ALMA Phasing Project
Reliability and Maintainability Report

ALMA-05.11.10.03-0002-A-REP

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Change Record

Version	Date	Affected section(s)	Reason/Initiation/Remarks
A.1	2013 Apr 8	All	Initial draft
A.2	2013 Apr 16	Sec 6.3	Add Spares column & more info
A.3	2013 Apr 19		GPS Model Number Change, doc number on title sheet
A.4	2013 May 17	many	Update Summary Table, other minor edits, GPS Model change again (oops!)

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1. Description

1.1. Purpose and Scope of Document

The ALMA Phasing Project (APP) will add some components to ALMA and will modify others. Components added are a mixture of custom designs and COTS items. The APP subsystem will be deployed across both the AOS and OSF operational environments and will also incorporate a fiber link between these two locations. Modifications to existing ALMA systems at a minimum include changes to cabling, software, and replacement of the master timing reference. The APP Project Plan [RD 01] requires this reliability and maintainability assessment as part of the deliverable document package.

This report addresses expected failure rates, delivered spares, and other issues related to maintaining the APP subsystem. Batteries are considered expendable items and do not contribute to the projected MTBF figures. MTTR and MDT depend upon response time within ALMA operations, shipping turnaround, and other factors beyond the control of the APP and are therefore not addressed in this report. The APP recommends however, that ALMA System Engineering project MTTR and MDT from the reliability data provided in this report.

2. Referenced Documents

[RD 01]	ALMA Phasing Project Plan
[RD 02]	ALMA Product Assurance Requirements ALMA-80.11.00.00-001-D-GEN
[RD 03]	ALMA Correlator Reliability, Maintenance, and Testing CORL-60.00.00.00-014-A-PLA
[RD 04]	APP Subsystem Bill of Materials ALMA-05.11.10.12-0001-A-BOM
[RD 05]	Reliability Prediction of Electronic Equipment - MIL-HDBK-217F
[RD 06]	ALMA Operations Plan ALMA-00.00.00.00-002-A-PLA
[RD 07]	ALMA System Technical Requirements for 12m array ALMA-80.04.00.00-005-C-SPE (Note: req. 617 in Ver. B defines a min. MTBF of 5 yrs., changed in Ver C to terms of array availability)
[RD 08]	“White Paper onT4Science Maser MTBF” Jan 2013

3. Abbreviations and Acronyms

AFR	Annualized Failure Rate
ALMA	Atacama Large Millimeter Array
ALT	Accelerated Life Test
APP	ALMA Phasing Project
CDL	Component Design Life
COTS	Commercial Off The Shelf
CRE	Change Request (for Engineering)
FIT	Failures In Time
FMEA	Failure Modes and Effects Analysis
IC	Integrated Circuit
ICD	Interface Control Document
IPT	Integrated Product Team
JAO	Joint Alma Observatory
LRU	Line Replaceable Unit
MDT	Mean Down Time
MPIfR	Max Planck Institute for Radio Astronomy
MTBF	Mean Time Between Failure
MTTR	Mean Time to Repair
NAOJ	National Astronomical Observatory of Japan
NRAO	National Radio Astronomy Observatory
PA	Product Assurance
PIC	Phasing Interface Card
PICA	PIC Assembly, includes ROACH2 as a mezzanine card
PMO	Project Management Office
QA	Quality Assurance
RD	Reference Document
RfW	Request for Waiver
SE	System Engineering
SPA	Software Product Assurance
VLBI	Very Long Baseline Interferometry

4. Equipment Included for Analysis

A complete list of APP components is itemized in the Bill of Materials [RD 04], but this report will focus on the items defined as LRUs which can readily be replaced on site by qualified ALMA technicians. In addition, ALMA reliability requirements are applied at the LRU level, so this is the obvious level at which to perform the analysis. This analysis differentiates between COTS and custom designs, since different sources of reliability available for the two categories leads to different prediction methodology.

4.1. COTS Items

- Mark 6 VLBI Recorder
- DWDM Module XW-100, Fiber Optic transceiver
- GPS Receiver, Symmetricon XLi
- iMaser 3000 and battery based UPS
- ATX Power Supply, 48V (used for PICA)

4.2. Custom Designs

- PIC
- Roach2
- SPF+ Mezzanine Card and adapter
- 1PPS Distributor (Not yet designed)

Note: Roach2 and SPF+ Mezzanine cards are treated as custom assemblies since these are open source designs and by default, APP is accountable for their reliability. These assemblies are specified to the same IPC standard as the correlator boards were (IPC-A-610), therefore the component quality is comparable to the correlator components.

