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The NASA VLBI2010 Proof-of-concept Demonstration and Future Plans

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Abstract

The next generation geodetic VLBI instrument is being developed with a goal of 1 mm position uncertainty in twenty-four hours. We have implemented a proof-of-concept system for a possible VLBI2010 signal chain, from feed through recorder, on the Westford (Massachusetts, USA) 18-m and MV-3 (Maryland, USA) 5-m antennas. Data have been obtained in four 512 MHz bands spanning the range 3.5 to 11 GHz to investigate the sensitivity and phase delay capability of the system. Using a new phase cal design, the phases have been aligned across four bands spanning 2 GHz with an RMS deviation of approximately eight degrees. Several components of the system will be improved for the prototype version of VLBI2010, including the feed, digital backend, and recorder, and these will be installed on a 12-m antenna that has been purchased and is ready for installation at the Goddard Space Flight Center outside of Washington, D.C., USA, site of the MV-3 antenna.

1. Proof-of-concept System

Recognizing that spatial and temporal fluctuations in the atmosphere delay are a major component of the error in position determination, the VLBI2010 Committee carried out a large number of simulations to arrive at design goals for the next generation geodetic VLBI antenna system [1]. A primary goal is the implementation of fast slewing antennas that attain high delay precision per observation. Taking into account existing and anticipated data recording capabilities, these translate to an antenna diameter of 12 m or larger and delay precision of approximately 4 psec. With funding from NASA's Earth Surface and Interior Focus Area, a proof-of-concept (PofC) project was initiated to demonstrate that the VLBI2010 concept is attainable.

Obtaining good sensitivity from relatively small antennas in a short time requires a large data acquisition rate. By spreading the data acquisition over four bands spanning 2-14 GHz instead of the two bands used by the current geodetic VLBI systems at S-band and X-band, enough phase precision is expected to be obtained to estimate both the phase delay and the dispersive phase deviation due to the ionosphere for each scan.

Of course the large total bandwidth increases the probability that radio frequency interference (RFI) will lie within the observed frequency range of the feed and receiver. Thus the band selection has been made tunable by using four separate UpDown Converters (UDC), one for each band. In addition to offering some RFI avoidance capability, the flexibility is important to be able to accommodate placing bands at S and X for compatibility with legacy antennas that are not able to upgrade, while having the option to use a higher minimum frequency to avoid RFI when only stations with the VLBI2010 broadband capability are participating.

The large instantaneously available bandwidth of the PofC front-end is made possible with the ETS-Lindren 3164-05 dual linearly-polarized broadband antenna. While this antenna has neither a frequency-independent beam size nor phase center, it was commercially available at the initiation of the project and was affordable. A new feed is under development with the desired properties.

Thus the solution for obtaining enough sensitivity and delay precision from fast, and therefore likely to be small, antennas is a dual polarization, wideband feed followed by four independent local oscillators and digital backends, recording at 2 Gbps on four Mark 5B+ recorders (Figure 1a). In order to increase the sensitivity, the feed and low noise amplifiers are cooled to 20 K. Phase and noise calibration signals are injected immediately following the feed. A new phase cal generator was designed and implemented to replace the obsolete S/X phase cal [2]. The amplified RF signals for each polarization are brought down on fiber optic cable to the control room where the signals are split, down-converted [3], digitized, and recorded. All of the control room electronics are contained in a single rack (Figure 1b).

