# Haystack Observatory Technology Development Center

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**Abstract**

Technology development at MIT Haystack Observatory were focused on four areas in 2012:

- VGOS developments at GGAO
- Digital backend developments and workshop
- RFI compatibility at VLBI stations
- Mark 6 VLBI data system development

## 1. VGOS Developments at GGAO

### 1.1. New Receiver Installation

A proof-of-concept (PoC) VLBI2010 receiver incorporating the Quadruple-ridged flared horn (QRFH) designed by Caltech was installed in spring 2011. The sensitivity of this PoC receiver met theoretical expectations in the 3-12 GHz spectrum [1], and it enabled processing of the first geodetic broadband VLBI observables. However, this system still did not meet the receiver requirements set forth for VLBI2010[1]. Firstly, the PoC receiver required a post-LNA 3.1 GHz filter to reject strong RFI that would otherwise saturate the receiver stages following the low-noise amplifier (LNA); this placed a 3 GHz lower limit on observing frequencies. The PSI-1601 fiber optic links incorporated in the PoC receiver were not specified for operation above 12 GHz and thus place a maximum observing sky frequency of 12 GHz. Furthermore, it was unknown at the time that these fiber optic links exhibited a noise figure that varied significantly (as much as 15 dB) across the operational frequency range. This introduces a significant loss of dynamic range in the PoC receiver and complicates the requirement to maintain a uniform 2500 Jy system-equivalent flux density (SEFD) uniformly across the 2-12 GHz spectrum. Lastly, the PoC frontend was not easy to service and maintain. In order to truly meet the VLBI2010 specified receiver requirements and to realize a system that can be easily serviced and maintained, Haystack Observatory initiated a receiver upgrade project that was focused on addressing these shortcomings. The following outline presents the high-level requirements of the receiver upgrade:

Upgrade Requirements:

- S-band coaxial downlink
- Electronic control of feed position
  - feed positioning uncertainty < 1mm
- Remote servicing of cryogenics
  - control vacuum pumps and valve
- Monitor
  - Cryogenic refrigerator temperature

[1] 12-m radio telescope capable of 2-14 GHz observations with SEFD < 2500 Jy [2].

  - Supply/return helium pressure
  - Air pressure in vacuum vessel
  - Crosshead motor electrical drive power

- Ease of receiver removal for servicing outside antenna
- In-situ access to the following components:
  - LNA power supply and cryo temperature sensor connectors
  - Bias box adjustments/test points
  - SMA connectors accessible to 5/16” wrench
  - Coupler outputs for RF sampling
  - Fiber optic connectors

The receiver upgrade was installed in mid-November 2012, and the sensitivity of the receiver will be characterized in early 2013.

## 2. Digital Backend Developments and Intercomparison Workshop

The MIT Haystack Observatory digital engineering staff have also developed new FPGA bitcode personalities for both the geodesy and astronomy applications. The latest versions are enhancements to the RDBE v1.4, which is a Polyphase Filter Bank (PFB) design producing real-valued samples in Mark 5B format that is detailed in [1]. The following new RDBE personalities were developed in 2012:

### 2.1. RDBE v1.5

This personality quantizes to two bits the full 512 MHz bandwith of each of the two IF input signals. Each IF input signal is formatted as Mark 5B and output as a TCP/IP transmission over a single network interface card (NIC) at a data rate of 2 Gbps. Since the data processed for each IF are transmitted over independent NICs, the aggregate output data rate of this personality is 4 Gbps.

### 2.2. RDBE v2.0

This personality processes four 512 MHz bandwidth IF input signals. The signal processor routes all thirty-two 32-MHz channels derived from a pair of IF input signals into a VDIF packet stream as complex-valued time samples at 4 Gbps. Each 4 Gbps VDIF stream is transmitted over an independent NIC using TCP/IP network communications, so the aggregate output data rate is 8 Gbps.

