Haystack Observatory Technology Development Center

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Abstract

Work at MIT Haystack Observatory is currently focusing on four areas: Mark 5C VLBI data systems, e-VLBI, digital backends, and VLBI2010 progress. We will describe each of these areas.

1. Mark 5C VLBI Data System

The Mark 5C is being designed as the next generation Mark 5 system, with a capability of recording sustained data rates up to 4096 Mbps. It will use the same disk modules as the Mark 5A and Mark 5B, thus preserving existing investments in disk modules. The Mark 5C data interface for both recording and playback will be 10 Gigabit Ethernet, which is rapidly becoming a widely supported standard. The use of 10GigE interfaces comes with some significant implications, however. Firstly, data sources must be designed to provide data streams in a format compatible with the Mark 5C requirements. And secondly, data playback through a 10GigE interface is a good match for a rising generation of software correlators. In the interests of backwards compatibility, the Mark 5C will also support a mode which writes disk modules in Mark 5B data format which can be correlated on existing Mark IV correlators that support Mark 5B. Some other characteristics of the Mark 5C include:

- The standard Mark 5C Ethernet packet format prescribes that each packet contains data from only a single frequency channel. Unlike almost all previous VLBI data systems, which constrain the number of recorded frequency channels to be 2^n, the Mark 5C will allow an arbitrary number of channels to be recorded.
- The Mark 5C will use the same Amazon StreamStor disk interface card as the Mark 5B+, but it will replace the FPDP I/O daughterboard with a newly designed (by Conduant Corporation) 10GigE interface card. Unlike Mark 5A/B/B+, no separate specialized I/O card is needed.
- At data rates above about 2 Gbps, it will be necessary to record to two 8-disk modules simultaneously in so-called 'non-bank' mode, which is not normally used by Mark 5A or Mark 5B/5B+.
- Mark 5C will include a Mark 5B emulation mode to create recorded disks that are in the Mark 5B data format and can be correlated directly on a Mark IV correlator.

The first prototype Mark 5C systems are expected to be available in mid-2008. Additional detailed information about the Mark 5C systems is available in the Mark 5 memo series (*http://www.haystack.edu/tech/vlbi/mark5/memo.html*), particularly memos 57, 58, 61, and 62.

2. e-VLBI Development

Haystack Observatory continues to develop the e-VLBI technique for VLBI data transfers:

- Implementation of automated e-VLBI data transfer capability at MPI correlator: Haystack has worked with the Bonn correlator at MPI to implement an e-VLBI data transfer capability similar to that at Haystack Observatory. This allows the direct transfer to Bonn of data that will be correlated there. Data from Onsala, Ny-Ålesund and Japan are now transmitted regularly to Bonn over their 1 Gbps network connection.

- 10GigE connection to Haystack: A 10 Gigabit network connection from Washington, D. C. to Haystack over the Bossnet network has been inaugurated in cooperation with MIT Lincoln Laboratory. This link is important for e-VLBI data transfers to Haystack and for the testing of the new VLBI2010 demonstration broadband system utilizing the Westford and MV-3 (at NASA/GSFC) antennas.
- Real-time e-VLBI processing of Mark 5B data: Work is nearly complete to support real-time e-VLBI using Mark 5B on the Mark IV correlator. We expect to use this system to demonstrate 2 Gbps real-time e-VLBI in the near future.

3. Digital Backends

In last year's Technology Development Center report, Haystack reported on the successful development of the first generation digital backend system, now called DBE1. The DBE1 system was developed collaboratively with the University of California at Berkeley using the so-called iBob board that was developed as a flexible general purpose radioastronomy signal processing platform using FPGA technology. DBE1 systems have now been successfully used in a number of geodetic and astronomical VLBI experiments. A second generation system, dubbed DBE2, is now being developed at Haystack based on a next generation iBob, dubbed iBob2. The iBob2 is being developed by Berkeley, NRAO, and South Africa as the common platform for digital backend development to meet the specific needs of both NRAO and Haystack. Haystack will design a polyphase-filter-bank (PFB) version of the FPGA code to process two 1 GHz-wide IFs into an 8 Gbps Ethernet packet stream compatible with the Mark 5C data system. NRAO, on the other hand, is planning to emulate several VLBA BBCs on an iBob2 board (dubbed VDBE), which will also produce a Mark 5C-compatible Ethernet data stream. The hardware for both the Haystack and the NRAO systems will be identical; only the FPGA code will be different, allowing an iBob2 system to adopt the personality of either DBE2 or VDBE. The cost of a DBE2/VDBE system is not yet well established, but will likely be considerably less than US$10K. The first prototype DBE2/VDBE systems are expected to be available for testing in mid-2008.

