APP Detailed Test Procedures

Version 1.3

Authors: Michael Hecht, Project Manager
Geoff Crew, Software Lead
Rich Lacasse, Hardware Lead
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Table of Contents

Applicable Documents

The following documents are part of this document to the extent specified herein. If not explicitly stated otherwise, the most recent issue prior to the release date of this document is referenced.

Ref.	Title	Doc. Number
AD-01	APP Integration and Test Plan	
AD-02	APP Project Plan	
AD-03	APP Requirements Document	
AD-04	APP Computing Management Plan	ALMA-05.11.60.01-001-A-PLA
AD-05	Commissioning and Science Verification Plan	ALMA-05.11.10..01-001-A-PLA
AD-06	Back End ICD	ALMA-05.11.10.49-0002-A-ICD
AD-07	Site ICD	ALMA-05.11.10.49-0001-A-ICD
AD-08	Correlator ICD	ALMA-05.11.10.49-0003-A-ICD
AD-09	Computing ICD	ALMA-05.11.10.49-0004-A-ICD
AD-10	General Safety Design Specification	ALMA-10.08.00.00-003-B-SPE
AD-11	System Technical Requirements	ALMA-80.04.00.00-005-B-SPE
AD-12	System Electrical Design Requirements	ALMA-80.05.00.00-005-C-SPE
AD-13	System Electromagnetic Compatibility (EMC) Requirements	ALMA-80.05.01.00-001-BSPE
AD-14	Product Assurance Requirements	ALMA-80.11.00.00-001-D-GEN
AD-15	Environmental Specification	ALMA-80.05.02.00-001-B-SPE
AD-16	Operations Plan	ALMA-00.00.00.00-002-A-PLAALMA
AD-17	Seismic Design Specifications for ALMA-AOS and ALMA-OSF	SYSE-80.10.00.00-002-BREP
AD-18	ALMA Interface Management Plan	ALMA-80.07.00.00-001-D-PLA

Reference Documents

The following documents supply additional information relevant to this document. If not explicitly stated otherwise, the most recent issue prior to the release date of this document is referenced.

Ref.	Title	Doc. Number
RD-01	Mark6 User's Manual	(draft)
RD-02	APP Optical Fiber Link system design	ALMA-05.11.40.01-0001-A-DSN
RD-03	Correlator Upgrades Manual	ALMA-05.11.31.05-0001-A-MAN
RD-04	ALMA Phasing Project Maintenance Manual	ALMA-05.11.10.05-0001-A-MAN
RD-05	Correlator Upgrades PAI Test Report	ALMA-05.11.30.03-0002-A-REP
RD-06	APP Correlator Upgrades Maintenance Manual	ALMA-05.11.30.05-0001-A-MAN
RD-07	APP Mark6/OFLS/PIC Acceptance Report	ALMA-05.11.50.03-0001-A-REP
RD-08	APP Mark6 Recorder Test Procedures	ALMA-05.11.50.02-0001-A-PRO
RD-09	APP Correlator Upgrades Acceptance Report	ALMA-05.11.30.03-0001-A-REP
RD-10	Intentionally left blank	
RD-11	APP Correlator Upgrades Manual	ALMA-05.11.31.05-0001-A-MAN
RD-12	Mark 6 Recorder Manual	
RD-13	APP Optical Fiber Link system prototype test report	ALMA-05.11.40.02-0001-A-xxx
RD-14	Sum Data LVDS Cable List	
RD-15	ROACH FPGA Requirements and Specifications	ALMA-05.11.31.15-0002-A-SPE
RD-16	Programming Manual for the Tunable Filter Bank	CORL-60.01.07.00-002-E-MAN
RD-17	64 Antenna Correlator Specifications and Requirements	ALMA-60.00.00.00-001-C-SPE
RD-18	ALMA Phasing Project Reliability and Maintainability Report	ALMA-05.11.10.03-0002-A-REP
RD-19	PIC Assembly Check-out Logs	ALMA-05.11.31.03-0001-A-REP
RD-20	APP Mark6 Recorder Module Test Report	ALMA-05.11.53.03-001-A-REP
RD-21	APP Optical Fiber Link test and installation report	ALMA-05.11.40.03-000x-A-xxx
RD-22	ALMA Phasing Project Hydrogen Maser Test Data Report	ALMA-05.11.21.03-0002-A-TDR
RD-23	APP Mark6/OFLS PAI Test Report	ALMA-05.11.40.03-0001-A-REP
RD-24	APP Update to Corr/Control Design	ALMA-05.11.61.01-0001-B-DSN
RD-25	Mark6 Command Set rev 1.2	
RD-26	Getting Started with your Mark6 rev 1.0.1	

Ref.	Title	Doc. Number
RD-27	Mark6 User's Guide v 1.0	
RD-28	Mark6 Usage Examples rev 1.0	
RD-29	APP H-Maser Procedures	ALMA-05.11.21.02-0001-A-PRO
RD-30	APP Tests on Absolute Timings	ALMA-05.11.61.03-0001-A-REP
RD-31	Mark6 Reliability and Power Requirements Study	Mark6 Memo #006

Document Change Log

DATE	SECTIONS AFFECTED	REASON FOR CHANGE	VERSION/ REVISION
2014-11-17	All	Added considerable detail to most sections	1.1
2014-11-25	Most	Filled in section numbers for tests related to AcRv	1.1
2014-11-25	Most	Filled in section numbers for tests related to Correlator Upgrades PAI	1.1
2014-12-2	Most	Filled in section numbers for other tests	1.2
2014-12-3	Several	Corrections per Geoff's 12/2/14 email. Add Correlator Upgrades Manual as an RD.	1.3

1 Document Overview & Scope

This document provides an overview of the detailed procedures for implementation of the ALMA Phasing Project (APP) Integration and Test (I&T) Plan. The purpose of this document is to convey how and where each requirement is satisfied. In cases where considerable additional information is required or where relevant documentation already exists, this is done by reference to those documents.

As shown schematically in Figure 1-1, the functional requirements specified in the APP Requirements Document [AD-03] are divided into *design* and *performance* requirements. Detailed test procedures for the performance requirements are further described in the Commissioning and Science Verification Plan and are the responsibility of the Science Team. The design requirement test procedures will be described here. Requirements flowing from the four APP Interface Control Documents (ICD) are also described here, as well as the distillation of the many ALMA requirements as described in the I&T Plan. Testing of software has been integrated into the normal ALMA software release process. For convenience, all APP requirements are listed in Appendix B of this document.

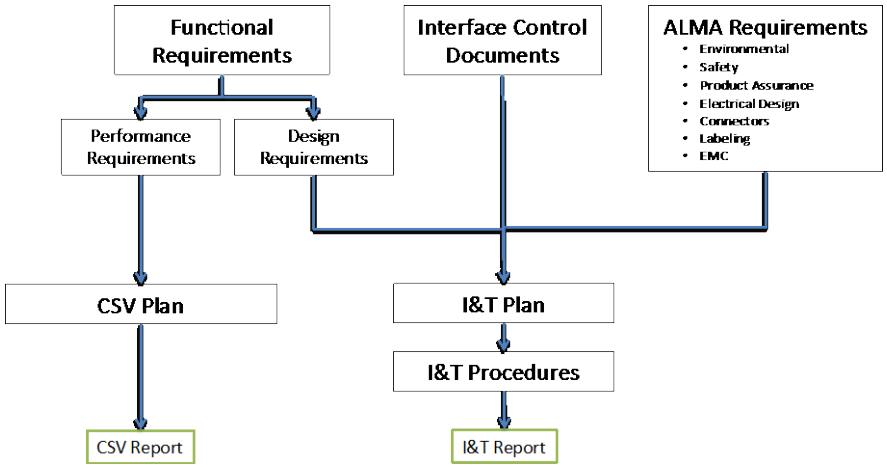

Figure 1-1: The APP detailed design satisfies (a) Functional requirements, comprising both performance and design requirements (b) Interface Control requirements, and (c) ALMA requirements. Verification of performance requirements is described in the Commissioning & Science Verification Plan. This document describes integration as well as verification of all other requirements

The Charlottesville integration and test activity served as a “dry run” for reassembly and health tests in Chile. Detailed procedural instructions were updated throughout the sequence, and a log of tools (voltmeters, temperature sensors, etc.) and materials was recorded. Equivalent tools and materials were identified at ALMA and set aside for OSF integration to form the Basic Toolkit referred to in Table 1-1. Unique items were provided to ALMA and added to the Toolkit.

