The "S3" VLBI Data Record/Playback System

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Future scientific applications of VLBI are being planned that will require significantly increased sensitivity in the VLBI systems. Such applications include space VLBI missions in which VLBI observations are to be carried out on rapidly rotating baselines with lengths exceeding 30,000 km. In order to provide the required sensitivity for continuum observations VLBI systems with data rates in the range 1024 Mbit/sec to 8192 Mbit/sec are required. The "S3" VLBI data record/playback system, under development in the Space Geodynamics Laboratory at CRESTech, based on an array of digital video tape transports, will provide user data rates of 1024 - 2048 Mbit/sec with an architecture suitable for upgrading to 4096 Mbit/sec and beyond as advances in tape transport technology permit.

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1. Introduction

Very Long Baseline Interferometry (VLBI) observations of extra-terrestrial objects rely on the reception, recording, and processing of very weak signals, often as weak as 10^{-18} watts or less. Improvements in signal to noise ratios of VLBI observations can be achieved by combinations of reductions in receiver system noise levels, increasing coherent averaging times, increasing antenna apertures, and, for continuum observations, increasing recorded signal bandwidths. Improvements in sensitivity in future space VLBI observations, based on data acquired during space missions characterized by rapidly rotating baselines with lengths exceeding 30,000 km, (see Hirabayashi (2000), Ulvestad (2000)), present VLBI system designers with particularly challenging problems arising in part from loss of correlated flux. Since receiver system performances are approaching quantum limits, and since it is impractical to consider delivering large aperture antennas into high Earth orbit, and since long coherent integration times (achievable in principle by stable, Earth-to-space local oscillator phase transfer methods) will smear the image in the uv plane as a result of baseline rotation; improving the recorded signal bandwidth by large factors appears to be one of the most attractive methods of improving VLBI system performance in preparation for future space VLBI missions. One attractive technique for achieving large increases in recorded signal bandwidth is through the use of arrays of digital tape transports or tape arrays.

2. The "S2" VLBI Data Record/Playback System

The Space Geodynamics Laboratory (SGL) pioneered the introduction of tape arrays into the field of VLBI observations with the development in the early 1990's of the "S2" (System 2) VLBI record/playback system Wietfeldt et al (1996), Cannon et al (1997), Carlson et al (1999). The S2 was developed as an array of eight VHS video tape transports capable of recording 128 Mbit/sec for durations of up to six hours without a tape change. The pioneering efforts of the Space Geodynamics Laboratory to develop high performance, low cost VLBI systems has resulted in more than 55 S2 VLBI data record/playback systems in use in more than a dozen countries world wide, engaged in a variety of radio astronomical and VLBI scientific applications.

3. The "S3" VLBI Data Record/Playback System

The "S3" VLBI data record/playback system, Cannon (2000), is designed as a follow-on generation system to the "S2" predecessor. Like its predecessor the S2, the S3 is based on television industry technology, in particular arrays of digital video tape transports.

The process of selecting tape transports for the tape arrays of a VLBI data record/playback systems such as the S2 and S3 presents the system designers with several choices. Both the television industry and the computer industry appeared to offer a technological basis for developing wide bandwidth VLBI data record/playback systems based on tape arrays.

At the time of the S2 development a choice had to be made between a design implementation based on arrays of video tape transports including VHS and 8 mm and a design implementation based on arrays of computer backup tape transports such as Exabyte that were also available at the time. The option of using arrays of computer backup Exabyte tape transports was never seriously contemplated however.

The decision to develop the S2 system using video technology rather than computer backup technology was arrived at as a result of our assessment of the relative merits of the two. We concluded that the requirement of the television industry to support continuously streaming signals for many hours on end without interruption (referred to in the industry as having to "feed the bear") suggested to us that the television technology was more naturally suited to VLBI applications than the computer backup technology which was designed for sporadic operation as a disc backup which may only occur at intervals of days or even weeks and months. The S2 development team also received anecdotal reports which indicated that attempts to keep digital data continuously streaming off computer back up tapes for hours on end were fraught with difficulties. Difficulties arose as a result of the very high fidelity (low bit error rate) required from computer backup devices, some of which is achieved by automated control processes that interrupt the tape transport operation in order to enforce data integrity requirements. There is no guaranteed minimum data rate on playback from such devices. Others arose from the simple failure of the computer backup tape transports themselves when used in a very high duty cycle environment for which they were not designed.

