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CONTENTS

Overview of the Twelfth TDC Meeting

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The twelfth meeting of the Technical Development Center was held on March 10, 1998 at the Kashima Space Research Center of the Communications Research Laboratory.

Attendance

CRL members

Kenichi Okamoto, Michito Imae, Mizuhiko Hosokawa, Yuko Hanado, Yukio Takahashi, Chihiro Miki, Hitoshi Kiuchi, Akihiro Kaneko, Taizoh Yoshino, Hiroo Kunimori, Jun Amagai, Hideyuki Nojiri, Toshimichi Otsubo, Masato Furuya, Futaba Katsuo, Fujinobu Takahashi (KSRC: Kashima Space Research Center), Noriyuki Kurihara (KSRC), Yasuhiro Koyama (KSRC), Junichi Nakajima (KSRC), Ryuichi Ichikawa (KSRC), Tadahiro Gotoh (KSRC), Tomonari Suzuyama (KSRC), and 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), and Masayuki Takemura (Kobori Research Complex, Kajima Corporation)

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

Minutes

1. Opening Greeting

Fujinobu Takahashi, the vice-director of IERS TDC at the Communications Research Laboratory (CRL), opened the meeting.

2. Activity Reports by Special Members

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

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

Seiichi Shimada reported on the effect of horizontal atmospheric asymmetry in GPS data analysis. He mentioned that the estimated horizontal station position had been improved but this is is not the case for the vertical position. He also demonstrated water vapor distribution in a time-space domain obtained from GPS data analysis.

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 of the Maritime Safety Agency as follows.

System improvement in accuracy targeting to 1 cm which is going on at the Shimosato SLR station has entered a final phase.

Measurements using a mobile SLR station made at Chichijima Island on the Philippine sea plate and which were separated by several years show motion of the island at 6 cm/year, which is consistent with VLBI measurements. Last summer the mobile station was located at Ishigakijima island. The measurements could barely be carried out due to the system's age. Next fiscal year, the mobile SLR station will be located at Wakkanai on Hokkaido.

The Hydrographic Department is planning to establish a fully automated GPS observation station at Danjo islands located west of Kyushyu which uses a solar battery and satellite communications link.

Deployment of the D-GPS network by the Aids to Navigation Department is going on as scheduled. About 30 sites will be established by the end of FY 1998.

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

Noriyuki Kawaguchi reported on the current status of the VERA project and VSOP as follows.

The main aim of the VERA (VLBI Exploration of Radio Astrometry) project has been slightly modified to emphasize the observation of invisible objects, that is, the precise measurement of the attractive motion of maser sources due to the gravitational field around black holes. An angle resolution (of better than) in an order of 10 micro arcsecs is required for this purpose. To obtain this angle resolution at least four, and if possible more than six, VLBI stations will be necessary for the VERA network in Japan. Urmuqi station will be a key station in improving the imaging ability of the VERA network. Furthermore, VERA can have better continuum sensitivity than VLBA at millimeter-wavelength by having wider observing bandwidth.

He also demonstrated the idea of a synthesis antenna by connecting a number of antennas distributed throughout Japan using ATM optical links in a "writing with one stroke" manner. He demonstrated that this idea would allow observations at up to 8 Gbps, if the communication link has 10-Gbps speed and five stations are connected.

As for the VSOP, Kawaguchi reported that "HALCA" is in good condition and space VLBI observations are carried out almost everyday. He told us that he hopes to compare VSOP results with high-angle resolution observation made by VERA at a higher frequency in the future.

Finally, he requested the Technical Development Center (TDC) at CRL to maintain the 34-m antenna as long as possible because of its importance to the Japanese VLBI community and to continue the development of a reliable gigabit recorder. He also hoped CRL would promote the development of a VLBI network in Japan connected by optical fiber links like a KSP.

Tokyo Gakugei University (*Kachishige Sato*)

Kachishige Sato introduced his recent work on the model calculation of rheological slip without friction at the subducting plate boundary. This study was motivated by the measurement of post-seismic crustal deformation measured by GPS after the 1994 Sanriku-Haruka-Oki earthquake, he said. He evaluated two types of rheological model for lower crust and uppermost mantle, the "Maxwell model" and the "three-element solid model", by comparing the actual observation results. He concluded that the "three-element solid model" better explains the observations.

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

Masayuki Takemura reported on his recent work investigating the historical seismograph records of the 1923 Kanto earthquake. He pointed out that what happens after large earthquakes is important in predicting future earthquakes. He said, we can learn many things from historically large earthquakes.

Geographical Survey Institute (*Mikio Tobita*)

Mikio Tobita reported that the Field System, which is VLBI system control software developed by the US VLBI group, has been successfully installed at the 26-m antenna site at Kashima. A fringe test using the Field System was successfully carried out on March 3, 1998, and good fringes were detected.

He also reported that the construction of a 32-m antenna at Tsukuba is complete. A fringe test was done on March 20. This new antenna has a high-speed slewing rate of up to 3 deg/sec. The reference point of the antenna was designed not to vary over 5 mm per year. This will be monitored through a local survey.

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

Hideo Hanada briefly reported on the current status of RISE (Research In SElenology) in the SELENE (SELenological and ENgineering Explorer) project. According to his report, SELENE will enter the PM phase in FY 1998. A workshop relating to RISE was held at Mizusawa in January, 1998.

3. Technical Development Reports

3.1 VLBI Technology Developed at CRL

VLBI technology developed at CRL was reviewd by CRL members.

3.1.1 Automated Observations System (*Yasuhiro Koyama*)

CRL has been developing automated observation/operation software for Japanese VLBI since the early 1980's. These are "KAOS", "MAOS", "NKAOS", and "KANAMEISHI" in chronological order. The latest one is for the Keystone Project. The format of schedule files tends to be unified into the VEX format in the case of international VLBI. Therefore our VLBI operation software should be modified to accept the VEX format. On the other hand, the Field System, which was developed by the US VLBI group, makes it possible to control hardware developed by CRL, such as K4 and GBR recorders. Details are reported in this issue (see page 6).

3.1.2 Antenna and Front-end System (*Noriyuki Kurihara*)

CRL developed not only a receiver system for the 26-m antenna at Kashima but also a GSI VLBI system. CRL has been cooperating with the National Institute of Polar Research on the Antarctic VLBI project. We can say that CRL has contributed to the progress of domestic VLBI stations. Thus CRL has the potential of designing an antenna system up to 30-m and a high-quality and reliable S/X receiver system. CRL can also evaluate the total performance of VLBI antenna.

3.1.3 Back-end and Recorder (*Hitoshi Kiuchi*)

We developed a K-3 back-end and a recorder system, which are compatible with the Mark-III system. Then we developed a K-4 back-end and recorder which are more compact than the K-3 system's and easy to operate. After the K-4 VLBI system, a KSP recorder equipped with an automatic tape changer was developed. This changer enables us to make observations for a long time without an operator. It also makes observation very easy.

3.1.4 Real-time VLBI Technique (*Hitoshi Kiuchi*)

A real-time VLBI technique has been developed by CRL in collaboration with the Nippon Telegraph and Telephone Corporation (NTT). High-speed optical fiber links were constructed between four KSP stations by NTT. We also developed a real-time correlation processing technique using data transmitted through high-speed links. Now we are conducting routine VLBI observations using 256-Mbps data.

3.1.5 Bandwidth Synthesizing Technique (*Tetsuro Kondo*)

The history of bandwidth synthesizing software in Japan was briefly reviewed. Initially it took more than one hour to process only a single observation of about six minutes. Now this has become less than one minute due to improvements in software and computer hardware. One of the special members of TDC requested the development of real-time bandwidth synthesizing software.

3.1.6 Data Analysis (*Yukio Takahashi*)

Data analysis software dedicated to the geodetic VLBI developed by CRL was reviewd. The software has been being updated year by year to reflect the latest physical model and theory into analysis. The current software (for KSP) is third generation in Japan. We plan to implement the following function in the future, such as astronomical and geodetic applications, wide-band VLBI analysis, differential-VLBI analysis, and phase synthesis analysis. One of the special members hoped TDC/CRL would contribute to the data analysis of the VERA project.

3.2 Current Status of the Keystone Project (Crustal Deformation Observation System in the Tokyo Metropolitan Area)

3.2.1 VLBI System (*Kouichi Sebata*)

Kouichi Sebata reported on the current status of KSP-VLBI as follows. Measurement accuracy has been drastically improved since last autumn due to the change in observation tactics from a daily five-hour session to a 24-hour session every other day. Even though KSP is designed for ease of use in operation, sometimes recovery is difficult from R&D experiments or unusual accidents. We are compiling an operation manual as well as operation know-how in our computer to allow special knowledge to be utilized and shared with operator. As the KSP operator can access these manuals through the WWW, he/she can cope with most difficulties without any specialist aid.

3.2.2 SLR System (*Hiroo Kunimori*)

Hiroo Kunimori reported on the current status of the KSP SLR system as follows. The second observation campaign of Kashima and Koganei stations was successfully carried out. Observations were made at all four stations. KSP SLR started regular observations on February 16, 1998.

3.3 R&D Experiment Reports

3.3.1 Survey Observation of Radio Sources using KSP (*Akihiro Kaneko*)

Akihiro Kaneko reported on survey observation using the KSP VLBI facility. Last autumn, KSP changed routine operation from an everyday basis to an every other day basis. Survey observations were then carried out during the rest period of routine KSP operation. The purpose of survey observation is to obtain information about the angle size of radio sources available for VLBI. So far 120 candidates in the Parks catalogue have been surveyed, and fringes were successfully detected on 57 sources.

3.4 Others

3.4.1 Current Status of Kashima 34-m Antenna (*Eiji Kawai*)

The current status of the Kashima 34-m antenna was reported on by Eiji Kawai. As almost ten years has passed since the antenna was constructed, deterioration can be seen in every part. As the antenna is old, continuous upkeep is required to maintain it in good condition. One of the special members of TDC appreciated CRL's efforts in assisting and collaborating on VSOP. He requested CRL to keep the 34-m antenna as long as possible. After Kawai's talk a general question was raised concerning the lifetime of the antenna. Replying to the question, Mikio Tobita of GSI commented that it was 30 years in the case of a new GSI 32-m antenna.

3.4.2 Current Status of Next Generation VLBI (*Junichi Nakajima*)

Junichi Nakajima reported on the current status of the 43 GHz receiver currently under development. He also reported on the interference problem at 1.6 GHz expected to arise from the low altitude communication satellites to be launched in the very near future. The effects and problems are now being investigated. One of the special members commented that this might cause severe interference for the VLBI station in space.

