Haystack Observatory Technology Development Center

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Abstract

With the completion of the Mark 4 correlator, current VLBI technology work at the Haystack Observatory is focusing on VLBI data systems for the future. The Mark 5 disc-based data system is well along in development and will enter field operation in 2002; approximately 20 Mark 5 units are expected to be deployed. In addition, the Mark 5 system will be used in a demonstration of ~1 Gbps electronic transmission of VLBI data over an IP network between Haystack and NASA/GSFC, a distance of ~700 km.

1. Mark 4 Correlator

Mark 4 correlators have been operational at USNO, MPI, JIVE and Haystack for about two years and have now completely replaced all Mark III and Mark IIIA correlators. Over the last year, significant enhancements have been made to Mark 4 correlator software to improve operational flexibility and efficiency. Among the most important are

- Multiple-stream processing (up to four simultaneous independent scans)
- Faster tape synchronization (typically <5 seconds)
- Double-speed tape playback

Though the Mark 4 correlator is now deemed mature, a low level of continued enhancements is planned over the next year, including:

- Support of Mark 5 VLBI data system
- Increase to 8 playback systems
- Quadruple-speed playback speed
- Refinement of baseline phase model

2. Mark 5 VLBI Data Systems

2.1. Mark 5 Demonstration System:

In early 2001, a demonstration Mark 5 system, shown in Figure 1, was developed and tested. This system has the following characteristics:

- Built entirely of COTS components for ~ $25K
- Based on standard PC platform
- Maximum data rate of 512 Mbps to 16 discs
- Recorded data directly from a Mark 4 formatter
- Data reproduced into a Mark 4 correlator for correlation

In March 2001, this demonstration system was used to record VLBI data at Westford Observatory at 256 Mbps, which was successfully correlated against Mark 4 tape data recorded at NASA/GSFC on the Mark 4 correlator at Haystack Observatory.

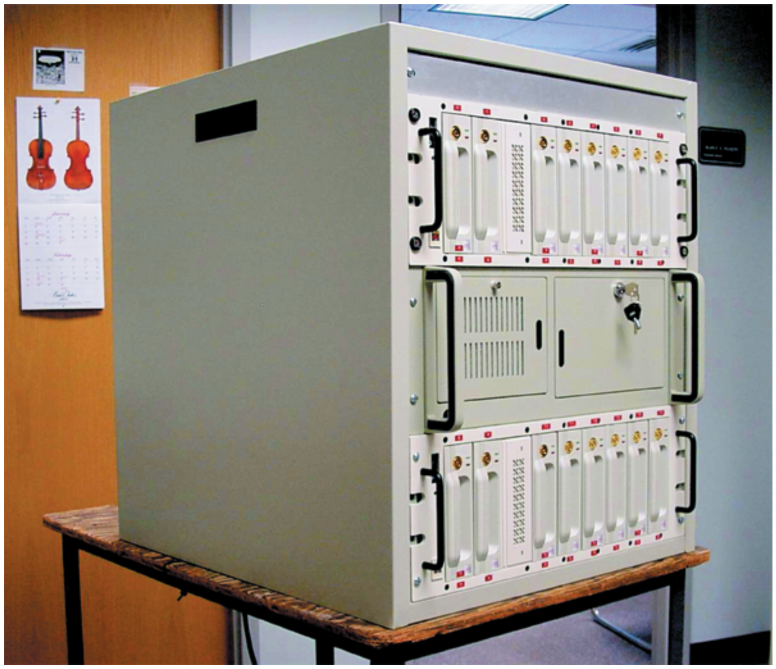

Figure 1. Demonstration Mark 5 System

2.2. Mark 5 Development Program

Based on the success of the Mark 5 demonstration unit, Haystack Observatory is now undertaking the development of an operational 1 Gbps Mark 5 system with support from BKG, KVN, MPI, NASA, JIVE, NRAO and USNO. The Mark 5 system is being developed in two stages:

1. Mark 5A: Records 8, 16, 32 or 64 tracks from a Mark4/VLBA formatter, up to 1024 Mbps (parity stripped), and plays back in the same Mark4/VLBA format. Direct replacement for Mark4/VLBA tape drives. Expect deployment of ~20 systems late spring 2002.
2. Mark 5B: VSI-compliant system, up to 1024 Mbps; no external formatter necessary. Will be backwards compatible to existing Mark4/VLBA correlator systems. Expect to deploy late 2003.