When considering the S3 system design, an assessment by SGL of several industry standard digital video record/playback systems resulted in the selection of the JVC "D9" (formerly known as JVC "Digital-S") tape transport as the fundamental element in the S3 tape array. The D9 tape transport is an evolutionary upgrade of the VHS tape format used in the S2 VLBI data record/playback system. The half inch tape format of D9 presents users with an optimal combination of durability, bandwidth, and capacity. Video bandwidths of the D9 family of tape transports will increase with time as the video industry upgrades to High Definition (HD) quality recording/playback.

The S3 VLBI data record/playback system consists of an array of eight D9 tape transports. Each of the eight D9 tape transports in the tape array records data at 128 Mbit/sec for a system aggregate data rate of 1024 Mbit/sec. The S3 uses a custom designed signal channel with electronics residing in a standard Compact PCI bus enclosure.

The recording medium for the S3 is a metal particle tape that is provided in standard cassettes which are identical in form to the VHS cassette. The eight S3 cassette tapes record data for approximately 2.5 hours when operating at the full aggregate bandwidth of 1024 Mbit/sec. Cost of recording media is approximately $150 (US) per hour when operated at 1024 Mbit/sec. Longer unattended record durations are possible at reduced bandwidths: 5 hours at 512 Mbit/sec, 10 hours at 256 Mbit/sec, and 20 hours at 128 Mbit/sec on the S3 system.

The S3 VLBI data record/playback system is provided with an optional robotic tape changer that enables long unattended record durations at 1024 Mbit/sec. In its present configuration the S3 robotic tape changer allows unattended operation of the S3 at 1024 Mbit/sec for as long as 65 hours. Using the S3 robotic tape changer, very long unattended record durations are possible at reduced bandwidths: 130 hours at 512 Mbit/sec, 260 hours at 256 Mbit/sec, and 520 hours at 128 Mbit/sec on the S3 system. The S3 robotic tape changer can be equipped with a bar code reader to implement automatic tape inventory management schemes.

4. The "S3-Extended" or "S3-E" 2048 Mbit/sec VLBI Data Record/Playback System

The Compact PCI bus and the S3 architecture will provide for expansion of the S3 system data rate up to 4096 Mbit/sec and beyond as higher data rate tape transports become available. In particular JVC has announced the introduction in late 2000 or early 2001 of the new D9-HD digital video tape transport designed for high definition (HD) television applications. The D9-HD will operate at double the data rate of the D9 and will enable the eight transport tape array of the S3 to be extended to data rates of 2048 Mbit/sec in a version of the S3 which has been dubbed by SGL as the "S3-Extended" or "S3-E" system.

Alternatively the D9-HD tape transport will enable the implementation of the 1024 Mbit/sec "S3" system in a compact array of only four tape transports, a version of the S3 which has been dubbed by SGL as the "S3-Compact" or "S3-C" system.

The use of the S3 robotic tape changer will provide the S3-E with an unattended operation duration of approximately 30 hours at a data rate of 2048 Mbit/sec.

5. The S3 System and the VLBI Standard Interface (VSI)

An international working group under the auspices of the International VLBI Service (IVS) and the Global VLBI Working Group (GVWG) has been meeting for approximately two years in an effort to prepare a specification for a VLBI Standard Interface (VSI) which would enable VLBI data acquisition systems, VLBI data record/playback systems, and VLBI correlators that comply with the interface specification to be "interoperable". The adoption of VSI allows for innovative development of VLBI technology to continue while at the same time ensuring that new VLBI technologies would be readily integrated into the activities of the international VLBI community as they are developed and made available. Agreement on the VLBI Standard Interface specification was recently announced and details may be obtained at *www.crl.go.jp/ka/radioastro/tdc/ivs/vsi/*.

The S3 VLBI data record/playback is being designed to be VSI compliant. SGL plans to interface the S3 1024 Mbit/sec data record/playback system to a pair of S2 VLBI data acquisition systems which are capable of providing an output data rate of 1024 Mbit/sec, matched to the S3 record data rate. SGL has also begun preliminary investigations into possible means of interfacing the S3 VLBI data record/playback system to the new MkIV VLBI data acquisition system and MkIV VLBI correlator which also operate at 1024 Mbit/sec in a standard mode.

6. The "S4" VLBI Data Record/Playback System

Future developments in tape transports can be expected to result in even higher data rate versions of the system, to be referred to by the moniker "S4", which will operate at data rates of 4096 Mbit/sec and beyond.

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