In order to compress the schedule without adding significant risk, the optical fiber links (OFL) and the hydrogen maser have been tested independently and shipped to Chile. In addition, four recorders and hardware associated with the Correlator upgrade have been tested for workmanship and shipped to Chile. As a result, sufficient hardware is already present at site for acceptance testing. Identical hardware, for further development and testing (if necessary), remains in Charlottesville. For PAI testing, a laboratory clock and direct fiber coupling substitute for the

maser and OFL respectively.

The dual objectives of the PAI and AcRv test sequences are to Verify that the components of the system satisfy their design specifications, and to Validate that they satisfy all requirements at the system level. To this end, the I&T plan mapped 16 test sequences (Table 1-1) onto the requirement sets described above. The remainder of this document describes those detailed test procedures, which are implemented in four distinct campaigns.

The purpose of PAS tests was simply to assure that components survived the trip to the OSF. These tests consisted mostly of visual inspection of and of applying power to each component. In addition, the PICs underwent the loop-back test described in RD-19 and the OFLs were tested as described in RD-21. Thus the testing associated with the PAS campaign in Table 1-1 below is significantly more limited than that of other campaigns. All equipment received at OSF passed the PAS tests as reported verbally by ALMA personnel and RD-21.

Table 1-1: Successful execution of these 16 test sequences will satisfy verification and validation of all requirements. Duration (hrs) is approximate.

Test		Campaign				Array Access		Test equipment @ ALMA	
#	Title	PAI	PAS	AcRv	CSV	hrs	subsystems	APP provided	ALMA provided
1	Health check (intensive)	X	X	X		3	Correlator	Basic toolkit	DVM, thermal camera
2	Health check (status)	X		X	X	1	Correlator	N/A	N/A
3	Document inspection and review			X		0	N/A	N/A	N/A
4	Software release			X	X	0	N/A	N/A	N/A
5	Offline Correlator and PIC tests	X	X	X		0	N/A	Basic toolkit	Oscilloscope, DVM
6	Off-line OFL tests	X	X			0	N/A	Basic toolkit	Optical power meter
7	Off-line maser tests			X		0	N/A	N/A	N/A
8	Off-line recording system extended test		X			0	N/A	N/A	N/A
9	Simulated observation	X		X		0	N/A	N/A	N/A
10	Back-end interface tests			X		3	Correlator, back-end	N/A	N/A
11	Computing interface tests	X		X		3	Correlator, maser, computing	N/A	N/A
12	Correlator interface & environmental tests			X		21	Correlator, computing	Basic toolkit	Oscilloscop, DVM, thermal camera
13	Site interface tests			X		0	N/A	Basic toolkit	N/A
14	On-sky interferometric observation				X	41	All	N/A	Beacon
15	Electrical, mechanical, safety and labeling walk-through			X		0	N/A	N/A	N/A
16	On-sky VLBI tests				X	72	All	GPS and quartz crystal	OSF antenna & LORR

2 Detailed test procedures

There are 16 subsections in this section, one for each of the tests listed in Table 1-1 above. Some of these tests are aimed at a certain class of requirements (e.g., test # 15), while others, by their very nature, touch on many of the requirements (e.g., test # 2). Each section is organized as follows. First, each subsection provides an overview of the testing associated with that section ("how" the test is done). Second, a list of the requirements verified by the tests in a given section is provided in a table. The Verification Method column in this table provides additional detail on how and why the particular requirement is verified and/or points to other documents containing detailed procedures that do this. There are three exceptions to this: tests 14 and 16 which are in the domain of CSV and test 7 because the Maser verification was covered in the Maser AcRv. These sub-sections simply list relevant requirements, for completeness, but do not provide the additional details provided in the other sub-sections. Finally, Appendix B of this document provides a summary of all of the project's requirements with pointers to the relevant sub-sections of section 2 of this document to show that all requirements are addressed.

2.1 Test #1, Health Check (intensive)

Campaigns: PAI, PAS, AcRv

There are two suites of health checks associated with the Phasing System. A simpler test, called "status" is covered in section 2.2 and is intended to be executed in preparation for a VLBI observation. A more complex test, called "intensive" is covered in this section. It includes all items covered in the status check and several additional ones. It is intended to be run to

- To initially verify that the system meets its specifications with ample margin;
- Verify that individual modules are functional;
- Verify that it is safe to add modules to the system;
- To help diagnose unusual failures

The tests covered by this section include the following types:

- Extended module diagnostics, beyond what is normally done in weekly tests or before a VLBI observation;
- Temperature measurements of certain modules;
- Waveform measurements using an oscilloscope;
- Voltage measurements to verify that the power supplied to APP modules is in range
- All tests included in section 2.

Since this test includes all the tests of test #2, all the requirements verified in test#2 are also verified in this test. In addition to those requirements, other requirements are verified by this test. These are listed in the table below. See section 2.2 for the list of additional requirements verified by test #1 and for explanations as to why the tests verify the requirements.

Rqmt #	Requirement	Verification Method
APP0190	**Correlator configuration:** The antenna summed data shall be provided as CAI-63.	[RD-05], section 2.3.10.1
APP0220	**PIC timing:** A 1pps clock synchronized with the maser shall be supplied to the PIC	[RD-30]
APP0390	**Interscan gap:** The APP system shall support scans separated by a minimum of ***10*** seconds.	[RD-07], section 5.1.2

Rqmt #	Requirement	Verification Method
APP0400	**Scan duration:** The APP system shall support scan durations between **10** and **900** seconds.	[RD-20], section 3.2
APP0490	**Antenna participation:** The phasing system shall be capable of phasing up an array consisting of an arbitrary odd number of antennas <64.	[RD-07], section 5.1.1: Summing of various numbers of antennas is demonstrated in this test.
BAK-0040	**1-PPS levels**. Verify that the 1-PPS signal level at the 1-PPS Distributor in the Correlator Room is compliant.	[RD-09], section 2.3.4.2: The waveform is measured in this test.
COR-0060	**Power dissipation**: Measure the current consumption of one PICA in maximum dissipation mode and multiply by 8.	[RD-05], section 2.3.11.1:
SIT-0010	**Component power dissipation:** Verify power dissipation under normal operating conditions for one or more of each of the following installed components: • Maser rack (3.1.5.1.1) • 1-PPS distributor (3.2.1.1) • Fiber Mux/DeMux (3.3.1.1) • Recorder (3.4.2)	[RD-05], section 2.3.11.2: 1-PPS distributor power is measured. [RD-13], section 3.4: OFL power is measured [RD-07], section 5.2.3, Recorder power is measured
SIT-0020	**Correlator upgrade cabling**	[RD-09], section 2.3.5.1, 2.3.7: Visual inspection and built-in tests were both used to verify the cabling.
ENVI-00070-00 / R	[AOS] All ALMA equipment shall be compatible with an ambient air pressure of 550 mbar ± 60 mbar, which corresponds to an air density of 0.7214 kg/m3 (typical average).	[RD-07]: All Correlator hardware as well as the OFL have been installed since July 2014 and have passed all relevant tests in this document at least once and quite a few of them on several occasions. Thus compatibility has been demonstrated by successful operation in the environment. Maser compliance was covered in the Maser AcRv

2.2 Test #2, Health check (status)

Campaigns: PAI, AcRv and CSV

This suite of tests is intended to be run routinely prior to a VLBI experiment. Since the Phasing System includes quite a few powerful semi-automated tests, this suite of tests shows that the system meets many of its requirements. This suite includes tests to

- Verify the integrity of the data paths through all components associated with the Phasing System data chain (Correlator, OFL, fibers, Recorders);
- Verify timing accuracy of the data;
- Verify that various monitor points are within normal ranges in the maser, Correlator, OFL and recorders;

This suite of tests exercises all the data paths at full data rate and tests that the results are exactly correct. Thus all requirements having to do with data rate, data transmission (including optical link), Ethernet frame details and Correlator configuration are satisfied by these tests. The suite also verifies the long-term stability of the maser by looking at the history of the 1-PPS signal against GPS. Finally, by checking logs and monitor points associated with the maser, Correlator, OFL and recorders, requirements having to do with logging are verified. For details see the table below.

