TECHNOLOGY DEVELOPMENT CENTER NEWS

COMMUNICATIONS RESEARCH LABORATORY

Serial No. 23 November 2003

CONTENTS

(continued on inside front cover)

- News - News - News - News -

The 3rd CRL TDC Symposium

Tetsuro Kondo (*kondo@crl.go.jp*)

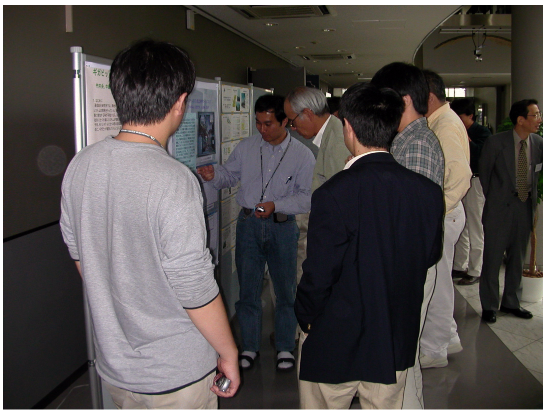
Kashima Space Research Center
Communications Research Laboratory
893-1 Hirai, Kashima, Ibaraki 314-8501, Japan

As a Technology Development Center (TDC) of the IVS, Communications Research Laboratory (CRL) held the third IVS Technology Development Center Symposium on October 8, 2003 at the Kashima Space Research Center. This symposium was devoted primarily to presentations of the state-of-the-art technology developments in Japan regarding VLBI. Fifty-nine people attended the symposium, and 19 oral presentations and 4 poster presentations were given during the day.

Progress of the technical developments of VLBI using the high speed network (e-VLBI) has been remarkable these days. The discussions were developed actively involving the network researchers attending the e-VLBI session.

The results of the relative VLBI observations of the "NOZOMI" Mars explorer, which finished the last earth swingby successfully in May, 2003 and is now heading towards Mars, were reported in the session about the position determination of spacecrafts. Moreover, a plan of the relative VLBI observations of the "HAYABUSA", which is under cruise towards the sample return from the surface of an asteroid, was also introduced. A future space VLBI (VSOP-2) mission was also introduced in the session of future plans.

Pictures taking on the third CRL Technology Development Center symposium held on October 8, 2003. Top: at the registration desk. Middle and bottom: in the large conference room (aural session).



Left: poster presentations.

Use of Ultrahigh-Speed Network in GALAXY Project

Hisao Uose (*uose.hisao@lab.ntt.co.jp*),
Sotetsu Iwamura and Kazunori Kumagai

NTT Laboratories
3-9-11, Midori-Cho, Musashino-Shi,
Tokyo 180-8585 Japan

Abstract: A joint research project on real-time very long baseline interferometry (VLBI) called GALAXY is being conducted by NTT Laboratories, the Communications Research Laboratory (CRL), the National Astronomical Observatory (NAO), the Yamaguchi University, and the Institute of Space and Aeronautical Science (ISAS) to explore the effectiveness of ultrahigh-speed communications technologies when applied to advanced scientific research. Using an ultrahigh-speed network allows us to raise the bandwidth of the radio signals used for the cross-correlation, so the performance of the observation system can be greatly improved. This paper outlines the technical issues related to communications in the project and current configuration of GALAXY network.

1. Introduction

In recent years, the application of ultrahigh-speed networks to advanced scientific research has started to attract a great deal of attention with the rapid improvement of research and education (R&E) networks funded by governments and parts of the private sector. Typical applications being tried include ones in the fields of high-energy physics, astronomy, genetic engineering, and distributed computing. Among them, the leader is real-time very long baseline interferometry (VLBI), which creates a large-scale virtual radio telescope and is a very precise system for measuring the earth 's rotation parameters using multiple distantly located antennas. VLBI itself is an established technology developed in 1960s and many scientific discoveries have been made in astronomy and geodesy using it.

The key point of our research project called GALAXY is to remove the performance bottleneck of the conventional VLBI scheme by using an ultrahigh-speed communications network to carry observed data, which previously had to be physically transported on magnetic tapes [1]. This was the first attempt in the world to use a high-speed digital communications network for a VLBI observation system. NTT 's objectives for the project are two-fold. One is to establish technologies for very-high-speed communications (gigabit-per-second class) in preparation for commercial services in the future. The second is to explore and prove the effectiveness of those technologies in advanced scientific areas, which are the first actual applications utilizing the capabilities of ultrahigh-speed communications technologies [2].

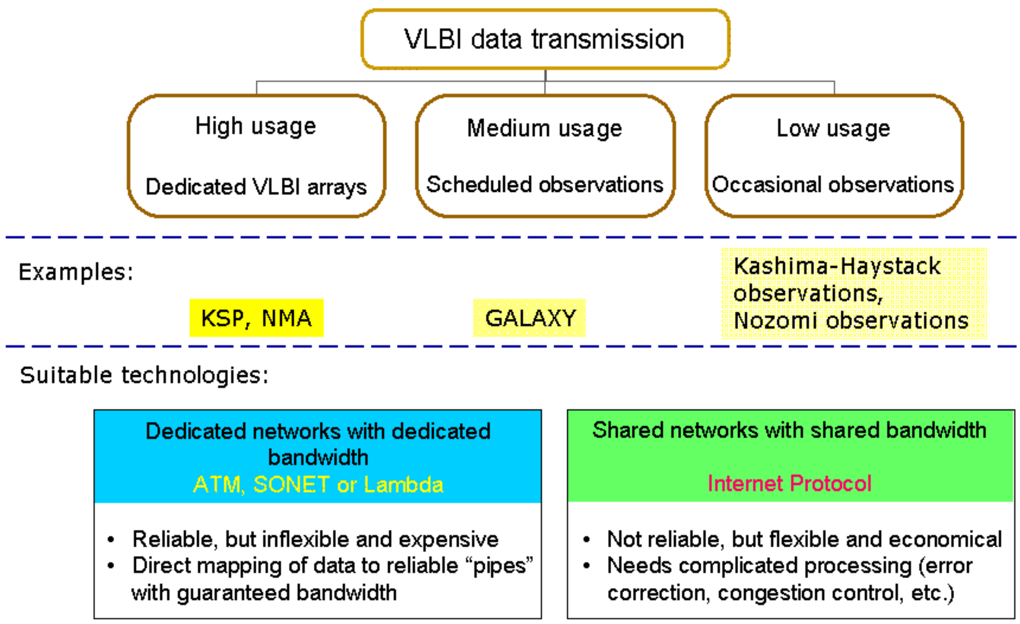


Figure 1. Data transmission technologies for real-time VLBI.

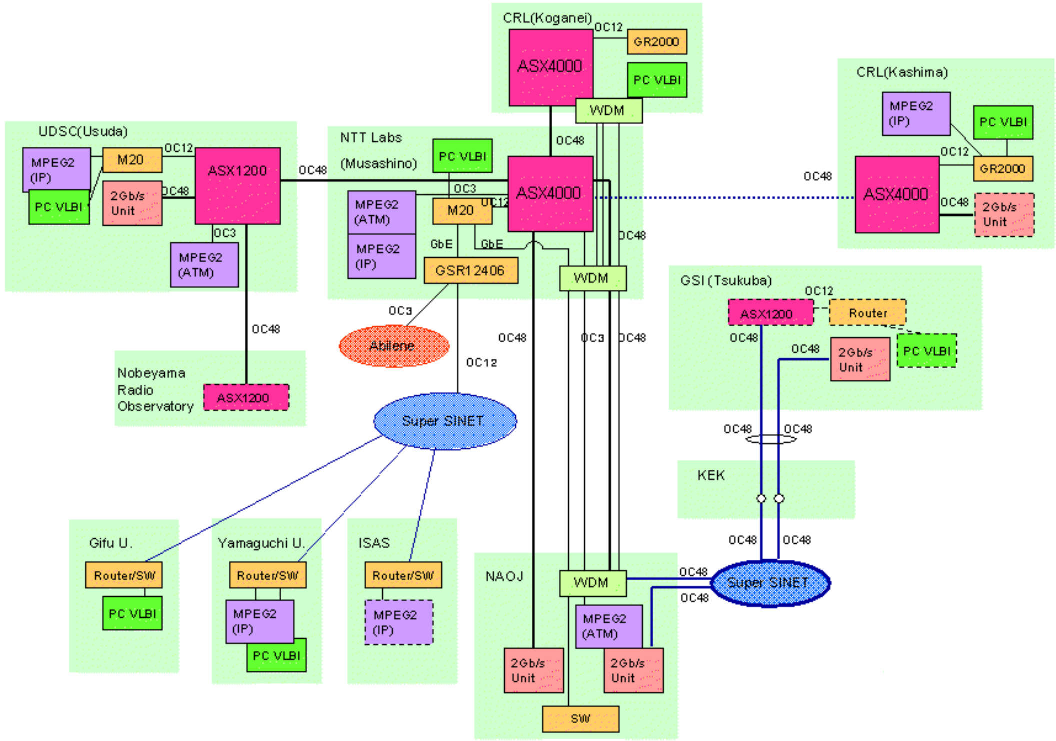


Figure 2. Configuration of GALAXY Network.

This paper explains the communications aspect of GALAXY project. First we discuss the data transmission technologies for real-time VLBI then the network configuration of GALAXY is described. Finally we mention future research plans.

2. Data transmission technologies for real-time VLBI

The requirements for the transmission technologies for real-time VLBI differ greatly depending on the style of the observation and the required bandwidth. Figure 1 explains suitable technologies for each case.

In the phase-1 project started in 1996, we built a dedicated experimental network for real-time VLBI and used ATM technology to carry the data. ATM technology has a rigorous bandwidth management capability providing the very reliable data transmission required for critical applications [3]. The relatively high cost can be justified for a high network usage case such as KSP where regular observations were conducted. In the medium to lower network usage cases, however, the use of dedicated bandwidth is not economical. To make the real-time VLBI experiment more affordable and widespread, IP technologies must be used effectively, because the R&E networks around the world are rapidly increasing their capacities and those networks are accessible from major public research organizations around the world at a small cost.

Therefore, in the phase-2 project started in 1998 we started to explore the use of IP technologies extensively within our experimental network along with ATM taking into account the collaboration with R&E networks around the world. Using IP for transferring very-high-speed data involves many challenging issues. With IP networks, “best effort” is the norm, so we must take measures to assure that the data streams are transmitted to the other end reliably without any degradation of the total throughput. From this viewpoint, we developed a very-high-speed VLBI data transfer system using multiple IP stream.

3. Configuration of experimental network

Figure 2 depicts the current physical configuration of GALAXY network and Figure 3 shows the interconnections with other R&E networks with which we are collaborating. Last year, the GALAXY network was integrated with GEMnet, which is another NTT research network. At the moment, we are upgrading links among NTT research centers with the latest wavelength division multiplexing (WDM) technologies to augment the capacity of GALAXY/GEMnet.

Connectivity with other research organizations has been greatly improved by interconnecting with other R&E networks. The connection to Super

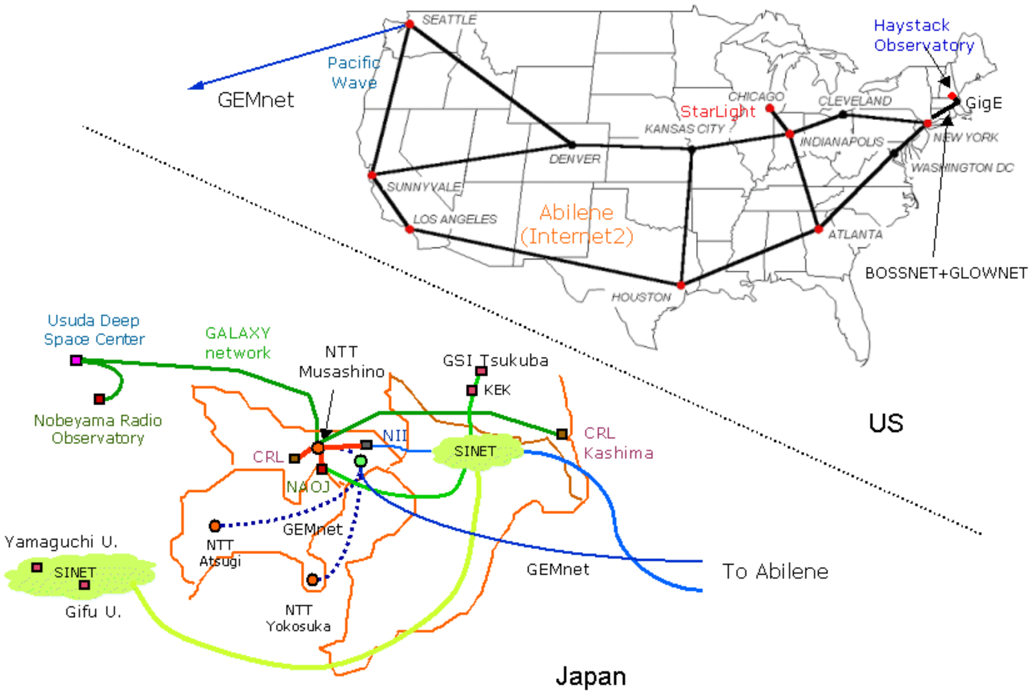


Figure 3. GALAXY/GEMnet and partner R&E networks.

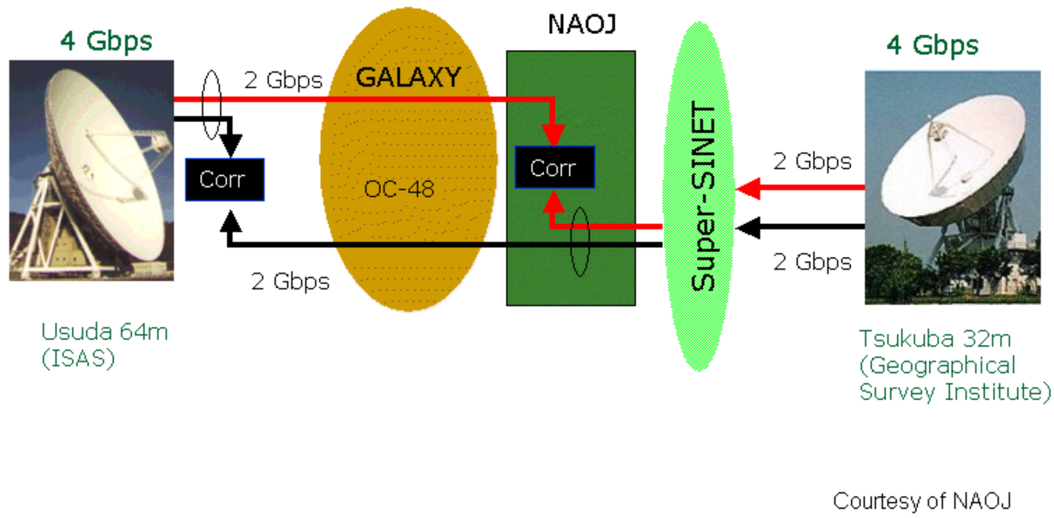


Figure 4. Collaboration with Super SINET (4-Gbps real-time experiment) .

SINET operated by the National Institute of Informatics (NII) has greatly improved the connectivity with domestic research organizations, especially national universities. We have a direct link to Super SINET at 600 Mb/s as well as 2.4-Gb/s SDH links. Figure 4 shows the configuration of the 4-Gb/s observation experiment in collaboration with Super SINET. We also have a direct link to Abilene, which is the backbone network of the Internet2 project in the United States. The collaboration with Internet2 provides us with connections to research organizations in the US as well as in other parts of the world via their international transit service (ITS).

We are continually upgrading our experimental network to adapt to our new requirements. One is to deploy more high-performance IP equipment to promote research on “Internet VLBI” and another is to use the latest photonic devices and transmission equipment developed by our laboratories in our network. A high-capacity data storage and video conferencing system supporting the remote distributed experiment have also been deployed.

To test the effectiveness of multimedia conferencing systems in these distributed laboratory environments, we have started to deploy a high-quality video conferencing system in the main experimental sites. The quality of both video and sound should be as good as possible to capture the environment of other locations not only in terms of the spoken words, but also the background noise and visual atmosphere. We are using MPEG2 encoders/decoders, echo cancellers, and large-screen plasma displays to create a high-quality cooperative working environment.

4. Conclusions and future plans

In December 2002 GALAXY team successfully achieved transmission and processing speeds of 2 Gb/s. The development of "Internet VLBI" systems and a distributed cross-correlation system using networked computers are other targets. With the success of IP VLBI data transmission, the possibility of making an international real-time VLBI observation system appears realistic. In addition, the combination of distributed data analyses and IP data transmission/packet routing should lead to a completely new type of VLBI observation. For example, IP multicast could be used to distribute observed radio signals to a large number of cross correlators in the Internet, many of which will be ordinary PCs equipped with mathematical software conducting necessary scientific calculations on demand. In combination with the multistream data transfer method described in the paper, very-high-speed distributed cross correlation will be possible.

References

[1] H. Uose, K. Irie, S. Iwamura, T. Kondo, J. Nakajima, H. Kiuchi, N. Kawaguchi, K. Fujisawa, Y. Murata, and H. Hirabayashi, "GALAXY and KSP: Real-time VLBI Trials in Japan," Proceedings of URSI, 2002.

[2] H. Uose, K. Irie, and S. Iwamura, "NTT 's ultra-high-speed networking experiment: a real-time VLBI project," Proceedings of SPIE Vol. #4845-08, 2002.

[3] H. Kiuchi, M. Imae, T. Kondo, M. Sekido, S. Hama, T. Hoshino, H. Uose, and T. Yamamoto, "Real-Time VLBI System Using ATM Network," IEEE Trans. on Geoscience and Remote Sensing, Vol. 38, No. 3, 2000.

[4] K. Fujisawa, N. Kawaguchi, J. Nakajima, H. Kiuchi, T. Kondo, H. Uose, K. Irie, S. Iwamura,and Y. Murata, "Astronomical observations with GALAXY, a real-time VLBI network", Proceedings of SPIE Vol. #4845-11, 2002.

Transmission of VLBI Data with a TCP/IP Parallel Transmission System

Kazunori Kumagai
(*kumagai.kazunori@lab.ntt.co.jp*),
Sotetsu Iwamura, and Hisao Uose

NTT Laboratories
Nippon Telegraph And Telephone Corporation
9-11, Midori-Cho 3-Chome Musashino-Shi,
Tokyo 180-8585 Japan

Abstract: Transmitting data from radio astronomy sites is an application that demands very high bandwidth and quality service(QoS). We have developed a parallel transmission system to transmit an extraordinary volume of observed data from telescopes to data processing sites. Not all the astronomical facilities were connected with high-quality networks, so to share data among many telescopes and processing units, we had to make a system that can work well even over IP networks where there is background traffic. Additionally, the problem of long fat pipes related to long-distance transmission has a significant impact because these facilities are located far apart. Parallel transmission can solve these problems by splitting the original data stream into multiple slower streams. In existing parallel transmission systems, it is difficult to reconstruct split data needed for astronomical purposes. We achieved such reconstruction by using a rubidium oscillator to synchronize devices. It can provide a frequency with enough stability and accuracy for one observation and is cheaper than a cesium oscillator. 256 Mb/s using 8 streams was achieved by this system. This throughput is much higher than the ideal throughput of a single stream. Moreover, high throughput and high availability are achieved even where there is background traffic.

1. Introduction

1.1 Background - VLBI

In order to develop new technologies capable of handling very high-speed applications, it is essential to solve the problems arising in specific applications in actual development. So, we tried to solve the problems invoked in very long baseline interferometry(VLBI). This technology produces high-definition images of a far galaxies or fine geodesic results by observing a signal from one radio source at several observatories and correlating the signals. The longer the distance between the observatories, the higher the definition of the image and the finer geodesic results.

Previously, VLBI researchers transferred signals to a correlator by recording them on magnetic tapes and physically sending them to the facility housing the correlator. We have developed methods of transmitting such signals (observational data) via computer networks. Because the volume of observational data is very large (Several terabytes for one observation) and the distances among our observatories are very long (see Figure 1), new data transmission methods are needed. We have developed them in collaboration with the Communication Research Laboratory, National Astronomical Observatory of Japan, the Institute of Space and Astronomical Science, and Yamaguchi University.

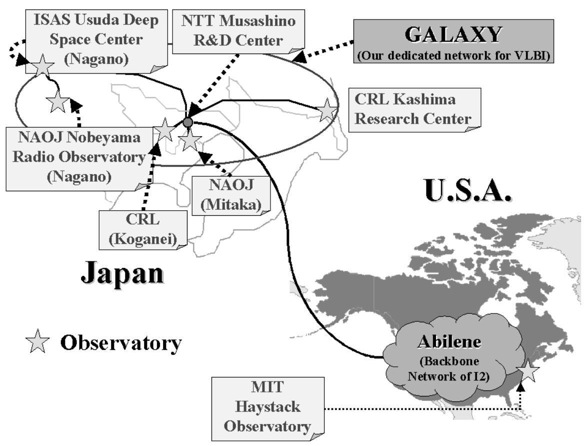


Figure 1. Our Research Network for VLBI, Abilene, and MIT.

1.2 Previous Achievement

We have already achieved 2 Gbps in our dedicated network by using asynchronous transfer mode (ATM) transmission device([1]). After this success, we started to develop an IP transmission system in order to collaborate with other research networks. For this purpose, we have to take into consideration the following points.

- Each observatory is quite separate from others.(For example, MIT Haystack Observatory is 10,000 kilo-meters away from CRL Kashima Research Center). Therefore, the long-fat pipe problem heavily affects the usability of networks.
- Not all the observatories are connected to high-quality networks, so packet losses happen.

- Researchers sometimes want to use dedicated correlators for VLBI[2],[3]. To use these devices, we must stably input data into these devices in real time. In the case of usual real-time transmission such as data transmission in remote video conference systems, a certain level of fluctuation input is acceptable. But in the case of VLBI, the fluctuation of input is almost unacceptable.

In the transmission via TCP/IP, we can improve the usability of networks by increasing the window size. But in this case, it is known that packet loss is inevitable, so this method is not a complete solution[4]. Therefore, we decided to use a parallel transmission, which can achieve high throughput by splitting the original data flow to multiple slower flows. This type of system has the following advantages.

- Even when round trip time is large (for example, the round trip time between CRL Kashima Research Center and MIT Haystack Observatory is 200-250 ms.) and packet loss exists, a parallel transmission can achieve high throughput which a serial TCP/IP flow with a large window size cannot.
- Even if some flows slow down, the effect on the whole of transmission is small.

Even though some parallel transmission systems and software have already been made, they cannot reconstruct the original data stream in real time. Therefore, we had to develop a new system for our purpose.

Initially, we made a UDP parallel transmission system as a prototype. This system achieved 256 Mbps with 8 flows[5]. We can achieve higher rate by increasing the number of flows.

1.3 Our New Achievement

UDP does not re-transmit data packets, so the UDP parallel transmission system cannot transfer enough accurate data in the network where packet loss too often happens. This time, we developed a TCP parallel transmission system in order to transfer accurate data over such a network. In an environment where there is packet loss or ACK packet delay is large, the throughput of a TCP flow usually oscillates because the window control algorithm changes the flow's window size. In such an environment, parallel transmission can quickly recover from a fall because the throughput of each flow is slow compared to serial transmission which achieves high throughput by itself. In this paper, we describe the results of a performance evaluation on our system.

2. Architecture of Our Parallel Transmission System

2.1 Components

Our system is composed of a parallelization device, a serialization device, transmitting PCs, receiving PCs, and a control PC. These devices are connected as illustrated in Figure 2. The parallelization device is connected to a sampler with an ID1 line and to the transmitting PCs with IEEE 1394 lines. The serialization device is connected to a correlator and to the receiving PCs in the same way. The transmitting and receiving PCs are connected to the network by Ethernet.

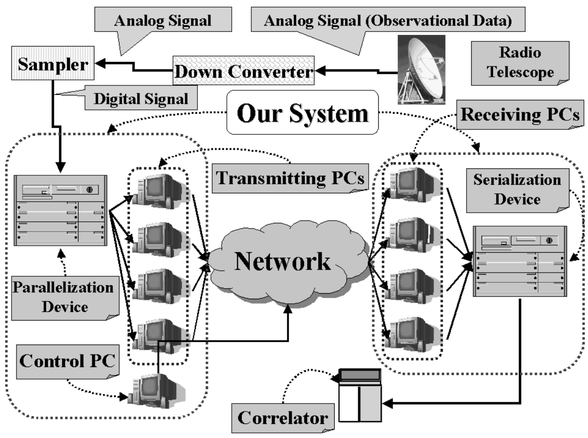


Figure 2. Diagrammic Inllustration of Our Parallel Transmission System.

The system control module in the control PC controls other modules in the transmitting and receiving PCs. Additionally, it controls the parallelization device via a parallelization device control module, and the serialization device via a serialization device control module. The flows of commands and observational data are illustrated in Figure 3.

Our system can work either in on-line mode for real-time correlation or in batch mode for offline correlation.

2.2 Data Transmission Procedure

The procedure for transmitting data between parallelization and serialization is composed of the following phases.

1. Initialization Phase: The system control module initializes all other modules. At that time, data re-transform modules change there observational data receiving port to listening mode.
2. Connection Phase: The system control module commands the data transform modules to

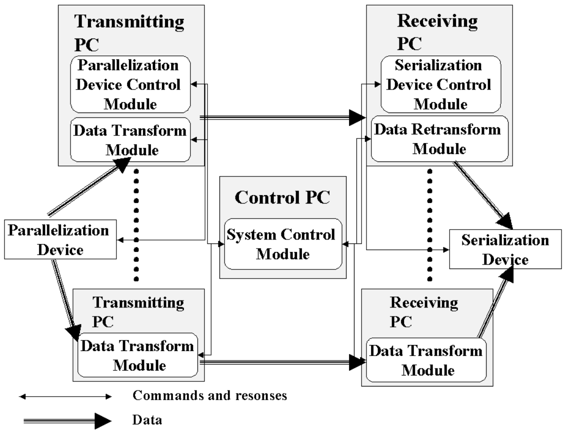


Figure 3. Modules in Our System and Relation among them.

make TCP connections to corresponding data re-transform modules.

3. 1394 Receiving Phase: After the TCP connections have been established, the system control module sends start commands to the data transmission modules and the parallelization device.
   - On-line Mode: Data transform modules receive observational data from the parallelization device via IEEE 1394 lines and transmit it to corresponding data re-transform module via the TCP connection, using the hard disks of transmitting PCs as buffers. The data re-transform modules save the received data in hard disks of receiving PCs until they reach the volume designated at initialization (buffering).
   - Batch Mode: At first, the data transform modules save all the received observational data on the hard disks of the transmitting PCs. After that, they transmit the data automatically.
4. 1394 Transmitting Phase
   - On-line Mode: When all the data re-transform modules have received the designated volume of data, the system control module sends start commands to all the data retransmission modules.
   - Batch Mode: When all the re-transform modules have received all the data sent by the corresponding transmission modules send, the system control module sends start commands to all the data re-transform modules.

   Once they have received a start command, all the data retransmission modules transmit observational data to the serialization device via IEEE 1394 lines.

The receiving PCs provide a buffer against fluctuations in the IP packets arrival interval and distortions in arrival order.

2.3 Division and Reconstruction of Data Flow

The data stream output from a down-converter is transmitted to a parallelization device and divided into multiple data streams.

The serialization device combines the multiple flows and reconstructs a single flow. This stream is transmitted to the real-time correlator. In order to accurately reconstruct a single stream, we must synchronize the devices. We chose to use a rubidium oscillator because it has enough accuracy over a short time.

3. Performance Evaluation

3.1 Purpose and Contents of the Experiment

In order to verify that our system can transmit a high bit-rate stream when the round trip time between the transmitting and receiving ends and packet losses are not negligible, we carried out experiments.

3.2 Experimental Environment

Our experiment network is illustrated in Figure 4. We made an experiment network where we could control the round trip time with a delay generator and generate packet loss with a bit error inserter. (If a packet has bit errors, it is discarded.) We generated bit streams with a pattern generator/error detector and investigated whether the stream was transmitted correctly or not, by inputting the output stream from the serialization device to the pattern generator/error detector, which compares the output and input streams.

3.3 Results

The experimental results verified that our system worked well even where the round trip time was equivalent to trans-pacific transmission and packet loss was not negligible.