A Mark 5A system may be upgraded to a Mark 5B system simply by replacing two PCI boards in the host PC.

The cost of either the 1 Gbps Mark 5A or Mark 5B recording or playback system (without discs) is expected to be <~$20K, with a do-it-yourself-kit cost <~$15K.

The Mark 5 system is based on disc drives with IDE interfaces, which are the most cost-effective consumer discs that can be procured. IDE discs can now be purchased for ~$2/GB and continue to drop rapidly, with prices expected to drop to ~$0.5/GB by ~2004-2005. At the same time, single-disc capacities continue to increase, with the expectation of single-drive capacity approaching 500-1000GB by ~2004-2005, which will allow 24-hour 1-Gbps unattended recording.

Disc drives are mounted in standard carriers made for multiple insertion/removal cycles. When modern disc drives are powered down, they are quite robust to external handling forces and can be shipped easily in padded containers. Including the carriers, the shipping weight per disc is $<\sim 1.3$ kg, so that the shipping weight of 16 discs is $\sim$20kg.

2.3. Other Benefits of Disc-Based Mark V VLBI Data System

There are a number of benefits of magnetic discs over magnetic tape:

- Rapid random access to any data
- Essentially instant synchronization on playback into a correlator
- Self contained; expensive tape drives are not needed. Can transparently take advantage of latest disc technology
- Rapidly increasing capacity and decreasing costs of discs

In addition, the system is being designed to fail gracefully with the loss or failure of individual discs. Data from all channels is automatically spread over all discs, so that the loss of a single disc loses only an equal fraction of data from all channels. The number of discs actually used may be anywhere from 1 to 16 depending on the data-rate and data-capacity requirements of a particular experiment.

2.4. Mark 5 Compatibility Considerations

The Mark 5 system is being designed for significant forward and backwards compatibility with existing VLBI systems. For example, data may be recorded with a VSI-compatible interface and re-played into a Mark4/VLBA correlator. Conversely, data may be recorded from a Mark4/VLBA system and re-played into a VSI-compatible correlator.

In addition, it is expected that existing interfaces to S2 recorders can be easily adapted to record on Mark 5B, which can then be re-played into either a VSI-compatible or Mark4/VLBA correlator.

This inter-compatibility among various systems will allow a much broader and more flexible use of existing VLBI facilities throughout the world.

2.5. e-VLBI Support

The Mark 5 system allows easy connection of a VLBI data system to a high-speed network connection. Because the Mark 5 system is based on a standard PC platform, any standard network connection is supported. Depending on the availability of high-speed network connections, this can be accomplished in at least two ways:

1. Direct Station to Correlator: If network connections allow, data may be transferred in real-time at up to 1 Gbps from Station to Correlator, either for immediate real-time correlation or buffering to disc at the Correlator.
2. Station Disc to Correlator Disc: If network connections are not sufficient to allow real-time transmission of data to the Correlator for processing, data may be recorded locally to disc at the Station, then transferred to disc at the Correlator at leisure for later correlation.

Depending on the available network facilities, either entire experiments or small portions of experiments may be transmitted electronically. The latter may be particularly useful for verifying fringes in advance of important experiments.

3. e-VLBI Development

Haystack Observatory has received support from DARPA to demonstrate 1-Gbps e-VLBI over a standard IP-based network between Haystack Observatory and NASA/GSFC. The Westford antenna at Haystack Observatory will be used in conjunction with the GGAO antenna at NASA/GSFC. Data will be transmitted in real-time from both antennas to the Mark 4 correlator at Haystack Observatory for correlation.

Part of the network path is over standard U.S. science network infrastructure, where the network links are shared by other users and the data must traverse many routers and switches. Part of the purpose of this test is to determine the real throughput of these networks under stressful shared conditions. Tests between Haystack Observatory and the Westford have already demonstrated sustained data rates of $\sim$980 Mbps over standard Gigabit Ethernet links through several switches, and we expect to achieve similar rates over the 700 km link between Haystack and NASA/GSFC. The full demonstration is scheduled for late spring 2002.

If these demonstrations are successful, we intend to seek support to extend Gbps e-VLBI to other sites within the U.S. as well as overseas to Europe and Japan.