Rqmt #	Requirement	Verification Method
APP0020	**Spectrum**: The APP shall be capable of processing 8GHz of input spectrum per polarization	[RD-23], Chapter 3: One data path with 2 GHz BW is demonstrated. [RD-07], section 5.1.3: Eight data paths with 8 GHz per polarization are demonstrated.
APP0050	**Data capture**: The APP shall have the capability to record 64Gbps of data and associated framing data.	[RD-23], Chapter 3: One data path with 8 Gbps of data is demonstrated. [RD-07], section 2.1.4.4: Eight data paths with with an aggregate data rate of of 64 Gbps are demonstrated.
APP0070	**Environmental:** All hardware permanently installed at AOS/OSF shall meet ALMA altitude/environmental requirements.	All hardware has been installed at AOS/OSF for many months. It has repeatedly satisfied all tests in [RD-05], [RD-07] and [RD-09], thus demonstrating compatibility with altitude and environmental requirements.
APP0080	**Environmental:** The recording systems shall be compatible with operation at OSF altitudes.	The recorders been installed at AOS/OSF for months. Initially two of the recorders underwent stress tests to verify compatibility. See RD-20 for details. Since then, four recorders have repeatedly satisfied tests in and [RD-07] Chapter 2, again demonstrating compatibility with altitude and environmental requirements.
APP0090	**Data transmission:** A high speed data 80Gbps connection shall link the equipment at the AOS to the OSF	[RD-07], section 2.1.4.4: Eight data paths with with an aggregate data rate of of 64 Gbps are demonstrated. (The capability of the system to meet 80 Gbps is covered in section 2.3.)

Rqmt #	Requirement	Verification Method
APP0100	**Environments:** The APP system shall be operable whenever ALMA is.	[RD-07]: It is clear from a review of these tests that they are integrated into the ALMA infrastructure and thus the Phasing System is capable of being used just like any other ALMA system.
APP0110	**Maser status:** The Maser status / health information shall be accessible via a network interface and recorded at least once every 10 minutes.	[RD-29], section 2.3: The status/health information is reviewed prior to each VLBI experiment (actually more often that that).
APP0180	**Correlator output:** The correlator shall operate in a mode where it provides to the PICs the antenna-summed data for each quadrant: 2 pol x 32 ch x 62.5 MHz, 2bits / sample, 16Gbps , 128 LVDS pairs	[RD-07], section 2.1.5: Standard Correlator mode 13 is used in this test.
APP0200	**Correlator self test**: Test capabilities shall be provided by the ALMA correlator to verify correct PIC operation.	[RD-09], sections 2.3.5.3, 2.3.5.4, 2,3,5,6 [RD-05], section 2.3.5, 2.3.6.1.1, 2.3.10.1, 2.3.10.2,
APP0230	**VDIF format:** The VDIF packet shall support 8, 16 and 32 channels.	[RD-07], section 2.4
APP0240	**VDIF encapsulation:** The VDIF packet shall be encapsulated as UDP/IPv4 payload.	[RD-07], section 5.2.1: The recorder is designed to accept only these type of packets. The fact that it accepts the packets from the PICs shows that the PICs meet this requirement.
APP0250	**Ethernet mtu:** The Ethernet interface shall support jumbo frames.	[RD-07], section 5.2.1: The recorder is designed to accept only these type of packets. The fact that it accepts the packets from the PICs shows that the PICs meet this requirement.
APP0260	**Ethernet bandwidth**: The Ethernet interface shall be 10Gbps.	[RD-07], section 5.2.1: The recorder is designed to accept only these type of packets. The fact that it accepts the packets from the PICs shows that the PICs meet this requirement.
APP0270	**Network infrastructure**: The data communication system linking AOS to OSF shall support multiplexing eight 10 GbE bi-directional channels onto a single fiber.	[RD-07], section 5.2.1: 8 channels are demonstrated in this test at an aggregate rate of 64 Gbps. (The bidirectional nature of the link is not needed for phasing, and is documented in
APP0280	**Data distribution:** The data shall be evenly distributed at 8Gbps over all optical channels.	[RD-07], section 5.2.1 The recorder saw similar, evenly divided, data streams in this test
APP0290	**Recording system:** The recorders shall be able to record at an aggregate rate of 64 Gbps.	[RD-07], section 5.2.1

Rqmt #	Requirement	Verification Method
APP0300	**Data integrity**: The recording system (recorder + optical fibers) shall capture at least 95% of the data packets.	[RD-07], Chapter 3
APP0440	**Minimum bands:** APP shall support simultaneous use of one to four ALMA frequency basebands	[RD-07], section 5.1.4: Four basebands are recorded in this test. Since the quadrants and recorders are individually controllable (basic ALMA software properties) any number from 1 to 4 is acceptable.
APP0470	**Observing correlator**: The ALMA correlator shall operate in a single Nyquist sampled, single region frequency division mode covering the full 2 GHz bandwidth on each quadrant	[RD-07], section 2.1.5: Test is conducted using such a mode, Correlator mode 13.
APP0530	**Independent quadrants:** The APP system shall support independent operation of the four correlator quadrants.	[RD-07], section 2.2
COR-0030	**Rack temperature increase** due to PICs	[RD-05], section 2.3.11.1: Power dissipated by PIC is measured to be about 30 W. [RD-09], section 2.3.5.3: The temperatures at various points in the racks are measured in this test. The insignificant amount of power dissipated by the PIC makes the temperature rise of the rack due to the pic impossible to measure (30W/4500W)
COR-0050	**PIC Comm. Ethernet card**: Verify that it is possible to communicate via Ethernet to each ROACH via the Engineering Port Computer	[RD-09], section 2.3.5.2:
COR-0070	**Firmware deliveries**: Verify that the correct microprocessor and FPGA personalities are installed.	[RD-09], section 2.3.4.4:
ENVI-00270-00 / R	[OSF] All ALMA equipment shall be compatible with an ambient air pressure of 750 mbar +/- 100 mbar, which corresponds to an air density of 0.96 kg/m3 (typical average).	[RD-07]: Two recorders were installed at the OSF in 2013 and an additional two in August 2014. They have passed all relevant tests in this document and quite a few of them on several occasions. Thus compatibility has been demonstrated by successful operation in the environment. (Also see test #8.)

2.3 Test #3, Document inspection and review

Campaigns: AcRv

Many requirements having to do with the system configuration and the interconnection of modules can most clearly be verified by referring to the system block diagram. This was used as a basis for the generation of cabling documentation which, by nature, is more obscure (see CIDL). The Maintenance Manual [RD-04] includes a description of the system at a level that is fairly easy to understand and also includes a system block diagram. For this reason, it is used as a basis for verification by review of documentation for several requirements below. APP cables are well labeled and ALMA can check the system block diagram against cabling documents and physical cabling if it so desires.

Requirements addressed:

Rqmt #	Requirement	Verification Method
APP0010	**Frequency reference:** All ALMA local oscillators shall be phase-locked to a common frequency standard.	[RD-04]: See System Block Diagram. Since the maser replaces the Rubidium in the Central LO, all of ALMA is phase-locked to it.
APP0020	**Spectrum**: The APP shall be capable of processing 8GHz of input spectrum per polarization	[RD-04]: See System Block Diagram. Each of the 8 data streams handles one polarization with a bandwidth of 2 GHz.
APP0030	**Polarization:** The APP shall generate dual-polarization signals.	[RD-04]: See System Block Diagram. Four of the data streams handle one polarization and the other four the other polarization.
APP0050	**Data capture**: The APP shall have the capability to record 64Gbps of data and associated framing data.	[RD-04]: See System Block Diagram. Each recorder handles two data streams of 8 Gbps each.
APP0090	**Data transmission:** A high speed data 80Gbps connection shall link the equipment at the AOS to the OSF	[RD-04]: See System Block Diagram. The data link between the two OFLs is shown to be 80 GbE. [RD-13], section 3.1 describes the testing and results to validate the 80 Gbps requirement.
APP0100	**Environments:** The APP system shall be operable whenever ALMA is.	All installed equipment meets all relevant ALMA environmental specifications (see Appendix B of this document). Also, there is no mention of any limitations to the delivered equipment in any of the delivered documentation. Therefore, this requirement is met. (See also test #2.)
APP0170	**Phasing data**: Channel average data from all relevant baselines and WVR data shall be available at the baseband cadence.	No verification needed. This capability currently exists at ALMA
APP0180	**Correlator output:** The correlator shall operate in a mode where it provides to the PICs the antenna-summed data for each quadrant: 2 pol x 32	No verification needed. This capability currently exists at ALMA in certain modes, including Mode 13 which is used in Test 2.