4. Conclusion of Experiments

Experiments verified that our TCP/IP parallel transmission system can transmit a data stream

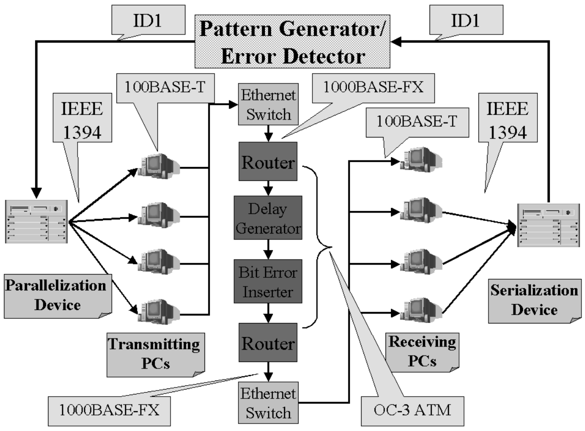


Figure 4. Experimental Environment.

that has sufficient quality for real-time VLBI processing by buffering at each receiving PC and synchronizing devices with a rubidium oscillator.

5. Unsettled Problems

Although our system has good performance , we have to fix the following problems in order to put our system into practical usages.

- The behavior of IEEE 1394 on Linux is instable. This is caused by the instability of a driver software for IEEE1394.
- The operation is complicated for beginners.
- Although we synchronize receiving PCs and a serialization device, they may become out of synchronization. So, our system cannot continue transmission for a long time. This break of synchronization is caused by interruption by some processes and so on.

It is very difficult for us to improve the driver for IEEE 1394. So, we have to wait the improvement by open source community.

In order to make our system easier for beginners, we should improve the user interface of a system control module.

We can synchronize devices for a long time by using a real time operation system on receiving PCs. (Now we use redhat Linux on transmitting and receiving PCs.)

We will try to solve these problems in order that our system become useful for VLBI researchers.

References

[1] N. Kawaguchi, K. Fujisawa, J. Nakajima, H. Uose, S. Iwamura, T. Hoshino, T. Hashimoto, H. Takagi “Gigabit Data Acquisition and the Transmission Experiment ”, *NTT R&D*, Vol. 50, pp. 824-830, 2001.

[2] Y. Koyama, T. Kondo, M. Sekido, R. Ichikawa, T. Yoshino, H. Kiuchi, J. Amagi, H. Uose, S. Iwamura “Achievements of Real-time Geodetic VLBI Experiments ”, *NTT R&D*, Vol. 50, pp. 839-844. 2001.

[3] H. Kobayashi, N. Kawaguchi, K. Fujisawa, H. Hirabayashi, Y. Murata “Experiments of Real-time Space VLBI by Using a High-speed Network ”, *NTT R&D*, Vol. 50, pp. 853-857. 2001.

[4] J. Padhye, V. Firoiu, D. F. Towsle, and J. F. Kurose “Modeling TCP Reno Performance: A Simple Model and its Empirical Validation ” , *IEEE/ACM TRANSACTIONS ON NETWORKING*, Vol. 8 , pp. 133-145, 2000.

[5] S. Iwamura, H. Uose, S. Nakagawa, T. Kondo, H. Kiuchi, J. Nakajima, K. Fujisawa “VLBI Data Transfer Over IP” , *NTT R&D* , Vol. 50, pp. 831-838, 2001.

High-temperature superconductor filter of 2.2GHz, Operating status against RFI

Eiji Kawai (*kawa@crl.go.jp*),
Junichi Nakajima, Hiroshi Takeuchi, Hiromitsu Kuboki, and Tetsuro Kondo

Kashima Space Research Center
Communications Research Laboratory
893-1 Hirai, Kashima, Ibaraki 314-8501, Japan

1. Introduction

In S/X-band radio-telescope systems, Radio Frequency Interference (RFI) had been occurred in S-band since IMT-2000 systems are introduced as the new mobile phone. As we reported in previous TDC News article (Kawai et al.,2002), Kashima 34-m antenna experienced severe RFI from a closely located IMT-2000 base station. The IMT-2000 broad-band communication system emit the relative strong transmission than previous digital phones. The S-band receiver's down-converter was saturated and observations were halted during April 2002. The receiver system was restarted by a narrow-band ambient filter installation after the Low Noise Amplifier (LNA). Then we have developed High-Temperature Superconductor (HTS) filter to recover wide-band reception (Kawai et al. 2003). The HTS filter fabricated on MgO substrate and YBCO-HTS film structure showed ideal passband. The unwilling out-band emissions are suppressed below -80dB from its passband. The S-band receiver regained full bandwidth required for minimum redundant channel allocation of band width synthesis.

2. Continuous operation of external cooled filter

Currently, the HTS filter cryostat is installed separately beside the LNA dewar. Pulse tube type cryostat is operated to sustain superconductivity temperature 70K. With a serial interface monitoring, the filter subsystem keeps temperature stable normally in the first 3-month. During annual maintenance of 34-m telescope power down, the subsystem is turned off. After its power up, the re-started subsystem cooled down to 70K within 2 hours. This is faster than LNA cryostat cool down. Actually cooling ability of the pulse-tube cryostat varies a little over applied inclination, no significant system temperature change was monitored, since the HTS is not thermal generating component. This is the first wide-band HTS filter in practical use.

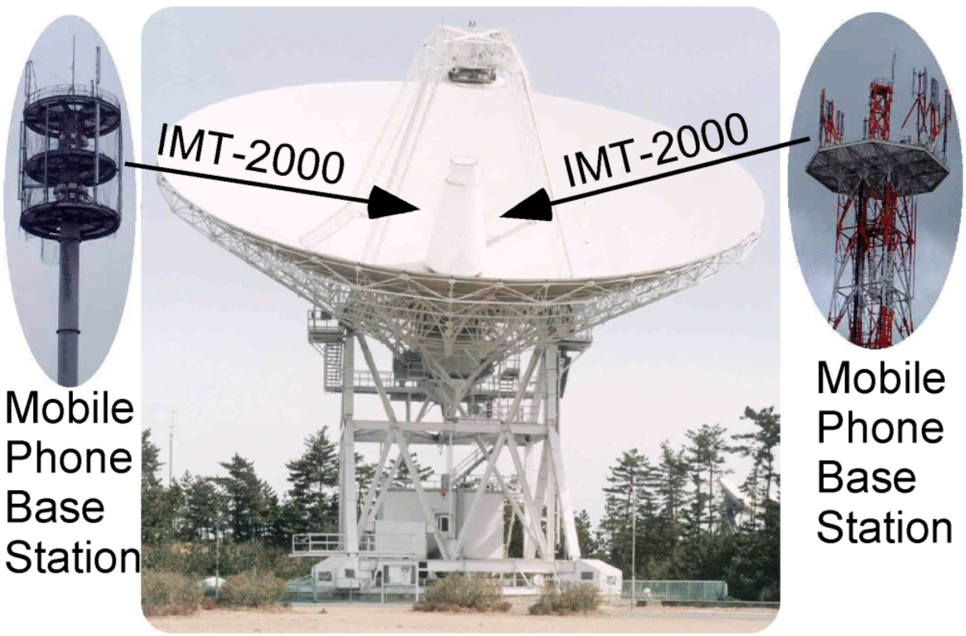


Figure 1. Kashima 34-m telescope located in dense population area. The antenna is surrounded by more than ten IMT-2000 base station of two major companies. The telescope can distinguish these base-stations by side-lobe coupling at low-elevation.

3. LNA overload measurement and filter position

Though the post LNA HTS filter rejects current RFI in-comings to S-band LNA, increasing RFI traffic in this frequency may completely saturate the LNA in future. In this case, to protect the LNA, the HTS filter will be installed to in front of the LNA. Evaluation of overloading level is discussed as follows. We used a signal generator (SG) tone injection from a cross guide coupler port of the receiver feed system where we usually inject phase-cal tones. Under condition of receiver feed connected to cold load, an SG is connected to the port and LNA output is measured to obtain P(-1dB) compression level. Figure 2 shows the measurement of -6.5dBm output. On the other hand, pointing telescope toward the strongest component of IMT-2000 signal, we measured the level of -17.6dBm by a power-meter. Thus roughly still there is 11dB margin until the LNA saturation. This measurement is done under initial deployment of IMT-2000 service and the number of IMT-2000 user is expected to be increased rapidly. Then these base stations will equip additional transmitters. Another source is interfere by personal user at close range. Observatory requests non-use of mobile phones near facilities. Usually it is difficult to turn off all mobile phones. These unwilling emission strongly interfered a few minutes observations. To avoid receiver overloading, We will monitor the RFI levels continuously. When the LNA under monitoring is supposed to be near its saturation, we will install the HTS in front of the LNA.

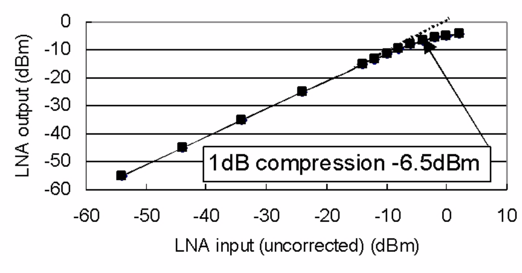


Figure 2. LNA overloading measurement by injecting CW tone. Comparing the measured P(-1dB) compression level and strongest incoming RFI, LNA margin until non-linear saturation is estimated.

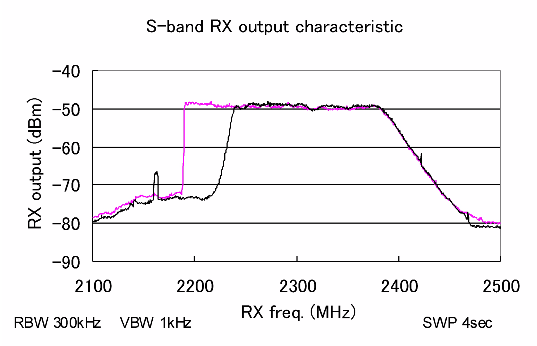


Figure 3. HTS filter and ATC(Ambient Temperature Filter) comparison. Thick line shows ATC filter passband limited in narrow-range and un suppressed strong RFI exists in nearby frequency. The HTS passband is wide and its cutoff shape is very steep. RFI is completely suppressed. Higher edge of the passband is determined by down-converter characteristics currently.

4. Summary

Figure 3 shows the S-band receiver RF spectrum by using normal ambient filter and HTS filter combination. The HTS filter recover the receiving ability lower to 2193MHz and RFI components from IMT-2000 system is completely disappeared. The HTS filter system is practilally used in various VLBI experiment. S-band radio utilities are increasing and the high performance filter subsystem is effective to protect weak radio observation under strong nearby emissions. Considering the RFI level and LNA saturation tolerance, filter position are selectable in front of LNA or after LNA. Since the IMT-2000 is strong RFI source, all VLBI stations are recommended to monitor the RFI level regularly to avoid unexpected observation failure.

References

Kawai.E. et al. S-band RFI problems at Kashima 34-m antenna and a passive filter for mitigation. IVS TDC News 21, Nov.,2002.

Kawai.E. et al. Wide-band high-temperature superconductor filter on 2.2GHz RFI mitigation. IVS TDC News 22, June,2003.

2-Gbps PC Architecture and Gbps data processing in K5/PC-VSI

Moritaka Kimura (*mkimura@crl.go.jp*),
Junichi Nakajima, Hiroshi Takeuchi, and Tetsuro Kondo

Kashima Space Research Center
Communications Research Laboratory
893-1 Hirai, Kashima, Ibaraki 314-8501, Japan

1. Introduction

Using high-speed PCs, PC-based data acquisition and processing systems are being developed. After the completion of 1-Gbps per unit system, in our experiment we have reached 2-Gbps per unit in recent integration of K5/PC-VSI. This is the highest PC recording speed ever performed and maximum performance realized under high speed PCI-bus architecture. Compared with 256Mbps magnetic recorders, this is 8 times faster and the price of the recording system is reduced to one hundredth (200,000 USD to 2,000 USD). Not only the system performance is drastically improved, connection to Internet through the Giga-bit ether ports are already equipped in the PC system. Anticipate the VLBI era of software correlation over the network connections, one concrete PC architecture is determined. Successive correlation resources are also prepared by PCs over the network.

2. PC Components selection of K5/PC-VSI

K5/PC-VSI system consists of the VSI compatible A/D sampler [1] and PCI data capture board [2] that is used for capturing sampled data in main memory. High-speed PCI bus and high-speed RAID are required for PC-VLBI. The list of PC components are shown in below table 1 . This mother board was selected to utilize high-speed PCI buses. One PCI socket (66MHz/64bit) is used for data capturing from VSI sampler, another PCI socket (133MHz/64bit) is used for RAID card for data storage. Since, 1G-byte main-memory is used as FIFO buffer, task switching overhead of OS, seek time of a disk and other process does not affect to continuous recording. Maximum data rate of 2Gbps can be performed by 8-disks RAID-0 mode. There is enough margin to perform RAID-5 to give high data reliability. Using two gigabit-ether ports, almost all sampling data are transmitted to correlation PC. When we use 250GB x 8 disks of a good buy price, 8 hours / 512M-bps, 4 hours / 1024M-bps or 2hours / 2048M-bps recording is possible. Each disk stored in simple removal case for media transportation. Increasing disk capacity, 24 hours Gbps observation without disk change become possible near feature.

Table 1. 2Gbps Acquisition PC components

Mother board	Rio-Works HDAMA
PCI-bus	133MHz/64bit×2,66MHz/64bit×2 33MHz/32bit×2
CPU	AMD Opteron 240×2
Memory	2Gbyte
Raid	HighPoint Rocket Raid 1820 (8-port Serial ATA)
HD	IBM-HITACHI Deskstar 250GB ×8
Network	Gigabit ether ×2(on board)
VSI-H	PC-VSI2000DIM Interface card
Price	2,000 USD (w/o HDDs and IF card)

3. Observation and Processing mode

Advanced from tape based system, flexibility of PC-VLBI enables researches various kind of observation modes. Show typical architecture in Figure 1, combination work of memory, hard disks, VSI capture board, high-speed network and high speed CPUs allow users this. They are used as both short term FIFO and storage. K5/PC-VSI currently supports following basic modes.

- Mode-1: Off-line stand alone observation
  This observation mode is similar to conventional tape recorders. Sampling data of AD unit is recorded to RAID, and disk-pack exchange is performed as if they are the tapes. After Observation, removal disk-packs are transported to the correlation PC. This observation mode is used in all usual VLBI stations to substitute recorders.

- Mode-2: Fringe-Check observation
  If observation station is connected to network, a part of observation data are transmitted to other site for immediate fringe check. In most of the observation, real-time correlation is not essential requirement, low speed network and sampling inspection of the dataset satisfy the users quicklook during observation period [3]. The K5/PC-VSI system is designed to record and data transmission simultaneously.

- Mode-3: Real-Time observation
  Where the observation station are connected high speed network, all sampled data are transmitted to network in real-time. If observation purpose does not require wide bandwidth, total data rate is compressed by re-sampling technique at CPUs. This mode is important in time critical observation like delta VLBI observation for satellite positioning.

- Mode-4: Single dish observation
  In spectroscopic observation, incoming raw data is processed directly without disk recording. Though in severe RFI and switching observation, preserved raw data in the K5/PC-VSI system can be applied to software processing algorithms of RFI removal and sensitivity increase.

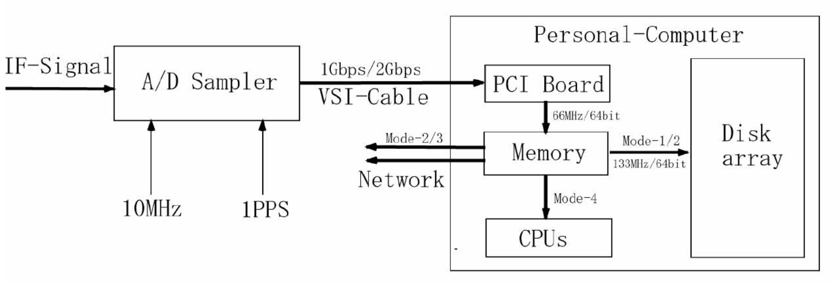


Figure 1. K5/PC-VSI and observation mode configuration. High speed PCI buses capability and high-speed CPU peripherals arrangement enables observation modes over the PC architecture. Sole PC I/O performance is limited below 2-Gbps in present bus architecture.

Table 2. Requirement of floating point operation speed for real-time processing with n-stations, 1k-point FFT with 1Gsps sampling rate

Number of station n	Number of baselines	Total operation speed [Gflops]	Operation speed per PC [Gflops]
2	1	60	30
3	3	96	32
4	6	136	34
5	10	180	36
6	15	228	38
7	21	280	40
8	28	336	42
9	36	396	44
10	45	460	46

Table 3. The number of floating point operation for n-stations, m-point FFT with m-samples.

Processing term	floating point
FFT(real-FFT)	$5/2m \log_2 \times m \times n$
Delay tracking and fringe rotation	$3m \times n$
Cross correlation and Integration	$4m \times n(n-1)/2$

4. PC Correlation Resource Estimation

When we process VLBI data stored in disks, even a slow PC can process whole data by spending long time. On the other hand most severe case is the real-time processing. This section deduce processing capability of multi CPUs system being planned at CRL. All data processing of K5/PC-VSI system is performed by software. The software developed at CRL uses Single Instruction Multiple Data (SIMD) functions which are equipped in recent CPUs such as Intel Pentium-3, Pentium-4, AMD Athlon and Opteron. In addition, the software is scalable to multi-CPUs and multi-PCs [2]. Since the software correlation employs FX algorithm, multi-baseline correlation is performed by increased number of PCs corresponding to number of station without vastly speed down. Using these characteristics, the performance of software correlation reached hardware correlation. For example, the requirement of PC specification for real-time correlation of 1Gsps and 1024 FFT points and number of station n are shown in Table 2. Total amount of operation is summed up from functions that are used in FX correlation, operation cost of each function are presented in Table 3. Actually, there are some data copies between memory to registers in each function, the required PC performance is roughly 3 times larger than table 2. As a consequence, 1Gbps multi-baseline real-time correlation, several high speed PCs that has capability of 100Gflops are required. Typical performance of recent CPU is 12Gflops, PC system equips 8-CPUs reach the ability. However, the software performance is highly depend skill in programming, a slight flaw in software code and code without high-speed technique can not be a correlation core of the high speed software correlator.

References

[1] Nakajima, J et. al. IVS CRL-TDC News No.17,pp.18,NOVEMBER 2000.

[2] Kimura , M et. al. IVS CRL-TDC News No.21, pp.31,NOVEMBER 2002.

[3] Nakajima, J et. al. IVS CRL-TDC News No.16,pp.15,JUNE 2000.

Data ownership evolution and flexible handling around PC VLBI

Junichi Nakajima (*nakaji@crl.go.jp*),
Moritala Kimura, Yasuhiro Koyama, and Tetsuro Kondo

Kashima Space Research Center
Communications Research Laboratory
893-1 Hirai, Kashima, Ibaraki 314-8501, Japan

1. Introduction

Huge VLBI raw data has been a matter difficult to handle. The data written on magnetic tapes can be used only by synchronized playback. Most of the VLBI users could not touch the data until they are processed at correlators. Recent improvement of PC-based VLBI technique (here after generally PC-VLBI) allows researchers to access the raw VLBI data directly. By the flexibility of file image transfer between the systems researchers can introduce their idea scheme into VLBI. As the examples, we have proved simple mutual data transfer over the Internet. Between Haystack observatory Mk-V and Kashima K-5 system accomplished file based compatibility (Koyama el al. 2003). The data transfer is expected to develop to VSI-E (VLBI Standard Interface -Ethernet). Finland Metsahovi observatory PC-VSIB and the Kashima PC-VSI (K-5 family) system achieved G-bps Internet observations and data compatibility through the VSI-H (VLBI Standard Interface Hardware, Whitney et al 2001, Kimura et al. 2003). As these efforts, using compatibility of PC-VLBI over the VSI-H and Internet (VSI-E), current VLBI system will be able to change over the key components from legacy units to the PC-VLBI smoothly. In addition, future VLBI applications will have benefit in its integration. In following sections, several evolution cases are written briefly.

2. PC based VLBI and Tape based VLBI coexistence

2.1 PC system introduction to tape based VLBI system and coexistence

Though the PC-VLBI systems realized ideal data handling environment, it is obvious fact that existing VLBI operation are running with tape systems. These systems are still important to support regular observations. Thus, smooth introduction of PC-VLBI system as a part of the tape system is the initial work. Figure 1 shows a scheme of partial PC-VLBI system installation in the place of tape decks. In observation, one of a station starts to use the PC-VLBI system as DIM (Data input module). The data is transferred over Internet (or VSI-E in future) and corresponding PC-VLBI unit will work as DOM (Data Output Module). The DOM acts like a tape deck. Then the hardware correlator will be able to work with the PC-VLBI system. During tape system are the majority, this is a preferred style for uninterrupted VLBI operation.

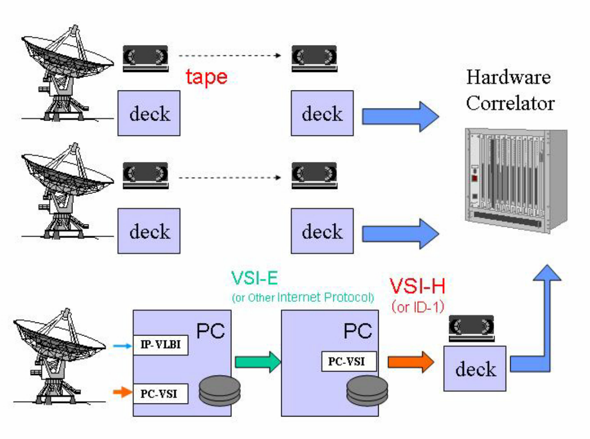


Figure 1. PC-VLBI introduction step to the existing tape VLBI system. VSI-H will be used to keep the compatibility of DIM and DOM. Tape transportation is disappeared for the PC-VLBI system.

2.2 PC-VLBI data ownership with remaining tape units

After a while, the tape system will be gradually replaced to PC-VLBI systems as in Figure 2. In the observation system, most of the data transfer will be done over the broadband network. Correlations are performed at high speed software. The software correlator is running at each acquisition PC or at massive calculation resources like GRID network. But it should be recognized that several remote sites as in separated islands will not be reached by high speed optical fiber in near future. Thus these stations in remote location will use tape or other kind of media. To handle these remaining media, VSI-H compatibility will be used to introduce data into the computer network. Since the correlation is done by software, the data delay from a few stations does not affect correlation set up. The software correlator carry out processing of existing baseline data first, then they will process rest of baselines.

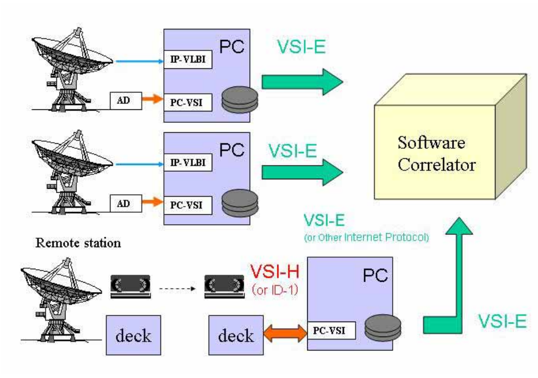


Figure 2. Once the PC-VLBI system get a majority of the VLBI system, software correlator shows advantages in VLBI data processing. Remote stations not connected via network will use transported media. The software correlation system accept the delayed media and accomplish correlation of remaining baselines.

2.3 Data recorder as a VLBI data archive unit

Once the PC-VLBI system is introduced to the VLBI observation network, unused tape decks and tapes will be left over. These systems are utilized again as a data archive units. Though the PC-VLBI system will be the next VLBI facilities, their ability to store data in long period is not matured yet. Optical media up to a few Tera byte will be realized in future. But until the ideal optical media coming, VLBI researchers can archive fringe test and special observation session from the PC-VLBI to the familiar magnetic recorders. Using the VSI-H, the data will be retrieved to data file in PC at the moment when they need. Figure 3 shows this application.

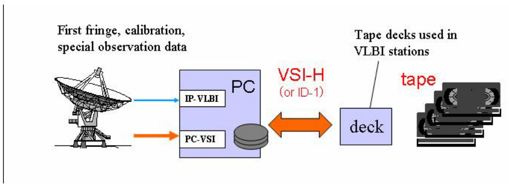


Figure 3. Behind increasing PC-VLBI terminal, remaining recorders are used as data archive units to keep important observation data.

3. Support new observation system

Flexibility of PC-VLBI is well given at integration of new VLBI observation system. In former VLBI scheme, most of the observations are arranged to the hardware specification of VLBI terminal and correlator. In other word, there was some limitation in observations and processing. In software centric PC-VLBI, the system will change this situation and researchers can integrate own observation system around PC bus architecture. As a typical case, Figure 4 shows wide/narrow band multiplex data acquisition system planned in K5 for observation of orbit determination VLBI. A single PC will acquire G-bps data (PC-VLBI) and narrow band data (IP-VLBI). Applying reliable high-speed software-core, observer integrate post-processing system too. All observation results are processed over network resources. Thus the researches can concentrate their scientific target without system integration from scratch.

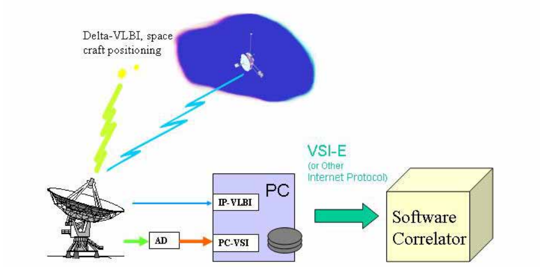


Figure 4. PC-VLBI enables flexible integration of new VLBI system.

4. Summary

Using the common hardware interface VSI-H and Internet data transfer which advance to VSI-E, VLBI community with matured magnetic tape system can smoothly change over to PC-based VLBI system. For a certain period, magnetic tapes can serve as T-byte order data archive unit. Once the PC-VLBI system is introduced, their flexibility allows users to introduce own new idea to its data acquisition and data processing.

References

Kimura.M. et al. "First detection of 2-Gbps wide-band fringes between two PC-based VLBI", IVS TDC News 22, June,2003.

Koyama.Y. et al. "Rapid UT1-UTC estimation from Westford-Kashima e-VLBI experiment", IVS TDC News 22, June,2003.

Whitney.A. "VLBI Standard Interface - Hardware Specification",International VLBI Service, 2003, http://ivscc.gsfc.nasa.gov

Diagnostic tools for the K5 system

Hiro Osaki (*osaki@crl.go.jp*),
Tetsuro Kondo, and Yasuhiro Koyama

Kashima Space Research Center
Communications Research Laboratory
893-1 Hirai, Kashima, Ibaraki 314-8501, Japan

1. Introduction

K5 is a personal computer (PC) based VLBI observing and data processing system. Recently it has been used in various observation experiments, such as Koganei-Kashima baseline geodetic experiments, "Nozomi" spacecraft positioning observations, a multiple baseline geodetic experiment in which five VLBI stations participated, and e-VLBI observations with Kashima and Westford VLBI stations to determine UT1-UTC within 24 hours. In these observations, it has been shown that K5 system has great advantages comparing with conventional VLBI recording system. One reason is that K5 has computer network capability. It is easy to run and monitor an observation session remotely using network. The data can be transferred via network after the observation session.

To make use of the K5 VLBI system in a routine experiment, it is important to develop a suit of diagnostic tools which checks the performance and functionality before the observations. Because K5 is a system developed on PC, it is possible to use many advantages of PC systems. By using software programs it is possible to ensure there is no problem when VLBI data are being recorded. In this report we present current status and future plans for such diagnostic tools, using the advantages that the system is constructed on PC. This will ensure the functionality of the system when K5 system is used in an observation session.

2. Concept of the diagnostic tools

As the K5 system is developed on PC, we have to take care a few possible mis-settings peculiar to PC systems. For example, observation data will not be recorded if there is a configuration error of the hard disk drives (HDD) of the PC. For instance, if the write permission of the data storage directory is not sufficient to the user account the data write will fail. There may also be other cases that the HDD used for the data storage is not mounted on the PC by mistake. Such errors can be easily checked and can be corrected by simple software programs which check the write permission and the remaining HDD space.

In addition, the functionality of the system can be easily checked by software programs because the system is constructed on the PC system. In the conventional VLBI system, it is not easy to check problems in the A/D samplers because it requires a data recorder, a data sampler, and a data processor to check the data, and not all of them is available every time. In case of the K5 system, such capabilities can be realized all in one in a PC. Moreover, it is possible to check the data by comparing or correlating with that of some other station, by transferring the data via computer network.

These examples illustrate outstanding capabilities of the K5 system for its easy diagnosing possibilities. Functionalities of the IP-VLBI sampler board, remaining HDD disk space, and some other issues of the system can be checked by using a set of software-based " diagnostic tools ". These tools will notify the operator if there is a potential problem in the system. This will ensure the success of the observation session. Therefore, we are now developing such diagnostic tools for the K5 system.

2.1 Current status

Some of the diagnostic tools for the K5 system have been developed. In this section, we will introduce these tools.

