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CONTENTS

The Metsähovi Solution for Gigabit VLBI

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1. Introduction

MRO has developed a PC-based data acquisition system for VLBI.

The system is based on the VSI standard interface[1] and is capable of recording any VSI-H compliant data source, including both new CRL-developed gigabit VLBI sampler data and existing VLBA or Mark IV data.

VSIB data I/O PCI board makes it possible to use conventional Linux PCs in continuously streaming high-throughput data acquisition and playback applications at data rates of 512 Mbits/s/PC and beyond. Furthermore, it is well-suited to data acquisition systems consisting of multiple PCs running in parallel and/or chained, resulting in both aggregate data rates of multi-Gbps and total on-line data volumes of several terabytes.

Because of board simplicity and low cost, and because of the use of standard PC hardware and low-cost IDE hard disks, even high-volume, high-throughput data acquisition systems can be realized at exceptionally low cost. We have made special effort to design the system to be compatible with the Mark5 system that is being developed at Haystack Observatory.

2. Design Philosophy

We are using a fundamentally different design philosophy than the other teams that are developing disk-based data acquisition systems.

Early in our project we noticed that the common PC technology has several bottlenecks that limit the performance in data acquisition and transfer:

- 32-bit PCI bus speed limits the performance to 600-700 Mbit/s
- Disk subsystem speed limits the performance to 500-700 Mbit/s
- Gigabit Ethernet speed limits the performance to 600-700 Mbit/s

While the other teams are designing single-PC solutions for Gbit/s data acquisition, we try to get the maximum performance from a commodity PC and build a scalable system. If the performance of a single unit is not one Gbit/s, that is no problem. We can use two units or three.

3. The VSI I/O Board for PC (VSIB)

The VSI input board (illustrated in accompanying Figure) is a low-cost 32bit/33MHz PCI interface that stores the incoming VSI data stream to microcomputer main memory with bus-master DMA.

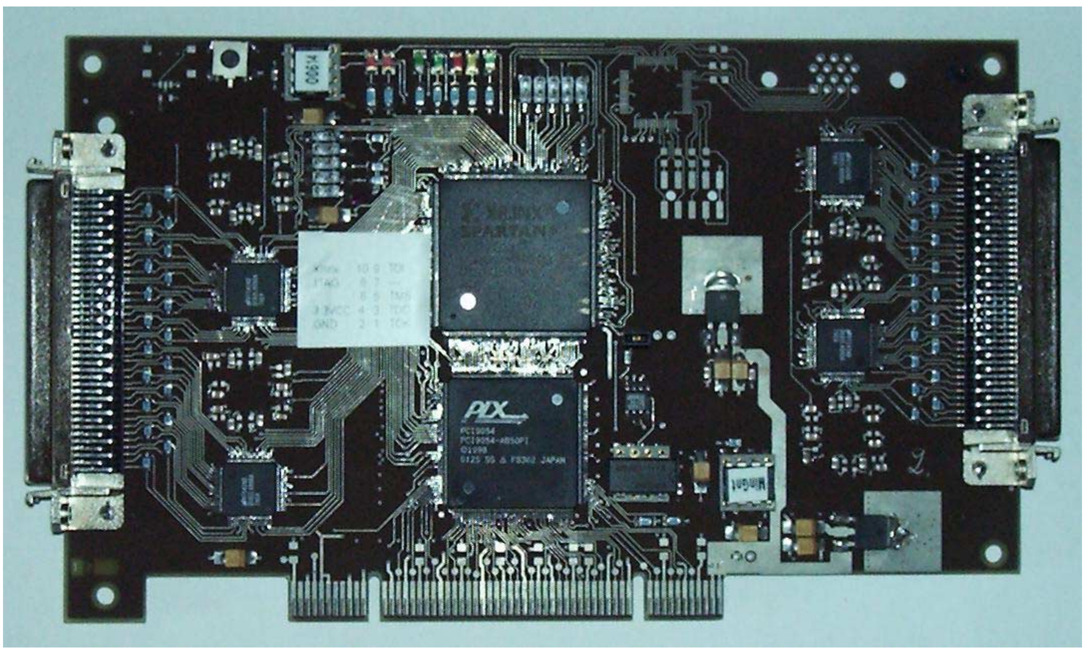

Figure 1. The VSIB data I/O PCI expansion board.

[1] `http://web.haystack.edu/vsi/index.html`

Data acquisition uses huge circular buffers in the PC main memory and can operate without main processor intervention.

The most important feature is that the VSIBs have two bidirectional VSI ports and can be daisy-chained to capture high-speed data. In this way the maximum sustainable speed of one computer does not limit the speed of the system.

VSIB has been designed as a standard half-size 32-bit, 33 MHz PCI expansion board. It is compatible with both 5V and 3.3V bus signalling with its "universal" dual-slot PCI card edge connector and it can thus be used also in most 64-bit, 64 MHz PCI slots.

3.1 On-Board Logic

Differential LVDS signals are processed with bus LVDS transceivers terminated with 100Ω resistors at both ends, ensuring that cable connections are always correctly terminated. A Xilinx FPGA provides signal routing and processing, and a 4 kB buffer FIFO memory between VSI and PCI bus interface, ensuring continuous data flow regardless of PCI bus latencies.

The Xilinx logic allows selection of all 32 VSI data bits, or a subset of 16 or 8 (VLBI "Mark 5A" compatibility). It also allows skipping VSI input data words with a counter in the range of 1..65535. Both of these features can be used to direct a single VSIB to process a subset of the whole VSI data stream. For instance, four VSIB boards can be set up to repeatedly "demultiplex" four consecutive VSI data words to four VSIB boards in a chain, effectively reducing the data rate requirements for a single PC host to a quarter of the original data stream.

3.2 PCI Bus Interface

For connecting to any 32-bit, 33 MHz PCI expansion bus, VSIB utilizes a PLX bus-mastering interface chip. The chip enables high-throughput scatter/gather bus-master DMA transfers to and from PC main memory. Depending on motherboard chipset performance, VSIB has been demonstrated to sustain data transfers in excess of 700 MBits/s.

PC main memory, arranged in ring buffer fashion, is used to allow VSIB to operate in conventional Linux operating environment without the need for any special real-time extensions. PCI bus interface hardware takes care of depositing data in large main memory ring buffer where Linux software can find it at its own pace.

4. Universal dual 40-pin cable to VSI converter (VSIC)

When we designed the VSI input board we needed a test vector generator and a signal level converter to capture real VLBI data.

We noticed that VLBI uses lots of cables with different pinouts and data polarity, but almost all cables use the same 40-pin flat cable connectors and differential RS-422 or ECL signalling. The new RS-422 line receivers have a common mode voltage range that is large enough to capture ECL signals, so we designed a universal VLBI cable to VSI converter that can interface to most of the cables used in VLBI.

The VSIC can be connected to Mark IV or VLBA formatter outputs or directly to VLBA sampler outputs. If the 1PPS marker that is needed in VSI is not available (for example in the formatter output cables) the VSIC can regenerate the 1PPS signal from the information in the frame headers.

5. Project status

At this moment three VSIBs and two VSICs have been built and tested.

Data capture has been extensively tested and 512 Mbit/s speed (for one unit) seems to be fully operational, which means that sustained 1 Gbit/s operation is possible with only two microcomputers.

Data playback has been tested at the JIVE correlator and seems to be fully working at speed of 256 Mbit/s per PC.

The documentation (schematics, frequently asked questions and PostScript files of the board layout) are available at "`http://kurp-www.hut.fi/vlbi/instr`".

High speed network connectivity of VLBI stations in Japan

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1. Introduction

In April 2002, an international workshop concentrating on the e-VLBI issues entitled "Connecting the Global VLBI Array in the New Era of High-Speed Networks" was held at Haystack Observatory. In the workshop, a lot of technical aspects were discussed among many researchers participated from around the world. As one of the consequences of the workshop, a group of representatives from regions and network researchers named as the e-VLBI task force was formed. The major purpose to form the task force was to draft a document to promote and enhance the activities to achieve e-VLBI observations at as many observing stations as possible. To begin with, each member of the task force was asked to investigate the current situation of the high speed network connectivity at VLBI observing stations in each region. This report summarizes the current situations of the high speed research networks and the connectivity of the VLBI stations in Japan.