3.4.3 Current Status of NAOCO at Kashima (*Tomonari Suzuyama*)

NAOCO, a simple correlator developed by the National Astronomical Observatory, is temporarily being installed at Kashima to allow spectrum observations to be made using the 34-m antenna. Tomonari Suzuyama reported that the installation is going well.

4. Closing Address

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

International workshop on GEodetic Measurements by the colocation of Space Techniques ON Earth (GEMSTONE)

25-28 January, 1999 Koganei, Japan
hosted by
Communications Research Laboratory

Communications Research Laboratory will host an international workshop named GEMSTONE (International workshop on GEodetic Measurements by the colocation of Space Techniques ON Earth) which is sponsored by the Science and Technology Agency in Japan in January of 1999.

Importance of colocation between the space techniques has been stressed. Although we had limited number of colocated stations in the past, the situation is changing. We can study systematic errors which may be invisible by a single technique, through the colocation. From a colocation, we may understand the behavior of the atmosphere and other physical effects. These study will lead us the reference frame improvement. On the other hand, we have to solve the technical problems such as ground surveying. This workshop will focus a topic of colocation in the aspects of the technical points and its contribution to the geodesy and astrometry. More information will appear on Web Site **"http://ksp.crl.go.jp/"**.

Instructions to use K-4 VLBI system with FS9 software

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1. Introduction

The K-4 VLBI data acquisition system has been developed by Communications Research Laboratory and are currently used at several VLBI stations. The system can be used for various modes of geodetic and astronomical VLBI observations. Recently, NASA Field System software has been implemented to be able to control the K-4 system. In this document, characteristics and specifications of the K-4 VLBI system are briefly described and instructions to use Field System to control the K-4 VLBI system are presented.

2. K-4 VLBI System

The K-4 VLBI data acquisition system at an observation station consists of the units listed below. In addition to these units, there are output interface units and correlator systems necessary at the time of correlation processing, but these systems are not supported by the Field System software and will not be described here.

- Local Oscillator ... 7632A, 7624
- Video Converter ... 7631A, 7623
- Input Interface ... DFC1100, DFC2100
- Data Recorder ... DIR1000, DIR1000L, DIR1000M
- Tape Changer (Optional) ... DMS24

The local oscillator unit generates phase locked local frequency signals based on a reference 10MHz (or 5MHz) signal. These signals are provided to the video converter unit where the IF signal is down-converted to video band signals by using image rejection mixers and low-pass filters. The model 7632A is capable to generate 16 local frequency signals from 99.9 MHz through 519.99 MHz, whereas the model 7624 is capable to generate 8 local frequency signals from 499.99 MHz through 999.99 MHz. The model 7631A video converter can convert 16 video channels and is used with the 7632A local oscillator unit. The model 7623 video converter can convert 8 video channels and is used with the 7624 local oscillator unit. In this case, two sets of each unit are used to configure 16 observation channels for usual geodetic VLBI experiments. Both video converter units have multiple low pass filters and the selectable bandwidths depend on the actual configuration of the unit.

Input interface unit digitizes the video band signals and record these signals by controlling the data recorder unit. DFC1100 has a single observation mode of 1 bit sampling - 16 channel - 4 Mbps (64 Mbps total). All three models of the data recorder unit can be used with the DFC1100 input interface unit. On the other hand, DFC2100 can be used with multiple observation modes. Among of these modes, only three observation modes, i.e. 1) 1bit-16ch.-4Mbps, 2) 1bit-16ch.-8Mbps, and 3) 1bit-16ch.-16Mbps, are currently supported by correlators at Koganei (CRL) and Tsukuba (GSI) correlators, and are supported by FS9 software. The difference of the three models of data recorder unit is the maximum speed of the data recording. The maximum recording speed of model DIR1000 is 256 Mbps and all three observation modes are possible. On the other hand, the maximum recording speeds of DIR1000L and DIR1000M are 128 Mbps and 64 Mbps, respectively.

Tape changer unit can change 24 ID1 cassette tapes for un-attended continuous observations. The current version of the FS9 software does not support the unit yet. The implementation is under progress.

3. Setup

First, the `/usr2/control/equip.ctl` file should be edited to reflect the actual configuration of the data acquisition equipments. The type of rack should be set as either k41 if the combination of model 7632A and 7631A is used, or k42 if the combination of model 7624 and 7623 is used. The type of recorder should be set as either k41 if the DFC1100 is used, or k42 if the DFC2100 is used.

Next, data and control cables should be connected. The input interface unit and the data recorder unit is connected with one data cable (VCD cable: blue) and one control cable (RS-422 cable: black). The data cable should be connected to the `DATA OUT` connector of the input interface unit and to the `DATA INPUT` connector of the data recorder unit. The control cable should be connected to the `TO DR` connector of the input interface unit and to the **REMOTE 4** connector of the data recorder unit. All the K-4 VLBI equipments are controlled via GP-IB data communication bus from the FS9 host computer except for the data recorder unit is actually controlled by the input interface unit via RS-422 but all the communications from the FS9 host related with the data recorder are done with the input interface unit. Each unit has a switch to set the GP-IB address. After setting a unique address to each unit, all the units should be connected to the FS9 host computer by GP-IB cables. Total length of the GP-IB cable should be kept as short as possible to prevent possible communication troubles (GP-IB specification allows up to 20 meters in total). Then edit the `/usr2/control/ibad.ctl` file and specify the configured GP-IB addresses. A sample file is shown below.

```
tc=dev02,4
d4=dev04,4
v4=dev05,4
l4=dev06,4
ca=dev07,0
```

In this example, the tape changer (`tc`) is set to the address 2 and the input interface (`d4`) is set to the address 4, etc. If the k41 rack is selected (i.e. model 7632A local oscillator unit and model 7631A video converter unit), `'v4'` and `'l4'` are used to specify the GP-IB addresses of the video converter and the local oscillator unit, respectively. If the k42 rack is selected (i.e. model 7624 local oscillator unit and model 7623 video converter unit), `'va'` and `'vb'` are used to specify two GP-IB addresses of the two video converter units, and, `'la'` and `'lb'` are used to specify two GP-IB addresses of the two local oscillator units.

Lastly, the file `/usr2/control/dev.ctl` should be edited to reflect which GP-IB devices are used at the FS9 host computer. Use `'board'` for the GP-IB board device name if a NI GP-IB communication board is used, and use `'/dev/ttyXX'` if a GPIB-RS232C converter box is used where XX depends on the actual configuration of the RS232C port (S1 for com1 port for example).

4. Regular Operations

Once all the equipments are connected and all the control files are properly edited, run FS9 software and issue a command `rec=init` from the FS9 console terminal. If the configurations were correct, the time code on the front panel of the input interface unit turns to all-zero for about a second and then returns to the normal state. This command initialize the unit and is often required after the system configurations were modified. Then execute `tape` command to check the data recorder unit, `vc` and `vclo` commands to check the K41 type rack, and `va vb vcla vclb` commands to check the K42 type rack. If the configurations were correct, responses will be shown in the log window.

If these commands did not work properly, be sure to update the FS9 software to newer versions. The curreently available official version does not support the K4 devices as of this time, and the actual version which is required to use the K4 VLBI system will be announced in the near future. At the time of observations, a procedure file and a snap command file have to be prepared by using DRUDG software later than the version NRV980302.

The K-4 VLBI system and other VLBI systems can be connected to the FS9 host computer simultaneously. Which system is actually used can be switched by editing the `equip.ctl` file. If one of the control files are modeified, `fs` program must be restarted to make these changes effective.

5. Related Documents

Following is a list of related documentations. If you do not have these documents, please request these documents to `koyama@crl.go.jp` or to `weh@vega.gsfc.nasa.gov`.

- Journal of the Communications Research Laboratory, vol. 38 (1991), *'special issue on the results of VLBI experiments at the Communications Research Laboratory (1984-1990)'*
- IERS TDC News, *issued biannually by Communications Research Laboratory*
- Proceedings of the Technical Workshop for APT and APSG, Kashima, December 1996
- VLBI Software Documentation, Field System, *NASA/Goddard Space Flight Center, Space Geodesy Program*

K-4 VLBI Data-Acquisition System

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Abstract: We have developed a new VLBI system based on the conventional K-4 system. The system was designed to achieve automated operation throughout the entire process, it is operated one operator for observation arrangement and correlation processing. The KSP system has two data transfer systems, one is a tape-based system and the other is a real-time system. The new acquisition system is designed to interface both systems, the two systems are possible to be operated simultaneously. The new acquisition system has multi-bit quantization sampling modes. The total data rate is up to 256 Mbps, and up to 16 video channels can be selected. Filterings are carried out in the digital filter. The digital filter is used because it results in good phase characteristics. This system is specially designed for the Key Stone Project, and an input interface unit is incorporated in the VSOP.

1. The New K-4 System

The KSP data-acquisition system (Figure 1), a high-end version of the K-4 system [*Kiuchi et al.*, 1997], has a maximum recording rate of 256 Mbps and is fully automatic. The different features of the systems are given in Table 1. The data-acquisition system consists of a reference distributor, IF distributor, local oscillator, video converter, input interface, output interface, data recorder, and digital mass storage system (automatic tape changer). The local oscillator synthesizes the local frequency signal for the video converter (Figure 2). This video converter converts windows in the IF-signal (500-1000 MHz) input into video signals. The frequency conversion is done by a image rejection mixer using single-sideband conversion. The output interface unit is used at a correlation processing station for tape-based VLBI.

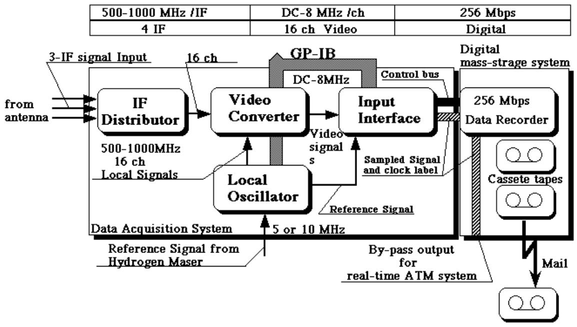

Figure 1. Block diagrams of the new K-4 (observing station configuration).