First, there are tools to show the amplitude distribution of the sampled data. Figures 1 and 2 show the resultant plots of such tools. These figures are obtained by feeding 700mV peak-to-peak 9kHz sinusoidal wave to this sampling board. The board was set to sample the data on 4-MHz, 8-bit, and 1-channel sampling mode. Figure 1 shows the amplitude distribution of the -full to +full range. This plot shows a Gaussian-type distribution of the sampled data around the center. If the distribution of the resultant plot suggests the signal level is too strong or too weak, the operator should adjust the level of the signals by adjusting amplifiers and at-

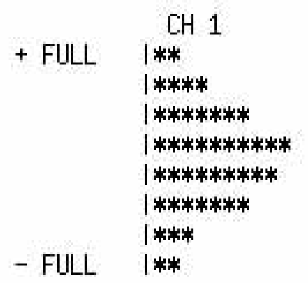


Figure 1. Amplitude distribution of the sampled data.

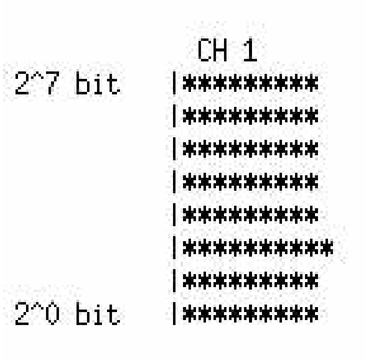


Figure 2. Frequency of occurrence of each 8-bit sampled data.

tenuators. Figure 2 shows frequency of occurrence of each 8 bit sampled data. Using these tools functionalities of the sampling board and the level of the input signal can be checked.

Second, there is a tool that can detect 1 PPS and 10 MHz signals. These signals are essential for the IP-VLBI sampler board to work. Using this tool, the operator can check whether these signals are supplied to the board, even if accessing and monitoring the system from a remote place via network.

Third, there is a program that sums up the data recording time of observations in a schedule and shows the total recording time. This program shows three candidates of the required data storage area, calculated with the total data rate of 64, 128, or 256 Mbps. The remaining disk space of the mounted drives is also shown. So the operator can check whether the remaining amount is enough for the observations. In a near future this program will be developed to calculate the actual required disk space and notify the operator whether the remaining disk space is enough.

As shown in these examples, it is possible to create various diagnostic tools for the K5 system, using PC-based facilities. In the next section we will introduce future plans of such diagnostic tools.

2.2 Future plans

Because PC-based system is flexible, there are more rooms for another kind of diagnostic tools. Here we will show the ideas of the diagnostic tools we are now planning to develop.

The first category of the tools will diagnose the system itself. K5 system is assembled using the IP-VLBI board and a PC. Generally the data writing performance depends on the amount of RAM, the speed of the bus, the linear density of the HDD, the rotating speed of the HDD, and so on. These factors must vary from PC to PC. Therefore the writing performance should vary from system to system. This determines the limit of the stable data-sampling rate. Therefore, it is important to measure the writing performance of the system by altering the data-sampling rate. The performance of the HDD also varies when the inside of the disk is used or the outside of the disk is used. Therefore, it is better to check the performance by altering the remaining HDD space too. In addition, HDD may have some bad sectors. Such sectors should be checked before the observations and should be marked so that they will not be used. These capabilities will also be realized by making software using PC facilities. In another case, the operator may want to check whether the time of the sampler board is correct. If the PC is connected to a network, it is easy to check the time and, if necessary, to synchronize the time of the board with the accurate time, by accessing to an NTP server.

The second category of the tools analyzes the given signal, including the experiment data, 1 PPS, and 10 MHz signals. Analyzing the data, it is possible to check whether there are phase calibration signals and whether the intensities of the phase calibration signals are appropriate for the experiment. Spurious signals and DC offsets can also be checked by analyzing the data. The operator can diagnose the linearity of the sampling by feeding controlled sinusoidal waves to the K5 system, if multiple bits are used for the observations. Using such diagnostic tools, the operator can check the data thoroughly and can ensure the functionality of the system.

3. Summary

In the present paper we described about diagnostic tools for the K5 system. These tools are being developed using the advantage of PC-based system. Using PC-based facilities, functionality of the system can be diagnosed easily compared with conventional VLBI recorder systems. Some of the diagnostic tools have been realized, and we are planning to develop the other diagnostic tools in the near future. By completing such tools, the reliability of the PC-based observation system will become robust.

Current Status of the K5 Software Correlator for Geodetic VLBI

Tetsuro Kondo (*kondo@crl.go.jp*),
Yasuhiro Koyama, and Hiro Osaki

Kashima Space Research Center
Communications Research Laboratory
893-1 Hirai, Kashima, Ibaraki 314-8501, Japan

1. Introduction

In the genesis of VLBI, correlation processing was performed by a software program, however routine processing of such as a 24-hour observation data was impossible due to less computing power. A hardware correlator was hence developed and has been used for a long time. Recently the progress in computing power is remarkable, and computing speed of a recent PC is much faster than that of the mini-computers and workstations of ten years ago.

Kashima VLBI group used to develop the "Software Correlator" named CCC (Cross Correlation in a Computter) for a fringe test of domestic VLBI observations [*Kondo et al.,* 1991]. The CCC performed correlation processing using the data prepared by the K-3 (or Mark III) decoder in the same way as a hardware correlator. The substance of CCC was a FORTRAN program running on an HP-1000 series mini-computer (e.g., 45F, A900, etc.). It took about 8 hours to obtain 64 lag correlation function by processing 16 Mbit data in the HP-1000 45F. The CCC was used in the actual fringe test of a domestic VLBI measurement in 1985, and we could get fringes. Although processing time was improved by a factor of 3 by use of the HP-1000 A900, it was not practical from the reason that not only data processing but also data transmission took time too much (typical transmission speed via telephone line at that time was only 1200 bps!). We had to wait for progresses of both computing speed and data transmission speed to put a software correlator in pratical use.

We have been developing a PC-based VLBI data-acquisition terminal named K5 dedicated to transmitting the data through the Internet [*kondo et al.,* 2000, *Kondo et al.,* 2002, *Osaki et al.,* 2002] since 2000. In parallel with the development of K5 hardware, a software correlator written in C language has also been developed for K5 data processing for geodetic use. The past experience of the CCC development was employed efficiently in the development of K5 software correlator. At present time, K5 software correlator can process 4 Mbps data in real time when it runs on a PC equipped with the Pentium III 1GHz processor or faster one. The K5 software correlator is now used for processing geodetic VLBI data as well as delta VLBI data observing a spacecraft such as "NOZOMI" (see it Ichikawa et al., [2003]). Current status of the performance of K5 software correlator is reported here.

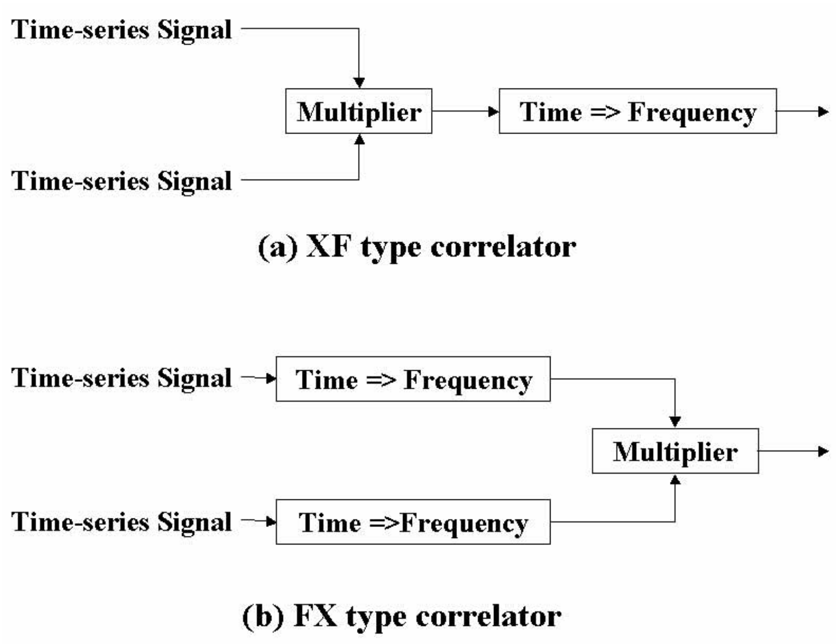


Figure 1. Two types of correlators.

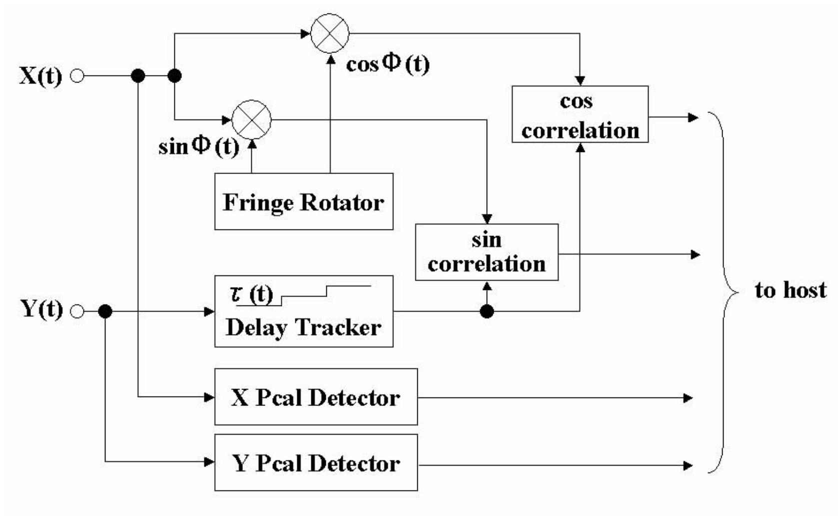


Figure 2. Schematic block diagram of the KSP correlator (XF type).

2. K5 Software Correlator

There are two types of correlators (Figure 1). One is the XF type correlator, which carries out cross-correlation directly on the time domain, then applies a Fourier transform to a frequency domain as required. The XF type corelator was developed to achieve faster processing speeds by reducing the number of delay lags. Because the correlation function of white noise is represented by a sharp peak, we can reduce the number of delay lags such as 32 or less. Thus an XF type correlator has been used for geodetic VLBI system (e.g., KSP, K3, Mark IV correlators). The other one is the FX type. Two stream of time domain data are first Fourier transformed to the frequency domain, then multiplied each other to obtain cross spectrum. Finally they are inverse Fourie transformed to get cross-correlation. This type of correlator can have longer delay lags easily and is well used for data processing of astronomical application which requirs higher spectrum resolution. VSOP correlator belongs to this type. Both types have been developed as K5 software correlators.

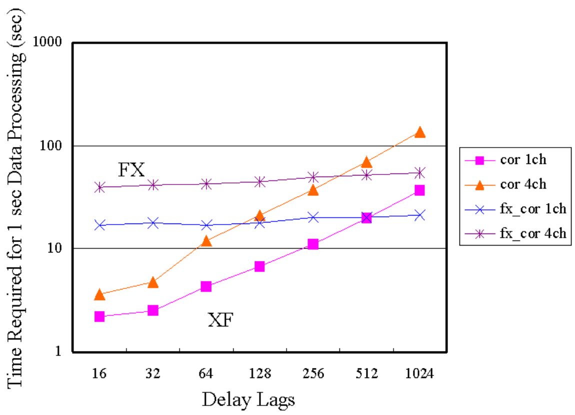


Figure 3. Current performance of K5 software correlator. Time required to process 1 sec data is plotted as a function of the number of delay lags for XF ("cor") and FX ("fx_cor") software correlators. Data are 1ch or 4ch 1-bit-8MHz sampling data, and the type of CPU type is Pentium-III 1GHz.

Figure 2 shows a schematic block diagram of the KSP hardware correlator. First we started the development of an XF type software correlator to compare the correlation results with those processed by hardware correlator. The same algorithm used in the KSP hardware correlator was introduced in the software correlator to assure geodetic results. Phase calibration (Pcal) signal detection was also implemented in the software. Then an FX type software correlator was developed. The substance of these correlators is a C program that can run on FreeBSD, Linux, and Windows operating systems.

3. Current performance status

Figure 3 represents the current status of the performance of K5 software correlators for geodetic VLBI data processing. Times required to process 1 sec data of 1ch or 4ch 1-bit-8MHz sampling data are plotted as a function of the number of delay lags for XF ("cor") and FX ("fx_cor") software correlators. A PC equipped with a Pentium-III

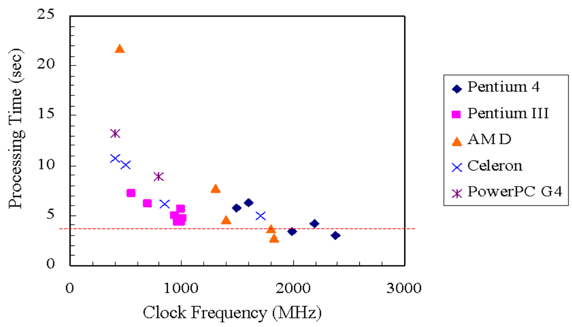


Figure 4. Comparison of the processing speed for various kinds of CPUs and clock frequencies. Data are 4ch 1-bit-8MHz sampling data and 32-lag correlation function is caluculated.

1GHz CPU was used for these evaluations. The processing speed of FX type is not so influenced by the increase in delay lags, but that of XF type increases in proportion to the number of lags. When the number of lags is less than 512, the processing speed of the XF type correlator is faster than the FX type.

We also tested the processing speed for various kinds of CPUs and clock frequencies, such as Pentium III, Pentium 4, AMD, Celeron, etc. Results are shown in Figure 4, where data used are 4ch 1bit-8MHz sampling data, and 32-lag complex correlation function is computed. It is demonstarted that real time processing is well possible when 1ch data are processed with a high performance CPU (time required for 1ch data processing can be estimated by dividing 4ch results by 4).

4. Conclusion

The K5 software correlators ("cor" and "fx_cor") were developed for geodetic VLBI data processing. Processing speed was somewhat sacrificed in the software development because we gave importance to the attainment of the same algorithm used in the hardware correlator in order to assure the geodetic results. K5 software correlators are software package written in C language in which neither special function intrinsic to CPU nor assembler program is used, so that it still has the room of improvement for further speed-up. Software correlator actually has the potential capability to process 1Gbps data in real-time as reported by *Kimura et al.* [2003]. As it is shown by *Koyama et al.* [2003] that geodetic results using the correlated data processed by K5 software correlator give reasonable results, we will shift our improvement effort to further speed up of the processing speed.

References

Ichikawa, R., M. Sekido, H. Osaki, Y. Koyama, T. Kondo, T. Ohnishi, M. Yoshikawa, and NOZOMI DVLBI group, An evaluation of VLBI observations for the positioning of the NOZOMI Spacecraft and the future direction in research and development of the deep space tracking using VLBI, IVS CRL Technology Development Center News, No. 23, pp.31-33, 2003.

Kimura, M., J. Nakajima, H. Takeuchi, and T. Kondo, 2-Gbps PC Architecture and Gbps data processing in K5/PC-VSI, *IVS CRL Technology Development Center News*, No.23, pp.12-13, 2003.

Kondo, T., J. Amagai, H. Kiuchi, and M. Tokumaru, Cross-correlation processing in a computer for VLBI fringe tests, *J. Commun. Res. Lab.*, Vol.38, No.3, pp.503–512, 1991.

Kondo, T., Y. Koyama, M. Sekido, J. Nakajima, H. Okubo, H. Osaki, S. Nakagawa, and Y. Ichikawa, Development of the new real-time VLBI technique using the Internet protocol, *IVS CRL Technology Development Center News*, No.17, pp.22-24, 2000.

Kondo, T., Y. Koyama, J. Nakajima, M. Sekido, R. Ichikawa, E. Kawai, H. Okubo, H. Osaki, M. Kimura, Y. Ichikawa, and GALAXY team, Real-time Gigabit VLBI System and Internet VLBI System, *IVS 2002 General Meeting Proceedings*, pp.142-146, 2002.

Koyama, Y., T. Kondo, H. Osaki, K. Takashima, K. Sorai, H. Takaba, and K. Fujisawa, Evaluation of the K5 system in geodetic VLBI experiments, *IVS CRL Technology Development Center News*, No.23, pp.26-30, 2003.

Osaki, H., T. Kondo, and M. Kimura, Development of versatile scientific sampling processor (VSSP) – A practical approach, *IVS CRL Technology Development Center News*, No.20, pp.7-9, 2000.

Total VLBI data management system using database server
–The organizer for VLBI@home–

Kazuhiro Takashima (*takasima@gsi.go.jp*)

Geographical Survey Institute
Kitasato 1, Tsukuba, Ibaraki 305-0811, Japan

1. Introduction

Do you:

* Miss important deadlines at work?
* Forget to return urgent phone calls?
* Lose papers that were “just here a minute ago ”?
* Have multiple layers of sticky notes on your computer?
* Leave projects unfinished for days, weeks, or even months at a time?

These questions were quoted from the advertisement of the book named “ORDER from CHAOS” by Liz Davenport published by Three Rivers Press. Personally, my answers will include many “yes” to these questions.

In VLBI community, we have the CATLOG system developed by NASA GSFC and USNO for the correlated data and Mark-III database. It 's a good tool to avoid missing data or wasting time to find specific data. We also have the TRACK web site maintained by NRAO for the magnetic tape media, Thin tape and Thick tape. With the help of these utilities, VLBI data management has been in order, because the data management is almost equals to the management of magnetic tape media so far. However, the recent introduction of disk media to record VLBI raw observations might change the data management into “CHAOS”. On disk media, it is easy to copy, move, or even delete the VLBI data. We might lose important VLBI raw data and/or attributes of those data such as location, frequency, or source information. I 'd like to propose a total VLBI data management system in this article.

2. System overview

The management system is not the storage of VLBI raw data or correlated data. The system overview is shown in Figure 1.

The DB server stores only management information such as a schedule, observing log data or correlation status. An example of the management flow is shown below.

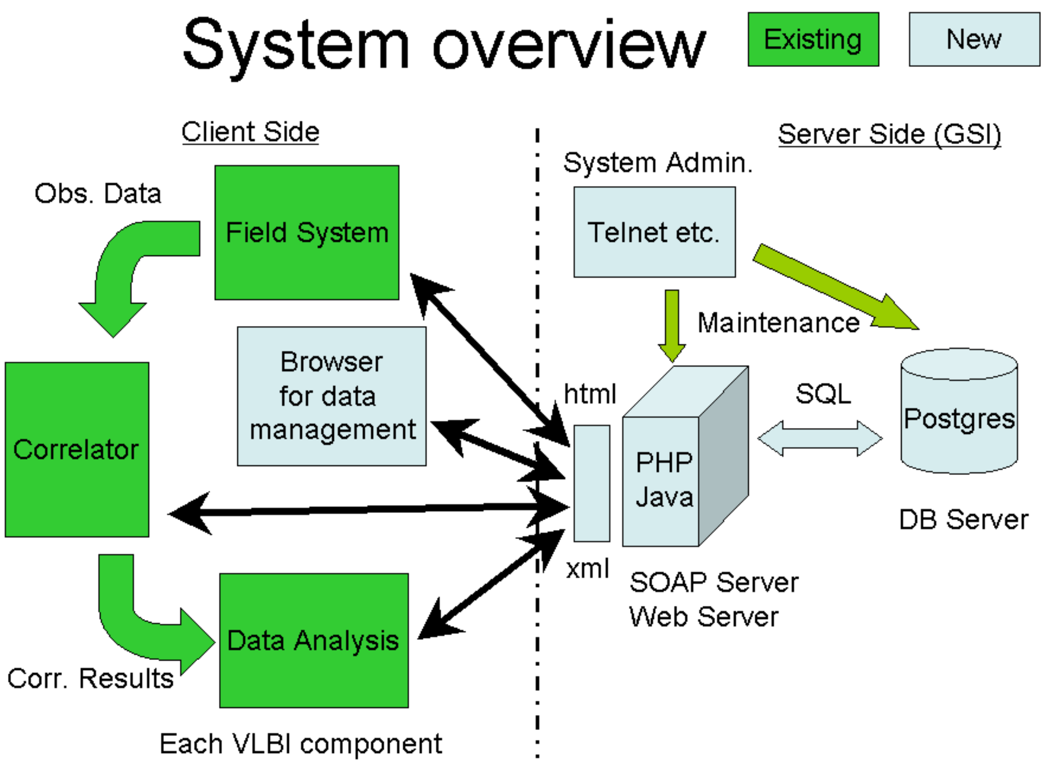


Figure 1. The system overview of the total VLBI data management system. The light gray part is the system proposed and dark gray is the existing system.

1) A scheduler registers a schedule file on the management system.
2) Each field system checks the observing schedule periodically.
3) If it finds the schedule assigned to the station, it downloads the schedule file from server and set up its observation automatically.
4) Observation
5) After observation, the field system submits the log file to the management system.
6) The management system reads the log file and sets up the correlation information for each station.
7) Each correlator checks the correlation information on the management system.
8) If it finds the uncorrelated data, it downloads the data from each station via network, and then correlates those data.
9) A data analyst receives a data correlation report from the management system, and then he/she downloads and analyzes the data.
10) Release the results to public.

3. Development schedule

The developing schedule consists of four steps, i.e. disk management, data management, hookup VLBI@home and total management system development (Figure 2).

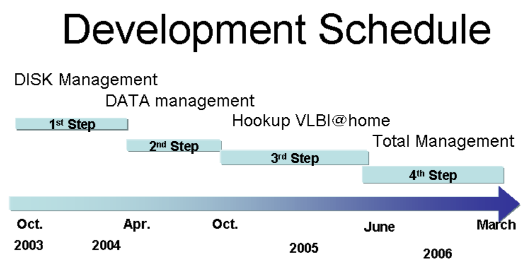


Figure 2. The development schedule.

1st Step : Disk management
This is the management system of PC hard disk module to record raw data. It 's similar to the current tape management system "TRACK ". The data disks are preassigned the eight digit ID e.g. "GSI12345 ". The system should keep up the status of disks such as the information of current location, experiment name, station name, correlation status, etc. by using ID as a key. The different point from TRACK is that it also keep up the specification of hard disks because there are a lot of kinds of hard disks in the market and the specification affects the writing rate or data capacity, compared to only two kinds of the magnetic tapes (Thin or Thick). In case of hard disks, the management system has an important role to prevent a theft of disks because there are general values in a PC hard disk, although it was not in VLBI-specific magnetic tapes.

2nd Step : Data management
The high-speed communication network urges the development of e-VLBI or IP-VLBI, and in near future recording medium, such as magnetic tapes or hard disks, will become unnecessary. As a result it 's not enough to manage the medium for data handling because VLBI data is in a file on PC. This data management system should keep up the information of each data file instead of disk medium.

3rd Step : Hookup VLBI@home
If software correlator is developed, the data processing task can be easily broken up into pieces that can be worked separately and in parallel. The processing method is similar to that of the SETI@home project which is a scientific effort to seek answer whether there is an intelligent life form outside the Earth. Following this, we call the project VLBI@home. In such a parallel processing scheme, the host computer should manage many client computers and the data processing. Therefore, this management system with database server can help VLBI@home projects.

4th Step : Total Management
Finally, the total management system is built to unify the above-mentioned 3 steps. We expect that this total management system reduces the burden of VLBI scientists.

References

K5 (IP-VLBI) disk management system (in Japanese)
http://vldb.gsi.go.jp/sokuchi/vlbi/tape_depot/

Database server (PostgreSQL)
http://www.postgresql.org/

Web Service (SOAP/XML) W3C
http://www.w3.org/2002/ws/

SETI@home
http://setiathome.ssl.berkeley.edu/

NRAO TRACK
http://track.nrao.edu/

Geodetic VLBI Experiments Using VSI-based Giga-bit VLBI System

Hiroshi Takeuchi (*ht@crl.go.jp*),
Junichi Nakajima, Moritaka Kimura,
Yasuhiro Koyama, and Tetsuro Kondo

Kashima Space Research Center
Communications Research Laboratory
893-1 Hirai, Kashima, Ibaraki 314-8501, Japan

1. Introduction

Communications Research Laboratory (CRL) has been developed Giga-bit VLBI system to improve the sensitivity of geodetic VLBI observations. There are a lot of advantages to use the Giga-bit VLBI system for geodesy. The band-width of 512MHz, which is four times wider than the currently operating conventional VLBI systems, enables us to use weaker radio-sources for geodetic observations, or to shorten the integration time when the ordinal radio-sources are used. The high sensitivity of the system allows us to use small-diameter antenna as a VLBI telescope. We had already reported on a compact VLBI system using 0.65-m antenna CARAVAN [*Yonezawa et al.,* 2002]. As another benefit of the Giga-bit system, we can point out that single-channel system is usable for it. Currently, most of the existing geodetic VLBI systems equip multi-cannel down-converters and phase calibration (PCAL) signal generators. Single-channel backend system can be installed easier than multiple channel system and the maintenance cost will be reduced. Moreover, complicated band-width synthesis process is not necessary, so that simple and fast algorithm can be applied to data analysis process.

The development of the Giga-bit VLBI system at CRL started in 1996 [*Nakajima,* 1996]. At first, it is used for radio astronomical observations to take advantage of its high sensitivity. Since 1999, several Giga-bit geodetic VLBI experiments have performed and improved gradually [*Koyama et al.,* 2000]. At the most of these experiments, relatively short-baselines about 100 km had used. In order to confirm the accuracy of the Giga-bit VLBI system used in relatively-long-baseline, we did comparison experiment between K-4 and Giga-bit VLBI system at Kashima-Tomakomai baseline. Details of the experiment and initial result of Giga-bit system are reported in this paper.

2. Experiments

In order to evaluate the performance of the Giga-bit VLBI system, two experiments were performed from July15, 2003 to July 16, 2003. The experiment named GEX-12 done at July 16 was comparative experiment between K4 and Giga-bit VLBI system. It was scheduled in time with the 24-hours geodetic experiment, JADE-0306, which was performed by Geographical Survey Institute (GSI). Domestic six stations using the K-4 system took part in the experiment. The Giga-bit VLBI system was also installed at Kashima 11-m and Tomakomai 11-m stations, both were part of the six stations. In the case of the K-4 system, X-band signals and S-band signals were recorded to correct the ionospheric propagation delay, but only the X-band signal was recorded with the Giga-bit VLBI system. In the experiment, integration time of each observation was configured to achieve enough signal-to-noise-ratios for the narrow-band system. However, the integration time was unnecessarily long for wide-band Giga-bit VLBI system. For this reason, we also carried out experiment in which integration time was optimized for a sensitivity of the Giga-bit VLBI system. This experiment named GEX-11 was performed at July 15 between Kashima and Tomakomai for 6 hours. Though the total observation time of GEX-11 was one-fourth of that of GEX-12, the number of observations was almost same (180 observations).

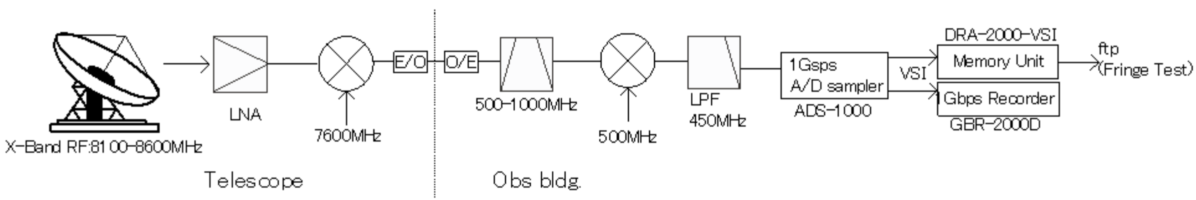


Figure 1. Schematic diagram of the down converter and recording system for the Giga-bit geodetic VLBI.

