Recent VLBI activities at the Communications Research Laboratory, Japan

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Abstract

Communications Research Laboratory (CRL) has led the development of VLBI technique in Japan and is keeping high activities in both observations and technical developments. CRL has promoted Key Stone Project (KSP) dedicated to monitoring the crustal deformation around the Tokyo metropolitan area using the space geodetic technique such as VLBI and SLR. In the KSP, real-time VLBI technique was developed and it has been applied to form a large big radio telescope connected by a high speed communications link. As for the next generation VLBI terminal, the Giga-bit VLBI system consisting of a high speed sampler (1Gsps/4ch/2bit) and a high speed digital data recorder (1024 Mbps) has also been developed. The first fringes using this system were successfully observed. Besides these developments, optical-linked RF interferometer has been investigated to measure phase delay precisely. The performance of GPS frequency reference receiver was tested to evaluate the possibility of its adoption as a frequency standard in VLBI observations in order to deploy VLBI-like techniques widely.

1. Introduction

A VLBI group in the Communications Research Laboratory (CRL) has a long history more than 20 years. In this report, we introduce our recent activities related to VLBI. CRL has developed a compact VLBI network named KSP consisting of four stations in and around the Tokyo metropolitan area, which is dedicated to monitoring the crustal deformation there. In 1995, the KSP started regular observations. Observations and analyses are fully automated in the KSP. Real-time VLBI technique was also developed on the KSP network. Now routine observations spanning 24 hours are carrying out every other day using the real-time VLBI technique. This real-time VLBI technique is now expanded to connect a 64-m antenna at USUDA and a 34-m antenna at Kashima besides KSP stations to increase sensitivity to detect very weak radio sources. Test observation was successfully carried out in December 1998. In parallel with the KSP operation, the

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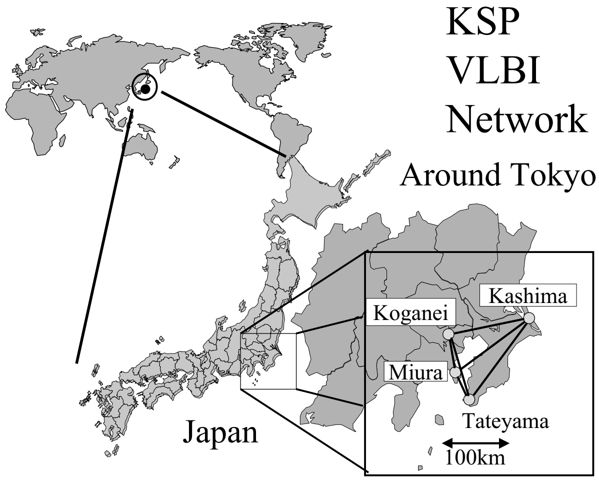

Figure 1. Location of the Keystone Project VLBI network.

Giga-bit VLBI system consisting of a high speed sampler (1Gsps/4ch/2bit) and a high speed digital data recorder (1024 Mbps) has been developed to increase the sensitivity of observations. The test observation using this system was made in July 1998, and the first fringes were successfully obtained. In addition to these developments, different approach to increase the accuracy of measurements has been investigated. It is optical-linked RF interferometer aiming to measure phase delay precisely. In the meantime, a GPS time and frequency reference receiver has shown remarkable progress in performance in recent years. It can supply stable signals at low cost. In order to deploy VLBI-like techniques widely, the performance of GPS frequency reference receiver was tested to evaluate the possibility of its adoption as a frequency standard in VLBI observations.

