigma_{\Delta L}(M) = {}^{1}/_{\sqrt{M}} * \sigma_{\Delta L}(1)$$

and we only require

$$\sigma_{\Delta L}(1) / P_{Sys} = {}^{1}/_{3} \sqrt{2} * 1 / \sqrt{B * T_s/2} \quad < -31.8 \text{ dB}$$

since both the error due to system noise and the error due to the spur go down as 1/sqrt(M). Therefore, an arbitrarily long integration will not be significantly impacted by the spur if the difference in the levels in the two are zero mean on time scales shorter than the switching cycle and the random component meets the above limit.

In the second case, where there is a systematic difference in the spur intensity in the two switching states, then $\sigma_{\Delta L}(M)$ will be constant no matter how large a value for M is used,

$$\sigma_{\Delta L}(M) = \sigma_{\Delta L}(1) < {}^{1}/_{3} * \sigma_{\Delta P}(M)$$

and therefore the limit on such a systematic offset is

$\sigma_{\Delta L}(1) / P_{Sys}$ < -55.6 dB

These two cases set the limits for the random and constant components of variations of L between the two switching states.

These are the equivalents to the case in interferometry for a coherent spur where suppression by Walsh switching or LO-offsetting may or may not be effective.

To verify the very tight requirement on a systematic spur difference in the two states, measurements with a reduced bandwidth could be used as was discussed for coherent spurs, Req #295.1

Variations in the broad-band system noise, Psys, between the two switching states could also add to any variation seen in sig_dL(M) / Psys. However, since the spur by definition is narrow compared to the resolution bandwidth, this effect can be removed by subtracting the variations measured in nearby spur free channels from the variation seen in the channel containing the spur.

One source of narrow spurious signals is emission from the WCA of FE cartridges in standby mode, including various harmonics of the unlocked YTO fundamental oscillator. There can be strong LO leakage from standby WCAs into the active cartridge. Although the frequencies of these signals are well determined and it should be possible to find safe parking LO1 frequencies, i.e., where the standby WCAs do not interfere with the active observations, the presence of numerous YTO harmonics greatly complicates this process.

This tightened requirement has not been considered in as built FE hardware and is not retroactively applicable to the acceptance of HW already designed or delivered at the time of issuing of this document.

7.2.30 Requirement # 297 - Spurious Signal: Stability of Integrated Spur Amplitude

Parameters	Req #	.#	Value	Sci #
Spurious Signal: Stability of spur amplitude integrated over 2GHz bandwidth of Total Power Detector	297		< -48 dB rms of a random component, and < - 72 dB constant difference component (the difference in two switching states of the aggregate spur signal power over the 2 GHz baseband, relative to the system noise power)	70 80
Allocation	N/A			

This is a new requirement that is not in [RD 13].

See [RD 17] for further discussion of spurious signals.

When using the 2 GHz Total Power Detector, the requirement on spurious signals is similar to Requirement # 295.2, except that it now refers to the time variation of the aggregate of all of the spurs in the 2 GHz baseband bandpass.

The limiting cases of 1) zero mean, random variations and 2) only a systematic offset also apply here, except the bandwidth is 2 GHz rather than 1 MHz. Keeping all other parameters the same, the requirements on variations are therefore 16 dB lower than those in Req #295.2.

If only random variation is present, case 1), the limit to the RMS of the aggregate spur intensity is

$$\sigma_{\Delta L}(1) / P_{Sys} = {}^{1}/_{3} \sqrt{2} * {}^{1}/\sqrt{B * T_s/2} \quad < -48 \text{ dB}$$

Similarly, if only a systematic offset is present in the aggregate spur intensity as the system is switched between two states, Case 2), in order to not have the spurs degrade a 16 hour observation,

$$\sigma_{\Delta L}(1) / P_{Sys} \quad < -72 \text{ dB}$$

The only way to verify these very low requirements is to measure the stability of the individual spurs using the spectral autocorrelator and calculating the RMS and offset of the aggregate of the spurious lines.

This new requirement has not been considered in as built FE hardware and is not retroactively applicable to the acceptance of HW already designed or delivered at the time of issuing of this document.

7.2.31 Requirement # 311 - Digital Signal Transmission

Parameters	Req #	.#	Value	Sci #
Digital Signal Transmission	311		The cable delay in each DTS should remain constant within ±8ns for at least 2 weeks.	
Allocation				

Within the Instrument Delay definition [RD 34] the delay associated to the DTS is called T_{PAD}.
This includes all the delay from the fiber connector in the Antenna Pad to the position in the correlator where the signals are actually "correlated".

The part of the DTS delay from the digitizer to until the fiber connector in the Pad, on the Antenna side, is considered constant and part of the T_{ANT} contribution.

The required stability would allow that a Delay Calibration, updating the stored values of T_{PAD}, is not necessary more than once every two weeks.

7.2.32 Requirement # 312 - Digital Signal Transmission – Bit Error Rate

Parameters	Req #	.#	Value	Sci #
Digital Signal Transmission – Bit Error Rate	312		The Bit Error Rate (BER) for each DTS should be better than 10^{-6}.	
Allocation				

When a communication error occurs in the DTS (typically a bit flip) it causes the affected sample to contain one value that doesn't correspond to the actual value sampled in the "sky signal".

This value was assumed in the [RD 35], reported as "extremely low" in [RD 36] that describes the communication protocol and confirmed to be a fundamental requirement into the ALMA System Design Description [RD 01].

The BER in this system is mainly associated to the power arriving to the DRX cards of the correlator from each corresponding DTX.

For what concerns the verification it is empirically established that when an antenna is placed in a Pad, the BER requirement is satisfied when the DTS optical power arriving at the DRX (measured as connection check after every antenna movement) is larger than -18dBm.

7.2.33 Requirement # 321 – Digitization: 2GHz nom ch bandwidth

Parameters	Req	.#	Value	Sci #
Digitization: 2 GHz nom ch bandwidth	321		2 GHz nominal channel bandwidth	
Allocation				

7.2.34 Requirement # 322 – Digitization: 3 bits, 4 GHz

Parameters	Req	.#	Value	Sci #
Digitization: 3 bits, 4 GHz	322		8 levels (3 bits), uniformly spaced, at 4 GSa/sec	
Allocation				

This requirement is intended only to provide the number of bits necessary for the digitization of the analogue signal in the BE. Accuracy and time stability of the digitization levels are defined at sub-system level.