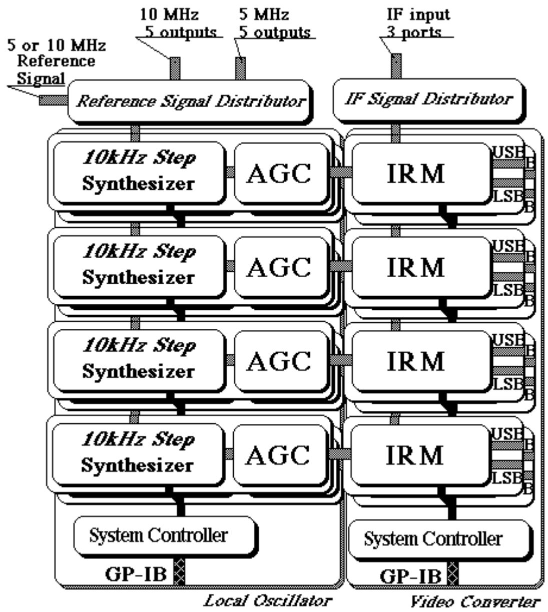

Figure 2. Block diagram of the new K-4 video converter and local oscillator.

1.1. Input Interface Unit

The input interface unit samples the video signal from the video converter (16-channel max.), and sends the digital data (256 Mbps max.) to the data recorder and/or the ATM transmitter (for a real-time VLBI system: in this issue) together with the time data. A block diagram of the input interface unit is shown in Figure 3. The acquisition system has one-bit and two-bit sampling modes for VLBI, and also has 4- and 8-bit sampling modes for general-purpose data acquisition. The anti-aliasing filtering is done in analog (32 MHz), and after sampling, the 16-MHz, 8-MHz, etc. filtering is done by the digital filter. The advantages of using the digital filter are that it can obtain good phase characteristics and can reduce coherence loss for wide bandwidths. Suitable coefficients of the digital filter can be selected for each observation; for example, the digital filter is used as a bandpass filter

Table 1. The different features of K-4 systems and other VLBI systems.

Functions	Stationary head		Helical scan head	
	Mark-III / K-3	*Mark-IV / VLBA*	*Conventional K-4*	*KSP (New K-4)*
Multi-bit sampling	*One-bit only*	*Two-bit*	*One-bit only*	✓
Threshold level adjustable	—	✓	—	✓
Digital filtering	*Analog*	*Analog*	*Analog*	✓
Bit error rate < 10^{-10}	10^{-4} -- 10^{-6}	10^{-4} -- 10^{-6}	✓	✓
Automatic bit synchronization	—	—	✓	✓
10 kHz step synthesizer	✓	✓	✓	✓
Pcal detection	—	—	✓	✓
Sampled raw data output	—	✓	Imperfect	✓
IF frequency [MHz]	100 -- 500	100 -- 500 500 -- 1000 VLBA	100 -- 500	100 -- 500 500 -- 1000 KSP

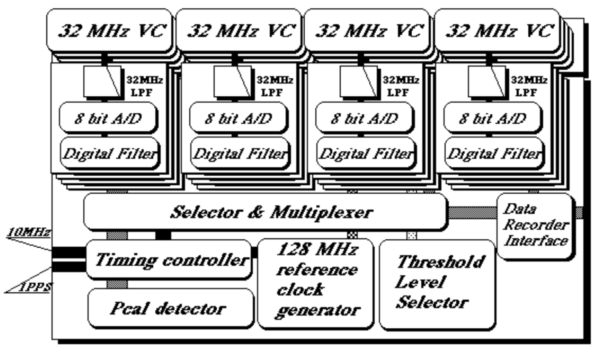

Figure 3. Block diagram of the new K-4 input interface.

for the line observation. The coefficients of the basically lowpass filter needed for Nyquist sampling are provided in the read-only memory (ROM). The output rate of data to the recorder or the ATM transmitter can be selected from five rates ranging from 16 to 256 Mbps. Time-code insertion can be at uniformly bit-space or at uniformly time-interval, or no time-code can be selected. In real-time VLBI, an uniformly bit spaced time code is used, as required by the ATM side. The suitable quantization threshold level of the A/D converter is adjustable. The configuration for one- and two-bit sampling is shown in Table 2. This input interface can be interfaced in analog to the Mark-III system with no modifications, using some BNC cables. This input interface is incorporated in the VSOP (VLBI Space Observatory Program).

*Table 2. New K-4 data configuration * = Mark-III mode, ** = VLBA mode, vs = VSOP mode.*

Sampling rate [Hz] 1 bit (2-level)					
Number of input channel	*Data recording rate [bps]*				
	256 M	128 M	64 M	32 M	16 M
16 ch	16 M**	8 M* **	4 M* **	2 M*	1 M*
8 ch	32 M**	16 M	8 M	4 M	2 M
4 ch	64 M	32 M	16 M	8 M	4 M
2 ch		64 M$_{vs}$	32 M	16 M	8 M
1 ch			64 M	32 M	16 M

Sampling rate [Hz] 2 bit (4-level)					
Number of input channel	*Data recording rate [bps]*				
	256 M	128 M	64 M	32 M	16 M
16 ch	8 M**	4 M**	2 M	1 M	0.5M
8 ch	16 M**	8 M	4 M	2 M	1 M
4 ch	32 M**	16 M	8 M	4 M	2 M
2 ch	64 M	32 M$_{vs}$	16 M	8 M	4 M
1 ch		64 M$_{vs}$	32 M	16 M	8 M

1.2. Data Recorder

We adopted a rotary-head type recorder that uses a cassette tape, which uses the ANSI (American National Standards Institute) X3.175-1990 ID-1 format. The data recorder's error rates during recording and replaying can be read through a host computer. Helical-scan recording is used to record high-rate digital signals. With a large cassette, the K-4 recorder provides up to 770 Gbits of data-storage capacity. The recording time is 200 min. (large cassette, 16-mm thick tape), with a 64-Mbps recording rate. Recording and playback are possible at different data rates: 256, 128, 64, 32, and 16 Mbps, making the data recorder suitable for many different applications. The playback heads are placed so that the recorded data are immediately played back during recording. This read-after-write facility makes it possible to monitor the error conditions of recording in real time. The bit error rate after correction was better than 1×10^{-10}. The data recorder employs a built-in diagnostic system, which is designed to detect operation errors or hardware faults. Error messages or warning information is fed to the host computer via the remote control interface, and to the front panel display. The periodicity of the time code is undesired for spectrum analysis. Only the sampled raw data are desired. The K-4 recorder has helical data tracks, two longitudinal annotation tracks and a control track (Figure 4). The VLBI data are recorded on the helical data tracks. A set of four helical data tracks has one track set ID number, which is a sequential number as a tape counter. The track set ID numbers are recorded on the control track, and can be read at any tape speed, even when fast forwarding or rewinding. There is an obvious relationship between the track set ID and the time code, and it is possible to manage the time code under the track set ID and time code block. The time data are written over the data train as the time code block in pre-observation. After the timecode block, the data timing is checked by track set ID, which means that the output data are only raw data digitized during observation. A data format fully compatible with the conventional K-4 system is also provided.

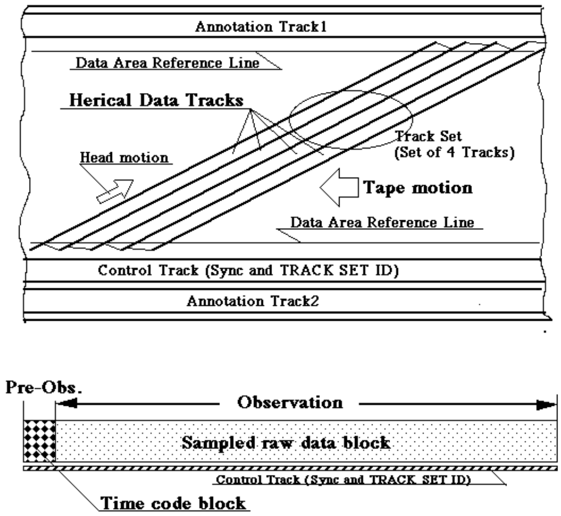

Figure 4. Tape format and data format.

1.3. Digital Mass Storage System (Automatic Tape Changer)

In KSP, we adopted an automatic tape changer as a digital mass-storage system (Figure 5). The system accommodates one tape drive and 24 tapes, or two tape drives and 16 tapes. The mass-storage capability is up to 2.3 TB. A barcode reader is built into the cassette-handling system to identify individual cassettes within the mass- storage system. Information from the barcode reader is available to the host controller via the remote control interface, and is written on the log which is utilized for correlation processing.

Figure 5. Digital Mass Storage System (Automatic Tape Changer).

2.1. View of the data acquisition system

A photograph of the data acquisition system is shown Figure 6. From left side, an ATM transmit-

Figure 6. View of the data-acquisition system.

Figure 7. View of the correlation processing system.

ter, an weather monitoring rack, an antenna control rack, a receiver control and monitoring rack, a backend rack, a digital mass-storage system. Three IF signals are received by IF receivers in the receiver control and monitoring rack. The IF signals send to an IF distributor in the backend rack. The two sets of video converters (500 – 1000 MHz : 8 ch/unit) converts IF signal to video signal. And the other video converter (100 – 500 MHz : 16 ch/unit) is prepared as a conventional K-4. The video signals are send to the input interface (black panel), and the digital data is send to the digital mass-storage system. The data is recorded on the magnetic tapes, or by-passed to the ATM transmitter.

2.2. View of the correlation processing room

A photograph in Figure 7 shows the view of the correlation processing room. We have two correlation processing systems, one is tape-based system (front) and the other is real-time system (left side). In the tape-based system, left side are digital mass-storage systems, and right side are correlation processor racks. In KSP, there are four sets of digital mass-storage systems, and 6-baseline correlators. The output interfaces are upper side, the correlators are lower two units in each correlation processor rack, and other parts are blank panels. It is possible to extend 10-baseline correlation system with these three racks. The tapes are loaded to or unloaded from the data recorder (lower side) automatically by digital mass-storage systems.

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Real-time VLBI system

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Abstract: We have developed a real-time VLBI system that uses a high-speed ATM (asynchronous transfer mode) network. In this real-time system, observed 256-Mbps/station VLBI data is transmitted through a 2.488-Gbps ATM communication network [STM-16] instead of being recorded onto magnetic tape. The system was specially designed for the Key Stone Project (KSP), which is concerned with measuring crustal deformation using four stations in the Tokyo metropolitan area in Japan. Cross-correlation processing and data observation are carried out simultaneously, and it takes about two hours to analyze crustal deformation data after the VLBI observation is completed. In regular geodetic VLBI experiments every other day lasting 24 hours, horizontal position uncertainty of about 1 mm and vertical position uncertainty of about 10 mm have been achieved. With the real-time VLBI system, one operator can handle both the observation and the correlation processing. The system was designed to enable automated operation throughout the entire process, and the obtained results are open to the public via the Internet (http://ksp.crl.go.jp).

