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II. OVERVIEW OF THE EXPERIMENT SYSTEM

II.3 THE WESTERN PACIFIC GEODETIC PROJECT'S DATA ACQUISITION AND PROCESSING SYSTEM

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ABSTRACT

Research into crystal oscillators has made remarkable progress in recent years, and the stability of selected such oscillators can reach 3×10^{-13}, a value comparable with the stability of the atmosphere. Instead of a hydrogen maser, a carefully selected crystal oscillator phase locked to a cesium frequency standard for 100-second time ranges was adopted as the time and frequency standard of a geodetic Very Long Baseline Interferometry (VLBI) experiment. The VLBI system operated in Marcus island, had to be transportable, especially the reference clock and data acquisition systems. The K-4 system uses a rotary-head cassette recorder that makes the system smaller and easier to operate. The system is a compact VLBI terminal, one fourth the weight and one fifth the size of the Mark-III and K-3 systems. The K-4 system can be made fully output-data compatible with the Mark-III and the K-3 systems by using input- and output-interface units. The correlation processing was handled by K-3 correlation processor. VLBI experiments were carried out for four years (from 1988) using these systems at a baseline of 1000 km+. The position of Marcus island was successfully detected within 5 mm, and its site velocity within 5 mm/year.

Keywords: K-4, data acquisition terminal, correlation processor

1. Introduction

It is difficult to transport a hydrogen maser and a K-3/Mark-III terminal for a temporary VLBI experiment to a remote island such as Marcus island. The frequency standard used for VLBI must be stable both for long time ranges (more than 100 sec) and for short time ranges (less than 100 sec). Short time-range stability is essential for maintaining coherence, and long time-range stability is necessary for regulating the durations of observations. Since the stability of the atmosphere as measured by VLBI is approximately 10^{-13} ($\tau < 1000$ sec), atmospheric-phase scintillation degrades the coherence of VLBI data, which is independent of the phase fluctuation of the reference signal. Research into crystal oscillators has made remarkable progress in recent years, and the stability of

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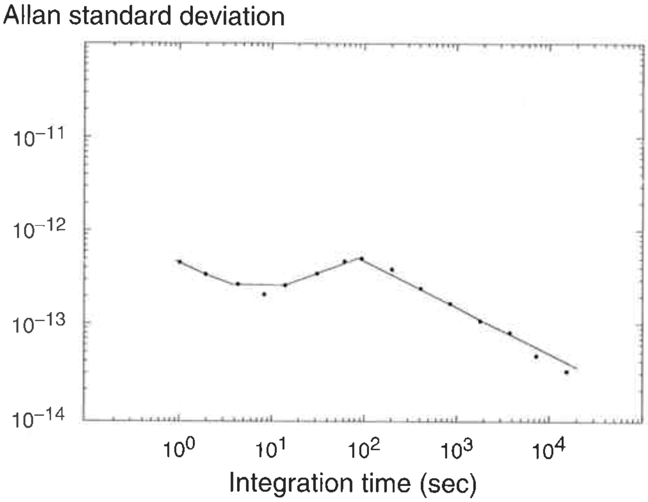

Fig. 1 Measured stability of the cesium-crystal system

selected crystal oscillators can reach $\sigma_y(\tau < 100\ \text{sec}) = 3 \times 10^{-13}$, which is comparable to the stability of the atmosphere. A new frequency system, which utilizes a selected crystal oscillator phase locked to a cesium frequency standard (a cesium-crystal system) was produced for time ranges of over 100 seconds, because the stability of the cesium frequency standard is better than that of the crystal oscillator over long time periods.

In general, the standard K-4 system is equivalent to the Mark-IIIa system, but we adopted a rotary-head cassette recorder in place of the stationary-head open reel recorder. This concept is conducive to high performance for error free recording and ease of operation in VLBI experiments. The standard K-4 system has become the main VLBI data acquisition tool for domestic VLBI experiments in Japan. Both the cesium-crystal system and the standard K-4 system, have been operated at remote Japanese islands in Antarctica. After a large quantity of data has been acquired on magnetic tape by a VLBI data acquisition terminal, it should be processed by a correlation processor. In our case, the processor used was a K-3.