2. Key Stone Project

In 1993, CRL started the establishment of the VLBI network dedicated to monitoring the crustal deformation around the Tokyo metropolitan area in Japan. This VLBI network consists of four stations (Fig.1), and was named “Key Stone Project” (KSP) network after the Japanese traditional saying that relates to earthquake prevention [*Koyama et al.,* 1998]. In September, 1996 the KSP entered a full operation phase consisting of daily observations spanning 5 to 6 hours using a conventional tape recording method system. Along with these daily observations, we established a real-time VLBI in cooperation with the Nippon Telephone and Telegraph Co [*Kiuchi et al.,* 1999]. Real-time VLBI means a correlation processing in real time using high-rate transmission links (maximum network speed is 2.4 Gbps) between the four KSP stations (Fig.2). This real-time processing has been used in routine operations since June 4, 1997. Since then the length of a session, which is a series of scans of quasars, has become free from a restriction arising from the correlation processing in the case of a tape-recording-based VLBI. We began routine 24-hour observations every two days on September 30, 1997.

Thus we have been making continuous improvement both in system hardware and in the observation method to improve measurement accuracy. Now repeatability reaches about a 2-mm level in baseline length in our VLBI network [*Kondo et al.,*1998].

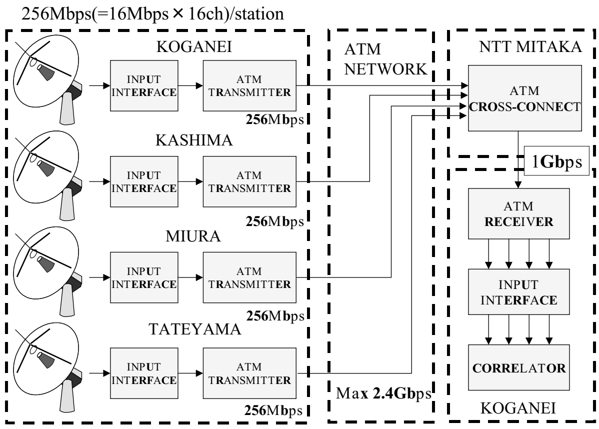

Figure 2. Block diagram of the KSP real-time VLBI system.

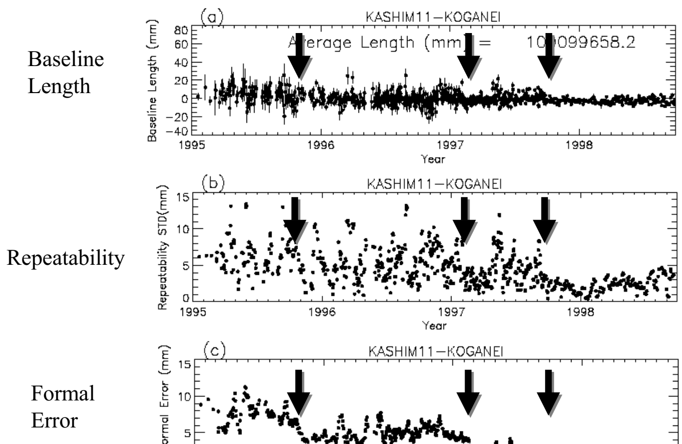

Figure 3. Evolution of baseline length between Kashima and Koganei (a), repeatabilities (b), and mean formal errors (c) of five continuous samples of baseline length.

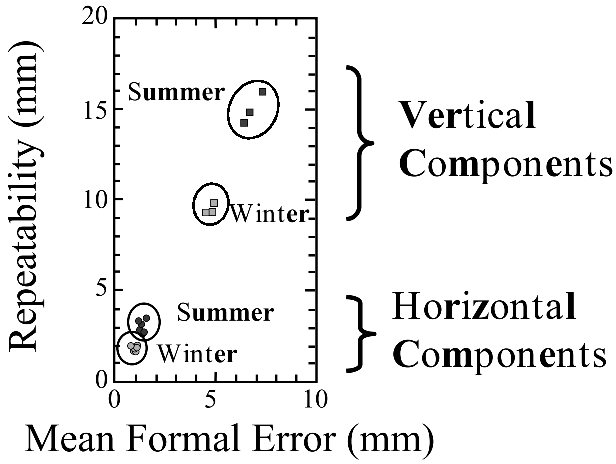

Figure 4. Scatter plots of repeatabilties and formal errors for horizontal station positions and vertical station positions, for the two sub-periods.

