

Haystack Observatory Technology Development Center

Chris Beaudoin, Brian Corey, Arthur Niell, Alan Whitney

Abstract

Technology development at MIT Haystack Observatory was focused on four areas in 2011: 1) Development of VLBI2010 receiver hardware, 2) Digital Backend development, 3) RFI compatibility at GGOS stations, and 4) Mark 6 VLBI Data System development.

1. Development of VLBI2010 Receiver Hardware

In 2011 Haystack Observatory was engaged in the development of a second receiver frontend for the new GGAO Cobham 12-m antenna as well as for the Westford antenna. Both receivers are based on the Caltech-designed/built QRFH shown in Figure 1 and the CRYO1-12 low-noise amplifiers, also developed at Caltech. The geometric design of these two feeds is quite different; the GGAO 12-m QRFH is circular [1] while the Westford QRFH is square. The difference in the geometric design is attributed to the difference in the Westford and GGAO 12-m reflector optical configurations; the GGAO 12-m requires a feed beamwidth of 100° while Westford requires a feed having 160° beamwidth.

Prior to installing the QRFH-based frontend on the GGAO 12-m antenna, Y-factor measurements of the frontend were conducted; these measurements demonstrated 30K noise temperature over 2-12 GHz. After installing the QRFH-based receiver on the GGAO 12-m, the broadband SEFD of the receiver was estimated from on-source/off-source total power measurements of Taurus A. Initially, the SEFD performance was poorer than expected due, it was discovered, to a misalignment of the subreflector. Repeated SEFD measurements were utilized to fine tune the position of the subreflector, and peak sensitivity was achieved when the subreflector was 15.9 mm further from the vertex than the original position. After re-aligning the subreflector, the receiver temperature was estimated by the Y-factor method, and the SEFD was immediately re-measured. Given the radio telescope's SEFD and system temperature, the aperture efficiency of the telescope was computed. Figure 2 shows the broadband aperture efficiency of the radio telescope as estimated from the measurements collected on day 249. The theoretically expected aperture efficiency of the 12-m radio telescope under illumination by its QRFH was computed by William Imbriale (JPL) using a custom physical-optics solver; Figure 2 shows this expectation as well. Given that the solution does not incorporate blockage losses from the support struts and subreflector, the agreement shown in Figure 2 is considered to be quite reasonable. The expected efficiency loss due to the supporting structure is under investigation.

Figure 2 also shows the system temperature of the complete receiver system, from frontend to backend in the control room, as measured on days 249 and 336. As can be seen, the system temperature on the first day increases significantly at higher frequencies. It was subsequently discovered that this was due to an unspecified increase in the noise figure of the microwave-over-fiber link. Additional gain, preceding the fiber link, was introduced to overcome the high frequency noise figure (at the expense of less saturation overhead) and led to the substantial improvement in receiver system temperature as shown in Figure 2 for day 336. Given the aperture efficiency reported in Figure 2 and the improvements in system temperature (day 336), the SEFD over the 3-12 GHz band is expected to be below 2500 Jy, which is the VLBI2010 goal. The fiber link was also

being driven into saturation by strong S-band RFI at GGAO. For this reason, a 3.9 GHz highpass pre-link filter was installed in the receiver; hence the system temperatures shown in Figure 2 are limited to 3 GHz on the low end of the spectrum. Until the GGAO receiver can accommodate S-band observing, it will not be fully compliant with VLBI2010 specifications. This is a topic of current investigation.

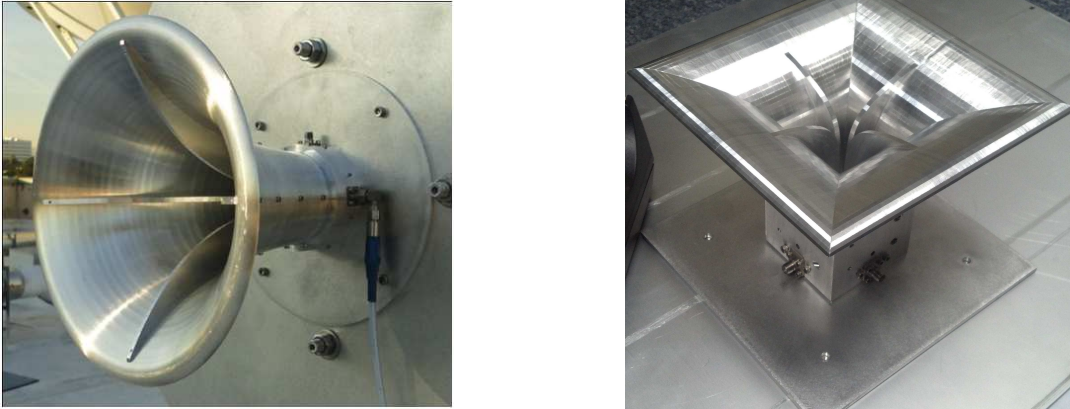


Figure 1. Broadband microwave feeds for NASA broadband receivers: (left) GGAO 12-m QRFH feed, (right) Westford 18-m QRFH feed.