### 2.3. RDBE v2.5

This is a derivative of the RDBE v2.0 that processes only two 512 MHz IF inputs, so the aggregate output data rate is 4 Gbps. Two IF inputs were deleted from the v2.0 personality to accommodate the limited resources on the ROACH board so that diagnostics critical to geodetic VLBI operations could be incorporated into this personality. The diagnostics include:

- Pulse calibration detection from raw 1024 MHz ADC samples
- Synchronous raw capture of the raw ADC samples relative to the RDBE 1 PPS epoch
- MASER-RDBE 1PPS and GNSS-RDBE 1PPS time delay monitoring

### 2.4. DBE Intercomparison Workshop

The second DBE intercomparison workshop was held at Haystack Observatory on 25-26 October 2012. This workshop provided a forum to explicitly address validation and interoperability issues among independent global developers of DBE equipment The first such workshop was held at Haystack Observatory in May 2009. The 2012 workshop took advantage of the completion of a new Instrumentation Lab at Haystack Observatory that provided the space and signal connections needed to efficiently support the comparison exercise. The results of this workshop can be found at the following link:

*http://www.haystack.mit.edu/workshop/ivtw/2012.12.17_DBE_testing_memo_final.pdf*

## 3. RFI Compatilibitity at VLBI Stations

The IVS appointed a task force comprised of IVS members Bill Petrachenko, Brian Corey, and Christopher Beaudoin to evaluate Radio Frequency Interference (RFI) power levels at current and prospective VLBI stations in order to assess the feasibility of broadband geodetic VLBI observations at these stations. In 2012, stations were requested by the IVS to provide RFI data, and the task force has conducted preliminary analyses of the data provided by the nine responding stations. A formal report is expected to be released in 2013.

## 4. Mark 6 VLBI Data System Development

### 4.1. First Demonstration of the 16 Gigabit Mark 6 Data Recorder

The availability of inexpensive, commercial-off-the-shelf high performance computing (HPC) hardware and the parallel development of broadband RF equipment for VLBI has enabled dramatically improved sensitivity for both astronomical and geodetic VLBI. The recognition of these technological developments provided the motivation for Haystack to develop the Mark 6 16 Gbps data recorder. In June 2012, a VLBI experiment utilizing a single Mark 6 recorder at each end of the Westford/GGAO baseline demonstrated 16 Gbps VLBI capability. The correlation amplitudes and signal-to-noise ratios for the 2 GHz bandwidth, dual polarization observations were within the expected range [3].

### 4.2. Current Capabilities

During this report period, operational Mark 6 software was developed, based upon the principles refined in the prototype software, but with an entirely new code base. The Mark 6 software is currently at revision 2; it splits the workload into modules that are called the control and data planes. The control plane software, which implements control and monitor functions, is written in python for ease of maintenance.

The data plane software performs the time-critical tasks of receiving the high-speed packetized data-streams, organizing them, and writing to disk files, and it is thus coded in C.

Two file-writing modes are supported: a single-file RAID mode and a multiple (1-32) disk scattered mode. The scattered mode allows disks to record data at whatever rate they are able, with the intent that it will be more robust in the face of slow or non-functioning disks. There is currently a stand-alone program, called *gather*, to recombine the separate files into a seamless single file for the correlator. It is expected that this functionality will eventually be built into the file-reading portion of the DiFX correlator, and perhaps into a general-purpose FUSE/Mark 6 file interface.

## References


[1] Beaudoin, C., Corey, B., Niell, A., Whitney, A., (2011) Haystack Observatory Technology Development Center, IVS 2011 Annual Report, NASA/TP-2012-217505, p. 283-286.

[2] Petrachenko, B.; Niell, A.; Behrend, D.; Corey, B.; Boehm, J.; Charlot, P.; Collioud, A.; Gipson, J.; Haas, R.; Hobiger, T.; Koyama, Y.; MacMillan, D.; Malkin, Z.; Nilsson, T.; Pany, A.; Tuccari, G.; Whitney, A.; Wresnik, J., (2009) Design Aspects of the VLBI2010 System. Progress Report of the IVS VLBI2010 Committee, June 2009, NASA/TM-2009-214180, 2009, 62 pages.

[3] Whitney, A.R., Beaudoin, C.J., Cappallo, R.J., Corey, B.E., Crew, G.B., Doeleman, S.S., Lapsley, D.E., Hinton, A.A., McWhirter, S.R., Niell, A.E. Rogers, A.E.E., Ruszczyk, C.A., Smythe, D.L., SooHoo, J., Titus, M., (2013) Demonstration of a broadband-RF VLBI system at 16 Gbps data rate per station, PASP, 125, PP. 196-203.