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CONTENTS

Overview of the Eleventh TDC Meeting

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The eleventh meeting of the Technical Development Center was held on September 18, 1997 at the Communications Research Laboratory.

Attendance

CRL members

Kenichi Okamoto, Michito Imae, Mizuhiko Hosokawa, Yuko Hanado, Yukio Takahashi, Chihiro Miki, Hitoshi Kiuchi, Akihiro Kaneko, Shin'ichi Hama, Taizoh Yoshino, Hiroo Kunimori, Jun Amagai, Hideyuki Nojiri, Toshimichi Otsubo, Masato Furuya, Fujinobu Takahashi (KSRC: Kashima Space Research Center), Noriyuki Kurihara (KSRC), Yasuhiro Koyama (KSRC), Ryuichi Ichikawa (KSRC), Mamoru Sekido (KSRC), Junichi Nakajima (KSRC), Tadahiro Gotoh (KSRC), Tetsuro Kondo (KSRC)

Special members

Noriyuki Kawaguchi (National Astronomical Observatory), Hideo Hanada (National Astronomical Observatory), Mikio Tobita (Geographical Survey Institute), Masayuki Fujita (Hydrographic Department, Maritime Safety Agency) Seiichi Shimada (National Research Institute for Science and Disaster Prevention), Kachishige Sato (Tokyo Gakugei University) Masayuki Takemura (Kobori Research Complex, Kajima Corporation)

Following special members could not attend: Tetsuo Sasao (National Astronomical Observatory), Shuhei Okubo (Earthquake Research Institute, University of Tokyo),

Minutes

1. Opening Greeting

Fujinobu Takahashi, the vice-director of IERS TDC at Communications Research Laboratory (CRL), opened the meeting with an introductory statement of the technical development center at CRL.

2. Reorganization of CRL and the Key Stone Project (*Taizoh Yoshino*)

Taizoh Yoshino represented a brief history of the IERS emphasizing its relation to the technical development center at CRL. After the reorganization of the VLBI participants in the IERS, the CRL was nominated again as one of the Technical Development Centers in September 1996. In the CRL, a team system was newly introduced in July 1997, where each team devotes to a specific subject in a limited period. The Keystone Project Team was born to run one of the major projects in the CRL. In the Keystone Project Team, crustal deformation in the Tokyo metropolitan area is studied using VLBI and SLR technology. Technical improvement is also expected as one of the activities. Relationship between the existing research sections and the team to perform technical developments was also explained.

3. Activity Reports by the Special Members

Each special member reported on the current status of the activities of each organization.

Nobeyama Radio Observatory, National Astronomical Observatory (*Noriyuki Kawaguchi*)

Noriyuki Kawaguchi reported on the current status of Nobeyama Radio Observatory and space VLBI project (VSOP) as follows. The VSOP is successfully going on, this is greatly owing to an international collaboration. He also mentioned a format converter developed by himself, which makes it possible to correlate the data taken by different recording systems. So far it is possible to convert among three kinds of recording formats. At the end of his report he expressed his hope that the technical development center at CRL will be a center able to produce an international standard.

Mizusawa Astrogeodynamics Observatory, National Astronomical Observatory (*Hideo Hanada*)

Hideo Hanada reported that RISE (Research In SElenology) in the SELENE (SELenological and ENgineering Explorer) project, which will be launched in 2003 to the Moon, and a lander will make a soft landing on the Moon while an orbiter stays in lunar orbit, has entered the development phase this fiscal year. However for budgetary reasons, the SELENE project is obliged to change its initial form to decrease costs. As a result of replanning the lunar lander comes to play the role of an engine for the orbiter, even though both had independent engines in the initial plan. Differential VLBI using signals from the lunar lander and a relay satellite which will be released from the orbiter is therefore postponed to one year after launch.

Geographical Survey Institute (*Mikio Tobita*)

Mikio Tobita reported Project'97 promoted by the Geographical Survey Institute (GSI), the Communications Research Laboratory (CRL), and the Hydrographic Department, Maritime Safety Agency (JHD) as a joint project. The Project'97 aims (1) to tie GPS, VLBI, and SLR, and to connect them to the origin of Japan geographic coordinates for the GIS campaign observations taken in October, 1997, (2) to make collocation observations of GPS, VLBI and SLR for the IERS, and (3) to tie KSP-VLBI/CRL, SLR and GPS/JHD, and a 26m antenna at Kashima/GSI to a GPS network operated by GSI.

He also expressed his thanks to the technical development center for continuous technical support during installation of the correlation processing system at GSI. Now a K-4 type correlator, available to process three baselines, is in operation at the GSI.

As for the experiment, proposed by Tobita at the 9th TDC meeting held in September 1996, with KSP antennas being utilized as fiducial points in SAR images by pointing them to an expected satellite direction, he reported that it did not get good results, i.e., no antenna was identified in the SAR images. Antennas were merely pointed to the satellite direction without any special treatment, such as placing a metal plane in front of the antenna feed horn to increase reflecting signals. This result was therefore partly expected before the experiment. Tobita however asked a continuous cooperation of CRL group to improve this experiment to obtain reasonable results because it is an excellent idea.

Hydrographic Department, Maritime Safety Agency (*Masayuki Fujita*)

Masayuki Fujita reported on the current status of SLR and GPS observations carried out by the Hydrographic Department, Maritime Safety Agency as follows.

SLR measurements made at Chichijima Island on the Philippine sea plate separated by several years shows motion of the island consistent with that obtained by others, such as VLBI measurements. Presently the position of Ishigakijima Island is being measured. The Hydrographic Department plans to start GPS observations on an uninhabited island next fiscal year.

Deployment of D-GPS network consisting of more than 20 sites in Japan promoted by the Aids to Navigation Department will be completed in the next fiscal year, which is earlier than the original schedule by one year.

National Research Institute for Science and Disaster Prevention (*Seiichi Shimada*)

After a brief self-introduction Seiichi Shimada talked about the current tendency of GPS analysis software to emphasize treatment of atmospheric delay effects in the analysis. They consider the effect of horizontal gradients in the zenith excess delays, as well as taking the mapping function into consideration. As for water vapor effects, a trial using numerical weather prediction data is starting to produce good initial conditions in the analysis.

Tokyo Gakugei University (*Kachishige Sato*)

Kachisige Sato, who moved from Mizusawa Astrogeodynamics Observatory, National Astronomical Observatory, introduced his recent studies. He has been investigating plate motion and deformation using space geodetic data. Comparing the results from VLBI and GPS data, he suggested that VLBI data are consistent with a plate motion model based on geological evidence, while GPS data seem to show some inconsistency with the model. The same inconsistency can be seen in SLR data, he said. He plans to investigate this discrepancy more detail.

Kobori Research Complex, Kajima Corporation (*Masayuki Takemura*)

Masayuki Takemura, a specialist of strong ground motions of earthquakes, said that he wants to contribute to the TDC/CRL from a unique position, because his major field is slightly different from that of other special members. Then he introduced his recent work investigating the 1995 Hyogo-ken Nanbu earthquake in comparison with historical large earthquakes. This comparative study shows that the Hyogo-ken Nanbu earthquake is not a special one but a common one often occurring in Japan as an intra-plate earthquake, he said. He pointed out that the local ground condition is an important factor for damage caused by earthquakes. It can be learned from the ground motion estimated from the directions of overturning tombstones. In the case of large earthquakes like the 1923 Kanto earthquake, damage becomes much larger and wider in area. We should recognize that we cannot adopt all results learned from the Hyogo-ken Nanbu earthquake to much larger earthquakes.

4. Technical Development Reports

4.1 Preliminary Report of 120 hour Continuous Observation on the Key Stone Project (Crustal Deformation Observation System in the Tokyo Metropolitan Area) VLBI Network (*Tetsuro Kondo*)

CRL has been carrying out daily observations using the real-time KSP VLBI network to monitor crustal deformation around the Tokyo metropolitan area. Tetsuro Kondo reported on an experiment carried out on the KSP VLBI network over 120 hours continuously from July 28 to August 1, 1997. Each session lasted for 24 hours and consisted of about 600 scans. Five sessions are included in the experiment. The main purpose of this experiment is to evaluate the accuracy limit achieved by the current system. Repeatability of measured daily baseline lengths represents a considerable improvement compared with that for routine daily observations of 6 hour duration. Thus daily 6-hour observations on the KSP network are modified to include 24-hour experiments every other day to increase the accuracy of measurements. One of the special members asked, how can the number of scans be increased to such a large number? Kondo replied that this is made possible by real-time correlation processing, which does not require an extra period in each scan which is necessary for tape synchronization in the case of tape-based VLBI. Thus we can reduce the time for each scan, resulting in an increase in the total number of scans.

4.2 Report on Real-time Correlation Processing Software RKATS (*Mamoru Sekido*)

Real-time correlation processing software RKATS developed for KSP-VLBI system was introduced by Mamoru Sekido. Because of an automatic fringe search and a dynamic clock offset adjustment, which are RKATS's important functions, continuous unmanned operation is achieved, he emphasized. One of the special members asked him, it is important for clock compensation to adjust a rate rather than an offset, isn't it? Is it actually necessary for a hydrogen maser frequency standard to adjust clock offset frequently? Sekido replied as follows. RKATS has both a rate and an offset adjustment function. For a practical use it is enough to adopt only an offset correction. A 1 pps signal of a station clock was sometimes reset to keep a time difference sufficiently small compared with the UTC.

4.3 Analysis of KSP GPS Observations from a Meteorological Point of View (*Ryuichi Ichikawa*)

Ryuichi Ichikawa reported on results obtained through the comparison between VLBI and GPS measurements which were simultaneously conducted with an experimental continuous observation from July 28 to August 1, 1997. The results showed that time variations can be seen in a geodetic solution of GPS results that are similar to those seen in VLBI results. He also mentioned that scatter in the east-west components obtained by GPS observation became larger when low elevation angles were included in an analysis, and this may be related to an inhomogeneous distribution of water vapor around a station. Regarding a systematic error seen in the position measured by GPS for Tateyama station, one of the KSP stations, he suspected the radome of the GPS antenna of influencing the results.

4.4 Current Status of KSP SLR System (*Hiroo Kunimori*)

Hiroo Kunimori reported on the current status of SLR system in the KSP as follows. A calibration for optic-electronic packages was carried out using colocation optics at Kashima configuring all four connected to a single telescope and one of lasers transmitting to the ground targets. Results demonstrated system stability to about 2 mm.

4.5. Tie of the KSP Network to the ITRF (*Yasuhiro Koyama*)

Yasuhiro Koyama reported on the result of experiment using the KSP VLBI network and the Kashima 34 m antenna as follows. The position of Kashima 34 m antenna is well determined in the international terrestrial reference frame (ITRF) through a number of international VLBI sessions. By connecting the KSP network with the Kashima 34 m antenna, station positions of KSP network in the ITRF were determined within a discrepancy of 1 cm for horizontal components and 3 cm for vertical components. Comparing these results with

ITRF coordinates of GPS ground bench marks, it is shown that the positions of KSP stations measured by VLBI and GPS are coincident with each other within 2 cm for horizontal and 5 cm for vertical components. However the discrepancies are not so small and the reasons for this are under investigation.

4.6 PCAL System at Urumqi Station (*Noriyuki Kurihara*)

Noriyuki Kurihara visited Urumqi VLBI station, China to improve the phase calibration (PCAL) system in July, 1997. He reported on the current status of Urumqi station and a preliminary result of VLBI observation carried out just after he installed an improved PCAL system. The new PCAL system seems to be working well but some problems still remain in the total system, he pointed out.

4.7 Current Status of Multimedia Virtual Laboratory Project (*Yukio Takahashi*)

Yukio Takahashi reported on applications for VLBI use in the Multimedia Virtual Laboratory (MVL) project. As for the VLBI applications, high speed transmission of a huge amount of data and a technique for real-time data processing on distributed stations become key items in system development. He showed an example of ideas about correlation processing as carried out at multiple stations simultaneously with sharing the data.

4.8 A Next Generation VLBI Terminal (*Hitoshi Kiuchi*)

Hitoshi Kiuchi presented his ideas about a next generation VLBI terminal. According to his idea, a data recorder will consist of 16 channels and each channel will record data at a rate of either 128 Mbps or 256 Mbps. The video bandwidth will be wider than 32 MHz (up to 64 MHz), which is realizable even with current technology. The input/output interface will be unified to use an optical interface.

By adapting parallel processing logic to a correlator, the speed of processing will reach 1 Gps per channel. An FPGA instead of a custom-made LSI will be used for correlator development because the debugging process becomes easier than that with LSI. The differences of recording and data format among VLBI systems throughout the world will be absorbed at the correlator.

4.9 Current Status of Development of Next Generation VLBI System Based on Gigabit Recorder (*Junichi Nakajima*)

Junichi Nakajima reported on the current status of development of next generation VLBI system based on a gigabit recorder (GBR-1000) as follows. Performance test of the sampler portion was carried out at the Nobeyama Radio Observatory. Auto-correlation was successfully detected by a GICO (GIgabit COrrelator).

