ISSN 1882-3440

TECHNOLOGY DEVELOPMENT CENTER NEWS

NATIONAL INSTITUTE OF INFORMATION AND COMMUNICATIONS TECHNOLOGY
Serial No. 30 October 2009

CONTENTS

The 8th NICT IVS-TDC Symposium

Hiroshi Takiguchi[1] (*htaki@nict.go.jp*), **and Yasuhiro Koyama**[2]

[1] *Space-Time Standards Group, Kashima Space Research Center, National Institute of Information and Communications Technology, 893-1 Hirai, Kashima, Ibaraki, 314-8501, Japan*
[2] *Space-Time Standards Group, National Institute of Information and Communications Technology, 4-2-1 Nukui-Kitamachi, Koganei, Tokyo, 184-8795, Japan*

The 8th IVS (International VLBI Service for Geodesy and Astrometry) TDC (Technical Development Center) symposium was held at Kashima Space Research Center (KSRC) of NICT on 18th February 2009. This symposium is held once every year to exchange the recent results and achievements related with technology developments of VLBI and other fields.

This time, 26 oral presentations and 3 poster presentation were presented at 4 sessions ("Software Development", "System Development", "Astronomical VLBI", "VLBI Experiments and Data Analysis"). In total, 39 researchers and students from 9 institutes (Geograhical Survey Institute, National Astronomical Observatory, Japan Aerospace Exploration Agency, Shanghai Astronomical Observatory, Yokohama National University, Kagoshima University, Hokkaido University, Elecs Industry co., ltd., and NICT) attended this symposium.

Figure 1. The symposium participants and the Kashima 34m antenna.

In each session, the interesting topics were presented. Especially at the System Development session, almost all presentations which considered VLBI2010 were reported. First, the technical developments at Kashima Space Research Center of NICT were introduced. At the status report of the development of next-generation AD sampler (ADS3000+), the author evaluated various sample mode, and obtained 4 Gsps fringe finally. And also, the present status of the compact VLBI system (MARBLE) development, and the proposal of VLBI Data Interchange Format (VDIF) as a common data format for flexible data processing at eVLBI were presented.

As for the topics of astronomy, the VLBI application for the VRAD mission of Japanese lunar explorer program KAGUYA, the activities of Chinese VLBI Network, and the observation of black hole structure were reported.

And also, the studies of development of a GPS software receiver and the computation of ray-traced troposphere delay were presented. These studies achieved high-speed computation by using GPUs. The presentation by students of Yokohama National University were very interested. Two students have researched to dissolve the delay of Earthquake Early Warnings (Kinkyu Jishin Sokuho) that was provided by the Japan Meteorological Agency (JMA) in the digital TV.

At the lunch break, a brief tour of the new compact antenna was offered. That antenna is a part of compact VLBI system named MARBLE (Multiple Antenna Radio-interferometer for Baseline Length Evaluation). The presentations about that antenna were also presented in this symposium.

Additionally, as the 20th anniversary of Kashima 34m antenna building memory, we offered special keynote presentation by Professor Kawaguchi of National Astronomical Observatory (see page 36).

We would like to thank all participants for the contribution to fruitful symposium. Here we have 9 papers in the proceedings. It would be our pleasure if these are useful to many persons. The materials of these presentations are available on the web at
`http://www2.nict.go.jp/w/w114/stmp/ivstdc/sympo090218/tdcsympo8.html` (*in Japanese*).

Figure 2. The state of the symposium.

Development of a GPS software receiver based on K5/VSSP and a GPU

Tadahiro Gotoh, Thomas Hobiger, Jun Amagai, Yasuhiro Koyama, and Tetsuro Kondo

Abstract: Graphics processing units provide low-cost massive parallel computing performance, which can be utilized for the implementation of a GPS software receiver. In order to realize a real-time capable system the crucial stages of the receiver should be optimized to suit the requirements of a parallel processor. First results from such a receiver development are presented together with a short overview of the hard- and software systems.

1. Introduction

Driven by the increase of CPU performance GPS/GNSS software receivers have become more and more popular as they offer a flexible and extendible platform for development and testing of new applications. Such a software radio can not only mimic the functionality of its hardware counterpart, but allows the user to carry out the signal processing chain with unprecedented floating point precision. Basically, software receivers can take over all the functionality of the hardware radios, once the digitized signals are accessible on the personal computer, but even modern multi-core CPUs are not capable of handling several channels in real-time. Thus, graphics processing units (GPUs) seem to be a possible way to go to overcome this drawback, without suffering the loss of the advantages a software receiver could bring.

2. Hard-ware stages

As mentioned before, software receivers require that the RF signals are down-converted and digitized by hardware components before they can be processed on the PC. Moreover, as the system which has been developed in this study is not only dedicated to GPS but can be also used for time-transfer applications using PRN-code like signals, flexible and robust hardware parts have been deployed. Several equipments which have been originally developed for Very Long Baseline Interferometry (VLBI) are used beside other off-the-shelf components. Figure 1 displays the hardware components which are utilized for the down- and analog/digital (A/D) conversion.