2. High speed research networks in Japan

In Japan, dedicated ATM network for VLBI observations was established under the collaboration between Communications Research Laboratory and NTT Laboratories in 1996. The network connected four Key Stone Project VLBI observation stations at Kashima, Koganei, Miura, and Tateyama with the maximum data rate of 2.4Gbps (OC-48) using ATM (Asynchronous Transfer Mode). 64m antenna at Usuda Deep Space Center of the Institute of Space and Astronautical Science (ISAS) and 45m antenna at Nobeyama Radio Observatory of National Astronomical Observatory (NAO) were connected to the Mitaka Campus of NAO in 1996 under the collaboration between ISAS, NAO and NTT Laboratories. The network was called OLIVE network and the maximum data rate was 2.4Gbps (OC-48) using ATM. These two networks were connected with each other in 1999 and the entire network was named as the Galaxy network (Figure 1). The network was then partially modified to transport IP (Internet Protocol) data stream between Usuda, Kashima, Koganei, and Musashino (Figure 2).

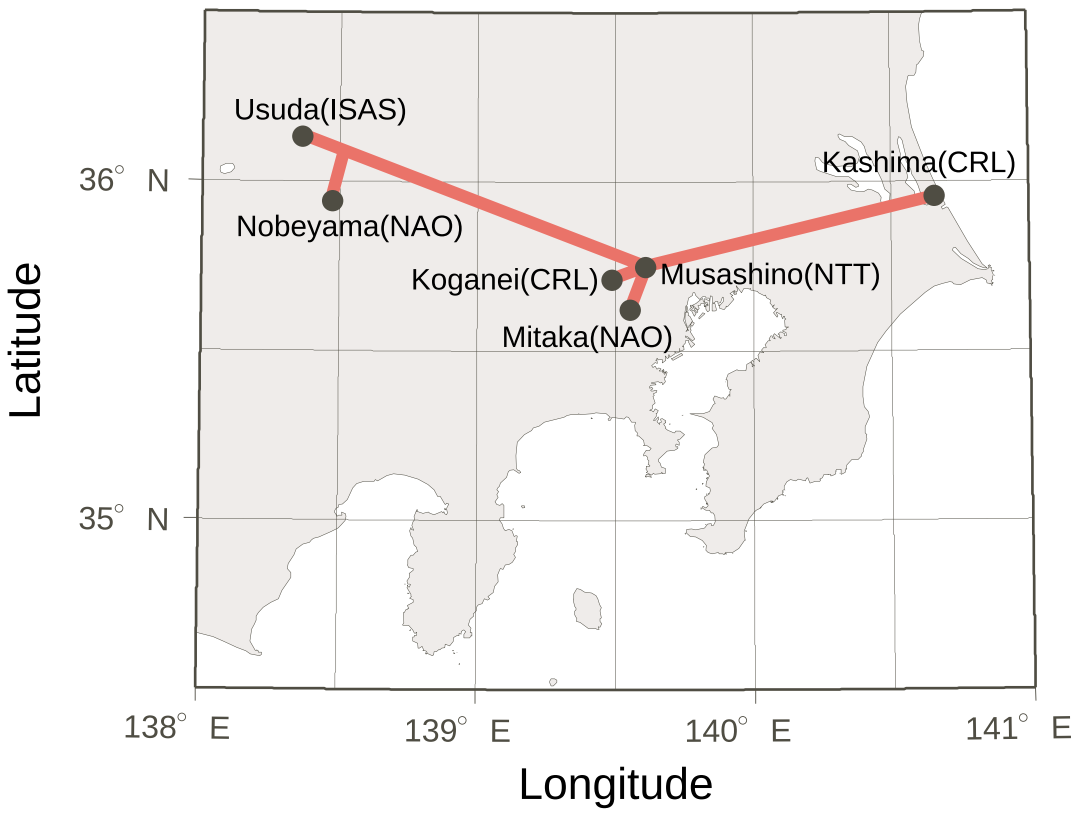

Figure 1. The geographical configuration of the Galaxy network.

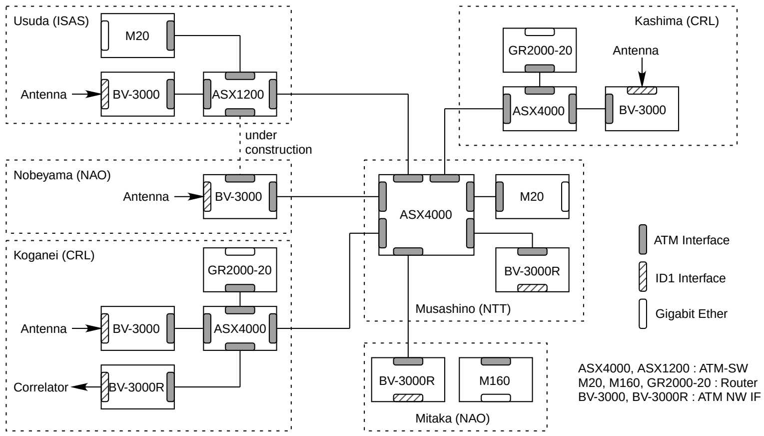

Figure 2. The logical configuration of the Galaxy network.

In addition to the dedicated network for the real-time VLBI observations, there are high speed research networks in Japan. Super-SINET and JGN (Japan Giga-bit Network) are the two major networks for research and developments for information technology. Super-SINET is now being established by connecting Universities and national institutes. The maximum data rate is 2.4Gbps (OC-48) and many VLBI observation stations are either preparing or proposing to be connected to the closest network nodes.

3. International Connectivity

There are at least three network routes to transfer high speed data stream between United States and Japan. One route is the GEMnet. GEMnet is a research network owned by NTT corporation and is connected to the Abilene network in the United States. The total data rate of the GEMnet is 33Mbps and 10Mbps is allocated to the connection with the Abilene network. The second route is the Super-SINET. The Super-SINET is connected with the Abilene network in the United States at the speed of 155Mbps. The third route is the APAN/TransPAC connection. Two 622Mbps connection lines are available between United States and Japan.

4. High speed network connectivity at VLBI stations in Japan

Current situation of the high speed network connectivity at VLBI station in Japan is summarized in the Table 1. At present, Kashima, Koganei, Usuda, and Nobayama are connected to the Galaxy network. The network speed is 2.4Gbps and the real-time VLBI observations at the data rate of 1024Mbps have been achieved between 34m antenna station at Kashima and 64m antenna station at Usuda. Recently, the 32m antenna station at Tsukuba has been connected to the Super-SINET at High Energy Accelerator Research Organization. Gifu university has a connection to the JGN network and a proposal has been submitted to the Super-SINET. Similarly, proposals are being prepared to be submitted to the Super-SINET for Tomakomai, Mizusawa, and Yamaguchi stations.

5. Future Plan

Network infrastructure in Japan and international connectivity are improving very fast, and the e-VLBI seems to be becoming feasible between Japan and the United States. VLBI observation hardware systems for e-VLBI observations are also under developments. Using these opportunities, a plan has been initiated to perform a demonstration experiment between Haystack Observatory and Galaxy network stations. At noted in the previous section, there are at least three routes to realize the e-VLBI observations between Japan and the United States. Within these three routes, the GEMnet route seems to be the most promising route to perform e-VLBI observations, since the Galaxy and GEMnet networks are operated by the NTT corporations. The Super-SINET is also a candidate. Although it requires to settle technical and policy related issues, the use of the Super-SINET will be pursued.

Acknowledgement: The author would like to appreciate many members of the Galaxy project and collaborators who provided the valuable information to compile the current network connectivity of the VLBI stations in Japan. Especially, the essence of the Figure 1 was provided by Dr. Hisao Uose of NTT Laboratories.