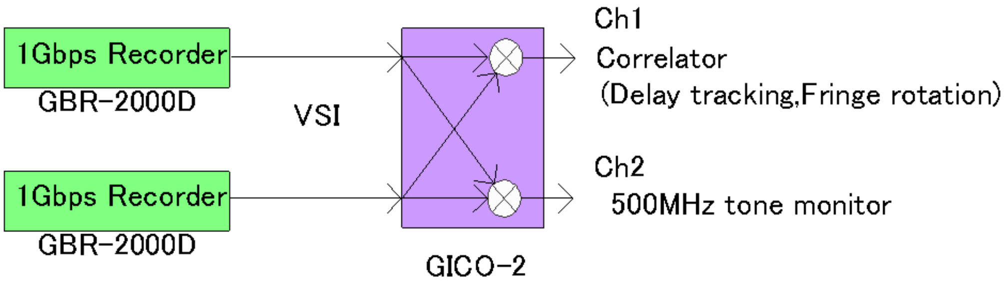


Figure 2. Correlator configuration of the Giga-bit VLBI system

Table 1. Results of the Experiments

	GEX-11 (6 hours)	GEX-12 (24 hours)	GEX-12 + K-4 (S-band)	K-4 System
Observation Band	X band	X band	S,X band	S,X band
Number of Baselines	1	1	1	15
RMS Delay Residual [ps]	81	138	89	120
Baseline Length [mm]	749810998.9±5.0	749811039.6± ± 8.8	749810980.44± ± 7.3	749810979.86 ± 4.4
Baseline Vector [mm]	x:−3680586331.0 ± 10.1 y: 2917515834.5 ± 8.5 z: 4300987705.3 ± 10.7	x:−3680586312.2 ± 18.9 y: 2917515785.0 ± 16.1 z: 4300987716.8 ± 19.7	x: −3680586346.2 ± 17.3 y: 2917515802.98 ± 15.1 z: 4300987669.9 ± 16.2	x: −3680586342.0 ± 9.3 y: 2917515815.1 ± 7.7 z: 4300987680.4 ± 9.9

3. Giga-bit VLBI System

The Giga-bit VLBI system used in these experiments consists of four components. A schematic diagram of the system is shown in Figure 1. The A/D sampler ADS-1000 has a capability to output 2-Gbps (1Gsps/2bit) VSI-H data. In the experiments, we used only the MSB data from ADS-1000. The 1-Gbps recorder GBR-2000D records VSI-H data from ADS-1000. The memory unit DRA-2000-VSI is used for fringe tests in the experiments. DRA-2000-VSI has a function to freeze sequential 1-second data from the continuous data stream and one can get the data as a file from the built-in FTP sever. The Giga-bit correlator GICO-2 is used for correlation process. GICO-2 has two correlation ports. Figure 2 is a schematic diagram of the baseband conversion system. A 500-MHz local oscillator signal leaks to the base-band output signal of the mixer and a low pass filter is used at the subsequent to reduce the leak. Despite using the filter, we can use the leaked 500-MHz CW to monitor a phase stability of the AD system. At the one of the GICO-2 correlator cores, a delay tracking and a fringe rotation are applied to obtain the astronomical fringes and at the other core, signals from two stations are simply multiplied to monitor phase variations of 500-MHz signal.

4. Results

The results of the experiments are listed in Table 1. They were calculated with Calc/Solve developed by NASA GSFC. Although the total observation time of GEX-11 was one-fourth compared with GEX-12, the obtained results are better than that of GEX-12. The advantage of the schedule optimization for the Giga-bit system can be confirmed from the result. To correct the ionospheric propagation delay for GEX-12, we used S-band data obtained by the K-4 system (The third row in Table 1). The result is very consistent with a multi-baseline result of the K-4 system (The fourth row in Table 1). In Figure 3, phase fluctuations of 500-MHz tone signal are shown. During the experiment GEX-12, a steep phase change occurred about 20:00 UT. We suspect that it is due to the change of the ambient temperature around AD. An accurate temperature regulation is required for the Giga-bit VLBI system.

5. Future Plans

At the present, only an X-band signal is recorded by the Giga-bit VLBI system. To establish a self-contained geodetic system by the Giga-bit equipments, we are developing a dual-band baseband conversion system for the Giga-bit geodetic VLBI.

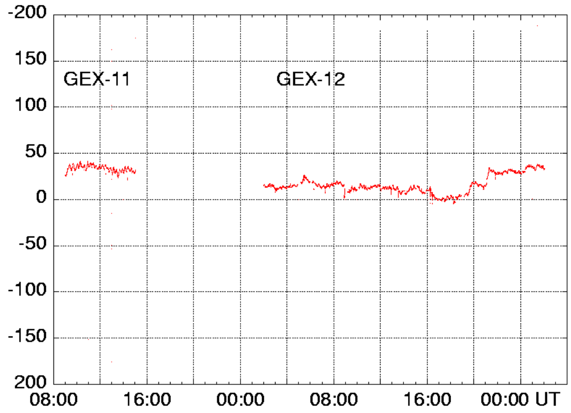


Figure 3. Phase fluctuations during the experiments. A steep phase change occurred about 20:00 UT during the experiment GEX-12.

In the system, both S-band and X-band signals are combined at down converter and recorded by a single channel 1Gsps A/D sampler. To achieve efficient geodetic observations, we are developing a 2Gsps A/D sampler and planning its future upgrade to 4Gsps. The lineup of the Giga-bit A/D samplers is listed in Table 2.

Table 2. Lineup of Giga-bit A/D samplers

ADS-1000	Up to 1Gsps/2bit sampling. Recorded with a Giga-bit recorder. Using a PC-VSI board, a 1Gbps recording to HDD is also available.
ADS-2000	Multi-channel sampler (16ch), 64Mbps/ch, 1-bit or 2-bits sampling.
ADS-4000 (developing)	Up to 2Gsps/2bit sampling.

References

Nakajima, J., Current Status of the Gigabit VLBI Recorder System, CRL IVS TDC news No. 9, pp. 17-18, 1996.

Koyama, Y., Kondo, T., Nakajima, J., Sekido, M., Ichikawa, R., Kawai, E., Okubo, H., Osaki, H., Takaba, H., Yoshida, M., and Wakamatsu, K., Geodetic VLBI Observations Using the Giga-bit VLBI system, CRL IVS TDC news No. 16, pp.11-14, 2000.

Yonezawa, I., Nakajima, J., Ohkubo, H., Tsuboi, M., and Kasuga, T., Development of compact VLBI system, CRL IVS TDC news No.21, pp.29-30, 2002.

Evaluation of the K5 system in geodetic VLBI experiments

Yasuhiro Koyama[1] (*koyama@crl.go.jp*), **Tetsuro Kondo**[1], **Hiro Osaki**[1], **Kazuhiro Takashima**[2], **Kazuo Sorai**[3], **Hiroshi Takaba**[4], **and Kenta Fujisawa**[5]

[1] *Kashima Space Research Center Communications Research Laboratory 893-1 Hirai, Kashima, Ibaraki 314-8501, Japan*
[2] *Geographical Survey Institute*
[3] *Hokkaido University*
[4] *Gifu University*
[5] *Yamaguchi University*

1. Introduction

After the prototype models of the K5 VLBI system were developed, the systems are beginning to be used for various VLBI observations such as the precise orbit determination of the spacecrafts Nozomi and Geotail [Kondo, et al., 2002; Ichikawa, et al., 2003; Sekido, et al., 2003] and the demonstration of international e-VLBI observations through close cooperations with Haystack Observatory [Koyama, et al., 2003]. Therefore, it is very important to ensure that there is no problem with the performance of the K5 VLBI system by comparing the results from the K5 VLBI system with the results from the conventional VLBI systems such as the K4 VLBI system. For this purpose, two geodetic VLBI sessions were carried out to evaluate the performance and functions of the K5 VLBI system. The first session was performed for about 24 hours from January 31, 2003 by using Kashima34-Koganei baseline. The second experiment was performed for about 24 hours from July 14, 2003 by using five VLBI stations at Kashima (34m), Tsukuba (32m), Tomakomai (11m), Gifu (11m), and Yamaguchi (32m). The details and results of these experiments will be reported in this paper.

2. K5 VLBI system

The K5 VLBI system is designed to perform real-time or near-real-time VLBI observations and correlation processing using Internet Protocol over commonly used shared network lines. Various components are being developed to realize the target goal in various sampling modes and speeds. The entire system will cover various combination of sampling rates, number of channels, and number of sampling bits by selecting subset of the available systems shown in Figure 1. For observations with low data sampling rates, the output signal of the base-band converters are sampled with the IP-VLBI board and the sampled data are directly processed with the PC system to which the IP-VLBI board is installed.

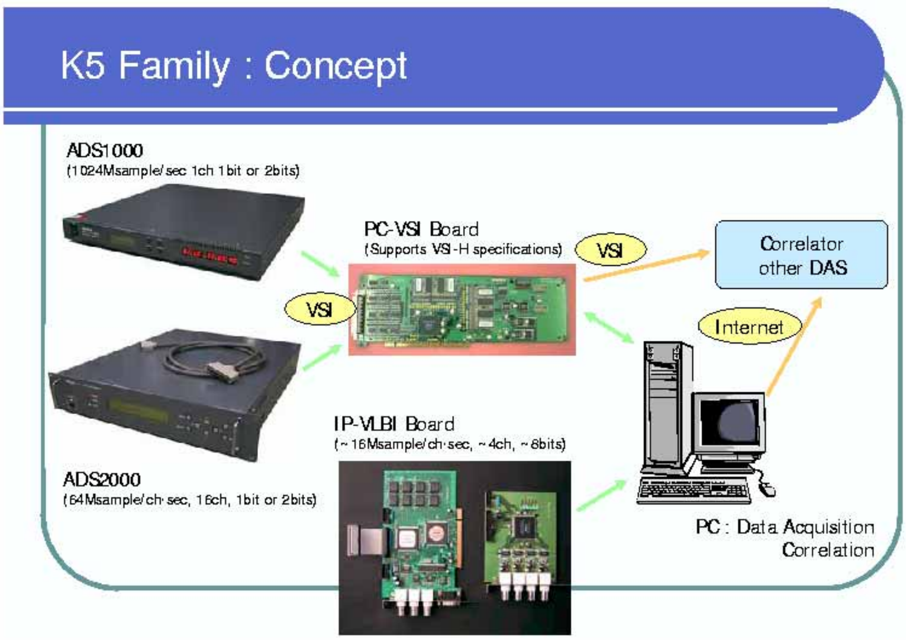


Figure 1. Concept of the entire K5 System.

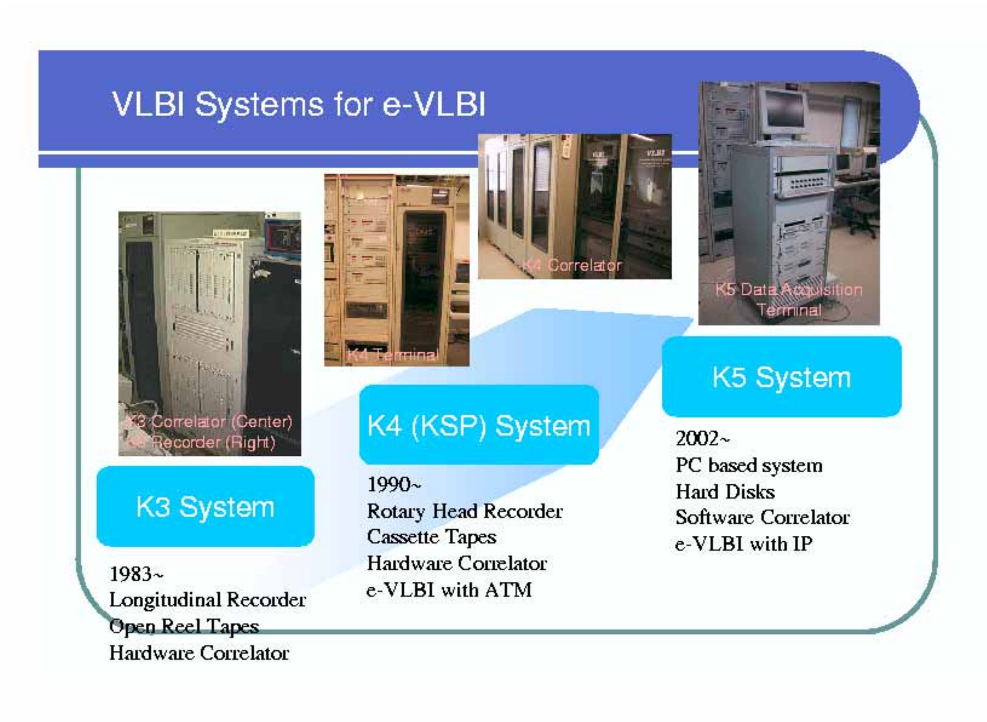


Figure 2. Developments of K3, K4 and K5 VLBI systems.

All the conventional geodetic VLBI modes of total data rate up to 512 Mbps with 16 channels are covered with this configuration. For a single wide frequency band (512 MHz) observations, ADS1000 data sampler unit is used as an A/D sampler and the sampled digital data are transferred to the PC system through VSI-H (VLBI Standard Interface - Hardware) interface with the PC-VSI board. ADS2000 data sampler unit is used for 16 channel observations with the total data rate of 1024 Mbps with 1 bit sampling mode or 2048 Mbps with 2 bits sampling mode. The sampled digital data from ADS2000 are also transferred to the PC system through VSI-H interface with the PC-VSI board. The same PC-VSI board will support data output function from the PC systems. Both IP-VLBI board and PC-VSI board is installed in the PCI (Peripheral Component Interconnect) bus of the PC systems.

As shown in the Figure 1, the K5 system is characterized by the use of conventional PC systems and the shared network based on IP (Internet Protocol). The data correlation can be performed by hardware correlators which support VSI-H specifications, but the target will be to perform correlation processing by the PC systems using software correlator programs. Similarly, the K4 system can be characterized by the use of rotary-head, cassette type magnetic tape recorders and the dedicated network based on ATM (Asynchronous Transfer Mode). Similarly, the K3 system can be characterized by the use of open-reel magnetic tape recorders (Figure 2).

The name of the K5 system is frequently used for the Versatile Scientific Sampling Processor (VSSP) system which is designed for geodetic VLBI sessions. Figure 3 shows the picture of the prototype system of the VSSP. It is consist of four UNIX PC systems. Each UNIX PC system has one IP-VLBI data sampling board, or also called as a VSSP board, on its PCI interfacing bus. Table 1 lists the specifications of the board. The board can sample 4 channels of base-band signals at various sampling rates ranging from 40kHz to 16MHz. The timing of the sampling is controlled by the provided 10MHz and 1-PPS reference signals so that precise timing information can be reproduced from the sampled data. Quantization bits can be set from 1, 2, 4, and 8. Because the board has these many sampling modes, it has many possibilities to be used not only for VLBI observations but also for various other scientific researches which require precise timing information in the data. Device driver software of the board has been developed on LINUX, FreeBSD, and Windows2000 operating systems, and FreeBSD is used in the prototype K5 data acquisition terminals. Two prototype K5 data acquisition systems have been configured. Four PC systems are mounted in the lower part of the 19-inch standard rack. A signal distributor unit for 1-PPS and 10 MHz signals and 16-channel base-band signal variable amplifier unit are mounted in the upper part of the rack. The monitor and the keyboard on the top of the rack are connected to the four PC systems by using a four-way switch. Each PC system is equipped with four removable hard disk drives of the data capacity of 120 GBytes each. The sampled data can be transferred to the network by using TCP/IP protocol or can be recorded to internal hard disks as ordinary data files. The maximum recording speed is currently restricted by the speed of the CPU and the speed of the PCI internal bus. Currently, the total recording speed of 512 Mbps has been achieved. It can be expected to record data up to 1024 Mbps by using faster PCI bus and faster CPU in near future. To process the data sampled with the K5 data acquisition system, software correlation processing program is also under development on FreeBSD and Linux PC systems. The correlation processing program receives data from K5 data acquisition systems over the network using TCP/IP protocol and then calculates cross correlation functions in real-time. It can also read data files on internal hard disks. These capabilities allow to transfer observed data in real-time if the connecting network is fast enough, or in near real-time if data buffering is required. Since easily re-writable software programs and general PC systems are used, the processing capacity and the function of the correlator can be easily expanded and upgraded.

Table 1. Specifications of the IP-VLBI (VSSP) board.

Reference Signals	10 MHz (+10 dBm) and 1-PPS
Number of Input Ch.	1 or 4
A/D bits	1, 2, 4, or 8
Sampling Freq.	40 kHz, 100 kHz, 200 kHz, 500 kHz, 1 MHz, 2 MHz, 4 MHz, 8 MHz, or 16 MHz
Bus Interface	PCI
Operating System	FreeBSD, LINUX, or Windows2000

3. Experiments

After completing two prototype K5 VLBI data acquisition terminals, 24 hours of geodetic e-VLBI experiment was performed using two 11-m antennas at Kashima and Koganei from January 31 to February 1, 2003. Eight channels were assigned to both X-band and S-band and the total data rate was 64 Mbps. Observed data were stored in the internal hard disks as the data files. The data files were read by the software correlation program and the cross correlation processing was performed after all the observations finished. Then the bandwidth synthesis processing was performed and the obtained data were analyzed by CALC and SOLVE software developed by Goddard Space Flight Center of National Aeronautics and Space Administration. During the observations, tape-based K4 data acquisition systems were used at both sites in parallel to compare the results. The data obtained with the K4 systems were processed with the K4 correlator at Kashima and analyzed similarly with the data obtained with the K5 systems. The results are compared in Figure 4 and Table 2.

Figure 3. Picture of the prototype K5 VLBI system (VSSP) configured with IP-VLBI boards.

Table 2. Comparison of baseline lengths estimated from the data obtained with K4 and K5 systems.

	No. of valid data	Baseline Length (mm)	RMS Residual Delay (psec)	RMS Residual Rate (fsec/sec)
K4	112	109099657.0 ± 6.7	76	136
K5	159	109099641.2 ± 3.2	33	92

Figure 4 shows the difference in group delay and delay rate obtained by the K4 VLBI system and the K5 VLBI system. The constant offset of the group delay can be absorbed as a part of the clock difference estimated through the data analysis processing and therefore it does not cause any problem in the data analysis. The RMS of the difference is calculated as 72.7 psec for delay rate and 118 fsec/sec for delay rate, and it can be concluded that the K4 and K5 systems are consistent with each other. Table 2 shows the estimated results from the data analysis. From these comparisons, it can be concluded that the estimated baseline lengths are consistent with each other within two time the estimated uncertainties. In addition, the comparison of the RMS residuals of delay and delay rates suggests the performance of the K5 systems is better than the K4 systems. The part of the reason of the improvement can be considered that the phase calculation of the phase calibration signals by the software correlation processing uses precise formula whereas the K4 hardware correlator uses a three level approximation for sine and cosine functions for faster processing and to make the design of the hardware correlator very simple.

Then the opportunity of a domestic regular geodetic VLBI experiment performed by Geographical Survey Institute (GSI) was used for the evaluation of the K5 VLBI system. The experiment JD0306 was performed for 24 hours from July 16, 2003. As a regular domestic experiment, four VLBI stations operated by GSI at Tsukuba (32-m), Shintotsukawa (3.8-m), Chichijima (10-m), Aira (10-m) participated with the K4 VLBI systems. At Tsukuba station, K5 VLBI system was used in addition to the K4 VLBI system. By using the same observing schedule, Kashima (11-m), Tomakomai (11-m), Gifu (11-m) participated in the experiment by using K4 VLBI system and K5 VLBI system in tandem. In addition, at Yamaguchi (32-m) station, K5 VLBI system with two PC units were used to perform observations only in X-band with 8 channels. At three stations (Kashima, Tomakomai, and Tsukuba), K5 prototype models shown in Figure 3 were used while PC systems configured with IP-VLBI boards were used at Gifu and Yamaguchi stations. Table 3 shows the comparison between results obtained from K4 VLBI system and K5 VLBI system for six baselines. Since the K5 VLBI system at Kashima and Gifu stations stopped recording for about six hours and 12 hours respectively during the observations, the number of valid data for baselines including Kashima and Gifu stations are fewer than the data from the K4 VLBI system. The comparison suggests that the estimated error obtained from both systems are comparable

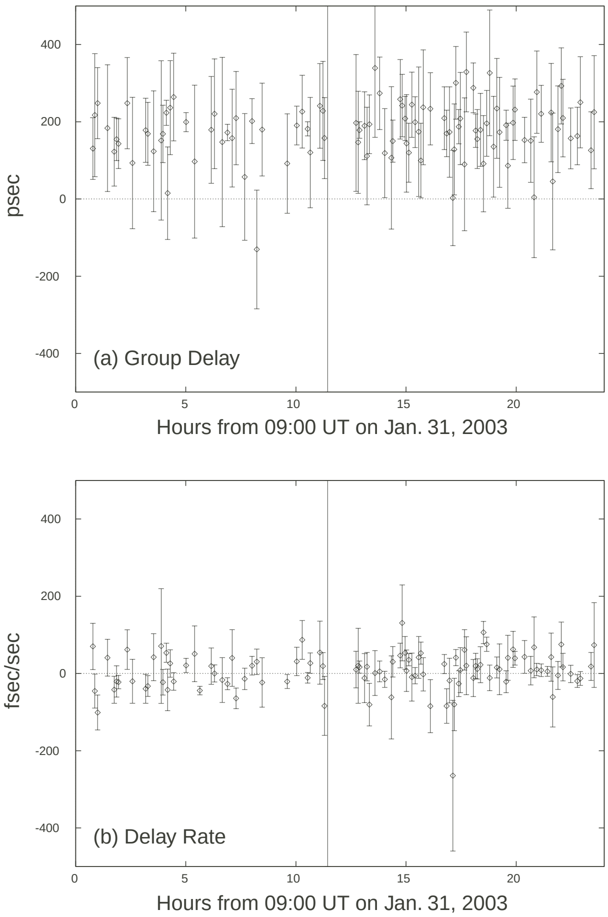


Figure 4. Difference of (a) group delay and (b) delay rate obtained from K4 and K5 systems. Horizontal axis is the time of the scan in hours from the beginning of the session while the vertical axis is the difference of group delay and delay rate. The error bars are one-sigma errors evaluated from $(s_K 4^2 + s_K 5^2)^{1/2}$ *where* $s_K 4^2$ *and* $s_K 5^2$ *are standard deviations of the data estimated from K4 and K5 systems, respectively.*

considering the number of available data and the estimated baseline lengths are consistent with each other considering the estimated error.

In Table 4, preliminary results of estimated coordinates of the Yamaguchi 32-m station based on the ITRF97 reference frame are presented. In the data analysis, site coordinates of the Tsukuba 32-m station was used as the reference and the X-band group delay data between Tsukuba-Yamagichi baseline were used. Since ionospheric correction can not be performed because only X-band data were taken at Yamaguchi station, it have to be noted that there might be a systematic error in the estimated coordinates.

Table 3. Comparison of baseline lengths estimated from the data obtained with K4 and K5 systems.

Baseline	System	No. of valid data	Baseline Length (mm)	RMS Residual Delay (psec)	RMS Residual Rate (fsec/sec)
Tsukuba-Kashima	K4	176	53811894.9 ± 2.1	53	158
	K5	130	53811891.6 ± 3.1	81	121
Tsukuba-Gifu	K4	184	311067474.0 ± 2.9	98	189
	K5	55	311067483.3 ± 4.0	58	136
Tsukuba-Tomakomai	K4	124	740526116.3 ± 4.4	103	165
	K5	169	740526119.4 ± 5.1	103	146
Kashima-Gifu	K4	174	358799168.6 ± 2.8	72	191
	K5	48	358799174.7 ± 4.5	92	144
Kashima-Tomakomai	K4	171	749810979.9 ± 4.4	115	125
	K5	108	749810985.5 ± 5.5	106	143
Gifu -Tomakomai	K4	154	902668931.2 ± 4.8	135	125
	K5	49	902668930.6 ± 6.1	116	138

Table 4. Estimated coordinates of the Yamaguchi 32-m VLBI station.

X :	-3502544258.3 ± 22.1
Y :	3950966396.9 ± 25.8
Z :	3566381164.9 ± 22.0

4. Conclusions

The results from two geodetic VLBI experiments between K4 and K5 VLBI systems were compared to ensure that the K5 VLBI system has expected capability and performance similar or better than the K4 VLBI system. The results from two different systems are consistent with each other considering the estimated error. From these comparisons, it can be concluded that there is no problem in using the K5 VLBI system for precise VLBI observations.

Acknowledgment: The authors would like to express sincere appreciation to many members of Geographical Survey Institute, Hokkaido University, Gifu University, Yamaguchi University, and Communications Research Laboratory for supporting observations of the VLBI experiments described in this report. We also would like to thank Geographical Survey Institute for allowing us the other stations to participate in the JD0306 session.

References

Osaki, H., Advancement of Versatile Scientific Sampling Processor (VSSP), IVS CRL TDC News, No. 21, pp. 16-17, 2002.

Kondo, T., R. Ichikawa, Y. Koyama, M. Sekido, and H. Osaki, VLBI ovservations using IP-VLBI system for orbit determination of deep space spacecraft - Group delay measurements of GEOTAIL and NOZOMI telemetry signals -, IVS CRL TDC News, No. 21, pp. 18-21, 2002.

Sekido, M., R. Ichikawa, H. Osaki, T. Kondo, and Y. Koyama, VLBI application for spacecraft navigation (NOZOMI) Part II, -Delay model and analysis-, IVS CRL TDC News, No. 22, pp. 12-15, 2002.

Ichikawa, R., M. Sekido, H. Osaki, Y. Koyama, T. Kondo, and NOZOMI VLBI group, VLBI application for spacecraft navigation (NOZOMI) Part I, -Overview-, IVS CRL TDC News, No. 22, pp. 10-11, 2002.

Koyama, Y., T. Kondo, H. Osaki, A. Whitney, and K. Dudevoir, Rapid turn arround EOP measurements by VLBI over the Internet, Proceedings of the IAG G02 Symposium in the 23rd. IUGG General Assembly, Sapporo Japan, July 2003 (*submitted*).

An evaluation of VLBI observations for the positioning of the NOZOMI Spacecraft and the future direction in research and development of the deep space tracking using VLBI

Ichikawa, R.[1] (*richi@crl.go.jp*), **Sekido M.**[1], **Osaki H.**[1], **Koyama Y.**[1], **Kondo T.**[1], **Ohnishi T.**[2], **Yoshikawa M.**[3], **and NOZOMI DVLBI group**

[1] *Kashima Space Research Center*
Communications Research Laboratory
893-1 Hirai, Kashima, Ibaraki 314-8501, Japan
[2] *Fujitsu Limted*
1-9-3 Nakase, Mihama-ku, Chiba 261-8588, Japan
[3] *Japan Aerospace Exploration Agency*
Institute of Space and Astronautical Science
3-1-1 Yoshinodai, Sagamihara, Kanagawa 229-8510, Japan

1. Introduction

We preliminary reported the results of the VLBI experiments for the NOZOMI spacecraft navigation before the second earth swingby on June 19, 2003 [see Ichikawa et al., 2003[1] and Sekido et al., 2003[2] in detail]. NOZOMI is the Japan's first Mars probe. In these experiments, we successfully detected group delay fringes of NOZOMI range signal for several baselines using a software correlation procedure. We provided 15 VLBI group delay data sets to the Institute of Space and Astronautical Science (ISAS). In this short report we describe the results of the experiments and future plans.

2. NOZOMI VLBI experiments

The final products obtained from the VLBI experiments were available with approximately 20 hours latency as shown in Figure 1. The several tens of gigabytes data sets were acquired at each station on the K5 system within 3-5 hours VLBI experiment. After the completion of each VLBI experiment, the data sets at Usuda, Gifu, and Koganei were transferred to the Kashima using a high-speed optical fiber network on TCP/IP protocol in under 3 hours. Correlation processing was completed at Kashima about 10-15 hours later. The estimation of clock parameter based on the quasar group delays was completed at Kashima 1 hours later. On the other hand, the removable data hard disks at other stations (Tomakomai, Tsukuba, Yamaguchi, and Algonquin) were mailed to Kashima. Thus, the latency to product the group delays using these satation data were up to several days.

The obtained group delays were compared with the NOZOMI orbit using range and range rate (R&RR) observables. Preliminary results demonstrate that the VLBI delay residuals are consistent with R&RR observables. However, the rms scatter between them are relatively large up to several tens nanoseconds as shown in Figure 2. The unresolved trend for the Kashima (CRL) - Tsukuba (GSI) baseline are also represented. One candidate

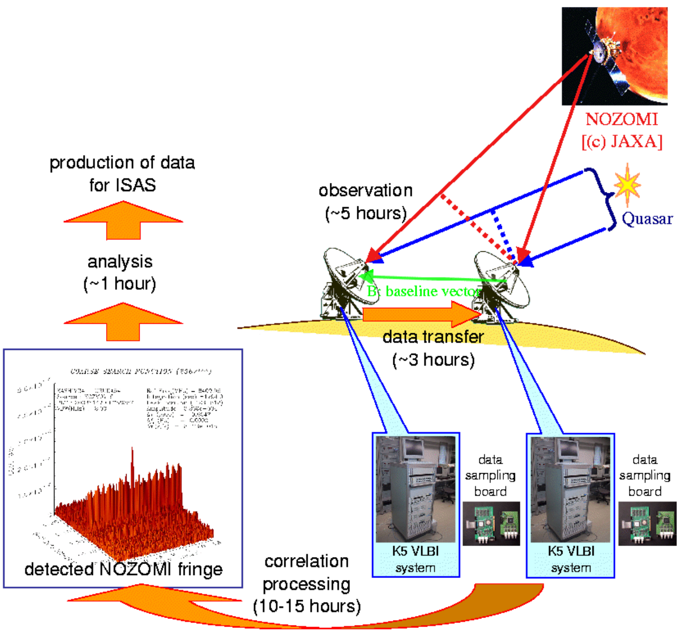


Figure 1. Schematic image showing NOZOMI VLBI data flow and analysis.

possibility of the trend is uncertainty of the a priori delay value predicted by the VLBI model. We are now evaluating our VLBI group delays by comparing with the R&RR results more deeply.