Rqmt #	Requirement	Verification Method
	ch x 62.5 MHz, 2bits / sample, 16Gbps , 128 LVDS pairs	
APP0190	**Correlator configuration**: The antenna summed data shall be provided as CAI-63.	[RD-04]: See System Block Diagram. The feedback path of the VLBI sum to the VLBI sum input is shown. [RD-14]: See entries for Correlator Card to CI card. These are the feedback to input 63. (See also test #1)
APP0210	**PIC output:** The output format of the PIC phased sum data shall be VLBI Data Format (VDIF) packets	RD-25 (Recorder Command Set) section 6, input_stream command shows that the recorder only accepts the legacy Mark5b format and VDIF. That we were ever able to record is conclusive evidence that we are fully VDIF compliant with our data.
APP0220	**PIC timing:** A 1pps clock synchronized with the maser shall be supplied to the PIC	[RD-04]: This connection is shown in the System Block Diagram. (See also test #1.)
APP0270	**Network infrastructure**: The data communication system linking AOS to OSF shall support multiplexing eight 10 GbE bi-directional channels onto a single fiber.	[RD-04]: See System Block Diagram. The data link between the two OFLs is shown to be 80 GbE. [RD-13], section 3.1 describes the testing and results to validate the 80 Gbps requirement. [RD-2] states that the design of the two OFLs are identical. This satisfies the bidirectional requirement.
APP0280	**Data distribution:** The data shall be evenly distributed at 8Gbps over all optical channels.	[RD-04]: See System Block Diagram. Eight 10 GbE channels are shown, each driven by identical PICs. Thus the data are evenly distributed.
APP0310	**Recorder control:** Commands to the recorders shall adhere to the VLBI Standard Software Interface Specification (VSI-S).	RD-25,Mark 6 command set document, section 1
APP0320	**Recorder media:** The data shall be recorded to standard disks.	RD-07, section 5.2.2
APP0330	**Media processing:** The disks shall be shippable for VLBI processing of data.	RD-07, section 5.2.2
APP0340	**Media insertion:** Reliability of the connectors / cables between the recorder and the module shall be consistent with at least 5 years of operation	RD-31
APP0350	**Media capacity:** The disk modules will hold a minimum of 9 hours of data.	64 Gb/s * 9hrs *3600s / 8 bits_per_byte = 260 TB. Capacity of recorders is 4 recorders x 32/recorder modules x 3 TB disks = 384 TB, well in excess of the 260 TB.

Rqmt #	Requirement	Verification Method
APP0360	***Experiment session:*** Each VLBI session shall be described in a manner compatible with existing VEX file systems in use at 3 mm and 1.3 mm observatories that are expected to participate in VLBI observations with ALMA.	N/A for hardware acceptance.
APP0370	**Session duration:** The APP system shall support sessions lasting up to 18 hours.	64 Gb/s * 9hrs *3600s / 8 bits_per_byte = 260 TB. Capacity of recorders is 4 recorders x 32/recorder modules x 3 TB disks = 384 TB. So this becomes an straightforward operational issue. Two sets of modules will need to be provided to support a session lasting 18 hours.
APP0390	**Interscan gap:** The APP system shall support scans separated by a minimum of ***10*** seconds.	RD-07, Section 5.1.2
APP0400	**Scan duration:** The APP system shall support scan durations between **10** and **900** seconds.	RD-20, section 3.2
APP0410	**Experiment scans:** The APP system shall complete at least ***90*** % of scheduled scans.	20, Section 3.2
APP0420	**Scan scheduling:** The APP system shall support scans scheduled in UTC time and shall start/stop within 2 seconds of the scheduled time.	RD-07, Section 2.3.3.4
APP0430	**Band support:** Band 3, 6 receivers shall be fully supported.	RD-04: See System Block Diagram. The data path shows no dependence on which receiver is being used. The key is whether the phasing algorithm is able to phase antennas at these bands. RD-07, Section 5.1.3
APP0440	**Minimum bands:** APP shall support simultaneous use of one to four ALMA frequency basebands	[RD-04]: See System Block Diagram. It shows that the system uses one to four Correlator quadrants. A basic property of the ALMA system is that the quadrants can be operated independently. Therefore the requirement is met.
APP0450	**IF frequency:** The APP system shall support faithful programming of the IF band specified by the VEX file.	RD-07, Section 5.1.3
APP0460	**TFB tunings:** The TFB channel placement shall be capable of being made compatible with the 2^n MHz sampling schemes of traditional VLBI.	RD-07, Section 5.1.3

Rqmt #	Requirement	Verification Method
APP0470	**Observing correlator**: The ALMA correlator shall operate in a single Nyquist sampled, single region frequency division mode covering the full 2 GHz bandwidth on each quadrant	RD-17 specifies all Correlator modes. APP uses standard mode 13 to satisfy this requirement.
APP0480	**LO Tuning:** All Antennas shall have the same LO tuning	No verification needed. This is an existing ALMA mode.
APP0490	**Antenna participation:** The phasing system shall be capable of phasing up an array consisting of an arbitrary odd number of antennas <64.	RD-14, System Block Diagram shows no limitation on the number of antennas except that antenna 63 (counting from 0) is dedicated to correlating the sum of antennas. RD-06, section 3 shows that the summing mask can contain any number of antennas. The "odd" number of antennas comes from the mathematics of summing 2-bit-sampled data. This is enforced in the high level software.
APP0500	**Antenna 63:** The antenna assigned to CAI-63 shall be part of the observing array but omitted from the phased sum	RD-04: See System Block Diagram. It is also clear that the normal ALMA data path in the Correlator is not disturbed (the phasing system "taps off" the data it needs), so any antenna can be part of the observing array. Omitting antenna 63 from the phased sum is ultimately governed by the high level software.
APP0510	**Log archival:** Information necessary for the post-observation (VLBI) correlation and analysis shall be archived.	RD-07, section 5.1.6
APP0520	**Independent systems:** The phasing and recording systems shall be operated separately.	RD-04: The System Block Diagram clearly shows that the hardware is independent. Separate operation is governed by the high level software design. RD-07, section 5.1.5
APP0530	**Independent quadrants:** The APP system shall support independent operation of the four correlator quadrants.	RD-07, section 2.2
ENVI-00040-00 / A	[Operating and non-operating compatibility with] The levels of earthquake acceleration that are likely to occur at the OSF and AOS	This applies only to the maser rack since other equipment was installed in existing racks. It was covered at the Maser AcRv
ENVI-00050-00 / R	Occurring downtime and time to repair for the equipment must be defined in each sub-system specification.	Covered primarily in RD-18, and also in RD-02
ENVI-00121-00 / R ENVI-00122-00 / R	[AOS operating and non-operating compatibility with] Maximum expected Gamma ray dose rates are 3.14 mSv/year	See ALMA Memo 462. All FPGAs are subject to gamma rays. FPGA personality changes due radiation from gamma rays or neutrons were detected at the rate of one every few hours in tests of the ALMA Correlator for the ~10,000 FPGAs in the Correlator TFB boards. ALMA currently ignores this. The additional disruption caused by an additional 8 FPGAs in the PICs will be too minor to be noticed. **We request a waiver.**

Rqmt #	Requirement	Verification Method
ENVI-00311-00 / R ENVI-00312-00 / R	[OSF Operating and non-operating compatibility with] maximum expected Gamma ray dose rates of 1.70 mSv/year.	This applies to the recorders. As stated above for ENVI-00121, FPGA disruptions occur statistically. At the OSF, given the lower elevation and smaller number and smaller physical size of FPGAs, the probability of a disruption is miniscule and can be dealt with in the same way as ALMA deals with this issue in other computers, by rebooting periodically. **We request a waiver.**

2.4 Test #4, Software release

Campaigns: AcRv , CSV

The requirements in this section are related to software monitoring. They are verified by observing the required logs.