Table 1. Network connectivity status of VLBI stations in Japan

site name	diameter (meter)	organi-zation	receivers	distance to a network node (km)	status	latitude (deg. N)	longitude (deg. E)
Shintotsukawa	3.8	GSI	S/X	?	no plan to be coneccted to networks	43.5	141.8
Tomakomai	11	HU	S/X, 22GHz (planned)	70	proposal is being prepared to Super-SINET	42.7	141.6
Mizusawa	10	NAO	S/X, 22GHz, 43GHz	118	proposal is being prepared to Super-SINET	39.1	141.1
Mizusawa	20	NAO	S/X, 22GHz, 43GHz	118	proposal is being prepared to Super-SINET	39.1	141.1
Tsukuba	32	GSI	S/X	0	connected (2.488Gbps) : Super-SINET : ATM	36.1	140.1
Usuda	64	ISAS	S/X, L, C, 22GHz	0	connected (2.488Gbps) : Galaxy : ATM	36.1	138.4
Kashima	34	CRL	S/X, L, C, 22GHz, 43GHz	0	connected (2.488Gbps) : Galaxy : ATM+IP	36.0	140.7
Kashima	26	GSI	S/X	0	station will be closed in 2002	36.0	140.7
Kashima	11	CRL	S/X	0	connected (2.488Gbps) : Galaxy : ATM+IP	36.0	140.7
Nobeyama	45	NAO	22GHz, 43GHz, etc.	0	connected (2.488Gbps) : Galaxy : ATM	35.9	138.5
Koganei	11	CRL	S/X	0	connected (2.488Gbps) : Galaxy : ATM+IP	35.7	139.5
Gifu	11	GU	S/X	0	connected (30Mbps): SINET:IP in addition, proposal has been submitted to Super-SINET (2.488 Gbps): fiber to the Super-SINET node (~60km) will become available in 2002	35.5	136.7
Gifu	3	GU	X	0		35.5	136.7
Yamaguchi	32	NAO	X, 22GHz (planned)	15	proposal is being prepared to Super-SINET	34.2	131.6
Aira	10	GSI	S/X	?	no plan to be coneccted to networks	31.8	130.6
Iriki	20	NAO	S/X, 22GHz, 43GHz	?	currently no plan to be coneccted to networks	31.7	130.4
Kagoshima	6	KU	22GHz, 43GHz	?	no plan to be coneccted to networks	31.5	130.5
Ogasawara	20	NAO	S/X, 22GHz, 43GHz	?	currently no plan to be coneccted to networks	27.1	142.2
Chichijima	10	GSI	S/X	?	no plan to be coneccted to networks	27.1	142.2
Ishigaki	20	NAO	S/X, 22GHz, 43GHz	?	currently no plan to be coneccted to networks	24.4	124.2

acronyms		
	CRL	Communications Research Laboratory
	GSI	Geographical Survey Institute
	GU	Gifu University
	HU	Hokkaido University
	ISAS	Institute of Space and Astronautical Science
	KU	Kagoshima University
	NAO	National Astronomical Observatory of Japan

Development of Versatile Scientific Sampling Processor (VSSP) – A Practical Approach

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1. Introduction

Recently a 4-channel PCI-bus VLBI data sampler board has been developed by Communications Research Laboratory and Nihon Tsushinki Co. Ltd. [Kondo et al, 2000] [Kondo et al, 2002]. This board gives us a chance to make a VLBI data acquisition system based on a standard personal computer (PC). The system will be useful not only in the VLBI community, but also in other scientific fields where accuracy of the timing of the data sampling is required. This system, hence, is named "Versatile Scientific Sampling Processor (VSSP)".

There are at least three advantages in developing PC data recording system. Firstly, the price of the system is inexpensive compared to ordinary VLBI recorder. Our system expected to be lower than US$40,000. Secondly the system becomes flexible because the user can modify the software. Thirdly, it is easy to adopt various computer technologies to make the system more convenient. For example, if observation experiment is made using this PC-based system, the data can be easily transported among the observation sites over the Internet. Moreover, developing computer technologies such as high-speed networks and distributed computing may be adopted without difficulty. In the present paper we will introduce a practical approach to produce this PC-based recording system.

2. Requirements of the VSSP system

The goal of the VSSP is to make a PC recording system comparable with today's standard VLBI recorder. In other words, the system can record 16-channel 256-Mbps 1-day VLBI observation data. In this section we will describe essential properties of the hardware and software necessary for this system.

2.1 Requirements of the hardware

The PCI sampler board is composed of a pair of 2 boards connected by a short flat cable. Hence, 2 open PCI sockets are necessary to install the board. Installing more than 1 set of the boards to 1 PC is not supported. The maximum recording rate of the sampler board is 64 Mbps (e.g. 4 channels $\times$ 16 Mbps). In order to realize 256 Mbps (16 channels $\times$ 16 Mbps) recording, hence, 1 VSSP system must be composed of 4 PCs and 4 sampler boards.

We have prepared 480 GB data storage area on each PC. The amount of the data storage area is decided as follows: during data recording at 64 Mbps, the data on the PC increases by 8 MB per second. If the system records one whole day continuously, the amount of the data on the PC increases by 8 MB/s $\times$ 1 day $\sim$ 690 GB. However, in case of VLBI observation we do not have to record continuously, especially while the antenna is slewing. Hence, 480 GB will be practically sufficient for our purpose. The storage area consists of four 120 GB IDE hard disk drives (HDDs). At present SCSI HDD is not adopted as data storage device because of the expensive price and difficulty of purchasing large volume drives. USB HDD and IEEE-1394 HDD are also rejected now because of the reliability of the device drivers on the operating system (OS) that we are using.

It is noteworthy that IDE devices have at least two limitations that the user should care. Firstly, a standard PC motherboard can adapt only 4 IDE devices, which are primary master, primary slave, secondary master, and secondary slave. Our system used four IDE HDDs for the data storage area. We need another HDD for OS and user applications. For this purpose 20 GB SCSI HDD is adapted with on-board SCSI port. If the motherboard has additional IDE ports, the user can use another IDE HDD instead of the SCSI HDD. Secondly, most of the motherboards available now cannot recognize IDE HDDs larger than 137 GB. If a user would like to adopt such HDDs, the user must choose one of the motherboards compliant with this limit.

The other parts of the PC are as follows: 1 on-board 10/100Base-T Ethernet port, one 1 GHz Pentium III CPU, and 512 MB RAM. This spec is similar to that of a standard PC today. The spec of our first VSSP PC are summarized as Table 1.

The sampling board itself is expected to work on rather obsolete system compared to this one.

2.2 Software environments

The device driver software for this sampler board is prepared for FreeBSD-4.x and MS-Windows 2000. Linux device driver will be available soon. Our system adopts FreeBSD-4.5 as the OS. Some data acquisition software and data analysis software for VLBI observation are under development

Table 1. Features of the first VSSP computer.

CPU	Pentium III (1 GHz)
RAM	512 MB
HDD	four 120 GB IDE disks (7200rpm, Ultra ATA/100 compliant) 20 GB SCSI disk
SCSI port	on-board SCSI controller
Ether port	on-board 10/100 Base-T controller
PCI bus	2 open PCI sockets

Table 2. Performance of the system with/without soft-updates.

	PC-1	PC-2
OS version	FreeBSD-4.5	FreeBSD-4.3
Soft-updates	enable	disable
Resultant file after 10 sec	200MB	87MB
Data writing rate	20MB/s	8.7MB/s

on FreeBSD. Those applications can be ported to Linux system without difficulty, if the device driver were available. Porting to MS-Windows 2000 may require some effort.

'Soft-updates' is enabled on our system. Soft-updates is a filesystem adopted by FreeBSD, which increases input/output (I/O) performance drastically. Originally FreeBSD filesystem has adopted synchronous (sync) I/O, which is known as a robust but slow I/O. Linux filesystem adopts another type I/O, called asynchronous (async). Async is known as a fast filesystem at the cost of the robustness against sudden system crash. Soft-updates is developed based on sync I/O by taking in the advantage of the async I/O. That is expected to be as robust as sync, and as fast as async. In the next section we will show the effectiveness of the soft-updates on our system.

3. Testing the effectiveness of FreeBSD soft-updates filesystem

In order to check the effectiveness of soft-updates, we have made a simple test on two identical PCs (PC-1 and PC-2). These two PCs are almost the same, except the one is installed FreeBSD-4.5 with soft-updates (PC-1), and the other is installed FreeBSD-4.3 without soft-updates (PC-2). The specs of the PCs are 1 GHz Pentium III CPU, 128 MB RAM, and 46 GB IDE HDD (7200 rpm, Ultra ATA/100 compliant), which is lower than that of the VSSP PC. The test is performed as follows: execute the following command, wait for 10 seconds, and then terminate the task by Ctrl-c.

```
cat /dev/zero > foo
```

This simple test will show the apparent data-writing rate onto the HDD. A dummy data file (here 'foo') is created on the HDD. The result is shown as Table 2.