7.2.35 Requirement # 323 – Sampling clock: fine delay steps

Parameters	Req	.#	Value	Sci #
Sampling clock: fine delay steps	323		Variable phase for fine delay, < 1/16 sample accuracy.	
Allocation				

This requirement was changed from its original value of 1/8 sample. See [AD 22] for the reasons for this change.

7.2.36 Requirement # 324 – Sampling clock: common to all ant IFP

Parameters	Req	.#	Value	Sci #
Sampling clock: common to all ant IFP	324		Common to all channels at an antenna.	
Allocation				

7.2.37 Requirement # 325 - Sampling clock synchronization to correlator

Parameters	Req #	.#	Value	Sci #
Sampling clock synchronization to correlator	325		The synchronization between the DGCK sampling clock fine delay adjustment, that requires a transition from 15/16 of the period back to zero or viceversa, and the corresponding coarse timing adjustment in the correlator, that changes by 1 unit the coarse delay, shall be better than ±500us	
Allocation				

The fine delay adjustment of the DGCK sampling clock of these "wrap-up" transitions (15/16 to 0 or 0 to 15/16) would require a coordinated change in the correlator coarse delay, by 1 sample period (250ps), in order to maintain the phase coherence in the correlated signals.

The fine delay adjustment in the DGCK is necessary to take into account the change of the "geometrical delay" during the observation; it can be re-adjusted several times within a TE interval (48ms), but it is unlikely that more than one of these "wrap-up" transitions occur in the same TE interval.

The coarse delay re-adjustment in the correlator can be performed only once per TE interval, but it is possible to schedule at which ms of the 48 in the interval the change will take place.

The two events, in the DGCK and in the correlator, shall be synchronized such that when the incoming signals are correlated they remain 250ps (1 DGCK sample period) out of phase for the shortest time possible, that given the time resolution in the correlator coarse delay adjustment, is of the order of 1ms.

7.2.38 Requirement # 411 – Tuning range and resolution: Baseband

Parameters	Req #	.#	Value	Sci #
Tuning range and resolution: Baseband	411		Any sky frequency may be placed at any: baseband frequency within ±10% of digitized BW	20
Allocation				

This is a requirement on the tuning step and range of the 1st and 2nd LOs (including FTS) and requires placing any accessible sky frequency within ±200 MHz of any point in the 2 GHz baseband. An exception is a sky frequency located within 1.8 GHz of an RF band edge. Observing frequency selection involves a combination of 1st and 2nd LO tunings. Details are given in [RD 01] section 3.1.1.3.

7.2.39 Requirement # 412 – Tuning range and resolution: FE IF

Parameters	Req #	.#	Value	Sci #
Tuning range and resolution: FE IF	412		1st IF frequency within ±10% of the 1st IF bandwidth.	20
Allocation				

This is a requirement on the tuning step and range of the 1st LO (including FTS) and requires placing any accessible sky frequency 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.

7.2.40 Requirement # 420 - Sub-arrays

Parameters	Req #	.#	Value	Sci #

Parameters	Req #	.#	Value	Sci #
Independently Tunable sub-arrays	420	M	It shall be possible to run at least 4 independent arrays (sub-arrays). Each of them can be pointed in different times to different sources and tuned to different frequency.	390
	420	T/7	It shall be possible to run at least 2 independent arrays (sub-arrays). Each of them can be pointed in different times to different sources and tuned to different frequency.	01010
Allocation				

This requirement is derived directly from [AD 01]: *"It shall be possible to have at least four sub-arrays in which the observing frequency and antenna control in each is completely independent of the others."* for the 64-Antennas correlator and from the draft document "ACA Scientific Specifications and Requirements" [RD 44] for the ACA Correlator.

7.2.41 Requirement # 425 - Sub-arrays switching time

Parameters	Req #	.#	Value	Sci #
Sub-arrays switching time	425		The generation of a sub-array, for a 300s observation, shall not increase the duration of execution of the relevant SB by more than 3% or 1 sigma, whichever larger.	
Allocation	1.5% to hardware and 1.5% to software			

The introduction of sub-arrays during an observation (see http://almasw.hq.eso.org/almasw/bin/view/CONTROL/SubarraySemantics for a definition of arrays and sub-arrays) shall not significantly affect the execution time of a given Scheduling Block.

The proposed requirement can be verified by running first a SB that includes only a 300s observation, without sub-arrays, and record the time needed for its execution.
Repeat then the same observation running another SB that this time includes the generation (and use) of one sub-array and record again the time needed for the execution.

The requirement asks that the two would differ by less than 3%.
If the duration of the execution of an SB is intrinsically variable such that its standard deviation is larger than 3% of the total execution time, then that 1-sigma becomes the pass/fail criteria threshold for this requirement.

For the purpose of System Characterization the same procedure can be repeated with the generation of two, three or four sub-arrays.
It is suggested that each of the successively introduced sub-arrays is allowed to account for no more than 3% or 1 sigma of the execution time of the SB with one sub-array less.

7.2.42 Requirement # 430 – Frequency tuning: within FE band, time

Parameters	Req	.#	Value	Sci #
Frequency tuning: within FE band, time	430		< 1.5 sec for intraband tuning over whole band.	40
Allocation				

In the event that the frequency tuning requires a change in the Laser Synthesizer frequency this requirement can only be achieved if the Laser Synthesizer is pre-tuned to the required frequencies. Also, although all local oscillators in the system can switch with sufficient speed, if the change in tuning requires a change in the IF Switch or Baseband variable attenuators the gain may not stabilize completely in 1.5 sec. See [AD 23] and for details.

7.2.43 Requirement # 431 – Frequency tuning: between FE bands, time

Parameters	Req		Value	Sci #
Frequency tuning: between FE bands, time	431		< 1.5 sec interband, switching to a FE band in standby mode.	50
Allocation				

This requirement can only be achieved if the Laser Synthesizer is pre-tuned to the required frequencies. Also, although all local oscillators in the system can switch with sufficient speed, if the change in tuning requires a change in the IF Switch or Baseband variable attenuators the gain may not stabilize completely in 1.5 sec. See [AD 23] and for details.

