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3.4 REAL-TIME VLBI SYSTEM

3.4.1 REAL-TIME VLBI DATA TRANSFER AND CORRELATION SYSTEM

By

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ABSTRACT

The Communications Research Laboratory and the NTT Telecommunication Network Laboratory Group have developed a highly precise very long baseline interferometry (VLBI) system using a high-speed asynchronous transfer mode (ATM) network. The observed data is transmitted through a 2.488-Gbps ATM network [STM-16／OC-48] instead of being recorded onto magnetic tape. In this system, cross-correlation processing and data observation are done simultaneously, one operator can handle both the observation and the processing. It takes about one hour to analyze the data after the observation and correlation completed. In regular geodetic VLBI experiments run every other day for 24 hours, a horizontal position uncertainty of about 1 mm and a vertical position uncertainty of about 10 mm were achieved. This system is a significant advance in VLBI and should provide more precise information about crustal deformation in the Tokyo metropolitan area.

Keywords: Real-time VLBI, ATM, Correlation system

1. Introduction

We developed an even more precise VLBI[1, 2] system for the Key Stone Project[3] (KSP), to measure crustal deformation in the Tokyo metropolitan area. Three of the four stations are unmanned, while the central station (Koganei) is run by one operator who manages the observation and correlation processing. Two systems with a horizontal accuracy of 1 mm are in operation, and 24-hour VLBI experiments are being run every other day. One system is tape-based, and the other is a real-time system. In the tape-based system, the observed data is recorded on magnetic tape at the observing site, and the tapes are sent to the correlation site by mail. The analysis is done the next day, so it takes at least one day to obtain the measured crustal deformation. This delay is eliminated in the real-time system, which uses an ATM[4] network to send the data. The network has a transmission capability of up to 2.488 Gbps through optical-fiber links. The four stations are connected to this ATM network. The data is transmitted from the remote observing stations to the correlation site, where it is processed in real time. The data is processed using the tape-based correlation processor and the analysis software. This real-time system greatly improves VLBI performance.

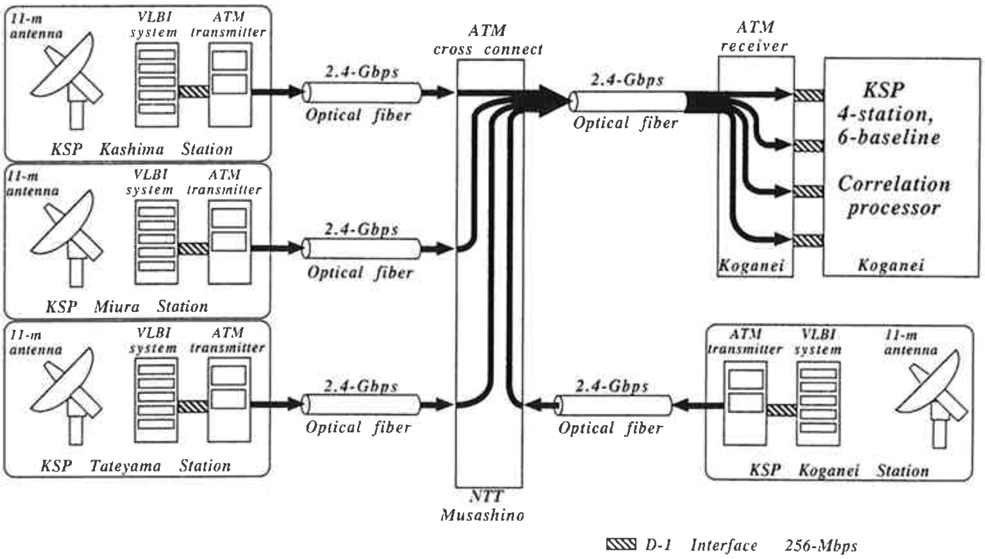

Fig. 1 Block diagram of real-time VLBI system.

2. ATM Network

A block diagram of the real-time VLBI system is shown in Fig. 1. The ATM network transmits the information in fixed-length packets called cells. A cell (AAL type 1) is composed of 53 bytes of data in total, a 5-byte header and a 48-byte payload, with 1 byte used as a sequence number to check for cell loss and mis-delivery. The signals input to the ATM transmitter are written into the payload of the ATM cell in arrival order (Fig. 2). The cell header showing the destination is attached when the payload is filled; the cell is then output to the 2.488-Gbps transmission path [STM-16/OC-48]. The signals from the four stations are transmitted to a cross-connect switch that merges them onto one path. A virtual path identifier (VPI) in the header shows the destination virtual path. It is possible to transmit data at various rates over the same transmission path.