2. The Cesium-Crystal System

The stability of the frequency standard used for short time periods is an important factor in maintaining the coherence of received signals in VLBI experiments. However, VLBI observations made from the ground always suffer from the effects of atmospheric scintillation, resulting in a loss of coherence. Therefore, the stability of the atmosphere determines the limit of the frequency standard for short time-range. The stability of the atmosphere was determined to be about 1×10^{-13} at 100 sec by VLBI. The stability of the hydrogen maser at 100 sec is 1×10^{-14}, which is sufficiently stable compared with the atmosphere, while recent technological progress has produced crystal oscillators with stabilities of 3×10^{-13} (BVA style AT-cut resonator(1)), which is almost the same as atmospheric scintillation.

In considering the potential use of the crystal oscillator as a frequency standard for short time-range VLBI, the coherence loss Lc due to the instability in the frequency standard for 100 sec

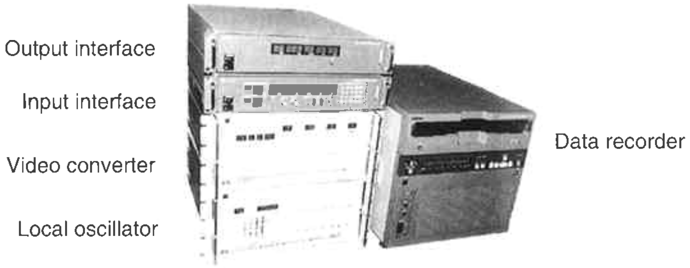

Fig. 2 The (standard) K-4 system

integration intervals can be estimated(2)(3). The calculated losses for the hydrogen maser and the crystal oscillator at integration intervals of 100 sec are 0.000123 and 0.041 respectively, which are small enough. However, long term stability of the frequency standard is necessary for regulating the results of each observation during analysis. Although the long term stability of the crystal oscillator is not acceptable for VLBI, the high performance cesium frequency standard has superior, and sufficient stability in the long term ($\sigma_y(\tau > 100) \leq 3 \times 10^{-13}$). If only the cesium frequency standard is used in VLBI experiments, however, it is impossible to maintain the coherence of the X band signal, as the stability of the cesium standard during short term signal integration is worse than $\sigma_y(1) = 10^{-12}$. Hence to satisfy the requirements of VLBI, a frequency standard is needed, which has the stability of the crystal oscillator for short time ranges and the stability of cesium for long time ranges. This can be created by using a crystal oscillator with its phase locked to a long time range cesium frequency standard. Figure 1 shows the measured stability of this cesium-crystal system. Results show that the crystal oscillator has good short-term stability but is inferior to the cesium frequency standard in the long term, while a cesium standard has excellent long-term stability but it is unusable for X band VLBI experiments. Therefore it can be seen that the combined cesium-crystal system meeting both requirements is better.

The optimum integration time depends on the stability of the crystal oscillator ($\sigma_y(1) = 4 \times 10^{-13}$) and that of the cesium frequency standard ($\sigma_y(1) = 3 \times 10^{-12}$). When using high performance commercial cesium, {SNR * coherence} reaches a maximum at about a 120-sec integration time. Since at that point the clock error is less than 0.05 nsec, it can be said that the optimum integration time for the system is 120 sec.

3. The K-4 Data-Acquisition System and Correlation Processing

The K-4 system consists of the following: (1) local oscillator, (2) video converter, (3) input-interface, (4) output-interface, (5) data recorder. This standard K-4 system (Fig. 2) is the first generation K-4 system. These systems use rotary-head cassette recorders that make them system smaller and easier to operate. At CRL, we are developing a new K-4 system multi-bit sampling, digital filter, and high-speed sampling capabilities. In this report we introduce only the first generation K-4 system. The standard K-4 system is a compact VLBI terminal, one fourth the weight and one fifth the size of the Mark-III and K-3 systems. The standard K-4 system can be made fully output-data compatible with the Mark-III and the K-3 systems by using input- and output-interface units. These units are compact and compatible with the Mark-III system. A block diagram of the data acquisition system is shown in Figure 3. The local oscillator synthesizes the local frequency signal for the video converter. The video converter converts one window in the intermediate frequency (IF)