The RF signals, which are also processed by a commercial hardware receiver (JAVAD), are received from standard geodetic GPS antenna (Ashtech choke-ring antenna). Thereafter L1 and L2 signals are down-converted to two intermediate

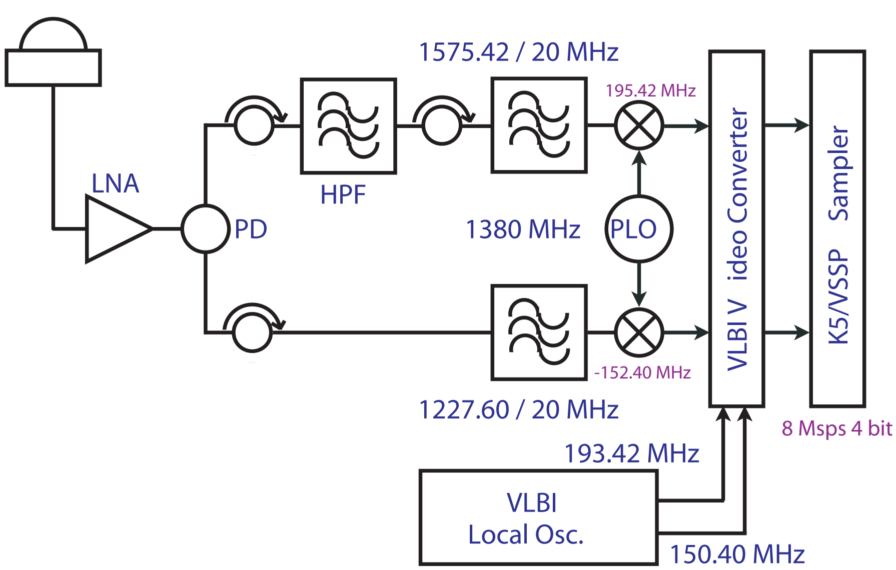

Figure 1. Hardware components which are used for down conversion and digitization of the GPS signals.

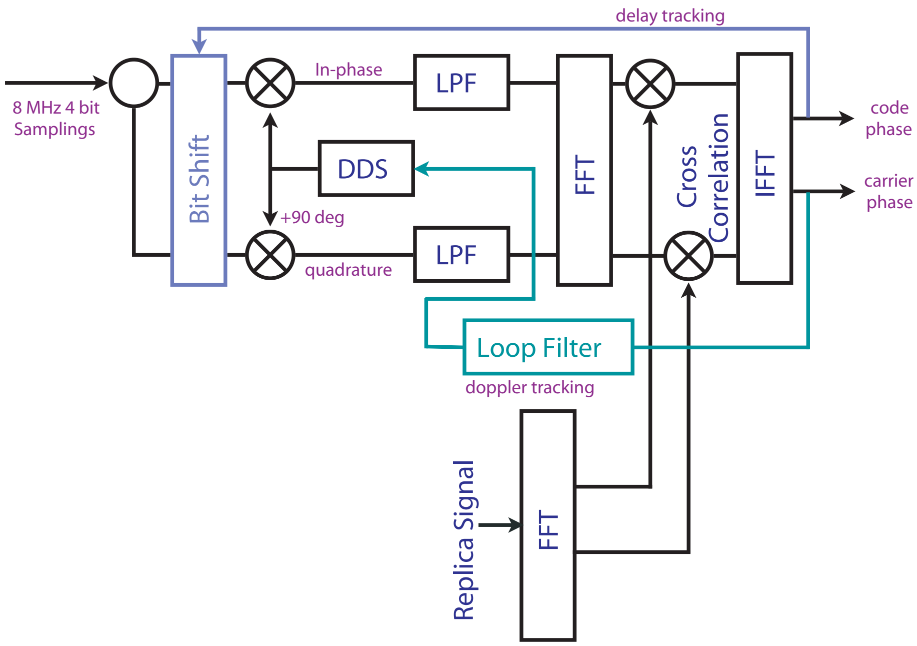

Figure 2. Schematics of the real-time software receiver, running on the GPU. The numerically controlled oscillator is updated via the Doppler tracking loop, ensuring a continuous tracking of the carrier phase. Delay tracking is performed via proper variation of the read-pointer which feeds the FX engine with data.

frequencies using a phase locked oscillator operating at 1380 MHz. These intermediate frequencies are fed to a video converter where they are mixed with the 2nd local oscillator running at 193.42 MHz. After this stage the signals are digitized via a sampler, which has been developed for VLBI. Since the digital signals are output via an USB 2.0 interface they can be directly handled by a PC. Although displayed in Figure 1, processing of L2 signals has been currently signals turned off and will be implemented in the near future. Thus, in the following the usage of L1 C/A code is considered only. Basically, a dual-frequency receiver can be realized from the following description by adding a second GPU which is dedicated to the processing of L2C code signals.

3. GPS software receiver implementation on a GPU

Based on the conclusion that an FX architecture has the potential to support real-time applications, a GPS software receiver has been designed and implemented by the help of CUDA [1], which provides a convenient interface for developing and porting programs to the GPU. Figure 2 shows the schematics of the complete multi-channel architecture, including the delay and Doppler tracking loop.

