EVLA LO Phase Stability and the Measurement Resolution Limits of the Round-Trip Phase Meter

Keith Morris[1], Steven Durand[1], Jim Jackson[1]

[1]National Radio Astronomy Observatory, 1003 Lopezville Road, Socorro New Mexico USA 87801, 505.835.7000, kmorris@nrao.edu, sdurand@nrao.edu, jjackson@nrao.edu

Abstract

The EVLA radio telescope requires a Round-Trip Phase (RTP) measurement system in order to produce phase-stable science. Phase delays in the fibers distributing the LO to each antenna are measured and used by the correlator to correct each baseline in the array. The phase stability specification for LO distribution requires that the system phase is stable to within 1.4ps over a 30-minute period, and that phase measurements have an uncertainty of less than 33fs over ten seconds. The measurement uncertainty of the RTP meter is approximately 35fs with a measurement repeatability error of 50fs. This paper provides an analysis of this measurement technique.

1. Introduction

The Very Large Array (VLA), located on the Plains of San Agustin fifty miles west of Socorro, New Mexico, consists of twenty-seven 25-meter parabolic antennas configured in the shape of a 35 km diameter "Y". A project to enhance the VLA was started in 2000, the Expanded Very Large Array (EVLA) project. The goal of the EVLA project is to increase the overall system bandwidth by a factor of 80 and to increase the sensitivity and spatial resolution of the present VLA [1]. The local oscillator and reference system has been in continuous operation since November 2003, allowing substantial time for performance testing of the central and antenna electronics and the fiber optic Local Oscillator (LO) transmission system.

The round trip phase (RTP) system has been one of the last systems to be added to the array. This system monitors the LO phase at the antennas and is used to compensate for the temperature- and stress-induced phase changes in the fiber optic cables. The RTP system is designed to continuously monitor each of the 27 antennas separately and can resolve 35fs changes in the phase of the 512MHz LO signal.

Phase stability is the key for proper operation of any interferometer. Ideally, all phase instabilities would arise only from atmospheric sources and be the only telescope performance limiting parameter. Phase errors, in the form of noise ($t < 1$ second) and drift ($t > 1$ second), can arise from anywhere in the system, and errors arising from atmospheric instability are indistinguishable from those arising from systematics. This paper focuses on the extent the fiber optic LO distribution effects phase stability, and the ability of the Round-Trip Phase Meter to measure those effects. The goal is to limit system-wide phase change to 18^{o} at any sky frequency over 30 minutes, and limit deviation from phase linearity to 1.4ps. The sensitivity of the array should be limited by atmospheric instability, and not systematic phase instability.

2. Local Oscillator System

The EVLA local oscillator system consists of the central LO and the antenna LO, Figure 1. The central LO produces a reference signal (512MHz) that is common to all antennas and is phase locked to a hydrogen maser. This common LO signal is distributed to all 27 antennas via a system of lasers, fiber optic cables, and photodiodes. A second oscillator located in the antenna is phase locked to this reference.

The fiber optic LO distribution system is a major source of phase instabilities that can not be thermally stabilized or placed in an electrical servo loop. These instabilities are introduced by temperature variations acting on the fiber, by mechanical stress on the fiber during antenna movement, and by drift in optical and electronic components. The purpose of the EVLA fiber optic RTP system is to measure the effect these instabilities have on LO phase.

