Stable Time and Frequency Transfer in the Atacama Large Millimeter Array

William Shillue,
Central Development Laboratory, National Radio Astronomy Observatory, Charlottesville, VA, USA
E-mail: bshillue@nrao.edu

The ALMA (Atacama Large Millimeter Array) is a single radio telescope of advanced design, composed of sixty-six high-precision 12-meter antennas located on the Chajnantor plateau in the Atacama Desert of Northern Chile. The plateau is at an elevation of 5,000 meters which gives a high degree of radio transparency due to low atmospheric water vapor. The telescope combines radio waves from all antennas to image the sky at frequencies between 30-950 GHz. To construct a high-fidelity image, exceptional stability is needed not just in the atmosphere but also the radio antenna structure, the millimeter wave radio receivers, and especially the first local oscillator in the receiver. Additionally, all receivers must be mutually coherent which requires a high-precision central timing and distribution system. A fiber optic transmission system sends timing and local oscillator (LO) signals to each telescope, with the central building and radio telescopes arranged as a hub with spokes. The maximum distance to an antenna is 15 km, and the antennas are movable to allow scientists to scale the array size to fit the science objective.

This paper will describe the ALMA LO and timing system. The receiver outputs are digitized and sent from the telescopes to the central building by optical fiber, where they are combined in a massive digital correlator, thus forming a multiple element interferometer. In order to construct high fidelity images, the entire signal path and the local oscillators must be highly stable. The specification for the phase stability level was determined so that contributions from the engineered elements: telescope, receivers, and local oscillators, would be less than the atmosphere under the best observing conditions. The specifications were very challenging, especially for the 1st LO which needed to provide stable phase (22 fsec RMS) for frequencies up to 938 GHz over a 15 km distance. The engineering of the system to meet this requirement will be described which consisted of a centrally based dual-laser heterodyne with low phase-noise (Laser synthesizer) transmitted by optical fiber which is used to phase-lock an antenna-based oscillator-multiplier frequency chain. Additionally, the fiber and many components in the path are stabilized by a round-trip phase-correction system that uses a stable laser reference (master laser).

Fig. 1: Four of the ALMA radio telescopes on the Chajnantor plateau in Chile (credit: ALMA (ESO/NAOJ/NRAO))

The ALMA radio telescope has been in scientific use since 2011. Recent results including instrumental perfomance over long baselines will be included. Also detailed will be the addition, in 2014, of further synchronization hardware which now allows ALMA to operate as a single telescope in a global millimeter-wave radio array for testing theories of general relativity and providing unprecedented imaging of black holes.

[1] J.F. Cliche, B. Shillue, "Precision timing control for radioastronomy: maintaining femtosecond synchronization in the Atacama Large Millimeter Array," IEEE Control System, Vol. 26, No. 1, pp. 19-26, 2006

[2] W. Shillue, et al, "A High-Precision Tunable Millimeter-Wave Photonic LO Reference for the ALMA Telescope," 2013 International Microwave Symposium Digest, Jun 2-7, 2013