The ACA Correlator

1. Benefit of the proposed Japanese ACA Correlator

The most important point is that the Japanese ACA Correlator always correlates data expressed in 3 bits. This 3-bit correlation greatly reduces the quantization loss inevitable with the 2-bit correlation (as in normal operation modes of the ALMA Baseline Correlator), and makes the ACA with 3-bit correlator 19% more efficient in observing time. This gain in efficiency is important, because this will increase the fraction of ALMA science programs that can use the ACA capability. All ALMA users who observe extended objects will benefit from the increased speed of the ACA, which enables more objects to be imaged with high fidelity.

2. The ACA Correlator and the "enhanced Baseline Correlator (eBLC)"

The eBLC refers to the Baseline Correlator (BLC) with the modified input digital filters as proposed by the correlator team at NRAO (ALMA Memo 441; Escoffier & Webber, November 2002). It is expected that this modification will significantly enhance the spectroscopic capability of the correlator, enabling a full 4-GHz IF band coverage with a high spectral resolution. This eBLC correlates the data in 2 bits, and the sensitivity gain mentioned in point 1 above is not attained. As was reported in the ALMA Board meeting in February, the expectations based on the design studies is that this modification (from BLC to eBLC) is possible without a large impact in cost and schedule of the ALMA construction.

The enhanced spectroscopic capability of eBLC, together with the Japanese ACA Correlator with an intrinsically high spectroscopic power, makes the entire ALMA system a really powerful tool for spectroscopy. There are several important scientific programs that are only possible with this combined power of eBLC and the Japanese ACA Correlator, and many more programs that can be done in much greater efficiency than with the original BLC. Because the Japanese science community has a strong need for such spectroscopic studies, we hope that the eBLC modification will be implemented during the construction phase. NAOJ may consider a contribution to the implementation of eBLC, if the NA/EU Parties think it desirable.

3. Compatibility, Operability and Feasibility

Compatibility:

The data taken with the ACA System are combined with the data from the 64-element array to get the final image of the object. There is no difficulty in combining the data set from the Japanese ACA Correlator and the data set from BLC or eBLC.

The difference in the correlator architecture may introduce some extra work in the software that controls the new correlator from Japan. This work will be done as a Japapnese contribution to the software development for ALMA. As the Japanese correlator hardware directly puts out spectral data, the software work itself is small.

Operability:

The Japanese ACA Correlator is not power-hungry. NAOJ has made a design study for the Second Generation Correlator in collaboration with the European correlator team in 2002. The result shows that a correlator for the 64-element array with the Japanese design would consume about 96 kW even with its high specification. The proposed Japanese ACA correlator for 16 element antennas is much smaller, and the estimated power requirement is about 24kW. For reference, the required power for BLC has been estimated as 127 kW (ALMA Project Book Chapter 10; January 7, 2002).

The different design of the correlator requires that the different set of spare cards need to be prepared in stock. Also the maintenance clew needs to gain extra knowledge to service two different types of machines. Our 20-year experience with our FX correlator in Nobeyama shows that the failure is very scarce. (Exchange of circuit board was only three times during the 20-year operation at Nobeyama.) The issue of the extra cost in operation is a subject for further negotiations.

Technical feasibility:

We have finished the basic design for the ACA correlator, and some technical elements (such as FFT with many spectral channels) has already been demonstrated by our experiments with a test correlator (2002). We are ready to enter the detailed design phase, and the delivery of the ACA correlator in 2007 is technically fully feasible.

Band-10

Scientific Justification

- **Band 10** was rated as *"top priority"* in the ASAC recommendation for the ALMA enhancements.
- The frequency band, **Band 10 (787 – 950 GHz),** is the highest frequency observing band of ALMA, and it offers the following unique science opportunities as summarized in ASAC report (Nov. 2001).
    1. **Band 10** provides the highest angular resolution for a given configuration.
    2. Offers unique science opportunities such as observations of the excited [CI] fine structure line, and red-shifted [CII] emission (for z = 1 to 1.4).
    3. Offers important science in high excitation lines of fundamental molecules such as CO (J=7-6) and HCN(J=9-8).
    4. Provides continuum flux density information at the highest frequency of ALMA, which will be important for accurate determination of the spectral energy distribution (SED) of objects like protostellar cores, protoplanetary disks, protogalaxies and active galactic nuclei.

Implementation Plan of Band-10

The technically key elements of Band-10 cartridge are new SIS Junction and cartridge itself. We have already settled a load map toward the implementation, which is in a way that the associated technical and schedule risks are minimized as much as possible. It is assured that the implementation during our construction phase is quite feasible.

- [SIS Junction]: NAOJ consolidated a plan for the development of two types of SIS junction, and the technology selection and fabrication of Band-10 junction. NAOJ constructed new facility for the Junction fabrication at Mitaka area and have started fabricating NbTiN Junction. The other group in CRL (Communication Research Laboratory in Japan) has been developing NbN Junction in collaboration with NAOJ, and the receiver noise temperature was successfully measured to be about 800 K in recent preliminary experiments. We had scheduled PDR for Band-10 SIS junction in March 2005 to review the junction performance for these two junctions, the technology selection process, and the fabrication plan.