Requirements addressed:

Rqmt #	Requirement	Verification Method
APP0110	**Maser status:** The Maser status / health information shall be accessible via a network interface and recorded at least once every 10 minutes.	RD-29, section 2.3. During AOS testing, the software was exercised and the status/health data was inspected.
APP0160	**Phasing efficiency (monitoring):** The phasing system shall monitor the efficiency of its solutions.	N/A This is a software requirement, not due until CSV.

2.5 Test #5, Off-line correlator and PIC tests

Campaigns: PAI, PAS, AcRv

The purpose of this test is primarily to cover any requirements related to Correlator Upgrades that are not covered elsewhere (primarily tests # 1 and 2). Tests that fall into this category include

- initial component check-outs, done prior to installing equipment in either the test fixture in Charlottesville or at its intended location at ALMA (not covered by a requirement) (documented in RD-05 and RD-19);
- demonstration of the required reliability

Requirements addressed :

Rqmt #	Requirement	Verification Method
APP0060	**Line Replaceable Unit Reliability (LRU):** All installed APP hardware shall satisfy ALMA LRU requirements.	As noted in RD-18, Correlator components have demonstrated reliability exceeding this requirement. Part of the process for obtaining units that are reliable at ALMA is burning them in before shipping. Both the PICs and associated supplies were burned-in in Charlottesville. This is reported in RD-19 (first tab) and RD-05, section 2.3.12.

2.6 Off-line OFL tests

Campaigns: PAI, PAS, AcRv

The OFL sub-system was designed by NAOJ and verified there prior to shipping. These tests are documented in [RD-13] and satisfy requirements as listed below. NRAO and Haystack personnel tested the OFL in conjunction with the recorders and PICs in Charlottesville. These tests are documented in RD-20. NAOJ personnel also tested the OFLs off-line at ALMA as part of a combined PAS and AcRv mission. These tests are documented in [RD-21]. Finally, although not listed here, any tests which use the OFL to transmit data implicitly test the OFL as well.

Requirements Verified:

Rqmt #	Requirement	Verification Method
APP0060	**Line Replaceable Unit Reliability (LRU):** All installed APP hardware shall satisfy ALMA LRU requirements.	RD-13, section 3.3, documents burn-in tests for the OFLs at NAOJ. This type of testing contributes to meeting this requirement. RD-13, section 3.6 documents that the unit operates with one of the two redundant supplies disabled. This contributes to the LRU's reliability. RD-21, sections 5.1 to 5.5 document link characteristics which are required for reliable operation.
APP0070 ENVI-00070-00 / R	**Environmental:** All hardware permanently installed at AOS/OSF shall meet ALMA altitude/environmental requirements.	RD-13, section 3.7, documents a test that verifies sufficient cooling capacity for operation at the AOS.
APP0270	**Network infrastructure**: The data communication system linking AOS to OSF shall support multiplexing eight 10 GbE bi-directional channels onto a single fiber.	RD-13, section 3.2, documents a test that uses an attenuator to simulate the AOS to OSF optical link and measures error rate. RD-13, section 3.1 documents a test which demonstrates the full data capacity over 1 fiber. RD-21, sections 5.1 to 5.5 verify that the network infrastructure is operating correctly at ALMA RD-23, sections x to y verify that the link is operating correctly in Charlottesville.
SIT-0010	**Component power dissipation.**	RD-13, section 3.4, documents measured power dissipation which is considerably less than required.

2.7 Off-line maser tests

Campaigns: AcRv

The maser requirements were covered at the maser AcRv and are therefore listed as N/A in this document.

Requirements addressed:

Rqmt #	Requirement	Verification Method
APP0120	**Maser stability:** The Maser shall be stable to: 10^{-13} Allen Variance for 1 sec integration time and $2x10^{-14}$ for 10 second integration time.	N/A (covered at Maser AcRv)

2.8 Off-line recording system extended test

Campaigns: PAS

The APP Mark 6 recorders have undergone extensive testing. This includes tests at Haystack using self-generated data sources, at Charlottesville using both self-generated and PIC-generated data and at the ALMA site using both self-generated and PIC generated data via fiber from AOS to OSF. The tests show that the recorders can reliably handle the specified data rate in the ALMA environment. See details in the table below.

Requirements addressed (single instance is to be tested):

Rqmt #	Requirement	Verification Method
APP0020	**Spectrum**: The APP shall be capable of processing 8GHz of input spectrum per polarization	RD-23, Chapter 23, shows that one recorder can handle 25% of the requirement, at PAI. RD-07, section 5.1.3, shows that the four recorders can handle 100% of the required spectrum. (AcRv)
APP0080	**Environmental:** The recording systems shall be compatible with operation at OSF altitudes.	RD-20 is dedicated to an extended test of the recorders at altitude to demonstrate that the recorders satisfy this requirement.
APP0290	**Recording system:** The recorders shall be able to record at an aggregate rate of 64 Gbps.	RD-07, section 5.2, shows that the four recorders can handle 100% of the required spectrum. (AcRv)
APP0300	**Data integrity**: The recording system (recorder + optical fibers) shall capture at least 95% of the data packets.	RD-23, Chapter 3, shows that the dropped packet capture rate at PAI with 30 km of cable is zero. RD-07, Chapter 3, shows that the packet capture rate at site is $< 2*10^{-6}$.

2.9 Simulated observation

Campaigns: PAI, AcRv

Rudimentary simulated observations were performed at both Charlottesville (PAI) and ALMA (AcRv). Their purpose is primarily to show compliance with AD-08 and to meet timing restrictions (in some cases, commands need to be received at certain times relative to the TE signal). The tests involve configuring the entire APP system for a simulated observation, recording data, and examining the recorded data for compliance with the requirements. Since the recorders are designed to reject packets that do not meet the specifications listed below [RD-25] the fact that the recorders accept packets verifies that the packets meet most of the requirements listed below. See the table below for details.

Requirements addressed :

Rqmt #	Requirement	Verification Method
APP0220	**PIC timing:** A 1pps clock synchronized with the maser shall be supplied to the PIC	[RD-30]
APP0230	**VDIF format:** The VDIF packet shall support 8, 16 and 32 channels.	[RD-07], section 2.4
APP0240	**VDIF encapsulation:** The VDIF packet shall be encapsulated as UDP/IPv4 payload.	[RD-07], section 5.2.1: The recorder is designed to accept only these type of packets. The fact that it accepts the packets from the PICs shows that the PICs meet this requirement.
APP0250	**Ethernet mtu:** The Ethernet interface shall support jumbo frames.	[RD-07], section 5.2.1: The recorder is designed to accept only these type of packets. The fact that it accepts the packets from the PICs shows that the PICs meet this requirement.
APP0260	**Ethernet bandwidth**: The Ethernet interface shall be 10Gbps.	[RD-07], section 5.2.1: The recorder is designed to accept only these type of packets. The fact that it accepts the packets from the PICs shows that the PICs meet this requirement.
COM-0010	**Protocol verification.**	RD-07, section 5.1.7 shows that all protocols are executed in a simulated observation. Analysis of the data shows that the protocols were *successfully* executed

2.10 Back-end interface tests

Campaigns: AcRV

The purpose of this test is specifically to verify that the requirements imposed by AD-06 are satisfied. Most of the requirements were covered at the Maser AcRv and so are listed as N/A in the table below. For the one remaining requirement, see the table below for details.

Requirements addressed (all units to be tested):

Rqmt #	Requirement	Verification Method
BAK-0010	Maser Rack Cabling	N/A
BAK-0020	CRG 5 MHz input power level	N/A
BAK-0030	CVR 10 MHz input power level	N/A
BAK-0040	1-PPS levels: Maser 1-PPS signal, measured at the Correlator room, must be a TTL with 10-ns rise time.	RD-09, section2.3.3.2 provides measurements of this signal

2.11 Computing interface tests

Campaigns: PAI, AcRv

The purpose of this test is specifically to verify that the requirements imposed by AD-06 are satisfied.

Requirements addressed:

Rqmt #	Requirement	Verification Method
COM-0010	Protocol verification.	RD-05, section 2.3.8 shows that all protocols are executed in a simulated observation with no errors. RD-07, section 5.1.7 shows that all protocols are executed in a simulated observation. Analysis of the data shows that the protocols were successfully executed
COM-0020	Recorder NTP capability.	RD-07, section 4.2 demonstrates this capability at PAS.