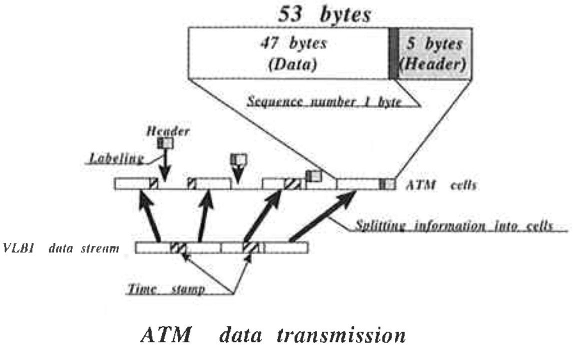
53 bytes
47 bytes (Data)
5 bytes (Header)
Sequence number 1 byte
Header
Labeling
ATM cells
Splitting information into cells
VLBI data stream
Time stamp
ATM data transmission

Fig. 2 Cell transmission in ATM network and cell structure.

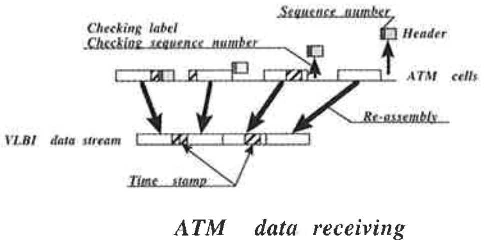
Sequence number
Checking label
Checking sequence number
Header
ATM cells
Re-assembly
VLBI data stream
Time stamp
ATM data receiving

Fig. 3 Cell reassembly in ATM receiver.

In the receiver (Fig. 3), the multiplexed signal (cells) is disassembled, then reassembled into signals corresponding to each station by using the destination in the cell header data. The system has functions that compensate for the transmission-line delay, absorb cell-delay fluctuations, and compensate for mistaken cell delivery and cell loss in the receiver. The delay suffered by each cell depends on the cross-connect switching timing. Therefore, the cell interval is not preserved in the network, so the arrival interval differs from the initial interval. This cell delay variation depends on the number devices the cells must pass through, the data rate, the transmission-line accommodation rate, and the traffic characteristics in the virtual path. The cell-delay fluctuations are absorbed in the receiver by using a 40-kbit buffer memory (more than 100 cells); the cells are reassembled so that the data is regularly spaced, the spacing is equal to that on the transmitter side.

Cell loss or mis-delivery may occur in the transmission of signals through the ATM network. For VLBI, mistaken delivery and cell loss that lead to bit-make and bit-slip actions are considered as fatal errors. If cell loss occurs, the lost bits are re-inserted using the same number of bits, and if a cell is mistakenly delivered, it is removed.

3. VLBI Data Acquisition System

The KSP data-acquisition system (Fig. 4), a high-end version of the K-4/KSP system⁽⁶⁾, has a maximum record-