4.10 An Evaluation of GPS Time/Frequency Receiver as a VLBI Frequency Standard (*Tetsuro Kondo*)

Tetsuro Kondo presented the results of an evaluation of GPS time/frequency receiver as a VLBI frequency standard. He measured the phase difference of 10 MHz signals from two independent GPS time and frequency reference receivers which are locked to GPS satellites. He then calculated Allan variances and coherence loss using the measured data. He said, as a result it is demonstrated that the GPS Time and Frequency Reference Receiver can be used as a frequency standard for frequencies lower than 1 GHz. He also mentioned that if we expand the fringe search process to include searches at least up to a third order phase change against time, then a GPS Time and Frequency Reference Receiver is adoptable as a frequency standard for VLBI operated at even higher frequencies, up to 8 GHz.

4.11 Millisecond Pulsar Observation Using 34 m Antenna at Kashima (*Yuko Hanado*)

Yuko Hanado introduced a millisecond pulsar observation system and reported on recent observation results. The results show good repeatability due to an upgrade of the software TEMPO which estimates the pulse phase of pulser. A new long-term-drift appears in the results, however. Comments on this report follow. Use of TEMPO as a black box may limit this study in the future. A pulse phase estimation software should be developed along with system development. As for an improvement of signal to noise ratio, a burst sampling technique is suggested.

4.12 Construction of New Station Disseminating Japanese Standard Time and Frequency at LF Band (*Michito Imae*)

Michito Imae introduced the new station transmitting standard radio waves at the LF band, under construction in Fukushima Prefecture, Japan. CRL is responsible for keeping Japan Standard Time (JST) and dissemination of standard time and frequency. At present, CRL disseminates the

JST and frequency using JJY (HF) and JG2AS (LF). However, interference is increasing at HF band, and JG2AS is not a permanent station. The investigation committee organized in CRL for dissemination of more stable and practical signals permanently recommended to unify both stations as a single LF station. Thus construction of the new LF station started. It will transmit standard signals at 40 kHz with a power in excess of 10 kW. Service will start in April, 1999.

4.13 Study on the Basic Technique of Satellite Positioning System (*Michito Imae*)

A basic technique of a satellite positioning system investigated at CRL, in particular in the field of frequency standards, for the purpose of future use was briefly introduced by Michito Imae. He showed topics which should be studied at CRL as follows: development of an on-board atomic frequency standard, a time keeping technique for a group of on-board clocks, and a technique for precise real-time orbit determination. He also presented his plan to include an atomic clock on the Engineering Test Satellite-VIII (ETS-VIII) which will be launched in 2002 by the National Space Development Agency of JAPAN (NASDA).

5. Closing Greeting

The closing greeting was delivered by Kenichi Okamato, the director of IERS TDC at Communications Research Laboratory.

The eleventh TDC meeting held at the headquaters of Communications Research Laboratory on September 18, 1997

Evaluation of Daily Repeatability of Baseline Lengths in the Key Stone Project VLBI Network

Tetsuro Kondo[1](*kondo@crl.go.jp*), **Kohichi Sebata**[2], **Jun Amagai**[2], **Masato Furuya**[2], **Noriyuki Kurihara**[1], **Hitoshi Kiuchi**[2], **Yasuhiro Koyama**[1], **Mamoru Sekido**[1], **Akihiro Kaneko**[2], **Yukio Takahashi**[2], **Ryuichi Ichikawa**[1] **and Taizoh Yoshino**[2]

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Abstract: VLBI measurements using four fixed VLBI stations around the Tokyo metropolitan area are producing continuous data of station positions and baseline lengths. Accuracy of baseline length measurements is evaluated on the basis of their repeatability in terms of root mean square variance in five adjacent sessions. Five day continuous observation sessions demonstrate that typical repeatability of about 1-2 mm in baseline length is achieved on our VLBI network.

1. Introduction

We have been carrying out routine daily VLBI observations (6 hours per day) to monitor crustal deformation around the Tokyo metropolitan area using four stations: Kashima, Koganei, Miura and Tateyama (Figure 1). The project is named the Key Stone Project (KSP) and is promoted by the Communications Research Laboratory. Each VLBI station is equipped with the same VLBI facility, i.e., a parabolic antenna with 11 m diameter and a highly automated data acquisition system dedicated to KSP. The longest distance between KSP stations is about 135 km (Kashima-Tateyama), so that the KSP network is very compact as a VLBI network. The KSP started regular observations using Kashima and Koganei stations in January, 1995. Later other stations joined and daily observations using all four stations started in September, 1996. Since then the observation system has experienced some refinements to improve its total performance. In parallel with the daily observations using a conventional tape recording method, we were establishing a real time correlation processing system using an ATM (asynchronous transmitting mode) network which combines four stations with a high speed digital link (maximum speed is 2.4 Gbps). Digitized signals observed at each station are transmitted to Koganei, where a KSP correlator is located, in real time through the ATM network. This real time processing has been used in routine operations since June, 1997.

As VLBI/KSP enters a stable operation phase, we have begun an evaluation of total system performance in terms of measurement accuracy. How accurately can we measure baseline length among KSP stations using the current system, which means both hardware and analysis software? To answer this inquiry, we conducted continuous observation over 120 hours on the KSP network from July 28 to August 1, 1997. These observations were successfully finished and the formal error of baseline length estimation for the last day is 0.7 mm, which is the champion value of KSP at present time. In this paper, we make an evaluation of results of the 120-hour-observation by comparing them with KSP results taken at other times.

2. Observations

Continuous 120 hour observation was carried out from July 28 to August 1, 1997 and was divided into 5 sessions. Each session lasts for 24 hours and includes about 600 scans of radio sources (quasars). Unmanned observations according to the same observation schedule distributed from the KSP central station, Koganei, were carried out at the all four stations. Observation status is always monitored at Koganei automatically. An observation and its correlation processing for 6 baselines is carried out simultaneously using data transmitted from each station through an ATM network which connects all stations to the Koganei central station.

Table 1 summarizes scheduled number of scans and valid scan number by session by baseline. Valid scan number means the number used for a baseline analysis. During the second session some problems occurred on the correlation processor, and Miura station was down for about 5 hours on the fourth session. These problems resulted in the low values of valid scans during the second and fourth session compared with the other sessions.

A baseline analysis is made on the basis of each session.

3. Method

We use baseline length analysis results to evaluate the accuracy of measurements, because the estimation of baseline length is robust against the

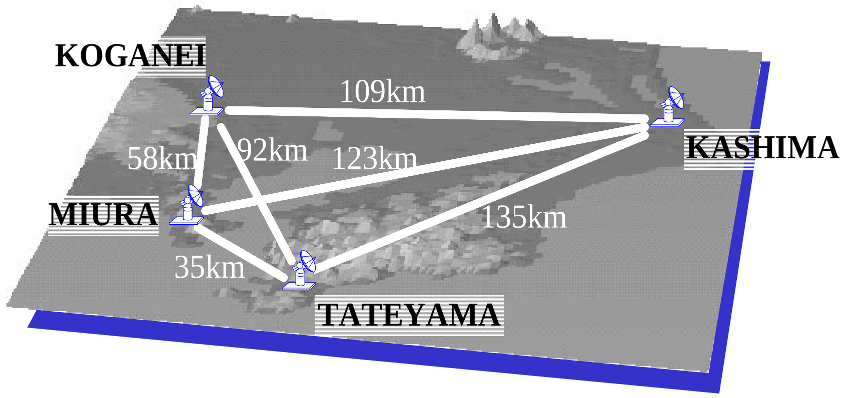

Figure 1. Key stone project VLBI network.

model uncertainty such as earth rotation parameters. Root mean square variance of continuous 5 samples of baseline lengths by baseline is compared with adjacent 5 samples in other period. As for the formal error corresponding to 5 sessions, we take a simple average of that of each session concerned. KSP observation participated by all four stations started in January, 1996. Initially a video bandwidth of 2 MHz was used. After a system reliability check, this was expanded to 8 MHz on June 1, 1997. To avoid any influence that this may cause we limit the period to June 1, 1997 to August 13, 1997 for an evaluation study.

4. Results

Figure 2 presents scatter plots of rms variance of baseline lengths of the 5 sessions, with its formal error defined as a simple average of each session's formal error. An open triangle in each panel represents a result for 5 sessions from July 28 to August 1, 1997, i.e., the period of continuous observations. In each panel ρ means correlation coefficient and N is the number of samples plotted in the figure. Weak correlation between rms variances and formal errors can be seen. Open triangles, results of 120-hour-observations, are mostly located at the lower-left edge of the population of samples. This means that an improvement in both repeatability and formal error can be seen for the 5 sessions when we compare them with other periods.

Table 2 summarizes comparison results between the entire period and 5 sessions for repeatability and mean formal error.

Repeatability of the 5 sessions varies from 1.3 mm to 2.5 mm. However we can see a clear improvement in repeatability with one exception in the case of the Kashima-Tateyama baseline. These results demonstrate that 24-hour observation in a day gives better repeatability than 6-hour a day observation.

5. Conclusion

We have monitored the deformation around Tokyo metropolitan area by using four VLBI stations dedicated to this purpose. It is important to know the limitation of accuracy achieved by the current measurement system for discriminating anomalies in crustal deformation.

According to an experimental observation lasting over 120 hours which consists of 5 sessions, the repeatability achieved by the current system is approaching 1 mm for baseline lengths.

We can see faint correlation between repeatability and formal error. This suggests that it is difficult to improve the repeatability by improving only the formal error, even though there ex-

Table 1. Summary of observations.

Session (Date)	Baseline	Number of Scans		
		Scheduled	Valid for Analysis	Valid/Scheduled (%)
97JUL28XX	KASHIMA–KOGANEI	593	487	82.1
(97/07/28)	KASHIMA–MIURA	593	550	92.7
01:10–24:51	KASHIMA–TATEYAMA	593	517	87.2
	KOGANEI–MIURA	593	518	87.4
	KOGANEI–TATEYAMA	593	510	86.0
	MIURA –TATEYAMA	593	546	92.1
97JUL29XX	KASHIMA–KOGANEI	598	390	65.2
(97/07/29)	KASHIMA–MIURA	598	386	64.5
01:13–24:51	KASHIMA–TATEYAMA	598	419	70.1
	KOGANEI–MIURA	598	417	69.7
	KOGANEI–TATEYAMA	598	395	66.1
	MIURA –TATEYAMA	598	462	77.3
97JUL30XX	KASHIMA–KOGANEI	598	507	84.8
(97/07/30)	KASHIMA–MIURA	598	496	82.9
01:10–24:51	KASHIMA–TATEYAMA	598	519	86.8
	KOGANEI–MIURA	598	489	81.8
	KOGANEI–TATEYAMA	598	507	84.8
	MIURA –TATEYAMA	598	556	93.0
97JUL31XX	KASHIMA–KOGANEI	599	483	80.6
(97/07/31)	KASHIMA–MIURA	599	446	74.5
01:13–24:54	KASHIMA–TATEYAMA	599	532	88.8
	KOGANEI–MIURA	599	426	71.1
	KOGANEI–TATEYAMA	599	504	84.1
	MIURA –TATEYAMA	599	455	76.0
97AUG01XX	KASHIMA–KOGANEI	597	526	88.1
(97/08/01)	KASHIMA–MIURA	597	568	95.1
01:17–24:52	KASHIMA–TATEYAMA	597	567	95.0
	KOGANEI–MIURA	597	540	90.5
	KOGANEI–TATEYAMA	597	526	88.1
	MIURA –TATEYAMA	597	576	96.5

Table 2. Summary of Comparison.

Baseline	Repeatability(mm)		Mean Formal Error(mm)	
	for 1997/6/1 –1997/8/13	for 5 sessions	for 1997/6/1 –1997/8/13	for 5 sessions
KASHIMA–KOGANEI	4.3±1.5	1.6	2.2±0.7	1.2
KASHIMA–MIURA	3.7±1.4	2.5	2.1±0.5	1.4
KASHIMA–TATEYAMA	4.7±1.8	4.1	2.3±0.5	1.4
KOGANEI–MIURA	5.2±2.5	1.3	2.5±0.9	1.1
KOGANEI–TATEYAMA	6.2±2.6	1.6	2.7±1.0	1.1
MIURA –TATEYAMA	4.6±1.9	2.0	2.1±0.5	1.0

ists a slight possibility. Improvement of the formal error is mainly due to system hardware or observation schedule. It is considered that a physical model, such as propagation delay model for the atmosphere, is related to an improvement of the repeatability in 5 days. Thus an improvement in a physical model should be rather investigated.