2.12 Correlator interface and environment tests

Campaigns: AcRv

The purpose of this test is to verify that requirements of AD-08 are satisfied. Details for each requirement are provided in the table below.

Requirements addressed:

Rqmt #	Requirement	Verification Method
COR-0010	Items to be delivered as listed in Table 1 of AD-08	The following Transfer Requests show that all required equipment as well as spares were shipped: TRF # — Title — Date CV50-14 — TLC brackets to OSF — 7/28/2014 CV43-14 — Spare SFP+ cards_Chile FedEx# — 6/18/2014 CV36-14 — 5th PIC/Roach shipment — 5/28/2014 CV34-14 — 4th PIC/Roach shipment — 5/12/2014 CV30-14 — 3rd PIC/Roach shipment — 4/23/2014 CV29-14 — OFLx2 to Chile — 4/23/2014 CV28-14 — ALMA Phasing Project — 4/10/2014 CV22-14 — CORR BIN+LVDS cables to Chile — 3/26/2014 CV2-14 — 1st PIC_RoachII_Chile — 1/17/2014 CV97-13 — APP_GPS_Ant_A4_LVDS. — 12/3/2013 CV73-13 — APP cables and PSU. — 9/17/2013 CV64-13 — Phasing project 1PPS PARTS. — 9/16/2013 CV45-13 — Phasing project PSU model. — 4/18/2013 Moreover, the system is now fully installed, proving that there are no missing parts.
COR-0020	PIC assemblies fit in Final Adder slots of correlator bins	All PIC assemblies have been installed in spare Final Adder slots of Correlator bins, proving that they fit.
COR-0030	Rack temperature increase due to PICs	RD-05, section 2.3.11.1 shows the power dissipated in one PIC as measured at PAI. RD-09, section 2.3.5.3 shows that the correlator is operating in a safe environment. The power dissipated by a PIC, approximately 30 W, is less than 0.06% of the total power dissipated by one quadrant. Therefore the temperature rise is impossible to measure due to noise in the measurement process.
COR-0040	Cabling additions	RD-09, section 2.3.4.1 documents an inspection where the correctness of installed cables was visually verified. RD-09 section 2.3.7.4 documents an automated test which would highlight incorrectly installed cables (a few were found this way!)
COR-0050	PIC Comm. Ethernet card	RD-09 section 2.3.5.5 documents a test in which Ethernet connections to all PICs were used to obtain PIC temperature readings temperature readings. This verifies the Ethernet communication capability.
COR-0060	Power dissipation	RD-05, section 2.3.11.1 shows the power dissipated in one PIC as measured at PAI.
COR-0070	Firmware deliveries	RD-09 section 2.3.4.4 lists the installed firmware. Comparison with the CVS repository (:pserver: [user]@cvs-project7.sco.alma.cl:2401:/project7/CVS) shows that these are appropriate.

2.13 Site interface tests

Campaigns: AcRv

The purpose of this test is to verify that requirements of AD-07 are satisfied. Details for each requirement are provided in the table below.

Requirements addressed:

Rqmt #	Requirement	Verification Method
SIT-0010	Component power dissipation.	Measure the power dissipation of each required module: • Maser rack: N/A (covered in Maser AcRv) • Fiber Mux/DeMux : RD-13, section 3.4 • PIC: RD-05, section 2.3.11.1 • Recorder: RD-07, Section 5.2.3
SIT-0020	Correlator upgrade cabling	RD-09, section 2.3.3.1 and 2.3.4.1 documents an inspection where the correctness of installed cables was visually verified. RD-09 section 2.3.5.3 and 2.3.5.4 documents an automated test which would highlight incorrectly installed cables (a few were found this way!)

2.14 On-sky interferometric observation (CSV only)

Campaigns: CSV

For completeness, this sub-section lists the requirements verified by on-sky interferometric observation. However, these requirements are not part of the hardware AcRv and thus are listed as N/A in the table below.

Requirements addressed:

Rqmt #	Requirement	Verification Method
APP0010	**Frequency reference:** All ALMA local oscillators shall be phase-locked to a common frequency standard.	N/A
APP0020	**Spectrum**: The APP shall be capable of processing 8GHz of input spectrum per polarization	N/A
APP0030	**Polarization:** The APP shall generate dual-polarization signals.	N/A
APP0040	**Polarization purity:** The APP shall not introduce more than 3% polarization leakage .	N/A
APP0100	**Environments:** The APP system shall be operable whenever ALMA is.	N/A
APP0140	**Phasing efficiency (stability):** The APP phasing efficiency shall be as stable as the atmospheric coherence timescale of the median antenna of the array.	N/A
APP0150	**Phasing efficiency (quality):** The phasing system shall achieve 90% of the theoretical SNR expected for a compact 4 Jy source at 230 GHz operated with 15 antennas with baselines less than 2km with no more than 0.8mm precipitable water vapor and mean RMS path fluctuations no more than 0.125 mm.	N/A
APP0360	**Experiment session:** Each VLBI session shall be described in a manner compatible with existing VEX file systems in use at 3 mm and 1.3 mm observatories that are expected to participate in VLBI observations with ALMA.	N/A
APP0430	**Band support:** Band 3, 6 receivers shall be fully supported.	N/A
APP0450	**IF frequency:** The APP system shall support faithful programming of the IF band specified by the VEX file.	N/A
APP0460	**TFB tunings:** The TFB channel placement shall be capable of being made compatible with the 2^n MHz sampling schemes of traditional VLBI.	N/A
APP0470	**Observing correlator**: The ALMA correlator shall operate in a single Nyquist sampled, single region frequency division mode covering the full 2 GHz bandwidth on each quadrant	N/A
APP0490	**Antenna participation:** The phasing system shall be capable of phasing up an array consisting of an arbitrary odd number of antennas <64.	N/A
APP0500	**Antenna 63:** The antenna assigned to CAI-63 shall be part of the observing array but omitted from the phased sum	N/A
APP0510	**Log archival:** Information necessary for the post-observation (VLBI) correlation and analysis shall be archived.	N/A
APP0520	**Independent systems:** The phasing and recording systems shall be operated separately.	N/A
APP0530	**Independent quadrants:** The APP system shall support independent operation of the four correlator quadrants.	N/A

2.15 Electrical, mechanical, safety, and labeling

Campaigns: AcRv

No requirements addressed.

Rqmt #	Requirement	Verification Method
SAFD-0050-00/	The essential characteristics, the recognition and observance of which will ensure that electrical equipment will be used safely and in applications for which it was made, shall be marked on the equipment, or, if this is not possible, on an accompanying notice.	ALMA personnel to inspect and verify
SAFD-0060-00/	The designers or brand name or trade mark shall be clearly printed on the electrical equipment or, where that is not possible, on the packaging.	ALMA personnel to inspect and verify
SAFD-0090-00/	that persons are adequately protected against danger of physical injury or other harm which might be caused by electrical contact direct or indirect;	ALMA personnel to inspect and verify
PA-00240-00/	Each configuration item shall be uniquely identified by serial number.	ALMA personnel to inspect and verify
PA-00250-00/	A serial number shall be permanently affixed to each configuration item using a method appropriate to the item which may be indelible ink, engraving, coded electronically readable chip or a combination of the above or equivalent methods. Serial numbers shall not be hand-written.	ALMA personnel to inspect and verify
PA-00860-00/	The documentation supplied in the Acceptance Data Package shall reflect the “as-built” version of the delivered equipment and shall contain sufficient information for the installation, operation and maintenance of this equipment.	ALMA personnel to inspect and verify
PA-00920-00/	All commercially purchased test and measurement equipment used in the execution of formal acceptance testing shall satisfy the requirements for metrology and calibration specified in Table 4.	We used ALMA test equipment for all tests. We request a waiver.
PA-001000-00/	When appropriate, the accompanying documentation shall be in the outer packaging layer and shall include the Acceptance Data Package, which includes the storage, handling, transportation, packing/unpacking procedures and relevant notes of caution and safety procedures.	N/A
PA-001020-00/	Labeling of shipment containers shall include: 1. nomenclature, model name and serial number (if applicable) of the item; 2. caution/warning notes for dangerous or toxic contents; 3. package orientation arrows; 4. for large items, weight and centre of gravity, handling and lifting points; 5. conditions and instructions for handling and unpacking, and 6. name, address, phone number of sender and recipient.	ALMA personnel to inspect and verify
PA-001030-00/	Labeling of shipment containers shall be permanent and legible and protected against wear.	ALMA personnel to inspect and verify