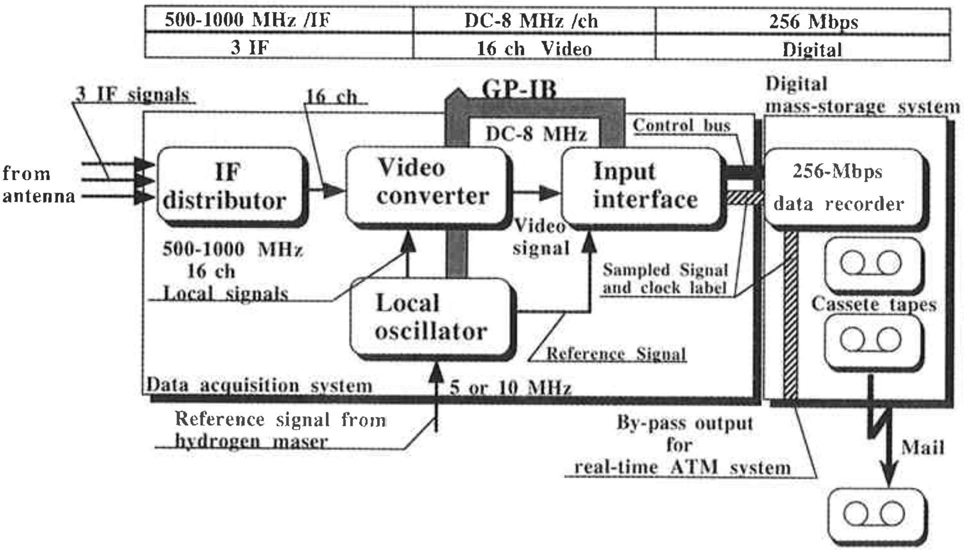
500-1000 MHz /IF
3 IF
DC-8 MHz /ch
16 ch Video
256 Mbps
Digital
3 IF signals
16 ch
GP-IB
Digital mass-storage system
DC-8 MHz
Control bus
from antenna
IF distributor
Video converter
Input interface
256-Mbps data recorder
Video signal
500-1000 MHz 16 ch Local signals
Local oscillator
Sampled Signal and clock label
Cassete tapes
Reference Signal
Data acquisition system
5 or 10 MHz
Reference signal from hydrogen maser
By-pass output for real-time ATM system
Mail

Fig. 4 Block diagram of data-acquisition system.

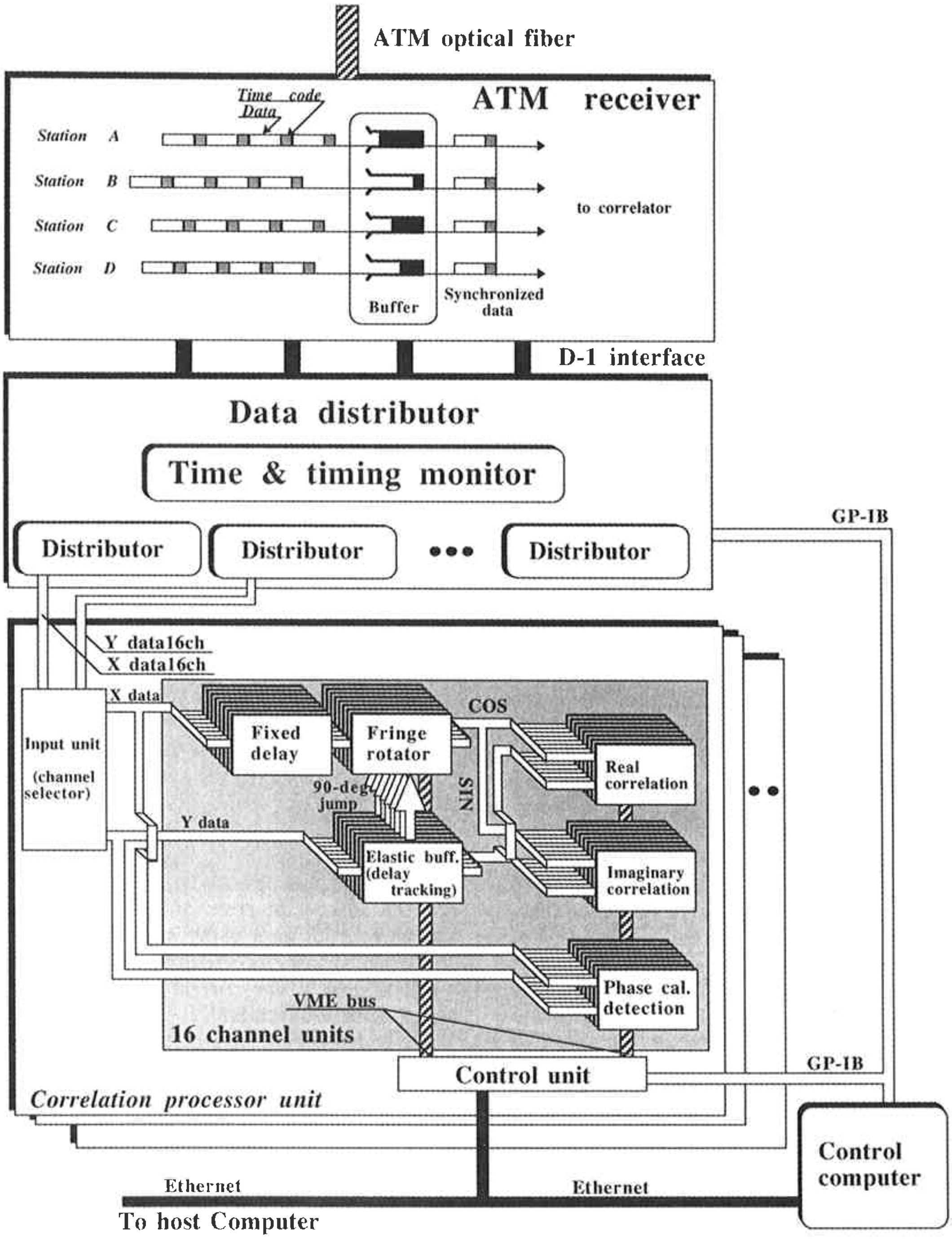
ATM optical fiber
ATM receiver
Time code
Data
Station A
Station B
Station C
Station D
Buffer
Synchronized data
to correlator
D-1 interface
Data distributor
Time & timing monitor
Distributor
Distributor
•••
Distributor
GP-IB
Y data16ch
X data16ch
X data
Input unit
(channel selector)
Fixed delay
Fringe rotator
COS
SIN
90-deg. jump
Y data
Elastic buff. (delay tracking)
Real correlation
Imaginary correlation
Phase cal. detection
VME bus
16 channel units
Control unit
GP-IB
Correlation processor unit
Control computer
Ethernet
Ethernet
To host Computer