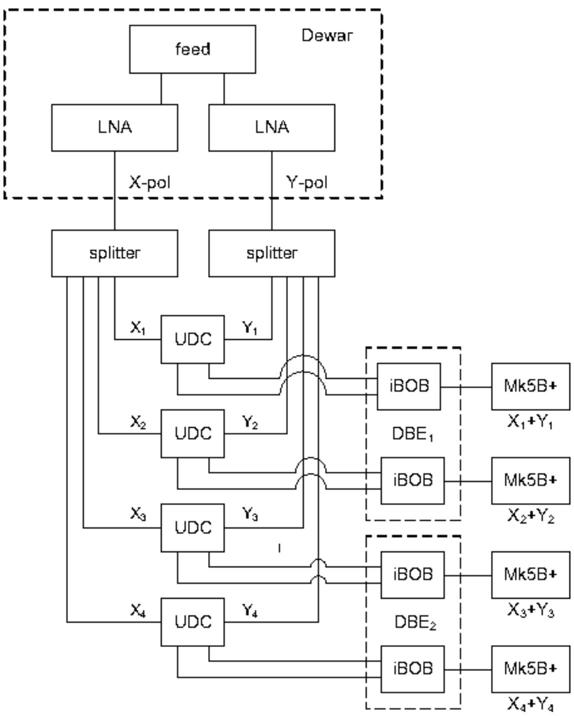

Figure 1. a) Configuration for the VLBI2010 system: LNA – low noise amplifiers; UDC – UpDown Converter (flexible local oscillator); iBOB/DBE – digital back end; Mk5B+ – high speed (2 gigabits per second) digital recorder; X and Y – two orthogonal components of linear polarization. b) Rack at Westford containing all of the VLBI2010 proof-of-concept backend equipment.

The PofC systems were installed on the Westford (Massachusetts, USA) 18-meter antenna and the MV-3 5-meter antenna at Goddard Geophysical and Astrophysical Observatory (Maryland, USA). Figure 2 shows the Dewar mounted on MV-3.

The optimum focus setting for Westford was determined by varying the distance of the Dewar from the vertex of the antenna for successive VLBI scans. The optimum focus is frequency dependent, and there appears to be a dependence on polarization at the higher frequencies. We expect these effects to be significantly reduced with the next generation of feed.

Figure 2. MV-3 5-m antenna at GGAO with the VLBI2010 proof-of-concept Dewar mounted at the Cassegrain focus.

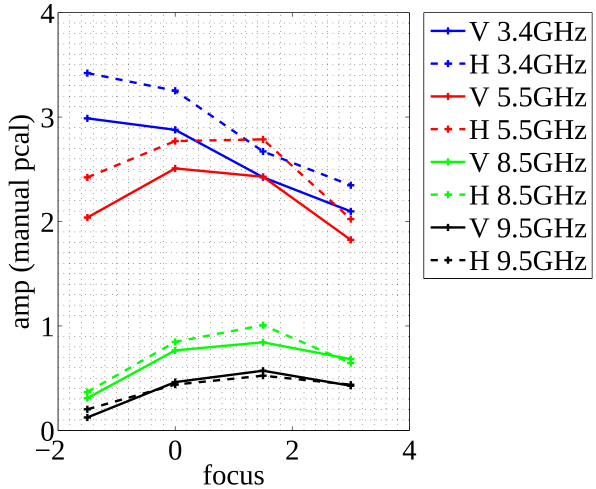

Figure 3. Amplitude as a function of focal distance for the Westford antenna. Frequency increases from top to bottom at focus = 0.

2. Results

The fundamental observable for the VLBI2010 system is planned to be the ambiguity-resolved phase delay. The quadratic phase term due primarily to the differential ionosphere will be estimated simultaneously with the phase delay. However, with two independent polarizations there are two estimates of the delay. These two estimates should differ only by a constant amount due to the uncalibrated electrical path lengths preceding the phase cal injection at each site, i.e., through the feed and coax to the injection points.

Several observations have been conducted to study various aspects of the broadband system and the associated delay observables. Firstly, observations of the source 4C39.25, which transits north of MV-3 and south of Westford, were conducted because of the large change in parallactic angle. This observation demonstrated the expected amplitude variation for the change in differential parallactic angle. The cross-correlation amplitudes for VV (called LL for historical reasons) and for HV (RL) are shown in Figure 4. The variations agree at least qualitatively with the expected characteristics.

Secondly, a pair of sources, 3C273 and 3C279, was observed alternately ten minutes at a time to see what changes might occur due to antenna movement. For the latter pair it is expected that there will be some common atmosphere delay variation that will cancel on differencing, although the sources are too far apart and the scans too long for very accurate differencing.