1. The real-time VLBI system

We have two VLBI systems in operation: one tape-based and the other a real-time system. In the KSP tape-based VLBI system, the observed data is recorded on magnetic tape at the observing site, and the tapes are sent to the correlation site by mail. The analysis is done the next day, so it takes at least one day to obtain a measured value of crustal deformation. This delay was eliminated by using an ATM network [*Sato et al.*, 1990]) to send the VLBI data, which has a transmission capability of up to 2.488 Gbps through an optical fiber link. The four VLBI stations of the KSP are connected by this ATM network, and the data transmitted from these remote observing stations to the correlation site in Tokyo is processed in real time.

A block diagram of the real-time VLBI is shown in Figure 1. The ATM network transmits information in fixed-length packets called cells. A cell (AAL type 1) is composed of 53 bytes of data in total, a 5-byte header and a 48-byte payload but

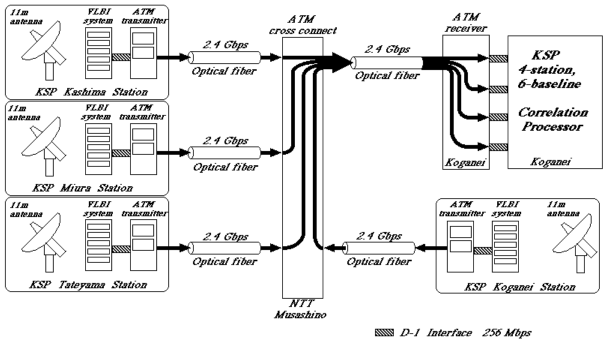

Figure 1. Block diagram of the real-time VLBI system.

1-byte is used as a sequence number to check for cell loss and mis-delivery. The signals input to the ATM transmitter are written in the payload of the ATM cell in arrival order. The header of the cell, which shows its destination, is attached when the payload becomes full, and the cell is output to the 2.488-Gbps transmission path [STM-16]. In the KSP real-time VLBI system, the signals from the four stations can be transmitted along one transmission path, and a cross-connect switch connects the multiple transmission paths. In the receiver, the multiplexed signal (cells) is separated into the data for each station and cells are disassembled and restored as digital signals after the destination in the header data is checked. The real-time VLBI system also has functions that compensate for delay, absorb cell-delay fluctuations in the transmission system, and compensate for mistaken cell delivery and cell loss in the receiver. In real-time VLBI, the data from each station is data synchronized in the receiver (Figure 2). To absorb the transmission-path delay, the signal begins to accumulate in the buffer memory from the time the time stamp (every 64 Mbit) is received. This time code is generated by the input-interface [*Kiuchi et al.*, 1997]. The readout for the buffer memory starts immediately after the time stamps from all observation stations have arrived allowing the timing to be synchronized. Because the data is output to the correlator after the timing has been synchronized, the output data for each station is correct up to the time on the time stamp. The KSP correlation processor is an XF type that uses field programmable gate arrays. The maximum processing data rate is up to 512 Mbps.

2. Results

The KSP system has two data transfer systems: a tape-based system and a real-time sys-

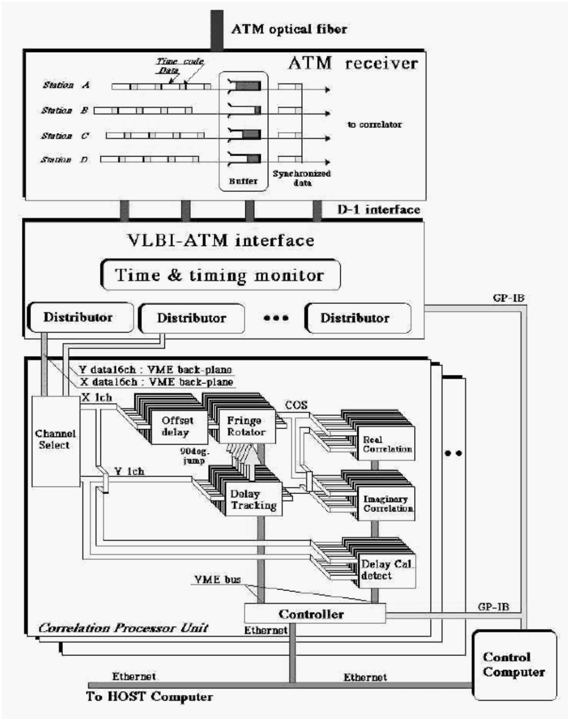

Figure 2. Block diagram of the data synchronization and cross-correlation processing in the real-time VLBI system. The data for an identical observation time taken at different stations differs in its arrival time due to the difference in the transmission-path length. To absorb the transmission-path delay, the signal begins to accumulate in the buffer memory from the time the time stamp is received. The accumulated period in the buffer memory is long when the transmission path is short, and vice versa. The readout from the buffer memory starts immediately after the time stamps from all observation stations have arrived. Thus the timing can be synchronized.

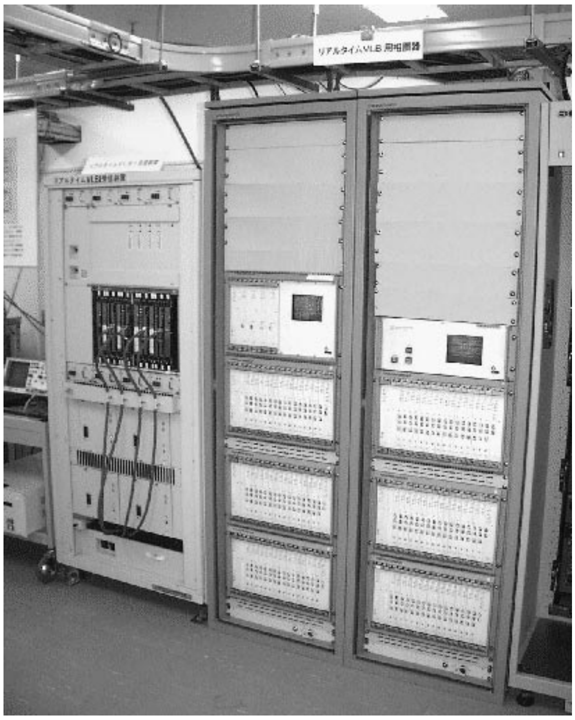

Figure 3. View of the real-time correlation processing system.

tem. The systems were designed to be fully automatic throughout the entire process, and only one operator is needed for observation and correlation arrangement. The two systems can be operated simultaneously. Using the tape-based system, we carried out daily 5-hour experiments starting in January, 1995. The real-time VLBI system has been used instead of the tape-based system since April, 1997. After a continuous 120-hour 256-Mbps test session (from July 28 to August 1, 1997), a 24-hour experiment was done every other day starting on September 30, 1997. In these regular geodetic VLBI experiments, a horizontal position uncertainty of about 1 mm and a vertical position uncertainty of about 10 mm, in terms of the internal estimation error represented by one sigma of standard deviation, have been achieved. All required observation and data analysis processes are fully automated, and the obtained results are available via the Internet (http://ksp.crl.go.jp). CRL has also developed an lower bits rate ATM system (STM-1: 155.6 Mbps) for international real-time VLBI experiments. We carried out real-time VLBI experiments between Koganei and Kashima using the STM-1 ATM network, good fringes were obtained.

3. View of the real-time correlation processing system

A photograph in Fig 3 shows the real-time correlation processing system. Left side is ATM receiver and other two racks are correlation processor racks. The correlators are lower three units in each correlation processor rack.

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Bandwidth Synthesizing Software KOMB

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A bandwidth synthesizing software can calculate residual delays with a time resolution of more than 0.1 nsec from raw correlator output data by synthesizing multichannel correlation data. This software is called KOMB in the VLBI system developed by CRL. We describe in this report KOMB's background and focus on its improvement in the processing speed.

In a geodetic VLBI observation, it is important to measure the difference between arrival times of radio signals from a common source (quasar) at two stations, which is simply referred to as the delay time. Time resolution is approximately the order of the reciprocal of the frequency bandwidth. Although we can record a limited amount of the frequency bandwidth signals on the magnetic tape,a wide bandwidth is needed to accurately observe delay time. Bandwidth synthesizing was therefore developed to increase the apparent bandwidth by combining a number of narrow bandwidth data. Phase calibration (PCAL) signals are injected in the input of a low-noise amplifier in order to synthesize the different frequency channel data coherently. KOMB first subtracts the instrumental phase difference of each channel from fringe phases by using PCAL phases. Then it calculates the fine delay resolution function, which is defined as a function of the trial delay and the delay rates. We will not include the detailed mathematical explanation of this data processing because it is not the purpose of this short report, but we will show an example of a fine delay resolution function calculated for actual VLBI data which was observed at 8 GHz on the Keystone Project network (Figure 1). KOMB was named after the shape of the fine delay resolution function which looks like a "comb".

KOMB was developed in 1983 on an HP1000/45F minicomputer in order to process the K-3 correlator output data which consists of 14-channel 8-bit-lag complex correlation data. Initially it took more than one hour to process a single observation data of six minutes. But by the end of 1984, the processing time improved to nine minutes for a six-minute observation. And 1989, it took only four minutes. This drastic speed-up in processing time was achieved by merely porting the software to an HP1000/A900 minicomputer.

In 1996, the software was ported to an HP9000/735 workstation and was modified to handle KSP's correlator output which is a 16-channel 32-bit-lag complex correlation data. By porting KOMB into this powerful workstation, the processing time significantly improved. It now takes less than 1 minute for a six-minute observation data. The improvement in processing time is summarized in Figure 2.

A workstation version of KOMB is being used at the Geographical Survey Institute to process their domestic VLBI observation data.

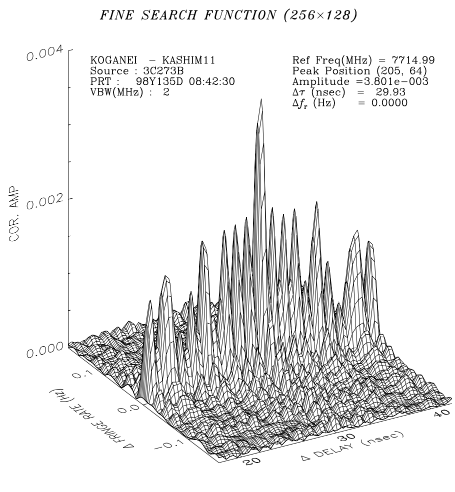

Figure 1. An example of a fine delay resolution function. KOMB was named after its "comb" like structure which is seen in the delay domain.