This result implies that soft-updates doubled I/O speed of PC-1. As it is already told in the present paper, VSSP requires 64 Mbps = 8 MB/s data recording rate on each PC. Here PC-2 barely satisfies the requirement. If some other disk access occurs during data is being recorded, the recording may possibly fail. On the contrary, I/O speed of PC-1 will be sufficient for realizing VSSP system. Hence, soft-updates filesystem is adopted in our system.

4. Miscellaneous notes on developing VSSP

4.1 The spec of the HDDs

The HDDs used in our VSSP system have a speed of 7200 rpm. They are also compliant with Ultra ATA/100 interface (an interface having a capability of 100 MB/sec data transport rate). Actually they are comparatively fast HDDs at present. If a slower HDD is used, the recording rate becomes slower. This causes a trouble on the system from time to time. For example, we have tested 64 Mbps recording using old 2 GB IDE HDD (5400 rpm). Sometimes the system becomes out of order while observation data is being recorded on this HDD. Hence, it is advisable to choose faster HDDs for the data storage area.

4.2 Amount of the RAM

Usually most operating systems do not write a new file onto the HDD during the file is being processed. Instead, the RAM works as a disk cache and the data is temporary stored on the RAM as a file image. The file image is transported to the HDD after a while. Hence if the system has large RAM, there is enough space to be used as a disk cache. For example, if 480 MB RAM can be used as a disk cache, 64 Mbps x 60 sec data can be stored on the RAM. Although this effect has not been confirmed by experiment, we can expect that the larger the RAM is, the faster the practical recording rate becomes.

4.3 Internal spurious noise

In order to set up the first VSSP unit, we prepared a 2U-size rack mount PC server. Figure 1 shows the front view of the PC server. A pair of sampler boards is installed as shown on Figure 2. Analyzing the data, some spurious noise was found

Figure 1. Front view of PC server.

Figure 2. A pair of sampler boards installed in PC server.

on the first and second channels of the board. We examined the PC server and the sampler board, and concluded that the noise comes from the motherboard. In this thin 2U-size rack mount case the sampler board and the motherboard is located close to each other. The first and second channels of the board are close to some chips on the motherboard, which makes the spurious noise. We could not avoid the noise because there was no enough space to install a shield to reject the noise. Or if there had been some other PCI sockets, the sampler board might have been moved to one of the sockets where less spurious noise was found. We will choose such PC case when developing the next VSSP unit.

5. Summary

In this paper we reported on inexpensive and flexible VLBI data acquisition system using PCs and PCI VLBI sampler boards. The system was composed of 4 units, 1 of which consists of a standard spec PC, 480 GB data storage HDDs, and 1 PCI VLBI sampler board. Now device driver software of the sampler board has been prepared for FreeBSD and Microsoft Windows 2000. Linux device driver will be available soon. We made a simple test of the system with/without FreeBSD soft-updates filesystem. The effectiveness of soft-updates became apparent. To improve the performance of the system, the speed of the data storage HDDs and the amount of the RAM are also important factors.

Our first VSSP unit was developed on U2-size rack mount PC server. Testing this unit, we found that some spurious noise came from the motherboard. In order to avoid such noise, it is advisable to choose a PC case with several excess PCI sockets, because the user can select one of the sockets where less spurious noise is found. The excess PCI socket space is also useful to install a shield to reject the noise.

The VSSP system is being developed as shown in the present paper. It is expected to work as a central part of the future VLBI observation system for data recording, data transporting, and data processing, by flexibly taking in various computer related technologies.

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Experimental observation of the GEOTAIL spacecraft using differential VLBI technique

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1. Introduction

We performed a preliminary differential VLBI (DVLBI) observation with National Astronomical Observatory (NAO) and the Institute of Space and Astronautical Science (ISAS) to determine precise orbit of the GEOTAIL spacecraft on June 4, 2002. The purpose of this observation is to establish the positioning technology for the interplanetary spacecraft using differential VLBI in real-time. Our main concern is to determine the PLANET-B (NOZOMI) orbit just before the second swing-by on next March [Yoshikawa et al., 2001]. It is significantly important to get the timing to maneuver the spacecraft before the swing-by. However, the usual range and range rate orbit determination will not be available because it will be difficult to point the high-gain antenna mounted the spacecraft toward the earth at that time. So we need a new technique to determine the precise orbit of the NOZOMI. We describe a preliminary result of the observation in this short report.

2. Data Recording System

We used a new VLBI system using Internet Protocol (IP) technology for data sampling and acquisition of the GEOTAIL spacecraft. This new system is one of the two kinds of the “IP-VLBI” under development at Communications Research Laboratory (CRL) and it will enable real-time VLBI observations anytime and, anywhere at a low cost [Kondo et al., 2002]. The “IP-VLBI board” for the system is designed so that all digital processing from signal sampling and, data transmission, to real-time correlation processing is preformed on multiple personal computers (PCs). The experimental observation of the GEOTAIL spacecraft is also aimed to evaluate our IP-VLBI system.

3. Observation and Preliminary Result

We performed a first DVLBI observation for the GEOTAIL spacecraft on June 4, 2002. An observing schedule is made based on a predicted spacecraft trajectory from 0630UT to 1400UT. In our observation a series of 2 short (about 30 minutes) sequences of differential VLBI observations were inserted into the schedule, using the sources, 3C279 and 3C274. A source geometry of the GEOTAIL spacecraft for each one minute epoch and radio sources are illustrated in Figure 1. We use Kashima

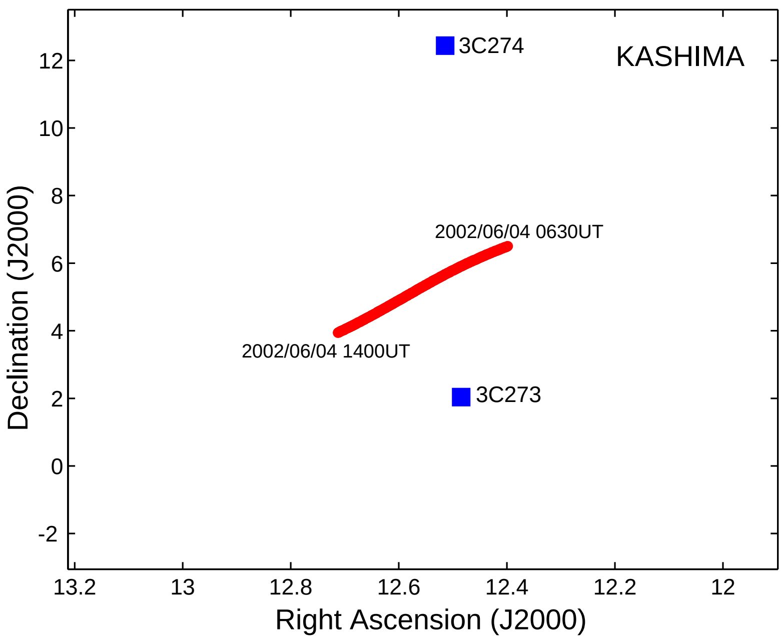

Figure 1. Source geometry of the GEOTAIL spacecraft(solid circles) and the radio sources(open squares) on June 4, 2002. The sources of 3C273 and 3C274 are used for the differential VLBI. Angular separations of the spacecraft from the two radio source are about 4.0 degrees and 8.0 - 10.0 degrees, respectively.