7.2.44 Requirement # 432 – Freq Switching: time & range

Parameters	Req #	.#	Value	Sci #
Freq Switching: time & range	432		Up to 10Hz rate with a < 10 msec (rise and fall time) (Frequency throw up to of 25 MHz sky frequency; Spectral line total power mode only & within the same FE band)	
Allocation	Front End and Back End			

The basic frequency changing time is chosen to match the antenna pointing settling time for fast switching. However, for calibration of the instrumental phase difference using a single source, faster frequency changing (<0.1s) is desirable.
The 10 msec time for small frequency changes is intended to support single-dish frequency-switched spectroscopy, and thus it does not require that accurate phase tracking be achieved at the new frequency within 10 msec.

7.2.45 Requirement # 433 – FE & LO1: number of bands in standby

Parameters	Req #	.#	Value	Sci #
FE & LO1: number of bands in standby	433		Up to two bands may be in standby mode while one band is in operational mode, or up to three bands in stand-by mode and none in operational mode.	50
Allocation	Front End			

This is a modification to Req #433 in the previous version of the System Technical Requirements [RD13] and Req #435 has been deleted. In [RD13] the combined, #433 and #435 required that Band 3 always be either in use or in standby mode, Now, any two bands may be in standby mode and the requirements on switching between standby and operational modes applies to any combination of bands. Also #433 now allows three bands be in standby mode and none in operational mode.

7.2.46 Requirement # 441 - Phase Switching: LO1 180d & 90d

Parameters	Req #	.#	Value	Sci #

Phase Switching: LO1 180d & 90d	441		180° and 90° phase switching inserted in the 1st LO	
Allocation	N/A			

This is a design guideline rather than a performance requirement.

The 180° Walsh switching is inserted in the 1st LO FLOOG and removed by sign reversal after digitization in the DTS Formatter. The 180° Walsh switching states are nested within the 90° Walsh switching states. The 90° Walsh switching is demodulated after correlation by selective binning of the correlator output. This inner, nested switching may use the same Walsh functions as in the outer switching loop. 90° phase switching and synchronization with correlator binning is only needed in the Sideband Separation correlator mode and should be disabled when not needed.

The 180° phase switching in the DTS Formatter provides suppression of spurious signals introduced after the 1st mixer and of DC offsets introduced in the digitization.

The amount of suppression is compromised by synchronization errors between the antennas. Among the 128 possible Walsh sequences, 64 sequences should be chosen based on their susceptibility to synchronization errors. Req # 444 constrains the permitted synchronization errors among antennas. See [RD 18] for a discussion of the relationship between Walsh number, synchronization errors and spur suppression.

The goal for 180° Walsh switching suppression is -30 dB.
The goal for 90° Walsh switching sideband separation is -30dB.
This performance can be subject to atmospheric turbulences behavior that would significantly degrade the achievable sideband separation.

7.2.47 Requirement # 442 - Phase Switching: Settling Time

Parameters	Req #	.#	Value	Sci #
Phase Switching: Settling time	442		1st LO PLL effective time constant to achieve the desired phase shall be < 1 µs.	
Allocation	N/A			

CREs:
A new value was inserted for this requirement based on the following CRE.

Req #442 - CRE "Change the Time to Phase Switch (Requirement # 442) specification in ALMA System Technical Requirements Document" ALMA-40.10.00.00-088-A-CRE (see Approved CRE-95) was approved by the CCB on 2008-Feb [AD 24].

Details of CREs may be found on EDM at http://edm.alma.cl/tiny/nmzun.html.

7.2.48 Requirement # 443 - Phase Switching: Walsh functions

Parameters	Req #	.#	Value	Sci #
Phase Switching: Walsh functions	443		Walsh functions, with maximum 128 sequence for 180° series; maximum 64 sequence for 90° series; orthogonal by antenna	
Allocation				

The 180° Walsh sequence will have a complete cycle time .016 seconds for up to 64 antennas. The 90° Walsh sequence will have a complete cycle time of 2.048 seconds.

7.2.49 Requirement # 444 – Phase Switching Synchronization

Parameters	Req #	.#	Value	Sci #
Phase Switching - Synchronization	444		Phase Switching synchronization between FLOOG (that applies the switch) and DTX (that removes it) in the same antenna shall be better than 100 ns Switching delay difference, among the 4 DTXs in each antenna shall be better than 100 ns After the delay correction applied in the Correlator, for antennas receiving the incoming signal in different times, the synchronization shall be better than 100 ns. Sign reversal relative to correlator dump, < 10 μs	

Parameters	Req #	.#	Value	Sci #
Allocation				

A different delay set is available in the DTS Formatter independently for each of four the baseband pairs. However, the relative delay cannot be allowed to be too large since 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 antenna at the input to the cross-correlator multiplier stage.

The switching synchronization 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 and affects the capability of 90deg switching to perform the side band separation.
The timing of the 90deg switching applied in the Front End must be corrected for all propagation delays in both timing and signal transmission, including the variable delay introduced in the correlator as an astronomical source is tracked.
Since the period of the 90deg switching cycles is around 2s a misalignment of 100ns is produces a very negligible effect.
Nevertheless the accuracy in the delay applied in the Correlator, to the signal arriving from each antenna, is driven by other, more demanding, factors (see for example Req. #311).

Sign reversal has been relaxed to 10us.
This is intended to be the accuracy of the correlator dump relative to the TE, a mismatch in this timing would compromise the capability of the 90deg switching to perform the sideband separation.
This requirement is considered not difficult to achieve and could be verified by reviewing the design of timings and synchronizations inside the correlator.