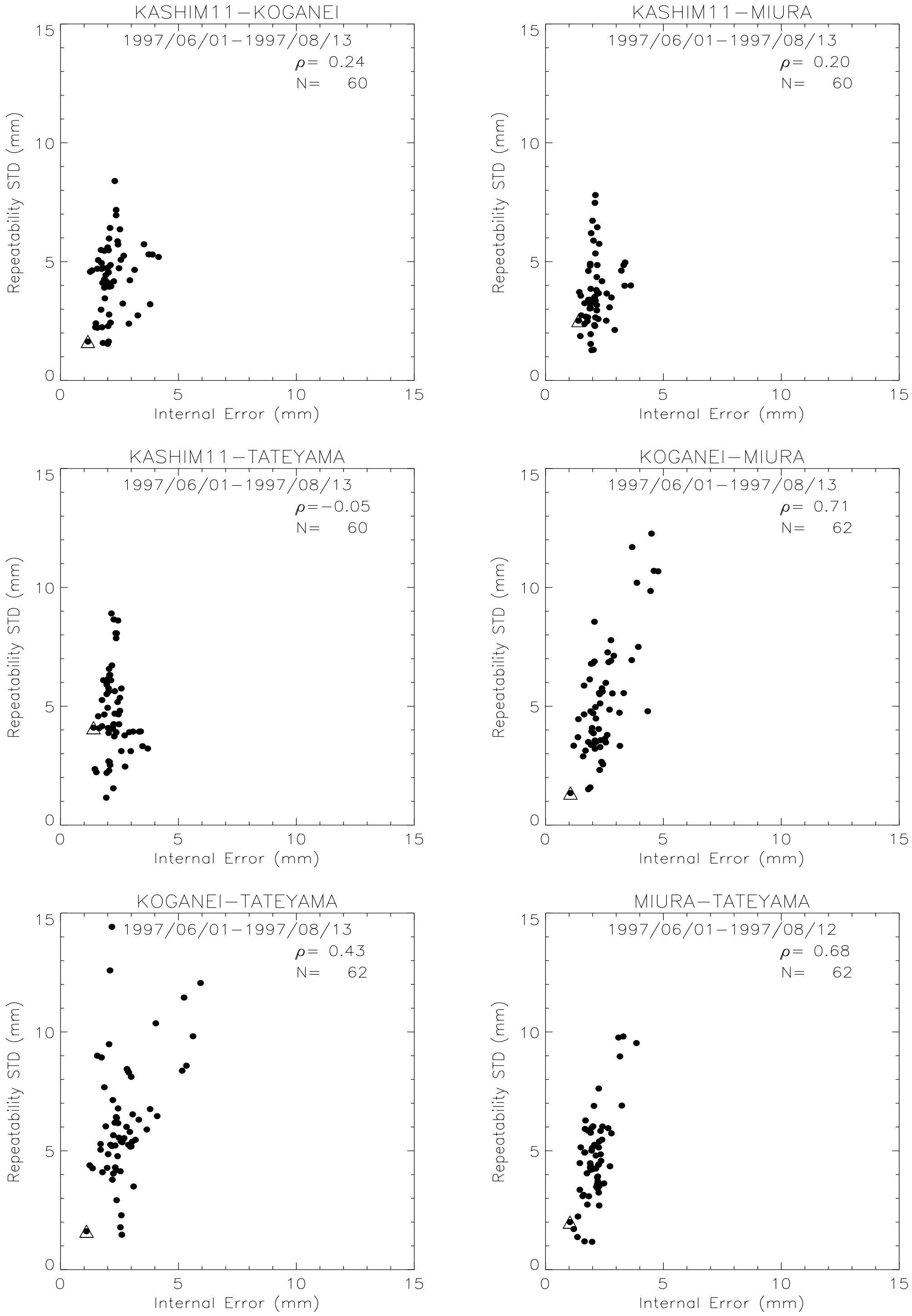

Figure 2. Repeatabilities and formal errors by baseline for the period between June 1, 1997 to August 13, 1997. Open triangles represent data for 120-hour observations. ρ is a correlation coefficients between parameters.

Performance of KSP Real-time VLBI Correlation Processing Software (RKATS)

Mamoru Sekido[1](*sekido@crl.go.jp*), **Tetsuro Kondo**[1], **Hitoshi Kiuchi**[2], **Hiroto Sato**[3], **Yasuhiro Koyama**[1], **and Tetsuo Masubuchi**[3]

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1. Introduction

Key Stone Project(KSP) real-time VLBI observations started in June of 1997 by using Asynchronous data Transfer Mode(ATM) network. Real-time VLBI correlation processing software "RKATS" has developed for fully automatic real-time VLBI data processing. Overview of RKATS was reviewed in TDC News No.9 p.15. In this report, "Dynamic Clock Adjustment" and "Automatic Fringe Search" functions are introduced as key functions for RKATS.

2. Differences between Tape-based VLBI and Real-time VLBI

The main differences of correlation processing between tape-based VLBI and real-time VLBI are listed in Table 1.

Real-time VLBI is advanced from the standpoint of automatic operation and rapidity of output, but interruption of correlation processing due to any problems leads to direct loss of data. Therefore, non-stop operability is strongly requested of real-time correlation processing software.

Except for hardware errors and software hang ups, most probable cause of data loss would be wrong clock parameters. Wrong clock parameters will move fringes out of the lag window of the correlator, and such data cannot be used for baseline analysis. Also, fringe monitoring and adjustment of clock parameters by an operator is difficult, because VLBI experiments may start at midnight and the operators are not supposed to be familiar with VLBI. Therefore we implemented "Dynamic Clock Adjustment(DCA)" and "Automatic Fringe Search(AFS)" functions in RKATS. By using these functions, fully automatic real-time daily VLBI observation has realized.

3. Automatic Fringe Search and Dynamic Clock Adjustment

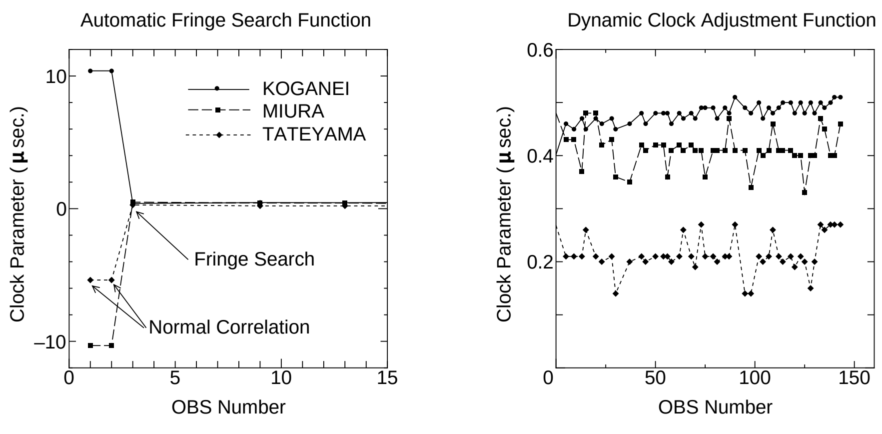

Figure 1. Performance test of AFS(left) and DCA(right) function. Clock parameter of Kashima is fixed as reference. For the performance test, clock parameters of Koganei, Miura, and Tateyama are artificially biased by 10μsec, −10μsec, and −5μsec respectively. At first, correlation has started in "Normal Mode" but fringes were not detected. Then RKATS changed the mode to "Fringe Search Mode" and detected fringes automatically. After that clock parameter was adjusted, the mode was returned back to "Normal Mode". In the "Normal Mode" operation, DCA function adjusts the clock parameter and keeps the fringes at the center of lag window.

Table 1. Differences between tape-base VLBI and real-time VLBI

	TAPE-BASE	REAL-TIME
Data transportation and replay	Human operation is inevitable at work of Magnetic tape transportation and tape mount on recorders	Real-time data transfer by ATM enables automatic operation.
Log information	Observation information and Clock parameter is provided by log file.	Information is collected by computer network just before the observation.
Trouble recovery	Trouble at data processing can be recovered by re-processing of recorded data.	Stop of data processing due to troubles leads to data loss directly.
Rapidity of output	Analysis result comes out 1-2 days after observation.	Analysis result comes out just 10-20 minutes after observation.

Table 2. Parameter for AFS and DCA

Parameter name	Meanings
Fringe Search Mode transition threshold	If ratio of fringe detection (#detected/#total) become lower than this value, correlation mode is changed to FSM.
Averaging Number	Averaging number for fringe detection ratio.
SNR threshold	SNR threshold to judge fringe detection.
Source list for DCA	radio source list, on which fringe is expected to be detected certainly.

Figure 1 shows the clock parameters are adjusted by AFS and they are kept almost within $\pm 0.1\mu sec$ by DCA function. AFS and DCA works as follows:

1. AFS: In the case that the station clock information is wrong and fringes are shifted outside of the lag window of the correlator ($\pm 1\mu sec$ at 16Mbps/ch, $\pm 4\mu sec$ at 4Mbps/ch), correlation mode is changed from "Normal Mode" to "Fringe Search Mode". Then "Fringe Search Mode" arranges all lags of 16 channels sequentially and makes the lag window wider ($\pm 16\mu sec$ at 16Mbps/ch, $\pm 64\mu sec$ at 4Mbps/ch) to get fringes. After fringes are detected, the station clock parameter is adjusted and a return is made to "Normal Mode".

2. DCA: Position of fringes within the lag window is monitored by the software. Clock parameters of each station are adjusted so that fringes are kept at the center of the lag window.

Even though the clock offset is changed by about a few hundred nanoseconds, no differences in the analysis results were observed.

Data processed in "Fringe Search Mode (FSM)" is unusable for baseline analysis. The frequency of transition to FSM must be as small as possible. For stabilization of AFS and DCA, RKATS has several parameters. They are listed in Table 2.

By optimizing these parameters empirically, RKATS can be tuned to operate as reliably as possible.

4. Summary

AFS and DCA are introduced as key functions of RKATS. Under the combination of RKATS and automated KSP system, baseline vectors among four stations are being measured automatically daily.

Keystone Project SLR : Kashima Accuracy Validation Test -Kashima Colocation-

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Abstract: The Keystone SLR network has been installed and is starting test observation on a single baseline from February 1997. The role of SLR is to provide a combination of techniques to contribute to baseline accuracy up to a few mm in 3-D. The calibration of the measured range is the most important work for SLR. It is normally achieved by using the laser ranging system itself to measure the distance to one or more local ground targets whose distances from the instrumental reference point have been accurately measured by geodetic survey. The difference between the laser ranging value and the survey value is then applied to satellite ranging measurements. In order to demonstrate stability and difference of the ranges within millimeters, we set up colocation optics for calibration of four optic-electronic packages, configuring all four packages connected to a single telescope and one of laser transmitting to the ground and satellite targets to receive simultaneous signals. Ranging to ground target in four hours results in a single shot precision of 4-6mm rms, and 15-second (normal point) precision of 2-3mm rms.

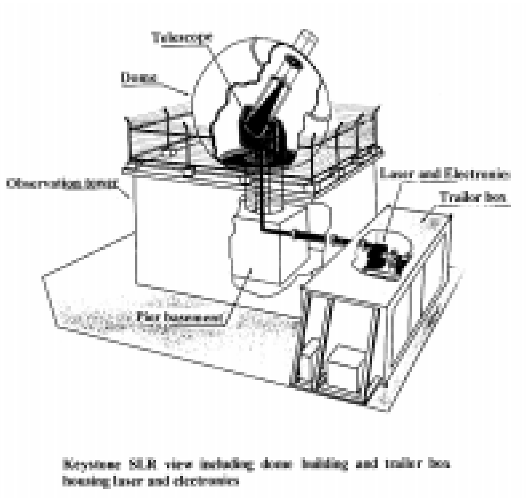

Figure 1. Schematic View of Keystone SLR.

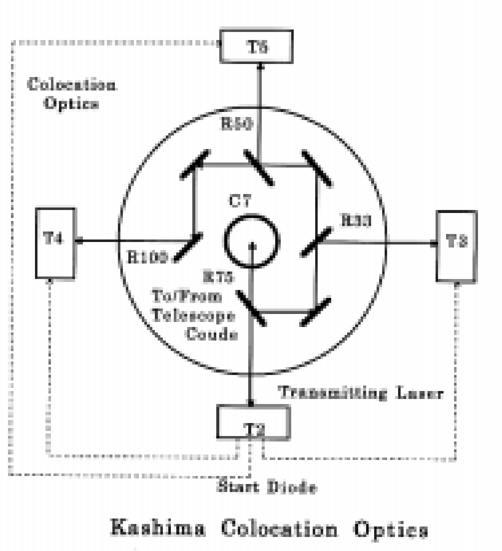

Figure 2. Kashima Colocation Optics.

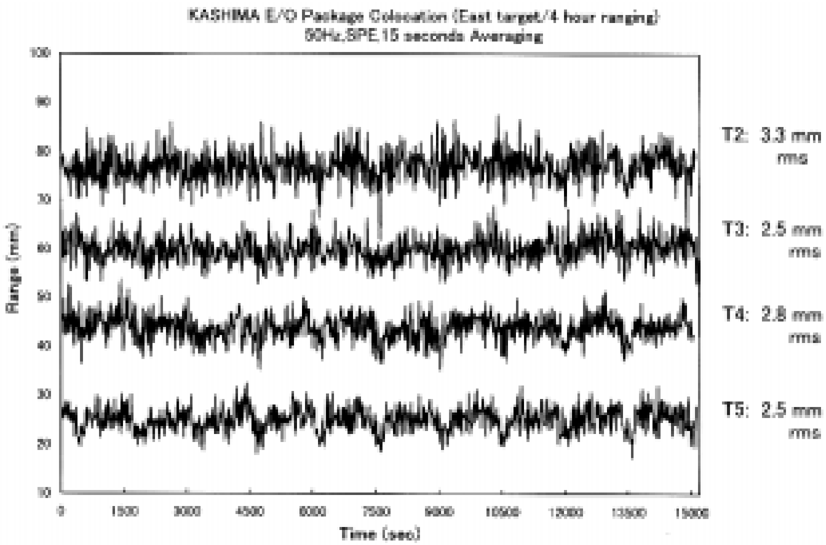

Figure 3. Kashima Colocation Ranges (50Hz, 15 seconds averaging).