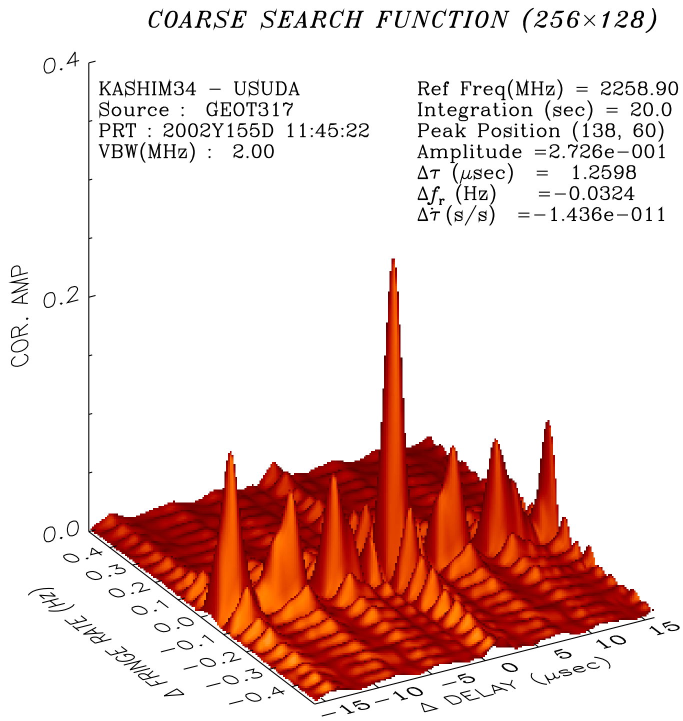

Figure 2. Observed fringes for the GEOTAIL S-band telemetry signals.

34-m and Kashima 11-m of CRL, and Usuda 64-m of ISAS antennas for DVLBI observations at S and X-bands with the K4 and the IP-VLBI systems. Another system, RISE terminal systems were also installed in these stations by the NAO group.

Figure 2 shows an example of the S-band fringes of the GEOTAIL, which was detected by using a preliminary VLBI data processing. This clear fringe suggests that a conventional analysis using group delay data sets is available to determine the spacecraft orbit. We will try to determine the orbit based on these data sets and the further analysis will be discussed in another report.

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Error estimation on VLBI measurement for spacecraft NOZOMI with continuous phase tracking

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1. Introduction

Possibility on VLBI observation of spacecraft NOZOMI [1] has been discussed in joint working group among VLBI related institute (Institute of Space and Astronautical Science (ISAS), National Astronomical Observatory of Japan (NAOJ), Communications Research Laboratory (CRL), and so on). Differential group delay VLBI observation with reference radio star (DDOR) is one of the choices of VLBI observation methods. The DDOR observation technique had been used by JPL since 1980's for interplanetary missions successfully. This technique requires multiple subcarrier signals spread in wide frequency range (several MHz). The NOZOMI's transponder was not , however, originally designed for the wide range sub-carrier transmission. Additionally radio link condition during the two swing-by (Dec. 2002 and June 2003) is supposed to become much poorer than ordinary condition. This kicked a motivation that VLBI is considered for space navigation for NOZOMI [1]. Then availability of DDOR for NOZOMI has been examined by JPL and CRL, independently. Another choice of VLBI observation method is phase delay measurements. It only need stable carrier signal from spacecraft, then it may rather suitable for the case of NOZOMI. Phase switching VLBI observation between target source and reference radio source has been sometimes used in astronomical VLBI observation. Difficulty in this method is phase connection between scan to scan for each target source and reference source. If the phase connection is failed, no results are expected from the observation. To eliminate this risk, also continuous phase tracking for the target source can be one choice of VLBI observation methods. Due to less calibration capability of radio propagation medium than phase switching method, the expected accuracy will be worse in the continuous phase tracking. Although, the requirement on spacecraft position measurement accuracy from ISAS is order of 100 mas as a comparable accuracy expected from range and range rate technique (R&RR), then continuous phase tracking is still a candidate of choices.

A test experiment was conducted for spacecraft GEOTAIL in June 2002 for checking data acquisition system and data processing. The results of this experiment may be reported somewhere.

In this paper, we discuss the expected accuracy with the continuous phase tracking method with finite distance VLBI (hereafter finite-VLBI) model. We suppose reference sources selected from International Celestial Reference Frame (ICRF) catalog are observed at the beginning and end of the observation for the purpose to solve clock parameter in VLBI analysis. And we assume that coordinates of the observation stations are well known on the International Terrestrial Reference Frame (ITRF), and ground based calibration data of atmosphere (weather data) and ionosphere (GPS data) are available to reduce the systematic error of spacecraft position as less as possible.

2. Finite-VLBI model

2.1 Difference between Finite-VLBI and normal VLBI

Spacecraft at a distance up to 30 light years have to be treated as finite distant radio source on in VLBI model since the curvature of the radio wavefront cannot be ignored [2]. The maximum difference of geometrical delay between the finite-VLBI and infinite (normal) VLBI delay model with earth-radius baseline is several hundreds of nano seconds at geocentric distance of 1AU (Figure 1). It corresponds to several thousands of wavelength at radio frequency 8.3 GHz. VLBI model of finite distance is presented by *Sovers and Jacobs* [2] (1996) and *Fukushima* [3](1994). Here a set of partial derivatives regarding right ascension, declination and geocentric distance is displayed by using Fukushima's model.

2.2 Partial Derivatives

Geometrical VLBI delay of finite distance radio source is expressed [3] by coordinates of radio source $\vec{\mathbf{x}}_0$ and station vector $\vec{\mathbf{x}}_i$ (i= 1,2) as:

$$c\tau = -\vec{\mathbf{k}} \cdot \vec{\mathbf{B}}, \qquad (1)$$

$$\text{where } \vec{\mathbf{k}} = \frac{\vec{\mathbf{r}}_{01} + \vec{\mathbf{r}}_{02}}{r_{01} + r_{02}}, \quad r_{\mathrm{ij}} = |\vec{\mathbf{r}}_{\mathrm{ij}}|, \quad \vec{\mathbf{r}}_{\mathrm{ij}} = \vec{\mathbf{x}}_{\mathrm{i}} - \vec{\mathbf{x}}_{\mathrm{j}}.$$

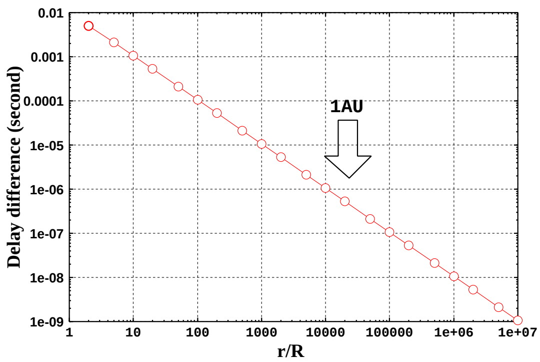

Figure 1. Maximum difference of geometrical delay between finite-VLBI and infinite (normal) VLBI model. Horizontal axis is distance from geocenter with unit of Earth radius. Vertical axis is delay difference (sec.)

Origin of the coordinates is placed at geocenter. Partial derivative respect to source coordinates $\vec{\mathbf{x}}_0$ is give by *Fukushima* [3] as,

$$\frac{\partial\tau}{\partial\vec{\mathbf{x}}_0} = \frac{1}{(1+\beta_{02})c}\{\vec{\mathbf{k}}_{02} - (1+\beta^*_{12})\vec{\mathbf{k}}_{01}\} \quad (2)$$

where

$$\beta_{\rm ij} = \vec{\mathbf{k}}_{\rm ij}\cdot\frac{\vec{v}_{\rm j}}{c}, \quad \vec{\mathbf{k}}_{\rm ij} = \frac{\vec{\mathbf{r}}_{\rm ij}}{r_{\rm ij}}, \quad \beta^*_{12} = \frac{\beta_{20}-\beta_{10}}{1-\beta_{10}}. \quad (3)$$

This partial derivative approaches to zero when the distances of the radio source increases $r_{10}, r_{20} \to \infty$. Partial derivatives of τ in terms of right ascension (α), declination (δ), on which VLBI has sensitivity, and geocentric distance of spacecraft (r) are

$$\begin{aligned}
\frac{\partial\tau}{\partial r} &= \frac{\partial\tau}{\partial\vec{\mathbf{x}}_0}\cdot\vec{\mathbf{i}}_r \\
&= \frac{1}{(1+\beta_{02})c}\{\vec{\mathbf{k}}_{02} - (1+\beta^*_{12})\vec{\mathbf{k}}_{01}\}\cdot\vec{\mathbf{i}}_r \\
\frac{\partial\tau}{\partial\alpha} &= r\cos\delta\frac{\partial\tau}{\partial\vec{\mathbf{x}}_0}\cdot\vec{\mathbf{i}}_\alpha \\
&= \frac{r\cos\delta}{(1+\beta_{02})c}\{\vec{\mathbf{k}}_{02} - (1+\beta^*_{12})\vec{\mathbf{k}}_{01}\}\cdot\vec{\mathbf{i}}_\alpha \\
\frac{\partial\tau}{\partial\delta} &= r\frac{\partial\tau}{\partial\vec{\mathbf{x}}_0}\cdot\vec{\mathbf{i}}_\delta \\
&= \frac{r}{(1+\beta_{02})c}\{\vec{\mathbf{k}}_{02} - (1+\beta^*_{12})\vec{\mathbf{k}}_{01}\}\cdot\vec{\mathbf{i}}_\delta
\end{aligned} \quad (4)$$

Where, $\vec{\mathbf{i}}_r$ is a unit vector from geocenter to the radio source, and ,$\vec{\mathbf{i}}_\alpha, \vec{\mathbf{i}}_\delta$ are unit vectors in directions of right ascension and declination at the radio source on a celestial sphere.