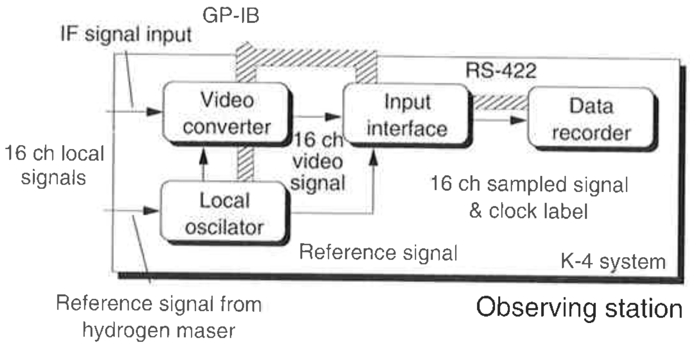

Fig. 3 The data acquisition site

signal (100–500 MHz) input into a video signal (0–2 or 4 MHz). The frequency conversion is achieved by an image rejection mixer using single sideband conversion. These blocks are the equivalents of the IF distributor, video converters (16 channels) and reference distributor of the Mark-III system.

The input-interface unit is used for data acquisition and recording at the VLBI observing station. It samples the video signal from the video converter, and sends the digital data to the data recorder together with the time data, which is derived from the external time standard signal. The output-interface unit is used at the correlation processing site. It converts the reproduced data into the appropriate output format, and sends it to the correlator. A format compatible with the Mark-III format is provided. Furthermore, another format which provides only digitized raw data signals, is provided for KSP correlator system (under development). When multi-baseline correlation processing is conducted, all the output-interface units are automatically synchronized with the main output-interface unit.

The two interface units mentioned make it possible to interface with current VLBI systems.

3.1 The Video Converter & The Local Oscillator

The local oscillator synthesizes the local frequency signal (500–1000 MHz in 10 kHz steps) for the video converter. The measured phase noise, which is calculated according to the measured Allan variance, is better than 3 deg. Coherence loss caused by this phase instability is less than 0.04%. The video converter and local oscillator are in commercial use as the first generation of the K-4 analog circuitry. The video converter converts windows in the IF signal input (100–500 MHz) into video signals (0–2 or 4 MHz). The frequency conversion is conducted by a single side-band image rejection mixer.

3.2 The Input-interface Unit

The input-interface unit samples the 16-channel (max.) video signal, and sends the sampled data to the data recorder proceeded by a time-data block. This format is quite different from that of the Mark-III. It was designed to make the best use of the K-4's recorder's abilities.

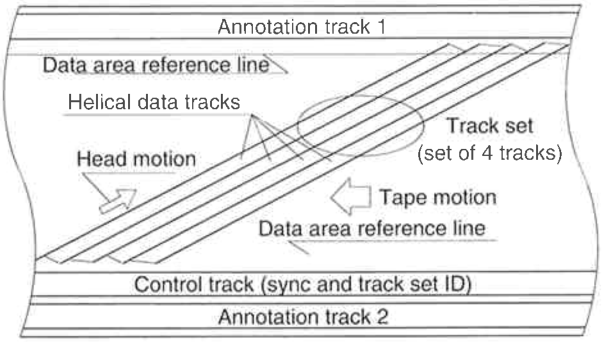

Fig. 4 Tape format and data format

3.3 The Data Recorder

A rotary-head recorer using a cassette tape (American National Standard 19 mm Type ID-1 Instrumentation Digital Cassette Format) was adopted. It is possible to read error rates from the data recorder whilst recording and replaying through the host computer. Helical scan recording is used to record digital signals at a high rate. With an L-size cassette, the K-4 recorder can provide up to 770 Gbits of data storage capacity at a recording rate of 64 Mbit/sec with a maximum recording time of 200 minutes (L-size cassette, 16 μm). Recording and playback are possible at different rates: 256, 128, 64, 32, 16 (Mbps), making the recorder suitable for many different applications. Superior Reed-Solomon error correction is performed by using custom encoder and decoder chips. The playback heads are located so that the recorded data can be played back immediately. This read-after-write facility makes it possible to monitor recording errors in real time. After correction, a bit error rate of less than 1×10^{-10} is achieved. The unit employs a built-in diagnostic system, designed to detect operation errors or hardware faults. Any error message or warning is fed into the host computer via the remote control interface, and from there to the front-panel display.