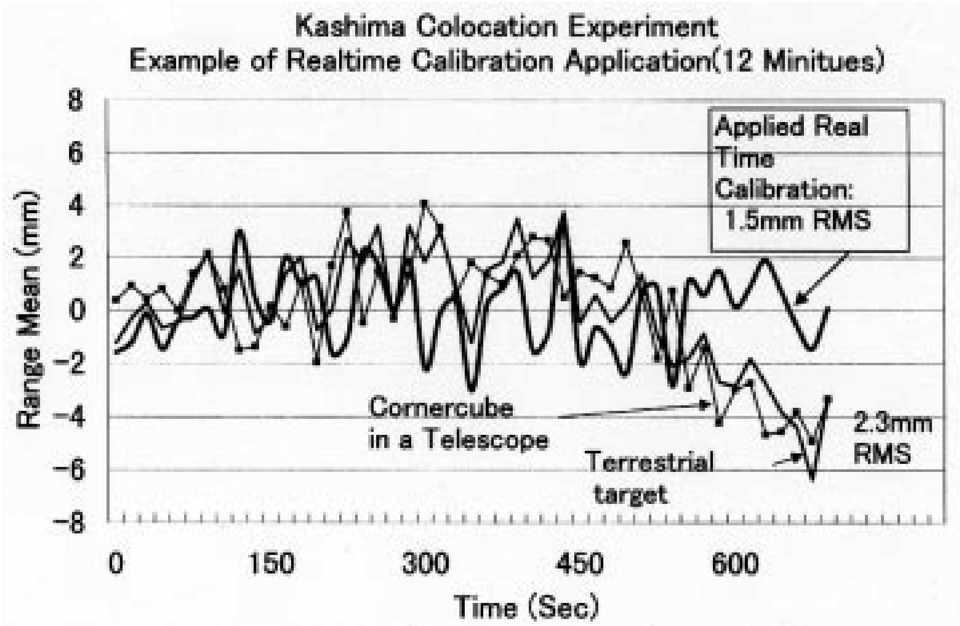

Figure 4. Kashima Colocation Real time calibration.

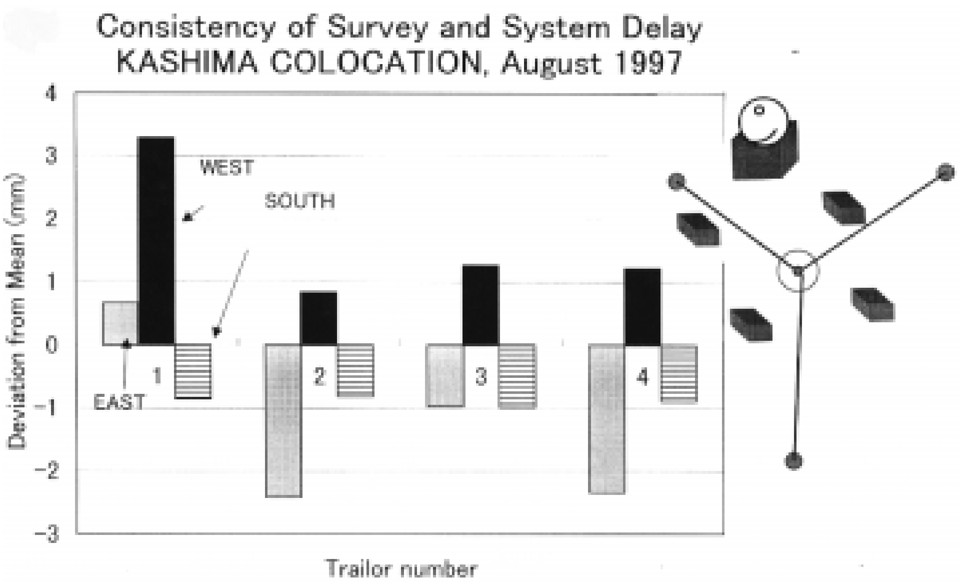

Figure 5. Kashima Colocation MINICO results.

We see a small common drift possibly due to laser characteristics, and demonstrated stability of 10 minutes. System delay reaches 1.5mm rms by applying real time calibration that uses a corner cube on the telescope aperture. MINICO (Mini Colocation) procedure which ensures consistency among survey and system delay is within ± 3mm, found significant discrepancies among ground target survey results.

Tie of the Key Stone Project VLBI Network to the International Terrestrial Reference Frame

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1. Introduction

In the Key Stone Project, site coordinates of three VLBI stations at Koganei, Miura, and Tateyama are estimated from the data obtained in each experiment while the site coordinates of the 11m antenna at Kashima for the Key Stone Project (KASHIM11) is fixed in the process of least-square estimations [*Koyama*, 1996]. The *a-priori* information of KASHIM11 coordinates should be given in the ITRF94 reference frame to make them consistent with other *a-priori* parameters. The source positions and Earth Orientation Parameters are taken from ICRF94 and EOP(IERS)90C04 series and its extensions reported in regular bulletins from IERS, respectively, which are consistent with ITRF94. It is also important to give accurate and reliable ITRF94 coordinates of KASHIM11 to tie the VLBI Network of the Key Stone Project with the global terrestrial reference frame. Estimated site coordinates of three VLBI stations in the Key Stone Project can be used as accurate reference points in the ITRF94 reference frame if the site coordinates of KASHIM11 station can be determined in the frame with sufficient accuracy. Two geodetic VLBI experiments have been performed to determine the KASHIM11 site coordinates in the ITRF94. The first one was performed for 24 hours on January 17, 1995 with 34m antenna station at Kashima (KASHIM34) and two Key Stone Project sites at Kashima and Koganei. The second experiment was performed for 23.5 hours on May 1, 1997 with KASHIM34 and four Key Stone Project sites. The estimated KASHIM11 positions are compared in Figure 1. In the figure, estimated positions are shown by ellipses which express the one-sigma uncertainty either in the horizontal plane or in the vertical plane.

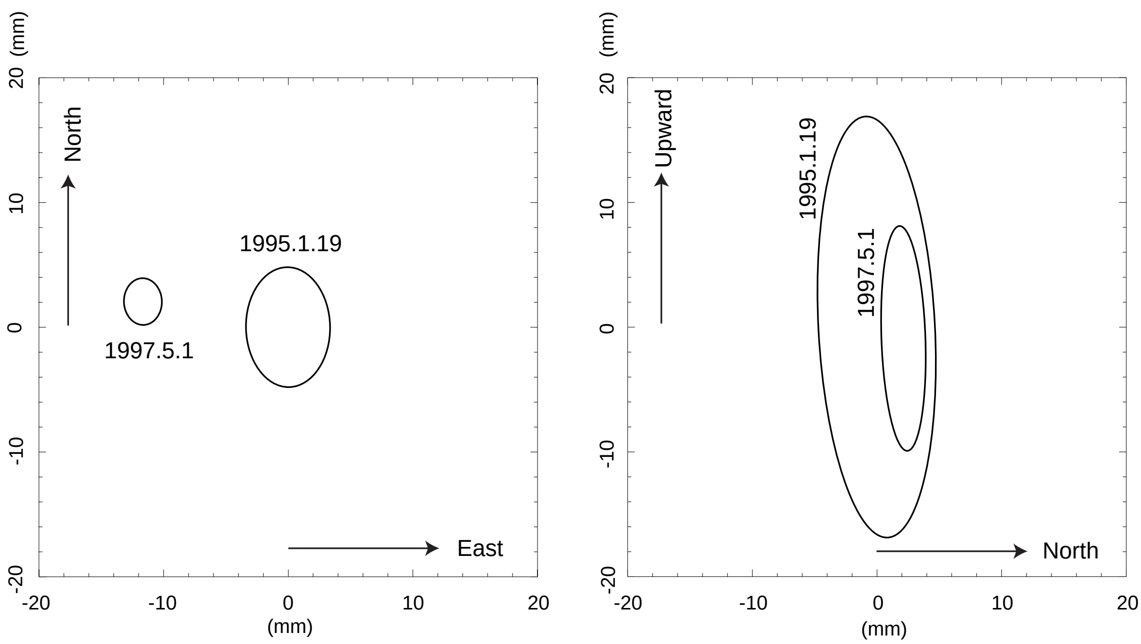

Figure 1. Comparison of KASHIM11 position estimated from two joint experiments. The ellipses express one sigma uncertainties of the estimated position (a) in the horizontal plane and (b) in the vertical plane.

Table 1. Estimated VLBI site positions R on January 1, 1997, and velocities V defined in the ITRF94 coordinate system.

Site			X	Y	Z
Koganei	R	(mm)	-3941937398.4 ± 5.8	3368150858.3 ± 4.7	3702235261.4 ± 5.0
	V	(mm/year)	7.5 ± 0.7	-5.2 ± 0.6	-15.8 ± 0.6
Kashima	R	(mm)	-3997505622.1 ± 6.1	3276878350.2 ± 4.8	3724240665.8 ± 5.2
	V	(mm/year)	5.1 ± 2.3	-3.6 ± 2.0	-19.8 ± 2.5
Miura	R	(mm)	-3976129918.1 ± 6.9	3377927833.6 ± 5.7	3656753813.7 ± 5.9
	V	(mm/year)	24.2 ± 1.1	-6.7 ± 0.9	-15.5 ± 1.0
Tateyama	R	(mm)	-4000983352.7 ± 5.7	3375275900.1 ± 4.7	3632213145.2 ± 5.0
	V	(mm/year)	33.5 ± 1.9	-13.3 ± 1.6	-24.0 ± 1.7

Uncertainties in the results from the first experiment are larger than the results from the second experiment mainly because KASHIM34-KASHIM11 baseline data were not correlated in the first experiment. From the comparison, vertical position and North-South component of the KASHIM11 station is consistent between the two experiments, while there is a significant discrepancy in the East-West component. The cause of this discrepancy is not known but it might have been introduced when the vertical alignment of the pedestal of the antenna at Kashima was corrected in February 1996. The movement of the intersection of the Azimuth and Elevation axes of the antenna was measured at the time of correction. From the measurements, the position of the KASHIM11 station moved by $4.4mm$ in the direction of N25°W. The discrepancy in Figure 1 is about $12mm$ mainly in the westward direction and is not fully explained by the correction made in February 1996. The situation will be made clearer in the future when more joint VLBI experiments are performed with KASHIM34 and Key Stone Project VLBI Network.

Table 1 shows the ITRF94 coordinates of four VLBI stations in the Key Stone Project VLBI Network estimated from the data obtained in the second joint experiment on May 1, 1997. The uncertainties of the site coordinates are one-sigma standard deviations and the uncertainty of the site coordinate of KASHIM34 given in the ITRF94 is not added to the uncertainties in the table. Site velocities in the ITRF94 are also shown in the table. Site velocity of the KASHIM11 station is assumed to be the same as the site velocity of KASHIM34 given in the ITRF94. The site velocities of the three other stations are the results obtained from the Key Stone Project VLBI experiments until the end of August 1997. While the uncertainty of the KASHIM11 site velocity is the value for KASHIM34 site velocity in the ITRF94, the uncertainties of site velocities of the three other stations are calculated from the results of Key Stone Project VLBI experiments and the site velocity uncertainties of the KASHIM11 station are not added.

2. Ground Survey Measurements

The relative positions of reference points of the SLR and GPS facilities with respect to the reference point of the VLBI antenna were measured by ground surveys. Reference points of VLBI and SLR are defined by intersection of azimuth axis and elevation axis of the antenna and the telescope, respectively. Reference point of GPS is defined by the phase center of the antenna and it is assumed to be the center of the top plane of the base plate of the antenna. The results are tabulated in Table 2 along with the results obtained from VLBI and GPS observations. Geographical locations of the three techniques at sites in the Key Stone Project Network are shown in Figure 2. VLBI results are the coordinates estimated from the experiment on May 1, 1997. GPS results were obtained by averaging three independent estimates from three days of observations from July 30, 1997. GPS observations were performed with the Ashtech receivers at four stations in the Key Stone Project Network and at Tsukuba (TSKB) which is an IGS site operated by the Geographical Survey Institute. Data were collected at 30 second intervals for 24 hours a day, and the observed data were analyzed by using Bernese Version 4.0 software which has been developed in Bern University. In the GPS data analysis, the coordinate of TSKB was constrained to an IGS solution based on the ITRF94 coordinate system. Thus the results from VLBI and GPS are based on the same reference frame.