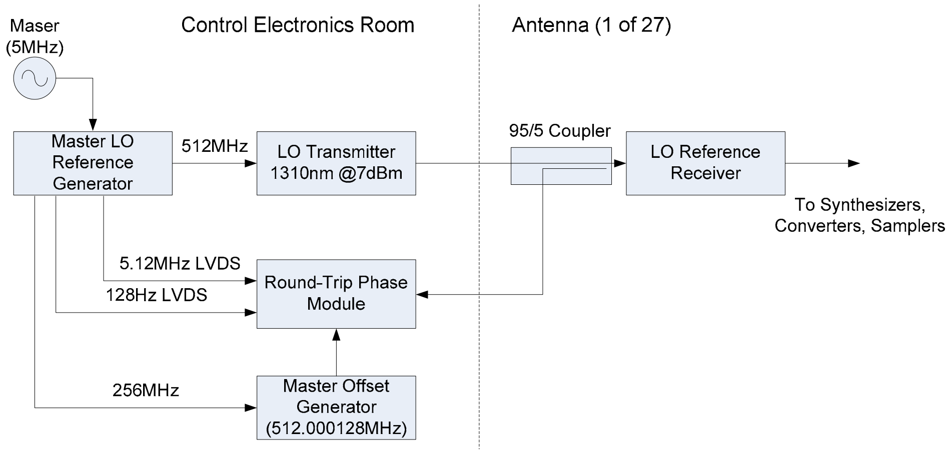

Figure 1, Block Diagram of the EVLA Fiber Optic LO Distribution System

The present RTP system uses a two-fiber approach. The first fiber is used to transmit the LO (512MHz) to the antenna. A portion of the optical 512MHz is returned by a second fiber to the central system through a fused-fiber optical splitter. This returned 512 MHz signal is used to determine the RTP measurement, as in Figure 2. This approach assumes that the two fibers, which are in the same jacketed bundle, have identical temperature coefficients and are exposed to identical temperature and stress changes. In addition, it is assumed that asymmetrical Brillouin scattering and other non-linear effects in the fiber are insignificant. If these assumptions are true, then any measured phase change made in the array center can be divided by 2 to estimate the phase change at each antenna.

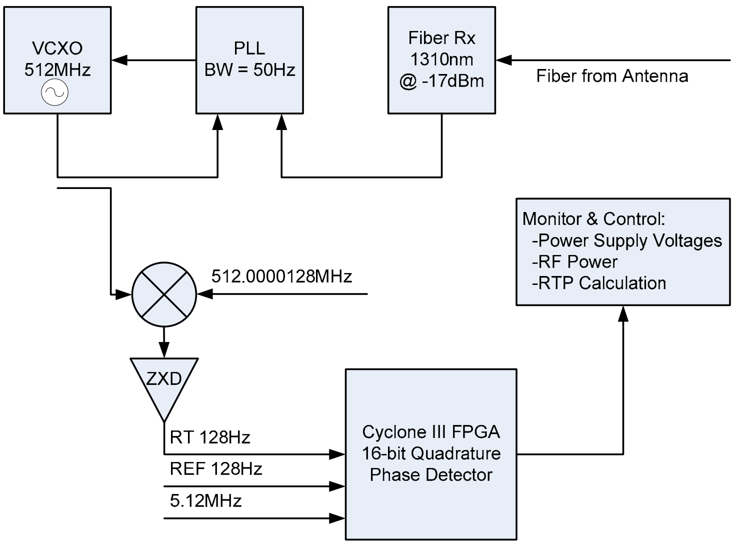

Figure 2. Block diagram of the EVLA Round Trip Phase Meter

3. Typical Round Trip Phase Data

In the EVLA, the round trip phase is recorded once per ten seconds. These data are the result of a 1280-point unweighted average and are reported to the correlator via the array monitor and control system, and the correction is applied in the correlation process in the form of antenna delays. The fiber-induced phase deviation can be measured by the round trip phase system. Figure 3 shows 120 hours of typical round trip phase data. The total phase varied about +/- 35ps daily about an arbitrary reference and, at this time of year, drifts about 25ps per day. It shows the effects of both the diurnal temperature of the unburied fiber and the seasonal temperature effects of the buried fiber.

4. Validity of the Two Fiber Approach

To test the validity of the two fiber approach, a third fiber was placed in parallel with the return fiber on antenna 17 and was monitored by a second RTP meter. Antenna 17 was located 4.6Km from the center of the array during this test. The two RTP meters are labeled ea17 and ea19, figure 3. The assumption is the difference between the two return fibers is an indication of the difference between the transmitting and receiving fibers. If there are large differences between two return paths in the same jacket, then it can be assumed that there are large differences between the transmitting and receiving fibers, which are also in the same jacket. Laboratory analyses of the meter-to-meter repeatability show measurement uncertainty of less than 50fs so it can be assumed that the differences between ea17 and ea19 are fiber induced. Figures 4 and 5 show the differences between the two nominally identical meters monitoring a single outbound fiber and two independent return fibers. The results of this test indicate that the measured phase difference of the two return fibers has a peak deviation of 1.3ps (18.7° at 40GHz) over any 30-minute period.