According to the ISAS announcement the NOZOMI completed its final Earth swingby operation on June 19 2003, and is on its way to Mars. NOZOMI passed within 11,000 km of the Earth in a manuever. NOZOMI's arrival at Mars is scheduled in the middle of December 2003.

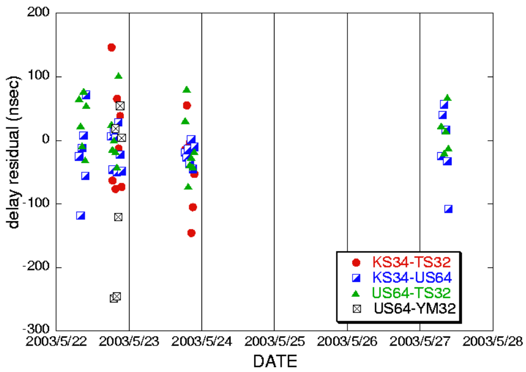


Figure 2. Residual delays between determined position using R&RR data by ISAS and VLBI group delay observables

3. Preparation of HAYABUSA VLBI experiments

Our main concern is to establish the differential VLBI positioning technique for the interplanetary spacecrafts in realtime. However, NOZOMI VLBI experiments are insufficient to develop the technique due to some problems such as signal weakness, narrow band width and so on. Thus, we are now preparing to perform another VLBI experiments. The one of the candidate targets is HAYABUSA, which was developed to investigate asteroids (see Figure 3).

HAYABUSA was launched on May 9 2003, and has been flying steadily towards an asteroid named "Itokawa," after the late Dr. Hideo Itokawa, the father of Japan's space development program. HAYABUSA is traveling through space using an ion engine. It will orbit the asteroid, land on it, and bring back a sample from its surface[3].

First, we evaluated the signal intensities of the candidate quasars to perform the differential VLBI experiments. We selected 24 quasars from the ICRF catalog considering the HAYABUSA trajectory during September 1 to December 31, 2003. The separation angles between the HAYABUSA and the quasars are less than 10 degrees at each

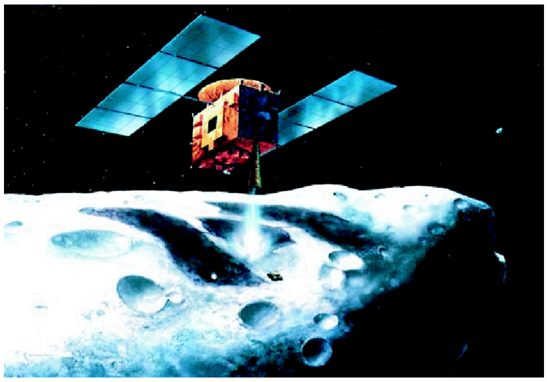


Figure 3. HAYABUSA Image (after JAXA/ISAS)

epoch. A source geometry of the HAYABUSA spacecraft and nearby quasars are illustrated in Figure 4. The signal to noise ratios of the detected quasar fringes are shown in Table 1. We are now planning to perform a first HAYABUSA VLBI experiment based on the signal intensity result.

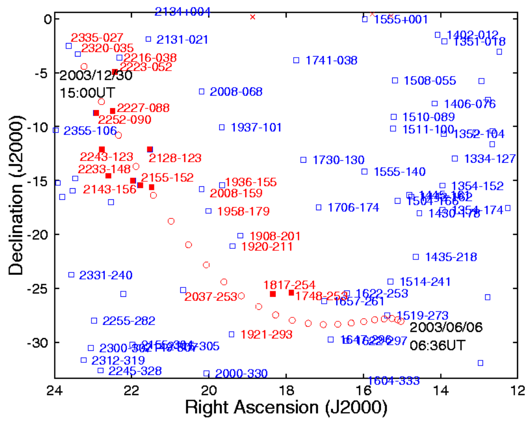


Figure 4. Trajectory of the HAYABUSA spacecraft (circles) and nearby radio sources (solid squares) from September 1 to December 31 2003.

4. Planed Activities

We have to carry out additional works to achieve our final goal as follows:

- Development of the analysis software for the spacecrafts positioning using phase delay observables
- Improvement of the finite distance VLBI model to expand its capability in a positioning of the low earth orbit satellites

Table 1. Signal to noise ratio of the detected quasar fringes nearby HAYABUSA spacecraft during Sep. 1 to Dec. 31, 2003. 3C454.3 and 3C84 are reference sources to check the quasar fringe.

source name	integ. time (sec.)	CH1	CH2	CH3	CH4
3C454.3(Ref.)	60	18.6	19	21.2	21.3
1748-253	600	8.9	8.8	8.6	8.2
1817-254	600	8.4	8.7	8.6	8
1908-201	600	14.9	16	10.3	12.3
1921-293	600	57	59.2	53.7	57.3
1920-211	600	19.9	13.6	13.8	12.3
1936-155	600	7.7	8	9.2	8.5
1958-179	600	16.4	19.5	16.4	15.3
2008-159	600	15	12.8	13.9	15.3
2037-253	600	8.5	8.4	8.4	8.3
2126-158	600	8.8	9.9	8.5	9.5
2128-123	600	27	28.6	26.4	25.7
2143-156	600	8.7	8.4	7.7	8.5
2155-152	600	16.9	14.3	13.3	15.4
2229-172	600	9.8	8.4	8.9	8.7
2216-038	600	20.4	21.6	22	22.5
2223-052	600	29.3	28.8	27.4	31
2227-088	600	20.9	19.3	19.2	21.7
2233-148	600	10	8.2	7.8	7.9
2243-123	600	12.9	14.7	14	12.9
2252-090	600	8.3	7.9	8.5	8.7
2254+024	600	9.1	8.2	8.3	8
2318+049	600	10.8	9.6	8.9	9.4
2320-035	600	10.7	8.3	8.6	8.7
2335-027	600	8.3	9.4	8	8.2
3C84(Ref.)	60	37.1	35.7	29	32.8

- Improvement of processing speed and efficiency for the VLBI data correlation using multiprocessor and high speed network
- Development of the differential VLBI software package such as the antenna tracking for the spacecraft, the automatic scheduling of the VLBI observation, the propagation delay estimation, and so on
- Validation of the NOZOMI VLBI experiments by comparing with R&RR data obtained by ISAS.

References

[1] Ichikawa et al., VLBI Application for Spacecraft Navigation (NOZOMI) Part I –Overview–, TDC News, No.22, pp 10-11, 2003.

[2] Sekido et al., VLBI Application for Spacecraft Navigation (NOZOMI) Part II –Delay Model and Analysis–, TDC News, No.22, pp 12-15, 2003.

[3] JAXA web site, http://www.muses-c.isas.jaxa.jp/English/index.html, 2003.

VLBI Application for Spacecraft Navigation (NOZOMI) – follow-up on Model and Analysis –

M. Sekido[1] (*sekido@crl.go.jp*), **R. Ichikawa**[1], **H. Osaki**[1], **T. Kondo**[1], **Y. Koyama**[1], **M. Yoshikawa**[2], **and NOZOMI VLBI Observation Group**[3]

[1] *Kashima Space Research Center*
Communications Research Laboratory
893-1 Hirai, Kashima, Ibaraki 314-8501, Japan
[2] *Institute of Space and Astronautical Science*
Japan Aerospace Exploration Agency
3-1-1 Yoshinodai, Sagamihara,
Kanagawa 229-8510, Japan
[3] *JAXA, CRL, NAO, GSI, Gifu Univ.,*
Yamaguchi Univ., Hokkaido Univ.,
and CRESTech/SGL

1. Introduction

Establishment of VLBI application technique for spacecraft navigation is one of our target of current projects, as we reported in previous issue of IVS CRL-TDC news [*Ichikawa et al.*, 2003; *Sekido et al.*, 2003]. We are going to briefly introduce current problems to be solved.

2. Delay Observable

For the VLBI experiments of spacecraft NOZOMI, several Japanese domestic VLBI stations and Algonquin observatory in Canada had joined in the observations. The modulated signal (range signal) transmitted from NOZOMI spacecraft has not so wide bandwidth inherently. Consequently, the accuracy of its group delay observable is not so high, and long baseline observation is one of the ways to increase the angular resolution of the observation.

Longer baseline VLBI observation requires higher accuracy in a priori delay/rate predictions, since fringe rotates faster and deviation of source coordinates affects to delay/rate more greatly than shorter baselines. Actually stable detection of fringes on intercontinental baselines (Algonquin and Japanese domestic baselines) suffered from some difficulty as reported previously [*Sekido et al.*, 2003]. We will discuss more on this problem in the next section. One of the causes of the problem was deviation of predicted orbit from true one, although it is inevitable for spacecraft differently from normal astrometric VLBI. To enable stable fringe detection under large delay rate offset, we need to expand rate window by reducing the integration duration of each bin.

Even the bandwidth of radio signal from spacecraft is narrower than that of quasar, its phase delay observable can be measured with high resolu-

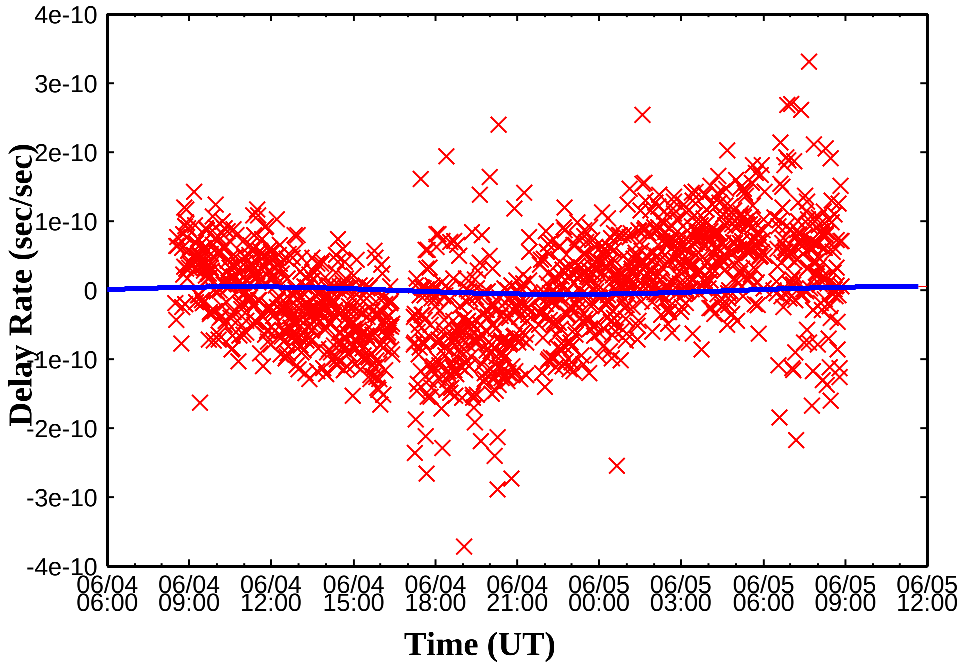


Figure 1. Difference of delay rates between observed by Doppler frequency measurements and theoretical calculation by CRL based on finite distance VLBI model (cross mark). The data is on Kashima - Algonquin (9000km) baseline on June 4 2003. Solid line indicates difference of delay rate between predictions of CRL and ISAS.

tion if we could resolve the ambiguity. It will provide a benefit to achieve high angular resolution even with combination of Japanese domestic VLBI stations. Domestic VLBI stations do not always have large diameter dishes, so signal to noise ratio (SNR) is not so high. To get higher SNR with weak line spectrum signal, frequency resolution has to be increased. The simplest way to increase frequency resolution is extending the time span in Fourier transformation, although it takes longer time for Fourier transformation to get higher resolution no more than one Hertz. In addition, The frequency received at observatory is drifting due to relative motion of the spacecraft and observer, and this effect cannot be eliminated at such high frequency resolution. For this purpose, we are developing a correlation software specific for line spectrum to measure fringe phase.

3. Delay rate comparison –CRL,ISAS, and Doppler measurements–

One of the caused of difference on delay rate between prediction model and observed delay rate, which is computed by Doppler frequency measurements, had come from deviation of prediction orbit of NOZOMI. The orbit data we used in the previous report (Figure 3 of *Sekido et al.* [2003]) was prediction orbit, which was propagated from determined orbit by range and range rate (R&RR) measurements in February 2003. So the prediction orbit at this time had larger error. Determined orbit by R&RR measurements in June was provided afterward. The geocentric angular distance between predicted and determined spacecraft coordinates differed by around twenty arc seconds. After using the determined trajectory of spacecraft, the discrepancy of delay rates between observed by Doppler measurements and the theoretical one has reduced to the half of that before (Figure 1). However the rate residual still remains about 1.e-10 sec/sec on 9000 km baseline.

ISAS also computed delay rate of VLBI observation based on numerical solution of light time equation for two legs from spacecraft to two observation stations. The difference of delay rate between ISAS and CRL is superimposed with solid line in Figure 1. These independent computations of delay rate coincide within the order of a few psec/sec. Since the theoretical computation of delay and delay rate are only for geometrical component, delay due to radio wave propagation medium will me remain as residual. Although, the difference of observed delay rate and theoretical one at order of 1.e-10 sec/sec is too large to be explained by propagation medium. It may suggest that determined orbit still might have error in order of several arc seconds.

References

Ichikawa R., Sekido M., Osaki H., Koyama Y., Kondo T., and NOZOMI VLBI group, 2003, "VLBI Application for Spacecraft Navigation (NOZOMI) Part I -Overview-", IVS CRL-TDC News, No.22, pp.10-11.

Sekido M., Ichikawa R., Osaki H., Kondo T., and Koyama Y., 2003, "VLBI Application for Spacecraft Navigation (NOZOMI) Part I -Delay Model and Analysis-" IVS CRL-TDC News, No.22, pp.12-15.

VLBI Observation by Receiving Narrow Bandwidth Signal from NOZOMI

Fuyuhiko Kikuchi (*fuyuhiko@miz.nao.ac.jp*), **Yusuke Kono, Ping Jinsong, Liu Qinghui, Kazuyoshi Asari, Koji Matsumoto, Seiitsu Tsuruta, Hideo Hanada, Nobuyuki Kawano, and NOZOMI VLBI group**

Earth Rotation Division,
National Astronomical Observatory of Japan (NAOJ)
2-12 Hoshigaoka, Mizusawa,
Iwate 023-0861, Japan

1. Introduction

An orbit of a spacecraft (s/c) is usually determined by using coherent 2-way range and range-rate (R&RR) measurements. The range observables are obtained by measuring the round trip light time between the s/c and the ground tracking station. On the other hand, the range-rate observables are obtained from measurements of the Doppler shift of the radio signal on coherent 2-way links by using an onboard transponder. In addition to R&RR, the VLBI (Very Long Baseline Interferometry) technique can be also used for positioning of the s/c. By measuring the difference of arriving time of same wave front of radio signal from the s/c at two separated antennas, VLBI can determine the angular position of the s/c in space. VLBI is sensitive to the direction perpendicular to line-of-sight (LOS) direction to the s/c from the tracking station in contrast to the R&RR. Combination of two kinds of observations can improve the accuracy of orbit determinations.

The VLBI technique has been adopted for the s/c positioning in the early stage of VLBI. JPL/NASA VLBI group used VLBI for tracking Apollo lunar missions and VEGA probes [1]. In Japan, VLBI method was used to track the geosynchronous satellite in the 1980 's. Recently, in order to improve this technique and to make it a common method for the s/c orbit determination, we observed the first Japanese Mars explorer "NOZOMI" by using a regional VLBI network and a new s/c VLBI tracking method. NOZOMI had two swing-bys by the earth in Dec. 2002 and June 2003 so as to be injected into a Mars orbit in 2004. During the period between these two swing-bys, the onboard high gain antenna could not point to the earth due to some operational problems. In this period, R&RR measurements cannot be obtained with sufficient SNR. To overcome this problem, the NOZOMI team of ISAS (Institute of Space and Astronautical Science) and the VLBI group of CRL (Communications Research Laboratory) collaborated to determine the NOZOMI orbit by using VLBI technique [2][3]. The s/c VLBI tracking group of NAOJ (National Astronomical Observatory of Japan) also took part in the observation from 13 to 27 in May 2003. The radio telescopes involved in this mission are listed in Table 1. In this paper, the results of the analysis by the method of correlating the NOZOMI carrier waves are shown.

Table 1. List of radio telescopes involved in the VLBI observation of NOZOMI.

Station	Antenna diameter (m)
USUDA	64
KASHIMA	34
MIZUSAWA	10
MIZUSAWA	20

Table 2. The narrow bandwidth VLBI sampling and recording system (S-RTP station).

Sampling rate:	200 kHz
Quantization:	6 bits
Number of channels:	4

2. Back-end system and correlation software

In radio astronomical and/or geodetic VLBI surveys, usually wide bandwidth signals (from several MHz to GHz) are recorded by fast sampling-rate systems, especially for obtaining the accurate group delay, which depends on signal bandwidth. In contrast with above systems, when applying the VLBI technique for the s/c orbit determination, it is not effective for the s/c to generate and emit such a wide bandwidth signal or for ground system to record and real-time process such a wide bandwidth signal. Usually, the s/c transmits narrow bandwidth downlink carrier wave and/or the modulated carrier wave. The group delay and delay rate should be obtained from the narrow bandwidth signals so as to get the instantaneous angle of the s/c and the angle variation in space. For this reason, we have developed a narrow bandwidth VLBI sampling and recording system, called S-RTP station, for the s/c VLBI tracking [4][5]. The detail performances of this system are listed in Table 2. This system has been used for NOZOMI observations.

The sampling rate of our system is very slow, therefore the amount of sampling data is small enough for correlation by a common used PC. For this system, correlation software has been also developed. The software is composed of modules of VLBI delay estimation and cross-correlation which includes the bit-shift and fringe- stopping. In a conventional correlator, delay is calculated on an assumption of plane wave coming from the radio sources. We modified the delay model of plane wave by spherical one for tracking of the s/c near from the earth [6]. The predicted propagation time from the s/c to the reference station is expressed by following equation.

$$\tau_{ref}(t) = \frac{|R_{sc}\left(t - \tau_{ref}(t)\right) - R_{ref}(t)|}{c} \quad (1)$$

where $R_{sc}(t)$ is the predicted position vector of the s/c every 1 minute which was distributed by ISAS, and $R_{ref}(t)$ represent the position vector of the reference station. t is the time based on the reference station, and c is the velocity of light. $\tau_{ref}(t)$ is obtained in iterative procedure as follows.

$$\tau^{i+1}_{ref}(t) = \frac{|R_{sc}\left(t - \tau^{i}_{ref}(t)\right) - R_{ref}(t)|}{c} \quad (2a)$$

$$\tau^{0}_{ref}(t) = \frac{|R_{sc}(t) - R_{ref}(t)|}{c} \quad (2b)$$

$\tau^{0}_{ref}(t)$ is an initial value of $\tau_{ref}(t)$. On the other hand, the propagation time from the s/c to the slave station is expressed by following equation.

$$\tau_{slv}(t) = \frac{|R_{sc}\left(t - \tau_{ref}(t)\right) - R_{slv}\left(t - \tau_{ref}(t) + \tau_{slv}(t)\right)|}{c} \quad (3)$$

where $R_{slv}(t)$ is the position vector of the slave station and $\tau_{ref}(t)$ is given from the Eq.(1). $\tau_{slv}(t)$ is obtained in iterative procedure as well as $\tau_{ref}(t)$. Finally the geometric delay between the reference and the slave station is obtained as follows.

$$\tau_g(t) = \tau_{slv}(t) - \tau_{ref}(t) \quad (4)$$

3. Signals of NOZOMI

Between two swing-by events, the downlink signal from NOZOMI was modulated for R&RR measurements. In ranging mode, downlink signal was consist of a carrier wave, two range tones, and some ambiguity tones. The carrier frequency $f_{carrier}$ of NOZOMI is 8411MHz. The range tone frequencies are $f_{carrier} \pm f_{carrier}/2^{12}$ ($f_{carrier}/2^{12}$ is about 515kHz). The ambiguity tones whose frequencies are $f_{carrier} \pm f_{carrier}/2^{n+12}$ (n =1,2$\cdots$) are added every 100 seconds for 60 seconds to solve the ambiguity of the range tones. In order to resolve the ambiguity of phase measurement by using group delay, the carrier wave and two range tones were separately recorded in 3 channels of S-RTP station. Moreover, to compensate the phase difference between channels of the video converter, the phase calibration signals at every 60kHz were mixed with the IF signals in front of the video converter. For calibrating the clock offset and clock rate between two VLBI stations, several QSOs with position precisely known were also observed before and after the tracking of NOZOMI. The signals were also recorded with IP-VLBI system at the same time [2][3]. Block diagram of narrow bandwidth receiving system is shown at Figure 1.

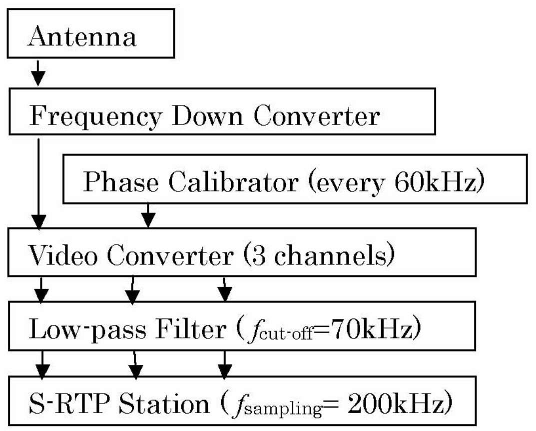


Figure 1. Block diagram of narrow bandwidth receiving system.

4. Results of Correlation

4.1 Estimation of Residual Fringe Phase

The correlation was done by software of FX mode. At first, the signals of the slave station were bit-shifted and fringe-stopped by using the delay predicted by Eq.(4). Then, the signals of the reference and the slave stations were cross-correlated during each parameter period (PP). In NOZOMI mission, a C/N of the signal recorded at the ground station was too low, so we use only ± 30Hz around the center frequency of the signals to increase the signal-to-noise ratio (SNR). The resulted residual fringe phases of the carrier waves and two range tones for USUDA64-KASHIMA34 baseline are shown in Figure 2. The residual fringe phases of carrier wave were obtained every 1.3 second PP, and SNR was 21. Its standard deviation was 10 degrees, which means that the position of NOZOMI can be determined with an accuracy of 30m assuming that the baseline is 200km and the distance between NOZOMI and ground station is 6×10^6 km. However, an ambiguity of $2n\pi$ (n is integer) is still included in the residual fringe phase. On the other hands, because the C/N of the range tones were less than carrier wave, we could obtain the residual fringe phase only for the USUDA64-KASHIMA34 baseline. Moreover, the transmission of NOZOMI was divided into 2 modes, A and B. In the mode A, the ambiguity tones were added to the range tones and decreased the C/N. So the residual fringe phases of range tones were not obtained for this period of 60 seconds (see A of Figure 2). On the contrary, the ambiguity tones were not added in the mode B and the residual fringe phases of range tones were obtained in this period of 40 seconds, and SNR is 13. Therefore the group delay analysis could only be done during the mode B.

4.2 Estimation of Group Delay

Before analyzing group delay, the effect of the separate band has to be removed from the residual

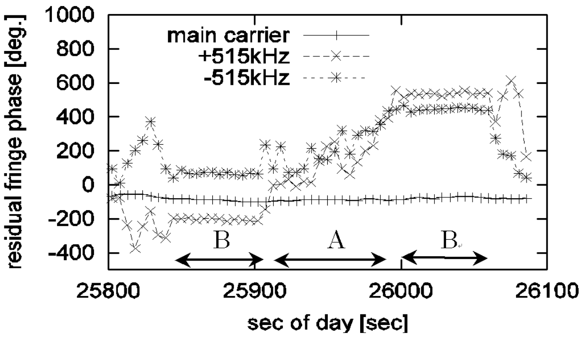


Figure 2. Residual fringe phases of the carrier wave and two range tones.

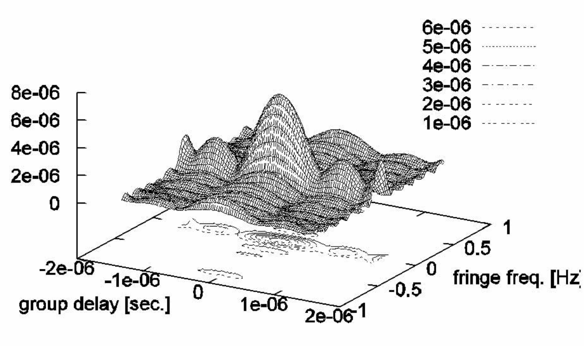


Figure 3. Detected fringe of NOZOMI.

fringe phase as following,

$$\Delta\phi'_i = \Delta\phi_i - \left(\phi^{ref}_{pcal,i} - \phi^{slv}_{pcal,i}\right) \quad (i = 1, 2, 3) \quad (5)$$

where $\Delta\phi_i$ is the residual fringe phase of ith channel and $\phi^{ref}_{pcal,i}$ and $\phi^{slv}_{pcal,i}$ are the phase of phase cals of the channel, respectively. The group delay of the signals are given by,

$$\Delta\tau_{group\ delay} = \frac{\Delta\phi'_{i+1} - \Delta\phi'_i}{2\pi(f_{i+1} - f_i)} \quad (6)$$

where f_i is the carrier frequency of ith channel. The result of group delay is shown in Figures 3 and 4. Its standard deviation was about 41 nsec. This error could be caused by the thermal noise of all the R&RR systems including the low-pass filter. The clock offset and clock rate were estimated from the observation of some QSOs by IP-VLBI through the conventional correlation. The estimated clock offset was 8.1×10^{-7} seconds and clock rate was -2.6×10^{-13} seconds/second. After the corrections of clock offset and clock rate, we compare the geometric delay obtained by above group delay analysis with the result of the VLBI group of CRL [2][3]. It was noticed that an average difference of delay was 58 nsec. This difference may result from the difference of video converter used at KASHIMA station and the different geometric delay models used by different groups.

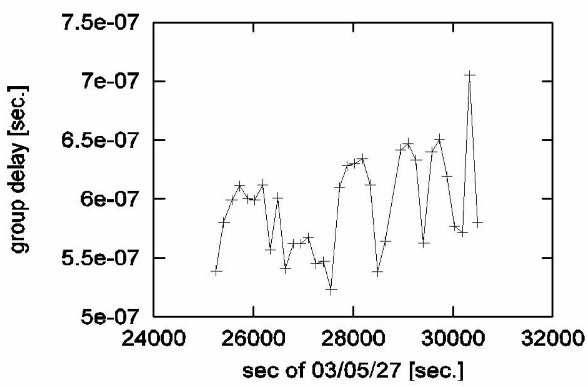


Figure 4. Group delays of NOZOMI signal.

The NOZOMI signal was too weak in this observation, however, it can be expected that the accuracy of the group delay would be improved to 9nsec when the SNR of received signal is 100.

5. Conclusion

The s/c VLBI tracking group of NAOJ participated in the VLBI observation of NOZOMI. In this mission we recorded three carrier wave signals by using narrow bandwidth sampling and recording system, and correlated these signals by using software method. The group delay was obtained every 100 seconds with standard deviation of 41 nsec. Due to the very low C/N, this result is not accurate enough for orbit determination of NOZOMI precisely, but we confirmed the validity of our new hardware and software VLBI systems. It is also confirmed that our new VLBI system has a capability of precise s/c tracking within the error of a few nsec when SNR is about 100.

References

[1]Sagdeyev, R.Z, et al., Differential VLBI measurement of the Venus atmosphere dynamics by balloons: VEGA project, A&A, 254, pp.387-392, 1992.

[2]Ichikawa, R., M. Sekido, H.Osaki, Y. Koyama, T. Kondo, and NOZOMI VLBI group, VLBI application for spacecraft navigation(NOZOMI) part -Overview-, TDC News No.22, pp10-11, 2003.

[3]Sekido, M., R. Ichikawa, H.Osaki, T.Kondo, and Y. Koyama, VLBI application for spacecraft navigation (NOZOMI) part –Delay Model and Analysis–, TDC News No.22, pp12-15, 2003.

[4]Kono, Y., H. Hanada, K. Iwadate, H. Araki, N. Kawano, Y. Koyama, and Y. Fukuzaki, The differential VLBI Observation of Lunar Prospector, IVS 2000 General Meeting Proceedings, pp346-349, 2000.

[5]Kono. Y., Precise three-dimensional positioning of spacecraft by multi-frequency VLBI and Doppler measurements, Dr. thesis, the Graduate University for Advanced Studies, 2002.