3.4 The Correlation Processing System

The K-4 recorder has helical data tracks, two longitudinal annotation tracks and a control track (Fig. 4). The track-set ID numbers are recorded on the control track, and can be read at any tape speed even during fast forward or rewind. The output-interface unit can control the synchronous replay of several data recorders, convert the track-set ID's for the data clock, and send the data to a correlator.

In multi-baseline correlation processing (Fig. 5), all of the output-interface units are daisy-chain connected via General Purpose Interface Bus (GPIB) and a timing control line. Therefore, the tape position data and the status data of all of the recorders can be exchanged via the output-interface units. The data played-back by the data recorder is written into a memory buffer. The main replay system (the main output-interface unit and the data recorder) and the sub-replay systems (the sub output-interface units and data recorders) can be synchronized in one-bit steps. The delay adjustment handled by controlling the buffer-memory (4 Mbits) and subsequent programmable shift registers (PSR). The signal (raw data) is unformatted instead of in Mark-III format.

The phase-difference measured between the playback and the external signals sent from the main replay system is monitored by the clock. The data measured is then sent to the main replay

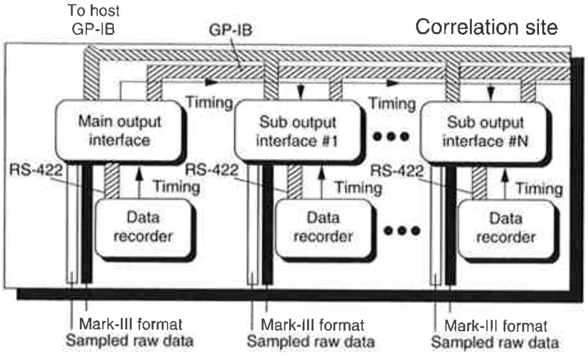

Fig. 5 The data processing site

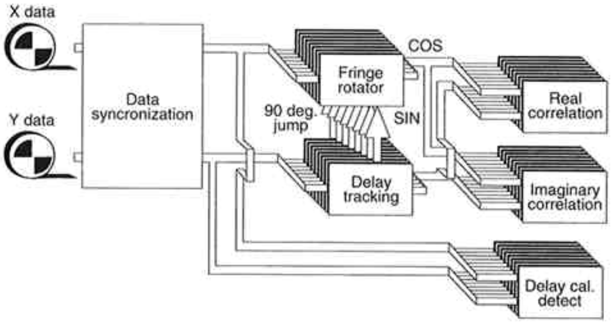

Fig. 6 The correlation processor

system, and used for bit synchronization (fine synchronization) between the main and sub-replay systems.

The cross correlation is carried out with an XF type K-3 VLBI correlation processor (Fig. 6), completed in 1984, which was designed to interface with the K-3/Mark-III data recorder. The K-4 output-interface is designed to be compatible with the K-3 Mark-III data recorder, and the output-interface unit has automatically data synchronization capability.

4. The Marcus Experiment

Experiments between Kashima and Marcus islands, (the most south-easterly points in Japan), were carried out once a year for four years as part of the Western Pacific Geodetic Project. At the Marcus island station, a 10 m diameter S/X dual band receiver was constructed. Since Marcus island is an isolated coral-reef island in the Pacific ocean, the station was not permanently manned all the VLBI observation equipment, including the frequency standard system and the data-recording system, were transported to the site each year from CRL. The VLBI system, which consists of the K-4 VLBI sub-system and the cesium-crystal sub-system, is quite compact and therefore has many advantages in operations such as this experiment where mobility is important. The present system is