7.2.50 Requirement # 446 – LO Offsetting

Parameters	Req		Value	Sci #
LO Offsetting	446		Offset LO1, LO2 or TFB LO from their nominal values by integer increments of $125MHz/2^{12}$ (30.5176 KHz)	
Allocation				

For the purposes of improving sideband suppression and suppression of spurious signals it shall be possible to offset LO1, LO2 and LOTFB from their nominal values. This requirement was imposed by Approved CRE # 78. Each antenna will have a different value

for the offset as defined by its antenna number N, an integer in the range 1---66. The required values for the offsets will depend on the particular observing mode (see RD 19 for definition of LO offset observing modes). The possible values for the offsets are listed below (where D is the quantum of LO Offset, (this comes from the frequency resolution of the digital LO in the TFB: 12-bit DDS accumulator at 125MHz gives D= 125MHz/2^{12} = 30.5176 kHz):
LO1: N*D or 2*N*D
LO2:±N*D or -3*N*D
TFB LO: ±N*D or 3*N*D

For the ACA correlator, which does not have a TFB LO, removal of a residual LO offset will be accomplished by shifting the frequency origin of the FFT spectra by an amount ND.

All LO offsets must be implemented with sufficient precision so that any residual phase drift is within the allowances of Table 1. This means that all LO offsets must be accurate to less than 10^{-5} Hz.

7.2.51 Requirement # 450 - LO Return To Phase: No Phase Ambiguity

Parameters	Req #	.#	Value	Sci #
LO Return to Phase: No phase ambiguity	450		All frequency synthesis unambiguous	
Allocation	N/A			

Unambiguous means that when the interferometer observing frequency is changed and then brought back to its former value, the instrumental phase difference between two antennas also returns to its former value. This is a requirement on the LO hardware design and is often referred to as the "return to phase" requirement.

The overall accuracy of return to phase should be small (~1/3) compared to the total phase drift with time; 1/3 *22 fsec = 7 fsec (for the 2nd LO phase angle, this requirement should be evaluated at 950 GHz). This will be hard to evaluate at the system level, so should probably be verified by sub-system tests.

7.2.52 Requirement # 451 - Delay Errors: Time, Phase Drift

Parameters	Req #	.#	Value	Sci #

Delay Errors: Time, phase drift	451		< 22 fsec, Allan SD with T = 10 to 300 sec (drift)	
Allocation	See Table 1			

There is no Scientific Requirement [AD 01] for long term delay/phase stability, drift.

The system level requirement is that the instrumental drift, after all corrections, be less than the delay drift introduced by the atmosphere under 95th percentile conditions. This sets the total instrumental delay drift requirement to 25 fsec and given here is the allocation to the electronics system. See Section 5.1.3 and Table 1 for further allocation among sub-systems.

The IF/LO2 phase drift requirement in Table 1 (the two entries: "2nd LO & Digitizer clock" and "Signal Path BE (IF common)" sums (RSS) to 6 fs. In the two-frequency fast switching observing, to keep the phase drift contributions from the IF/LO2 and the RF/LO1 systems equal at Band 10, the IF/LO2 requirement in phase variation should be ~1/9 of the RF/LO1 requirement at Band 10. Therefore a goal for IF/LO2 phase drift should be 0.73 degrees or 2.3 fs.

7.2.53 Requirement # 452 - Delay Errors: Time, Phase Noise

Parameters	Req #	.#	Value	Sci #
Delay Errors: Time, phase noise	452		< 65 fsec, RMS about 10 sec average (noise)	290
Allocation	See Table 1			

Science Requirement #290 calls for corrected visibility phase to be less than 167 fsec on 10 second time scales. This requires the short term, per antenna, instrumental delay noise to be < 0.707 * 167 = 118 fsec. The System Requirements extends this to require that the instrumental delay/phase noise, after all corrections, be less than the delay noise introduced by the atmosphere under 95 percentile conditions. This sets the total instrumental delay noise requirement to 75 fsec. The allocation here for the combined FE and BE electronics systems is 65 fsec. See Section 5.1.3 and
Table **1:** Allocation of Temporal Instrumental Delay/Phase Errors
(per antenna errors, in fsec)
for further allocation among sub-systems.

CREs:

Band 1 – CRE "Change Request for Band 1 Phase Noise" ALMA-56.11.00.00-024-A-CRE (see CRE-254 and BECRE-9) was approved by the CCB on 23-Nov-2010 [AD 25].

For Band 1 only, the 1st LO contribution to the phase drift is increased from 53 fsec to 88 fsec, and thus the total phase noise of the electronics system goes from 65 fsec to 96 fsec.

Details of CREs may be found on EDM at http://edm.alma.cl/tiny/nmzun.html.

7.2.54 Requirement # 454 - Delay Errors: Continuous operation

Parameters	Req #	.#	Value	Sci #
Delay Errors: Continuous operation	454		System shall typically operate for at least one hour with no step discontinuities in system delay > 10 fsec	
Allocation				

Step discontinuities in delay would be disruptive to antenna location (baseline) calibration, and if frequent enough, disruptive to astronomical observations. Such step discontinuities would not be addressed by the delay drift requirement. The delay step requirement applies to equipment operating in a severe, not typical, ALMA environment (e.g., temperature change at sun rise; vibration under full slew). As an example, this requirement will determine the range of adjustment in the 1st LO Line Length Corrector (LLC). On time scales longer than an hour, it is permissible to reset the LLCs.

7.2.55 Requirement # 456 - Delay Errors: Ant, small angle, systematic

Parameters	Req #	.#	Value	Sci #
Delay Errors: Ant, small angle, systematic	456	M	Systematic, for (az,el) change of 2.0deg, < 8 fsec	
	456	T	Systematic, for (az,el) change of 4.0deg, < 8 fsec	
	456	7	Systematic, for (az,el) change of 4.0deg, < 8 fsec	
Allocation				

There is not yet a Scientific Requirement for long term delay stability.

Systematic changes of instrumental phase with small changes of antenna pointing will have the same effect as an antenna position error reduced by sine(delta angle). This effect is differential between two antennas and differential over 2 degrees of movement and is expressed as the requirement for a single antenna. This error may arise from differences in the mechanical structure of the antenna (e.g., quadruped, subreflector mechanism or BUS), the Front End mechanical support (e.g., FESS, cryostat, cartridge mount), or in the antenna LO distribution system (electrical path length changes due to cable wraps or module motion). This requirement applies after all corrections for repeatability are applied.
Given, the permitted antenna position error is 65 um, assume 2.0 degrees angular switching to a calibrator, and setting the contribution from systematic instrumental delay errors due to antenna motion equal to the phase error arising from antenna position error, then the permitted delay error is < 65* sine(2.0d) = 2.27um => 7.6 fs.