[6]Fukushima, T., Lunar VLBI observation model, A&A, 291, pp.320-323, 1994.

Orbit determination of spacecraft in deep space by Delta-VLBI technique: current situation and future

Makoto Yoshikawa[1] (*makoto@pub.isas.jaxa.jp*), **Takaji Kato**[1], **Tsutomu Ichikawa**[1], **Hiroshi Yamakawa**[1], **Jun'ichiro Kawaguchi**[1], **Yasuhiro Murata**[1], **Takafumi Ohnishi**[2], **Shiro Ishibashi**[2], **Shigeo Tsujimoto**[2], **Katsutoshi Kurosu**[2], **and NOZOMI Delta-VLBI group**[3]

[1] *Japan Aerospace Exploration Agency Institute of Space and Astronautical Science 3-1-1 Yoshinodai, Sagamihara, Kanagawa 229-8510, Japan*
[2] *Fujitsu Limted 1-9-3 Nakase, Mihama-ku, Chiba 261-8588, Japan*
[3] *JAXA, CRL, NAO, GSI, Gifu Univ., Yamaguchi Univ., Hokkaido Univ., and CRESTech/SGL*

1. Introduction

At present, we are operating two interplanetary spacecrafts. They are "NOZOMI", Mars explorer of Japan and "HAYABUSA", an asteroid sample return mission. In order to determine their orbits, we use a conventional method using range and range rate (RARR). In addition to this method, we have strong hope to use Delta-VLBI technique for the orbit determination.

The orbit determination by using Delta-VLBI technique is very promising, because the accuracy of the orbit determination will be much better and because we can plan more flexible missions. Moreover, NOZOMI has a serious trouble since April 2002, and we are under the situation that we have to establish a new method for orbit determination for NOZOMI. That is the method using Delta-VLBI technique.

In this paper, we show the results of Delta-VLBI observations for NOZOMI, and we mention about our future plans.

2. Delta-VLBI observation for NOZOMI

The Japanese Mars Explorer NOZOMI was launched in July 1998. In the original plan, it would have arrived at Mars in October 1999. The original orbit plan is shown in Fig.1. However, when the spacecraft left from the earth to Mars, there occurred a problem and the orbit plan was forced to change (Fig.2). In this new plan, NOZOMI will arrive at Mars at the beginning of 2004 after two earth swingbys. Anyway, at this schedule change, there was no problem for the orbit determination of NOZOMI, and we were going to determine its orbit by the conventional RARR method. (At present, NOZOMI is on the orbit that arrives at Mars at the middle of December 2003.)

Another problem occurred in July 1999. The S band down link was stopped. NOZOMI has S and X bands, so X band was used for down link since then. Therefore, this trouble was not so serious for the communication with NOZOMI, but from the point of the orbit determination, this trouble causes some problems. One of the problems is a small acceleration associated with the reorientation of NOZOMI. X band uses the high gain antenna, so we need rather frequent attitude maneuvers to point it to the earth. Acceleration occurs at each attitude maneuver, and it makes the orbit determination rather difficult.

There is another problem, which is much more difficult. We found that in some period between the

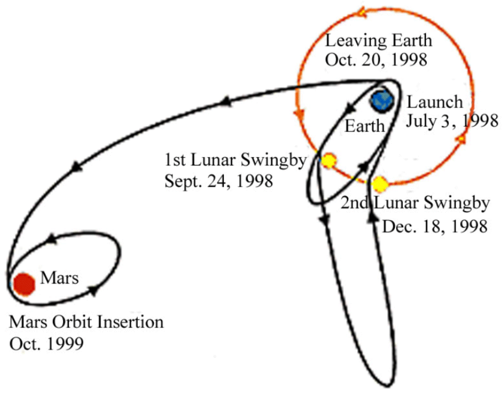


Figure 1. Original orbit plan of NOZOMI.

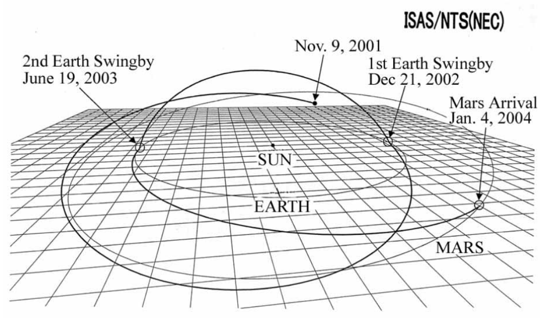


Figure 2. New orbit plan of NOZOMI.

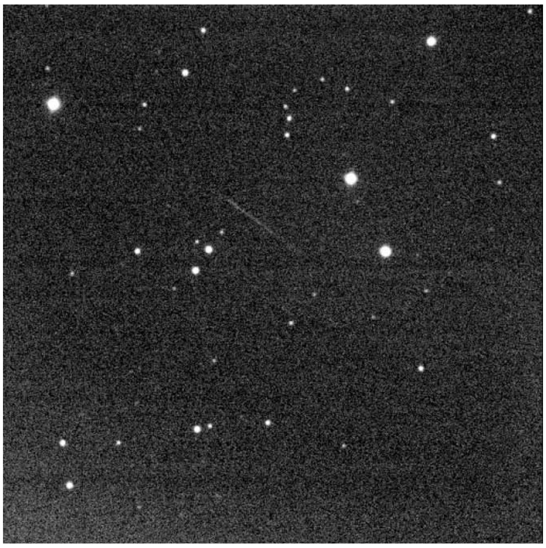


Figure 3. The trail of NOZOMI at the second earth swingby. This photograph was taken at June 19, 2003, 11:39:16 UTC by Mr. Akimasa Nakamura at Kuma Kogen Astronomical Observatory in Ehime prefecture in Japan. The trail of NOZOMI is seen faintly at the center. The field of view is 12 arc seconds, and the exposure time is 12 seconds. The magnitude of NOZOMI is about 15 or 16.

two earth swingbys it is difficult to get the range data, because we cannot make the attitude of NOZOMI to point its high gain antenna to the earth. This is one of the reasons why we started to consider the use of Delta-VLBI technique to the orbit determination of NOZOMI.

And then the most serious problem occurred in April 2002. By strong solar flare one of the power units was stopped, and we could not get the telemetry from NOZOMI. Moreover we could not control its attitude and orbit. After this trouble, many attempts were done and finally we were able to get some information from NOZOMI and to control the attitude and orbit by some special methods. But we could not put the attitude of NOZOMI at the desirable one to get range and Doppler data. So sometimes we could not get range and/or Doppler data, and this made the Delta-VLBI method much more important.

Under this very critical situation, the two earth swingbys (on 21 December 2002 and 19 June 2003) were carried out successfully. At the earth swingbys, we asked several observatories in Japan to observe NOZOMI. And at the second swingby, one of the observatories succeeded to take the image of NOZOMI. Fig.3 shows the trail of NOZOMI, which was taken at the predicted time and position (Fig.3).

We tried both RARR method and Delta-VLBI method for the orbit determination for these two swingbys. As the result, we managed to determine the orbit of NOZOMI by RARR method accurate enough to carry out these swingbys. Because of the constraint of the attitude control of NOZOMI, the tracking data was taken by using not main beam of the high gain antenna but its side lobe for the most time. Therefore the Doppler data was not normal and it has strange bias. We developed a special technique to use such unusual Doppler data for the orbit determination by RARR.

As for the Delta-VLBI, we did many observations. And we were able to derive the delay time by carrying out correlation analysis. However, the results have rather large scattering (about several 10 nsec) and systematic error as shown in Figs.4-7. These figures show the O-C of the delay time, where "O" is Delta-VLBI observation results which were analyzed by Communications Research Laboratory (CRL) and "C" is calculated values based on the orbit determination result by RARR method.

We tried to determine the orbit of NOZOMI by using these Delta-VLBI data, but the results were not good. We think the reason is the large scattering of the data. We will carry out further analyses to solve this problem.

3. Future plans

Although the attempt to carry out the orbit determination of NOZOMI by Delta-VLBI technique has not been successful yet, we would like to continue to try this method much further. Of course firstly we are going to analyze the data for NOZOMI further. In addition to NOZOMI, we have another spacecraft, that is HAYABUSA (Fig.8).

HAYABUSA, which is the spacecraft for the asteroid sample return mission of Japan, was launched on 9 May 2003, and it will arrive at an asteroid in 2005. It has a special engine called "ion engine". The thrust level of the ion engine is not large but it works continuously. Such low continuous thrust makes the orbit determination rather difficult. We would like to try Delta-VLBI technique for the orbit determination of HAYABUSA as well as the RARR method.

We have another plan related Delta-VLBI. In Japan, a new organization for space activity has started since October 2003. This organization is called Japan Aerospace Exploration Agency (JAXA). In JAXA, there is only one VLBI station, that is Usuda Deep Space Center. Up to now, Delta-VLBI observations for spacecraft have been carried out in collaboration with other organizations, such as CRL, NAO (National Astro-

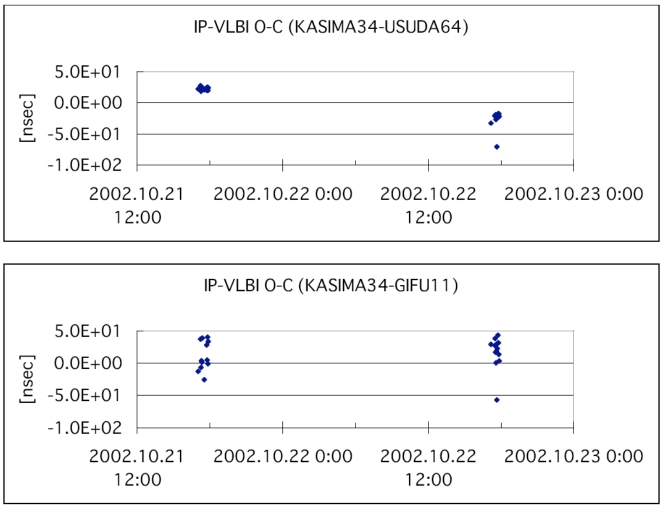


Figure 4. O-C of delay time taken by IP-VLBI system on Dec. 21-22, 2002. The baseline is Kashima-Usuda (above) and Kashima-Gifu (below).

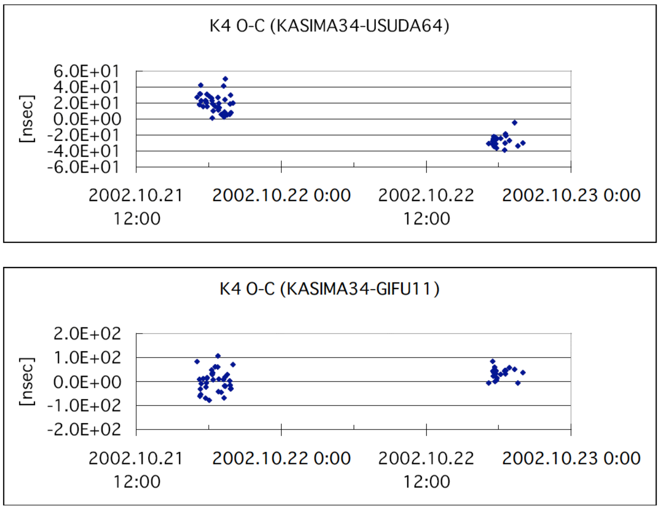


Figure 5. O-C of delay time taken by K4 system on Dec. 21-22, 2002. The baseline is Kashima-Usuda (above) and Kashima-Gifu (below).

nomical Observatory of Japan), GSI (Geographical Survey Institute of Japan), Gifu university, Yamaguchi university, Hokkaido university, and Canada (CRESTech/SGL). Such collaboration is very important and we would like to continue this wide collaboration. However it is also important to have Delta-VLBI facilities in JAXA itself, because Delta-VLBI should be used in the daily tracking as well as emergency tracking. Therefore, at present we have just started to consider the possibility of installing the Delta-VLBI facilities at Uchinoura Space Center. If this is possible, JAXA has two VLBI stations, Usuda and Uchinoura.

We studied how much the Delta-VLBI between Usuda and Uchinoura can make the accuracy of the orbit determination better. One of the results is shown in Fig.9. This is for a certain period of HAYABUSA, where Doppler data is not effective for the orbit determination. This result shows that the Delta-VLBI with the baseline of Usuda-Uchinoura is quite effective for the orbit determination.

As a summary, we say again that the Delta-VLBI method is very promising for the orbit determination of spacecraft in deep space. We have done many Delta-VLBI observations for NOZOMI, and we were able to get delay time as the result. However, we have not been successful to use the Delta-

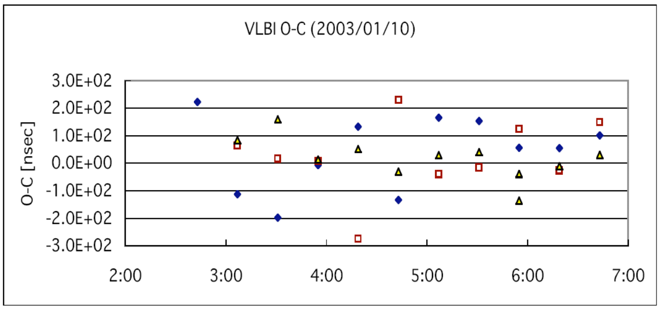


Figure 6. O-C of delay time taken by IP-VLBI systemt on Jan. 10, 2003. The baseline is Usuda-Koganei(◆),Usuda-Gifu(□), and Kashima-Usuda (△).

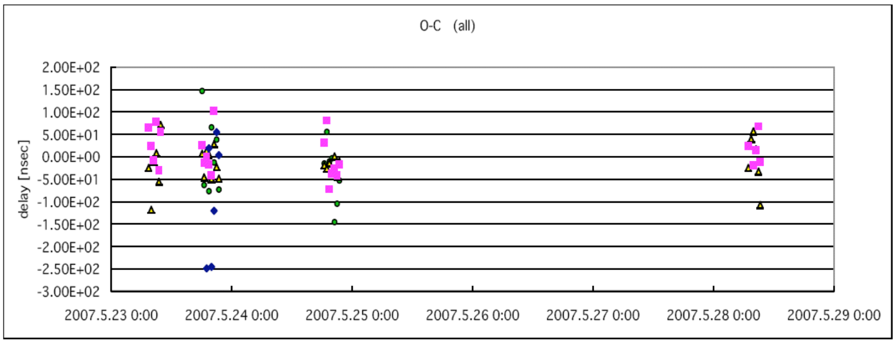


Figure 7. O-C of delay time taken by IP-VLBI system on May 22-27, 2003. The baseline is Kashima-Tukuba (●), Kashima-Usuda (△), Usuda-Tsukubai (■),Usuda-Yamaguchi (◆).

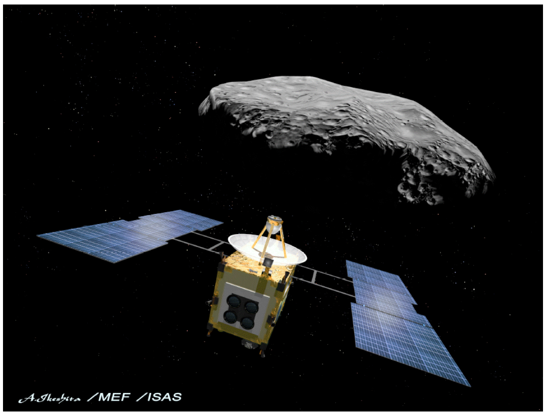


Figure 8. HAYABUSA (MUSES-C) mission. (by A. Ikeshita / MEF / ISAS).

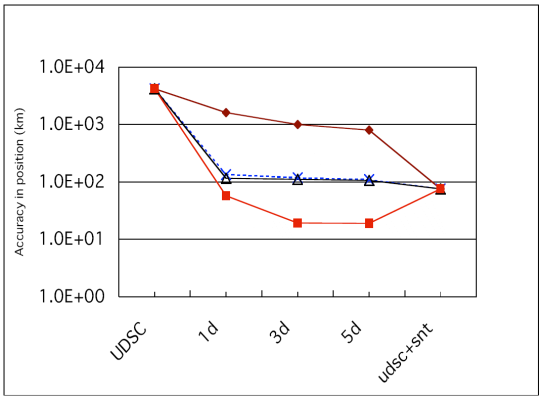


Figure 9. Analysis of position accuracy. The data labeled "UDSC" indicates the accuracy obtained by RARR method using only Usuda station. The data labeled "1d", "3d", and "5d" mean that Delta-VLBI data is also included for the RARR orbit determination and the number is the number of data passes of Delta-VLBI observation. The data labeled "udsc+snt" indicates the accuracy by RARR method using Usuda and Santiago stations. Four different baselines were analyzed: Usuda-Kashima (◆), Usuda-Mizusawa (×), Usuda-Uchinoura (△), and Usuda-Canberra (■).

VLBI data for the actual orbit determination. We will continue our work and we hope we can establish new orbit determination method by using Delta-VLBI technique.

We are grateful to the many people and organizations for their kind and devoted help.

Present Status of Gravimetric Missions in SELENE/RISE

Hideo Hanada[1] (*hanada@miz.nao.ac.jp*), **Takahiro Iwata**[2], **Noriyuki Namiki**[3], **Koji Matsumoto**[1], **Seiitsu Tsuruta**[1], **Toshiaki Ishikawa**[1], **Kazuyoshi Asari**[1], **Hirotomo Noda**[1], **Yusuke Kono**[1], **Jinsong Ping**[1], **Qinghui Liu**[1], **Fuyuhiko Kikuchi**[1], **Kousuke Heki**[1], **Nobuyuki Kawano**[1], **and RSAT/VRAD group**

[1] *National Astronomical Observatory, 2-12 Hoshigaoka, Mizusawa, Iwate 023-0086, Japan*
[2] *Japan Aerospace Exploration Agency, 2-1-1 Sengen Tsukuba, Ibaraki 305-8505, Japan*
[3] *Kyushu University, 6-10-1 Hakozaki, Higashiku, Fukuoka 812-8581, Japan*

1. Introduction

In SELENE project which is Japanese lunar exploration using H-2A rocket with the launch of 2005, we have two gravimetric missions, RSAT and VRAD. RSAT mission consists of 4-way Doppler measurement of a main orbiter through a relay satellite in addition to 2-way Doppler and ranging measurements of the satellites and it realizes a direct observation of gravity fields in the far side of the Moon for the first time. VRAD mission, on the other hand, consists of observations of orbits and gravity fields of the Moon by VLBI and it makes three dimensional observations of orbits in cooperation with RSAT for the first time. We will obtain a highly accurate lunar gravity model by the new methods and will investigate property of the lunar core and elastic property of the lunar crust referring to LALT (Laser Altimeter in SELENE) and LLR (Lunar Laser Ranging) data as well as the new gravity data.

2. RSAT/VRAD Mission

There are two sub satellites, a relay satellite (Rstar) and VRAD satellite (Vstar) in SELENE and they are separated from a main orbiter when it has a semi-major axis of 3000km and 2,200km, respectively. Usuda Deep Space Center (UDSC) transmits S-band uplink signal to Rstar and a part of it is returned and the rest is forwarded to the main orbiter. Doppler shift of the signal going from UDSC to the main orbiter via Rstar and coming back in the same way but being converted from S to X-band at Rstar is measured at UDSC (4-way Dopler measurement) in RSAT mission. Two way Doppler measurement of the signal directly returned from Rstar as well as ranging of Rstar are also carried out for determination of independent motions of the two satellites.

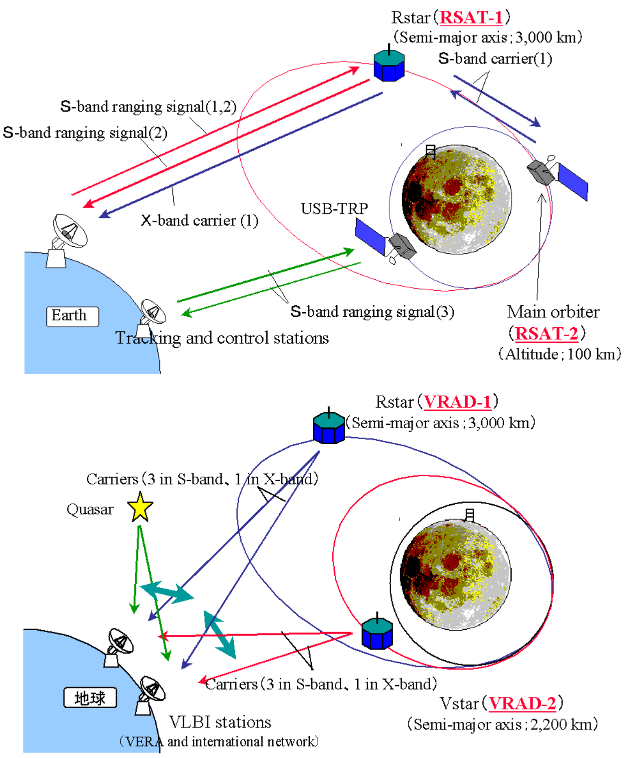


Figure 1. Concepts of gravimetric missions. Upper: RSAT, lower: VRAD.

Three carrier waves in S-band and one in X-band which are emitted from Rstar and Vstar are used for VLBI measurement of the satellites in VRAD mission. A multi-frequency VLBI has been proposed for the purpose of precise positioning using the phase delay and the optimum frequency spacing for three frequencies in S-band, 2212, 2218 and 2287 MHz, and one in X-band, 8456MHz, has been obtained [*Kono et al.,* 2002]. This method uses carrier waves of lower power consumption instead of noise and is appropriate for positioning of a spacecraft. It has been shown by VLBI experiments using carrier waves from Lunar Prospector that measurement error of phase delay of the carrier waves was possibly less than 10 degrees which was equivalent to positioning error of about 20cm on the Moon. Concepts of the gravimetric missions are shown in Fig. 1 [*Iwata et al.,* 2002].

3. Instruments for RSAT/VRAD Mission

Instruments used for 2-way Doppler and ranging measurements are S/X-band cross dipole antennas, S-band transponders, S-band diplexers, S-band hybrids, telemetry and command units and they are onboard both Rstar and Vstar. We have also two radio sources for VLBI onboard both Rsatr and Vstar. In addition to them, an S/X-band transponder, an S-band power amplifier, an X-band power amplifier, S-band omini antennas, S-band switches and S-band band pass filters on board Rstar and an S-band transmitter/receiver, an S-band diplexer and an S-band hybrid onboard the main orbiter are used for 4-way Doppler measurement.

We have completed designing and manufacturing of flight model for RSAT/VRAD mission and have begun performance test combined with the sub satellites Rstar and Vstar. S-band omni antennas newly developed for RSAT mission has experienced performance test under low temperature and phase pattern test. Total system for 4-way and 2-way Doppler measurements including instruments onboard and ground system was evaluated in March of 2003 at UDSC and the expected accuracy was achieved. Rstar and Vstar themselves have experienced mechanical and thermal test and no special problem was arose. A separation and rotation mechanism for Rstar and Vstar which was also newly developed showed good performance onboard μ-Lab Sat.

4. Ground System for VRAD Mission

Carrier waves in S and X bands received by a VLBI antenna are converted to video signals by a video converter in the K-4/Mark-III system and they are recorded either by the K-4/Mark-III system like conventional VLBI experiments or by a narrow band recorder especially developed for VRAD experiments. The narrow band recorder (S-RTP Station, System Design Service Corp.), consisting of 4 channels for the video signals and one for a reference clock signal, samples and digitizes the video signals at 200kHz intervals with 6 bit resolution. Seven narrow band recorders are prepared for VRAD mission and they will be distributed to domestic stations belonging to VERA and foreign stations which will participate in VRAD mission.

We are developing software which controls local frequencies in a video converter by 10kHz steps and attenuators by 1dB in order to put the video signals which are affected by Doppler shift into the narrow band channels of 70kHz with appropriate levels. Cross correlation procedure for determination of phase differences is also developed and is evaluated by comparing results obtained by different software with identical data.

5. Observation Schedule

The gravimetric mission consists of 4-way Doppler measurements (FWD), differential VLBI observations (VRAD), 2-way Doppler and ranging observations (RSRD) and telemetry and command operation (TCM). Besides, there is a standby mode (STBY) when battery power of the satellites is not enough. Number of operations which can be conducted at once is restricted due to supplied power. We cannot do anything else when we carry out FWD operation. RSRD or TCM can be collaborated with VRAD operation provided that the satellites is fully lit by the sun.

FWD has first priority over any other mission because a chance of communications among two satellites and the Earth is very limited and because it is operated only when the main orbiter is in the far side. . Observation schedule is made considering the following conditions: 1) whether Rstar and Vstar are seen from the Earth, 2) whether the main orbiter is in the far side of the Moon, 3) whether Rstar and Vstar are lit by the sun, 4) whether communications among the main orbiter, Rstar and the Earth are possible, 5) whether batteries are fully charged, 6) whether temperatures in Rsat and Vstar are in an appropriate range, etc.

We make a plan to conduct double intensive observations each of which consists of one month period under participation of foreign stations. The domestic network VERA will take part in VRAD mission for the whole mission period of one year. We are developing an international network for VRAD mission from the points view of baseline length in north-south and east-west directions, and BKG Wettzell, Shanghai Astronomical Observatory, Urumqi Astronomical Observatory and Hobart Observatory are expected to constitute the international network. It is necessary to make adjustments of machine time between the VLBI stations including VERA.

6. Improvement in Gravity Model

There are serious problems in gravity models obtained so far: 1) only 2-way Doppler measurement is used, 2) there is no direct observation of gravity field of the far side (Ill-posed problem). A-priori constraint is necessary due to no far side data and large error is expected in the far side accordingly. Gravity anomaly near lunar rim, on the other hand, may not be correctly estimated. It is because sensitivity of Doppler measurement from the Earth for motion of a satellite perpendicular to the lunar surface is very low and there is no other Doppler measurement in the direction perpendicular to the surface in the rim region

These problems will be solved and a new gravity model will be obtained by RSAT/VRAD mission. Accuracy of the gravity field will be improved for wide range by tracking of 3 satellites of different altitudes, accuracy in the far side will also be improved by 4-way Doppler measurements, and gravity anomaly near rim region will be estimated correctly by three dimensional observations cooperated with Doppler and VLBI measurements. Simulations show that accuracy of the new gravity model is better than the present model by more than one order [*Matsumoto et al.,* 2002].

7. Summary

For the gravimetric mission is SELENE, we have carried out the following items:

1) Performance test of instruments on board,
2) Development of software for scheduling and telemetry monitoring,
3) Adjustment of schedule for VERA and international VLBI network,
4) Development of software for operation and correlation of VLBI measurements,
5) Development of data base system,
6) Development of receiving and recording system for VLBI data

References

Iwata, T., Sasaki, T., Kono, Y., Hanada, H., Kawano, N., Namiki, N., Results of the critical design for the selenodetic mission using differential VLBI methods by SELENE, Proc. 2nd. IVS General Meeting, 377-380, 2002.

Kono, Y., H. Hanada, N. Kawano, K. Iwadate, Y. Koyama, Y. Fukuzaki, Precise positioning of spacecrafts by multi-frequency VLBI, Proc. 2nd. IVS General Meeting, 179-183, 2002.

Matsumoto, K., K. Heki and H. Hanada, Global lunar gravity field recovery from SELENE, Proc. 2nd. IVS General Meeting, 381-385, 2002.

Black Hole Imager, Pre-Horizon Telescope In the Southern Hemisphere

Makoto Miyoshi[1] (*miyoshi@miz.nao.ac.jp*), **Jose K. Ishitsuka**[1], **and Shinji Horiuchi**[2]

[1] *National Astronomical Observatory, Japan 2-21-1 Osawa, Mitaka, Tokyo, 181-8588, Japan*
[2] *Center for Astrophysics and Supercomputing, Swinburne University of Technology Mail stops 31 P. O. Box 218 Hawthorn, Victoria, 3122 Australia*

1. Introduction

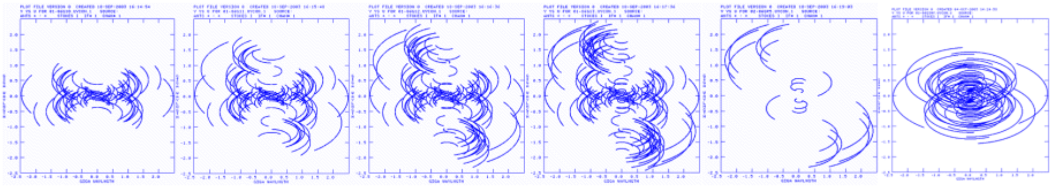
Imaging black hole systems is one of the final goals in VLBI astronomy. For this purpose, SgrA*, the massive black hole at our galactic center is the best target because of the apparent size of black hole system is the largest of all, for example, the black hole shadow (=about 5Rs) is more than 30 micro arc seconds in diameter, actually the largest one among those of known black hole candidates. Recent observations indicate 3.7×10^6 $M_\odot$ as the black hole mass of SgrA* (Schödel et al. 2002). If accepted the value, the black hole shadow is more than 45μ as in diameter. However the scattering effects by surrounding plasma have blurred the intrinsic black images and then previous cm-VLBI observations of SgrA* could not reach the true face so far. In order to escape from the effects, we should accomplish mm to sub-mm VLBI observations of SgrA*. Here we show uv- simulations for checking imaging performance of several hypothetical arrays. First we show the case of 86GHz ground based VLBI whose spatial resolution is quite insufficient for resolving the black hole shadow but has capability for imaging jet eruptions if occur, and then show the case of 230GHz VLBI. The best array configuration is the inversed VLBA location at the southern hemisphere (called E-array here), while the realistic sub-mm array composed of 5 stations show bad image results though important information will be obtained from visibility analysis. We adopted here the previous estimated mass of 2.6×10^6 $M_\odot$ (Ghez et al. 2000) and the corresponding shadow size of 30μas in diameter.

