NORTH AMERICAN ARC
ALMA Regional Center

North American ALMA Science Center

Commissioning Plan for the ALMA Correlator Upgrade Project (Phase 1)

NAASC Memo # TBD

Author: Crystal Brogan (CUP Subsystem Scientist)

(In consultation with: Stuartt Corder, Rich Lacasse, Rachel Rosen, Rodrigo Amestica, Todd Hunter, Alain Baudry & Baltasar Vila-Vilaro)

Date: January 25, 2017

1. Introduction

The purpose of this document is to describe the timeline, parameter space, and effort required for the science commissioning of Phase 1 of the ALMA Correlator Upgrade Project (CUP) based on information as it is currently known at the PDR stage. This plan will undergo further refinement for the CDR. An acronym glossary is available at the end of the document.

2. Big Picture Timeline

To set the stage and provide a big picture view of the process we begin by describing some of the major milestones in the context of the ALMA standard Cycle timeline. This timeline is complementary to the detailed engineering / software project plan presented in the Correlator Upgrade Project Plan. In normal operations, an ALMA Cycle begins on October 1, for a proposal call that occured the preceding March (deadline in April), and ends on Sept 30 of the following year. In this timeline we have assumed that the “Hardware-in-the-Loop” (HIL) simulator will be deployed as planned in 2019 using BL correlator cards and is available by mid-2022 for upgrade to the new CUP cards for the purpose of critical pre-deployment hardware and software testing.

Table 1: Big Picture Timeline for CUP Phase 1 in Context of ALMA proposal cycles

Cycle	Activity	Date	Description
5	HIL Simulator PDR	mid-Feb 2018	PDR for Hardware in Loop (HIL) Simulator
5	CUP Phase 1 PDR	end-Feb 2018	PDR for Phase 1 Correlator Upgrade Project (CUP)
5	ALMA Board Decision	mid-April 2018	Ruling on whether HIL Simulator and Phase 1 CUP move to construction
6	CUP Phase 1 CDR	April 2019	Determination if on schedule for deployment
6	Cycle 7-prep	mid-2019	HIL Simulator (BL correlator cards) ready for normal commissioning/validation activities
7	Cycle 8-prep	March 2020	Cycle 8 (CUP deployment Cycle - 2) Call for proposals includes advanced warning of planned Cycle 9 extension, and shared risk in Cycle 10 for CUP along with preview of new capabilities
8	Cycle 8 Start	Oct 1 2020	Cycle 8 starts as normal
8	Cycle 9-prep	March 2021	Call for proposals Cycle 9. This cycle will run longer by 1 Month using BL correlator
9	Cycle 9 Start	Oct 1 2021	Cycle 9 Starts as normal
9	Cycle 10-prep	Oct 30 2021	Details for OT validation of CUP shared-risk modes required for Cycle 10 Phase 1
9	Cycle 10-prep	March 2022	Cycle 10 Call for proposals: shared risk using Phase 1 CUP, modes must be described
9	Cycle 10-prep	July-2022	HIL Simulator converted to CUP Phase 1 cards and pre-deployment software testing begins

9	Cycle 11-prep	Oct 30 2022	Details for OT validation of CUP modes required for Cycle 11 Phase 1 (if different than Cycle 10)
9	Cycle 9 End	Oct 31 2022	Cycle 9 Ends 1 month later than normal
10	CUP Hardware Deployment	Nov 1 2022	First quadrant cards deployed and undergo initial validation followed by Go-No-Go decision point
10	CUP Continued Deployment and Begin Commissioning	Dec 1 2022	Commissioning begins and proceeds in parallel with deployment to remaining quadrants
10	Cycle 11-prep	March 2023	Cycle 11 Call for proposals using CUP in full operations, normal Cycle schedule
10	Cycle 10 Start	March 13 2023	Goal for Shared Risk observing to begin
10	Cycle 10 End	Sep 30 2023	Cycle 10 (shared risk) ends
11	Cycle 11 Start	Oct 1 2023	Cycle 11 begins, normal cycle

Tablenote: Milestones directly related to the CUP itself are colored red. Related Operations milestones are colored black. Milestones for the OT that are dependent on the CUP are blue.

It is notable that the Phase 1 CUP is scheduled to be deployed during the austral summer of 2022/2023 corresponding to Cycle 10. This has ramifications for the 12m-array configuration and weather that will be available during the commissioning and Shared-Risk PI observation periods. If ALMA continues on its current roughly 2-year configuration cycle, even-numbered cycles are in extended configurations during the austral winter. This implies that the CUP commissioning will take place using a relatively compact configuration, but also that extended configurations will be available during the “Shared Risk” period of PI observations (~ starting around June if past even-numbered cycle timing holds true). Depending on the exact configuration schedule it may be desirable to schedule an explicit “long baseline” check-out period before science observing in long baselines begins.