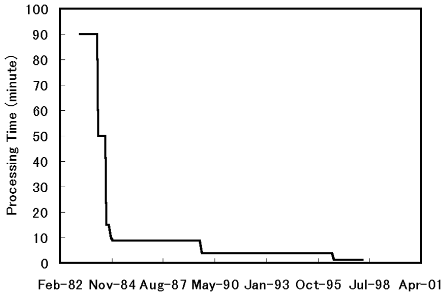

Figure 2. Evolution of KOMB processing time for one observation of six minutes.

Data Analysis Software

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1. Introduction

I introduce the VLBI software developed by CRL (Communications Research Laboratory). As the first generation, CRL had developed our own software system (K-3 software system) which is compatible with the Mark-III system. It had been used for international and domestic VLBI during 1983-1989. CRL developed a compact K-4 VLBI system which uses the K-4 recorder, and also develop the data processing software for the K-4 recorder and new data analysis software. This system is a second generation which was used during 1989-1997. Since 1993, CRL had developed the crustal deformation monitoring system for Tokyo metropolitan Area. We call it "Key Stone Project (KSP)". CRL developed the new software. This is the third generation which is available since 1995. Figure 1 shows the outline of VLBI data processing and analysis software. These software are referred to the Review of the Radio Research Laboratories Vol.30 in 1984 (Japanese), some papers [*Takahashi et al.*, 1991; *Takahashi et al.*, 1995] and the Review of CRL vol.42 in 1996 (Japanese).

2. K-3 software

The software system consists of 8 software programs, namely; scheduling software (KASER), data base setting software (KASET), correlation processing software (KROSS), bandwidth synthesis software (KOMB), tape format conversion software (KONV), a priori calculation software (KAPRI), parameter estimation software (KLEAR) and data base handling software (KASTL). The software systems were developed using HP1000-45F and 10L computer system. The characteristic of our system is to be used the same data base (K-3 data base) by all software from scheduling to analysis. The data base used the HP data base handler (IMAGE1000). The k-3 software system was developed from 1981 to 1984 according to the following considerations;

1) that all software should be systematized to use the same data base and the same physical model;
2) its data base should be developed independently by CRL;
3) it should be compatible with the Mark-III system;
4) it should introduce its own conceptual and physical model.

Data are combined for common attributes, and the key word (key item) of the attribute is added. The data base is made up of the network of key items which are linked to detail values. The data for each item can be easily accepted at random by selecting the key item. The K-3 data base is useful for random access, that is, the reading and modification of individual items. All software can use the same values and data is transferred between software through the common data base. No inconsistencies exist for common values, such as physical constants, positions of sources and stations for all software. However, the sequential access for the K-3 data base is slower than that for the Mark-III data base. The K-3 data base requires a large region of the disk and any change in the structure would be laborious. The Mark-III data base is better in a minicomputer since access speed is a serious problem, but the conception of K-3 data base is better in a high performance computer and for the many modifications of the data.

The data base setup software and data processing software must be developed by our own. A priori software had the tide model with the 484 periodical terms [*Manabe et al.*, 1984].

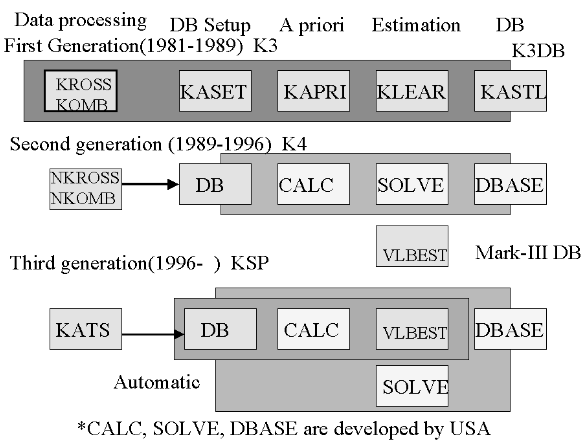

Figure 1. Software developed by CRL.

3. K-4 software

CRL developed the "K-4" system using the K-4 recording system [*Hama et al.*, 1991] and the analysis system for the new computer system HP1000 A900. For the precise compatibility, we adopted the Mark-III data analysis software, such as the software for the data base handler, the software

(CALC) for the calculated delay and delay rate, and the parameter estimation software (SOLVE). Thus, they are easy to install in the new computer system and they are compatible with the worldwide data base used in geodetic VLBI. However, we had developed our own software to set up the data into the Mark-III data base.

The new correlation processing software for K-4 system is controlled by the new computer system HP9000-330. The BASIC language is used since it can control the commands of GP-IB sequentially, and it is especially easy to check and modify. The correlation data send to other computer system HP1000 A900, and the bandwidth synthesis software runs in the minicomputer.

A priori delay and rate are necessary to make a correlation processing for every parameter period (PP). Their delay and delay rate are obtained using the 0th deviation (τ), the 1st deviation ($\dot{\tau}$), the 2nd deviation ($\ddot{\tau}$), and the 3 order derivation ($\dddot{\tau}$)) with respect to time. In the old software, these values are the coefficients of Taylor expansion in the middle of the observation. The difference between the calculated delay and the true delay is larger at the beginning and end of each observation in according to be far from the middle of the center. In this software, the 0th, 1st, 2nd,3rd deviations are obtained using the approximation of the four order polynomial formulation. The entire duration of each observation is divided into 4 parts ($-2\Delta T$ to $-\Delta T$, $-\Delta T$ to 0, 0 to ΔT, ΔT to $2\Delta T$ while $4\Delta T$ is the complete duration). Furthermore the delays are calculated for the 5 points ($-2\Delta T, -\Delta T, 0, \Delta T, 2\Delta T$). Calculated values for each observation are calculated for the least square fittings.

The calculation method in the correlation processing software are based on CALC. For atmospheric delay, we corrected for height in the zenith path delay since some stations are located in elevated regions which are over 1000 m above sea level.

This software can facilitate data processing both among K-3 (Mark-III) recorders, and among the new K-4 recorders, and also the correlation between K-3 recorders and K-4 recorders. In correlation between the K-3 and K-4 recorders, the K-4 recorder serves as the master for synchronization and it is not controlled. This control of the synchronization is the same as the control among the conventional K-3 systems. One command "COR" in the recording system is used to automatically synchronize K-4 system with other K-4 systems. Before fine automatic adjustment, rough tape synchronization to within 1 sec is achieved by using the position search command "PRL". Figure 2 and

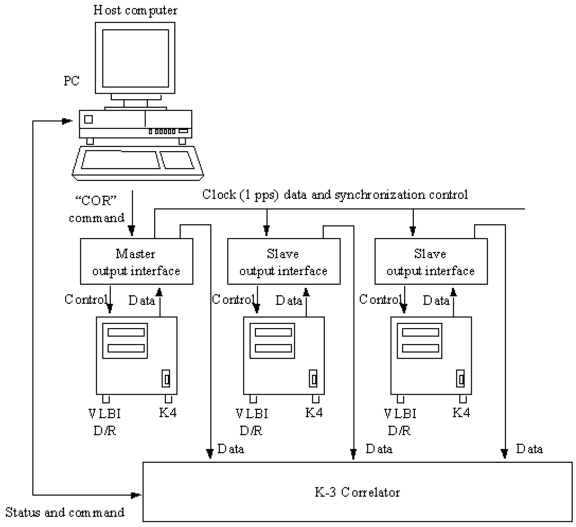

Figure 2. The correlation processing among K4 recorders.

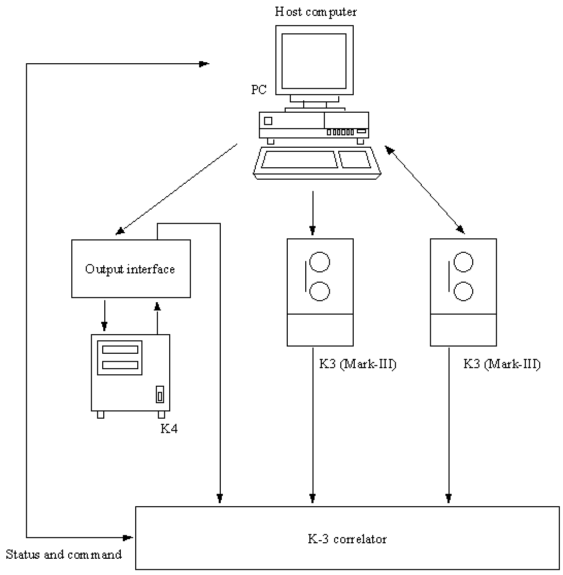

Figure 3. The correlation processing between K4 recorder and Mark-III recorder.

3 show the correlation processing for each system combination.

The data base setup software inputs various data for VLBI into the data base. We originally developed this software. The bandwidth synthesis software produces the files including the observation delay and delay rate for every observation and baseline. First, we collect the data from these files to produce a new observation data file. Secondly, we calculated the ionospheric delay corrections to input into the ionospheric correction data file. Thirdly, we calculate the ephemeris data using the JPL ephemeris "DE200/LE200" to input into the ephemeris data file. Fourthly, the temperature, the atmospheric pressure, the humidity at the site and the cable delay calibration are retrieved from the log file, and the interpolated data is calculated for each observation to input into the new calibration data file. Fifthly, we prepare for the precise earth rotation parameters, and we set up the earth rotation parameters into the earth rotation parameter file. Finally, we collect the all data and we set up them into the data base.

We also developed the software for converting the recording data from K-4 tape to Mark-III tape for both high and low density. It is necessary for the case that we conducted the VLBI experiments using K-4 system and we must send the observation data to NASA.

Furthermore, we developed the new parameter estimation software (VLBEST). This estimation method is the almost same as the estimation software (SOLVE) except for the QR solution. We can modify the estimated software easily, and it is used for KSP software.

4. KSP software

Since 1993, CRL had developed the KSP projects. In KSP, VLBI and SLR (Satellite Laser Ranging) facilities are established at four observation sites in the Tokyo metropolitan area and the precise position of four sites are measured every day or every other day [*Takahashi et al.*, 1994; *Kurihara et al.*, 1996]. The data of KSP is useful to research the crustal deformation and the dynamics in this area. The precision reaches less than 1mm and the repeatability is about 2mm for each experiment. The real time VLBI system is necessary to monitor the abnormal movement of the stations related with the big earthquakes. The station movements are measured in mm precision just after the experiment.