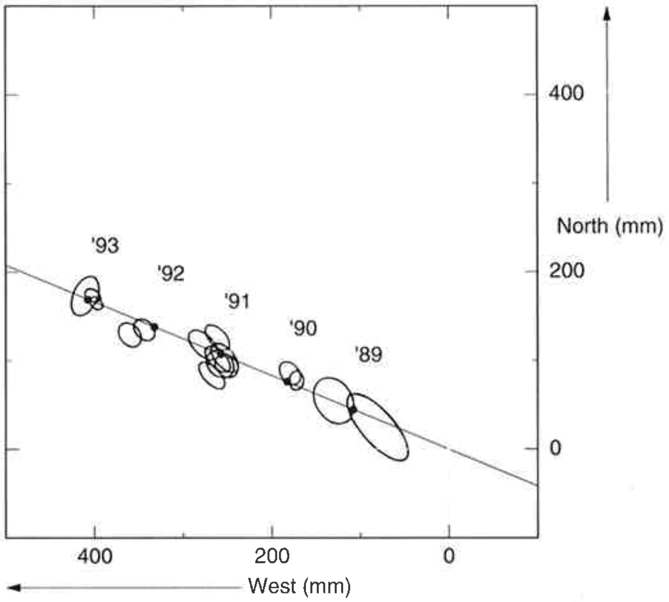

Fig. 7 Estimated positions and their 1 σ margins of error of the Marcus station are shown on the horizontal plane. (The cesium-crystal system was used as a reference signal from 1989 to 1992, and a hydrogen maser was used in 1993).

the smallest VLBI data acquisition system in the world. The K-4 is a data acquisition system which developed at CRL for transportable VLBI station applications. The frequency stability of the integrated frequency standard system is poorer than that normally found in a hydrogen maser, but provided a properly designed observation schedule is used, the overall results of geodetic VLBI measurements are comparable to those obtained during conventional experiments. To compensate for the poor frequency stability, only strong radio sources were selected and the recording time for each observation was restricted to 150 seconds (typical integration time is 120 seconds), thereby increasing the total number of observations.

Good fringes were obtained using this system. The baseline lengths at the epoch (1991.1.1), and their rates of change were estimated by a linear fit by applying least square residual method to the data. The results of the estimated rates were then compared with the expected values provided by the plate-motion model. The baseline length was determined within 5 mm and the site velocity was determined within 5 mm/year. These results are shown in Fig. 7. The excessive baseline measurements of Marcus may represent the west ward motion of the Marcus station with respect to the inner area of the Pacific Plate. The Marcus station was shut down after the last experiments in 1993.

We transported a hydrogen maser (CH1-75: made in Russia) to Marcus island in 1992 and in 1993. In 1992, the hydrogen maser did not work due to problems with the air conditioner, but we managed to carry out the experiments using the cesium-crystal system. In 1993, the experiments were carried out using the hydrogen maser, and the results were consistent with those using the cesium-crystal system for the previous three years. The results show the effectiveness of using a cesium-crystal system as the VLBI frequency standard (even for VLBI experiments with baselines of over 1000 km).

5. Summary and Conclusion

In the Western Pacific Geodetic Project, on Marcus island, an isolated coral reef island in the Pacific ocean, all VLBI observation equipment, including the frequency standard system and the data recording system, were transported to the site from CRL each year. The VLBI system used which consists of the K-4 VLBI sub-system and the cesium-crystal sub-system, is quite compact, and therefore has many advantages in experiments like this, where mobility is important. This system is the smallest VLBI data acquisition system in the worlds, and was also accurate enough to allow us to detect the position of Marcus island within 5 mm and its site velocity within 5 mm/year.

References

(1) A.E.E. Rogers, "The sensitivity of a very long baseline interferometer," Radio Interferometry Techniques for Geodesy, NASA Conference Publication 2115, 1980.

(2) H. Kuchi, J. Amagai, S. Hama, T. Yoshino, N. Kawaguchi, and N. Kurihara, "Instrumental delay calibration by zero baseline interferometry for international VLBI time comparison," J. Rad. Res. Labs., **34**, 143, pp. 115–139, November 1987.

(3) J. Amagai, H. Kiuchi, and N. Kawaguchi, "Short baseline experiment using the highly transportable VLBI station," IEEE-IM Special issue, April 1989.