3. Critical Correlator Functions and Capabilities

In Phase 1 of the CUP, the digitizers, Tunable Filter Bank (TFB) Cards, etc upstream of the correlator will not be changed. This suggests that there should not be changes to the basic bandpass filter shapes and bandpass stability due to the upgrade. Cards that will be upgraded include the Station Cards, Station Interface Cards, and Correlator Interface Cards. Properties that will be most affected by the Phase 1 CUP are those that depend critically upon timing/sequencing/communications within the correlator and activities that require a large number of rapid calculations. Essential capabilities that will need careful scrutiny include:

- Delay compensation (coarse and residual delay adjustments)
- Subarrays
- Quantization correction
- Normalization of the correlation products by the autocorrelations
- 90-degree Walsh (Sideband separation technique for Bands 9 & 10) requires complex sequencing that happens within the correlator
- 180-degree Walsh and TWO_LO-offsetting (Bands 3-8); note there should not be any impact to 180-degree Walsh or TWO_LO-offsetting sequences themselves which happen upstream of the correlator, but there could be impact due to the known deficiency of 180-degree Walsh for birdie removal and signal loss for high spectral resolution modes (http://edm.alma.cl/forums/alma/dispatch.cgi/f.iptlevelrel/docProfile/101070/). At the highest spectral resolution the loss may be as much as 7%.
- Online Hanning smoothing
- Online channel averaging (presently, channel averaging by factors of 2, 4, 8, and 16 are supported; for extragalactic projects larger values up to a factor of 64 would be beneficial post-CUP)
- Mixed mode operation: TDM in some basebands and FDM in others
- Multiple spectral windows per baseband, up to 4 per BB, 16 in total (as is commissioned now on the BL correlator) is the minimum requirement
- Integrity of ethernet interface between correlator and CDP nodes (packet losses will result in partially blanked data)
- Verify no change to BDF flagging outcomes (no changes are expected to be necessary to the software heuristics)
- Verify correlation of ACA antennas using the Phase 1 CUP is working properly. The highest spectral resolution CUP modes will not be

reproducible by the ACAC (channel width < 3.8 kHz). It is anticipated that ACA projects needing very high spectral resolution (expected to be few in number) will be observed using the CUP. No special issues are anticipated.
- Verify high time resolution (but low spectral resolution) modes typically used for Solar observing
- ALMA Phasing for VLBI capability (things that may be affected are the phasing interface cards (PICs), the 1 pulse per second signal distributor, and the phasingController software)

We suggest that all of these functions and capabilities must be fully vetted for the start of post-CUP shared-risk PI science except for the ALMA Phasing for VLBI capability which will require a later campaign with specialized expertise onsite. It is also possible that given the commissioning timeframe during a historically poor-weather time of year (Jan-Feb) that 90-degree Walsh for Bands 9/10 will require final science validation after the formal commissioning period ends.

4. Prioritization of Correlator Modes

In addition to the functions and capabilities laid out in Section 3, the CUP offers a wide range of bandwidth/channelization/polarization product combinations. The full set of correlator modes afforded by the Phase 1 CUP is listed in Tables 2a, 3a, and 4a in 2017-12018-ALMA-Upgrade-Specifications.pdf, for single, dual, and full polarization, respectively. There are a daunting 67 modes possible (in principle) with the Phase 1 CUP. We recommend that some of these options deserve higher priority for commissioning than others based on their likely popularity / scientific benefit.

To date only 2x2-bit[1] Nyquist sampling modes have been commissioned on the BL Correlator. For bandwidth < 2 GHz FDM modes, 4x4-bit correlation and Twice Nyquist sampling are also possible and come with 12% and 7% improvements to the spectral sensitivity, respectively. These modes have not been implemented heretofore because these modes come with a decrease in available bandwidth and poorer (larger) spectral resolution, the latter often unpalatable with the already relatively poor spectral resolution afforded by the BL Correlator. It is also notable that the narrowest 31.25 MHz bandwidth mode was never implemented on the BL

[1] The correlation should properly be written as 2-bit x 2-bit, but for simplicity we write 2x2-bit.