Fig. 5 Block diagram of correlation-processing system.

ing rate of 256 Mbps and is fully automatic. It consists of a reference distributor, an IF distributor, a local oscillator, a video converter, an input interface, a data recorder, and a digital mass storage system (automatic tape changer). The local oscillator synthesizes the local frequency signal for the video converter, which converts the windows in the IF-signal (500-1000 MHz) input into video signals. The frequency conversion is done using an image rejection mixer and single-sideband conversion. The input interface samples the video signal received from the video converter and sends the digital data to the data recorder and/or the ATM transmitter together with the time-data, which is phase locked to an external time reference. The input interface quantizes the 16-channel (max.) video signal and produces a data train of 256 Mbps (max.). The K-4 input interface was designed to make the best possible use of the recording ability (up to 256 Mbps) of the K-4 recorder (which uses the ANSI ID-1

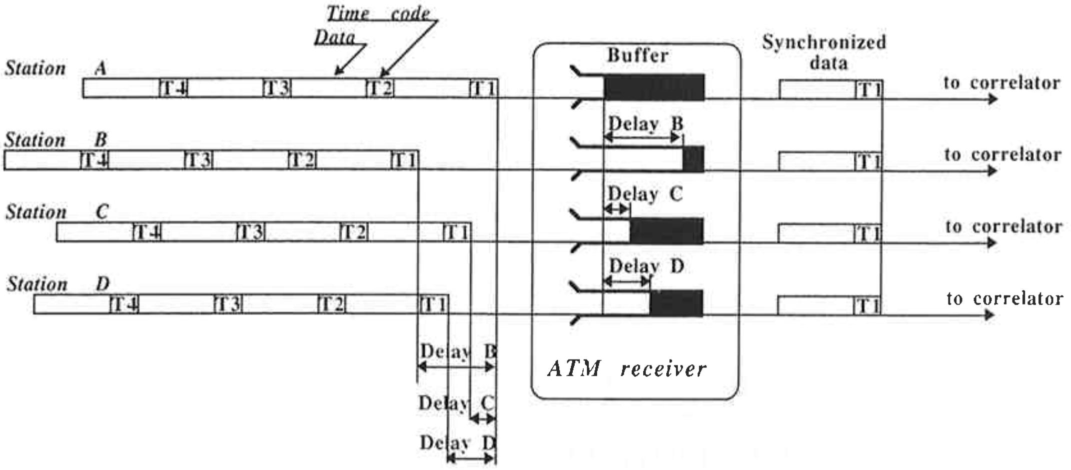

Fig. 6 Data synchronization in real-time VLBI. The data for an identical time taken at different stations differs in arrival time by the difference of the transmission path length. To absorb the transmission path delay, the signal begins to accumulate in the buffer memory from the time when the time stamp is received. The accumulated period in the buffer memory is long when the transmission path is short, and is short when the transmission path is long. The readout of the buffer memory starts immediately after the time stamps from all observation stations have arrived. Thus the timing can be synchronized.

