An ALMA Beamformer for VLBI and Phased Array Science

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Abstract

Phasing all of the 12m ALMA dishes together will enable the array to function as a single telescope with an effective aperture of ~ 85m diameter. In conjunction with other (sub)mm wavelength facilities, a phased ALMA will serve as the high sensitivity anchor for (sub)mm VLBI arrays capable of resolving super massive black holes on Schwarzschild radius scales. Current (sub)mm VLBI arrays have already detected time variable Schwarzschild radius scale structure in Sgr A*, the presumed $\sim 4\times10^6$ $M_{\rm sun}$ black hole at the center of the Milky Way [1,2]. Harnessing the full collecting area of ALMA will transform short wavelength VLBI arrays by doubling angular resolutions and improving sensitivity by an order of magnitude. At 1.3mm and 0.8mm wavelength, VLBI arrays including a phased ALMA will be able to time-resolve changing structures at the event horizon of Sgr A*, search for periodic signatures of orbiting hot-spots in the innermost accretion flow, and study the jet launching region of the M87 jet with Schwarzschild radius resolution. A phased ALMA will also be a sensitive pulsar/transient observatory with the ability to search for shallow spectrum pulsars towards the Galactic Center and study known high frequency magnetars with sub-ns time resolution. This presentation will focus on the technical considerations of constructing and integrating a phased-array processor into the ALMA system. A detailed plan and design that conforms to all ALMA requirements and the construction schedule will be described. This design will enable initial VLBI and phased array science projects to be carried out with ALMA within 3 years.

1 Design Overview of the ALMA Beamformer

Phasing of the ALMA system is possible on target sources due to the fact that the ALMA correlator produces $(n)(n-1)/2$ baseline phases but only $(n-1)$ antenna phase corrections need to be specified to allow coherent summing of all (n) antenna signals. If we assume the full 8 GHz ALMA bandwidth and both polarizations, observations of Sgr A* (3 Jy at 230 GHz) will result in a signal-to-noise for each antenna phase of ~ 850 if $n = 25$ antennas are used in the phasing solution. This corresponds to rms variations in antenna phase corrections of less than $0.1°$, with negligible phasing coherence losses for target sources stronger than ~ 100 mJy at 230 GHz.

Phased ALMA has always been recognized as a desired functionality, and most of the necessary architecture to construct a phased vector sum of the antenna signals already exists within the ALMA Correlator system [3], as shown in Figure 1. The phasing loop starts in the Station Electronics Block of the ALMA correlator at the Tunable Filter Bank (TFB) cards, which segments the IF into 62.5 MHz slices. The TFB card can apply the phase shift (computed later in the loop) for each antenna to produce the vector sum as well as a digital gain for optimum weighting. The