The comparison between ground survey results and two space geodetic measurements of VLBI and GPS showed an agreement within $20mm$ in horizontal components, and $35mm$ in the vertical. The discrepancies were larger than expected from the accuracies of the ground survey measurements and

Table 2. Positions of SLR and GPS reference points seen from VLBI reference point obtained by (1) ground survey measurements and (2) VLBI and GPS observations.

	Site		Eastward (mm)	Northward (mm)	Upward (mm)
(1)	Koganei	SLR	17420.8	−31359.6	−1975.0
		GPS	3493.0	−23843.2	−1769.9
	Kashima	SLR	12387.9	76693.2	7725.0
		GPS	18285.7	−24052.4	−4471.4
	Miura	SLR	16603.7	−74138.4	−2240.0
		GPS	−17031.7	6363.9	−4489.0
	Tateyema	SLR	−37205.4	−15229.3	−2056.0
		GPS	−34009.6	−19653.5	−297.0
(2)	Koganei	GPS	3477.3 ± 1.7	-23859.1 ± 1.7	-1774.7 ± 8.6
	Kashima	GPS	18283.3 ± 1.6	-24068.3 ± 1.8	-4450.4 ± 9.1
	Miura	GPS	-17041.9 ± 2.0	6347.7 ± 2.2	-4454.5 ± 10.3
	Tateyama	GPS	-34010.9 ± 1.6	-19672.9 ± 1.8	-285.5 ± 8.6

estimated uncertainties from VLBI and GPS. But the discrepancies can be decreased if we consider that there are inconsistencies between the results from VLBI and GPS. It is possible that either the KASHIM34 position or the TSKB position provided in the ITRF94 coordinate system may have a significant error which corresponds to a part of the discrepancies in the comparison in Table 2. If the KASHIM34 coordinates used in the VLBI data analysis had in fact an error of $8.5mm$ in Eastward direction, $17.6mm$ in Northward direction, and $-14.9mm$ in Upward direction, then the discrepancies do not exceed $8mm$ in the horizontal components and $20mm$ in the vertical component, and these values seem to be reasonable. These comparisons demonstrated the importance of the precise ground survey measurements for the collocation studies to tie different space geodetic techniques. Further VLBI experiments and GPS observations will improve the tie between VLBI and GPS as well as the tie of the Key Stone Project VLBI Network to the ITRF coordinate system.

3. Concluding Remarks and Future Plans

The Key Stone Project VLBI Network has been tied to the ITRF94 coordinate system through two joint VLBI experiments with KASHIM34 or other global VLBI stations such as the 26m antenna at Kashima Space Research Center. The tie will be improved by repeating such experiments in the future. Regular and extensive observations of VLBI, SLR, and GPS will be compared with each other to improve consistencies and accuracies by using the information obtained from the tie measurements.

Acknowledgments

The authors would like to express deep appreciations to colleagues in Geographical Survey Institute for GPS observations at Tsukuba and data correlation of a joint VLBI experiment of Key Stone Project and 34m antenna at Kashima.

Reference

Koyama, Y., Automated Remote Operation System and Data Analysis System for the Key Stone Project, Proceedings of the Technical Workshop for APT and APSG 1996, pp.139, 1996.

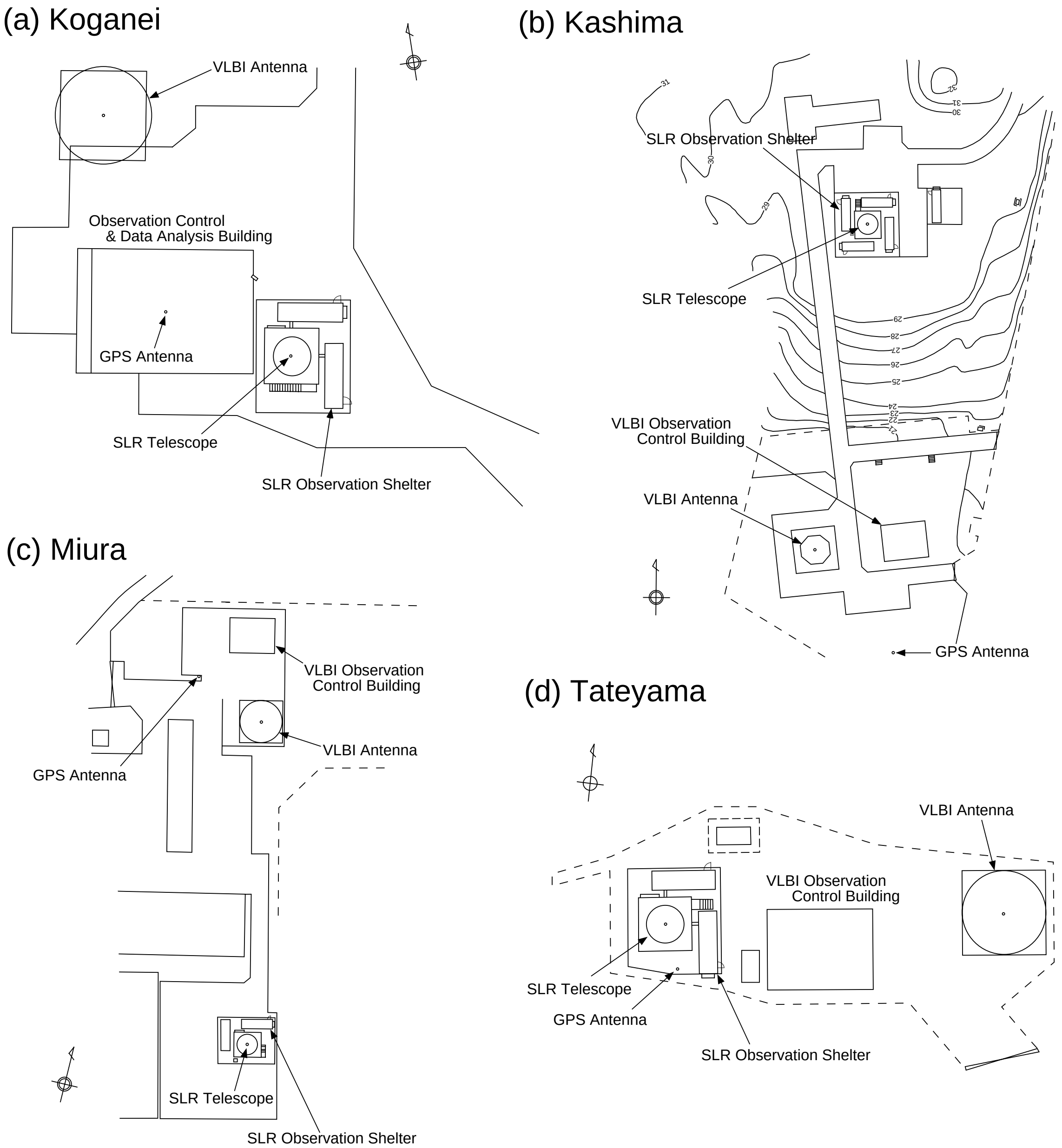

Figure 2. Geographical locations of three space geodetic measurement facilities at (a) Koganei, (b) Kashima, (c) Miura, and (d) Tateyama sites.

Evaluation of a GPS Time and Frequency Reference Receiver as a VLBI Frequency Standard

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1. Introduction

In recent years a GPS time and frequency reference receiver has shown remarkable progress in performance, and has come to be widely used as a frequency standard supplying highly stable signals (1×10^{-12}/day) at low cost. Although its stability is less than that of H-maser($\sim 1 \times 10^{-14}$/day) conventionally used for VLBI, its lower cost is attractive when we consider wide deployment of VLBI and VLBI-like techniques. We have therefore evaluated the performance of the GPS receiver and the possibility of its adoption as a frequency standard in VLBI observations.

2. Method and Results

An HP58503A is one of the GPS receivers commercially sold as a time and frequency reference receiver. It provides 1 pps signals synchronized to UTC within about 100 nsec as well as stable 10 MHz signals. We located two GPS antennas closely to each other; separation between them was only about 7 meters. Two receivers (HP58503A) were connected to the antennas independently. After sufficient running of receivers (3 days) according to the instructions attached with the receiver, we measured the phase difference between 10 MHz signals from two receivers for 6 days starting from June 29, 1997. Analog output from a phase comparator (HP K34-59991A) is converted into digital signals with a sampling period of 1 sec. Digitized data are stored in a notebook PC (Figure 1).

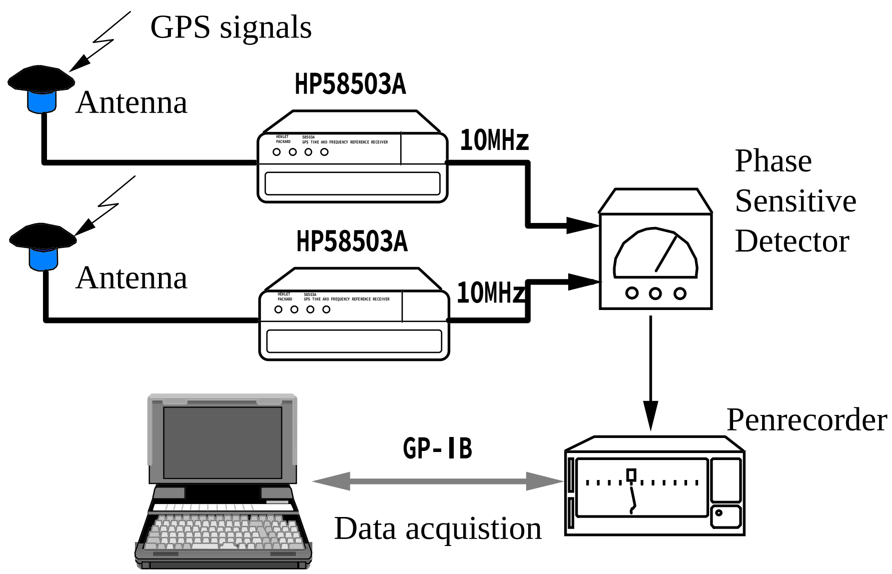

Figure 1. Schematic block diagram of observation system.

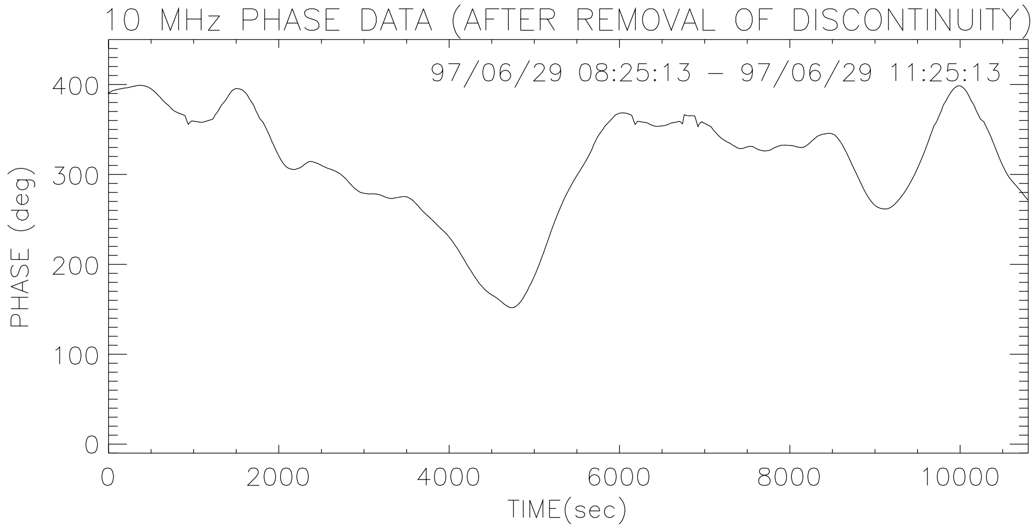

Figure 2. Observed phase data for 3 hours. Discontinuities due to a comparator are already removed

There are 72 discontinuities in raw phase data spanning 6 days due to inherent characteristics of the comparator, i.e., a trip of 360 degree occurs when the phase crosses the 360 or 0 degree boundary. These discontinuities should be removed before further statistical analysis is carried out. Figure 2 shows the observed phase after removal of discontinuity. Small data discontinuities still remain in the data.

The Allan variance is a good measure for evaluating stability of reference signals. We calculated the Allan variance at an averaging time τ from the phase data at 10 MHz as follows,

$$\sigma_y^2(\tau) \equiv \langle \sigma_y^2(2, \tau, \tau) \rangle = \langle (\bar{y}_{k+1} - \bar{y}_k)^2 \rangle / 2 \qquad (1)$$

where

$$\bar{y}_k = \frac{\phi(t_k + \tau) - \phi(t_k)}{2\pi\nu_0\tau} \qquad (2)$$

where $\phi(t_k)$ is the phase at time t_k and ν_0 is the frequency at which the phase measurement is made (=10 MHz). We divide phase data into 24 sets of 6 hour spans. Figure 3 shows the Allan variances calculated for each phase data set. The results show stability of better than 10^{-11} for an averaging time range less than 1000 sec. This is almost the same performance expected from specifications of the receiver. Scatter on the plots seen for time range less than 1000 sec is attributed to small discontinuities still left in the phase data as mentioned before. System noise level is sometimes larger than the receiver performance for the time range less than 10 sec. However we can say that it reaches the level described as typical characteristics in the specifications of the receiver, i.e., $\sim 2 \times 10^{-12}$ at 10 sec.

