Real-Time VLBI System Using Public Communication Lines

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Abstract A real-time VLBI (Very Long Baseline Interferometer) system using public communication lines is proposed for diagnosis of VLBI facilities and a research of atmospheric radio wave propagation. Since the system uses narrow band waves such as beacon waves from geostationary satellites or maser emission from cosmic sources, it is possible to transmit data through public communication lines in real time. To evaluate the performance of the system, the beacon waves have been received using Kagoshima 6m and Mizusawa 10m radio telescopes, and the efficacy of the system has been confirmed.

1. Introduction

A VLBI system is widely used for geodesy and radio astronomy [1]. In a tape-based VLBI system, observed data are recorded on magnetic tapes at observing sites, and the tapes are sent to the correlation site by mail. It takes several days to get results of the correlation processing. If there were malfunctions in the VLBI facilities, they are not found until the results are obtained. This inefficiency in VLBI observation requires the development of a diagnostic system by which the VLBI facilities can be checked simultaneously with the observation. Moreover, the accuracy of VLBI observation is much influenced by the fluctuation of atmosphere. If the fluctuation can be monitored in real time, it is possible to change the observation schedule dynamically to improve the efficiency of overall observations. In this report, a real-time VLBI system using public communication lines is proposed and experimental results to evaluate the performance of the proposed system are discussed.

2. Real-time VLBI system

A block diagram of the real-time VLBI system to be developed is shown in Fig.1. The system consists of receivers for usual VLBI observation and a newly developed sub-system composed of A-D converters, data communication devices and computers for data processing.

2.1 Radio waves received

For the real-time diagnostic system for VLBI using tens-kbps communication lines, narrow-band radio waves such as beacon waves from geostationary satellites are used. For the research of atmospheric radio wave propagation, cosmic

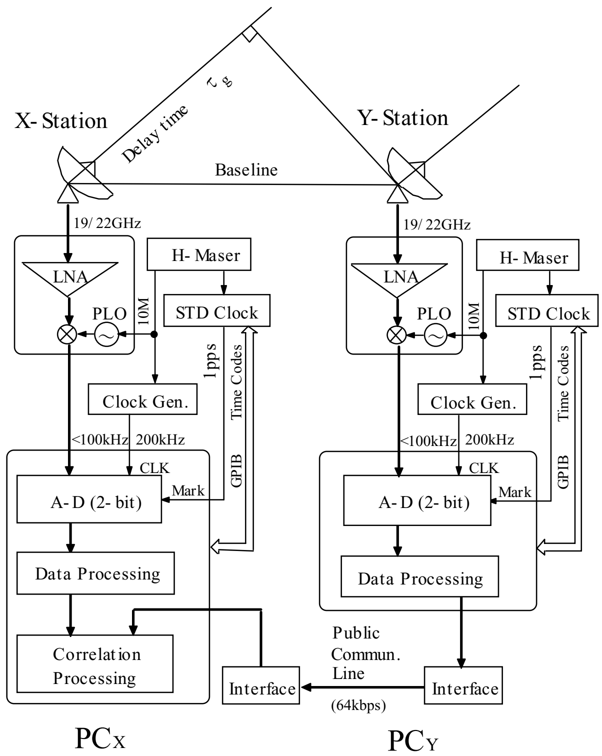

Fig.1 Block diagram of the real-time VLBI system

maser emission of about 100 kHz bandwidth is also used.

2.2 Receivers

Each of the receivers consists of a low noise amplifier (LNA), frequency converters using a phase locked oscillator (PLO), a hydrogen maser (H-Maser) oscillator and a standard clock (STD Clock). In usual VLBI systems, a received signal is converted into the range from several MHz to tens MHz. In our system, however, it is converted into the range of several tens kHz, which is given by the lower limit of the VLBI receiver output.

2.3 A-D converter

The analog signal from the receiver is transformed into 2-bit digital data by an A-D converter. The sampling frequency is set at 200 kHz so that cosmic maser emission of about 100 kHz bandwidth can be used as an input signal. The sampling clock is supplied from a clock generator using a 10MHz signal of the hydrogen maser oscillator.