5. Methodology

COTS

- In several cases, commercially purchased LRUs have MTBF figures provided by the manufacturer. Given the spectrum of parameters by which this number can be determined, the consumer is frequently unaware of what this number actually conveys or how it was derived. Some manufacturers use actual field data, others use accelerated life testing (ALT), others use predictive modeling, or a combination of testing and modeling is sometimes used. In addition, MTBF has traditionally been used for repairable equipment and is frequently misinterpreted as the expected lifetime. Therefore, some manufacturers of non-repairable equipment (particularly disk drives) are now providing reliability in terms of the Component Design Life and Annualized Failure Rate. Fortunately, T4Science reports their MTBF for the maser based on actual field failures across their entire maser production history. Nevertheless, figures provided by manufacturers were simply reported for most of the COTS items.

<u>*CUSTOM DESIGNED LRUs*</u>

- Reliability data is frequently extrapolated by manufacturers from accelerated life test of discrete components or assemblies, using elevated environmental stresses to simulate a much longer time period. Failure statistics for discrete components are typically given in FIT data, which are in turn used as input parameters for the reliability model of a larger assembly, which is then typically converted to MTBF. These prediction methods, largely a probability problem, are commonly accepted for use in the absence of actual field data. However, according to Juran's Quality Handbook (5th ed. Section 48.30):

  "Carefully collected field data, when available, may provide the most accurate information about how components and systems behave in the field."

  For this reason, the ALMA Correlator IPT used actual data from several decades of experience with large, vey similar systems to predict failure rates for the ALMA Correlator [RD 03]. The APP submits that the PIC is a similar design to other Correlator boards and therefore can be treated as simply another correlator board. In addition, the Roach2 assembly and associated mezzanine modules are also very similar to the correlator hardware and will be treated as the other correlator boards have been. Reliability analysis sometimes also includes the total connection count, but connections have not been a significant failure mode in large NRAO correlators, so the ALMA Correlator IPT did not include connections in reliability predictions.

5.1. Reliability and Maintainability Goals

The APP is committed to deliver LRUs that meet the ALMA reliability requirements of no less than 5 years MTBF [RD 07 Ver B, req. 617]. This report itemizes the expected MTBF for each of the APP deliverables in this category and APP seeks to achieve the following reliability and maintainability goals:

- Project expected failure rates at the LRU level with minimum target of 5 years
- Gather and archive results from any burn-in time realized prior to delivery
- Identify early life failure modes so root causes can be addressed
- Differentiate between repairable and non-repairable failures
- Identify single point failures
- Recommend repairs to be performed in-house vs. returns to vendor
- Identify dominant failure modes and potential mitigation for prevention
- Identify components with self-diagnostics and critical parameter monitoring

5.2. Sources and Types of Reliability Data

The following sources and types of reliability data are referenced in this analysis:

1) Accelerated life tests (use of elevated stress to simulate life cycle)
2) Life tests on actual systems in long term field deployment
3) MTBF provided by equipment supplier
4) FIT data either supplied by manufacturer or derived from MTBF
5) Component Design Life
6) Annualized Failure Rate

6. Results of Analysis

6.1. COTS Items in MTBF (years)

- ***Mark 6 VLBI Recorder components:*** from manufacturer supplied data in hours
  - Motherboard ~ 57 years (500,000 hrs)
  - Main Power supply – EMAC ASL 6850P - 10.8 years (95.15Khrs.)
  - Expansion Pwr sup. - EMAC HG2-6400P - 15.4 years (135.3K hrs)
  - OS disk for PC - WD Caviar Blue series : 85.6 years (750K hrs hrs)
  - Data Disks 8/module – WD Caviar Black series 17.1 years (150K hrs)
  - 10G NIC cards – 570 years (5, 000K hrs.)
  - HBA cards – 228 years (2,000,000 hrs.)

  Note: Western Digital no longer reports in MTBF, providing instead CDL of five years and AFR of .8% (as of 2012). The MTBF figures given above are slightly dated, but were given here because they are more useful and also to be consistent with reporting for other components in this system. In addition, WD does not differentiate between their high reliability line (black) and their general desktop line) when reporting CDL and AFR, the figures given above apply to all their products. WD Tech Support was not able to provide any further reliability details nor did they provide any figure for altitude derating. Other drive manufacturers are known to derate the maximum operating temperature by about 20% at the 3,000M altitude limit.