- [Cartridges]: We have already designed the optics of Band-10 cartridge (ALMA memo No.458) and developed its prototype (pre-EM) using Nb-based SIS junction. The prototype is being tested on ASTE 10m telescope in terms of engineering performances and we succeeded in the spectroscopic observations of CO (J=7-6) with the prototype (see figure 1). We scheduled the production of engineering model for Band-10 cartridge using NbTiN (or NbN) junction in 2004, which is based on the prototype and feedback from such engineering tests. Pre-production and production are planned to be started from 2008 and 2010, after the qualifications of EM and the pre-production model, respectively.

Value

For the implementation of Band-10 cartridges, we need to fabricate the new type of SIS Junction such as NbTiN or NbN Junction and cooled multiplier as a key part for LO. These parts are expected to be costly compared with costs scaled from those for Band-9, considering the effort needed for introducing such new technology to Band-10. We should, therefore, have the non-linear escalation of Value from Band-9 to Band-10.

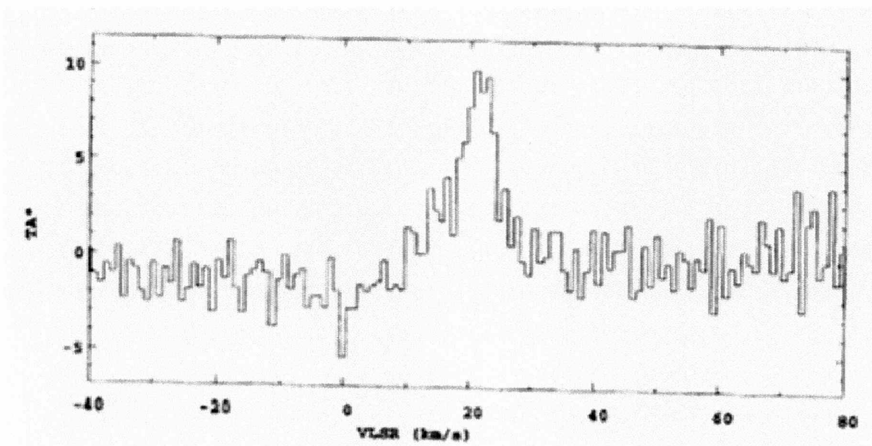

Figure 1. CO(J=7-6) spectrum at 807 GHz obtained toward a star forming region, M17, with a band-10 prototype cartridge on ASTE 10-m telescope (on-source integration time is 70 seconds).

An implementation plan of the "Photonic Hybrid" option for the ALMA 1st local oscillator

1. A need for "Photonic Hybrid" option in the submillimeter bands

The large number of frequency multiplications in the baseline design may limit the sensitivity (due to coherence loss) and phase stability especially for Band 10. NAOJ proposes to adopt "Photonic Hybrid" option in the 1st LO to improve the performance and also to retain expandability to the future "Photonic Direct" option for all frequency bands which has been considered to be an ideal LO system for ALMA. The "Photonic Hybrid" option includes the "Photonic Direct" option at lower frequencies in which frequency multipliers are not necessary.

2. Implementation Plan (see Fig. 1.)

- The total LO system is divided into two parts; central LO system and antenna-based LO system. In the NAOJ proposal, antenna-based LO system includes a two-laser system followed by Direct Photonic Drivers (DPD) shown in Fig. 2 [ALMA memo 435] and corresponding power amplifiers/multipliers. The central LO part could be the same as the baseline design.
- Two-laser system is used to generate sufficient optical power to drive photomixers instead of using optical amplifier. Fringe tracking and phase switching can be incorporated by using DDS (Direct Digital Synthesizer) in PLL (Phase Lock Loop) control of one of the lasers. Therefore, this configuration could be fully compatible with the baseline design in its computer control. It is possible to use the system in common for both the baseline ALMA and the ACA System .