For high-sampling rates data can be read from a hard-disc, but for moderate sampling rates it is possible to run the receiver in real-time mode, reading the data-stream via a ring-buffer. Each update Doppler loop cycle is used to transfer the results, i.e. delays, phases and amplitudes, back to the CPU and to copy new sampled data to GPU memory. The K5/VSSP sampler[2], which is used for this study, provides quantization levels of 1,2,4 and 8 bits and sampling rates up to 64 Msps. One and two bit quantization lead to a significant decrease of precision of the obtained observables. On the other hand, the four and eight bit representations don't differ significantly. Therefore, four bit representation seems to be the best trade-off between data-size and quality of the analog signal representation. Decoding of the of the bit-stream, which is transmitted via the USB bus, can be done efficiently on the CPU by the help of a look-up table and the unpacked signed integer values can be filled into the ring-buffer where they are waiting to be transmitted to the GPU. If data is expected to be processed off-line, the incoming bit-stream will be recorded to hard disc at first, and decoded directly before it is sent to the GPU.

4. Results

4.1 Verification against hardware receiver output

Since the JAVAD hardware receiver tracks the same signals which are fed to the software receiver chain, it is possible to compare the obtained observables since they are expected to differ only by a constant offset caused by different cable lengths. Figure 3 displays the results from such a comparsion for a selected PRN.

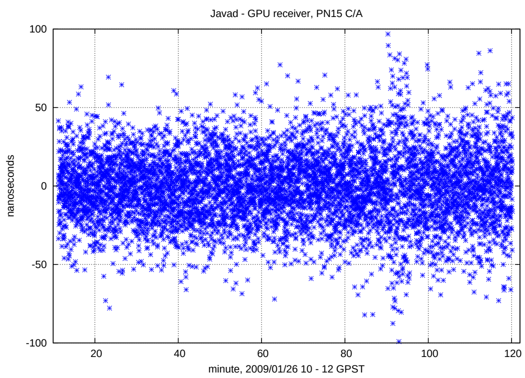

Figure 3. Javad vs. GPU software receiver. Differences of the C/A code delays obtained for PRN15 on 2009, DOY 26 at 11:00 UT.

4.2 Formal error of the observables

Based on the 1kHz raw-output, one can apply a linear least-square fit to each 1000 data-points in order to obtain 1 Hz phase and delay observables which can be processed by geodetic analysis software packages. The residuals from these fittings can be used to calculate root mean square (RMS) values for each PRN. These RMS values can be interpreted as formal errors of the observables and are expected to be mainly dependent on the elevation angle. Figure 4 shows results for different PRNs, which validates the elevation angle dependence of the formal errors.

5. Outlook and fields of application

The GPU seems to be an ideal candidate for the realization of a GPS software radio as it offers huge parallel processing power and supersedes the CPU concerning cost/performance. In order to realize a real-time dual-frequency GPS receiver one could equip a PC with two GPU cards which would allow separate processing of L1 and L2 signals. Despite other GPGPU applications, the available bandwidth of the PCI bus does not appear as an additional bottle neck, even if data-rates up to 64 Msps

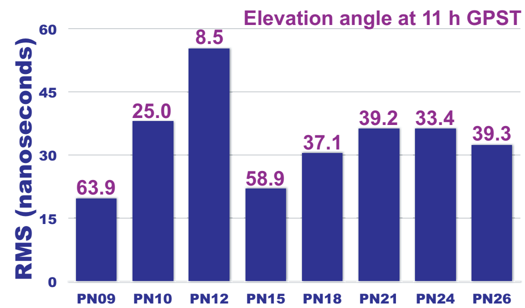

Figure 4. RMS of the delays for different PRNs, together with their elevation angle at 2009/DOY 26, 11 h GPS time.

would be sent between the CPU and the GPU. Like any other software receiver, the realized implementation is very flexible and can be adapted to new signals or applications without huge modifications. Moreover, testing of new algorithms or creation of innovative applications can be done within very short development time. For example, the GPU software receiver has been successfully applied to time- and frequency transfer experiments, which operate with similar PRN code signals as GPS. Other applications like mitigation of multipath and ionosphere monitoring are under development.

References

[1] NVIDIA (2008a), CUDA Programming Guide 2.1, http://developer.download.nvidia.com/

[2] Kondo T, Koyama Y, Takeuchi H, Kimura M (2006), Development of a New VLBI Sampler Unit (K5/VSSP32) Equipped with a USB 2.0 Interface, in: Behrend, Dirk, Baver, Karen (Eds.), International VLBI Service for Geodesy and Astrometry 2006 General Meeting Proceedings. NASA/CP-2006-214140, 195-199.

Accelerating the computation of ray-traced troposphere delays by GPUs

Thomas Hobiger (*hobiger@nict.go.jp*),
Ryuichi Ichikawa,
Yasuhiro Koyama,
and Tetsuro Kondo

National Institute of Information and Communications Technology
4-2-1 Nukui-Kitamachi, Koganei
184-8795 Tokyo
Japan

Abstract: The computation of ray-traced slant delays from numerical weather models is a demanding task, if a large number of rays have to be processed or if real-time operation is anticipated. Thus, ray propagation solvers have been ported to graphics processing unit (GPU), which provides huge parallel processing performance at low cost. A comparison with results obtained on the CPU verify that modern graphic cards can provide identical results, but significantly accelerate the computation by nearly a factor of 20.

