Equipping the Submillimeter Array for VLBI

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Abstract

VLBI observations at a wavelength of 1.3 mm have confirmed structure in SgrA* on scales of just a few Schwarzschild radii [1]. More sensitive observations in the next few years, if sufficiently sensitive, could confirm a tentative detection of time variable structures [2] predicted by models of flaring activity in SgrA*. A key improvement in sensitivity is provided by the deployment and commissioning of a VLBI phased array processor at the Submillimeter Array (SMA) on Mauna Kea. This new instrument enables the SMA and the neighboring single dish submillimeter telescopes, CSO and JCMT, to contribute to future VLBI observations with all their collecting area.

1 Introduction

Over the next decade, our group proposes to combine existing and planned mm/submm facilities into a high sensitivity, high angular resolution "Event Horizon Telescope" that will bring us as close to the edge of black hole as we will ever come. This effort will include development and deployment of submm dual polarization receivers, highly stable frequency standards to enable VLBI at 230-450GHz, higher bandwidth VLBI backends and recorders, as well as commissioning of new submm VLBI sites. The instrument is called The Event Horizon Telescope (EHT). The Submillimeter Array is expected to make a key contribution to the EHT as the center of phased array operations on Mauna Kea. We describe the development of a VLBI processor which enables the SMA to function, together with CSO and JCMT, as a high sensitivity VLBI station on Mauna Kea.

2 Technical developments

The SMA VLBI Processor was developed with the aid of hardware, libraries and tools developed by the Collaboration for Astronomy Signal Processing and Electronics Research (CASPER) at UC Berkeley. The sampling, delay correction and summing are implemented using CASPER iADC and iBOB FPGA hardware. Delay correction is accomplished using a vernier arrangement of coarse, fine, and superfine delays, the latter utilizing an interpolating FIR filter. Each iBOB board, equipped with two iADCs, can accept four 500 MHz bandwidth analog inputs, so two are needed to sample eight channels. The coherent sum of each set of four antennas is communicated via 10 Gbit s\textsuperscript{-1} serial links to a downstream iBOB processor board where the two groups are summed coherently to form the eight-antenna signal needed for VLBI. This board also houses a customized version of the Mark5b Digital Back End design, and the data are routed directly to the Mark5b+ data storage terminal. A background calibration correlator provides systematic corrections to delay and phase dynamically in real time. The calibration correlator is implemented on the Berkeley Emulation Engine 2 (BEE2).

Figure 1 shows a schematic of the eight-antenna SMA VLBI phased array processor based on the CASPER technology. The natural capabilities of the hardware lead to an elegant eight-antenna design, with the extension to ten antennas leading to quite inconvenient structures. For this first implementation of the phased array system, if either the CSO or the JCMT are included in the eight antenna sum, a single SMA antenna will be dropped for each.
We plan to add additional stations to the submillimeter VLBI array over the next decade to assemble an “Event Horizon Telescope” (EHT) bringing a variety of existing submillimeter facilities, as well as those under construction into our VLBI array. As part of the EHT effort, a similar phased array system is being deployed at the Combined Array for Research in Millimeter Astronomy (CARMA), with elements of the design developed collaboratively. It is possible that a similar instrument may be deployed at the Plateau de Bure Interferometer. We expect the experience gained in antenna phasing will help the development of an ALMA phased array system, though such a system will be quite different technically.

4 Testing and results

We have developed a convenient technique called “local VLBI” to test the system without the complications of true VLBI involving another station with maser locked references. This technique phases up a sub-array of the SMA, with one SMA antenna designated as the “comparison” antenna. This antenna is tuned as if it were a stand-alone VLBI station, with a slight tuning offset to simulate the fast fringe rate of a long VLBI station. The comparison antenna is equipped with a standard VLBI Digital Back End (DBE), which stores data on a Mark5B+ data recorders. We correlate the phased array VLBI data with comparison antenna data and compare the fringe amplitude against that expected given known factors like antenna sensitivity, system temperature, source strength, etc. The number of antennas added into the phased array sum is varied to confirm the phasing efficiency is as expected.

Figure 2 shows detected fringe amplitudes against number of antennas phased. The data was taken on the quasar 3C454.3 in November 2009. Since only one side of the baseline is phased up, the fringe amplitude varies as the square root of the number of antennas in the phased array sum. Due to latency instability in one of the 10 Gbit s⁻¹ serial links the phaseup is limited to four antennas. This issue has now been resolved.
In April 2010 we ran phased array tests including a long baseline to the SMTO on Mount Graham in Arizona, in addition to the comparison antenna. A similar relationship between fringe amplitude and number of antennas in the sum was observed.

5 Conclusion

The SMA VLBI processor is a pioneering wideband digital approach to converting submillimeter interferometers to be standalone VLBI stations. The instrument both enables the SMA to make a significant contribution to sensitive submillimeter VLBI campaigns, and informs VLBI conversion efforts at other sub-millimeter interferometers.

6 Acknowledgments

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7 References