Rqmt #	Requirement	Verification Method
APP-XXXXX-XX	APP-provided hardware shall conform to all applicable requirements and guidelines for identification and labeling of ALMA equipment as specified in ALMA-80.02.00.00-016-A-SPE	ALMA personnel to inspect and verify
APP-XXXXX-XX	APP-provided connectors shall conform to all applicable requirements specified in Standard for AC Plugs, Socket-Outlets, and Couplers: ALMA-80.05.00.00-004-B-STD	ALMA personnel to inspect and verify
APP-XXXXX-XX	APP-provided hardware shall conform to all applicable ALMA System Electrical Design Requirements as specified in ALMA-80.05.00.00-005-C-SPE	ALMA personnel to inspect and verify
APP-XXXXX-XX	APP-provided hardware shall conform to all applicable ALMA System EMC Requirements as specified in ALMA-80.05.01.00-001-B-SPE	ALMA personnel to inspect and verify

2.16 On-sky VLBI tests

Campaigns: CSV

Requirements addressed:

Rqmt #	Requirement	Verification Method
APP0040	**Polarization purity:** The APP shall not introduce more than 3% polarization leakage .	N/A
APP0140	**Phasing efficiency (stability):** The APP phasing efficiency shall be as stable as the atmospheric coherence timescale of the median antenna of the array.	N/A
APP0150	**Phasing efficiency (quality):** The phasing system shall achieve 90% of the theoretical SNR expected for a compact 4 Jy source at 230 GHz operated with 15 antennas with baselines less than 2km with no more than 0.8mm precipitable water vapor and mean RMS path fluctuations no more than 0.125 mm.	N/A
APP0460	**TFB tunings:** The TFB channel placement shall be capable of being made compatible with the 2^n MHz sampling schemes of traditional VLBI.	ON/A

- Plan: **APP Commissioning and Science Verification Plan**

Appendix A: Acronyms

AcRv	Acceptance Review
ALMA	Atacama Large Millimeter/Sub-millimeter Array
AOS	(ALMA) Array Operations Site
APP	ALMA Phasing Project
ASIAA	Academia Sinica Inst. of Astron. and Astrophys.
CAN	Controller Area Network
CCC	Correlator Control Computer
CDP	Correlator Data Processor
CDR	Critical Design Review
CIC	Correlator Interface Card
CLO	Central Local Oscillator
CORBA	Common Object Request Broker Architecture
CRG	Central Reference Generator
CSV	Commissioning and Science Verification
CVR	Central Variable Reference
CVS	Concurrent Versions System (software revision control system)
DiFX	Distributed Fourier Transform (Correlator)
FPGA	Field Programmable Gate Array
GbE	Gigabit Ethernet
GPS	Global Positioning System
GUI	Graphical User Interface
ICD	Interface Control Document
I&T	Integration and Test
JAO	Joint ALMA Office
LRU	Line Replaceable Unit
LTA	Long Term Accumulator
LVDS	Low Voltage Differential Signaling
MIT-HO	Mass. Inst. of Tech. Haystack Observatory
MMR	Monthly Management Review
MPIfR	Max Planck Institute for Radio Astronomy
MTU	Maximum Transmission Unit
NAOJ	National Astronomical Observatory of Japan
NRAO	National Radio Astronomy Observatory
OFL	Optical Fiber Link
OSF	(ALMA) Operations Support Facility
PA	Product Assurance
PAI	Provisional Acceptance In-House
PAS	Provisional Acceptance on Site
PIC	Phasing Interface Card
PICA	PIC Assembly
PPS	Pulse Per Second
RAM	Random Access Memory
RID	Review Item Discrepancy
RMS	Root Mean Square
ROACH	Reconfigurable Open Architecture Computing Hardware
SCC	Station Control Card
SITR	System Integration and Test Review

SNR	Signal to Noise Ratio
SVN	Subversion (Apache)
TE	Timing Event (a 48 millisecond ALMA-wide timing signal)
TFB	Tunable Filter Bank
TRR	Test Readiness Review
UTC	Coordinated Universal Time
VDIF	VLBI Data Interchange Format
VEX	VLBI Experiment File
VLBI	Very Long Baseline Interferometry
VOM	VLBI Observing Mode
VSI-S	VLBI Standard Software Interface Specification
WVR	Water Vapor Radiometer
XML	Extensible Markup Language

Appendix B: Requirements

The three tables in this appendix provide a cross-listing of the ALMA Phasing Porject requirments to the tests (from Table 1-1) which verify and validate these requirments.

Table B-1: Cross-listing of Functional Requirements.

Rqmt #	Requirement	Test
General		
APP0010	**Frequency reference:** All ALMA local oscillators shall be phase-locked to a common frequency standard.	3, 14
APP0020	**Spectrum**: The APP shall be capable of processing 8GHz of input spectrum per polarization	2,3,8, 14
APP0030	**Polarization:** The APP shall generate dual-polarization signals.	3, 14
APP0040	**Polarization purity:** The APP shall not introduce more than 3% polarization leakage .	14, 16
APP0050	**Data capture**: The APP shall have the capability to record 64Gbps of data and associated framing data.	2,3
APP0060	**Line Replaceable Unit Reliability (LRU):** All installed APP hardware shall satisfy ALMA LRU requirements.	15
APP0070	**Environmental:** All hardware permanently installed at AOS/OSF shall meet ALMA altitude/environmental requirements.	2, 6, 12, 13
APP0080	**Environmental:** The recording systems shall be compatible with operation at OSF altitudes.	2,8
APP0090	**Data transmission:** A high speed data 80Gbps connection shall link the equipment at the AOS to the OSF	2,3
APP0100	**Environments:** The APP system shall be operable whenever ALMA is.	2, 3,12, 14
Maser		
APP0110	**Maser status:** The Maser status / health information shall be accessible via a network interface and recorded at least once every 10 minutes.	2, 4
APP0120	**Maser stability:** The Maser shall be stable to: 10^{-13} Allen Variance for 1 sec integration time and $2x10^{-14}$ for 10 second integration time.	7
APP0130	**Frequency source:** Switching between the ALMA rubidium clock and the APP Maser shall be a manual procedure.	15
Phasing		
APP0140	**Phasing efficiency (stability):** The APP phasing efficiency shall be as stable as the atmospheric coherence timescale of the median antenna of the array.	14, 16

Rqmt #	Requirement	Test
APP0150	**Phasing efficiency (quality):** The phasing system shall achieve 90% of the theoretical SNR expected for a compact 4 Jy source at 230 GHz operated with 15 antennas with baselines less than 2km with no more than 0.8mm precipitable water vapor and mean RMS path fluctuations no more than 0.125 mm.	14, 16
APP0160	**Phasing efficiency (monitoring):** The phasing system shall monitor the efficiency of its solutions.	4
APP0170	**Phasing data**: Channel average data from all relevant baselines and WVR data shall be available at the baseband cadence.	3
Correlator		
APP0180	**Correlator output:** The correlator shall operate in a mode where it provides to the PICs the antenna-summed data for each quadrant: 2 pol x 32 ch x 62.5 MHz, 2bits / sample, 16Gbps , 128 LVDS pairs	2,3
APP0190	**Correlator configuration**: The antenna summed data shall be provided as CAI-63.	3
APP0200	**Correlator self test**: Test capabilities shall be provided by the ALMA correlator to verify correct PIC operation.	2,12
PIC		
APP0210	**PIC output:** The output format of the PIC phased sum data shall be VLBI Data Format (VDIF) packets	3
APP0220	**PIC timing:** A 1pps clock synchronized with the maser shall be supplied to the PIC	1,9
APP0230	**VDIF format:** The VDIF packet shall support 8, 16 and 32 channels.	2, 9
APP0240	**VDIF encapsulation:** The VDIF packet shall be encapsulated as UDP/IPv4 payload.	2, 9
APP0250	**Ethernet mtu:** The Ethernet interface shall support jumbo frames.	2, 9
APP0260	**Ethernet bandwidth**: The Ethernet interface shall be 10Gbps.	2, 9
Optical		
APP0270	**Network infrastructure**: The data communication system linking AOS to OSF shall support multiplexing eight 10 GbE bi-directional channels onto a single fiber.	2, 3
APP0280	**Data distribution:** The data shall be evenly distributed at 8Gbps over all optical channels.	3
Recorders		
APP0290	**Recording system:** The recorders shall be able to record at an aggregate rate of 64 Gbps.	2, 8/10
APP0300	**Data integrity**: The recording system (recorder + optical fibers) shall capture at least 95% of the data packets.	2, 8
APP0310	**Recorder control:** Commands to the recorders shall adhere to the VLBI Standard Software Interface Specification (VSI-S).	3
APP0320	**Recorder media:** The data shall be recorded to standard disks.	3
APP0330	**Media processing:** The disks shall be shippable for VLBI processing of data.	3
APP0340	**Media insertion:** Reliability of the connectors / cables between the recorder and the module shall be consistent with at least 5 years of operation	3
APP0350	**Media capacity:** The disk modules will hold a minimum of 9 hours of data.	3, 14