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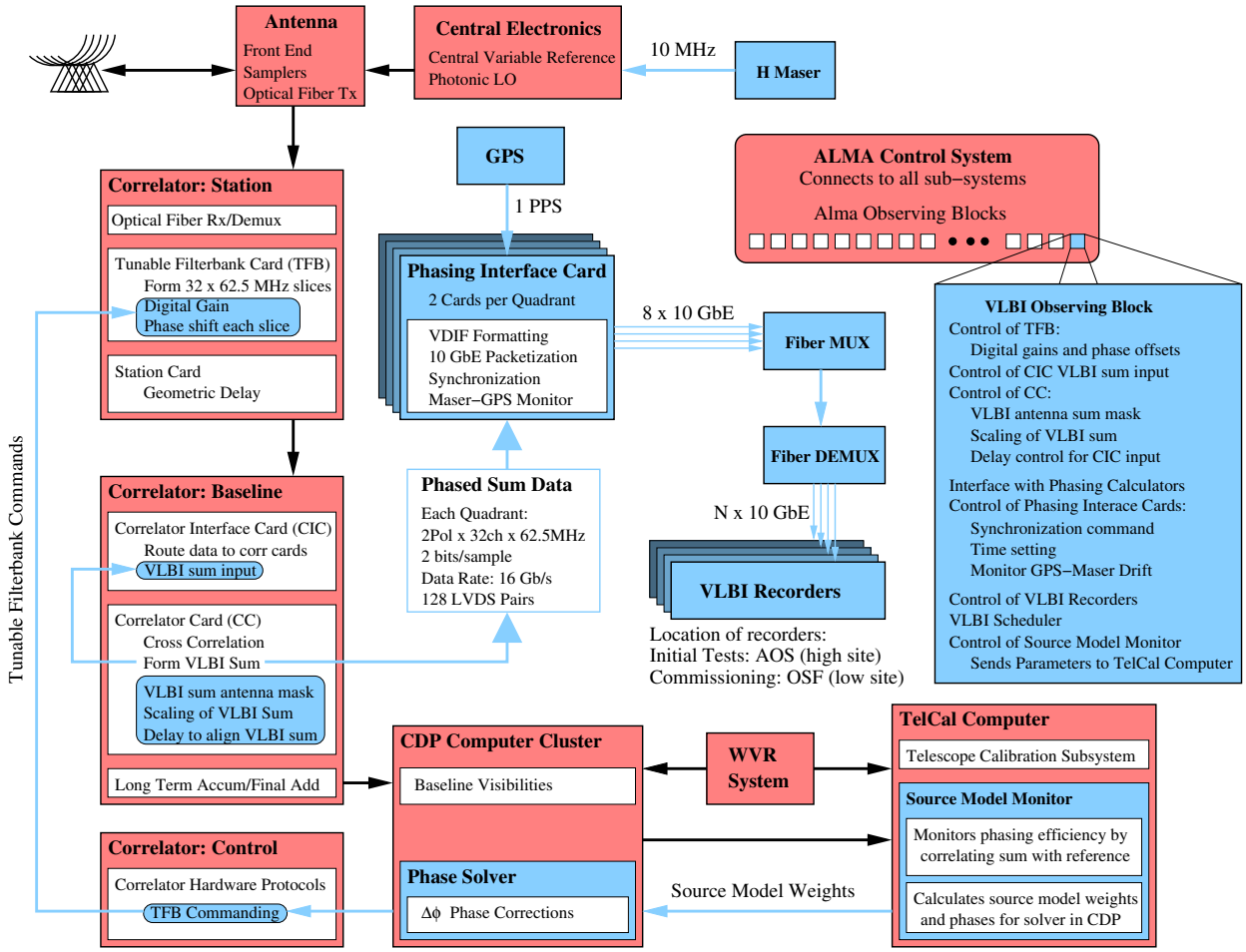

Figure 1: Functional block diagram of a proposed phasing system for ALMA VLBI operations. Existing components are shown in orange; new components required for a complete phasing system are shown in blue.

62.5 MHz slices enter the Baseline Electronics Block, where the Correlator Interface Card (CIC) routes the data to Correlator Cards (CC). The CC's already contain firmware logic to produce the vector sum over all antennas using a pre-set antenna mask. Each sum is scaled to 2 bits to ensure proper state counts and routed to two destinations. The summed signals are fed back to the CIC to correlate against a single comparison antenna to monitor phasing efficiency. The summed signals are also routed to Phasing Interface Cards (PIC), where the data are formatted for VLBI and sent via fiber to the Operations Science Facility for recording.

Correlated baseline data enter the Correlator Data Processor (CDP), where the phase solver solves for the residual antenna phases for the TFB cards to apply, closing the loop. The phase solver interfaces with the ALMA TelCal computer to obtain a source model for sources with structure on ALMA scales (e.g., Sgr A* and M87). For faint sources, the TelCal computer can also apply phase corrections from water vapor radiometry (to extend the atmospheric coherence time) and/or fast-switching to a nearby calibrator (especially at longer wavelengths).

An international technical team has been assembled from numerous institutes, including MIT Haystack Observatory, NRAO, ASIAA, MPIfR, NAOJ, U. Concepción and U. Bordeaux. The proposed system has been designed in consultation with ALMA technical teams in order to minimize impact on ALMA during the ALMA construction phase. It is anticipated that the complete ALMA phasing system can be completed in four years, with commissioning tests and early science observations possible before the end of the project.

2 References

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