1. Introduction

The direct usage of ray-traced slant delays for space geodetic techniques has been recently confirmed [Hobiger et al., 2008a] and a dedicated software package named "Kashima Ray-tracing Tools (KARAT) " (described in Hobiger et al. [2008b]) has been developed for this purpose. Nevertheless, even sophisticated algorithms do not allow to compute more than about 1000 rays/sec. on a standard single core CPU. Considering that an average type 30-sec RINEX observation file contains up to 30,000 rays/day it becomes clear that this performance is not enough to handle a large number of stations and/or provide ray-traced troposphere corrections in (near-) real-time. Taking into account its reasonable cost w.r.t to modern CPUs, the GPU as an alternative parallel processing platforms seems to be an ideal candidate for running the ray-tracing calculations.

2. Ray-tracing on the GPU

Driven by the demand of different scientific and application oriented fields, video card vendors provide software tools which allow simple and straightforward software development running on the GPU [Nguyen, 2007]. Based on the existing KARAT modules, a parallel version of the Thayer algorithm has been developed. Since the available memory on the graphic card (table 1) does not allow to store the complete weather model on the GPU a special algorithm has been developed which selects a dedicated region around the station for which slant delays have to be computed (see Hobiger et al. [2009]). In order to handle the iterative process which steers the starting elevation angle until the outgoing elevation angle meets the vacuum elevation angle (see e.g. Hobiger et al. [2008b]) each ray is checked for this condition when the uppermost layer is reached. If this criteria is fulfilled, the ray is flagged and not processed anymore. If all rays are flagged the ray-tracing is stopped and the results are copied from back to the CPU. Details of the algorithm can be found in Hobiger et al. [2009].

3. Results

Using the hard- and software components listed in table 1 a ray-tracing comparison between CPU and GPU based results has been carried out. Based on 24 hours of meso-scale analysis weather data for July 1st, 2008 a total number of 30,000 randomly generated rays for IGS station GMSD has been processed on the CPU as well as on the GPU.

Table 1. Utilized soft- and hardware components

	CPU	GPU
	Intel Core 2 Q9450	NVIDIA GeForce GTX 280
Cores	4	240
Clock	2660 MHz	1296 MHz
Memory	4 GB	1 GB
Compiler	g++ 4.3	nvcc 2.0
OS	Fedora 9 (64 bit)	

3.1 Differences CPU-GPU

The output from both runs was taken and differences were computed in order to conclude on systematics between the GPU and CPU solutions for the obtained delays and bending angles. Figure 1 depicts the delay differences, yielding only negligible discrepancies in the nanometer range. The systematic increase of the differences is assigned to different treatment of floating point numbers (details discussed in Hobiger et al. [2009]). A similar comparison for the obtained bending angles (figure 2) reveals systematic differences in the micro arc second range, which is also negligible and far beyond any accuracy goal for ray-tracing with numerical weather models. The elevation dependent pattern of the differences can also be related to different treatment of floating point operations on the

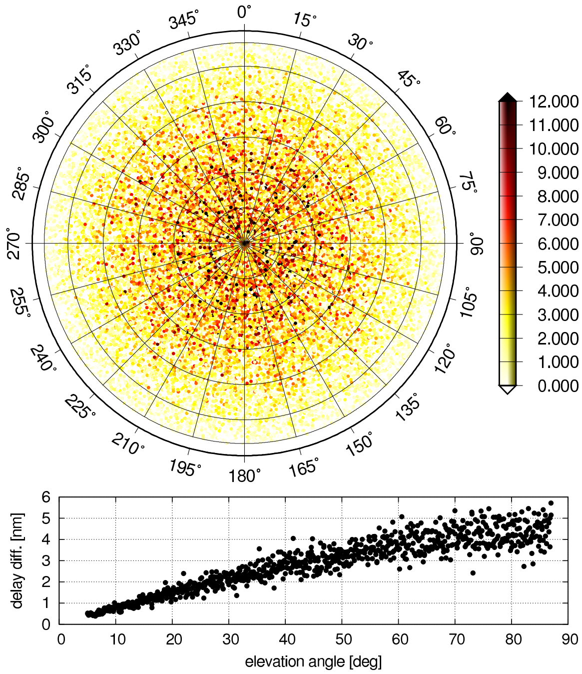

Figure 1. Absolute values of the delay differences (in nanometer) between the CPU and GPU results for different azimuth and elevation angles (upper plot). The lower plot shows the azimuthal mean values using an elevation bin width of 0.02 degrees.

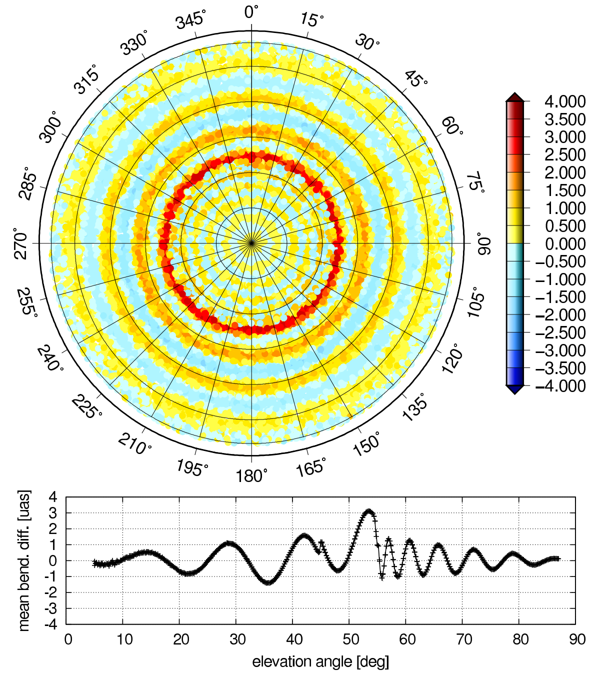

Figure 2. Bending angle differences (in micro arc seconds) between the CPU and GPU results for different azimuth and elevation angles (upper plot). The lower plot shows the azimuthal mean values using an elevation bin width of 0.02 degrees.