format(7)). The output data rate to the recorder or ATM transmitter is selected from five rates ranging from among 16 to 256 Mbps. Time-code insertion can be done using a uniform bit space or uniform time interval; also no time-code mode can be selected. In real-time VLBI, a uniformly bit-spaced time code is used because it is required on the ATM side. This input interface is also used in the VLBI Space Observatory Program (VSOP). The recorder input, output interface, and ATM interface all followed the ID-1 standard. So the data recorder was able to interface with the ATM. The input/output signal of the ATM transmission system was adapted to the data interface used for the tape-based K-4/KSP system, enabling the tape-based correlation-processing system to be used as a real-time system.

4. Real-time Correlation Processing System

The real-time VLBI correlation system (Fig. 5) processes the data by using a tape-based correlation processor and analysis software. To unify the interface signals of the real-time system with the tape-based system, the real-time system is equipped with a facility for automatic data synchronization in one-bit steps.

In real-time VLBI, the signals are separated by the virtual-path isolating function of the receiver into the signals from each observation station. To absorb the transmission-path delay differences, the data from each station is synchronized in the receiver (Fig. 6). Time stamps composed of the year, day, time, minute, and second and a SYNC code, which is used for time-code recognition, are inserted into the data at regular intervals (every 64 Mbits). To absorb the transmission-path delay, the signal begins to accumulate in the buffer memory from when a time stamp is received. This time stamp is generated by the input-interface(6). Readout starts immediately after the time stamps from all observation stations have arrived, allowing the timing to be synchronized. Because the data is output to the correlator after the timing has been synchronized, the output data for each station is correct up to the time of the time stamp. The size of the buffer memory is 4 Mbytes, sufficient to hold more than ± 5 ms of data (equivalent to a ± 1000-km transmission-path delay). Automatic data synchronization in one-bit steps is there by achieved. The data is distributed by a data distributor, which is not the output interface of tape-based system.

The correlation processing system for the real-time VLBI can use the same correlation system as the tape-based VLBI system. The correlation-processor is an XF type using field-programmable gate arrays (FPGAs) on a VME board. The correlation processor (Fig. 5) is composed of an input unit, 16 channel units, and a control unit. They are assembled on VME boards. The delay-tracking functions in each unit (channel), are independent of the frequency, come together in the input unit. One of the 16 channel units is a 32-complex-lag correlator with a 32-MHz clock.

5. System Check

To investigate the applicability of an ATM network to a VLBI system, we conducted various tests.

A bit-error rate check was run using a man-made test data. Test patterns were generated and sent from the transmitter side to the receiver side for more than 24 hours. No bit errors were detected.

Geodetic results were compared with those of the tape-based and real-time systems. The real-time and tape-based comparisons were run simultaneously using the KSP network. The data bypass facility of the data recorder made it possible to run them simultaneously. Cross-correlation processing was done simultaneously with