Correlator, because it requires Twice Nyquist sampling. The 4x4-bit Nyquist sampling mode has been prioritized for commissioning as the option with the most potential gain, and is currently scheduled for software development and commissioning on the BL Correlator for Cycle 7. It will be very advantageous for the CUP deployment to have this mode already understood and commissioned in advance. Twice Nyquist will continue to be deferred to the future. Thus, for the Phase 1 CUP we suggest that commissioning of the 2x2-bit and 4x4-bit modes receive high priority (i.e. on the critical path to PI observations), with Twice Nyquist sampling and the combination with 4x4-bit being again deferred to the future. This brings the number of modes needing post-CUP validation down to 35 (14, 12, and 9 for single, dual, and full polarization, respectively). It is also the case that the single polarization correlator modes are infrequently utilized on the BL Correlator, and only to obtain higher spectral resolution than otherwise currently possible. With the Phase 1 CUP, we suspect these modes will be even less used, and thus could be commissioned at low priority after an initial basic integrity test.

Additionally, all of the modes will not require the same level of scrutiny - it should be possible to check the extrema carefully (TDM + FDM with max and min bandwidth modes with 2x2 and 4x4-bit correlations) and then quickly validate the others as they will not test or stress the hardware / software in unique ways.

5. Preliminary Deployment and Commissioning Schedule

Table 2 gives a preliminary schedule for the deployment and commissioning of the Phase 1 CUP, focusing on the overall timeline and the interaction of the three key commissioning teams: Engineering, Software, and Science. For this preliminary schedule the activities are broken down by week-long intervals and major activities. We have assumed that the deployment begins on Oct 31, 2022 (week 1), and a goal start for Science Operations to begin on March 13, 2023. We have built in an initial three week period for the deployment and testing of the 1st quadrant at the AOS, followed by a “Go-No-Go” meeting where it will be decided whether to continue on with the full deployment. At this point, in the event that some catastrophic unanticipated problem has been revealed it would be possible to reinstall the 1st quadrant with BL correlator cards and postpone the CUP until a later date. Such an unexpected delay is very unlikely, but a status evaluation at this stage seems wise before proceeding to full deployment.

Table 2: Preliminary Deployment and Commissioning Schedule

Week	Start Date	Main Activities	Who Needs to be Onsite or Available
1	Oct 31, 2022	Deploy 1st quadrant and complete engineering checkout	Engineering team
2	Nov 7, 2022	Validate correlator software using 1st quadrant (all antennas, 1 BB)	Engineering team on call / Software team
3	Nov 14, 2022	Initial limited commissioning checkout / continued software testing (all antennas, 1 BB)	Commissioning team / Software team
4	Nov 21, 2022	Week starts with 1-day Go-No-Go review of progress so far followed by US Thanksgiving	Telecon all parties
5-7	Nov 28, 2022	Deploy remaining 3 quadrants / correlator software testing in parallel	Engineering team / Software team
8	Dec 19, 2022	Continued software integration and testing with all quadrants / begin CSV if possible	Engineering team on call / Software team / Commissioning team on call
9	Dec 26, 2022	Break for Christmas and New Years holidays	None
10-13	Jan 2, 2023	CSV of high priority functionality and modes. Main science commissioning data taking period	Software team on call / Commissioning team
14-15	Jan 30, 2023	February shutdown begins with typical 2 week full AOS power shutdown	Commissioning and if needed, software teams working remotely on acquired data
16-17	Feb 13, 2023	CSV for remaining items	Software team on call / Commissioning team

18-19	Feb 27, 2023	End-2-End tests in prep for Science Operations	Commissioning team / Science Operations team
20	March 13, 2023	Begin shared risk PI observations	Science Operations team

6. Prerequisites

This commissioning plan assumes that several other subsystems are ready for the Phase 1 CUP deployment and commissioning Nov. 1, 2022 including critically:

- Cycle 10 Phase II OT - required to create SBs for commissioning observations. Indeed, if the decision is made to offer a more restricted list of Cycle 10 CUP capabilities than we want to get commissioned it may be necessary to have two Phase II versions - one for CSV purposes and one for the PI P2G (SB preparation) process.
- Cycle 10 scientific software requirements (SSR) code including the Science Observing Script (SOS) - required to use automatic calibrator queries, Tsys spectral specs, etc. Any changes to SSR that are needed to support the new correlator capabilities will need to be ready.
- Downstream data rate handling: Data Capture, TelCal (online calibrations) including full resolution spectral Tsys, NGAS (archive), etc (please see the data rate memo for more information)
- Cycle 10 Pipeline - as early in the Phase 1 CUP commissioning period as possible we plan to employ standard pipeline calibration and imaging to both validate the pipeline and allow commissioning staff to focus attention on the spectral outcomes.