The time when A-D converting starts is recorded as Time Codes referring a standard clock via GPIB. The output of A-D converter is composed of 3- byte time codes followed by a sequence of 3–bit datum. Each datum consists of 1 bit of 1 pps signal and 2 bits of observed signal.

2.4 Data processing

In order to transmit data through communication lines of several tens kbps, the following data processing is performed in a personal computer. Figure 2 shows the data formats in each data processing.

At first, the signal extraction from the output of A-D converter is made by an $N_{\rm ex}$ -point FIR band pass filter. Next, the extracted signal is down-sampled with the scaling factor $1/N_{\rm ds}$ as shown in Fig.2(2). When the frequency of the extracted signal is f_B, the frequency of the down-sampled beacon wave is given by

$$f_{\rm B}' = \left| f_{\rm B} - \frac{f_{\rm AD}}{N_{\rm ds}} \left[\frac{f_{\rm B} N_{\rm ds}}{f_{\rm AD}} + 0.5 \right] \right| \qquad (1)$$

where [•] denotes to get the maximum integer less than the value in the bracket.

The data are divided into a sequence of cells for 1 second, and all the 1pps signals are deleted. As shown in Fig.2 (3), time identifiers and time codes are added to every head of the cells for time synchronization in the correlation processing.

2.5 Data transmission

The block diagram of data transmission is shown in Fig.3. The computers are connected to ISDN by TA (Terminal Adapter) and DSU (Digital Service Unit). The data cells are transmitted by FTP.

2.6 Correlation processing

To diagnose the VLBI facilities, the cross-spectrum is calculated. The correlation phase variation is also calculated to detect the variation of the path length caused by atmospheric distur-

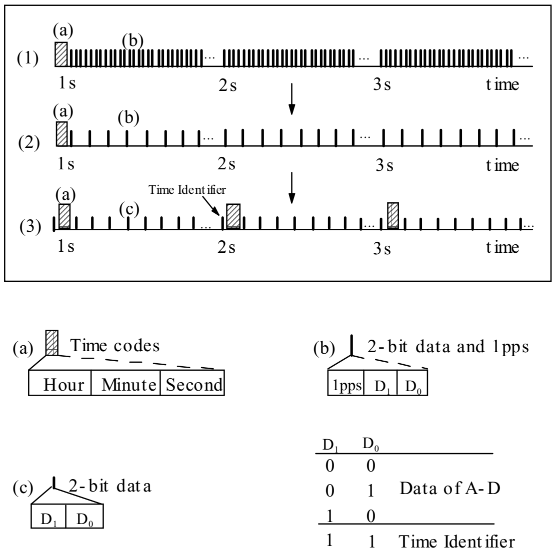

Fig.2 Data format

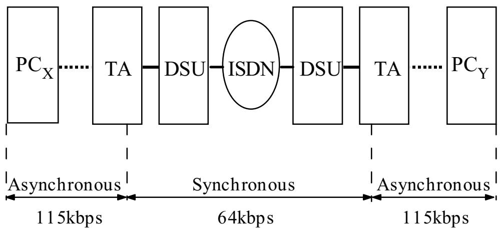

Fig.3 Data transmission

bance. Since the sampling frequency is low, the correlation processing is made by software.

For the data, $X(n)$ and $Y(n)$, at the stations X and Y, the cross-correlation function $C_{XY}(l)$ is given by

$$C_{\rm XY}(l) = \frac{1}{N_{\rm cor}} \sum_{n=1}^{N_{\rm cor}} X(n) Y(n-l) \qquad (2)$$

where l is the number of lag and $N_{\rm cor}$ is the number of the processed data. The cross-spectrum of $C_{XY}(l)$ can be obtained by FFT.