Methodology: Average delay for 10 sec; move antenna cyclically every 10 sec. Interpolate and difference delay between two states; continue for 2000 sec; average difference. Perform this test at several antenna az/el; RMS the results without removing a mean.

The splitting of this requirement in a budget among various contributors would be very useful for the design of the individual parts, but in this phase of the project is impossible.

In this updated version of the document it is introduced also the distinction, in the requirement, between the 12m and 7m Antennas.
This tightened requirement has not been considered in as built FE hardware and is not retroactively applicable to the acceptance of HW already designed or delivered at the time of issuing of this document.

7.2.56 Requirement # 457 - Delay Errors: Ant, small angle, random

Parameters	**Req #**	**.#**	**Value**	**Sci #**
Delay Errors: Ant, small angle, random	457	M	Random, for (az,el) change of 2.0deg: < 15 fsec	
	457	T	Random, for (az,el) change of 4.0deg: < 15 fsec	
	457	7	Random, for (az,el) change of 4.0deg: < 15 fsec	
Allocation				

Random errors in total instrumental delay while small changes are made in antenna pointing will have the same time scale as that of fast switching time, e.g., 10 seconds. This is a component of delay noise and would most likely arise in the LO distribution system in the antenna (cable wraps).

Methodology: Average delay for 10 sec; move antenna cyclically every 10 sec. Interpolate and sum the delay in the two states; continue for 2000 sec; calculate the variance of this series about its mean and divide by 2. Result is rms noise of time series. Perform this test at several antenna az/el; RMS the results without removing a mean.
The splitting of this requirement in a budget among various contributors would be very useful for the design of the individual parts, but in this phase of the project is impossible.

In this updated version of the document it is introduced also the distinction, in the requirement, between the 12m and 7m Antennas.
This tightened requirement has not been considered in as built FE hardware and is not retroactively applicable to the acceptance of HW already designed or delivered at the time of issuing of this document.

7.2.57 Requirement # 458 - Delay Errors: Ant, Large Angle, Systematic

Parameters	**Req #**	**.#**	**Value**	**Sci #**
Delay Errors: Ant, large angle, systematic	458		az ± 180 º rms < 100 fsec el ± 40 º rms < 50 fsec	280
Allocation	N/A			

This requirement on delay change with large angle antenna motion is in addition to Req #151 and #451 which constrains the delay/phase variations with time.

Stability of phase/delay during large angle antenna motion is needed for antenna position determination and for large scale astrometry observations.

A possible verification method is as follows. Measurement should made by moving the antenna over the indicated az/el range, stopping at 5 positions, reversing the process and differencing the delay from that of the first data point. The rms of the resulting differences, without subtracting the average, should then be calculated.

See notes for Req #456 for systematic variations with small angle changes.

7.2.58 Requirement # 459 - Delay Errors: Ant, Large Angle, Random

Parameters	Req #	.#	Value	Sci #
Delay Errors: Ant, large angle, random	459		for full range of permitted az,el : < 32 fsec	
Allocation	N/A			

See notes for Req #457 for random variations with small angle changes.

7.2.59 Requirement # 460 - Frequency stability

Parameters	Req #	.#	Value	Sci #
Frequency stability	460		Allan std dev, frequency < 2e-11 for T = 20-300 sec.	
Allocation				

This requirement is driven by the delay error that is introduced when the master oscillator drifts in frequency in an array of unequal path lengths to the various antennas. To achieve negligible contribution of this effect (1/10 of 22 fsec, which is the delay error contribution of electronics #451), frequency change should be df/f < 2e-11, under the assumption of the 15 km cable difference and of the LLC keeping the cable change to zero (15km *2 / light speed *22e-15 /10). We adopt the same definition of Allan Standard Deviation $ASD_f(2,T,\tau=T)$ as those of amplitude (defined in the note of #261).

7.2.60 Requirement # 461 - VLBI: Number of Arrays

Parameters	Req #	.#	Value	Sci #
VLBI: Array number	461		VLBI Support shall be provided to minimum one Array	380
Allocation				

7.2.61 Requirement # 470 - Absolute frequency accuracy

Parameters	Req #	.#	Value	Sci #
Absolute frequency accuracy	470		<5e-10	
Allocation				

The highest spectral resolution of the ALMA is about 5 kHz (#530), thus 1/10 of this is 500 Hz (0.0015 km/s resolution at 100 GHz), which is enough for line observations. 500 Hz at 1 THz corresponds to 5e-10.

7.2.62 Requirement # 481 - Array time: accuracy

Parameters	Req #	.#	Value	Sci #
Array time: accuracy	481		Maintained within 10 μsec of UTC.	
Allocation				

48 msec Timing Event (TE) is synchronized to 1PPS signal from the GPS receiver [RD 37].

7.2.63 Requirement # 482 - Array time: knowledge

Parameters	Req #	.#	Value	Sci #
Array time: knowledge	482		Difference from UTC known to within 100 nsec.	
Allocation				

7.2.64 Requirement # 490 – Shielding effectiveness receiver cabin

Parameters	Req	.#	Value	Sci #
Shielding effectiveness receiver cabin	490		The shielding effectiveness of the antenna receiver cabin shall be at least 20 dB up to 12 GHz	
Allocation				

This requirement applies when the cabin door is closed and the 75 cm diameter primary vertex hole clear aperture at the antenna is sealed.

7.2.65 Requirement # 492 - Max fiber optic cable length (CLO)

Parameters	Req #	.#	Value	Sci #
Max fiber optic cable length (CLO)	492		The fiber optic cable (LO, DTS & M/C) length from the AOS Technical Building to an antenna station shall be < 15 km	
Allocation				

The fiber cable length to four stations (212, 214, 215, and 216) may be at or slightly exceed the 15 km limit. In the detail network design, a best effort will be made to keep these cable lengths less than 15 km. The correlator is able to handle much larger cable lengths than 15 km; the significant constraints are imposed by the LO reference and data transmission systems.