CPU and GPU. This is confirmed by the fact that at 45 degrees a jump occurs, which can be assigned to different implementation of trigonometric functions.

3.2 Performance measures

In order to compare the ray-tracing performance between the CPU and the GPU, a varying number of observations (up to 30,000) has been processed. The average performance, measured in ray/sec., is displayed in figure 3. Although the computation time on the GPU contains the overhead of the data-transfer over the PCI bus, ray-tracing on the graphic card outperforms the CPU already after a few hundred of rays. If the number of rays exceeds 10,000 the GPU solution is already 12 times faster and 30,000 rays can be processed in approximately 1/18 of the time taken on the CPU. Due to the fact that the number of parallel threads can be distributed sometimes more and sometimes less efficiently the performance curve of the GPU is not steadily increasing, but reveals small jumps which are also discussed in Hobiger et al. [2009].

4. Conclusion and outlook

Computation of ray-traced troposphere slant delays is a time-consuming effort which can be reduced significantly if this task is carried out on the GPU. It could be verified that results agree well with those obtained from computations on the CPU, leaving only negligible differences due to different implementation of floating point operations. Based on these findings, the current ray-tracing software will be revised and ray-tracing modules will be replaced with those which support computations on the GPU. Thus, the usage of the GPU will help to realize a ray-tracing service providing the user with troposphere corrections in (near-) real-time, given that numerical weather models are available as predictions. Moreover, other applications with a large number of rays (e.g. InSAR, Foster et al. [2006]) can be now supported within a reasonable amount of processing time. Since the performance of GPUs is expected to continue growing similar to the last years, the relatively cheap computation power of the graphics card appears to be good choice for scientific problems, which can be translated to parallel processing task, like the one discussed here.

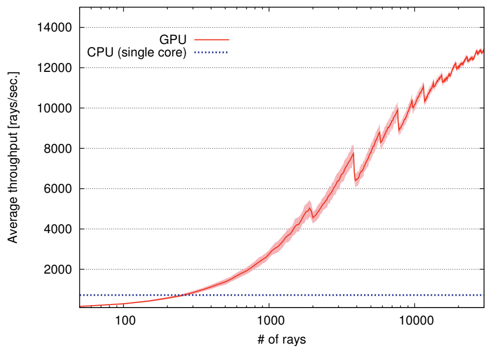

Figure 3. Ray-tracing performance of the CPU and GPU measured in rays/second. The solid line represents the mean performance together with the formal error (at the 3σ level) from GPU computations for a varying number of rays. For each number of rays 64 runs were carried out and averages, as well as standard deviations have been computed. The dashed line shows the corresponding single CPU performance. The same processing scheme has been applied to the CPU computations, whereas no error boundaries are displayed as there has been hardly any performance variation on the CPU.

Acknowledgments: We are grateful for an incentive research fund of NICT which enabled us to purchase the necessary hardware components. Early parts of this research were carried out under a fellowship of the Japan Society for the Promotion of Science (project P06603).

References

[1] Foster J., B. Brooks, T. Cherubini, C. Shacat, S. Businger, and C. L. Werner (2006), Mitigating atmospheric noise for InSAR using a high resolution weather model, *Geophys. Res. Lett.*, 33, L16304, doi:10.1029/2006GL026781, 2006.

[2] Hobiger T., R. Ichikawa, T. Takasu, Y. Koyama, and T. Kondo (2008a), Ray-traced troposphere slant delays for precise point positioning, *Earth Planets Space*, Vol. 60 (No. 5), pp. e1-e4, 2008.

[3] Hobiger T., R. Ichikawa, Y. Koyama, and T. Kondo (2008b), Fast and accurate ray-tracing algorithms for real-time space geodetic applications using numerical weather models, *J. Geophys. Res.*, 113, D20302, doi:10.1029/2008JD010503, 2008.

[4] Hobiger T., R. Ichikawa, Y. Koyama, and T. Kondo (2009), Computation of troposphere slant delays on a GPU, *IEEE Transactions of Geoscience and Remote Sensing*, in print, 2009.

[5] Nguyen H. (2007), "GPU Gems 3: Programming Techniques for High-Performance Graphics and General-Purpose Computation", Addison-Wesley Professional, 2007.