2.7 Fringe stopping

The frequencies of $X(n)$ and $Y(n)$ are different because of the Doppler effect caused by the different relative motion of the satellite to the stations X and Y. The Doppler shift f_R is given by [1]

$$f_{\rm R} = f \cdot \frac{\Delta L(t_2) - \Delta L(t_1)}{c \cdot (t_2 - t_1)} \qquad (3)$$

where f is the frequency of the beacon wave of the satellite, ΔL is the difference of the path

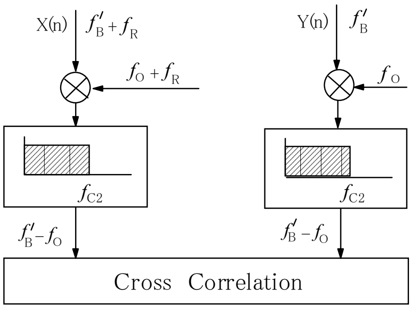

Fig.4 Fringe stopping

lengths between the stations X and Y from the satellite, t_1, t_2 are observation time, and c is the velocity of light. Since the Doppler shift f_R, which is several Hz, is very small compared with $f_B{}'$ of the beacon waves, addition or subtraction of a local frequency $f_0 >> f_R$ is made to both signals, and f_R is added as offset to one of the signals. A flow chart of the frequency compensation, i.e., the fringe stopping, is shown in Fig.4.

3. Experiments

3.1 Experimental system

Experiments to evaluate the performance of the system to be developed is done for beacon waves of about 19GHz for four satellites, Super-

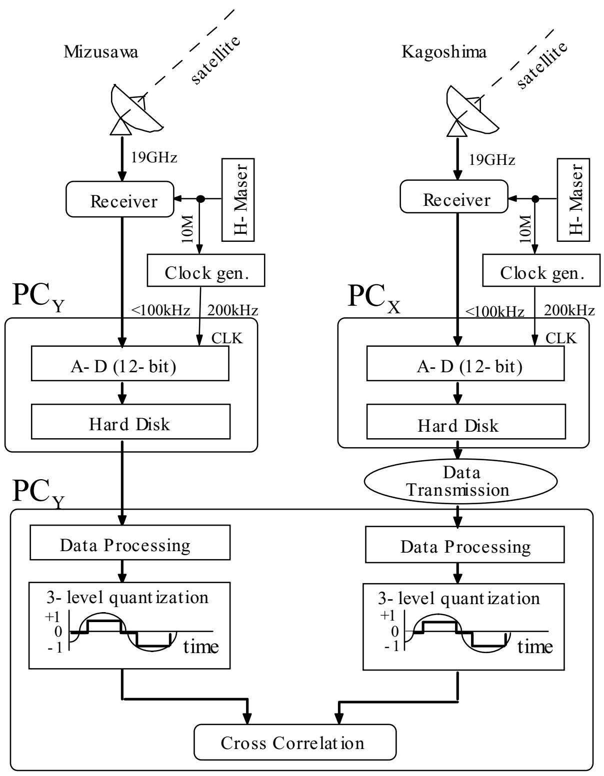

Fig.5 experimental system

Table 1 Experiment parameters

Parameter	Symbol	Value
Beacon wave freq. At A-D input	f_B	67.1k
Lower cutoff freq. Of BPF	f_1	62.1k
Upper cutoff freq. of BPF	f_2	72.1k
Local frequency	f_0	5k
Number of sample points of BPF	N_{ex}	21
Scaling factor in down-sampling	$1/N_{ds}$	1/10

bird-A, Superbird-B, Nstar-a, Nstar-b, on Oct. 19, 1999. The sub-systems were connected to the Kagoshima 6m and the Mizusawa 10m radio telescopes. The system was almost the same with the proposed one except for inputting the dada with general-purpose 12-bit A-D converters instead of the 2-bit A-D converters and recording the raw data into hard disks before data transmission to make a detail analysis. The experimental configuration is shown in Fig.5.

3.2 Results and discussion

The observation was done for 5 minutes a satellite. The data were transmitted from Kagoshima to Mizusawa by FTP. Then, extraction of the beacon waves, re-sampling and 3-level quantization were done.

The fluctuation of the cross-correlation phase was obtained by integration over 0.1 second. The experiment parameters are shown in table 1. The experimental results for Nstar-a are shown in the following.

The cross-spectrum obtained is shown in Fig.6. The peak at 2.1kHz agrees with that calculated using f_0=5kHz and Eq.(1).