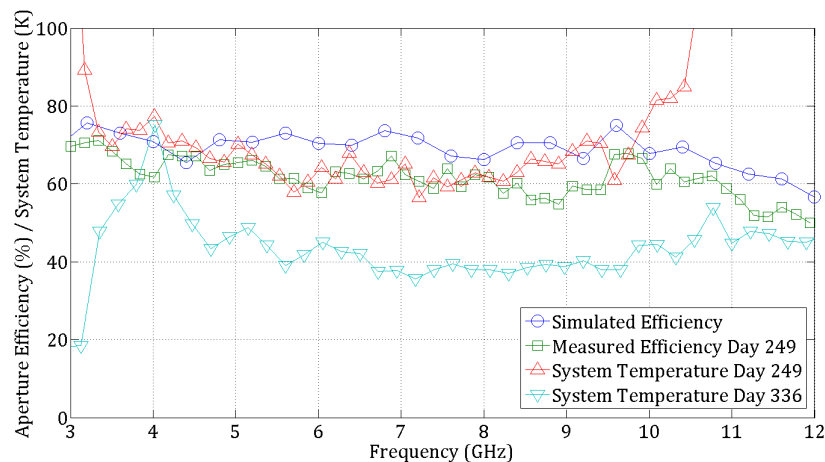


Figure 2. Simulated and measured (on day 249) aperture efficiencies of the GGAO 12-m under illumination by the QRFH. Also shown is the measured system temperature of the GGAO 12-m receiver on days 249 and 336 of year 2011, before and after the introduction of additional pre-fiber gain, respectively. Strong 4 GHz RFI was present on day 336.

2. Digital Backend Development

In the past year collaborations between Haystack and NRAO have continued to further the development of the RDBE subsystem. In 2011 the RDBE geodetic polyphase filter bank (PFB)

personality bitcode version 1.4 was officially released, and RDBEs can now be ordered through DigiCom¹ for new station construction and current station upgrades. The RDBE provides 16 user-selectable 32 MHz channels from a choice of 16 uniformly-spaced channels in each of the 512 MHz IF inputs. Initially, a PFB personality providing 8 MHz channels was also planned for development for compatibility with operational S/X observations. However, a development in the DiFX correlator now supports the correlation of channels of differing bandwidth, provided there is common spectral overlap in the channels. This feature of the DiFX software provides the final missing link required to allow RDBE backends to co-observe with stations incorporating legacy baseband converters.

3. RFI Compatibility at GGOS Stations

Haystack Observatory has been involved in studies of the compatibility of DORIS and the SLR aircraft radar with the VLBI2010 receiver since these two active techniques pose a potential to degrade VLBI data quality and, in the worst case, damage the frontend of the VLBI receiver at a fundamental GGOS station. To support this effort, X-band power level measurements of the SLR aircraft tracking radars at GGAO were conducted to verify the expected radiation properties of these systems. The results of this study have been reported in [2].

As described in [2] GGAO operates two SLR systems, NGSLR and Moblas7, both of which employ aircraft-tracking radars. To avoid potential damage to the 12-m frontend electronics, both SLR systems and the 12-m system now have programmed pointing masks to exclude observations within 30 degrees of the other technique. These masks are not intended to avoid degradation of broadband VLBI data; such masks would be prohibitively large and would severely impact operations [3]. For this reason, Haystack is involved in an electromagnetic-barrier study, the goal of which is to reduce the pointing restrictions on the unshielded radar and VLBI systems. The DORIS transmitter at GGAO does not pose a threat of damaging the electronics of the 12-m receiver.

4. Mark 6 Data System Development

The demand for greater VLBI observation sensitivity continues to push required data-acquisition and playback rates to higher and higher levels. The current Mark 5 generation of data systems tops out at sustained 4 Gbps per system. However, near-term demands are for 8 Gbps, pushing to sustained recording and playback at 16 Gbps within about a year. These rates are required to support the 1-mm global measurement precision demanded by the VLBI2010 system.