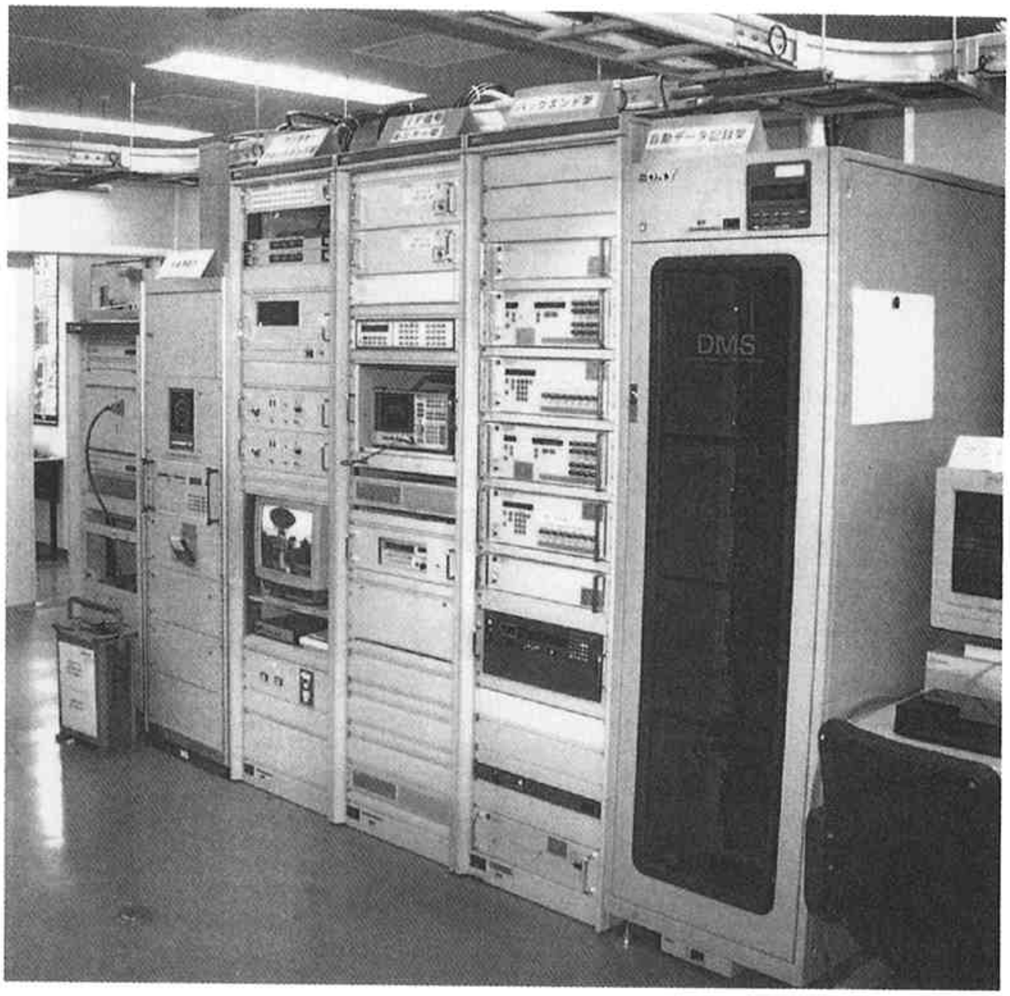

Fig. 7 Photograph of data-acquisition system. Shown from left is the ATM transmitter, the weather-monitoring equipment rack, the antenna-control equipment rack, the receiver-control and monitoring equipment rack, the backend equipment rack, and the digital mass-storage system. Three IF signals are received by IF receivers in the receiver-control and monitoring equipment rack. They are sent to an IF distributor in the backend equipment rack. Two sets of video converters (500 - 1000 MHz: 8 ch／unit) convert the signals to video signals. The video signals are sent to the input interface (black panel), and the digital data is sent to the digital mass-storage system. The data is recorded on magnetic tapes or sent to the ATM transmitter.

observation. The data rate selection; 256, 128, 64, 32, 16 (Mbps), of the ATM was automatically synchronized to input data. After correlation, the data was analyzed using the SOLVE 5.0 and CALC 8.1⁽⁸⁾ software developed by the Goddard Space Flight Center. The IERS standards⁽⁹⁾ were used for the model calculation. The Earth rotation parameters (ERP) for the *a priori* calculation were obtained from the IERS forecast data. The signal sources were 16 stars. Over 100 observations were made over five hours. The differences between the results obtained using the real-time and tape-based systems were less than 2 mm along the baseline vector and 2 mm along the baseline length. The correlated amplitude using the tape-based system was coincident with that of the real-time system. There were no effective differences between the results of the two systems.

For four 22-hour real-time VLBI experiments, we obtained a formal error in the baseline length (109099656.11 mm) of 1.78 mm and a station position error (in vector) of less than 1.8 mm. The RMS of the residual delay from the fitting line using daily experimental data was 1.3 mm, which is within the formal error (1.8 mm).