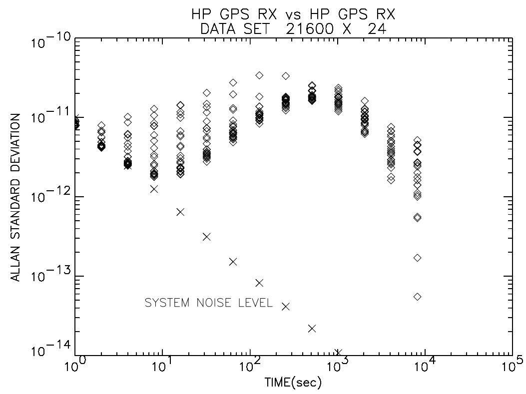

Figure 3. Root Allan variance calculated for 24 sets of phase data. Each data set spans 6 hours. Measuring system noise lebel is represented by symbol "×".

Next we evaluate coherence loss when this frequency standard is applied to S (2.2 GHz) and X (8.8 GHz) band observations. Using measured phase data, coherence after N sec integration is calculated as follows,

$$r_N = \frac{1}{N}\left|\sum_{n=1}^{N} e^{i\theta_n}\right|, \qquad \theta_n = \mathrm{C} \times \phi(t_n) \qquad (3)$$

where C is a ratio of observation frequency and 10 MHz, i.e., 220 and 880 for 2.2 GHz and 8.8 GHz respectively, and $\phi(t_n)$ is a phase at time t_n. We assume no coherence loss for 1 sec integration. Coherence calculated this way is shown in Figure 4. In this calculation phase data are divided into 48 sets of 3 hour span. As shown in the figure coherence decreases as the integration period increases. Even at 10 sec integration they are down to about

0.7 and about 0.3 for 2.2 GHz and 8.8 GHz, respectively. They are further decreased down to 0.1 for 100 sec integration, which is a typical accumulation period in a geodetic VLBI. Therefore it seems to be difficult to adopt for VLBI observations.

Fringe searches in VLBI correlation processing are relevant to this problem. Correlator outputs integration results every second or every several seconds. These time segmented data are further integrated with phase change being adjusted by a time-linear function to maximize integrated correlation amplitude. This process is called a "fringe search".

We adopt a similar technique in a calculation of coherence. Firstly phase variation during accumulation period is fitted by a polynomial function using a least squares method. Then we calculate coherence using residual phase after fitting. We use a polynomial of degree 1 to 3.

Figure 5 shows results in case of the first order polynomial being adopted. This is the case just like a "fringe search" in geodetic VLBI processing. We can see remarkable increase in coherence. At 100 sec, almost no loss can be seen for 2.2 GHz. Even for 8.8 GHz, coherence keeps value of 0.3. Figure 6 presents results when a third order polynomial is adopted. It is seen that an integration period without loss can extend to about 300 sec for 2.2 GHz and about 100 sec for 8.8 GHz. Thus adopting the fringe search process for integration, the GPS Time and Frequency Reference Receiver can be used as a frequency standard for VLBI observations made at S and X bands. However, the observed delay time obtained this way should be carefully examined for utilization in further analysis such as a baseline length analysis, because clock stability is an important factor to connect a scan, which is a continuous observation of a radio source, between neighboring observations in further analysis, and fluctuation of the clock between observations remains as an unknown parameter.

3. Conclusion

We have evaluated the performance of GPS Time and Frequency Reference Receiver (HP58503A) to determine whether it is adoptable as a frequency standard in VLBI observations. Firstly we measured phase difference between 10 MHz signals output from two independent receivers. Then we calculated the Allan variance to evaluate the stability at average times ranging from 1 to 10000 sec. Coherence loss was also calculated from the actual phase data. As a result it is demonstrated that the GPS Time and Frequency Reference Receiver can be used as a frequency standard if we expand the fringe search process to account for third order variations with time.

Acknowledgments

The authors would like to thank Hiroo Kunimori, KSP/SLR group leader, for offering two GPS time and frequency reference receivers (HP58503A) for this study.

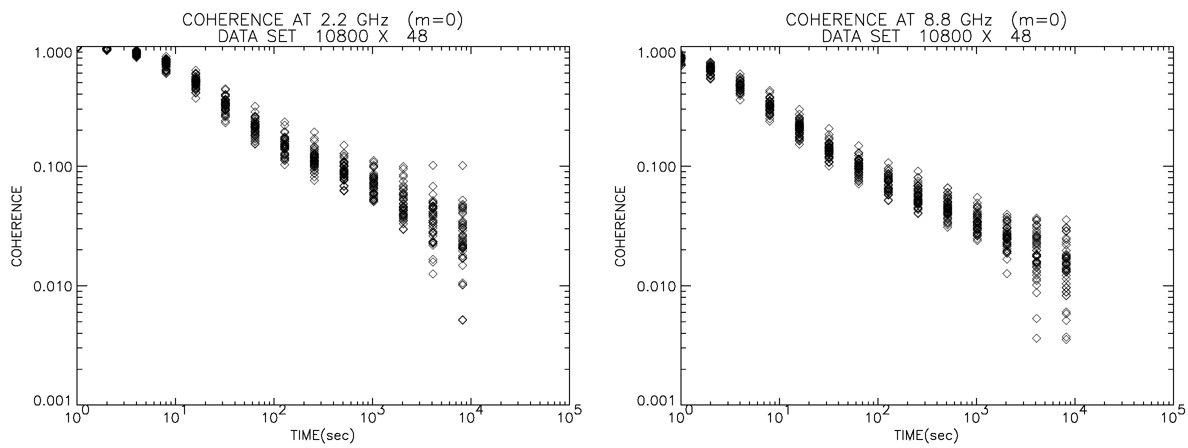

Figure 4. Coherence calculated from the phase data versus integration time for 2.2 GHz (left panel) and 8.8 GHz (right panel).

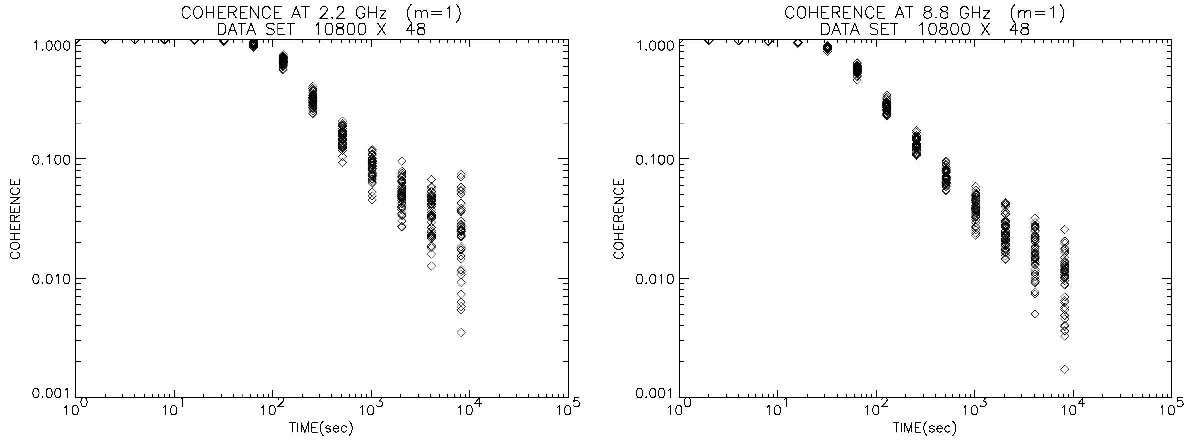

Figure 5. Coherence calculated using residual phase data after a linear drift is removed versus integration time for 2.2 GHz (left panel) and 8.8 GHz (right panel).

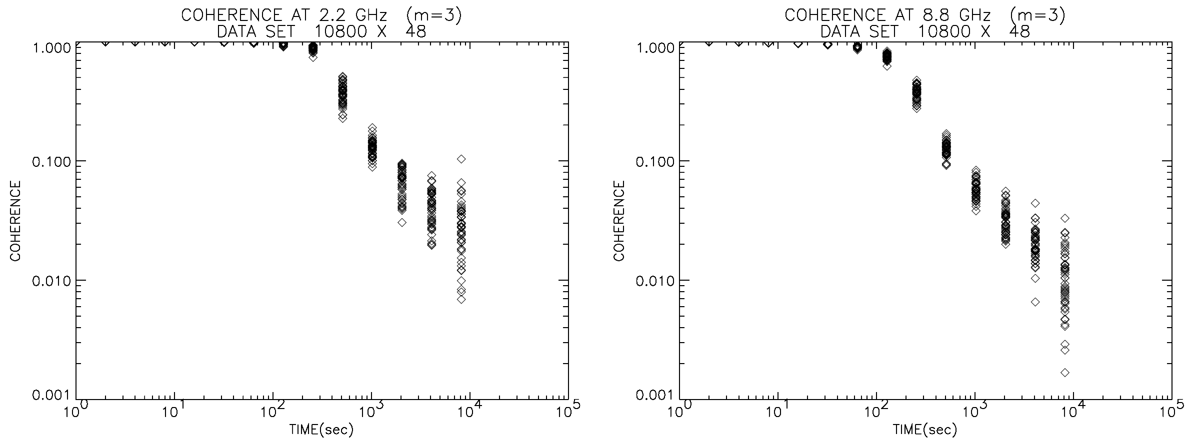

Figure 6. Coherence calculated using residual phase data after a third order polynomial fit versus integration time for 2.2 GHz (left panel) and 8.8 GHz (right panel).

Millisecond Pulsar Observation System at CRL

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1. Introduction

It is known that millisecond pulsars having a millisecond pulse rate maintain extremely stable pulse timings over the long term. As for the first discovered millisecond pulsar PSR1937+21 with 1.6 ms pulse period, fractional frequency stability was reported on the order of 10^{-14} for 2.6 years averaging times [*Taylor*,1991], which is comparable to a cesium clock. With such characteristics, millisecond pulsars are expected to be used as probes for detecting the background of gravitational waves and fluctuations in the interstellar medium, and as stable frequency standards [*Fruchter et al.*, 1995].

Communications Research Laboratory (CRL) is the national institute of time and frequency standards in Japan, and we aim to apply the millisecond pulsars to the frequency standards. We developed a basic observation system using our 34m antenna at Kashima in 1992 [*Hanado et al.*, 1993], and succeeded in detecting PSR1937+21. Based on this result, we develop a more sensitive system using an Acousto-Optic Spectrometer (AOS) [*Goutzoulis and Abramovitz*, 1988]. This report introduces this system and current observation results of PSR1937+21.

2. Concept of System Design

It is difficult to measure precise pulse timing of millisecond pulsars because their signals are quite weak and signal-to-noise ratios are not good. The flux density of PSR1937+21, which is one of the strong millisecond pulsars, is only about 4mJy at 2GHz (calculated from *Foster et al.*[1991]). Because our 34m antenna is not so large for millisecond pulsar observation, we require a highly sensitive pulse-detecting system.

One way to improve a system's sensitivity is to expand its observing bandwidth. For pulsar observations, however, we must note the dispersion effect caused by interstellar plasma. Owing to this effect, observed pulse shape is broadened as the receiving bandwidth increases. In order to avoid this problem, a wide-band signal must be divided into narrow bands at first, and recombined after canceling the dispersion delay in each narrow band. Such a process is called de-dispersion [*Lyne and Graham-Smith*, 1990]. A filter-bank method is popular for de-dispersion, but we use an AOS instead of a filter-bank method in our system.

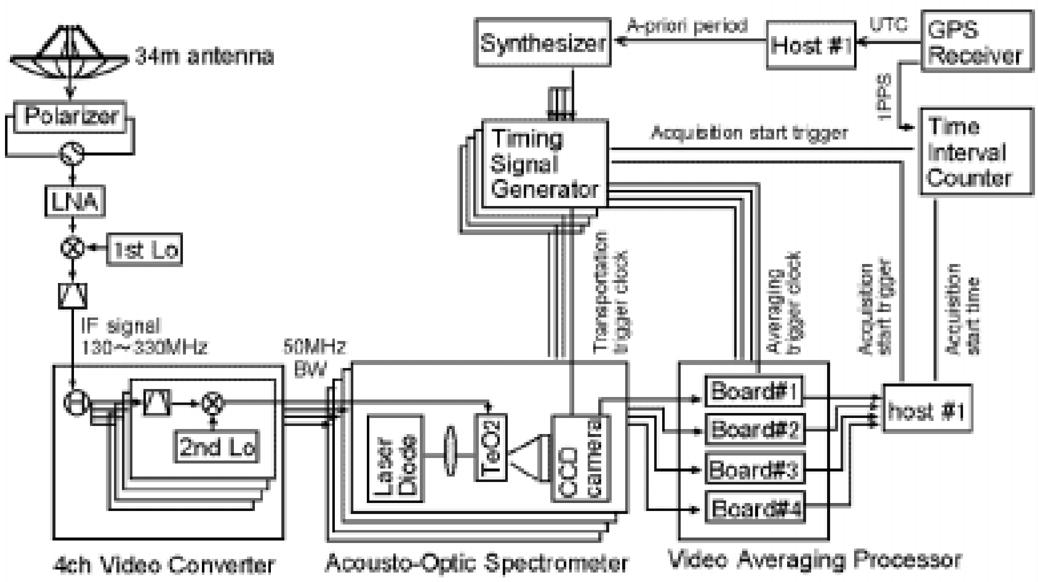

Figure 1. Block diagram of millisecond pulsar observation system at CRL.