- ***DWDM Mux/Demux Module:*** 2 used in system, manufacturer supplied data in hours per 9 channel DWDM, eight channels used, one available for spare
  - XW-100 - 1343 hours
  - Power Supply employs 2x redundancy in current shared configuration

- ***GPS Receiver:*** from manufacturers supplied data in “Demonstrated” hours
  - Symmetricon Xli – 18.1 years (159,076 hours)

- ***iMaser 3000:*** manufacturer supplied data from history of units in field [RD 08]
  - iMaser 3000 - > 20 years

- ***Sunpower ATX Power Supply, 48V:*** manufacturer supplied data, one for each PIC in system (8)
  - SPS-1000P-48 – 14 years (122.5K hrs)

6.2. Custom Designs in MTBF (years)

- ***Phasing Interface Card:*** MTBF derived from ALMA Correlator predictions are based on actual field failures of similar systems [RD 08]. Predicted failure rate of ALMA Correlator – one IC failure every two weeks (336 hours) from a population of 55K ICs (one failure per 1.848 x 10^7 device*hours). The ALMA Correlator is classed as a benign, ground based system (per definition in [RD 05], in a controlled environment, so no derating is needed for the circuit boards.

  ALMA Correlator failure rate = 1 failure per 1.848 x 10^7 device hours

  If this failure rate is scaled to FIT (failures per 1x10^9 device*hours):

  1x10^9 / 1.848x10^7
  ALMA Correlator FIT (Failures per billion device*hours) = 54.11

  Note that actual failures in the ALMA correlator suggest a smaller FIT, but the known failure modes to date have not been precisely categorized. In this early stage of operation, failure modes are suspiciously related to date codes, poor power conditioning, and other external stimulus that would skew the true FIT/MTBF value.

  This FIT value of 54.11 represents the predicted rate per IC. Failure rate predictions for ICs are distributed across all the typical IC types. Since the PIC has 40 such typical devices:

  40 x 54.11 = 2164 (FIT for PIC)
  MTBF = 1/FIT x 1 x 10^9
  MTBF = 1/2164 * 1 x 10^9 = 462,022 hours * 1yr/8766hrs
  PIC MTBF = 52.7 years

- ***Roach2:*** MTBF is derived using the same method as for the PIC, with an IC count on Roach2 of 90 such typical devices:

90 x 54.11 = 4870 (FIT for Roach2)
MTBF = 1/FIT x 1 x 10^9
MTBF = 1/4870 * 1 x 10^9 = 205,339 hours * 1yr/8766hrs
Roach2 MTBF = 23.4 years

- ***SPF+ Mezzanine Card and Adapter:*** MTBF is derived using the same method as for the PIC, with an IC count on the SFP+ Mezzanine card of 10 such typical devices:
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10 x 54.11 = 541 (FIT for SPF+ Mezzanine Card)
MTBF = 1/FIT x 1 x 10^9
MTBF = 1/541 * 1,848,429 hours * 1yr/8766hrs
Roach2 MTBF = 211 years

- ***1PPS Distributer (Not Yet Designed)***

6.3. Maintainability Summary

(the following table is a work in progress. As more data are gathered, format may still change and holes will fill in)

	MTBF Years	ALMA Tech Can Swap	Repair In-House	Vendor Repair	Needs PM Or Cal.	Single Point Failure - Array/ phasing	Fans or ext. moving parts	Self Diag or Mon. vitals	In System /Spares Deliv.
Mk 6 MB	57	●	N	●	-	N/N	-		
Mk 6 Main PS	10.8	●	○	●	-	N/N	F		
Mk 6 Exp PS	15.4	●	○	●	-	N/N	F		
Mk 6 OS Disk	85.6	●	N	N	-	N/N	Y		
Mk 6 Data 8 Disk Pack	17.1	●	○	N	-	N/N	Y		
Mk 6 NIC	570	●	N	○	-	N/N	-		
Mk 6 HBA	228	●	N	○	-	N/N	-		
DWDM-ZR	12,700	●	N	○	-	N/N	-		
DWDM-SR	16,080	●	N	○	-	N/N	-		
DWDM-PS	46	●	○	●	-	N/Y	-		

DWDM-FANS	4.6	●	N	N	N2	N/Y	F		
GPS Rx	18.1	●	N	●	-	N/Y	F		
Maser	20	●	N	●	N1	Y/Y	-	Y	
PIC ATX PS	14	●	○	●	-	N/N	F		
PIC	52.7	●	○	○	-	N/N	-	Y	8/2
Roach2	23.4	●	N	○	-	N/N	-		8/2
SPF+ Mezz	TBD	●	N	○	-	N/N	-		8/2
SPF+ xcvr	TBD	●	N	○	-	N/N	-		8/2
1PPS Dist.	TBD	●	●	N	-	N/Y	-		1/1

● Fully
○ Partially
Y Yes
N No/Not at all
Nx See Note
\- Not Applicable

N1 – Maser requires Hydrogen to be replenished 12~15 years, also periodic calibration
N2 – DWDM fans employ redundancy, but should be monitored for failure

Note: A distinction is made for single point failures; array level SPFs vs. phasing capability SPFs.