In order to meet these needs, Haystack Observatory, in collaboration with the High-End Network Computing Group at NASA/GSFC, has embarked on the design of a 16-Gbps VLBI data system. Unlike its Mark 5 predecessor, the Mark 6 system is based entirely on commercial-off-the-shelf hardware. The only exception is the continued use of customized 8-disk modules which are similar to the disk modules used in the Mark 5 system and which provide the necessary portability demanded by the geodetic VLBI application. We are partnering with Conduant Corporation of Longmont, CO, who also partnered with Haystack on the Mark 5 system, for development of specific items to support the custom Mark 6 disk modules, and who will also act as the manufacturer

¹Digicom Electronics, Inc. info@digicom.org

and distributor of Mark 6 systems for the global VLBI community.

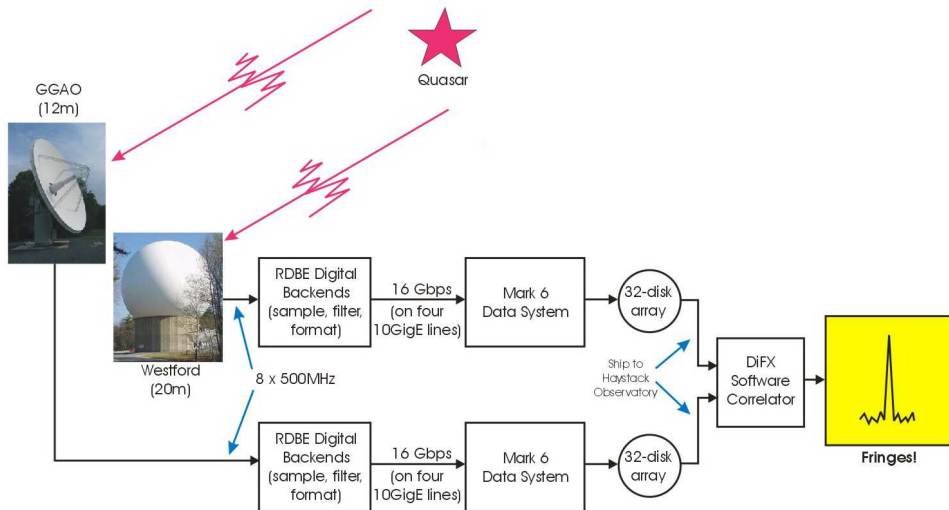


Figure 3. Diagram of the experimental setup for the 16 Gbps Mark 6 demonstration.

The cost of the Mark 6 system will be lower than that of the Mark 5 system, but the data-rate capability will be four times greater. This will help to significantly reduce the cost of supporting the new demand for higher data rates. The Mark 6 system is expected to be available for operational use in the latter half of 2012.

In late October 2011, early Mark 6 prototype systems were used in a VLBI demonstration experiment between the Westford 18-m and GGAO 12-m antennas. Figure 3 shows a diagram of the experiment setup. Eight duplicated 512 MHz bands were processed through RDBE backends to produce four 10GigE data streams of 4 Gbps each, which were recorded at each station to 32 disks on a Mark 6 system. The data were processed with the DiFX correlator at Haystack Observatory. The cross-correlation of all eight bands showed nominal results, verifying the operation of the prototype Mark 6 system.

Acknowledgements

We wish to thank Ahmed Akigray (Caltech), Sandy Weinreb (Caltech), and Bill Imbriale (JPL) for their contributions to the development of the GGAO and Westford receiver frontends.

References

- [1] Akgiray, A., Weinreb, S., Imbriale, W., and Beaudoin, C. "Circular Quadruple-Ridged Flared Horn Achieving Near-Constant Beamwidth Over Multi-Octave Bandwidth; Design, Measurements and System Performance," Submitted for Publication to IEEE Transactions on Antennas and Propagation.
- [2] Beaudoin, C. and Cappallo, S., MOBLAS7 and NG SLR Radar Power Level Measurements Collected at GGAO, MIT Haystack Observatory VLBI Broad Band Memo Series, No. 37, 2011.
- [3] Beaudoin, C., Corey, B.E., Petrachenko, W.T., "Radio frequency compatibility of VLBI, SLR, and DORIS at GGOS stations," poster presented at AGU 2010 fall meeting in San Francisco, CA.