The fluctuation of the cross-correlation phase without fringe stopping is shown in Fig.7 (a). It varies at a rate of 3.0Hz, which is nearly equal to the value of 3.007Hz calculated by Eq.(3). Results after the compensation for the Doppler shift are shown in Figs.7 (b) and 8. Figure 8 shows that there remain two kinds of magnitude of the

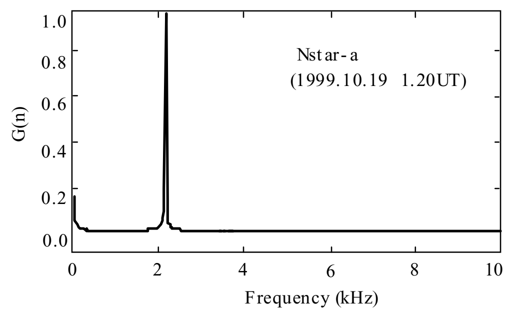

Fig.6 Cross-spectrum

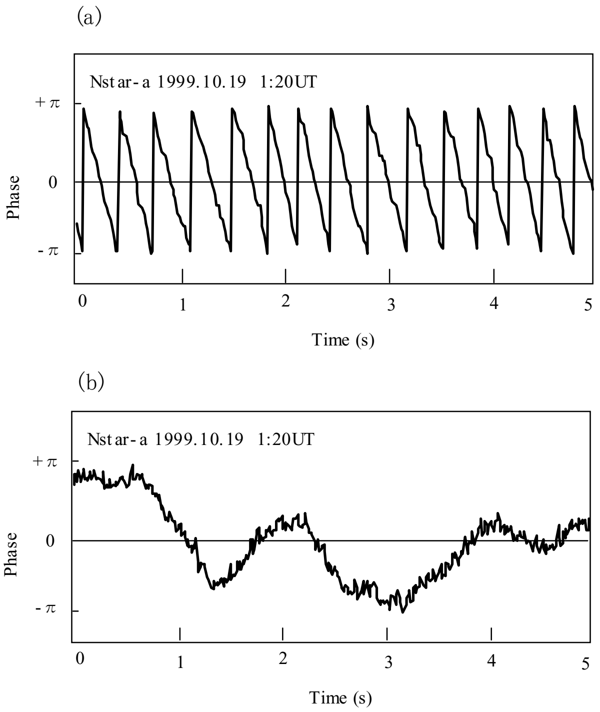

Fig.7 Time variation of cross-correlation phase. (a) without fringe sopping and (b) with fringe stopping.

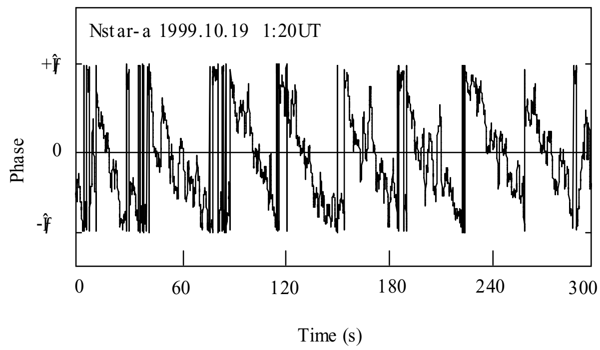

Fig.8 Time variation of cross-correlation phase of 5 minutes. The fringe stopping was done.

time variation of phase. That of the order of 1Hz is probably caused by fluctuation of the atmosphere [2] and by the instability of the observation facilities. That of about 0.03Hz is probably caused by the uncertainty of the orbital elements of the satellite. Further studies are required to identify the origin of these phase variations.

4. Conclusions

The real-time VLBI system using public communication lines was proposed. A prototype sub-system was connected to the Kagoshima 6m and the Mizusawa 10m radio telescopes, and the beacon waves of the satellites were received. The cross-spectra were obtained in 1 second, and the fluctuation of the phase for 5 minutes was obtained in 20 minutes. The bit rate is 40kbps, data of which can be transmitted through public communication lines such as ISDN. It is concluded that VLBI facilities can be diagnosed in real time and that the variation of the atmospheric radio wave propagation can be monitored in nearly real time. This system for beacon wave observation will be also applied to a diagnostic system for international VLBI.

Acknowledgments

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