Figure 3 shows the evolution of measured baseline lengths for the Kashima-Koganei baseline, and the standard deviations and mean formal errors of the five continuous samples of the baseline length data for the period from January, 1995 to September, 1998. The formal error obtained from each baseline analysis almost corresponds to the standard deviation of O-C residuals after parameter fitting in a session. We can see stepwise structures in the plot of mean formal errors, in particular at three epochs (at the end of October, 1995, at the middle of February, 1997, and at the end of September, 1997). This demonstrates a drastic improvement in system. The first two correspond to improvements in the system hardware (such as an increase in temperature stability in a receiver room) while the last one corresponds to the extension of the session time. As a seasonal effect can be seen in Figure 3, we divided a year into two sub-periods representing winter and summer seasons (i.e, October, 1997 to March, 1998 and April, 1998 to September, 1998) and made statistical calculations for the two sub-periods. In Figure 4, averaged repeatabilities and mean formal errors of station positions are plotted for these two sub-periods. The simple average of repeatabilities (formal errors) of station positions for all stations for east-west, north-south, and vertical components for the winter season are 1.9 mm (0.9 mm), 1.8 mm (1.0 mm), 9.5 mm (4.7 mm), those for the summer season are 3.0 mm (1.3 mm), 3.0 mm (1.4 mm), and 15.0 mm (6.8 mm), and those for full year are 2.5 mm (1.1 mm), 2.4 mm (1.2 mm), and 12.3 mm (5.9 mm), respectively.

Both repeatability and mean formal error become worse in the summer season by factors about 1.6 and 1.4 compared with those in the winter season. Moreover the repeatability is worse than the mean formal error by about a factor of two.

The real-time VLBI technique realized on the KSP-VLBI network has been expanded to connect a 64-m antenna at USUDA and a 34-m antenna at Kashima to form a "large virtual radio telescope" to increase sensitivity to detect very weak radio sources [*Takahashi et al.*,1998]. Test observation was successfully carried out in December 1998.

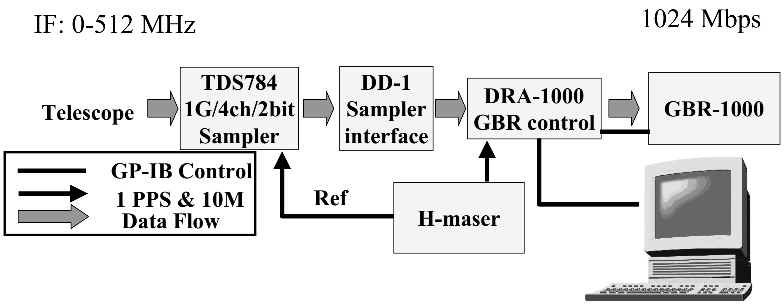

Figure 5. Schematic diagram of the Giga-bit VLBI system for observations.

3. Giga-bit VLBI System

We started the development of the Giga-bit VLBI system in 1995 to improve sensitivity of the VLBI system. Test observations were carried out on the Kashima-Koganei baseline of KSP VLBI network on July 10, 1998. And the first fringes were successfully detected[*Koyama et al.*,1998].

Figure 5 shows the block diagram of the giga-bit VLBI system. Baseband IF signals are sampled by TDS784 (Tektro) sampler with a speed of 1 Gsps (=1024 Msps). TDS784 can digitize four analog data channels at 1 Gsps with 2 bits per sample. A DD-1 sampler interface selects one channel data and transfer the 1 Gsps 1 bit per sample data to a high speed digital data recorder TOSHIBA GBR-1000. The original GBR-1000 recorder has a recording speed at 958 Mbps. The internal clock rate was hence increased by 7 % to achieve the recording speed of 1 Gsps.

Data were processed by GICO (Giga-bit COrrelator) which consists of UWBC (Ultra Wide Band Correlator) originally developed for the Nobeyama Millimeter array of the National Astronomical Observatory. The processor is an XF type correlator with the 256 lags of cross-correlation function capable to process at 2048 Mbps.