Delay rate of finite-VLBI is given by *Fukushima* [3] as

$$\begin{aligned}
\frac{\partial\tau}{\partial t} &= \frac{\beta_{01}-\beta_{02}+\beta_{10}-\beta_{20}}{1+\beta_{02}} \\
&= \frac{\beta_{01}-\beta_{02}+(1-\beta_{10})\beta^*_{12}}{1+\beta_{02}}.
\end{aligned} \quad (5)$$

And partial derivative of delay rate with respect to the radio source coordinates $\vec{\mathbf{x}}_0$ is

$$\frac{\partial^2\tau}{\partial t\partial\vec{\mathbf{x}}_0} = \frac{1}{1+\beta_{02}}\times \left\{\frac{\vec{\mathbf{v}}_1-\vec{\mathbf{v}}_0}{r_{01}} - \frac{\vec{\mathbf{v}}_2-\vec{\mathbf{v}}_0}{r_{02}} - \frac{(\beta_{02}+\beta_{20})\vec{\mathbf{k}}_{20}}{r_{20}} + \frac{(\beta_{01}+\beta_{10})\vec{\mathbf{k}}_{10}}{r_{10}}\right\} .(6)$$

Here, terms of higher order than second order of β were eliminated. By using this partial, partials in terms of α, δ, and r are given as:

$$\begin{aligned}
\frac{\partial^2\tau}{\partial t\partial r} &= \frac{\partial^2\tau}{\partial t\partial\vec{\mathbf{x}}_0}\cdot\vec{\mathbf{i}}_r \\
\frac{\partial^2\tau}{\partial t\partial\alpha} &= r\cos\delta\frac{\partial^2\tau}{\partial t\partial\vec{\mathbf{x}}_0}\cdot\vec{\mathbf{i}}_\alpha \\
\frac{\partial^2\tau}{\partial t\partial\delta} &= r\frac{\partial^2\tau}{\partial t\partial\vec{\mathbf{x}}_0}\cdot\vec{\mathbf{i}}_\delta.
\end{aligned} \quad (7)$$

3. Error from propagation medium

Excess path delay comes from propagation medium of atmosphere and ionosphere are the most significant error source in continuous phase tracking observation. We suppose ground based calibration data are available to reduce systematic error of spacecraft position as less as possible. Ionospheric total electron content (TEC) data measured by global or regional GPS network will be available for ionospheric delay correction.

Here, we put an assumption that these ground based calibration data give appropriate estimate of each excess path delay. In other words, excess path length estimated from calibration data is supposed to be distributed randomly around the true one. Errors for each components are considered as follows:

Dry troposphere Excess path length due to dry component of troposphere is 2.3 m in zenith direction. Since it is known that atmosphere obey hydrostatic equilibrium to a high degree of accuracy, most of dry component excess path length can be predicted by ground-based pressure measurement. One hecto-Pascal of ground pressure error corresponds 2.3 mm zenith excess path. Factor of mapping function is about 6 at 10 degrees elevation angle. Here we conservatively assume 3 cm as error of dry component of excess path length .

Wet troposphere Excess path of water vapor (hereafter we call as wet component of troposphere) is difficult to predict accurately from ground-based wether measurement, since it is not well mixed in the air. Roughly wet tropospheric excess path length in zenith direction changes with weather condition from 1 cm to 30 cm. Here we put the error at 14 cm by including mapping function.

Ionosphere Excess path of the ionosphere has dispersive characteristic, which means it depends on radio frequency inversely in proportion to square of radio frequency. When number of total electrons in the line of sight per square meter is TEC ($\times 10^{16}$ electrons/m^2) and radio frequency is f GHz, excess path length at microwave frequency region is given by $30.4TEC/f^2$ cm. Total amount of in zenith direction TEC at middle latitude has daily changes from 50 to 100 TEC Units (10^{16} electron/m^2) under small turbulence condition. Accuracy of global ionosphere model derived from GPS observation is around 3 TECU [4], which corresponds to excess path length of 1.3 cm at 8.3GHz. By taking into account the factor $\sqrt{2}$ from two ionosphere paths in VLBI observable and factor of mapping function, we assume error of ionospheric excess path as 11 cm.

From the assumption that each calibration data is unbiased estimator of each excess path component, total error caused from propagation medium is evaluated $\sqrt{3^2+14^2+11^2} = 18$ cm. This length correspond to about 1800 degrees of phase error at 8.3 GHz. This phase error is used in covariance analysis in the next section.

Error of phase delay rate is evaluated with ,

$$\delta\frac{\mathrm{d}\tau}{\mathrm{d}t} = \delta\tau \sec z \tan z \frac{\mathrm{d}z}{\mathrm{d}t} + \frac{\mathrm{d}\delta\tau}{\mathrm{d}t}\sec z,$$

where, z is zenith angle, and simple mapping function $\sec(z)$ was assumed. Since changing rate of zenith excess path (second term of right had side) is not known, here we used only elevation change rate (first term of right hand side) by using zenith excess path error as $\delta\tau = 30$ cm. When z=80 degree, delay change rate is derived as 2.4 ps/s at equatorial region for zero declination radio source. when middle latitude stations are observing middle declination radio source, delay rate becomes 0.01 Hz at 8.3 GHz.

4. Covariance Analysis

Spacecraft NOZOMI is planed to experience two swing-byes with the Earth in December 2002 and in June 2003 [1]. Declination of NOZOMI from viewpoint of geocenter is around $-10 \sim -20$ before the first swing-by (Figure 2) and it keeps high declination (more than 60 degree) after the 1st swing-by till to the 2nd swing-by. Covariance analysis on VLBI measurement of NOZOMI was performed for three epochs: Nov. 4 2002 (decl. = -10 deg.), Dec. 4 (decl. = -17 deg.), and Feb. 2 2003 (decl. = 66 deg.). Parameters of NOZOMI at these epochs are listed in Table 1.

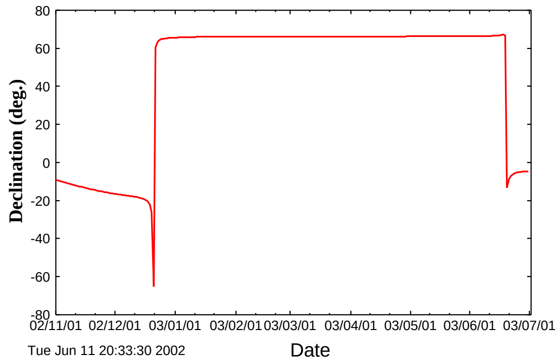

Figure 2. Declination of NOZOMI in the period Nov. 2002 - Jun. 2003.

Table 1. Parameters of NOZOMI at three epochs. The column of r/R is geocentric distance with unit of earth radius, and V_{los} and $\frac{\mathrm{d}V_{los}}{\mathrm{d}t}$ are geocentric velocity and acceleration of NOZOMI in line of sight.