Technical Developments Towards VLBI2010

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

National Institute of Information and Communications Technology, 4-2-1 Nukui-Kitamachi, Koganei, Tokyo 184-8795, Japan

Abstract: At Kashima Space Research Center of NICT, two main research projects are running. One is the e-VLBI project for rapid estimation of the Earth Orientation Parameters, i.e. dUT1 and wobble parameters. The other project is to develop Multiple Antenna Radio-interferometer for Baseline Length Evaluation to demonstrate the capability to measure precise baseline length which can be used as the reference for the other geodetic measurements like Global Positioning System. For these projects, we are performing research and developments of new hardware systems and software programs for observations, data processing, and data analysis. Most of these developments are considered to be consistent with the concepts of VLBI2010 and will contribute to realize the VLBI2010 system.

1. Introduction

Discussions of the next generation geodetic VLBI system, VLBI2010, started in 2003 under the auspice of the working group 3 of the IVS. In the final report of the working group, which was published in 2005, key concepts of the VLBI2010 were defined and presented. Following the discussions made by the working group, the VLBI2010 committee was established under the IVS and the status report of the committee was just presented in the end of 2008. National Institute of Information and Communications Technology (NICT) has been performing research and developments related with the VLBI observing systems and data processing systems as the activities of Technology Development Center of IVS. Since the goals of the VLBI2010 are to realize 1mm position accuracy on global scales, to realize continuous measurements for time series of station positions and Earth orientation parameters, and to decrease the turnaround time to process the observed data within 24 hours, a lot of technological developments have to be performed. In this report, our current development projects which are aimed to contribute for the realization of the VLBI2010 concepts, are reported.

2. Data Acquisition System

Since around 2000, NICT has been developing K5 VLBI Observation System as the new VLBI back-end system. In contrast to the previous K4 VLBI system, which was developed with the specially designed high-speed cassette tape recording system, the K5 VLBI system can be characterized as a system designed with the commodity products such as personal computers, hard disks, and network components. This strategy has been quite successful since both high flexibility and high performance have been realized in the VLBI observation and data processing system. We have developed two classes of the data acquisition terminal as the K5 system. One is the K5/VSSP (versatile scientific sampling processor) system series (Kondo et al., 2008) and the other is the K5/VSI system series (Koyama et al., 2008). The K5/VSSP system and its next generation K5/VSSP32 are designed to support current global geodetic VLBI observations and are actually used for the IVS sessions at several stations including Kashima, Tsukuba, Syowa, and Koganei IVS stations.

On the other hand, the other K5 data acquisition terminal, i.e. K5/VSI, has been developed to support much higher data rate than the commonly used data rate at present. To input the data streams from the VSI-H compliant devices, such as the A/D sampler units, a special board called PC-VSI board has been developed. The board is installed in the PCI-X expansion bus slot in a PC running Linux, and it can support high-speed data transfer and recording up to 2 Gbps with each board. By using two PC systems running Linux, each equipped with a PC-VSI board and a RAID controller board, one K5/VSI recording terminal (Figure 1 and Figure 2) can be configured. Since the K5/VSI recording terminal can record data streams input through VSI data ports, it is considered to be a DTS unit with only DIM capabilities. One K5/VSI recording terminal consists of two rack-mounted Linux operating PC units and necessary auxiliary components like an LCD (liquid crystal display) display, a keyboard, a mouse, and a switch for the components. Each PC unit is installed with a PC-VSI board and a RAID controller board on its PCI-X expansion bus slot. Sixteen 1 TB hard disks are connected to and controlled by each RAID controller board to configure the RAID-0 system. As the results, 32 TB of total data capacity and 4.096 Gbps maximum data rate have been realized with each K5/VSI data acquisition terminal. If the data are recorded continuously, the total capacity can support recordings up to 17.36 hours. The capacity of the recording terminal can also be enlarged by replacing the hard disk units if high-volume hard disks with more than 1 TB of disk capacity become available in the future. Since the RAID controller board is used in a Linux PC environment, the data files can be easily accessed from application programs as simple data files on the Linux operating system.

Figure 1. K5 Recording Terminal (Front View).

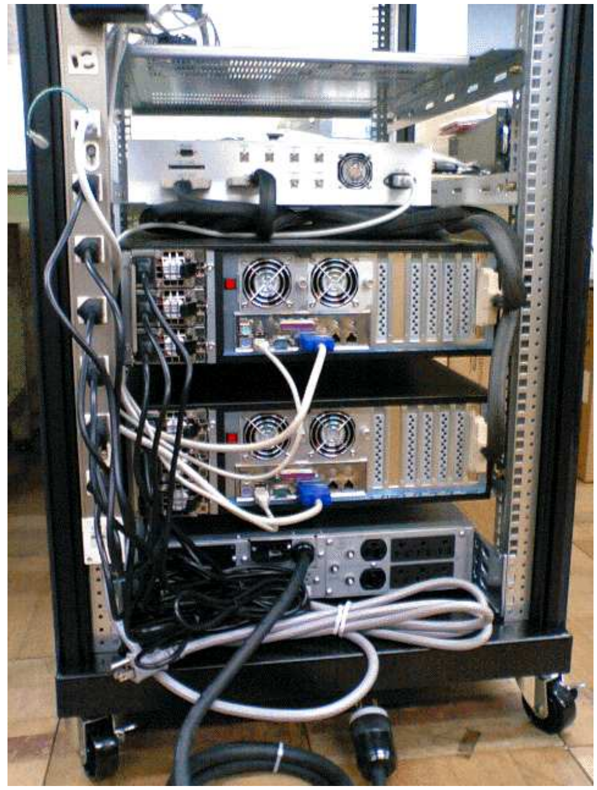

Figure 2. K5 Recording Terminal (Rear View).