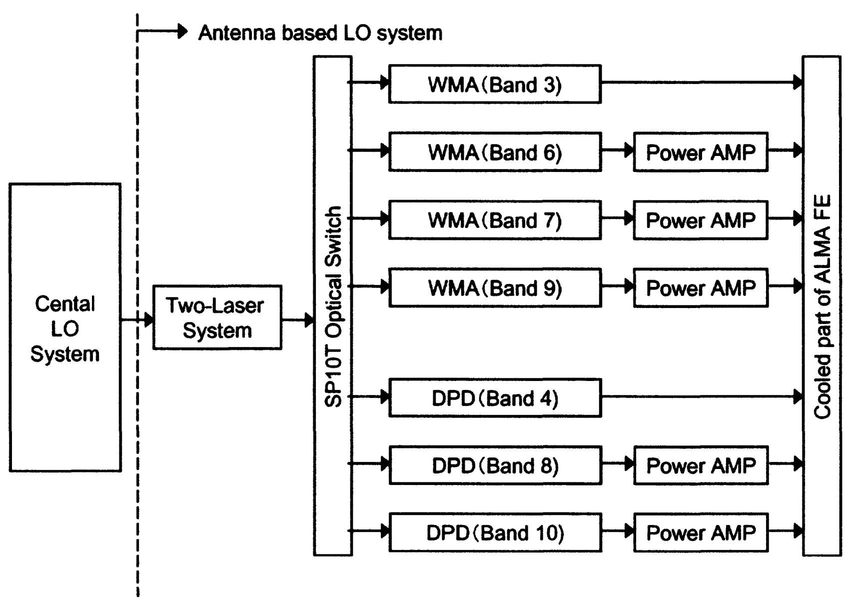

Figure. 1. Antenna based LO system in the case of a combination of DPD and WMA.

- The antenna-based LO system requires only one two-laser system for all frequency bands and thus the cost of the "Photonic Hybrid" option is the same or even lower compared with installing many Warm Multiplier Assemblies (WMA) for all bands. It is desirable to unify the LO system for all bands. However, in order to minimize the impact on the baseline ALMA, the 1st LO part of the antenna-based LO system could be a combination of DPD and WMA as indicated in Fig. 1.

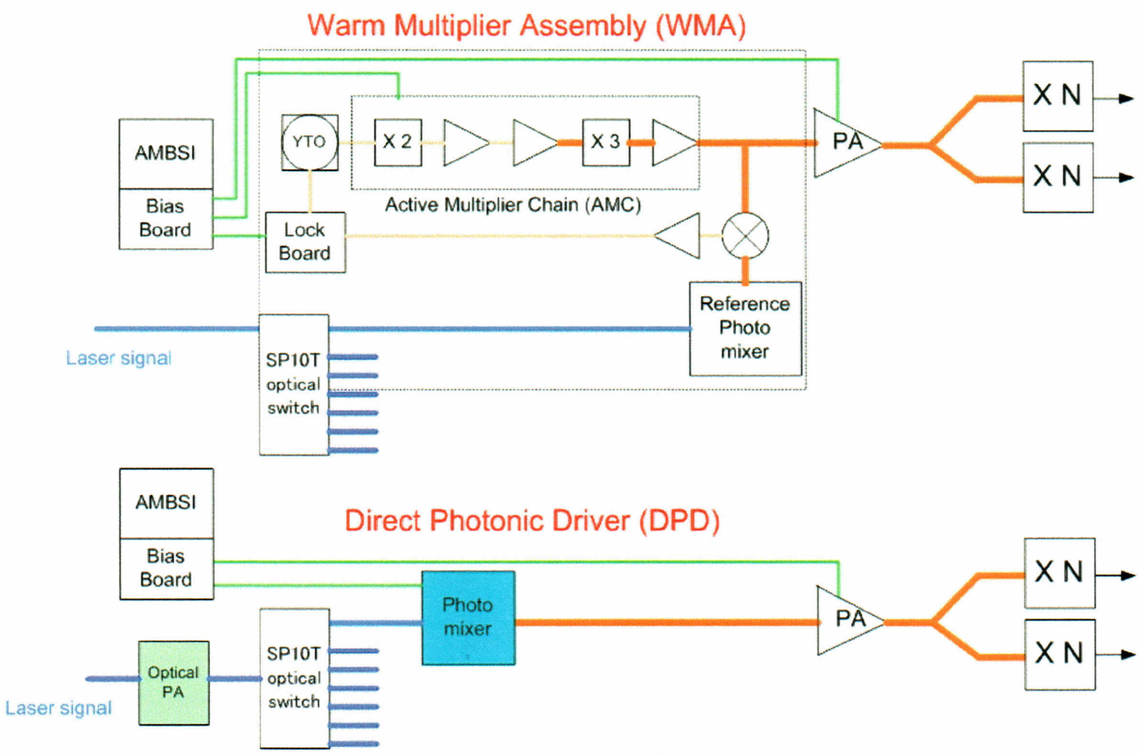

Figure 2. Comparison of the Warm Multiplier Assembly (WMA) and the Direct Photonic Driver (DPD).

3. Current status

- It was demonstrated that the photonic LO with a UTC-PD photomixer at 100GHz band can meet the ALMA specifications. A similar photomixer is being developed for 350GHz in aiming a "Photonic Direct" option up to 350GHz.
- The performances of a "Photonic Hybrid" LO consisting of a laser system, a W-band photomixer, a W-band power amplifier, and frequency multipliers was demonstrated to be sufficiently powerful to pump an SIS mixer at 490 GHz [ALMA memo 449]. The noise temperature measured at 490 GHz was 135 K, which was comparable with that pumped by Gunn oscillator and multipliers.
- A prototype of the two-laser system is developed and is being evaluated.