The observation is conducted by a remote control and the data analysis is carried automatically [*Koyama et al.*, 1996a; *Koyama et al.*, 1996b]. We need the rapid results, and we realize the real time VLBI system in KSP [*Kiuchi et al.*, 1996]. New data correlation software had developed corresponding to real time VLBI [*Kondo et al.*, 1996; *Sekido et al.*, 1996]. The system is completed and the regular experiments have been conducted every two days automatically without no operator. There is one operator at correlation center to check the system at the begin of the experiment and to monitor the system only during working time. The software is very advanced.

5. Other software

We proposed the new estimation using the differential method [*Takahashi*, 1992]. This method was applied to the clock estimation. It did not depend on judgments of analyst or need clock estimation.

The estimation parameters in the geodetic VLBI are station positions, earth rotation parameters, atmospheric delay parameters, and the clock offset and clock rate of a frequency standard. The clock epoch is divided into the estimation period. The estimation parameter increases according to the clock parameters, the computer needs more time and a large work area. The clock information is unnecessary for the geodetic VLBI, and it is undesirable to include it in the estimated parameters. We propose an analytical method which uses the modified values without the clock information. This method can be applied to other estimated parameters such as atmospheric delay parameter.

We assumed that the clock changes could be approximated to the linear change during the three observations. The modified delay value was calculated to cancel out the clock and clock rate using three sets of data as following formula;

$$\frac{\tau_i - \tau_{i+1}}{t_i - t_{i+1}} - \frac{\tau_{i+1} - \tau_{i+2}}{t_{i+1} - t_{i+2}} \tag{1}$$

where τ_i is each observed delay, t_i is the observation time, and i is observation number.

We obtained the differential values for each observations. The number of data is decreases by only 2. However, the error matrix has the correlation between the observations. We must consider the effects of the correlation between the neighbor differential values. The detail is referred to the paper [*Takahashi*, 1992]. Our method is also suitable for the use of frequency standard whose stability is best for the 1000 seconds period.

6. Conclusion and Future

CRL have been developed the VLBI software. The correlation mixing the different VLBI system was realized at the first time. The software was also corresponding to the new K-4 VLBI system. The software in KSP may the most advanced system in the world. The many results was obtained by our software, such as domestic VLBI, Antarctica VLBI, Japan-China VLBI, KSP etc.

The future plan of the software is to develop the differential VLBI software for the new observation by the high speed switching, which NAO in Japan plans as VERA project. CRL has been developing the wideband VLBI system more than 1 Gbps. In the system, the number of channels is a few (one or four channels). We will develop the data processing and analysis software for the system. Furthermore, we want to develop the VLBI software available for both for astronomy and geodesy (astrometry).

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The Kashima 34-m Antenna Status Report

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The Kashima 34-m parabolic antenna can receive 1.5, 2, 5, 8, and 22 GHz bands. Now we are equipping it with a 43 GHz band receiver. The antenna was built in March 1988 and has recently become too old to work properly. So we are currently taking steps to restore it. In order to prevent corrosion of the antenna specific direction due to geographical conditions, we regularly change the stow position of the antenna AZ (Azimuth) . As the radio wave reflection paint on the subreflector gets corroded, we are treating the damaged surface. Maintenance is frequently done to prevent the top of the AZ rail from corroding. And to make it suitable for the Japanese environment. We installed an AZ and EL (Elevation) motor cover to protect the motor (Figure 1) and we also waterproofed the AZ rail cover (Figure 2). Maintenance is difficult when a cover is used to protect the rail and wheel. So in order to make maintenance easier, we made a rail cover opening (Figure 3) and a transparent wheel cover (Figure 4). Other minor but serious problems are as follows. The receiver power was turned off occasionally when the receiver control PC hang-up. The azimuth encoder shows slight different value from the real angle after the antenna turns 360 degrees in azimuth which in the future may obstruct high-frequency observations. These problems are currently being checked on.

Figure 2. An AZ moter cover and a part of rail cover.

Figure 3. A part of rail cover and a rail cover opening.

Figure 1. An AZ moter cover to protect the motor.

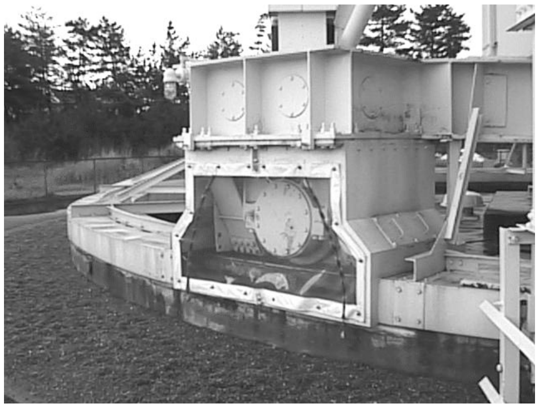

Figure 4. A transparent wheel cover.

Preliminary Experiments of Improved Optical-Linked RF Interferometer

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1. Introduction

We developed a radio interferometer with fiber optic links modulated in radio frequency (Optical-linked RF interferometer) [*Amagai, et al.*, 1996]. We already showed the effectiveness of this interferometer by some preliminary experiments but the delay compensation method had a problem. After applying the delay compensation there still remained significant uncompensated delay caused by refractive index difference. We improved delay compensation method using reflection of optical delay calibration signal. This paper presents the configuration of improved system and the results of signal-to-noise ratio analysis. The results of preliminary experiments to confirm the effectiveness of new delay compensation method are also presented.

2. Configuration of the System

Figure 1 shows the configuration of the improved optical-linked RF interferometer. A signal with a radio frequency up to 15 GHz (objective signal) is detected by the antenna at each observation site (Stations A and B), amplified by a low-noise amplifier (LNA), and converted to an optical signal on the carrier at a wavelength of 1310 nm by a laser diode(#1 or #2). The optical signals are transmitted through optical fibers to the analysis station, and then electric signals are reproduced from the received optical signals (at #3 or #4). Common local signals (SG) are used to convert the reproduced signals to video signals which are processed by a correlation processor.

Delay changes that occur in the optical fibers are compensated for by the calibration signals, which make a round trip between the analysis station and the observation sites. We usually use comb tones for the calibration signal [*Rogers*, 1970], but a noise can also be used. The use of comb tones is assumed for the estimation of the practicable cable length (described in the next section). A calibration signal at radio frequency (cal. signal) is generated at the analysis station, converted to an optical signal on the carrier at the wavelength of 1550 nm (#5), and divided into two signals by an optical power divider (#6). Then each divided signal is transmitted using a wavelength division multiplexer (WDMs #7 or #8) to each observation site through the same

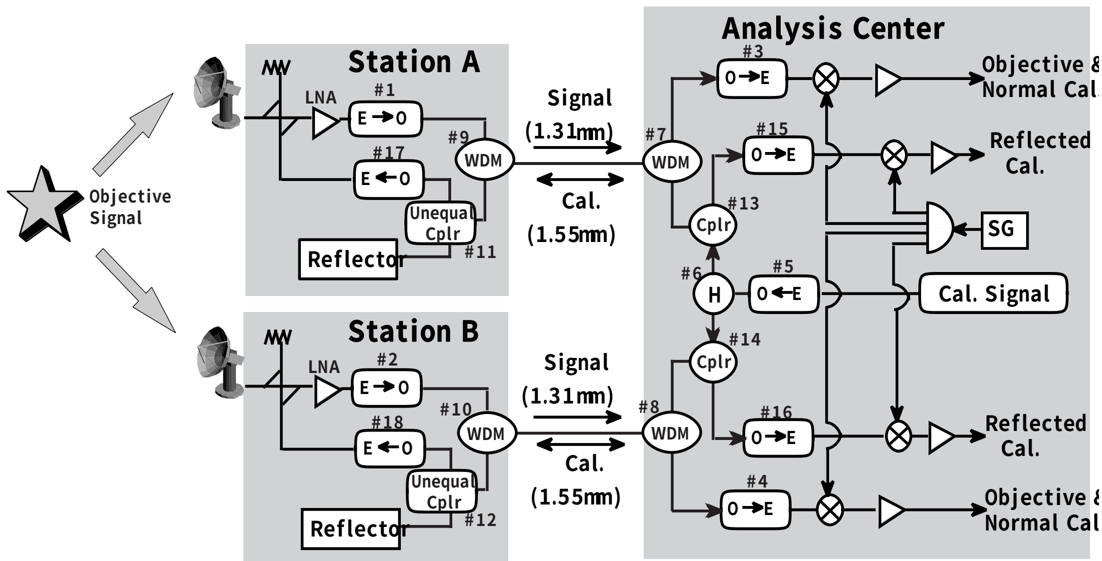

Figure 1. System configuration of the optical-linked RF interferometer.

optical fiber that feeds the objective signal. At each observation site the calibration signal is selected out again by a WDM (#9 or #10) and then by using an optical coupler with unequal divide ratio (#11,#12) it is divided into two optical signals with different intensity: normal cal. signal and reflected cal. signal. The normal cal. signal is converted to an electric signal at the observation site (#17 or #18) and is injected into the receiving system through a directional coupler installed just before the LNA. The normal cal. signal is processed as the phase calibration signal of a usual geodetic VLBI. The reflected cal. signal is directly reflected by an optical reflector and returns to the analysis station through the same optical fiber. At the analysis station, the returned reflected cal. signal is selected out by the WDM (#7 or #8) and is fed to a photo detector (#15 or #16) via the optical directional coupler (#13 or #14). The reflected cal. signals converted to electric signals for both stations are converted to lower frequency and processed in the same manner as the normal cal. signal.

3. Practicable Cable Length

Practicable cable length is investigated from two points of view : the signal-to-noise ratio of the objective signal; and the signal-to-noise ratios of the calibration signals.

The equivalent input noise analysis of the optical link with an Ortel 3541A laser diode and an Ortel 4515A photo detector shows that the practicable cable length to maintain coherence of the objective signal was estimated to be less than 63.3 km [*Amagai, et al.*, 1996].