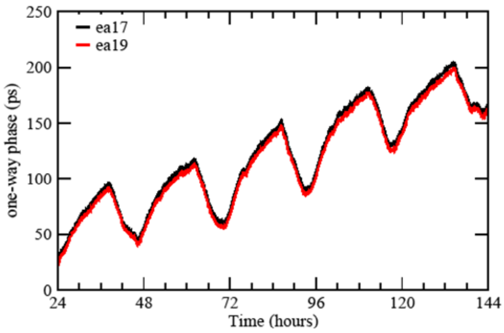

Figure 3. Typical RTP measurements, showing diurnal temperature effects on LO delay and the seasonal effects of the buried fiber

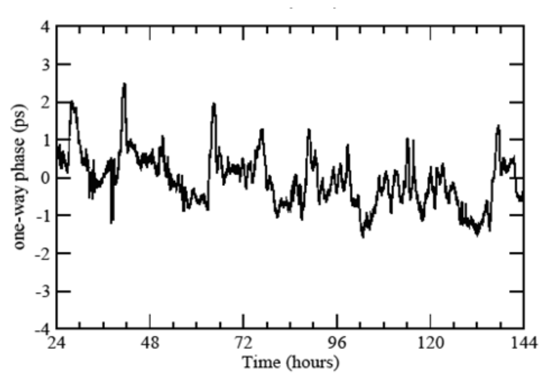

Figure 4. Field measurement of round-trip phase error for the interval shown in Figure 3

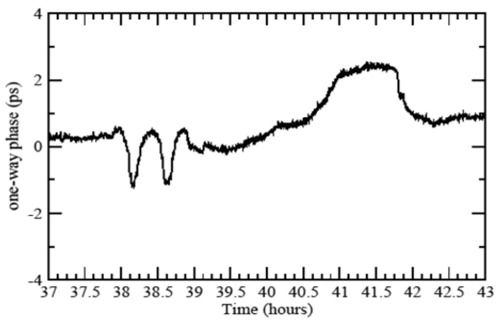

Figure 5. Detail of the plot of the second spike in figure 4. Peak deviation over any 30-minute period is approximately 1.3ps.

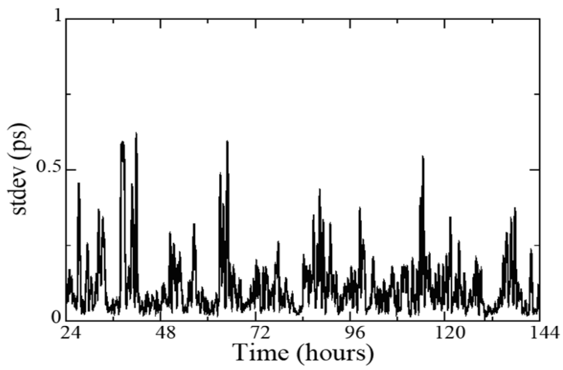

Figure 6: 30-minute standard deviation of the two-fiber difference.

The 30 minute standard deviation of the data in figure 4 is shown in figure 6. These data indicate that the uncompensated difference of the fibers for the worst 30 minute intervals to be about 0.6ps (8.6° at 40GHz). If the transmit fiber and the original return fiber had the same performance as the two return fibers in this test then these data would indicate that the two fiber approach has a accuracy limitation of about 9° at 40 GHz. This is comparable to the EVLA design specification which requires an accuracy of 18° at any sky frequency.

Thirty minutes is the longest likely interval between astronomical calibrations; the correlator interpolates linearly between phase calibrations and adds an appropriate delay to the correlation every 10 seconds. Therefore, the specification includes a maximum deviation from phase linearity, which is 1.4ps. The data in Figure 7 is sampled every 30-minutes and linearly interpolated between samples. This is subtracted from the measured data, and the residuals are shown in Figure 8, which shows peak deviation of 1.2ps.