4. Optical-linked RF Interferometer

The concept of optical-linked RF interferometer is a connected-element interferometer. RF signals received by antenna are directly converted into optical signals and then transmitted through a fiber optic link instead of use of metal lines like a coaxial cable. In a connected-element interferometer, common local oscillator signals are used for the frequency conversion of RF signals from each antenna. Thus no clock parameter estimation is necessary in a baseline analysis unlike an general VLBI analysis for geodetic

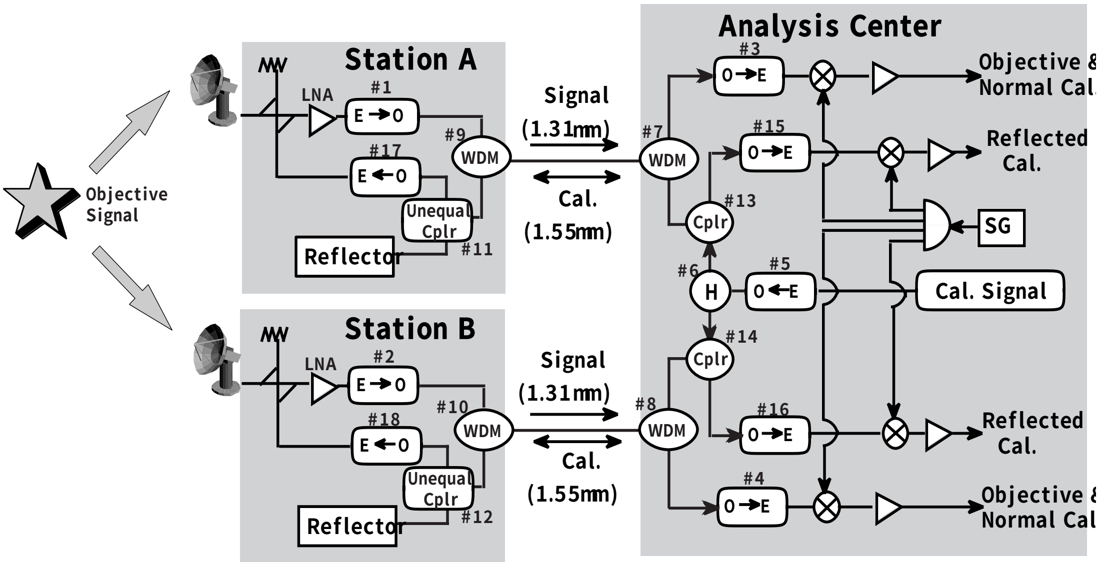

Figure 6. System configuration of the optical-linked RF interferometer.

purpose. Even though higher stability against the temperature change is expected for optical fiber link than metal lines, delay change occurred in the transmission line should be compensated for the application of precise geodetic observation.

Figure 6 shows the configuration of the optical-linked RF interferometer that can compensate the fiber delay with high accuracy [*Amagai et al.*,1998]. Signals received by antenna at each site are amplified by a low-noise amplifier (LNA) and converted to optical signals on the carrier at a wavelength of 1310 nm by a laser diode. The optical signals are then transmitted through optical fiber to the analysis center. There optical signals are converted to electronic signals and they are further converted into video signals using common local signals. Then video signals are cross-correlated. In this system, delay changes occurring in the optical fibers are compensated by using phase calibration signals injected in front of LNA. This is the same method used in the geodetic VLBI. Further delay changes caused by refractive index difference are compensated by using calibration signals optically reflected from each site.

Maximum fiber length capable to use in this system was estimated from signal-to-noise ratio analysis at fiber optic links. It was estimated to be about 40 km when the combination of Ortel 3541A laser diode and Ortel 4515A photo detector is used.

5. GPS Receiver for Use of VLBI Frequency Standard

The performance of GPS time-and-frequency reference receivers has advanced to the point where they are now widely used to supply a highly stable signals (1×10^{-12}/day) at a low cost. Although their stability is less than that of the hydrogen-maser frequency standard (H-maser clock) ($\sim 1 \times 10^{-14}$/day) conventionally used for VLBI, their lower cost is attractive when we consider the wide deployment of VLBI and VLBI-like techniques. We evaluated the performance of a GPS receiver by measuring its phase stability to determine whether it is suitable for supplying a standard frequency for VLBI observations.

