ALMA & ACA Subarraying – Technical Considerations

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Some ability to cross correlate signals from the 12-m antennas of the bilateral ALMA telescope and the four 12-m and twelve 7-m antennas of the Atacama Compact Array is required, although detailed operational and scientific requirements for this capability have not been defined. The purpose of this document is to describe the ALMA baseline technical implementation for (1) the LO distribution scheme, and (2) the data transmission system, in order to drive discussion of the subarraying requirements.

Subarray Requirements

Scientifically speaking, a subarray is defined as any set of antennas observing the same astronomical source with similar FE/BE setups. In the ALMA technical documentation, a subarray is defined as any subset of antennas that is utilizing a common LO reference. The LO reference is developed in the laser synthesizer, so the number of laser synthesizers is equal to the number of subarrays. The ALMA subarray requirements are:

1. From the ALMA Science Requirements: [SCI-90.00.00.00-0390-00]. It shall be possible to have at least four subarrays where the observing frequency and antenna control in each is completely independent of the others.

2. From the ALMA System Requirements: [SCI-420] Independently tunable subarrays=4

In addition, the ALMA System Design Description document mentions some IF, signal processing, and correlator requirements for subarray operation modes. Although unstated, it is generally assumed each of these subarrays can contain any subset of available antennas (i.e. 0-50).

The ACA project book (Feb 17 2004 version) indicates that the ACA will be operated as two subarrays – one containing the four 12-m antennas, the other the twelve 7-m antennas. The ACA correlator treats all 16 ACA antennas equally, i.e. cross correlates all of them, according to ALMA-J documentation.

Baseline Plan

The current ALMA baseline plan calls for 4 sub-arrays for the bilateral array and 2 separate sub-arrays for the ACA. This arrangement is shown in Figure 1.

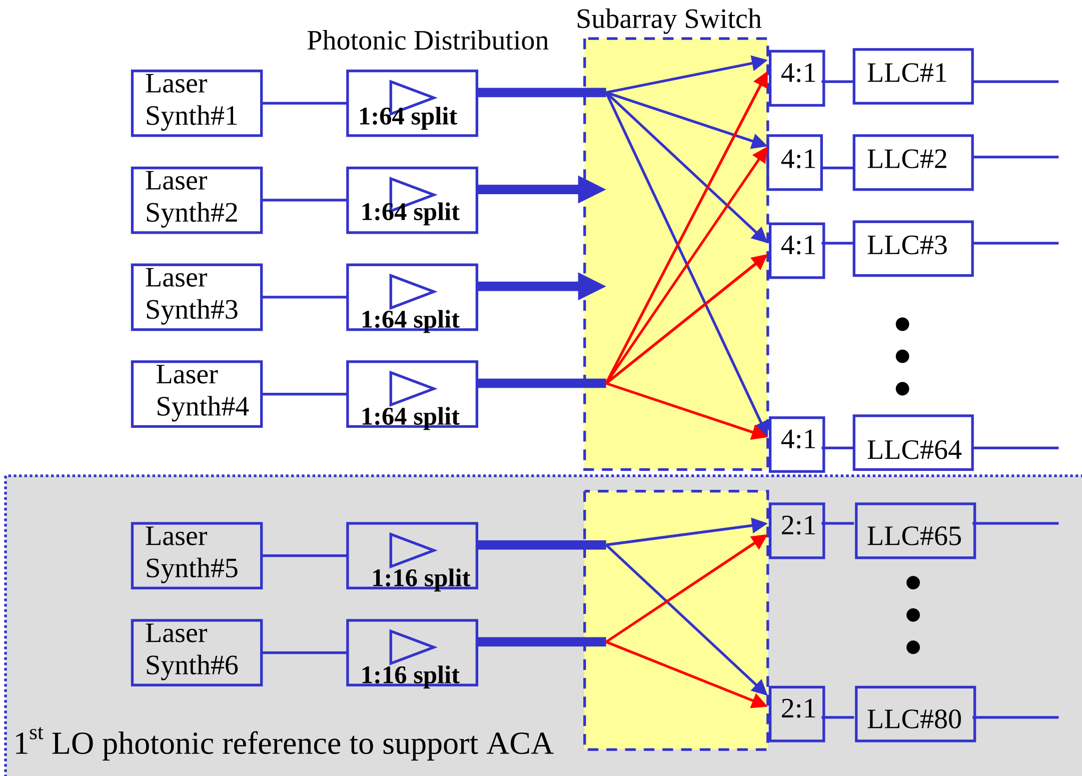

Figure 1 - Baseline Plan for Four Subarrays supporting 64 ALMA-B antennas (or fewer) . Two additional, independent subarrays supporting ACA antennas are shown. In this configuration, there is no cross-correlation that can be implemented betwen the two arrays by electronic switching.