3. Digital Back-end System

As the VSI-H compliant high speed A/D sampler units, three series of the models, i.e. ADS1000, ADS2000, and ADS3000, have been developed (Koyama et al., 2008). ADS1000 is capable to sample wide frequency band of 512MHz at the fixed sampling rate of 1024MHz either with 1 bits/sample or 2 bits/sample sampling modes. ADS2000 is capable to sample 16 independent baseband channels with 64MHz sampling rate and either with 1 bits/sample or 2 bits/sample sampling modes. ADS1000 units are currently used at many astronomical VLBI stations including VERA stations, KVN stations, and JVN stations. ADS2000 units are now mainly used when we perform real-time e-VLBI observations with EVN and Australian VLBI stations. On the other hand, ADS3000 unit has been designed to support both single channel sampling mode like ADS1000 and multiple channel sampling mode like ADS2000 by utilizing a high speed FPGA (field programmable gate array) chip and a high speed A/D sampling chip. ADS3000 sampler units can sample wide frequency bandwidths of the baseband signal up to 1024 MHz with a sampling rate of 2048 Msps. A high-speed FPGA chip is equipped inside the unit and can be used to process the input data stream for digital filtering and digital baseband conversion processing. By developing a specialized program for the FPGA chip, ADS3000 has a potential to support various observing modes without hardware baseband converters. After developing two units of the ADS3000, we started to extend the capabilities of the unit by adopting a faster A/D sampler chip and two new FPGA chips replacing one older FPGA chip in ADS3000. Figure 3 shows the pictures of the extended version of the units which we named as ADS3000+.

The EV8AQ160 A/D sampler chip was recently released from the e2V corporation and was adopted for the development of ADS3000+. The chip is capable of sampling high-speed analog data at a rate of up to 5 GHz. The chip can work at a clock rate of up to 2.5 GHz and the input signal can be sampled at the double speed of the clock rate. By using this capability, the maximum sampling speed of the ADS3000+ system is now 4096 Msps, al-

Figure 3. ADS3000+ Digital Back-end System.

though it will be necessary to develop a mechanism to handle such a high-speed data stream inside the unit. To process the high-speed digital data from the sampler chip, two FPGA chips have been configured. These two FPGA chips are cascaded on the processing board of the ADS3000+ system. The first-stage FPGA chip is used for high-speed data processing, such as de-multiplexing and multiplexing the data, and the second-stage FPGA chip is used for complex data processing, such as digital filtering and digital base-band converter processing. Figure 8 shows the schematic diagram of the ADS3000+, and Table 4 summarizes the major differences in the design of the ADS3000 and ADS3000+ units. Currently, necessary software programs to be loaded on two FPGA chips are under development. In the beginning, only limited simple functions will be realized and ADS3000+ will only support simple observing modes, such as the sampling rate of 2048 Msps for two baseband signal channels. In the next step, digital filtering and baseband converting programs will be developed and loaded onto the second-stage FPGA chip to support multiple channel observations. If this capability is realized, current hardware baseband converter units will become unnecessary and the VLBI observing system will become much simpler.

4. Wide-band Observing System

For the next generation VLBI2010 observing systems, the use of wide frequency receiver system has been proposed. NICT has been developing the MARBLE (Multiple Antenna Radio-interferometer for Baseline Length Evaluation) system with the close cooperation with Geographic Survey Institute (GSI) and the quad ridge horn antenna has been adopted as the primary feeds of the small telescopes (Ichikawa et al., 2008, Ishii et al., 2009). The 1.6m small telescope system has been developed as the first such telescope for the MARBLE system and has been placed on the roof top of the building near the 34m antenna VLBI station at Kashima Space Research Center of NICT (Figure 4).

Figure 4. 1.6m Small Telescope for MARBLE System.

Currently, the received signal from the quad ridge horn antenna with the frequency range of 2 to 18 GHz is divided into two observing bands in S-band (2-4 GHz) and X-band (6-9GHz) and the other frequency range is discarded. Therefore, in the future, we would like to utilize the capability to receive wide frequency range of signal by upgrading the receiver system of large telescopes of the MARBLE system like the 34m antenna at Kashima. Thus, we expect the MARBLE system to become the valuable testbed to evaluate the wide-band delay concept of the VLBI2010.

5. Software Correlator and Automated Data Analysis

In the discussions of the VLBI2010, it is assumed that the software correlator system will be adopted to realize flexible and efficient data processing for the VLBI2010. The K5 software correlator system has been used at various places including the Tsukuba Correlator of GSI where INT2 intensive IVS sessions are routinely processed. The reliability and the effectiveness of the K5 software correlator has been demonstrated by the fact that the recent INT2 session data are regularly processed within one day after each session. The faster processing code of the K5 software correlator has also been developed and the operational correlator system has been realized at Mitaka Correlator of the National Astronomical Observatory of Japan (NAOJ) (Kimura, 2008). The correlator system has the improved capabilities compared with the

VERA (VLBI Exploration of Radio Astrometry) hardware correlator system which has been used to process the VERA and VSOP (VLBI Space Observatory Program) observations.