6. Conclusion

A photograph of the data-acquisition system is shown Fig. 7. The photograph in Fig. 8 shows the real-time correlation system. The KSP system uses two data-transfer systems: a tape-based system and a real-time system. Both systems were designed to be fully automatic, so only one operator can handle both the observation and correlation processing. The two systems can be operated simultaneously. Using the tape-based system, we ran 5-hour experiments daily starting in January 1995. The real-time

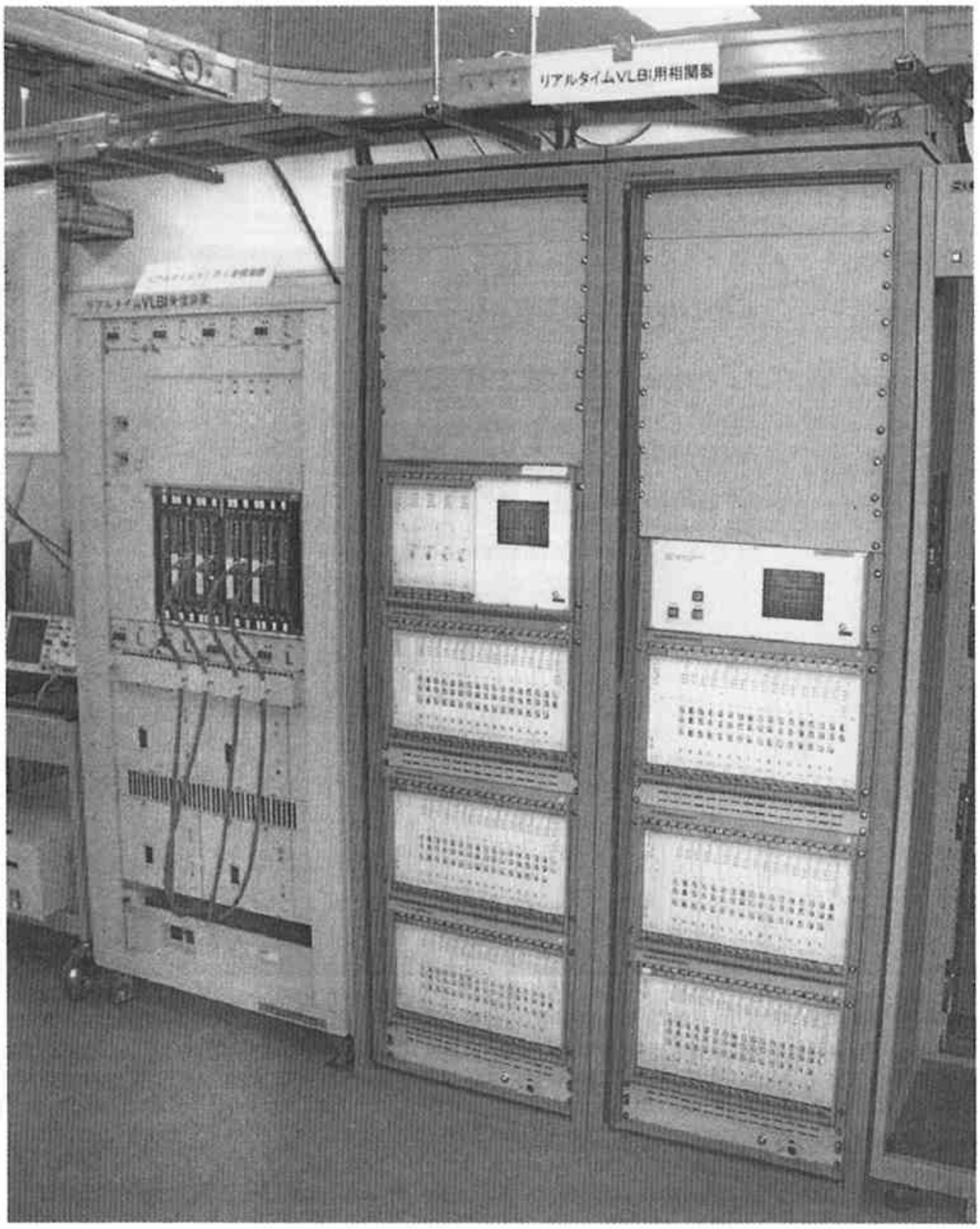

Fig. 8 Photograph of correlation system. On the left is the ATM receiver and on the right are two correlation-processor racks. The correlators are the lower three units in each correlation-processor rack.

VLBI system has been used instead of the tape-based system since April 1997. Following a continuous 120-hour 256-Mbps test session (from July 28 to August 1, 1997), a 24-hour experiment has been run every other day starting September 30, 1997. In regular geodetic VLBI experiments run every other day for 24 hours, a horizontal position uncertainty of about 1 mm and a vertical position uncertainty of about 10 mm were achieved. The obtained results are available to the public via the Internet (http://ksp.crl.go.jp).

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