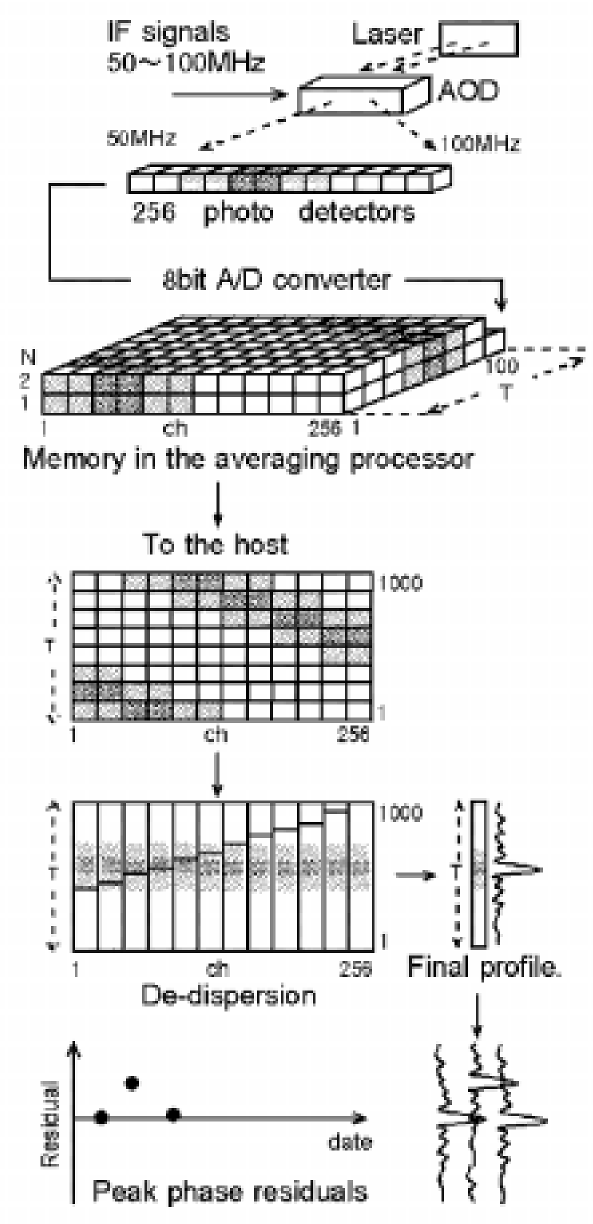

Figure 2. Data flow from the AOS to the host computer.

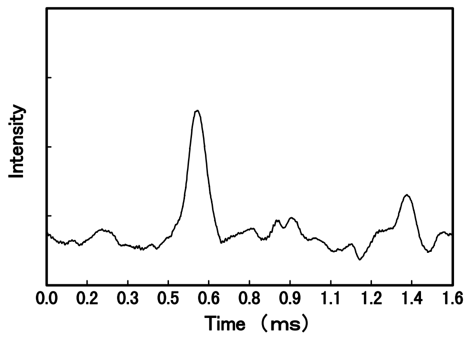

Figure 3. Pulse profile for PSR1937+21 at 2GHz band. Integration time is about 14 minutes and receiving bandwidth is 150MHz.

AOS is a spectrometer using an acousto-optic device such as a single crystal of TeO_2 for spectrum analyzing. This spectrometer can divide a wide band signal into many narrow channels simultaneously by a small crystal, so it makes the system simple and compact.

Long integration time is another way to improve sensitivity, which is achieved by accumulating many pulses. For this purpose we developed a high speed averaging processor which can average pulses 2^{24} times without data transportation to the host computer. It can eliminate dead time in data processing by performing internal calculations during the next data acquisition, and we can obtain the averaged data almost in real time.

3. Observation System

Figure 1 is a block diagram of our observation system using the 34m antenna at Kashima Space Research Center of CRL, and Figure 2 shows its data flow. The system's parameters are listed in Table 1. We use 2GHz band for pulsar timing observations. An IF signal with 200MHz bandwidth is divided to 50MHz x 4units at video converter. Each 50MHz bandwidth is divided to 200kHz x 256ch by the AOS, then transported to the video averaging processor serially. This transporting time for one line is 12.8 μ sec (=50ns $\times$ 256ch), which limits time resolution. When the transportation trigger is set to 1/100 of the pulsar period, the time resolution becomes about 16 μ sec for PSR1937+21. The video averaging processor works as an 8-bit A/D converter, and an averager which allows 224 pulses' addition (= 7 hours' integration for PSR1937+21) in each channel. At the host1, the averaged data of each channel are combined after the dispersion-delay calibration carried out in 1/1000 steps of pulsar period, and final pulse profile is defined. From this profile, the peak phase is defined as arrival pulse timing. Host2 calculates the a-priori pulse period, and supplies it in real time to the synthesizer which controls the averaging trigger clock of the timing signal generator. For this calculation, we use the program TEMPO which is the Princeton pulsar timing analysis package [*Foster and Backer*, 1990]. The reference clock of this system is synchronized with UTC via the GPS satellites. The difference between UTC and the internal clock of the timing signal generator is monitored by a time interval counter.

Table 1. Parameters of the millisecond pulsar observation system at CRL.

Antenna diameter	34m
Observation frequency	2120 - 2320 MHz
Total bandwidth	200 MHz (50 MHz × 4 units)
Frequency resolution	200 kHz (50 MHz / 256 ch)
Time resolution	16 μ sec
A/D converter resolution	8 bit
Number of pulse-addition	2^0 - 2^{24}

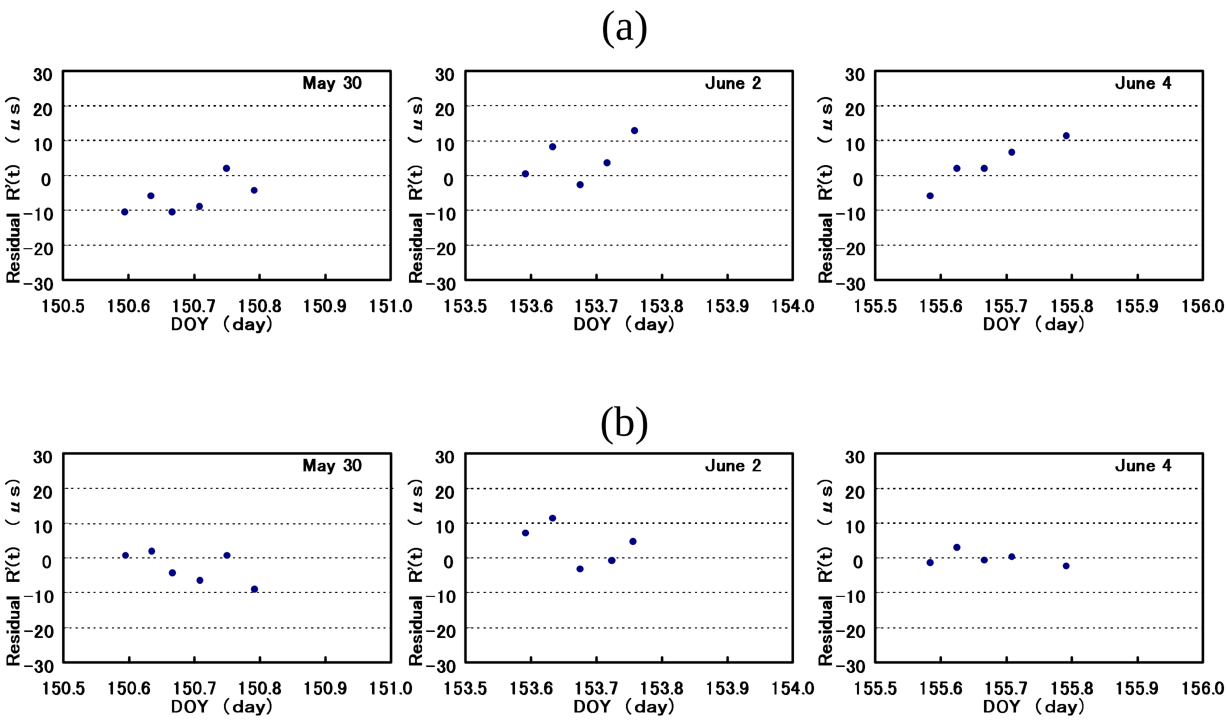

Figure 4. Residuals of peak phase for PSR1937+21. (a) Observation data using a database calculated by VAX TEMPO. (b) The same days' data corrected by a database calculated by UNIX TEMPO.

4. Observation of PSR1937+21

We carried out the preliminary observations of PSR1937+21 at 2GHz band. Figure 3 shows the pulse profile made after averaging 524288 pulses (= integrating about 14 minutes). From such averaged profiles, peak phases are defined. Figure 4 shows the residuals $R'(t)$s calculated as follows, which shows the phase fluctuation:

$$R'(t) = R(t) - R_{ave}$$
$$R(t) = \phi_{obs}(t) - \phi_{calc}(t)$$

here $\phi_{obs}(t)$ is an observed peak phase, $\phi_{calc}(t)$ is a calculated a-priori phase, and R_{ave} is an average of all $R(t)$s over three days. Residuals observed on May 30, June 2, and June 4 tend to increase in one day (Fig. 4(a)). We suppose it is due to the mismatch of a-priori calculation, because we used the old database made by old TEMPO (VAX version) in these observations. Then we corrected the observed data by using new TEMPO (UNIX version). The UNIX version uses a newer ephemeris compared with that of the VAX version. After this correction, the residuals' drift seems to be flat (Fig.4(b)), and the standard deviation is improved to 4.8 μ sec from 7.2 μ sec. From these results, it seems to be better to use UNIX TEMPO.

After June 19, we use UNIX TEMPO for the observations, remain. Figure 5 shows the obser-

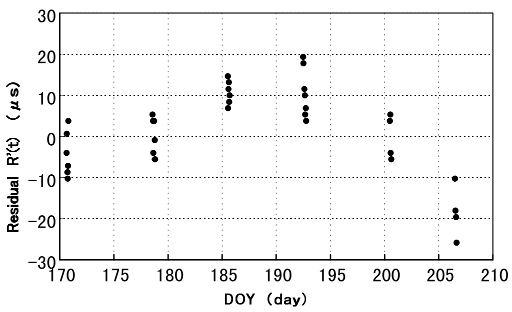

Figure 5. Peak phase residuals for PSR1937+21 observations using UNIX TEMPO.

vation results from June 19 to July 25, and the residuals show a systematic trend. Perhaps it is because of the misuse for the program or hardware problem, and we are now trying to clarify the cause.

5. Conclusion

We developed a millisecond pulsar timing observation system using the Kashima 34m antenna, and succeed in detecting PSR1937+21. It is one of the smallest antennas for millisecond pulsar observation in the world. Using this system, continuous observations have been carried out for PSR1937+21. The standard deviation of observed peak phases is about 4.8 μ sec which shows the current observation precision. This value is reasonable in terms of the system's performance and the observation conditions.

However some problems exist in our system yet. We must check the a-priori pulse period calculation because the observed peek phases show some systematic trend. In addition, some noise exists in the pulse profile which may make the observation precision worse. We are trying to solve these problems in order to get better observation precision.

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Construction of New LF Station for Time and Frequency Service

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1. Background of New LF Station

Communications Research Laboratory (CRL) has the responsibility for national frequency and time standards in Japan. Depending on this charter CRL has been engaged in research and services in this domain, such as

(1) Development of primary frequency standards,
(2) Time keeping,
(3) International precise time transfer,
(4) Dissemination of standard frequency and time signals.
(5) Related basic researches.

Concerning the dissemination of standard frequency and time, CRL employs several dissemination ways, such as standard time signal transmission using HF and LF bands, dial-up time service using telephone lines (called Telephone JJY) and Network Time Protocol stratum-1 server for computer networks.

The construction of a new LF station for time and frequency service is one of the activities for dissemination service at CRL.

2. Why LF Time Service?

CRL started transmission of JJY (HF time signal service) in 1940. But its quality or frequency stability is not enough for recent needs, because

- HF signal has about 10^{-7} or 10^{-8} frequency stability at receiving point due to ionosphere while the transmission signal has 10^{-12} to 10^{-13} stability.
- around Japan area there are several HF standard time service stations, such as BPM from China, BSF from Taiwan, HLA from Korea, and WWVH from Hawaii. Due to these foreign standard time signals, it is difficult to discriminate JJY from the others, especially in the western part of Japan.