2. Assumed arrays for simulations

Here we select the following 6 array configurations for simulations of testing performance for SgrA* imaging.

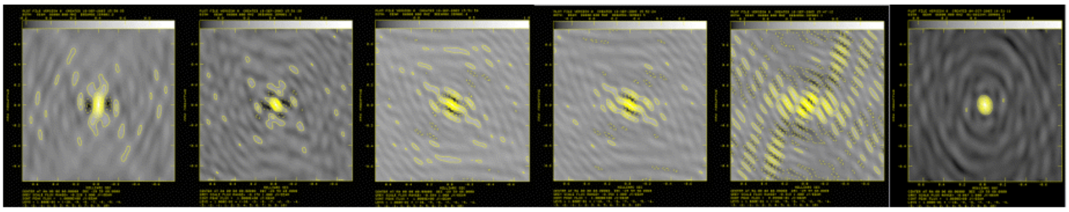
- Array A: the present VLBA (NRAO) including 10 of 25-m dishes. The adopted sensitivities at both 86GHz and 230GHz are based on typical system temperature $\sim$150K (except MK, 100K for MK) and antenna efficiencies $\sim$0.2 for real 86GHz conditions. Needless to say, the actual VLBA antennas have neither 230GHz receivers nor sufficient antenna surface accuracy. This is only for configuration simulations.
- Array B: the VLBA plus a virtual station located at Huancayo in Peru. The virtual Huancayo antenna is 25-m in diameter with efficiency of 0.7 for both frequencies. The assumed system temperature is 100K. The location is in lat.12.0375°S. in long. 75.2942°W. , 3375-m in altitude.
- Array C: the VLBA plus the Huancayo station and the ALMA in Chile. As phased ALMA, we adopted 70-m in diameter with efficiency of 0.7 for both frequency. The assumed system temperature is 80K. The location is in lat. 23°S. in long. 67.4°W. , 5000-m in altitude.
- Array D: the VLBA plus the Huancayo station, the ALMA and the SEST (ESO) in Chile. SEST is 15-m in diameter with efficiency of 0.8 for both frequencies, which is better than the real. The assumed system temperature is 100K, also better than the real. The location is in lat. 29.25°S. in long. 70.733°W. , 2400-m in altitude.
- Array E: the SMA (CfA & ASIAA) in Hawaii, CARMA in eastern California, the Huancayo, the ALMA and the SEST (ESO) in Chile. These except for Huancayo are actually realistic stations for performing 230GHz VLBI for SgrA*. The SMA and the SEST are now operation, while the CARMA and the ALMA are under construction. Here we adapted phased SMA is corresponding to 25-m in diameter with efficiency of 0.6. The system temperature is assumed 100K here. For CARMA as phased mode, 30-m in diameter with efficiency of 0.6, and system temperature of 150K are assumed.
- Array F: the inversed VLBA, located at the southern hemisphere. Except locations of stations, all parameters are common as those of Array A.

Figure 1 shows the uv-coverage of above 6 arrays at 86GHz. The uv-coverage of VLBA (Array A) in is notoriously worse in north-south direction for SgrA*(Fig1. a). Adding stations in South America reinforces the north-south coverage of the VLBA alone (Fig.1. b, c, d). The uv-coverage of Array E for SgrA* is large but quite sparse (Fig. 1 e). The



a) Array-A b) Array-B c) Array-C d) Array-D e) Array-E f) Array-F

Figure 1. The uv coverage of each array for SgrA (86GHz).*



a) Array-A b) Array-B c) Array-C d) Array-D e) Array-E f) Array-F

Figure 2. The dirty beams of the arrays for SgrA. The scale is 1.5mas (0.56mas) in each side for 86GHz (230GHz).*

corresponding synthesized beams (or dirty beams) are shown in Figure 2. As expected judging from the sharpness of main beam, the spatial resolutions of array B, C, and D are about three times better in declination than that of array A. The main beam of array E is certainly small but also exists side lobes with quite high peak comparable to that of main beam. The array F shows high main beam and quite low side lobes as shown in Figure 2 (f).

3. Image models for SgrA* at 86GHz and 230GHz

We used two kinds of model images for SgrA*. One is for 86GHz simulation while the other is for 230GHz. From visibility analysis of VLBA observations at 86GHz, the apparent shape of SgrA* are modeled as Gaussian brightness distributions (Shen et al. in preparation). From the estimated size we here adopt Gaussian with major axis of 0.2 mas and minor axis of 0.15 mas (PA=80°) as outer edge size. We also put the black hole shadow (elliptical shape with 30μas$\times 24\mu$as, PA=80°) at the center. Further cone shape jets (0.5 mas in length) are added in both sides. Such a jet may be observed if something occurs in SgrA*(Figure 2a).

From primitive VLBI observations at 215GHz the outer size is estimated about 0.1mas in diameter (Krichbaum et al. 1998). In order to test for imaging the black hole shadow or not at sub-mm VLBI, we adopted the value as outer diameter while the same size is used for the black hole shadow (elliptical shape with 30μas$\times 24\mu$as, PA=80°). This is a model image for 230GHz simulations (Figure 3a).

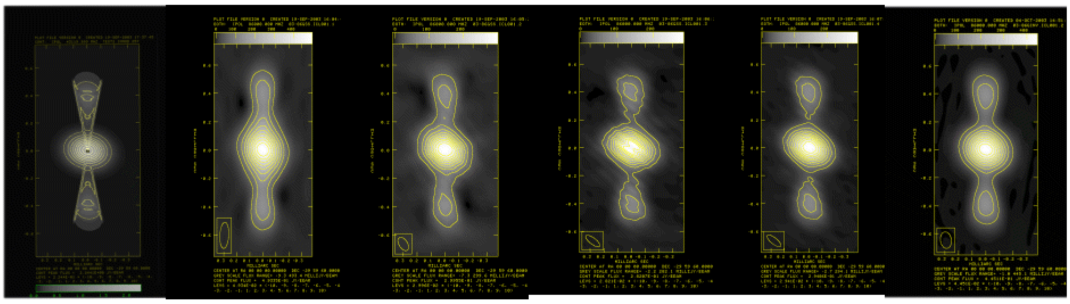
4. Results from Clean

Figure 3 shows the clean results of the 6 arrays. With each array we can recognized the jets eruption (0.5 mas in length) if occurs. Array A, namely the VLBA fails to recognize the cone shape that widening towards the end while other arrays detecting the widening though the performance differences exist. From the lack of spatial resolutions, it seems impossible for ground-based array to find the black hole shadow in SgrA* at 86GHZ even without the scattering effect. The adding station in South America, Huancayo in Peru for example to the present VLBA, will improve the spatial resolution three times in declination that is true for all frequencies.

Figure 4 shows the results of CLEAN at 230GHZ simulations. The images from array A and E are not so good while there is a certain dip at the image center from other arrays.

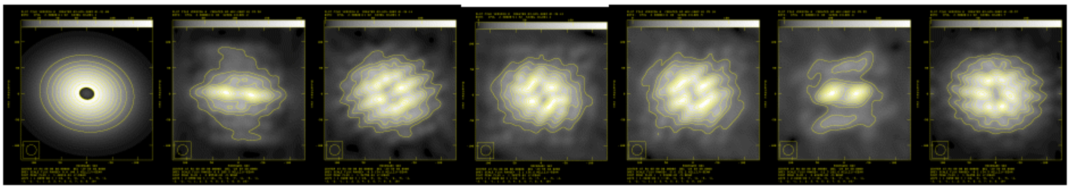
5. Discussions

The best array for imaging of the SgrA* black hole (shadow), at least from these simulations is



a) Model b) Array-A c) Array-B d) Array-C e) Array-D f) Array-F

Figure 3. Clean Results from several array configurations at 86GHz. The each square size is 1.5mas in declination and 0.75 mas in right ascension.



a) Model b) Array-A c) Array-B d) Array-C e) Array-D f) Array-E g)Array-F

Figure 4. Clean Results from several array configurations at 230GHz. The each square size is 0.25mas both in declination and in right ascension.

the inversed VLBA (array F). Namely 8000km in extent, 10 in station number, sensitivity at least the same of the performance 86GHz, location at the Southern hemisphere are required.

The realistic array composing from 5 stations-SMA, CARMA, SEST, Huancaiyo, and ALMA - is not insufficient for imaging itself but visibility analysis will be very important for detecting black hole shadow.

We however must mention here that analysis of small amount of visibility from like array E is important for measuring the diameter of black hole shadow and estimating the mass of the black hole although the uv-coverage is insufficient to get good synthesis image from them. Actually we can begin black shadow investigation with visibility analysis from sparse array. We will report somewhere about visibility analysis.

References

Ghez et al., The accelerations of stars orbiting the Milky Way's central black hole, Nature , 407, 349-351, 2000

Schödel et al., A star in a 15.2-year orbit around the supermassive black hole at the centre of the Milky Way, Nature 419, 694-696, 2002 Shen et al. in preparation

Krichbaum et al., VLBI observations of the galactic center source SGR A* at 86 GHz and 215 GHz, A&A, 335, L106-L110, 1998

A 32 m Antenna Project in Peru

José K. Ishitsuka[1] (*pepe@hotaka.mtk.nao.ac.jp*), **Mutsumi Ishitsuka**[2], **Makoto Inoue**[1], **Masatoshi Ohishi**[1], **Kenta Fujisawa**[3], **Takashi Kasuga**[4], **Masato Tsuboi**[5], **Keisuke Miyazawa**[1] (∗) **and Shinji Horiuchi**[6]

[1] *National Astronomical Observatory, Japan*
[2] *Instituto Geofísico del Perú, Peru*
[3] *Yamaguchi University, Japan*
[4] *Hosei University, Japan*
[5] *Ibaraki University, Japan*
[6] *Square Kilometer Array, Australia*
(∗) *retired*

1. Introduction

By adding a station in southern hemisphere like Peru, a marvelous improvement in u-v coverage could be obtained with the VLBA for sources near equator. Currently a plan is being developed to convert a 32-m telecommunications antenna used for INTELSAT in the Peruvian Andes into a radio astronomy facility operated by the Institute of Geophysics in Peru (IGP) and local universities with assistance from the National Astronomical Observatory of Japan (NAOJ).

Initially, the antenna will be tuned to receive spectral lines of Methyl Alcohol at 6.7 GHz to survey and monitor Young Stellar Objects by smaller modifications from the present system. As the surface accuracy of the main dish is better, observations at higher frequencies could be expected in the future. On the other hand since the antenna location is unique in the southern hemisphere, geodetic observations at S/X band should be done to measure plate tectonics in South America.

2. Location

The Sicaya antenna station (see Feigure 1) is located on a small hill in a beautiful open flat valley that is similar to Owens Valley in California or Nobeyama in Japan where world famous radio observatories are located. The Huancayo observatory of IGP is just 5-km away from the Sicaya antenna station. The antenna looks still in very good condition without no apparent rust probably due to its location at 3375 m of high altitude and being far away from sea side. The structure of the antenna is well suited to upgrade receivers in future. The receiver room is on the ground floor and connected with the main antenna dish and sub-reflector with a beam transfer reflector guide system. That allows us to install the receivers on the ground floor and to work on these easily. Here is detail of the antenna that we got from the Japanese company NEC who made it:

Figure 1. Estación Terrena de Sicaya, Huancayo - Perú.

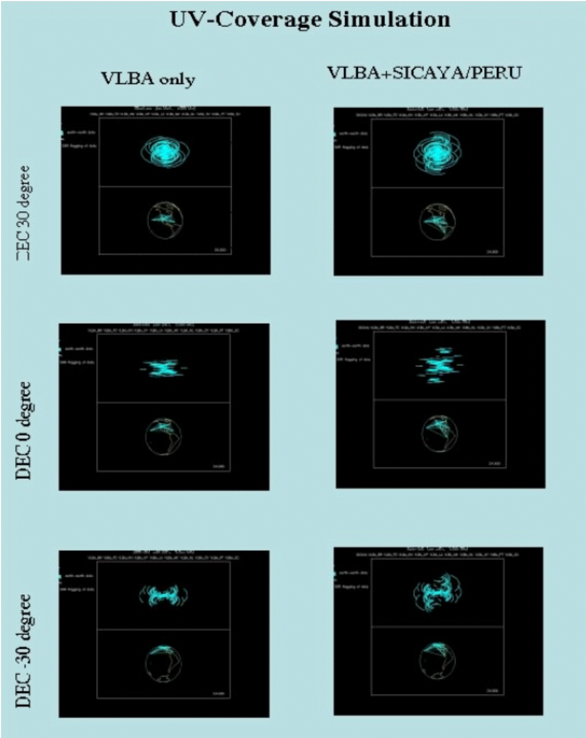


Figure 2. uv-Coverages Simulation adding the Peruvian antenna to the VLBA system. (Simulation made by S. Horiuchi).

Latitude:	−12° 02 ’15 ”
Longitude:	−75° 17 ’39 ”
Altitude:	3,375 m
Built year:	1984 to 1985
Antenna type:	Cassegrain system
Diameter of main dish:	105 ft (32m)
Frequency band:	6 GHz (transmittion) 4 GHz (reception)
Antenna mount:	Wheel Track type AZ-EL mount
Antenna moving speed:	0.3 degree/s for both AZ and EL
Surface accuracy:	1.09 mm rms (without wind), 1.26 mm rms (with 13 m/s wind)

3. Conclusion

The advantage of the addition of the Sicaya 32-m telescope in the Peruvian Andes to the VLBA is remarkable especially for low declination and southern declination sources (See Figure 2). Discussions are now taking place to investigate how to upgrade this telescope so that both single dish and VLBI observations can be undertaken. However we believe that joining VLBA for VLBI observations is one of the most exciting aspects of the project. Geodetic measurements of plate tectonics in the active Andes region will be useful for geophysics and earth rotation sciences, and it would be also a grate contribution for the development of sciences in Peru.

References

Horiuchi, S., D. Murphy, M. Ishitsuka and J. Ishitsuka, “Potential Improvements to VLBA uv-Coverages by the Addition of a 32m Peruvian Antenna ”, Future Directions in High Resolution Astronomy, A Celebration of the 10th Anniversary of the VLBA, Socorro, New Mexico, USA, June, 2003.

VSOP-2: a Proposal for a near future Space VLBI Mission

Hisashi Hirabayashi (*hirax@vsop.isas.jaxa.jp*)

Institute of Space and Astronautical Science
Japan Aerospace Exploration Agency
Yoshinodai 3-1-1, Sgamihara, Kanagawa
229-8510, Japan

Abstract: HALCA, the first dedicated satellite for space-VLBI, was launched in February 1997, and VSOP observations have been successfully undertaken at 1.6 and 5 GHz. The VSOP-2 mission is planned to have frequency bands of 8, 22, and 43 GHz, with dual polarization, a 1 Gbps downlink bit-rate, and a phase referencing capability. The mission proposal will be submitted to ISAS/JAXA in October 2003, with the earliest possible launch, if approved, in 2010.

1. Introduction

The first space VLBI experiment with a TDRSS satellite was successful in 1986 (Levy et al. 1986), paving the way for a dedicated space VLBI mission. The Institute of Space and Astronautical Science (ISAS) launched the first space VLBI satellite, HALCA, in 1997. HALCA's orbit has an apogee height of 21,400 km, perigee height of 560 km, inclination angle of 31 degrees, and orbital period of 6.3 hours.

In June 1997, the first 1.6 GHz images were generated and in July the first 5 GHz images were produced at the VLBA correlator. In April 1998, 22 GHz fringes to HALCA were first detected at Socorro for the flaring water maser in Orion-KL (Kobayashi et al. 2000). HALCA has been operated for the VSOP (VLBI Space Observatory Programme) project in cooperation with many organizations and radio telescopes around the world. HALCA's status earlier in the mission has been reviewed by Hirabayashi et al. (1998), Hirabayashi et al. (2000a), and Edwards and Hirabayashi (2001).

Scientific observations are being routinely undertaken at 1.6 and 5 GHz. VSOP observations are mostly devoted to AGN. Parsec-scale jets and, in some cases, the shadow of plasma disks are visible with VSOP angular resolution. Hydroxyl (OH) masers, pulsars, and X-ray binaries are among other objects observed. More information about VSOP is available from the papers referenced above and from http://www.vsop.isas.ac.jp.

2. VSOP-2 Planning

A next-generation space VLBI mission Working Group was formed in May 1997 after the detection of fringes on baselines to HALCA. Following the successes of VSOP, a near-term next generation Japanese space VLBI mission, currently referred to as VSOP-2, is being planned (Hirabayashi et al. 2000b, 2001; Hirabayashi 2003) in collaboration with international partners. A web page has been established at <http://www.vsop.isas.ac.jp/vsop2/> for the VSOP-2 project.

The VSOP-2 science goals include: study of emission mechanisms in conjunction with the next generation of X-ray and gamma-ray satellites; full polarization studies of magnetic field orientation and evolution in jets, and measurements of Faraday rotation towards AGN cores; high linear resolution observations of nearby AGN to probe the formation and collimation of jets and the environment around supermassive black holes; and the highest resolution studies of spectral line masers and megamasers, and circum-nuclear disks. Higher observing frequencies, cooled receivers, increased bandwidths and larger telescope diameters will result in gains in resolution and interferometer sensitivity by factors of about 10 over the VSOP mission. An angular resolution of approximately 25 microarcseconds at 43 GHz will be achievable, corresponding to about 10 Schwarzschild radii at the distance of M87.

The VSOP-2 spacecraft will employ a 9 m off-axis paraboloid antenna. The observing bands will be 8, 22, and 43 GHz. The VSOP-2 satellite will be placed in an elliptical orbit with an apogee height of about 25,000 km and a perigee height of 1,000 km, resulting in a period of 7.5 hours. Unlike HALCA, the VSOP-2 satellite will receive both LCP and RCP, and use cryogenic coolers for the two higher frequency bands to reduce the system temperature. Observing requires a two-way link between the satellite and a tracking station, for a wideband down link at 1 Gbps, and with the uplink used to transfer a reference signal.

The international cooperation and coordination required for VSOP observations make it one of the most complex space science missions undertaken, and a lot has been learnt for future space VLBI missions. A similar level of collaboration will be essential for the success of VSOP-2. Submission of the VSOP-2 proposal to ISAS will take place in October 2003 and consequently launch on an ISAS M-V rocket could be as early as 2010. By the time of the launch of the VSOP-2 spacecraft a number of new arrays and telescopes will also be in operation, with 1 Gbps and higher recording widely available. Thanks to the VSI standard, and the simplicity of DAT design, and the development of disk-based recording, compatibility problems should not be as serious as they were for VSOP.

ISAS was merged with two other institutions to form the Japan Aerospace Exploration Agency (JAXA) in October 2003. However, the VSOP-2 mission proposal will be evaluated by the ISAS Science Steering Committee as for previous ISAS missions.

3. New Aspects for VSOP-2

The on-board radio astronomy antenna is one of the most critical parts of the spacecraft. The development of an off-axis mesh antenna with a segmented (modular) radial rib design has been in progress over the last three years at ISAS. The backup and deployment structure is based on the ETS-VIII project antennas, which are scheduled to be launched in 2006. To achieve a surface accuracy as high as 0.3 mm (rms), radial ribs will help shape the surface without too much cable structure. The radio astronomy receivers for the 22 and 43 GHz bands will be cooled, which will have appreciable impact on the spacecraft design.

The frequency for the 1 Gbps VLBI data link is 37-38 GHz (down-link), and for the (up-link) reference frequency is 40 GHz. The use of both senses of polarization will help for the maximum use of the allocated band. Studies and trade-offs have been done taking into account both the quantization loss, circuitry complexity, and down-link power.

Phase-referencing observations remove atmospheric phase fluctuations and consequently can increase the coherence time. Although this capability was not considered in the ordinal VSOP mission design successful 'in-beam' phase-referencing observations have nevertheless been carried out with the quasar pairs 1308+326 and 1308+328, separated by 14.3' (Porcas et al. 2000) and 1342+662 and 1342+663, separated by 4.8' (Guirado et al. 2001). Furthermore the VERA array (see http://veraserver.mtk.nao.ac.jp/index.htm) of the National Astronomical Observatory of Japan (NAOJ), which consists of four 20 m antennas with dual beam systems, will enable phase-referencing technique to be explored in great depth. VERA is able to observe at all three VSOP-2 bands making it be a good partner for VSOP-2 co-observing.

Nodding of the whole spacecraft quickly between the calibrator and target sources is possible with the addition of 2 Control Moment Gyroscopes (CMGs) to the 4 momentum reaction wheels (RWs). For phase-referencing observations, orbit accuracies of 50 cm(8 GHz), 6.5 cm (22 GHz), and 1.8 cm (43 GHz) are required, and to detect water maser proper motions in AGN requires a 2 cm accuracy. Orbit determination of a few-cm accuracy could be achieved by adding GPS receivers with a high precision 3-dimensional accelerometer, or by using both GPS and Galileo receivers, according to simulations performed at JPL for the VSOP-2 orbit.

These new developments for VSOP-2 can be pursued further for the planning of following space VLBI missions.

4. Further into the future

A multi-spacecraft mission is attractive for several reasons, providing better (u,v) coverage, better angular resolution, and good coverage of observable sky. Also, a space-space interferometer would provide better coherence. A two-spacecraft mission, iARISE, has recently been studied in the U.S. (Fomalont et al. 2002). We think that the possibility of a shared launch of VSOP-2 with another spacecraft, or with a second spacecraft launched separately could be possible options after the approval of the VSOP-2 mission.

The desire to go to higher frequency bands to probe the AGN central engine is natural because the AGN core can be optically thin and also we gain in angular resolution. So, millimeter and sub-mm space-VLBI are also very attractive long future missions to prove relativistic phenomena related to jets and super-massive black holes. The potential of sub-mm VLBI has, for instance, been illustrated for observations of Sgr A* by Falcke et al. (2000).

So, as a near-term mission, launching a spacecraft for sub-mm VLBI with the phased ALMA array on an experimental basis is another possibility, before a full sub-mm VLBI mission.

There are lots of new areas for space VLBI in the far future. For space VLBI at sub-mm wavelengths we need an on-board oscillator and good coherence, and/or optical communication between the space elements, and/or direct correlation in space, etc. VSOP-2 will serve as a good continuation, and extension, of space VLBI activity, and as the next step towards more ambitious missions in the future.

References

Edwards, P.G. and Hirabayashi, H. 2001 in New Century of X-ray Astronomy (ASP Conf. Ser. 251) eds. H. Inoue and H. Kunieda, p. 348

Falcke, H. Melia, F., and Agol, E. 2000, ApJ, 528, L13

Fomalont, E. et al. 2002, Whitepaper submitted to NASA's SEU roadmap team, http://universe.gsfc.nasa.gov/docs/roadmap/iarise_whitepaper.pdf

Guirado, J.C., et al. 2001, A&A, 371, 766

Hirabayashi, H. et al. 1998, Science, 281, 1825 and erratum 282, 1995

Hirabayashi, H. et al. 2000a, PASJ, 52, 955

Hirabayashi, H. et al. 2000b, in Astrophysical Phenomena Revealed by Space VLBI, ed. H. Hirabayashi, P.G. Edwards, and D.W. Murphy (ISAS), p. 277

Hirabayashi, H. et al. 2001, in Galaxies and their Constituents at the Highest Angular Resolutions (IAU Symposium 205), eds. R.T. Schilizzi, S.N. Vogel, F. Paresce, and M. Elvis, p. 428

Hirabayashi, H. 2003, in Future Directions in High Resolution Astronomy: A Celebration of the 10th Anniversary of the VLBA (ASP Conf. Ser.) eds. J.D. Romney and M.J. Reid, in press

Kobayashi, H. et al. 2000, in Astrophysical Phenomena Revealed by Space VLBI, eds. H. Hirabayashi, P.G. Edwards and D.W. Murphy, p. 109

Levy, G.S., et al. 1986, Science, 234, 187

Porcas, R.W., et al. 2000, in Astrophysical Phenomena Revealed by Space VLBI, ed. H. Hirabayashi, P.G. Edwards, and D.W. Murphy (ISAS), p. 245

- News - News - News - News - News - News - News - News - News -

Smallest Backend in Preparation

Junichi Nakajima (*nakaji@crl.go.jp*)

Kashima Space Research Center
Communications Research Laboratory
893-1 Hirai, Kashima, Ibaraki 314-8501, Japan

Simply connect your satellite dish and a digital volt meter to the box. Then you will complete an own smallest radio telescope. The tiny prototype box includes IF amplifier, splitter, detector and variable gain DC amplifier.

Every summer CRL held scientific camp for nominated high-school students. The tiny telescope soldering construction is now one of the popular course. CRL received good reputations to this teaching material, we will release the small backend both in kit and completed unit. Details of the course and the material will be presented in the next issue of the TDC news. I may add that the unit can be used instead of worn-out power meter in VLBI site.

Developments for the next space VLBI mission, VSOP-2

Yasuhiro Murata[1] (*murata@vsop.isas.jaxa.jp*), **Hisashi Hirabayashi**[1], **Inoue Makoto**[2], **and Next generation space VLBI working group**

[1] *Institute of Space and Astronautical Science Japan Aerospace Exploration Agency 3-1-1 Yoshinodai, Sagamihara, Kanagawa 229-8510, Japan*
[2] *National Astronomical Observatory 2-21-1 Osawa, Mitaka, Tokyo, 181-8588, Japan*

Abstract: As the presentation by Hirabayashi (2003) in this proceeding, we are planning VSOP-2 mission. We are making various kinds of developments for the misson. We introduce the developments for the large antenna, fast switching scheme using CMG, low noise receiver, gigabit data transmission, and high data rate sampling on board. We also study the system configuration of the VSOP-2 satellite and the orbit to fit the expected roket, M-V. VSOP-2 science goals include the imageing the accretion disk around the massive blackhole in the nuclei of the active galaxies, studies of magnetic field orientation and evolution in jets, and the highest resolution studies of spectral line masers and mega-masers. Here we describe the development of the space antenna, high speed sampler, and the satellite system.

1. Description of VSOP-2 satellite

VSOP-2 satellite has the 10m-class antenna with the low noise receivers and a downlink data rate of 1 Gbps. It will detect both LCP and RCP in the band of 8, 22, and 43 GHz. The receivers of 22, and 43 GHz are cooled to around 30 K with the cryogenic coolers to reduce the system temperature. The onboard sampling frequency is more than 1 Gsps.

Sensitivity is ultimately limited by the coherence time, which becomes increasingly affected by atmospheric fluctuations above the ground telescopes at higher frequencies. Several possibilities for "phase-referencing" to improve sensitivity by extending the coherence time are under study. The comparison of the specifications of the VSOP and VSOP-2 satellites is shown in Table 1.

Observing frequencies up to 43 GHz will allow high angular resolution observations of the optically thin emission in many AGN cores. An apogee height is 25,000 km will allow an angular resolution of 38 micro-arcseconds to be achieved at 43 GHz, corresponding to around 10 Schwarzschild radii at the distance of M87.

2. Design of VSOP-2 satellite

A schematic view of VSOP-2 satellite is shown in Figure 1. VSOP-2 satellite will be launched by ISAS M-V rocket. The orbit is 25,000 km apogee, 1,000 km perigee, and the 7.5 hour period. The design of the satellite is changed from the last meeting

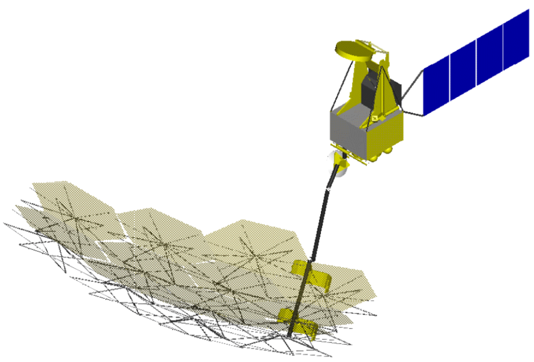


Figure 1. A schematic view of VSOP-2 satellite.