Four laser synthesizers are planned for the bilateral array; two for the ACA. The four bilateral laser synthesizers would tune the 1st LO synthesizers only on the 50 bilateral antennas, and the two ACA laser synthesizers would tune the 1st LO only on the 16 ACA antennas. In this configuration, a bilateral laser synthesizer would be able to tune a 1st LO on any bilateral antenna; and likewise an ACA laser synthesizer would tune a 1st LO on any ACA antenna. A Photonics Distribution and Subarray Switch is planned to direct any LO output to the appropriate antenna. Each Bilateral Photonic Distribution would have one input (one for each laser synthesizer) and 64 outputs. Likewise, each ACA Photonic Distribution would have one input and 16 outputs. The Subarray Switch is 4:1 for the bilateral array and 2:1 for the ACA array. The LO being switched is at light frequencies so that it can be propagated on fiber optics. The optical switch is also operated at optical frequencies, making it a bit more expensive than an electronic switch.

ACA proposal

The ACA group advanced a proposal during a meeting in Garching in March 2005, to change the baseline configuration for LO distribution. The proposal was to add two additional subarrays (as currently planned) but to make them fully integrated with the ALMA-B array. This is shown in Fig. 2. We call this ***array-wide subarraying (AWS)***, as all antennas can now be driven off one laser synthesizer.

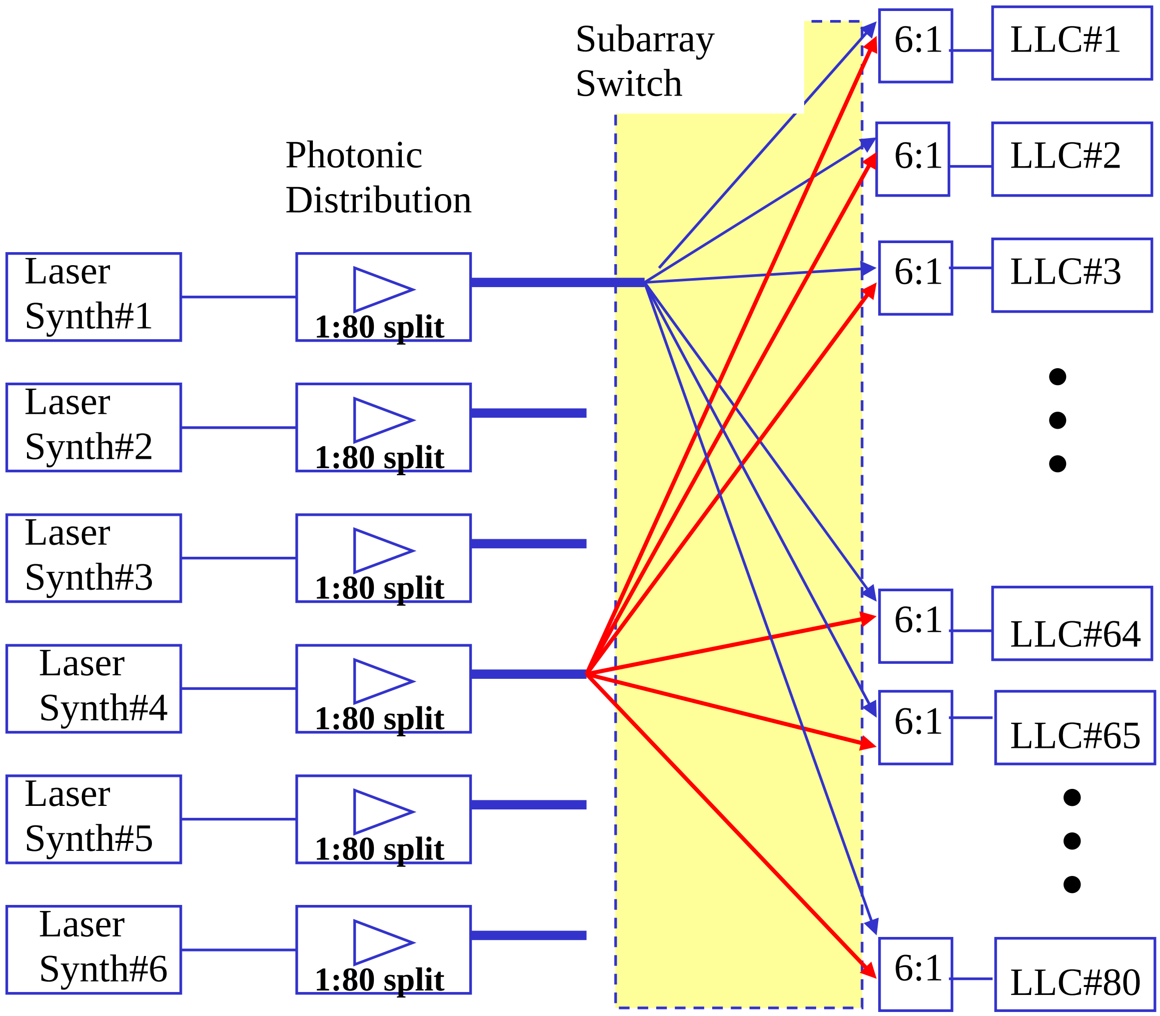

Figure 2 - Six fully integrated subarrays. Joint LO distribution between the two arrays is possible by use of the Subaray Switch.