The conditions for the normal cal. signal and the reflected cal. signal are restricted by the input and output powers. The power of one calibration signal tone at the input of the laser diode is −20 dBm; i.e., the calibration signal consists of the comb tones with a frequency interval of 10 MHz and a bandwidth of 1 GHz, and maximum input power of the laser diode is 0 dBm. The power of one normal cal. signal tone at the injection point at the antenna site should be 10 dB higher than the noise power level of −148.6 dBm/kHz (the equivalent noise temperature of the low-noise amplifier is assumed to be 100 K), and the power of one reflected cal. signal tone at the output of the photo detector at the analysis station should be 10 dB higher than the noise power level of −142.6 dBm/kHz (thermal noise of the photo detector is assumed to be 300 K and equivalent noise temperature of the amplifier following the photo detector is assumed to be 100 K). We estimated the maximum cable length of the optical fiber according to the above conditions with controlling the distribution ratio of the unequal coupler installed at the antenna site. Table 1 lists the results of the estimation. The maximum cable length is estimated to be 40.7 km. In this condition, distribution ratio of the unequal coupler should be 0.927 : 0.073. Consequently, the practicable cable length is estimated to be less than 40.7 km.

4. Preliminary Experiments

The system configuration for the experiments is the same as that in Figure 1 except a common signal, instead of a signal coming from an antenna, is fed into each receiving system. Cables with the same length and the same components are used for each receiving system. In an actual radio-interferometer observation, objective signals are noises from radio stars and are processed by a correlation processor to obtain the correlation function. From the correlation function we can estimate the time difference between the arrival times of the signals for two stations. But under the conditions of the preliminary experiments, where the delay is too small and delay rate is completely zero, too much undesired correlation prevents us from getting a good correlation function and we cannot estimate the time delay precisely. We therefore adopted comb tones (with a frequency interval of 10 MHz and a frequency range from 8100 to 8500 MHz) for the common objective signal. Because this common objective signal is the same as the calibration signal and cannot be distinguished, we measured these two signals alternately. When these signals reached the analysis station, they were converted to IF signals with a frequency range of 100 to 500 MHz and then converted again to video signals with a frequency range of 0 to 2 MHz. The local frequency for video conversion was scanned from 109.99 to 489.99 MHz with a 20-MHz step. Each tone in the signals thus appeared at 10 kHz in the video band. Phase was measured by using a K4 input-interface [Kiuchi, et al., 1997], in which the signals were quantized for 1-bit and the phase of each tone signal was measured by synchronous detection using a 10-kHz signal generated inside the K4 input-interface.

We evaluated the delay compensation method mentioned in Section 2. We determined the group delay using the least squares method applied to the spectra of phase differences between two receiving systems. The phase delay can be calculated by dividing the phase difference at the center frequency (8300 MHz) by the radio frequency. We prepared one 10-m cable, two 5-m cables, and one 3-m cable and measured the delays for four pairs of these

Table 1. Link budget for reflected calibration signal and normal calibration signal.

Reflected calibration signal

	Loss [dB] optical	Loss [dB] electric	Power [dBm]
cal. signal power			-20.0
O-E, E-O conversion		-34.5	-54.5
3-dB coupler	-3.5	-7.0	-61.5
directional coupler	-3.5	-7.0	-68.5
WDM	-0.5	-1.0	-69.5
optical-fiber cable	-12.2	-24.4	-93.9
WDM	-0.5	-1.0	-94.9
unequal coupler	-0.8	-1.7	-96.6
reflector	-0.5	-1.0	-97.6
unequal coupler	-0.8	-1.7	-99.2
WDM	-0.5	-1.0	-100.2
optical-fiber cable	-12.2	-24.4	-124.6
WDM	-0.5	-1.0	-125.6
directional coupler	-3.5	-7.0	-132.6

Normal calibration signal

	Loss [dB] optical	Loss [dB] electric	Power [dBm]
cal. signal power			-20.0
O-E, E-O conversion		-34.5	-54.5
3-dB coupler	-3.5	-7.0	-61.5
directional coupler	-3.5	-7.0	-68.5
WDM	-0.5	-1.0	-69.5
optical-fiber cable	-12.2	-24.4	-93.9
WDM	-0.5	-1.0	-94.9
unequal coupler	-11.9	-23.7	-118.6
directional coupler (electric)		-20.0	-138.6

Conditions	
cable loss (optical)	-12.2 dB
cable loss / km	0.3 dB/km
cable length	40.7 km
distribution ratio	0.927 : 0.073

cables. Delays after the delay compensation are expected to be 0 because the common objective signal was fed into both receiving systems.

Table 2 lists the measured group delay and the phase delay for four pairs of cables. The errors listed in the table were calculated from the phase residuals after least square fitting. The determination precision of the phase delay is more than 100 times better than that of the group delay. The results show that every observed delay was less than 100 psec and the cable delays were almost compensated for successfully, however for group delays there still remains significant uncompensated delay for the cases of the cable length differences of 7, 5 and 2 m. The ambiguity of the phase delay is a half of the radio frequency; i.e., 60.2 psec in this case. The observed group delay should thus be within +/− 30 .1 psec to get the correct phase delay. Though we could not get the correct phase delay, except for the cable length difference of zero, the phases for every frequency component after delay compensation were less than 10 deg and were not consistent with the observed group delay. The observed group delays were therefore apparent and the cable delay compensation was thought to be properly applied. The phase delays listed in Table 2 were calculated by using expected ambiguity instead of observed group delay. Though total band width was limited to 400 MHz by the instrument available for this experiment, a system with the bandwidth of 1 GHz is now available. Using the system with such a wide bandwidth, we can improve the precision of determining group delay and, consequently, the ambiguity problem mentioned above can be resolved.

Figure 2 shows the observed phase delays obtained with delay compensation using a reflected cal. signal and those obtained with not using a reflected cal. signal. For the latter case, we used nominal refractive indexes of 1.44692 for the wavelength of 1310 nm and 1.44402 for that of 1550 nm to compensate the effect caused by the difference of refractive indexes. The figure shows that an expected phase delay of zero was observed when using a reflected cal. signal for each cable length difference except 2 m. We can also see that the absolute value of the phase delay obtained without a reflected cal. signal increases proportionally to the cable length difference. The reason for this proportional increase is thought to be due to the incorrectness of the refractive indexes. From this experiment, we confirmed that by using the reflected cal. signal we can measure absolute delay within an error of 100 psec for group delay and 1 psec for phase delay.

5. Conclusion

We investigated a radio interferometer with fiber-optic links modulated in the radio-frequency range. By analyzing the signal-to-noise ratio, it was found that the practicable cable length is limited to 40.7 km by the link condition for the calibration signal.

Table 2. Delay measurements.

cable length difference [m]	Delay [psec] group delay	Delay [psec] phase delay
7	-54.0 ± 31.9	-0.33 ± 0.44
5	-94.6 ± 38.1	0.39 ± 0.53
2	-33.1 ± 32.4	-0.95 ± 0.45
0	7.4 ± 21.5	0.10 ± 0.30

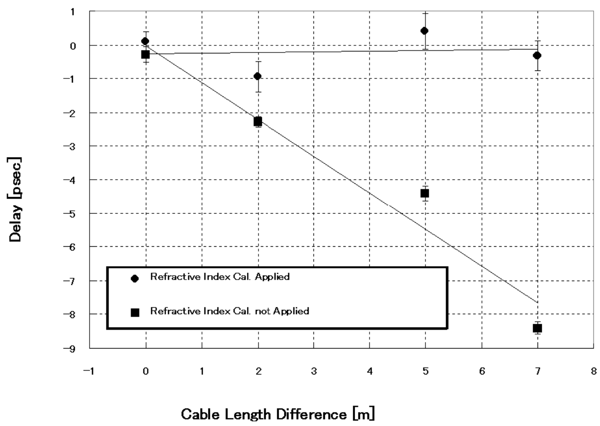

Figure 2. Relationship between the measured phase delay and the cable length difference.

The results of preliminary experiments with this interferometer lead to the conclusion that the optical-fiber delay is successfully compensated for (within an error of 100 psec for group delay and 1 psec for phase delay) by calibration signals in the radio-frequency range. Though we demonstrated that we can determine the absolute delay not only for group delay but also for phase delay, we should note that it is difficult to use phase delay for an actual experiment where an objective signal passes through a dispersive medium because the phase delay does not directly correspond to the group delay in such a condition.

In future research, we will conduct an experiment with a real radio-interferometer system to demonstrate the effectiveness of the optical-linked RF interferometer.

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The Comparison between VLBI and GPS data

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1. Intoroduction

VLBI and SLR revealed the current plate motion within a precision less than 1mm/year. Recently, GPS are observed the detail crustal deformation in dense. It is important to compare the data reliability between these measurements (VLBI, SLR, GPS)

CRL (Communications Research Laboratory) had established the domestic network of the Crustal Deformation Monitoring System in the Tokyo Metropolitan Area. We call this projects "Key Stone Project (KSP)". The KSP is useful to compare the results among VLBI, SLR and GPS. The four stations are Koganei in Tokyo, Kashima in Ibaraki, Miura in Kanagawa and Tateyama in Chiba. The baseline lengths are from 30km to 110km. The VLBI antenna is 11m antenna and SLR is 75cm optical telescope.

Almost daily 5 hours VLBI observation was started since 31th January in 1995 in the mode of 56Mbps on the baseline of Kashima and Koganei. The Miura and Tateyama stations were participated in the VLBI experiments on December 1995 and on September 1996, respectively. The daily 5 hours VLBI observation in the mode of 256Mbps was started on 19th February 1997. The 24 hours VLBI experiments were started on 30th September 1997 every other day. The real time VLBI system has been available in our project (KSP) in cooperation with NTT company in Japan since April 1997. The correlation is done in real time. The SLR observations were started in 1997. There are GPS stations of GSI near KSP stations within a few km as stations of the dense GPS network in Japan constructed by GSI. The data of GSI and KSP data were opened by WWW. The GPS station near Miura is not good, and we use the GPS data of Yokosuka station a little far from Miura. Other GPS stations are located a few km within the VLBI stations. We can compare the VLBI data and GPS data.

At first, we compare the data quality of VLBI with GPS in this network. The quality and reliability of VLBI and GPS data are obtained in the domestic network. Secondly, we indicate the variations with the periodic terms of one month to one year for both VLBI and GPS data. We are interested in the true and pseudo variation of the station position.

2. Comparison of VLBI and GPS data

2.1 Velocities

The velocities of Koganei, Miura, Tateyama stations relative to Kashima stations are compared. The measurement error of velocities in KSP are 0.2mm-0.5mm/year for horizontal movements, and 1-2mm/year for vertical movements. The measurement errors of GPS stations are similar to VLBI data. The velocities of GPS stations are different from the velocities of VLBI stations. The discrepancy is 0.7mm/year for the horizontal movements of Koganei station and 2mm/year for other stations. It is 3 times of the measurements error. The discrepancy of vertical movements is greater than 8mm/year. The vertical movements is not uncertain for the short period.