4. VLBI2010

The major innovation of the VLBI2010 concept is the use of a relatively small antenna (~12 m) with a receiver spanning a very wide bandwidth (~2-15 GHz). Observing will utilize four 0.5-1 GHz-wide bands spread across the 2-15 GHz receiver capability in order to gain a group delay precision sufficient to resolve the more accurate phase delay. This concept has come to be known as the *broadband delay* system.

Haystack Observatory has been working with NASA/GSFC and HTSI, along with consultation from Bill Petrachenko and others, to develop a demonstration system using the broadband delay concepts. Several advances in technology are necessary in order to create such a system:

Broadband feed: Only recently have feeds with sufficient bandwidth become available to implement the broadband concept. The feed for our initial tests is a commercial wideband (2-13 GHz) unit, chosen because it is readily available and relatively inexpensive. A specially designed feed for VLBI2010 is expected to become available in a year or two. A complication is that these feeds receive linear polarization, not the circular polarization that we have traditionally used; in order to deal with antenna parallax differences, it will be necessary to capture both linear polarizations.

Digital backend: Digital backends are a necessity for the broadband systems for several reasons: 1) absolute uniformity and repeatability, 2) wide-bandwidth capabilities, and 3) low cost. For the demonstration system, the DBE1 unit designed jointly by Haystack Observatory and the University of California at Berkeley is being used.

High-data-rate data-acquisition system: Multiple Mark 5B+ systems, capable of recording 2 Gbps each, were used at each antenna in the demonstration systems. Processing was done on the Mark IV correlator at Haystack Observatory. The Mark 5C development, described above, will be capable of recording 4 Gbps on each system.

In order to demonstrate that the broadband concept is feasible, we have implemented a broadband demonstration system, using the Westford and MV-3 (at NASA/GSFC) antennas, that utilizes all of the components of a broadband delay system. The combined sensitivity of these two antennas is somewhat less than that of two high-efficiency 12 m antennas but sufficient to demonstrate that the concept is valid.

The broadband demonstration system consists of the above-mentioned commercial feed to cover the frequency range ∼2 GHz to ∼13 GHz in two linear polarizations, along with two low-noise amplifiers (LNAs). The feed and the LNAs are both cooled to approximately 20K, and the output of each LNA is carried over wideband "RF" optical fiber to the control room where the signals are split into four paths corresponding to the four frequency bands. An Up-Down Converter (UDC) translates both polarizations of each band to a common 500 MHz-wide intermediate frequency (IF) that is digitized and filtered by the Digital Backend and recorded on a Mark 5B+ recorder. To observe in four bands requires four UDCs, four Mark 5B+s and two dual-board DBE1s at each site.

One entire broadband system was installed on MV-3 during the last week of October. The Dewar was mounted at the Cassegrain focus in the location of the original X-band feed, as can be seen in Figure 1. For the first test we observed at X-band in the usual geodetic band. Westford used the operational NASA X-band receiver and LO but recorded using a DBE1 and Mark 5B+. Since only one band was being recorded, the data rate was only 2 Gbps.

On 19 November 2007 fringes were found for both linear polarizations from MV-3. Vertical polarization was carried on optical fiber, horizontal on coax. The SNRs on 3C279 were 127 and 117 for 125 seconds of data, close to our predictions. The system temperatures were measured as approximately 45K and 35K on fiber and coax, respectively. Some fringe-phase differences between the polarizations were observed that are not yet understood and are being studied. We have also begun construction of an identical system for Westford where the Dewar will be mounted at prime focus. Eight UDCs and four dual-board DBEs will be constructed to observe in four frequency bands. At that time the next round of testing will evaluate the efficiency of the broadband system mounted on the Westford antenna.

5. Acknowledgements

The broadband demonstration system is funded by NASA's Earth Surface and Interior Focus Area through the efforts of John LaBrecque, Chopo Ma, and Herb Frey.

Figure 1. Jay Redmond and Bruce Whittier installing the Dewar on the 5 m MV-3 antenna.

Important contributions were made by all participants: Arthur Niell and the BBDev Team (in reverse alphabetical order) Bruce Whittier, Mike Titus, Jason SooHoo, Dan Smythe, Alan Rogers, Jay Redmond, Mike Poirier, Chuck Kodak, Alan Hinton, Ed Himwich, Skip Gordon, Mark Evangelista, Irv Diegel, Brian Corey, and Tom Clark.

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