Date	α (deg)	δ (deg)	r/R	V_{los} (km/s)	$\frac{\mathrm{d}V_{los}}{\mathrm{d}t}$ (mm/s^2)
02/11/4	44	-10	2.3e3	-4.3	0.84
02/12/4	42	-17	7.7e2	-3.2	0.076
03/ 2/2	277	66	1.8e3	2.3	-0.47

4.1 Phase delay measurement

According to current orbit plan, right ascension and declination coordinates of NOZOMI will change with angular velocity of a few arc minutes per day even in stable period between the two swing-byes (Figure 3). Then this large proper motion and radial distance from geocenter were included in our parameterized observation model. Fringe phase as observable is given by residual of phase delay after subtraction of a priori phase delay model based on a priori space craft position. Linearized observation equation for small variation of right ascension, declination, and geocentric distance is given as follows:

$$\begin{aligned}\Delta\phi = \; & 2\pi f\frac{\partial\tau}{\partial\alpha}\{\Delta\alpha_0 + \Delta\dot{\alpha}(t-t_0)\} \\ + \; & 2\pi f\frac{\partial\tau}{\partial\delta}\{\Delta\delta_0 + \Delta\dot{\delta}(t-t_0)\} \\ + \; & 2\pi f\frac{\partial\tau}{\partial r}\{\Delta r + \Delta\dot{r}(t-t_0)\} + \delta\phi\end{aligned} \tag{8}$$

Partial derivatives were computed by using equation (4) and a priori orbit information of NOZOMI. Error of phase delay observable was assumed to be 1800 degrees as discussed in section 3. and observation time span was from rising up of the spacecraft till to its setting in. Elevation cut off angle was set as 10 deg. Phase delay sampling interval is 30 min. Under these conditions, covariance matrices were computed on Kashima-Usuda

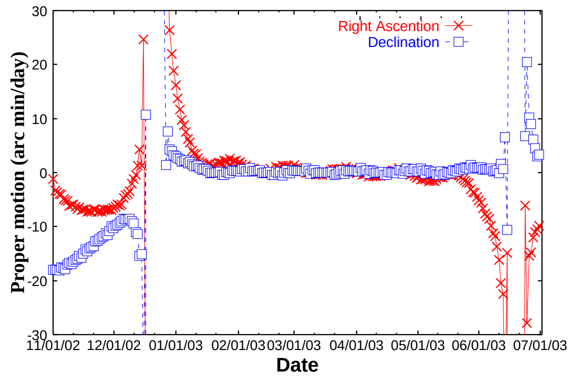

Figure 3. Proper motion of NOZOMI : × indicates proper motion in right ascension and □ indicates proper motion in declination.

Table 2. Covariance matrix of phase delay observation of NOZOMI on each baselines (see text). Initial phase, right ascension, declination, geocentric distance, and there time derivatives were used as modeling parameters. Partial derivatives are computed based on orbit information at Feb. 2 2003. σ indicates estimation error and $C_{a,b}$ is correlation between parameter a and b.

Baseline	σ_α (mas)	$\sigma_{\dot\alpha}$ (mas/h)	σ_δ (mas)	$\sigma_{\dot\delta}$ (mas/h)	σ_ϕ (deg.)
K-U	190	18.7	207	38	600
K-A	12.5	1.2	20.0	4.1	1300
K-G	3.2	1.4	11.3	1.3	1290

Baseline	σ_r (km)	$\sigma_{\dot r}$ (km/s)
K-U	7.6e4	4.2
K-A	7.4e3	0.36
K-G	5.1e3	0.14

	$C_{a,b}$	$\dot\alpha$	δ	$\dot\delta$	ϕ	r	$\dot r$
K-U	α	0.39	0.53	0.81	-0.32	-0.41	-0.71
	$\dot\alpha$	1	0.73	0.15	0.03	-0.72	-0.05
	δ	–	1	0.29	0.20	-0.96	-0.23
	$\dot\delta$	–	–	1	-0.46	-0.12	-0.92
	ϕ	–	–	–	1	-0.01	0.19
	r	–	–	–	–	1	0.05
K-A	α	-0.04	-0.35	0.98	-0.41	0.19	-0.97
	$\dot\alpha$	1	0.74	0.04	0.42	-0.79	-0.12
	δ	–	1	-0.27	0.90	-0.98	0.19
	$\dot\delta$	–	–	1	-0.34	0.10	-1.00
	ϕ	–	–	–	1	0.0	0.29
	r	–	–	–	–	1	-0.03
K-G	α	-0.66	-0.52	0.55	0.57	0.51	-0.30
	$\dot\alpha$	1	0.86	-0.58	-0.95	-0.87	0.12
	δ	–	1	-0.41	-0.87	-0.99	-0.04
	$\dot\delta$	–	–	1	0.40	0.36	-0.86
	ϕ	–	–	–	1	0.0	0.10
	r	–	–	–	–	1	0.10

(K-U), Kashima- Algonquin (K-A), and Kashima-Goldstone (K-G) baseline (Table 2). Although, covariance analysis was performed also for epochs of Nov. 4 and Dec. 4 of 2002, intercontinental baseline cannot keep enough mutual visibility in those epochs, and errors of spacecraft position were larger than arc second. Consequently they are not practically useful for navigation, thus their results are eliminated here. Fortunately spacecraft will keep high declination between two swing-by epochs (Figure 2), thus observation condition is better for

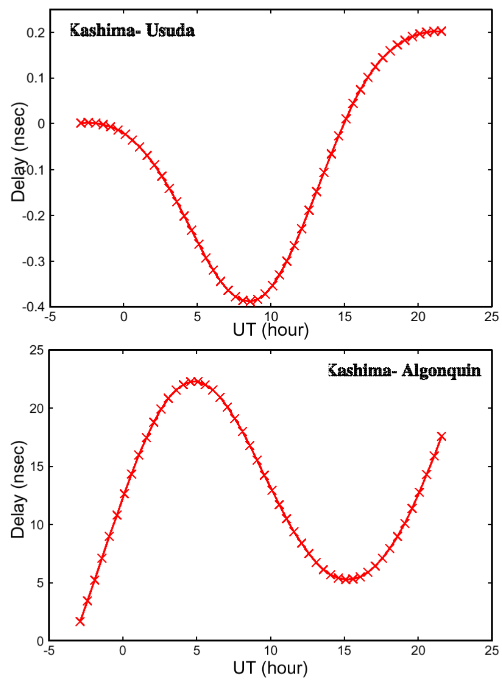

Figure 4. Variation of geometrical delay cause by change of radial distance based on orbit information of NOZOMI at Feb. 2, 2003. Upper panel is that of Kashima-Usuda baseline (200km) and lower one is that of Kashima-Algonquin baseline (9100km).

VLBI position measurements during this period.

The formal error of Table 2 shows that intercontinental baseline will achieve mas order of accuracy, and even with domestic 200 km K-U baseline will satisfy 100 mas accuracy, which is required from ISAS, in declination.

It is interesting to see that estimated error of the spacecraft coordinates is larger on K-A baseline than that of K-G baseline, nevertheless projected baseline of K-A is longer than that of K-G. Long projected baseline gives higher angular resolution and higher astrometric accuracy in normal VLBI. This strange result is a characteristic of finite-VLBI, and it was caused from that geocentric distance r and its time derivative $\frac{\mathrm{d}r}{\mathrm{d}t}$ were included in the observation model. The high correlation (97 %) between α and $\dot r$ on K-A baseline will be responsible for that. Also high correlation between δ and r is remarkable on all baselines.

Two example of geometrical delay variation caused by change of radial distance based on NOZOMI's orbit information is displayed in Figure 4. These examples indicate that parameterized modeling of radial distance is necessary for finite distance spaecraft observation, since change of radial distance causes significant change of geometrical

Table 3. Covariance matrix of phase delay observation of NOZOMI on each baseline. Initial phase, right ascension, declination, and their time derivatives were used as modeling parameters. Partial derivatives are computed with orbit information on epoch Feb. 2 2003.