7.3 Detection and Correlation

7.3.1 Requirement # 511 - Analog power detectors: accuracy

Parameters	Req #	.#	Value	Sci #
Analog power detectors: accuracy	511		Analog power detectors, baseband channel (2 GHz): Accuracy 1% of full scale (after linearity correction).	
Allocation				

7.3.2 Requirement # 512 - Analog power detectors: sampling interval

Parameters	Req #	.#	Value	Sci #
Analog power detectors: sampling interval	512		0.5 msec at >99 % efficiency	
Allocation				

Sampling interval set by requirements of OTF imaging while using analogue total power detectors.

7.3.3 Requirement # 513 - Analog power detectors: 8 GHz

Parameters	Req #	.#	Value	Sci #
Analog power detectors: 8 GHz	513		Not used for astronomy; for engineering monitoring only. Requirements are in BE sub-system requirements	
Allocation				

7.3.4 Requirement # 520 – Tunable Filter Bank to 64-Ant Correlator

Parameters	Req #	.#	Value	Sci #
Tunable Filter Bank to 64-Ant Correlator	520		32-subchannel tunable filter bank	
Allocation				

The filter bank for 64-Ant Correlator is described briefly in System Design Description [RD 01], section 2.6.1, and more fully in Quertier et al., [RD 08] and [RD 48].
The correlator modes, which make use of the TFB features, are the FDM.
64-Ant Correlator is also required to operate in a mode that bypasses the filter bank in case the TDM is engaged.

7.3.5 Requirement # 521 – Quantization resolution

Parameters	Req #	.#	Value	Sci #
Quantization resolution	521		At antenna, first quantization, 8-level (3b); At 64-Ant Correlator, 4level (2b) and 16 levels (4b); At ACA Correlator, the second requantization >= 16 levels (4bit)	190
Allocation				

The quantization noise resulting from 3-bit sampling at the antennas reduces the SNR by 0.96. The re-quantization to 2-bit (4 levels) (or 4-bits (16levels)) after the tunable filter bank introduces additional loss of 0.88 (2-bit) and 0.99 (4-bit, (at a loss of x4 in frequency resolution). The combined loss depends on the observing mode [RD 12].

- For Frequency Division modes where the Tunable Filter Bank cards are active the total digitization loss is the product of 0.96 with 0.88 or 0.99 (for 2-bit or 4-bit correlation).
- In Time Division Mode the BL digitization efficiency is close to 0.88 (there is no requantization and no 4-bit modes).
- In TDM and with 3-bit correlation the efficiency is that of the digitizer 0.96.

7.3.6 Requirement # 530 – Spectral resolution, minimum for 64-Ant Correlator and ACA Correlator

Parameters	Req #	.#	Value	Sci #
Spectral resolution, minimum for 64-Ant Correlator and ACA Correlator	530		<5 kHz	30
Allocation				

The value 3.3 kHz matches the scientific requirement for .01 km/sec resolution at the lowest observing frequency (100GHz). Achieving the finest resolution may require using reduced bandwidth and/or processing a single polarization. In the current design of 64-Ant Correlator, a channel spacing of 3.8 kHz (satisfying the requirement) is achieved by processing one polarization channel per quadrant at 31 MHz bandwidth, or an aggregate bandwidth of 125 MHz for all quadrants [RD 49]. By using all quadrants to process the same channel, the resolution can be 4 times smaller or all polarization products can be formed but the total bandwidth is then 31 MHz. Same channel spacing is achieved with ACA Correlator design without constraints.

7.3.7 Requirement # 541.1 – Correlator output rate: cross-correlation

Parameters	Req #	.#	Value	Sci #
Correlator output rate: cross-correlation	541.1		16 msec integrations and readout interval, all baselines.	240
Allocation				

The minimum readout interval is limited by the data rate, and is available only by limiting the bandwidth or spectral resolution or number of baselines. In case of phase switching, a complete cycle time for data accumulation in Correlator Data Porcessors (CDP) might be limited up to 2.048 seconds (see #443).

7.3.8 Requirement # 541.2 – Correlator output rate: auto-correlation

Parameters	Req #	.#	Value	Sci #
Correlator output rate: auto-correlation	541.2		1 msec integrations and readout interval, all antennas.	240
Allocation				

7.3.9 Requirement # 542 – Correlator output rate

Parameters	Req #	.#	Value	Sci #
Correlator output rate	542	M	128M complex correlations per second.	
	542	T/7	300M complex correlations per second.	
Allocation				

This requirement defines the rate over the digital interfaces into the Correlator Data Porcessors (CDP) and is different from the rates into the Archive (#610).

Regarding 64-Antenna Correlator, 16 32-bits (4 byte) data ports (62.5 MB/sec) at correlator quadrants (4 per quadrant) are connected to 16 CDPs. Thus currently the maximum output is 62.5 MB/sec *16 = 1 GB/sec as total. This corresponds to 125 M complex correlations per seconds, i.e. 1 (GB/sec) / 4 (byte) / 2 (real/imaginary).

Regarding ACA, the maximum output rate is expected for the following observation mode: 4 total power antennas and 12 antenna interferometer with readout intervals of 1 msec (auto) and 16 msec (cross), 4 autocorrelations (1 msec) and 66 cross- and 12 auto-correlations (16 msec), 8192 frequency channels per baseband, and 4 baseband pairs. Output rate will become about 300 M complex correlations per second ((66+12)*8192*4/0.016+4*8192*4/0.001). This corresponds to 300M*4(byte)*2(real and imaginary)/4(baseband)=0.6 GB/s per baseband, which is defined in [RD 38][RD 39].

7.4 General

7.4.1 Requirement # 610 – Archive writing rate

Parameters	Req #	.#	Value	Sci #
Archive writing rate	610	M	>= 60 MB/sec.	
	610	T/7	>=3.6 MB/sec.	
Allocation				

Regarding the 12-m Array, the required archiving rate is 6% of the maximum correlator output rate. [RD 40] defines the expected rates as 6MB/sec average and 60 MB/sec peak. Regarding the ACA, the values are 6% of those of the 12-m Array, i.e., 0.36 MB/s average and 3.6 MB/s peak. These data rates are determined on the basis of the maximum baseline numbers; the 12-m Array will have 2016 (N*(N-1)/2) baselines at most, and the ACA will have 120 baselines at most, where N is antenna numbers (64 for the 12-m Array and 16 for the ACA). The rates are scaled by the ratio of baseline numbers. [RD40] defines the expected rates as 0.36MB/sec average and 3.6 MB/sec peak.