Rqmt #	Requirement	Test
Experiment		
APP0360	***Experiment session:*** Each VLBI session shall be described in a manner compatible with existing VEX file systems in use at 3 mm and 1.3 mm observatories that are expected to participate in VLBI observations with ALMA.	3, 14
APP0370	**Session duration:** The APP system shall support sessions lasting up to 18 hours.	3
APP0390	**Interscan gap:** The APP system shall support scans separated by a minimum of ***10*** seconds.	1, 3
APP0400	**Scan duration:** The APP system shall support scan durations between **10** and **900** seconds.	1, 3
APP0410	**Experiment scans:** The APP system shall complete at least ***90*** % of scheduled scans.	3
APP0420	**Scan scheduling:** The APP system shall support scans scheduled in UTC time and shall start/stop within 2 seconds of the scheduled time.	3
APP0430	**Band support:** Band 3, 6 receivers shall be fully supported.	3, 14
APP0440	**Minimum bands:** APP shall support simultaneous use of one to four ALMA frequency basebands	2, 3
APP0450	**IF frequency:** The APP system shall support faithful programming of the IF band specified by the VEX file.	3, 14
APP0460	**TFB tunings:** The TFB channel placement shall be capable of being made compatible with the 2^n MHz sampling schemes of traditional VLBI.	3, 14, 16
Observing		
APP0470	**Observing correlator**: The ALMA correlator shall operate in a single Nyquist sampled, single region frequency division mode covering the full 2 GHz bandwidth on each quadrant	2, 3, 14
APP0480	**LO Tuning:** All Antennas shall have the same LO tuning	3
APP0490	**Antenna participation:** The phasing system shall be capable of phasing up an array consisting of an arbitrary odd number of antennas <64.	1, 3, 14
APP0500	**Antenna 63:** The antenna assigned to CAI-63 shall be part of the observing array but omitted from the phased sum	3, 14
APP0510	**Log archival:** Information necessary for the post-observation (VLBI) correlation and analysis shall be archived.	3, 14
APP0520	**Independent systems:** The phasing and recording systems shall be operated separately.	3, 14
APP0530	**Independent quadrants:** The APP system shall support independent operation of the four correlator quadrants.	3, 14

Table B-2: Cross-listing for ICD requirements.

Item #	Item	Test
Back End		
BAK-0010	Maser Rack Cabling	10
BAK-0020	CRG 5 MHz input power level	10
BAK-0030	CVR 10 MHz input power level	10
BAK-0040	1-PPS levels	1,10
Computing		
COM-0010	Protocol verification.	9, 11
COM-0020	Recorder NTP capability.	11
Correlator		
COR-0010	Items to be delivered	12
COR-0020	PIC assemblies fit in Final Adder slots of correlator bins	12
COR-0030	Rack temperature increase due to PICs	2,12
COR-0040	Cabling additions	12
COR-0050	PIC Comm. Ethernet card	2,12
COR-0060	Power dissipation	1,12
COR-0070	Firmware deliveries	2,12
Site		
SIT-0010	Component power dissipation.	1, 6,13
SIT-0020	Correlator upgrade cabling	1, 13

Table B-3: Cross-listing of ALMA requirements

Requirement #	Requirement	Test
Environmental		
ENVI-00070-00 / R	[AOS] All ALMA equipment shall be compatible with an ambient air pressure of 550 mbar ± 60 mbar, which corresponds to an air density of 0.7214 kg/m3 (typical average).	1, 6, 13
ENVI-00040-00 / A	[Operating and non-operating compatibility with] The levels of earthquake acceleration that are likely to occur at the OSF and AOS	3
ENVI-00050-00 / R	Occurring downtime and time to repair for the equipment must be defined in each sub-system specification.	3
ENVI-00121-00 / R	[AOS operating and non-operating compatibility with] Maximum expected Gamma ray dose rates are 3.14 mSv/year	3
ENVI-00122-00 / R	[AOS operating and non-operating compatibility with]Maximum expected neutron dose rates are 0.80 mSv/year	3
ENVI-00270-00 / R	[OSF] All ALMA equipment shall be compatible with an ambient air pressure of 750 mbar +/- 100 mbar, which corresponds to an air density of 0.96 kg/m3 (typical average).	8
ENVI-00311-00 / R	[OSF Operating and non-operating compatibility with] maximum expected Gamma ray dose rates of 1.70 mSv/year.	8
ENVI-00312-00 / R	[OSF operating and non-operating compatibility with] Maximum expected neutron dose rates of 0.25 mSv/year.	3
Safety		
SAFD-0050-00/	The essential characteristics, the recognition and observance of which will ensure that electrical equipment will be used safely and in applications for which it was made, shall be marked on the equipment, or, if this is not possible, on an accompanying notice.	15
SAFD-0060-00/	The designers or brand name or trade mark shall be clearly printed on the electrical equipment or, where that is not possible, on the packaging.	15
SAFD-0090-00/	Persons are adequately protected against danger of physical injury or other harm which might be caused by electrical contact direct or indirect;	15
Product Assurance		
PA-00240-00/	Each configuration item shall be uniquely identified by serial number.	15
PA-00250-00/	A serial number shall be permanently affixed to each configuration item using a method appropriate to the item which may be indelible ink, engraving, coded electronically readable chip or a combination of the above or equivalent methods. Serial numbers shall not be hand-written.	15
PA-00860-00/	The documentation supplied in the Acceptance Data Package shall reflect the “as-built” version of the delivered equipment and shall contain sufficient information for the installation, operation and maintenance of this equipment.	15
PA-00920-00/	All commercially purchased test and measurement equipment used in the execution of formal acceptance testing shall satisfy the requirements for metrology and calibration specified in Table 4.	15
PA-001000-00/	When appropriate, the accompanying documentation shall be in the outer packaging layer and shall include the Acceptance Data Package, which includes the storage, handling, transportation, packing/unpacking procedures and relevant notes of caution and safety procedures.	15
PA-001020-00/	Labeling of shipment containers shall include: 1. nomenclature, model name and serial number (if applicable) of the item; 2. caution/warning notes for dangerous or toxic contents; 3. package orientation arrows; 4. for large items, weight and centre of gravity, handling and lifting points; 5. conditions and instructions for handling and unpacking, and 6. name, address, phone number of sender and recipient.	15
PA-001030-00/	Labeling of shipment containers shall be permanent and legible and protected against wear.	15

Requirement #	Requirement	Test
Other		
APPGEN-001	APP-provided hardware shall conform to all applicable requirements and guidelines for identification and labeling of ALMA equipment as specified in ALMA-80.02.00.00-016-A-SPE	15
APPGEN-002	APP-provided connectors shall conform to all applicable requirements specified in Standard for AC Plugs, Socket-Outlets, and Couplers: ALMA-80.05.00.00-004-B-STD	15
APPGEN-003	APP-provided hardware shall conform to all applicable ALMA System Electrical Design Requirements as specified in ALMA-80.05.00.00-005-C-SPE	15
APPGEN-004	APP-provided hardware shall conform to all applicable ALMA System EMC Requirements as specified in ALMA-80.05.01.00-001-B-SPE	15