Lastly, an independent 10 minute 6.4–8.4 GHz observation of 4C39.25 was also conducted. The results of this observation show that the RMS of the fringe phases after phase cal correction is approximately 8°, which corresponds to a group delay uncertainty of ∼10 psec. (See Beaudoin and Niell, this volume, for figure.)

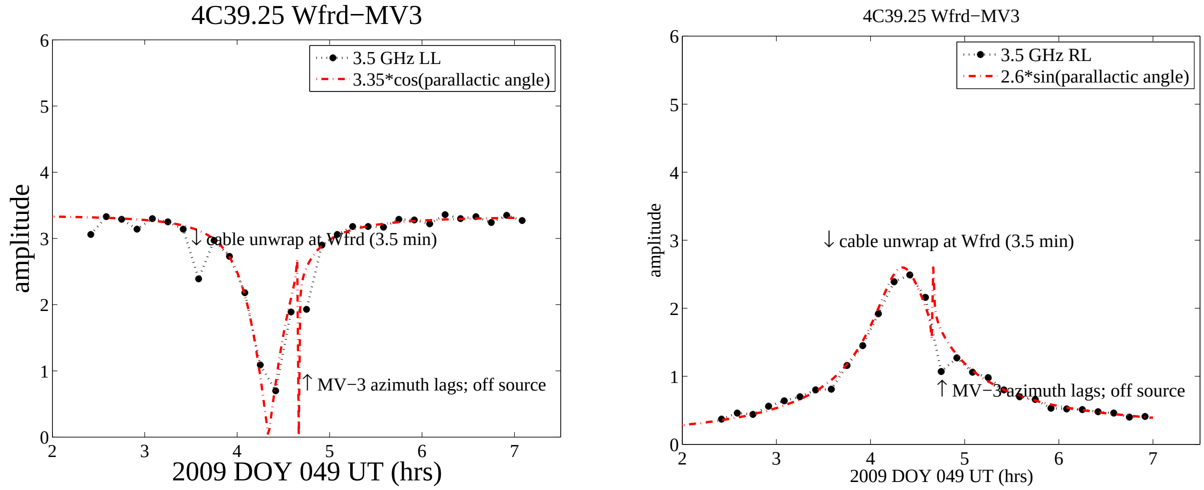

Figure 4. Cross-correlation amplitudes for LL (VV) and RL (HV) polarizations for 3.5 - 4 GHz band. The amplitude of the fitted curve is estimated from the data, not from any a priori system calibration and source information. Parallactic angle refers to the difference of the parallactic angles.

3. Next Steps

The PofC demonstration has taken much longer than anticipated, but finally there is a data set to work with to investigate the best way to derive the phase delay observable. Although not discussed here, the post-correlation analysis program fourfit has been enhanced to fit all four bands of one polarization with an ionosphere term, in preparation for estimating the ionosphere contribution along with the other scan observables.

Many improvements are in progress for the prototype system. The most significant is the construction of a 12-m antenna to replace MV-3 at GGAO. The phase cal unit will be installed in a temperature control box. The iBOB and Mark 5B+ combination will be replaced by the RDBE and Mark 5C. The quadridge feed will be replaced by the Eleven feed. All of these will improve either the sensitivity or the delay measurement precision and accuracy.

4. Acknowledgments

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References

1. Beaudoin, C., Niell, A., Post-Correlation Processing for the VLBI2010 Proof-of-Concept System, this volume.

2. Petrachenko, B., et al., Design Aspects of the VLBI2010 System: Progress Report of the IVS VLBI2010 Committee, In: International VLBI Service for Geodesy and Astrometry 2008 Annual Report, NASA/TP-2009-214183, D. Behrend and K. D. Baver (eds.), 13-67, 2009.

3. Rogers, A. E. E., Tests of New "Digital" Phase Calibrator, Haystack BBDev Memo #023, available at *http://www.haystack.mit.edu/geo/vlbi_td/BBDev/023.pdf*, 2010.

4. Rogers, A. E. E., Updown Converter Notes, Haystack Mark 5 Memo #070, available at *http://www.haystack.mit.edu/tech/vlbi/mark5/mark5_memos/070.pdf*, 2010.