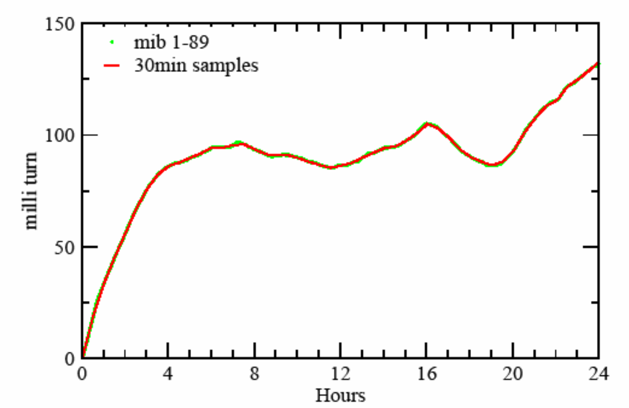

Figure 7. RTP measurement sampled every 30 minutes and linearly interpolated between samples.

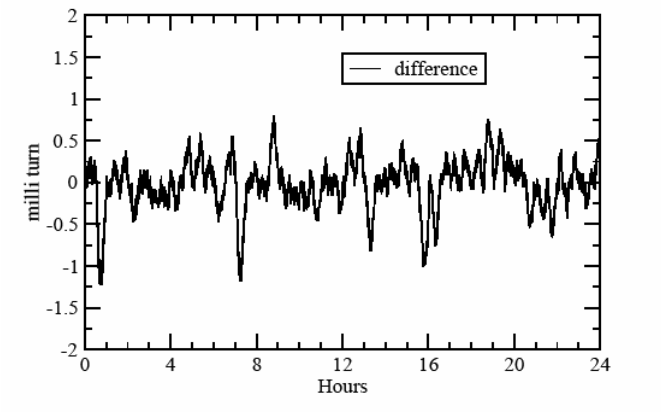

Figure 8. Deviation from 30-minute piecewise-linear reconstruction of RTP measurement

5. Conclusion

A round trip phase measurement system has been developed to measure the phase stability of the EVLA LO distribution system. The measurement system has a meter-to-meter repeatability uncertainty of 50fs and a single-meter uncertainty of approximately 35fs.

The measurement system was used to characterize the performance of the fiber optic LO distribution system. The measurements indicate that the phase performance of the installed LO system marginally meets the EVLA design goals of a linear phase slope of less than 18^{o} over 30 minutes at any sky frequency, and a deviation of less than 1.4ps about a linear slope calibration.

These preliminary results indicate that the installed LO hardware will produce an interferometer in which atmospheric variations are the dominant phase performance-limiting parameter. The EVLA LO system is well-designed and meets the required coherence and phase stability specifications. This indicates that, as-built, the EVLA telescope will meet the proposed performance goals of increased sensitivity, spectral resolution and frequency.

6. Acknowledgments

The authors like to express gratitude to Vivek Dhawan for his guidance and technical support during this development. The authors also like to express gratitude for the contributions of the following individuals: Barry Clark, Matt Luce, Hichem Ben-Frej, and Mike Revnell.

7. References

1. Fomalont, E.B. and Perley, R. A., *Lecture 5: Calibration and Editing, Synthesis Imaging in Radio Astronomy II*, Edited by G.B. Taylor, C. L. Carilli, and R. A. Perley, San Francisco: Astronomical Society of the Pacific, 1999

2. Thompson, A. R., Moran, James M., and Swenson, George W. Jr., *Interferometry and Synthesis in Radio Astronomy*, New York: John Wiley & Sons, 1986

3. Bagri, D., *VLA Electronics Memorandum No. 169: 600MHz Round Trip Phase Correction a nd Effect of Waveguide Ripple and Non-Reciprocity of Path on IF Phase*, March 1978

4. Thompson, A.R., *VLA Electronics Memorandum No. 202: Directional Frequency Offsets in Round-Trip Phase-Measuring Schemes, with Application to the IRAM Array and the VLA*, March 1981