7.4.2 Requirement # 614 – Monitor Points

Parameters	Req #	.#	Value	Sci #
Monitor Points	614		It shall be possible to access to the monitor points of each LRU, assembly, sub-system, as defined in the ICDs, for normal Observatory operations, contingency operations, maintenance or troubleshooting.	
Allocation				

This requirement has been reworded with respect to the previous issue in order to remove ambiguities in the text. See [RD 47] for a plan of detail requirements of archive access.

7.4.3 Requirement # 615 - LRU self identifying

Parameters	Req #	.#	Value	Sci #

Parameters	Req #	.#	Value	Sci #
LRU self identifying	615		All Line Replaceable Units (LRU) with an AMB or ARTM node shall be self identifying to the ABM.	
Allocation				

7.4.4 Requirement # 616 – Control Points

Parameters	Req #	.#	Value	Sci #
Control Points	616		It shall be possible to access to the control points of each LRU, assembly, sub-system, etc for normal Observatory operations, contingency operations, maintenance or troubleshooting This is valid unless the asynchronous control access is forbidden by the case-by-case ongoing activities.	
Allocation				

This requirement has been modified in a way similar to #614.
It is important to notice that the Monitors should be always available, whereas the Controls, since could interact with the ongoing activities, can be temporarily blanked.

The M&C definitions are also the basis to define the alarms and the relevant reduction rules. These definitions anyway are left to the lower level detailed specifications.

7.4.5 Requirement # 617 – Availability

Parameters	Req #	.#	Value	Sci #
Availability	617		The availability of the Array shall be larger than 85% with a goal of 95% for steady ALMA Operations.	
Allocation				

The requirement has been redefined compared to that in RD13.

From ALMA Operations Plan (Version D – Chapter 5.3, AD 26)

The Joint ALMA Observatory shall have high operational availability once construction has been completed. Existing large, interferometric radio telescopes achieve operational availability, also called operational readiness, values of between 85 and 95 percent.

The definition of Availability for a complex interferometric instrument outfitted with a superset of the instrumentation needed for any one science project, and able to (or needing to) adapt observing programs to changing environmental conditions, can be difficult.
We adopt a simple definition of availability, as follows

Availability = (AntennaHoursUsed)/(AntennaHoursAvailable)

The quantity "AntennaHoursUsed" is simply the total number of antenna hours which have been collecting science or calibration data, and the "AntennaHoursAvailable" is the total number of non-weathered-out antenna hours in that same period. This definition does not degrade availability as a result of severe weather, but does degrade availability for any reason that makes an antenna unavailable for a science observation.
Subsystems that affect all or many antennas (e.g. a correlator failure or central reference failure) will have a larger weight in the final availability number.
The goal for ALMA is to achieve a steady-state availability of 95% during mature operations phase.

7.4.6 Requirement # 618 – System Restart: calibration

Parameters	**Req #**	**.#**	**Value**	**Sci #**
System Restart: calibration	618		It shall be possible to perform warm restart (soft resets) or power cycles of equipment at the module, sub-system and system level, including the Full System Restart, without recalibrating the telescope beyond those calibrations carried out during normal observation activities.	
Allocation				

The intent is to avoid lengthy recalibration after a routine equipment restart. Restart can mean a reboot of computers, power cycling a module or a rack, reset of a module or sub-

system like the correlator, power cycling an antenna, rebooting the computer network up to the level of what is known as the Full System Restart.
All those calibrations already foreseen in the sequence of activities normally done for an observation are, of course, permitted.
Not permitted are those activities that require changes in the TMCDB and/or recalibration procedures that affect the time needed to return the Observatory into its "ready for observations" status.
Outside the scope of this requirement are all the cases of failure, troubleshooting, investigation, commissioning, characterization, planned or unplanned maintenance that require major system shut down.

7.4.7 Requirement # 619 – System Restart: time

Parameters	Req #	.#	Value	Sci #
System Restart: time	619		It shall be possible to restart any part of the system, including the full system, in less than 15 minutes.	
Allocation				

This includes rebooting the complete computing network at all antennas. It also includes automatic self-checks and calibrations. The 15 minutes is the time it takes until the operators are able to start interacting with the system. It does not include time needed for thermal stabilization after power cycling. If disks of operational system become corrupted, restarts will take much longer than 15 minutes as they will need to be check. This should not be common.

7.4.8 Requirement # 621 - WVR: Installed on all antennas

Parameters	Req #	.#	Value	Sci #
WVR: Installed on all antennas	621	M	Installed on all antennas	
		T	Installed on all antennas	
		7	NA	
Allocation				

7.4.9 Requirement # 622 - WVR: Correction error & rate

Parameters	Req #	.#	Value	Sci #
WVR: Correction error & rate	622	M	Path length correction error (rms) $\delta L < (0.01w + 10)$ µm, with a sampling rate <1 Hz.	290
		T	Path length correction error (rms) $\delta L < (0.01w + 10)$ µm, with a sampling rate <1 Hz.	290
		7	NA	
Allocation				

Here δL, in µm, is the residual rms fluctuation in atmospheric delay after the application of the WVR correction and w is the condensed water vapor depth along the line of sight, given in millimeter. The requirement matches the current WVR specification [RD 46], which applies to fluctuations about the 5 min average, and at constant air mass.

7.4.10 Requirement # 623 - WVR: Beam direction

Parameters	Req #	.#	Value	Sci #
WVR: Beam direction	623	M	Divergence from observing beam < 10 arcmin.	
		T	Divergence from observing beam < 10 arcmin.	
		7	NA	
Allocation				

7.4.11 Requirement # 631 - Phased array

Parameters	Req #	.#	Value	Sci #
Phased array	631		Array shall be usable as a single station (phased up)	370
Allocation				

7.4.12 Requirement # 632 - Real-time phased array

Parameters	Req #	.#	Value	Sci #
Real-time phased array	632		Real-time phasing up is required.	370
Allocation				

The possibility for real time phasing is required.