2.2 Data quality and reliability

We investigate the data quality and reliability of VLBI data in KSP and GPS data. Since 31th January 1995, the 5 hours VLBI experiment in the mode of 56Mbps was started in KSP. There are two epochs when the status of data were drastically changed. The first epoch was on 19th February in 1997 (epoch 1) when the observation mode changes to 256 Mbps (still 5 hours observation), and the second epoch is 30th September 1997 (epoch 2) when the 24 hours experiment in the mode of 256Mbps was started. The PCAL at Kashima station was improved near epoch 1, and the quality of the data related with Kashima station was improved.

We investigate the r.m.s. of the averaged values within any interval which the data period is divided into. Figure 1,2 shows the r.m.s. of the averaged values for the east and upward movements at the

Koganei station relative to the Kashima station. (a) means the data of 5 hours 56Mbps/64Mbps VLBI experiments till epoch 1. (b) means the data of 5hours 256Mbps VLBI experiments during epoch 1 to epoch 2, and (c) means the data of 24hours 256Mbps VLBI experiments since epoch 2. The dispersions of GPS data since August 1996 are also indicated in the Figures as the data (d).

The values of 1 day (faster variations) means the error of each data. The errors of horizontal movements are 4-6mm, 4mm, 2mm and 2mm for 5hours 64Mbps VLBI, 5hours 256Mbps VLBI, 24 hours 256Mbps VLBI and GPS in this turn. Each data error of GPS is similar to one of 24hours VLBI data. Each data error of the vertical movement is 2-3cm, 2cm, 1cm and 1cm in this turn, respectively.

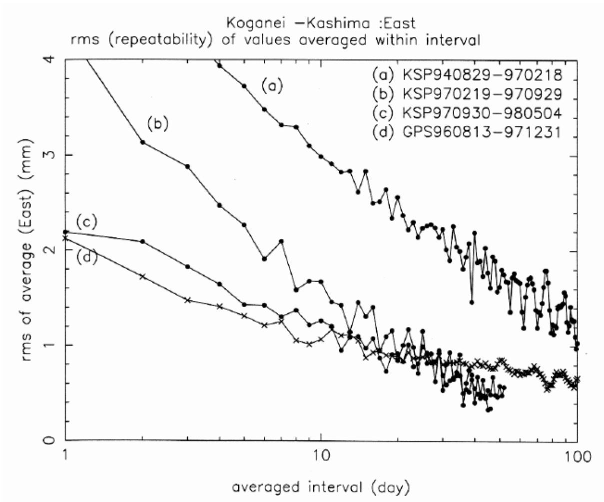

Figure 1. Comparison of r.m.s of the averaged East-West movements between VLBI and GPS data (Kashima-Koganei 109 km).

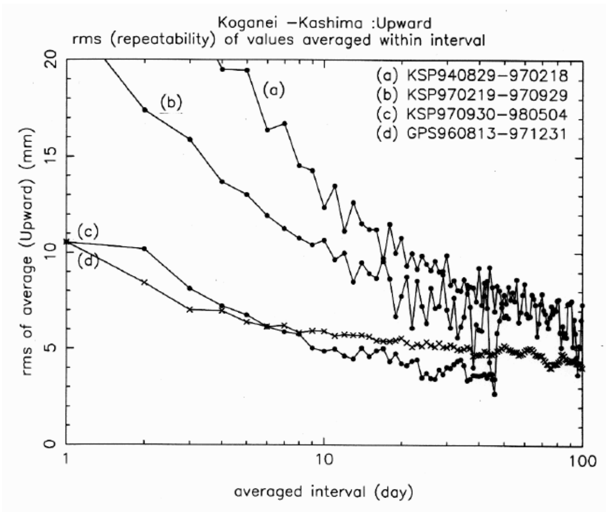

Figure 2. Comparison of r.m.s of the averaged Upward movements between VLBI and GPS data (Miura-Tateyama 35 km).

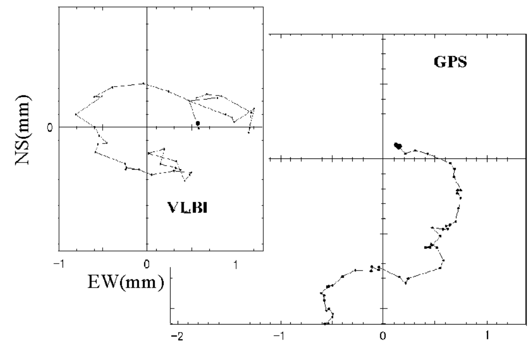

Figure 3. Comparison between VLBI and GPS of pattern of horizontal movements of Koganei relative to Kashima from 1997.10.1 (30days shifted average).

The physical interpretation is mainly revealed by the systematic variation. However, each errors has a large random variation, and it is difficult to reveal the physical phenomena. If we average each data, large random errors are canceled out and the systematic variation appears. Furthermore, we are interested in the variations with the periodic terms from one month to one year, that is, seasonal and annual variation. It is important to know how the position changes beside the velocity. We examine the errors (reliability) of the variations with the terms longer than one month. For these variations, the horizontal errors are 1mm, 0.5-1mm and 0.5mm for GPS data, 5hours 256Mbps data and 24hours 256Mbps data in this turn, respectively. The vertical errors are 5mm, 5mm and 2-4mm in this turn, respectively. In general, the reliability of the variations longer than one month by VLBI is better than GPS data. The VLBI data may be stable for the long period than GPS data.

2.3 Pattern of the movements

We investigate the horizontal movements. We plot the trace of the horizontal movements. Each data has a large random error, and we use an averaged value within a interval. The averaged interval is 30 days, and we use the box average (shifted average). The systematic variations longer than 30

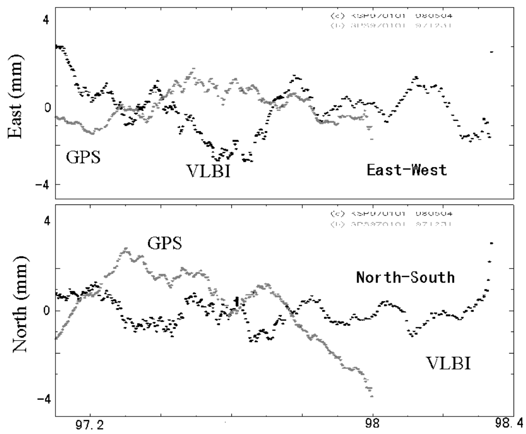

Figure 4. VLBI and GPS variation on Kashima-Koganei 109 km.

days are found. We also compare the pattern of the horizontal movements to check the reliability of the systematic variations. If the variations are similar between the different measurements techniques, such as VLBI, GPS and SLR, the variations is true. Figure 3 shows the patterns of horizontal movements for 24hours 256Mbps VLBI data and GPS data during October to December in 1997. This is the movements of Koganei station relative to Kashima station. The right figure is VLBI data, and the left is GPS. The scale is the same. The pattern of the horizontal movements for VLBI data is different from one for GPS data. Figure 4 shows the box averaged values within 30 days for the east and north movements of VLBI and GPS data on Koganei-Kashima baseline since 1997. The variations vs. time are found in detail. The large systematic variations of VLBI data is different from GPS data. However, the fine variations shorter than one week are sometime similar between VLBI and GPS data. These fine variations may be caused by atmospheric effects.

We also investigate the variation of whole GPS raw data relative to time. The GPS data at some stations is seemed to be in annual GPS has a little large systematic variation for long term at some station. One reason of the systematic variation in GPS data may be the change of the length and trend of GPS pole caused by the temperature change.

3. Conclusion

We conclude the comparison between GPS and VLBI data as follows;

1. KSP is the good test-bed to make a comparison among VLBI, SLR and GPS.
2. 256Mbps 24 hours experiments at KSP is the same quality as GPS data for each data.
3. VLBI is better than GPS for short term variation longer than one month.
4. The pattern of horizontal movements of KSP VLBI data is disagreed with one of GPS data.
5. The variation within one week is agreed with GPS. It may be caused by the atmospheric effects.

Acknowledgments

The GPS data is produced by GSI (Geographic Survey Institute) in Japan. We are grateful for GSI staffs.

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Letter to the Editor

Dr. Harald Schuh of DGFI (German Geodetic Research Institute) sent a following letter to the editor of TDC News. We are pleased to get his acceptance to give it as an article of the TDC News.

Munich, May, 6th, 1998

Dear Dr. Kondo,

Last week an important national conference on Earth rotation and reference Systems took place in Wettzell. One of the most exciting topics was the real-time VLBI. In my talk, I refered to the Japanese Key Stone project as the world-wide first successful realiziation of broad-band VLBI in real-time. Real-time VLBI was also a main topic in a symposium on 'Instrumental challenges in geodesy' at the XXXIIIrd General Assembly of the European Geophysical Society in Nice. It's very important for German and European activities to have such an excellent example which the IERS VLBI Technical Development Center developed. We'd like to observe the Earth rotation parameters by VLBI in near real-time because they are needed for precise positioning and navigation (e.g. by GPS), for space tracking and also as references for other on-line observing techniques of the Earth rotation (e.g. laser gyros, supra-fluid helium gyros).

Let me inform you, please, that it is intended to develop the real-time capability of the Wettzell VLBI station in the near future. I hope that these developments could learn from your experiences and real-time VLBI experiments between Wettzell and Japan will be possible, soon.

Working on geodetic VLBI for almost 20 years let me also express my thanks for sending me the TDC News which is an extremely interesting publication useful for my whole group. I read all the articles carefully. In particular we are interested on all reports dealing with the broadband communication between the radiotelescopes and the central processor and those dealing with automation of the data analysis. Also papers on more general aspects, e.g. reference frames, Earth rotation are very useful for us.

As the impact of the Key Stone project on the international VLBI activities is considerably large I would be very pleased to see these efforts continuing or even growing and I send you and all the TDC members our best wishes for the future.

Yours sincerely

Harald Schuh

(Head of Earth rotation section at DGFI (German Geodetic Research Institute), responsible for the VLBI group at DGFI)

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. 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 on the World Wide Web (WWW). The URL to view the home page of the Radio Astronomy Applications Section of the Kashima Space Research Center is : **"http://www.crl.go.jp/ka/radioastro/"**. The URL to view the Keystone project's activity is **"http://ksp.crl.go.jp/"**.

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