Provided the normal Cycle development timelines are followed for Cycle 10, we expect that the Cycle 10 Phase II OT, SSR, and the pipeline will be ready at the start of CUP deployment Nov 1, 2022 since they normally must be ready for a Oct 1 Cycle-start. In order for the planned and critical pre-deployment software testing on the HIL simulator to take place beginning July 2022, much of the online software development will already need to be available by that date.

7. Criteria for Success

For the process of science validation of the Phase 1 CUP it is important to know what constitutes successful operation of a particular mode or capability. We envision three scenarios:

1. The initial validation of the 1st quadrant can best be done with simple science-like SBs of quasars covering a limited number of use cases to check basic data integrity, labeling, and pipeline processing.
2. For the science validation post-CUP full deployment, we will validate by directly comparing new observations against existing Cycle 9 BL correlator data for modes that are equivalent to (or can be mimicked by) the Phase 1 CUP. For this purpose, Cycle 9 SBs with appropriate characteristics will be compiled in advance of commissioning, for which CSV post-CUP SBs will be created. Wherever possible, choosing observations of non-variable, compact sources will allow a direct comparison of spectral line profiles between the BL and post-CUP data. We will call this ensemble the "Cycle 9 benchmark data".
3. A few modes (full spectral resolution and wide bandwidth) will require science like-SBs that cannot be directly mimicked by the BL correlator, but we will "enhance" suitable projects from the Cycle 9 benchmarks so that there will be some basis for comparison.

8. Science Commissioning Team

Given the tight schedule for the science commissioning and validation, it will be highly desirable to form a relatively small but dedicated (in terms of time allocation) team. We believe that a team composed of the CUP subsystem scientist, 2 experienced JAO System Astronomers, 2 other experienced ALMA commissioning / EOC staff (probably from NA), and 2 SACM/Data Analysts type staff for data reduction support can get the job done. Coordination of the commissioning effort will be done by the subsystem scientist in close collaboration with the commissioning, engineering, and software teams. Ideally the CUP commissioning will be a large fraction of the functional duties for the team members during the commissioning period, and that some effort is available starting in August 2022 for coordination activities to begin (at the level of a weekly telecon). After the formal commissioning period ends March 13, 2023, there will be lower priority items, and items requiring special circumstances (ALMA phasing, longest baselines, possibly Band 9/10 90-deg Walsh if weather has been too poor during commissioning period) remaining to be validated. It is expected that these items will be scheduled for either future mini-campaigns or gradually as part of normal EOC activities, so some lower level of effort from the team to support these activities will also be needed over the course of another 6-months or so.

Acronym glossary

ACA Atacama Compact Array
ACAC Atacama Compact Array Correlator
ALMA Atacama Large Millimeter and submillimeter Array
AOS ALMA Array Operations Site (location of ACA and BLC)
ARC ALMA Regional Center (NA: NRAO-Charlottesville, Europe: ESO-Garching, East Asia: NAOJ-Mitaka)
BB BaseBand (a downconverted RF signal where the lowest frequency is near DC)
BDF Binary Data Flagging
BLC BaseLine Correlator (the ALMA 64-station correlator)
CDP Correlator Data Processor (a cluster of CPUs)
CDR Critical Design Review
CSV Commissioning and Science Verification
CUP Correlator Upgrade Project
DA Data Analyst
EOC Extension of Capabilities
FDM Frequency Division Multiplexing (a BLC mode)
HIL Hardware in the Loop
JAO Joint ALMA Observatory (headquartered in Santiago, Chile)
NAASC North American ALMA Science Center (the NA ARC)
NGAS Next Generation Archive Storage
OT Observing Tool (Phase I = PI proposal submission; Phase II = SB preparation)
P2G Phase II Group (as well as referring to the group who do this work, the process of creating Phase II SBs using the OT is often referred to as “P2G”)
PI Principal Investigator
PIC Phasing Interface Card
PDR Preliminary Design Review
OSF Operations Support Facility (ALMA mid-level activity site)
SACM Science Archive Content Manager (Primary JAO data reduction team)
SB Scheduling Block (XML instructions for an ALMA observation)
SOS Science Observing Script
SSR Science Software Requirements
TDM Time Division Multiplexing (a BLC mode)
TFB Tunable Filter Bank
TelCal (ALMA) Telescope Calibration software
VLBI Very Long Baseline Interferometry