Baseline	σ_α (mas)	$\sigma_{\dot\alpha}$ (mas/h)	σ_δ (mas)	$\sigma_{\dot\delta}$ (mas/h)	σ_ϕ (deg.)
K-U	110	13	42	14	570
K-A	2.5	0.7	1.2	0.3	570
K-G	2.2	0.7	1.1	0.2	570

Baseline	$C_{a,b}$	α	$\dot\alpha$	δ	$\dot\delta$	ϕ
K-U	α	1	0.211	0.05	0.57	-0.51
	$\dot\alpha$	–	1	0.26	0.21	-0.23
	δ	–	–	1	0.06	-0.04
	$\dot\delta$	–	–	–	1	-0.89
K-A	α	1	-0.40	0.15	0.27	0.32
	$\dot\alpha$	–	1	-0.40	-0.74	-0.84
	δ	–	–	1	0.52	0.43
	$\dot\delta$	–	–	–	1	0.82
K-G	α	1	-0.22	0.09	0.00	0.17
	$\dot\alpha$	–	1	-0.52	-0.59	-0.88
	δ	–	–	1	0.46	0.51
	$\dot\delta$	–	–	–	1	0.64

delay in interferometric measurement. If they are not included in the model, quasi-sinusoidal delay will be absorbed in (α, δ) parameters, and they will contain systematic error. In case the examples (Figure 4), 120 - 160 mas of systematic coordinates error will be caused regardless of baseline length. For comparison purpose, covariance matrix of the case that r and $\frac{\mathrm{d}r}{\mathrm{d}t}$ are excluded from modeling parameters is listed in Table 3. In this table, the formal error becomes smaller than the former case and it become smaller on longer baseline as it is in normal VLBI.

4.2 Phase delay rate measurement

An advantage of phase delay rate measurement is that observable is ambiguity free. In contrast to that differential phase delay measurements has a risk of insertion of phase ambiguity between scans, phase delay rate observation allows intermittent observation without any risks. Thus switching observation with reference ICRF sources will be possible to calibrate phase delay rate error by propagation medium. Drawback of this method is lower spatial resolution than phase delay measurement.

Observation model including first time derivative of spacecraft position is

$$\begin{aligned} \frac{1}{2\pi}\delta\left(\frac{\mathrm{d}\phi}{\mathrm{d}t}\right) &= f\left(\frac{\partial^2\tau}{\partial t\partial\alpha}\right)\{\Delta\alpha + \Delta\dot\alpha(t-t_0)\} \\ &+ f\left(\frac{\partial^2\tau}{\partial t\partial\delta}\right)\left\{\Delta\delta + \Delta\dot\delta(t-t_0)\right\} \quad (9) \\ &+ f\left(\frac{\partial^2\tau}{\partial t\partial r}\right)\{\Delta r + \Delta\dot r(t-t_0)\} \end{aligned}$$

Table 4. Covariance matrices of phase delay rate observation for NOZOMI. Right ascension, declination, geocentric distance, and their derivatives are used for modeling parameter. partial derivatives are computed with orbit information on Feb. 2 2003.

Baseline	$\sigma_\alpha)$ (mas)	$\sigma_{\dot\alpha}$ (mas/h)	σ_δ (mas)	$\sigma_{\dot\delta}$ (mas/h)
K-U	3200	470	7700	1300
K-A	100	18	660	110
K-G	98	12	330	61

Baseline	σ_r (km)	$\sigma_{\dot r}$ (km/s)
K-U	7.9e5	48.3
K-A	6.5e4	3.2
K-G	3.3e4	1.9

Baseline	$C_{a,b}$	$\dot\alpha$	δ	$\dot\delta$	r	$\dot r$
K-U	α	0.18	-0.12	0.54	0.18	-0.57
	$\dot\alpha$	1	0.19	0.38	-0.20	-0.38
	δ	–	1	-0.02	-0.99	0.07
	$\dot\delta$	–	–	1	0.10	-0.99
	r	–	–	–	1	-0.15
K-A	α	-0.62	-0.37	0.73	0.35	-0.72
	$\dot\alpha$	1	0.57	-0.71	-0.56	0.71
	δ	–	1	-0.06	-1.00	0.05
	$\dot\delta$	–	–	1	0.04	-1.00
	r	–	–	–	1	-0.03
K-G	α	0.11	0.02	0.71	-0.06	-0.72
	$\dot\alpha$	1	0.59	-0.14	-0.59	0.13
	δ	–	1	-0.07	-0.99	-0.04
	$\dot\delta$	–	–	1	0.02	-1.00
	r	–	–	–	1	0.01

Partial derivatives was computed with equation (7) based on orbit information of NOZOMI on Feb. 2, 2003. Error of observable was assumed to be 0.01 Hz at 8.3 GHz. Covariance matrices were computed for each baseline : Kashima-Usuda (K-U), Kashima-Algonquin (K-A), and Kashima-Goldstone (K-G) are listed in Table 4.

When phase delay rate is used as observable, only intercontinental baseline will be able to satisfy the requirement of 100 mas accuracy. As it is the same with phase delay measurement, K-G baseline gives better results than K-A baseline, nevertheless K-A baseline is longer than K-G.

5. Conclusion

Accuracy of coordinates measurement of NOZOMI with VLBI was discussed under the conditions: (i) continuous tracking VLBI observation, and (ii) single baseline VLBI observation, and assumption (iii) propagation medium is the most significant error source and ground based calibration data will give unbiased estimator of excess path length for each component of them. Phase delay and delay rate errors are put at 1800 degree, and

0.01 Hz at 8.3 GHz. As results of covariance analysis with finite-VLBI model based on orbit data of NOZOMI in Feb. 2003, following estimates are obtained. (1) Phase delay measurement with intercontinental baseline will gives a few mas accuracy of spacecraft coordinates in the plane perpendicular to the line of sight. Even with domestic baseline, 1 μ radian of accuracy will be available. (2)Phase delay rate measurements has advantage of ambiguity free, thus calibration of propagation medium with switching observation with reference source is easy. This method can achieve 0.1 arc second accuracy with intercontinental baseline, but domestic baseline is ineffective with this method.

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CRL VLBI Group received Tsuboi Award from the Geodetic Society of Japan

The VLBI group of Communications Research Laboratory received a Tsuboi award from the Geodetic Society of Japan on May 30, 2002. The Tsuboi award, established in commemoration of the Japanese distinguished geophysicist Prof. Chuji Tsuboi, is given to an individual or group who made a remarkable achievement in the field of geodesy. The reason of the award for CRL VLBI group is the contribution to VLBI technical development over many years and systematic research works of plate motion and crustal deformation. In particular, the achievements accomplished in the period from 1980s to early 1990s are awardwd. Thus CRL VLBI group has a chance to receive an award again for later works, according to the chair of the award selection committee who made a speech at the ceremony. (*Tetsuro Kondo*)

Photo 1. Accepting the award from the chair of the Geodetic Society of Japan.

Photo 2. The plaque of the Tsuboi award.

2002 FIFA World Cup football games were held at Kashima

Three matches of the stage 1 of the 2002 FIFA World Cup football games were held at the Kashima Soccer Stadium in June. The stadium is located very close to the Kashima Space Research Center. Teams of Argentina, Croatia, Germany, Ireland, Italy and Nigeria visited Kashima and showed us very exciting games to around the world. If you noticed our antenna was broadcasted on TV, please let us know! (*Yasuhiro Koyama*)

Photo 3. Kashima Soccer Stadium on June 5, 2002.

Photo 4. German vs Ireland on June 5 at Kashima.

Highway bus service has connected Kashima to the world

The accessibility to the Kashima Space Research Center from around the world became much more convenient than ever! Two bus companies started regular highway bus service between New Tokyo International Airport (NARITA) and Kashima. The bus runs 8 times a day and it takes only about a hour to and from the airport. The bus stops right front of the Kashima Space Research Center and the one way fare is 1000 yen if return ticket is purchased at the same time (otherwise 1200yen).
(*Yasuhiro Koyama*)

Photo 5. Bus stop for Kashima at Narita airport.

Photo 6. Kashima Space Research Center and a bus for the Narita airport.

"IVS CRL Technology Development Center News" (IVS CRL-TDC News) published by the Communications Research Laboratory (CRL) is the continuation of "International Earth Rotation Service - VLBI Technical Development Center News" (IERS TDC News) published by CRL. In accordance with the establishment of the International VLBI Service (IVS) for Geodesy and Astrometry on March 1, 1999, the function of the IERS VLBI technical development center was taken over by that of the IVS technology development center, and the name of center was changed from "Technical Development Center" to "Technology Development Center".

VLBI Technology Development Center (TDC) at CRL is supposed

1) to develop new observation techniques and new systems for advanced Earth's rotation observations by VLBI and other space techniques,
2) to promote research in Earth rotation using VLBI,
3) to distribute new VLBI technology,
4) to contribute the standardization of VLBI interface, and
5) to deploy the real-time VLBI technique.

The CRL TDC newsletter (IVS CRL-TDC News) is published biannually by CRL.

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.
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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/"**.

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