The photonic distribution described above would now consist of 6*80=480 outputs going into 80 6:1 switches, which will most likely entail greater expense than the previously described plan (although costs not estimated).

Technical Discussion

It would appear that the motivation for AWS is to have flexibility for cross-correlating antennas from both arrays without human intervention at the AOS technical building (that is, remote implementation of subarrays rather than a procedure involving human intervention at the patch panel). However, it must be noted that both the baseline plan and the ACA proposal described above achieve this only for the LO distribution, not for the astronomical signal data path – the returning astronomical data terminates (for both arrays) at the combined patch panel, and therefore implementing AWS would usually involve fiber reconfiguration of the returning data (specifically, connecting the bilateral correlator inputs to the ACA antennas and/or vice versa).

If remote switching of antennas between bilateral and ACA subarrays is envisaged, then both the LO and return data path switching must both be remote. In this case, both the LO and DTS patch panels may need to be replaced or enhanced by complex and expensive optical switches. Replacing the patch panel might reduce the maintenance load for operations (note that replacing the Ethernet communications patch panel with a routing switch has been discussed), however it is unclear if commercially available or affordable switching equipment is able to meet the requirements for the returning data (switching approximately 200 optical inputs to 80 outputs, each 16 Gbps).

The phase stability performance should be similar in both plans. The ALMA and ACA subarrays in the baseline plan could set to the same frequency, but having two different laser synthesizers would mean that short term phase noises are uncorrelated in the signals returning from the two antenna types. This would likely be OK, since the short term phase requirement is already so stringent. Any slow drifts of phase would be at least partially correlated because all of the laser synthesizers are synchronized to the same 5 MHz reference. Any slow drift that occurs after this synchronization would be uncorrelated. This is mostly from the photonic distribution and subarray switch. The slow phase drift specification for these will be at a level that is sufficient for VLBI at 270 GHz. Typical interferometric observing modes incorporating regular phase calibration (e.g. fast switching) should remove any phase drifts associated with the different laser synthesizers.

Amplitude Calibration

A document describing observing and calibration modes for ALMA is in preparation by the Science IPT. One issue that arises is setting a consistent amplitude scale between the two arrays – to do this, regular interferometric observations where the four ACA 12-m antennas (at least) return 16 Gbps digital signals via fiber which are cross correlated with the ALMA 12-m array are required. In addition the four ACA 12-m antennas are planned to provide total-power information to support imaging of the ALMA 12-m array data sets – once again, combined observations to enable consistent flux scale definition are required. Exact requirements on how long, how often etc. are not available. Science IPT has been asked to quickly review this subject; their response is in an accompanying document.

To enable this kind of interaction between the bilateral array and the ACA we suggests the following: a 1:2 split of all 16 returning ACA data fibers in the AOS-TB patch panel, and the permanent routing of these 16 split signals to both the bilateral and ACA correlator. In this way, the ACA signals are always available for cross correlation with the bilateral array on the bilateral correlator, without intervention required at the patch panel. Consequences:

- There will be a 3dB loss in the ACA returning data signals; we suggest this may be within the margin considered for the link, but the additional of optical amplifiers – if needed – should not be expensive.

- In 2012 (as the bilateral array approaches 50 antennas) some of the bilateral correlator input ports allocated to the ACA would need to be used by bilateral antennas. Long before this time it should be possible to define and implement alternative technical solutions to deal with this issue, and (importantly) the detailed scientific and operation requirements will be far better understood at that point after numerous years of use.

- This solution means that both the LO distribution and data return can be flexibly configured remotely to achieve calibration and/or scientific observations. The additional cost (16 1:2 splitters in the patch panel, possibly 16 optical amplifiers for the returning ACA data) seems small when compared to the flexibility gained.

Additional technical solutions have also been identified by BE management, but the suggestion above seems like a good starting point for discussion.

Summary

- The baseline ALMA LO distribution and patch panel plans will likely fulfill the subarraying requirements of the bilateral project and the ACA (operating independently).

- This baseline plan will also enable LO distribution of sufficient quality to enable cross correlation between antennas from the two arrays (involving dedicated reconfiguration of returning data fibers in the AOS-TB, and possibly more phase calibration sections in the observing schedule to remove any short or long term phase drifts between the sets of antennas driven by different synthesizers).

- The ACA proposal for a unified LO distribution completely removes any concerns about these short or long term phase drifts between subarrays driven by different laser synthesizers (baseline plan), but adds an unknown cost and complexity, and does not remove the requirement for human involvement at the patch panel in the AOS TB for the returning data signals.

- To completely remove all need for human intervention in the AOS-TB when cross correlating antennas from the two arrays, the patch panel approach would need to be replaced or supplemented by a large high-performance optical switch. This has not been considered to date, and the cost and feasibility of this is unclear.

- To provide consistent amplitude scales between the two arrays, daily observations on the 12-m array including the ACA antennas are suggested. This can be achieved by inserting a 1:2 split of the ACA 7-m and 12-m signals in the AOS-TB patch panel to enable permanent routing of the signals to the bilateral correlator.