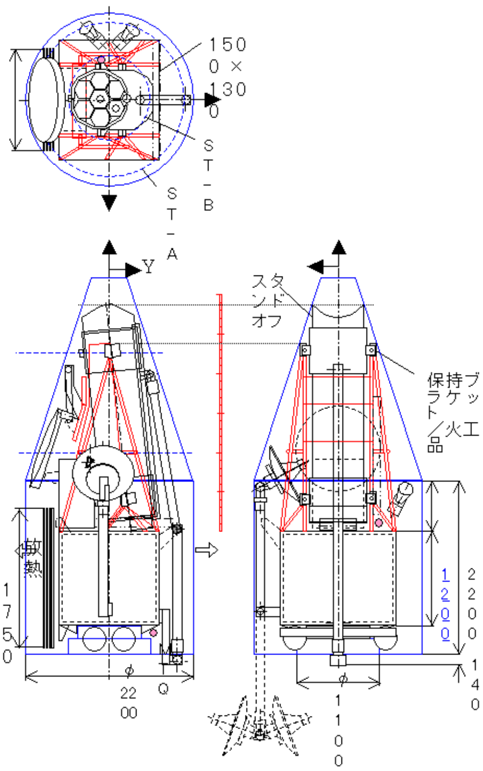


Figure 2. VSOP-2 satellite launch configuration with M-V faring interface.

Table 1. Comparison of the specification of VSOP, VSOP-2 and VLBA. There are other observing band in VLBA. The sensitibity is related to the sensitivity of ground telescope. Sensitivities are calcurated assuming to observe with VLBA.

	VSOP	VSOP-2	VLBA
Antenna Diameter	8m	9m	25m
Apogee Hight	21,500 km	25,000km	0 km
Orbit Period (hour)	6.3	7.5	24
Polarization	LCP	LCP/RCP	LCP/RCP
Data Bandwidth	128 Mbps	1 Gbps	512 Mbps*
Observing Band (GHz)	1.6, 5, (22)	8, 22, 43	8,22,43,86 etc
Maximum resolution	0.36 mas	0.038 mas	0.096 mas
Sensitivity (5/8 GHz)	158 mJy	22 mJy	7.9 mJy
(22 GHz)	N.G.	39 mJy	23 mJy
(22 GHz phase ref.) (1.5 hour integ time)	impossible	9.1 mJy	5.3mJy
Launch (earliest case)	1997	2010	

* We adopt the maximum data rate of VLBA, this is not the operational case.

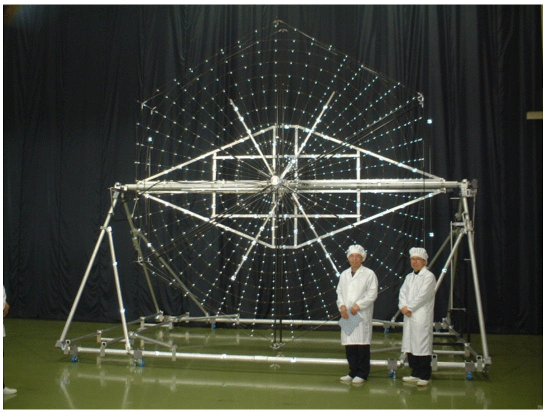


Figure 3. Picture of 2 gentlemen with a full scale model of the central part of a single antenna module to evaluate the adjustment of the surface accuracy.

to fit it to the nose-faring of the M-V. The target total weight is 910 kg. The image of the satellite with the M-V nose-faring is shown in Figure 2.

The design of the VSOP-2 satellite is based on HALCA design, but there is some new items we must take account. 1) large off-axis paraboloid antenna 2) Cooler requres more power. VSOP-2 has the total power of about 1.8 kW, which is about double of HALCA supply. This means that we must take care about the management of the thermal control. 3) Add 2 CMG 's (control momentum gyro) for the fast switching observation, and GPS receiver and the accelarometer for the cm order accurate orbit determination, to carry out the phase-referencing observation.

3. Development for VSOP-2 satellite

3.1 Antenna Development

One of the technical challenges is be the requirement placed on the surface accuracy of the mesh antenna by the highest observing frequency of 43 GHz (a wavelength of 7 mm). A 7-segment, offset 10-m class antenna is under development. This antenna is has a lighter weight, and easier adjustment mechanism, than that of HALCA. The basic concept of this type of antenna was developed by NASDA (now JAXA) for the ETS-VIII mission. However, the planned surface accuracy of ETS-VIII is lower than that required for the VSOP-2 mission. We made the model of the full scale 1 segment model (Figure 3) to evaluate how accurately the antenna surface can be adjusted. We confirmed that we can get an accuracy of less than 0.2 mm rms.

3.2 High speed sampler radiation test

One of the problems for VSOP-2 is how to sample the data on-board, if we follow the same approach as HALCA. We assume a giga-bit rate of data sampling to obtain the desired sensitivity. However, we can not find any A/D sampler LSI chips qualified for use in space. We tested a 10 Gbps, 1 bit sampler and a 1:16 demultiplexer, to demonstrate a possible solution for the on-board high speed sampler. We carried out a 1000 krad total dose test and a single event test. We confirmed we can use those LSI's on the VSOP-2 orbit.

3.3 Giga-bit data link

A giga-bit data transmission requires more than 1 GHz bandwidth frequency allocation. The only possible band based on frequency allocation regu-

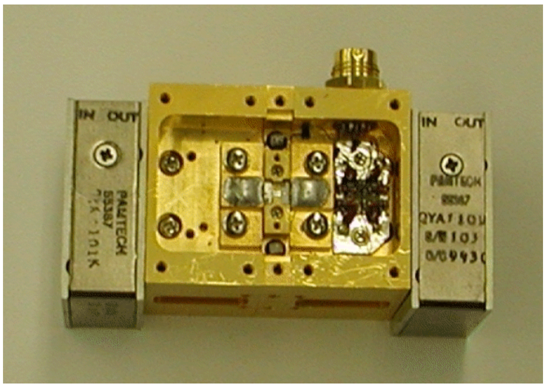


Figure 4. Picture of the assembled GaAs MMIC Q-band receiver.

lations is 37-38 GHz. The uplink frequency will be moved to 40 GHz. We studied the link budget, and found that the condition is more severe than that of HALCA Ku link, but still it is possible. We are developing the modulator and demodulator for the giga-bit data transmission. We adopt the OFDM (Orthogonal Frequency Division Multiplex) method with 8 channel QPSK modulation, to allow the CMOS type circuit for the modulator, and reduce the emisson in the outband of the transmitting band.

3.4 Cooled frontend

43 GHz GaAs MMIC cooled receiver is developed using the commertial MMIC LSI for the room temperature use (Figure 4). The current top date of the noise temperature is about 40 K at 20 K physical temperature, which is not the lowest but enough charactaristic. We will develop the new design with low power consumption,and small size to fit for the satellite limitation. We also developing the scheme how to cool the system to get the enough performance.

3.5 Possibility of the phase-referencing

Phase referencing observations are a powerful method to determine accurate relative positions of radio sources, and longer integration times for weaker sources. High speed switching between sources less than 1 minutes period, and about 1,cm accuracy orbit determination are required. We are now studying the possibility of fast switching using the 2 control moment gyro 's (CMG) which is a higher torque actuator, with the combination of 4 reaction wheels which are used for the normal attitude control. We succeed to make the fast switching with 1 minutes period, 3.5 degree separation (Figure 5). We are also studying the possibility of obtaining a higher orbit accuracy using an

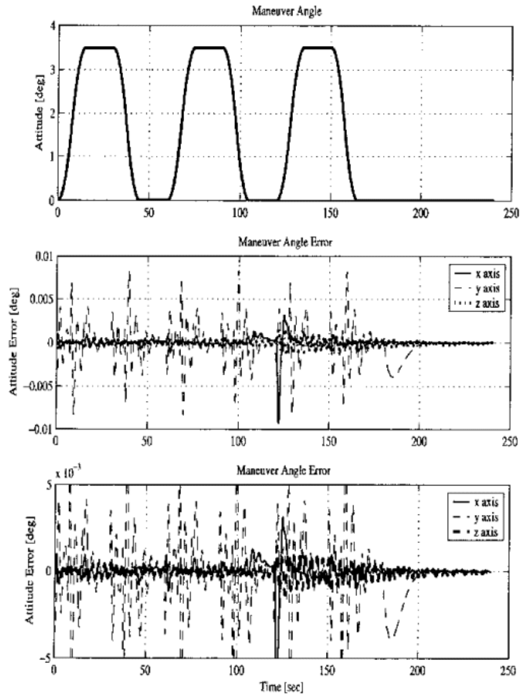


Figure 5. Simulation of the fast switching using 2 control momentums gyro and 4 reaction wheels. Top gives the motion of the pointing direction from 0 to 3.5 degree offset. Middle and lower panel shows the error of the attitude. Lower panel gives the magnified scele error.

on-board GPS system and accelerometer (Wu and Bar-Sever 2001).

4. Summary

We are now make a proposal of VSOP-2 mission to be submitted ISAS/JAXA. There are some of technically charenging items, and we made development some of them. We have the prospect that it is possible to realize this misson, in spite of some difficulties.

Finally, we gratefully acknowledge all collaborators who have joined discussions about the VSOP-2 mission. This mission is planned based on discussions with researchers from JPL, NRAO, CfA (US), DRAO, SGL (Canada), ATNF (Australia), JIVE (Europe), Univ. of Ibaraki, Hosei Univ., Yamaguchi Univ., NAOJ, and ISAS (Japan).

References

Hirabayashi, H. 2003, in this proceedings.

Wu, S.-C., and Bar-Sever, The Institute of Navigation, 14th International Technical Meeting, September 11-14, 2001 Salt Lake City, Utah

Development of a primary feed system for the parabolic rectangular reflector antenna dedicated for planetary radio emission

Hiroaki Misawa[1]
(*misawa@pparc.geophys.tohoku.ac.jp*),
Riichi Kudo[2], **Fuminori Tsuchiya**[1],
Akira Morioka[1], **and Tetsuro Kondo**[3]

[1] *Planetary Plasma and Atmospheric Research Center, Tohoku University*
Aza Aoba, Aoba-ku, Sendai 980-8578, Japan
[2] *Network Innovation Laboratories, NTT*
1-1 Hikarinooka, Yokosuka
Kanagawa 239-0847, Japan
[3] *Kashima Space Research Center*
Communications Research Laboratory
893-1 Hirai, Kashima, Ibaraki 314-8501, Japan

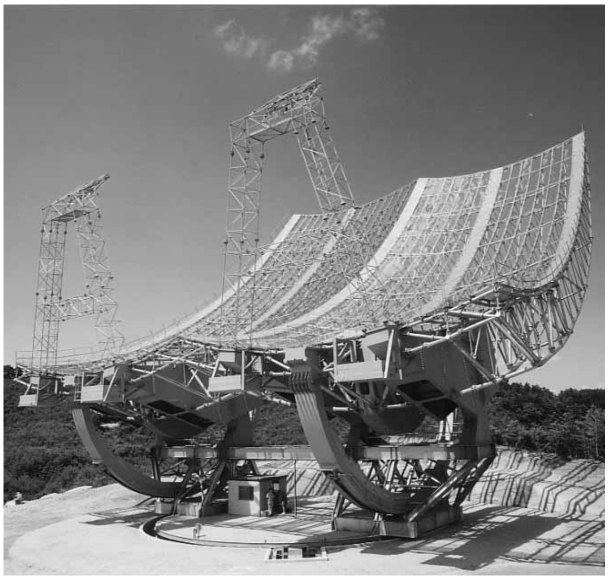


Figure 1. Panoramic view of the parabolic rectangular reflector antenna named IPRT. The aperture size is 33m(azimuth)×31m(altitude).

1. Introduction

Tohoku University has established a meter to decimeter wave range radio telescope, named IPRT (Iitate Planetary Radio Telescope), in 2001 at Iitate, Fukushima, Japan. The antenna of the radio telescope is a fully steerable offset-parabola type with the physical aperture area of 1023m2, and composed of a pair of same-shaped parabolic rectanglar sections (16.5m×31m) installed on one alt-azimuth mount (Figure 1). The radio telescope has been dedicated for exclusive and regular observation of planetary radio emissions to investigate electromagnetic environment of planets, particularly Jupiter's inner magnetosphere [*Misawa et al.*, 2001, *Tsuchiya et al.*, 2002].

On the observations of planetary radio emission, whose intensity is generally rather weak (at most several Jy's), polarization characteristic is one of key parameters to investigate the electromagnetic environment. It is therefore important to develop a primary feed system suitable for this unique shaped antenna with a high efficiency. We have developed the feed system, which is installed at the primary focus of IPRT and provided with a plane reflector (2.4m×2.4m), based on both numerical calculation and actual measurement of beam pattern. The estimated aperture efficiencies for both horizontal and vertical polarizations were finally achieved to be nearly 70%. In this report, we introducef the primary feed system briefly with process of the development.

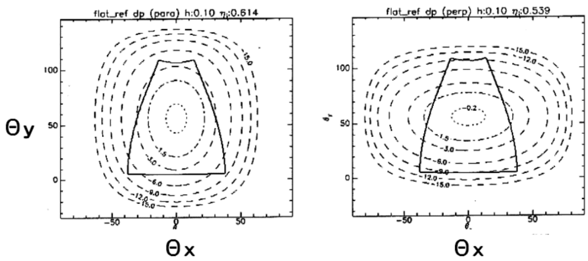


Figure 2. Calculated illumination patterns of the simple half-wave dipole element with a plane reflector for horizontally (left panel) and vertically (right panel) polarized components. The height of the element from the plane reflector is set to be 0.1λ, where λ is a wave length (0.92m at 325MHz). A quasi trapezoidal figure in each panel (bold line) represents the parabolic rectangle reflector viewed from the focus position. Contour lines represent relative power in a unit of dB with respect to the beam center. The estimated illumination efficiencies are 61% and 54% for horizontally and vertically polarized components, respectively.

2. Illumination efficiency

The primary feed system for a parabolic circular reflector antenna is generally composed of orthogonally crossed dipole antennas to measure polarization at a wave length of meter to decimeter. In case of IPRT, since the reflector is rectangular whose

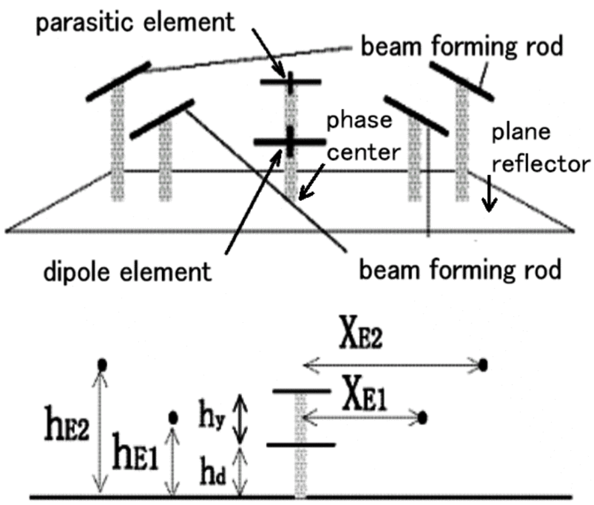


Figure 3. Schematic illustration of the new feed system with parasitic elements and beam forming rods. Major examined parameters are shown in the lower panel.

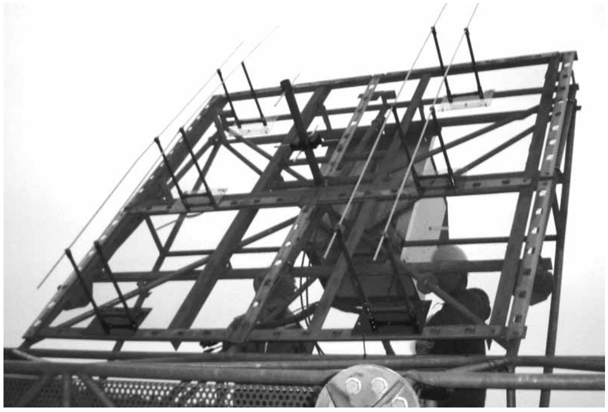


Figure 4. Panoramic view of the new feed system.

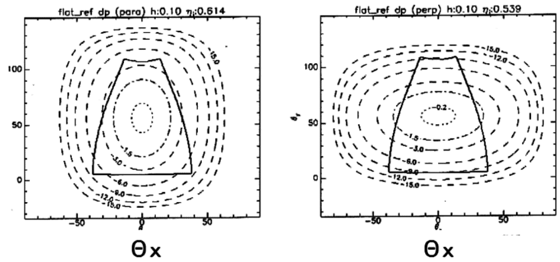


Figure 5. Illumination patterns of the new feed system measured using an approximately 1/6 scale model in the radio anechoic chamber. The display format is the sama as that of Figure 2. The position parameters are selected to be 0.25λ and 0.35λ for hd and hy, respectively, and 0.49λ, 0.43λ, 0.65λ, and 0.76λ for hE1, hE2, XE1, and XE2, respectively. The length of dipole and parasitic elements is selected to be 0.38λ and 0.39λ, respectively. Illumination efficiencies for both polarized components are achieved to be nearly 70%.

side lengths are not same each other (16.5m and 31m), it is almost impossible to obtain same illumination efficiencies for horizontally and vertically polarized components with simple crossed dipole antennas. In Figure 2, we show a result of illumination patterns for a simple half-wave dipole feed system, where the length and position of dipole elements with respect to the plane reflector are set to achieve almost maximum efficiency on IPRT; i.e, 61% and 54% for horizontally and vertically polarized components, respectively. Here the illumination patterns are numerically calculated with the moment method [*Harrigton,* 1968] for the observation frequency of 325MHz.

The reason of lower illumination efficiency of vertical polarization is mainly caused by larger leakage of illumination beam of vertical feed system. In order to reduce the leakage and revise illumination efficiency, we modified the primary feed system by adopting the following two ideas; i.e. 1)addition of a parasitic element: – adoption as the 'Yagi' antenna, to the half-wave dipole elements for both horizontally and vertically polarized components, and 2)addition of beam forming rods to the elements for vertically polarized component. As for the latter idea, effectiveness of the beam forming rods has been confirmed for polarization measurement with a cylindrical parabola antenna by *Kildal and Sorngard* [1980]. A schematic illustration and a panoramic view of the newly developed feed system are shown in Figure 3 and 4, respectively.

An illumination pattern for the new feed system was numerically calculated with the moment method, and positions of parasitic elements and beam matching rods, which enable high and almost same illumination efficiencies for the two polarized components, were investigated. In addition to the numerical calculation, the illumination patterns were actually confirmed using an approximately 1/6 scale model with the far-field measurement system in the radio anechoic chamber of Communications Research Laboratory, Japan. As the result, we have derived a suitable arrangement of the elements and rods which enables the illumination efficiencies of almost 70% for both polarized components, and show the illumination patterns measured in the radio anechoic chamber in Figure 5.

3. Aperture efficiency

In this study, we derived an aperture efficiency (η_{ap}) by estimation based on i) evaluation of several characteristic parameters of the antenna, and ii) actual measurement of signal intensities for ex-

traterrestrial radio sources whose radio flux densities are already known.
i) η_{ap} derived by evaluation of antenna parameters: An aperture efficiency of a reflector antenna is given by the following equation,

$$\eta_{ap} = e_r \eta_i \eta_t \eta_{rs} \eta_{bk} \tag{1}$$

Here, e_r is a radiation efficiency which represents a degree of signal conversion ratio from a radio wave to an electric signal: – a degree of impedance matching. We have achieved $e_r \sim 100\%$ by adjusting height and length of the elements. η_i is an illumination efficiency which we already introduced in the previous section. η_t, η_{rs}, and η_{bk} are transmission loss efficiency, random surface error efficiency and aperture brockage efficiency, respectively. The surface of the main reflector and plane reflector of the primary feed system is made of a stainless mesh with the pitch size of 2cm and 1cm for the main and plane reflectors, respectively. The total η_t value of the antenna is estimated to be nearly 99.5% at 325MHz. The undulation of main reflector surface was actually measured and the average surface roughness was estimated to be 8mm-rms. This result gives $\eta_{rs} \sim 98.8\%$ at 325MHz. As for the aperture brockage, since IPRT is the type of offset parabola antenna, the aperture brockage is considered to be negligible: $- \eta_{bk} \sim 100\%$. Thus, based on the evaluation for each efficiency, aperture efficiency is finally estimated to be nearly 69%.
ii) η_{ap} derived by actual measurement: When we measure some extraterrestrial radio source whose radio flux density is S, received signal power P is given by the following equation,

$$P = 0.5 A_e G \Delta f S \tag{2}$$

where G and Δf are system gain and effective band width of a receiver system, respectively. A_e is effective aperture area given by the product of physical aperture area A_p ($1023\mathrm{m}^2$) and an aperture efficiency η_{ap}. On the receiver system of IPRT, it is provided with the gain calibration system which consists of hot and cold loads at the front-end section, then G can be obtained with the so-called Y-factor method, and Δf is selectable at either 5 or 10MHz [*Tsuchiya et al.,* 2002]. The η_{ap} value is therefore derived using known or measurable parameters as,

$$\eta_{ap} = 2P / A_p G \Delta f S \tag{3}$$

We measured η_{ap} by observations of intense extraterrestrial radio sources, such as 3C144(Tau-A), 3C405(Cyg-A) and 3C461(Cas-A). As the result, the actual aperture efficiency of IPRT was derived to be 61∼71% based on the measurement of these radio sources. The somewhat large ambiguity of aperture efficiency is mainly caused by uncertainties of absolute radio flux density of the radio sources and the hot load temperature (see *Tsuchiya et al.* [2003]). Thus, it is confirmed that numerically expected aperture efficiency is almost achieved on the actual radio telescope system, and usage of a parasitic element and beam matching rod is actually effective for the parabolic rectangular reflector antenna.

4. Summary

We have examined a primary feed system suitable for the parabolic rectangular reflector antenna of Iitate Planetary Radio Telescope (IPRT). The illumination efficiency of the feed system has been investigated with numerical calculation with the moment method, and actual measurement using a small scale model in a radio anechoic chamber. It is suggested that the usage of a dipole antenna combined with a parasitic element and beam forming rods is one of the suitable feed systems to measure both horizontally and vertically polarized waves with high illumination efficiency. An actual measurement of an aperture efficiency of IPRT with the developed primary feed system has been made by means of extraterrestrial radio sources, and it is finally confirmed that the aperture efficiency is achieved to be nearly 70% for both horizontal and vertical polarizations.

Acknowledgment: The authors would like to appreciate Masato Tanaka and Yoshiyuki Fujii, Communications Research Laboratory for their assistance on measurement of characteristics of the primary feed system in the anechoic chamber and helpful suggestions on development of a beam forming feed system.

References

Harrison, R. F., in Field computation by moment methods, Macmillan press, New York, 1968.

Kildal, P., E. Sorngard, Circularly polarized feed for cylindrical parabolic reflector antennas, IEEE Trans. Antenna Propagat., AP-28, 210–215, 1980.

Misawa, H., A. Morioka, F. Tsuchiya, Y. Miyoshi, T. Watanabe, R. Kudo, and T. Kondo, Newly developed meter to decimeter wave range radio telescope for the investigation of planetary environments, Proc. 34th ISAS Lunar Planet. Symp., 175–178, 2001.

Tsuchiya, F., H. Misawa, Y. Miyoshi, T. Watanabe, R. Kudo, A. Morioka, and T. Kondo, Performance test of newly developed radio telescope and receivers at the Iitate Observatory, Proc. 35th ISAS Lunar Planet. Symp., 211–214, 2002.

Tsuchiya, F., H. Misawa, R. Kudo, Y. Miyoshi, T. Watanabe, A. Morioka, and T. Kondo, First light of Jovian synchrotron radiation with the Iitate Planetary Radio Telescope, Proc. 36th ISAS Lunar Planet. Symp., 222–225, 2003.

- News - News - News - News - News - News - News - News - News - News - News -

100th meeting of the Geodetic Society of Japan was held at CRL

Yasuhiro Koyama (*koyama@crl.go.jp*)

Kashima Space Research Center
Communications Research Laboratory
893-1 Hirai, Kashima, Ibaraki 314-8501, Japan

The fall regular meeting of the Geodetic Society of Japan was held at the Headquarter of Communications Research Laboratory (Koganei, Tokyo) for three days from October 22, 2003. The society is having regular meetings in fall and spring. The fall meeting of this year was the 100th memorial meeting and honorably CRL was awarded as the host. The first meeting of the society was held in the next city of Koganei (Kodaira) in 1954 with only 11 presentations while there were 109 presentations and about 200 participants in the 100th meeting. To memorize the meeting, a board was prepared and each participant signed with short messages (see the picture below). The background design was taken from the cover page of the Journal of the Geodetic Society of Japan. It looks like the orbits of satellites and the Earth, but some may feel it is associated with the Earth's interior or the surface of the flat water with ripples according to their interested research fields.

LOC Chair : Taizoh Yoshino
LOC members : Tetsuro Kondo, Yasuhiro Koyama, and Ryuichi Ichikawa

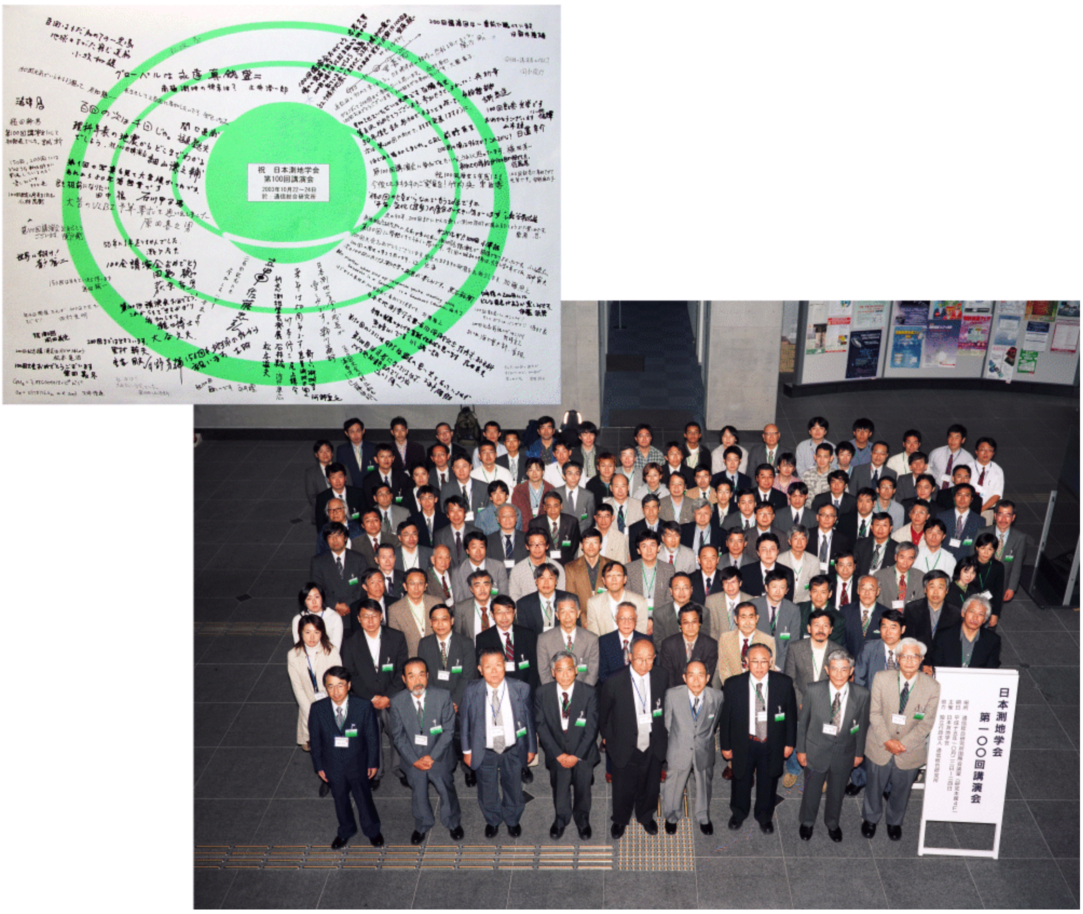


Photo 1. Collection of the writing and the participants of the 100th meeting.

"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. Inquires on this issue should be addressed to T. Kondo, Kashima Space Research Center, Communications Research Laboratory, 893-1 Hirai, Kashima, Ibaraki 314-8501, 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/"**.

IVS CRL TECHNOLOGY DEVELOPMENT CENTER NEWS No.23, November 2003

International VLBI Service for Geodesy and Astrometry
CRL Technology Development Center News
published by
Communications Research Laboratory, 4-2-1 Nukui-kita, Koganei, Tokyo 184-8795, Japan