We conducted test VLBI observations on May 13, 1998 on the Kashima-Koganei baseline (about 109 km in length) to confirm the performance of a GPS time-and-frequency reference receiver. The configuration of the test observation is shown in Fig. 7. At the

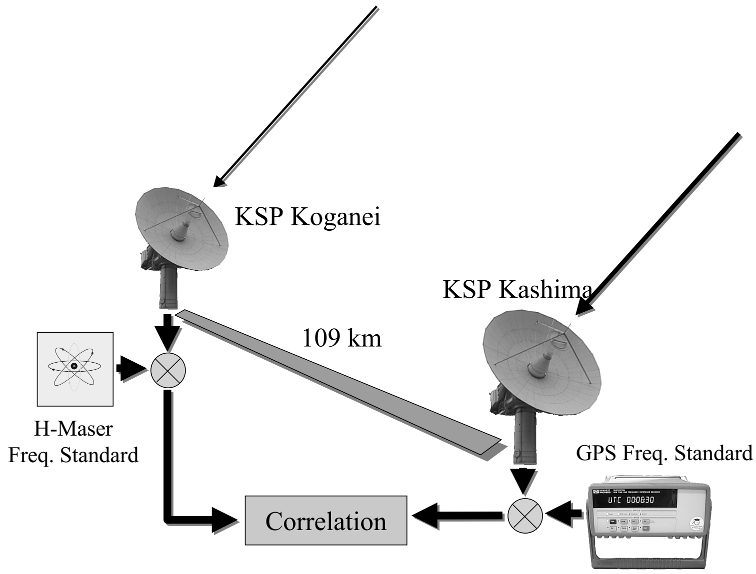

Figure 7. Configuration of test VLBI observation using GPS frequency standard.

Kashima station, the system-reference frequencies were supplied by a GPS reference receiver (HP 58503A) instead of an H-maser clock, while an H-maser clock was used at the Koganei station. Both "real-time" VLBI and "tape-based" VLBI were carried out. Cross-correlation processing was carried out in real time at the Koganei station using data transmitted through an asynchronous transfer mode network. Cross-correlation processing using the recorded data was performed later. The correlation-period units were set to 3 s. Two types of fringe searches were used in integrating the time-segmented correlation data. One was a normal fringe search in which only the linear-phase change with respect to time was compensated for. The other one was a fringe search using a third-order polynomial function with respect to time.

The coarse delay search functions obtained using these fringe searches are shown in Fig. 8. The received radio source was 3C273B, and the integration period was 90 s. Only one channel in the 8-GHz band is shown in the figure. There was a scattered structure in the delay rate direction for the normal fringe search (Fig. 8(left)) due to a higher-order phase change that could not be compensated for by the linear phase-change correction. There was a simple peak structure and a larger correlation amplitude when a third-order polynomial function was applied (Fig. 8(right)).

To compare these results with those for conventional VLBI observation, we conducted the same observation two days later and using H-maser clocks at both stations. The relation between the correlation amplitude and integration period for both observations is shown in Fig. 9. A third-degree polynomial search was used for the observation made using the GPS clock. For the H-maser experiment, no difference was observed between search methods. For the GPS experiment, the correlation amplitude fell when the integration period exceeded 100 s. In other words, we can say, a GPS time-and-frequency reference receiver can be used to supply a standard frequency for VLBI for frequencies up to 8 GHz if a third-order fringe search is used and the integration period is less than 100 s.