On the other hand LF signal has following advantages over the HF signal

- High stability, about 10^{-11} to 10^{-12}, in the area of ground wave
- There is no interference time service signal using Japanese LF band (40 kHz) around Japan
- There is a big market, such as radio controlled clocks and watches, using LF time signals

In the global view, the ground standard time service is shifting to LF band from HF band, such as DCF-77 and MSL in England, increased power of WWVB in USA.

Of course this is the age of GPS, and using GPS signals everyone can make easily obtain positioning to better than 100 m and get time signals better than 1 microsecond. But in our policy, the LF time signal can coexist with GPS for the following reasons:

(1) the frequency stability of LF signal is of the same order as GPS in the case of SA,
(2) the receiver of LF signal is more simple compared to a GPS receiver,
(3) LF signal can be received inside buildings.

3. Outline of CRL's New LF Station

Location	:	southern part of Fukushima prefecture (about 200 km north of Tokyo)
Antenna type	:	top loading umbrella type antenna mounted on a 250 m main tower
Carrier Frequency	:	40 kHz
Transmitter	:	50 kW (solid state type)
Effective radiation power	:	$>$ 10 kW (more than ten times greater than present station)

Construction schedule

Fiscal year 1997	:	building and bases for antenna
Fiscal year 1998	:	antenna tower, transmitters, etc.

4. Applications of LF Signal

Application areas of the new LF standard signal are expected to be the following:

For time signal:
Radio controlled clocks and watches
Time control of public transportation
Time maintenance of meteorological equipment and seismometers, etc.

For frequency standard:
Keep tractability of the frequency standard to the national frequency standard for industry
Radio frequency regression

Basic Research of Key Technologies for Next Generation Global Navigation Satellite System

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1. Introduction

GPS (Global Positioning System) is one of the most popular navigation systems and it is used in very diverse application areas, such as precise geodesy, time comparison, meteorological purposes.

On the other hand discussions for the next generation global navigation system (GNSS), and how Japanese government can contribute to this system has been made on several occasions.

Depending on such discussion, the committee of space development of Japan made a scenario for next generation GNSS.

Its basic policy is:

Japan should establish basic research and development items to contribute to the next generation GNSS, such as on board atomic clock, precise time and frequency transfer between ground clock and satellite on board clock and precise and real time orbit determination technique.

CRL has started research and development on the above items during this fiscal year.

2. R & D Items for Next Generation GNSS

CRL has initiated the following main research and development items this year:

(1) Development of on board Hydrogen Maser type frequency standard; Atomic standard section is in charge of this item. They started development of Hydrogen Maser type frequency standard in cooperation with a Japanese private company. They are going to construct a prototype within four years. It will be have almost same frequency stability as a laboratory type and its weight will be 50 - 70 kg.

(2) Highly accurate time and frequency transfer technology between ground station and satellites: Frequency and time standards section started development of an accurate time and frequency transfer technique between space and ground station. They are planning to use two way transmission mode to cancel the effects of propagation medium, such as ionosphere and troposphere, and use carrier phase of the signal to obtain precise measurement.

(3) Highly precise and real time orbit determination technique. Concerning this item, CRL has just started discussions concerning the method which should be most suitable for the next generation GNSS system.

3. Relation to the ETS-VIII Satellite

ETS-VIII satellite is "Experimental Technology Satellite VIII" which will be launched in 2002. NASDA (National Space Development Agency) has plans to equip this satellite with atomic clocks. The on-board atomic clocks will be commercial type Cesium clocks. By using these atomic clocks NASDA plans to carry out basic experiments in navigation.

A working group for the satellite navigation system was organized by the members of CRL and NASDA to discuss the function of the ETS-VIII on-board atomic clock equipment and experiments using it.

Figure 1. TDS784A Gigabit samplers under test.

Giga-bit VLBI, Progress on Giga-bit Sampler

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1. Status

Giga-bit samplers (see Figure 1 on page 28) were tested at the Nobeyama radio observatory (see the previous issue of TDC news for details of the VLBI giga-bit sampler). Both CRL-VLBI and NRO-spectrometer group carried out the test. The DSO (Digital Sampling Oscilloscope) sampler consists of a modified DSO part and an interface for successive processor. The interface unit is working as a de-multiplexer of the data stream for each purpose. Nobeyama 25-multi-beam receiver for 45m radio telescope will use the DSO sampler with 1 Gsps (sampling per second) 2-bit 4-channel. Although there is a difference in the interface unit channel configuration, we agreed to unify the DSO sampling part. This will simplify the maintenance procedure at the manufacture. Radio astronomical society will be able to accommodate each other with sampler on site. In September whole astronomical giga-bit sampler had been gathered at Nobeyama. We measured all DSO sampler at the same bench. Several static and dynamic parameters to evaluate AD performance had been measured. Table 1 shows the unified astronomical sampler major specification.

2. Measurement

Each channel of the sampler works 1024 Msps 2-bit for scientific data sampling. We have checked AD performance. Although the TDS784 is completed as the time-domain measurement instrument, longterm frequency-domain AD characteristics should be examined for astronomical purposes. We have measured following parameters for the first step .

Differential Liniarity Error In 2-bit sampling, AD deviation from ideal transition spacing (DLE) exists. Improper code-width between the transitions will give bad AD linearity. Statical distribution of output-code bin will not represent actual level distribution. In our astronomical data processing, there is no DLE calibrating hardware. DLE is expected to be very small. Following equation,

Table 1. TDS-spec Comparison between the VLBI & Spectrometer

	VLBI	Spectrometer
(TDS784 modified)		
Sample rate(M)	1024/512/256	1024/512/256
Channel Input	4/4/4 (*1)	4/4/4
AD Quantaization	2	2
Output Datarate	128MHz x64	128MHz x6
Total Datarate	8Gbps	8Gbps
(Interface)		
Input Datarate	128MHz x64	128MHz x64
Handle rate(M)	1024/512/256	1024/512/256
Select channels	1/2/4	4/4/4
Quantaization	1 or 2(*2)	2
Output connector	D-Sub	SCSI-halfpitch
Total datarate	2Gbps	8Gbps
(Processor)		
Instrument	Recorder	Auto-correlator
Datarate	1Gbps (x2) (*2)	2Gbps (x4)

Notes: 1: unified version. 2: single recorder use MSB bit only.

Table 2. Differential Linearity Measurement Result of two VLBI sampler

	#1		#2	
	DLE2	DLE1	DLE2	DLE1
ch-1	0.072	0.082	0.010	0.030
ch-2	0.032	0.068	0.040	0.004
ch-3	0.074	0.046	0.038	0.016
ch-4	0.074	0.076	0.042	0.004

$$DLE = \frac{T_{n+1} - Tn}{V_{fs}/2^N} - 1(LSB)$$

defines DLE measured with LSB. Table 2 shows the measured TDS784 DLE between 3 transitions under 2-bit sampling. Measured DLE is small enough to neglect in the latter part.

Offset Error DC offset also results in the deviation of code appearance. Trouble will occur in the latter part digital processing especially in correlation. Few mV DC offset had confirmed in the AD raw data. To cancel out this, additional offset can be applied from the TDS front panel. Rather important longterm drift and temperature dependence will be measured separately.

Spectrum Auto-correlation result of a period was used to check the spectral characteristics. UWBC correlator in the Nobeyama observatory was used for preliminary test. 64 MHz harmonics was observed in cetain channel data. The bug was fixed.

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Message to the Key Stone Project

Prof. T. A. Herring of Massachusetts Institute of Technology kindly gave his message to the Key Stoneproject Team when he finished his stay at the Communications Reserach Laboratory as a gusest scientist in September, 1997. We are happy to open it as an article of the TDC News getting his acceptance since it is full of suggestions for the technical develoments.(*T. Y.*)

Dear Taizoh-san and Keystone Project Team,

I would like to thank you and the Keystone Project Team for a most enjoyable visit. I was very impressed by the facilities here at CRL and at Kashima. The Keystone Project is unique in the world and it seems that it has the potential to make great contributions to our understanding of the Earth and modern geodesy. The VLBI system in the Keystone Project is the only current system running real-time and on such short baselines. The SLR system is also unique in the proximity of the systems and its collocation with VLBI and GPS. As such, you have a unique opportunity to address a number of critical issues in Earth sciences. To me, one of the most important issues to address is the "stability" of the Earth. While our representation of the motions of points on the Earth surface is through linear motions with occasional episodic displacements and post-seismic motions, there is mounting evidence, mainly from GPS, that the actual behavior of the Earth may be more complicated. The deviations from secular motion are generally less than 10 mm in horizontal components and seem to be of large scale (i.e., correlated over may hundreds of kilometers). But so far, there is little evidence that two different geodetic systems see the same deviations. In this regard, the collocated Keystone systems are unique in a tectonically active region. Because the non-secular motions appear correlated over large distances, the expected signal sizes on a small network are likely to be only a few millimeters. This is the case in California where the RMS scatter of daily positions estimates for many of the GPS stations separated by <100 km is between 1 and 2 mm for horizontal components and 5-10 mm in height. Of course in California there is only a GPS network and it is not possible to compare GPS to other space geodetic signals.

For the Keystone Project I see several tasks that would greatly increase our understanding of geodetic systems and the Earth. With this system, it should be possible to have millimeter accuracy results available from all three geodetic systems and the detailed comparison between them should reveal much about these systems and the Earth. For VLBI, I think you should investigate using phase delays which should improve the delay precision by a factor of ten or so; it will be interesting to see how much the station position estimates improve with this increased data quality. For GPS, you could potentially improve the phase center models for the antennas through the comparison of the position estimates from VLBI, GPS and SLR, and through detailed studies of the phase residuals. One interesting approach here would be to use the PRESTAR system with its clock shared with a nearby GPS receiver using an omnidirectional antenna. Such as system is being developed in the US for in-situ calibration of GPS antennas. One of the largest uncertainties in GPS measurements arises from the phase center variations of the GPS antennas. SLR has, in principle, a major advantage over GPS and VLBI due to its much lower sensitivity of atmospheric water vapor. There is also an intrinsic strength in making a direct range measurement rather than the biased range measurements implicitly make by GPS and VLBI. The challenge in SLR is to realize these advantages; at the moment it appears that SLR generates geodetic results which are not of higher quality than GPS and VLBI even in the height component. Understanding why this is so, and improving the performance of SLR seems to be a high priority. The Keystone system is again unique in being able to address these fundamental issues.

For all systems, it seems that the availability of the JMA 10 km resolution atmospheric data sets will allow detailed studies of the effects of atmospheric propagation on geodetic systems. Establishing how large the effects of inhomogeneity in the atmosphere are is an important task. Of great utility to the whole geodetic community would be the development a parameterization of these inhomogeneities so that they could be estimated from the geodetic data themselves thus extending the currently used zenith delay and gradient estimation strategies. If the VLBI/SLR and GPS systems do not generate the same results between collocated stations then CRL is in a unique position to understand and correct the deficiencies in each of these systems. Ultimately, if the systems can be shown to agree at the 1 mm level, at least in the changes of the positions that they measure, then again the Keystone Project is in a unique position to improve the accuracy of all three systems to better than 1 mm. Ultimately it is not clear what will set the final accuracy achievable with any of these systems: it could be the atmosphere or the solid Earth itself. The operation of these systems and the redundancy of the measurements systems should definitively establish the effects to be expected before, during, and after earthquakes. Motions after earthquakes should establish the rheological properties of the Earth and the forces acting on it after an earthquake. Detection of a reliable pre-seismic signals, measured by three independent systems, would be of fundamental importance in the study of earthquakes. Of course, these signals may be too small to detect currently, but the Keystone Project is in a unique position to be able to address this issue with multiple techniques.

Again I thank you for a wonderful visit, and I look forward to seeing some great results coming out of the Keystone Project.

Best Regards

Tom Herring.

VLBI Technical Development Center (TDC) at the Communications Research Laboratory (CRL) is supposed to do

1) the development of new observation techniques and new systems for advanced Earth's rotation observations by VLBI and other space techniques,

2) the promotion of research in Earth rotation by advanced methods in VLBI,

3) the distribution of new VLBI technology.

The TDC meeting, attended by the ordinary members from inside the CRL and the special members from the outside, is held twice a year. The special members advise the committee, concerning the plan of technical developments. The TDC newsletter is published biannually by CRL to inform the IERS community its current activities.

This news was edited by Tetsuro Kondo and Yasuhiro Koyama, Kashima Space Research Center, who are editorial staff members of TDC at the Communications Research Laboratory, Japan. The editors wish to thank Dr. O. J. Sovers for his kind help in the correction of the news translated from Japanese to English. Inquires on this issue should be addressed to T. Kondo, Kashima Space Research Center, Communications Research Laboratory, 893-1 Hirai, Kashima, Ibaraki 314-0012, Japan, TEL : +81-299-84-7137, FAX : +81-299-84-7159, e-mail : kondo@crl.go.jp.

Summaries of VLBI and related activities at the Communications Research Laboratory are available from the home page of the Radio Astronomy Applications Section of the Kashima Space Research Center on the World Wide Web (WWW). The URL to view the home page is : **"http://www.crl.go.jp/ka/radioastro/"** .

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