7.4.13 Requirement # 633 - Phase sub-array possible

Parameters	Req #	.#	Value	Sci #
Phase sub-array possible	633		Sum output available for any subset of antennas.	370
Allocation				

7.4.14 Requirement # 650 - Mosaic Image Dynamic Range

Parameters	Req #	.#	Value	Sci #
Mosaic Image Dynamic Range	650		Mosaic Image Dynamic Range > 1000 at band 7 and lower frequency Bands under atmospheric condition which does not dominate the image dynamic range.	220
Allocation				

Science Requirement #220 sets the minimum image dynamic range as 1,000 and is taken to apply to mosaic images only. Science Requirement #70 sets the minimum image dynamic range as 50,000 and is taken to apply to an image consisting of a single field.

The requirement on mosaic image dynamic range only applies at band 7 and longer wavelengths. To achieve this, the rms pointing error must be < 1/30 HPBW (Sci Req #260) and primary beam shape must be known to better than ±0.06 of the primary beam response down to the -10 dB point (Sci Req #270).

7.4.15 Requirement # 660 – Solar Filter: RF attenuation

Parameters	Req #	.#	Value	Sci #
Solar Filter: RF attenuation	660		The nominal RF attenuation in dB shall be A = 4 + 2λ, where λ is the wavelength millimeters, in a RF frequency range 84 GHz to 950 GHz. The actual attenuation shall be no more than 2 dB below the nominal value and no more than 4 dB above the nominal the value at all frequencies.	360
Allocation	Front End			

The requirement has been changed from the previous version of the System Technical Requirements [RD 13]. See a [AD 27] for detail scientific justifications. Regarding bands 1 and 2, there is no guaranteed performance [RD 41].

7.4.16 Requirement # 667 – Solar Filter: System performance specifications

Parameters	Req #	.#	Value	Sci #
Solar Filter: System performance specifications	667		System performance specifications a) Gain stability a-1) ASD < $2.0*10^{-3}$ on time scales of 0.05 to 100 seconds; applies to all antennas a-2) ASD < $4.0*10^{-3}$ on time scales of 100 to 300 seconds; applies to all antennas b) Phase stability b-1) < 150 fsec, RMS about 10 sec average (noise) b-2) < 50 fsec, Allan SD with T = 10 to 300 sec (drift) c) Polarization c-1) ON-AXIS: for the Antenna plus Front End the cross-polarization shall be < -13 dB before calibration c-2) OFF-AXIS: for the Antenna plus Front End, the cross-polarization shall be < -13 dB before	360

Parameters	Req #	.#	Value	Sci #
			calibration This applies out to the -6dB contour of the primary beam	
Allocation				

The requirement has been updated from the previous version of the System Technical Requirements [RD 13].

Amplitude stability: Req#261 and #262 specify the stability under the normal observations. Under the solar observing conditions including observations of calibrators near the Sun, we temporary adopt the specified values. Assuming an RSS calculation, extra instability during solar observations is allocated to be 1.7e-3 at 0.05 to 100 sec and 2.6e-3 at 300 sec. One of the expected contributors is the change of solar filter's RF attenuation level by its temperature change (not only gain but also noise contribution). See section 5.2 for more details of gain stability as well as system stability of noise (currently no system requirement for noise). It is expected to be very difficult to confirm the requirement by test because signals of calibrators are very weak with the solar filter inserted. Thus verification by design is expected to confirm the requirement.

Phase stability: Table 1 specifies the total instrumental delay error under the normal observations. Under the solar observing conditions including observations of calibrators near the Sun, we temporary adopt twice the value under the normal observations. The delay/phase error of 150 (noise) and 50 fsec (drift) correspond to 19 and 6 degrees at 345 GHz.
This on Phase stability is a new requirement that was not taken into account in the design and already provided HW.

Polarization: Req#224 and #225 specify the cross-polarization under the normal observations. Under the solar observing conditions, we adopt -13 dB for instrumental contributions. In the case of calibration needed, artificial sources at the AOS will be needed because signals of calibrators are very weak with the solar filter inserted.

There are currently no system requirements on wavefront error contribution. See [RD 42] (withdrawn) for details. For the moment, the component verification test [RD 43] didn't show any significant error. Astro-holography measurements with and without the solar filter are expected to address this error (CSV-1776).

7.4.17 Requirement # 680 – Receiver protection from CloudSat

Parameters	Req #	.#	Value	Sci #
Receiver protection from CloudSat.	680		Receivers shall be protected from the overflight of a radar satellite, such as CloudSat.	
Allocation	Antenna IPT and Computing IPT to deliver adequate control software for that.			

Both during regular observations and during antenna transportation, to minimize the risk of receiver damage during the overflight of a cloud radar satellite such as CloudSat, the feed shutter is automatically closed when zenith angle is < 1 degree and antenna will not track into this range. To be applicable to satellites other than Cloudsat more detailed specifications will be required.

7.5 ACD Requirements

7.5.1 Requirement # 1222 – ACD frequency coverage

Parameters	**Req #**	**.#**	**Value**	**Sci #**
ACD frequency coverage	1222		Ambient RF Load - cover RF frequency range corresponding to Bands 1-10; Hot RF Load – cover RF frequency range corresponding to Bands 3-10	
Allocation	Front End			

7.5.2 Requirement # 1223 – ACD Calibration Loads temperatures

Parameters	**Req #**	**.#**	**Value**	**Sci #**
ACD Calibration Loads temperatures	1223		Ambient RF Load – receiver cabin temperature; Hot RF Load – 60-90 degrees Celsius	
Allocation	Front End			

7.5.3 Requirement # 1224 – ACD Calibration Loads accuracy

Parameters	**Req #**	**.#**	**Value**	**Sci #**
ACD Calibration Loads accuracy	1224		Total calibration uncertainty: Ambient RF Load +/-0.3 K; Hot RF Load +/- 1 K[a];	
Allocation	Front End			

[a] at 70 degrees Celsius.

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