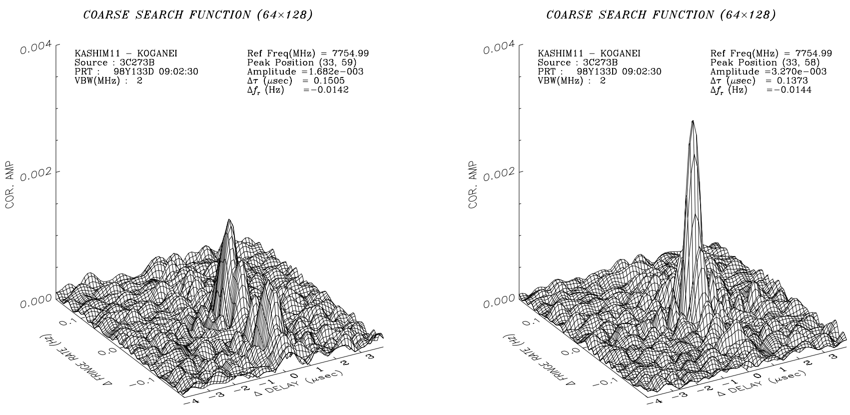

Figure 8. Coarse delay search function for normal (left panel) and third-order (right panel) fringe search.

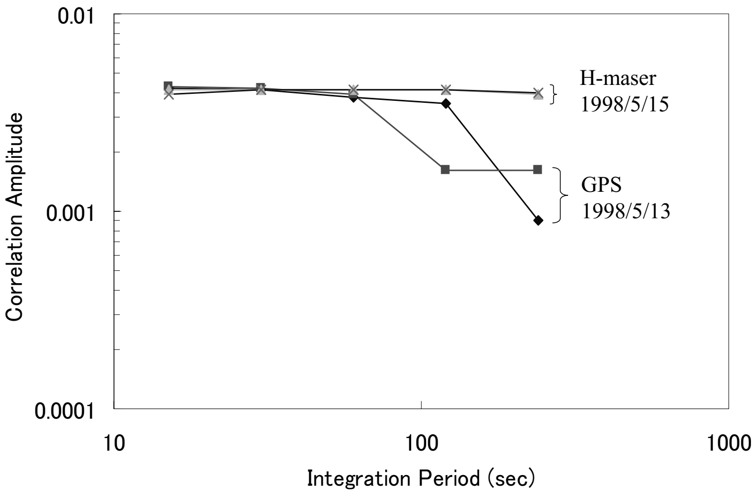

Figure 9. Relation between correlation amplitude and integration period for two test observations: in one H-maser clocks were used at both stations, and in the other a GPS reference receiver was used at one station.

Acknowledgments

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References

Amagai, J., H. Kunimori, and H. Kiuchi, Preliminary experiments of improved optical-linked RF interferometer, Technical Development Center News CRL, No.12, 20-23, 1998.

Kiuchi, H., T. Kondo, M. Sekido, Y. Koyama, M. Imae, Hoshino, Uose, Real-Time VLBI Data Transfer and Correlation System, *J. Commun. Res. Lab.,* 1999.

Kondo, T., N. Kurihara, Y. Koyama, M. Sekido, R. Ichikawa, T. Yoshino, J. Amagai, K. Sebata, M. Furuya, Y. Takahashi, H. Kiuchi, and A. Kaneko, Evaluation of repeatability of baseline lengths in the VLBI network around the Tokyo metropolitan area, *Geophys. Res. Lett.*, *25,* 1047-1050, 1998.

Koyama, Y., N. Kurihara, T. Kondo, M. Sekido, Y. Takahashi, H. Kiuchi, and K. Heki, Automated geodetic very long baseline interferometry observation and data analysis system, Earth Planets Space, *50,* 709-722, 1998.

Koyama, Y., J. Nakajima, M. Sekido, and M. Kimura, The first fringes from the Giga-bit VLBI system, Technical Development Center News CRL, No.13, 14-16, 1998.

Takahashi, Y., H. Kiuchi, A. Kaneko, S. Hama, J. Nakajima, N. Kurihara, T. Yoshino, T. Kondo, Y. Koyama, M. Sekido, J. Amagai, K. Sebata, N. Kawaguchi, H. Kobayashi, M. Iguchi, T. Miyaji, H. Uose, and T. Hoshino, The plan of the big virtual telescope using the high speed communications network, Technical Development Center News CRL, No.13, 17-19, 1998.