The automated data analysis system was first developed in the Key Stone Project (KSP) which started in 1994. In the final stage of the KSP VLBI observations, all observed data at four 11-m stations were transferred to Koganei station in real-time and processed at the same time using the K4 real-time correlator system. The correlated data were immediately analyzed by using the VLBEST software program and the results of the data analysis were uploaded on the web server within 30 minutes after each observing session. The similar data analysis are currently performed by using the K5 software correlator system and the automated scripts utilizing OCCAM data analysis program in the ultra-fast dUT1 observing sessions. In the year 2008, it was demonstrated that the dUT1 parameter can be estimated from the intensive type 1 baseline VLBI observations within 5 minutes after the last scan in the observing session by using Kashima(34m)-Onsala baseline (Koyama et al., 2008). Currently the scripts are used at Tsukuba correlator and the INT2 intensive sessions are regularly processed. We are collaborating with GSI and Onsala observatory to demonstrate the automated data analysis after the quasi-real-time e-VLBI data processing of global type 24-hours and multiple baselines regular IVS sessions. We expect we will be able to estimate not only the dUT1 parameter but also wobble parameters within a few minutes after the multi-baselines session. For the data handling, a newly defined database was constructed based on the NetCDF data format. Since the NetCDF is the well established data format for easy data handling and excellent transportability among different operating systems, we consider this database architecture can be used as the basis for the next generation database system for the VLBI2010.

6. Outlook

As reported in the previous sections, we are performing research and developments under the several projects and most of these developments are in the same or harmonized direction with the VLBI2010 concepts. For the realization of the VLBI2010 concepts, it will be very important to demonstrate and evaluate the new concepts and we expect our developments will contribute in this direction.

References

[1] Kondo, T., Y. Koyama, R. Ichikawa, M. Sekido, E. Kawai and M. Kimura, Development of the K5/VSSP System, J. Geod. Soc. Jpn., pp.233-248, Vol.54, No.4 (2008)

[2] Koyama, Y., T. Kondo, M. Sekido, J. Nakajima, M. Kimura and H. Takeuchi, Adaption of the VLBI Standard Interface to the K5 VLBI System, J. Geod. Soc. Jpn., pp.249-258, Vol.54 No.4 (2008)

[3] Ichikawa, R., A. Ishii, H. Takiguchi, H. Kuboki, M. Kimura, J. Nakajima, Y. Koyama, T. Kondo, M. Machida, S. Kurihara, K. Kokado, and S. Matsuzaka, Development of a Compact VLBI System for Providing over 10-km Baseline Calibration, Proc. 5th IVS General Meeting, pp.400-404, 2008

[4] Ishii, A., R. Ichikawa, H. Takiguchi, K. Takefuji, Y. Koyama, S. Kurihara, K. Kokado, and D. Tanimoto, Geodetic VLBI Experiments by a Small VLBI Antenna with a Broad-band feed, NICT IVS TDC News, No.30 (this issue), 2009

[5] Koyama, Y., M. Sekido, T. Hobiger, H. Takiguchi, and T. Kondo, Development of Automated Data Processing System for Ultra Rapid dUT1 e-VLBI Sessions, Proc. 5th IVS General Meeting, pp.405-409, 2008

[6] Kimura, M., Development of the software correlator for the VERA system III, NICT IVS TDC News, No.29, pp.12-14, 2008

Improvement of System Compatibility via eVLBI and VDIF (VLBI Data Interchange Format)

M. Sekido[1], M. Kettenis[2], C. Phillips[3], A.Whitney[4], Y. Koyama[5], H. Harai[5]

[1]*Kashima Space Research Center, NICT,Japan*
[2]*Joint Institute for VLBI in Europe, Netherlands*
[3]*Haystack Observatory, MIT, USA*
[4]*Australia Telescope National Facility,CSIRO, Australia*
[5]*New Generation Network Research Center, NICT,Japan*

Abstract: The advantage of eVLBI is not only the benefits of quick output of the observation results, but also it come with flexible data processing with software correlator and improvement of system compatibility among the inhomogeneous VLBI data acquisition systems.

VLBI Data Interchange Format (VDIF) as a common data format was proposed and ratified at the 8th e-VLBI workshop held at Madrid. The system compatibility is a essentially important issue for VLBI, since co-observation is bases of VLBI product. The VDIF is going to be a standard data format for VLBI. It will enable mutual collaboration between any combinations of the radio telescopes in the world, and will enhance the VLBI productivity.

1. Introduction

The eVLBI is a technology of connecting radio telescopes by high speed computer network. Observed data at remote observation sites are collected to a correlation center quickly. These are realized owing mainly to improvement of three components: (1) computational power of personal computer (PC), (2) high speed network capacity, and (3) disk storage capacity. These improvement of computer and Information Technology has made it possible that huge amount of VLBI data to be processed by software VLBI correlator and data format conversion by software. In fact, NICT and GSI (Geographical Survey Institute) have been using software correlator for regular geodetic VLBI observations. Software correlator is going to be used for Radio astronomical observations at LBA[3] in Australia and VLA[2] in the USA.

The technology of eVLBI has drastically reduced

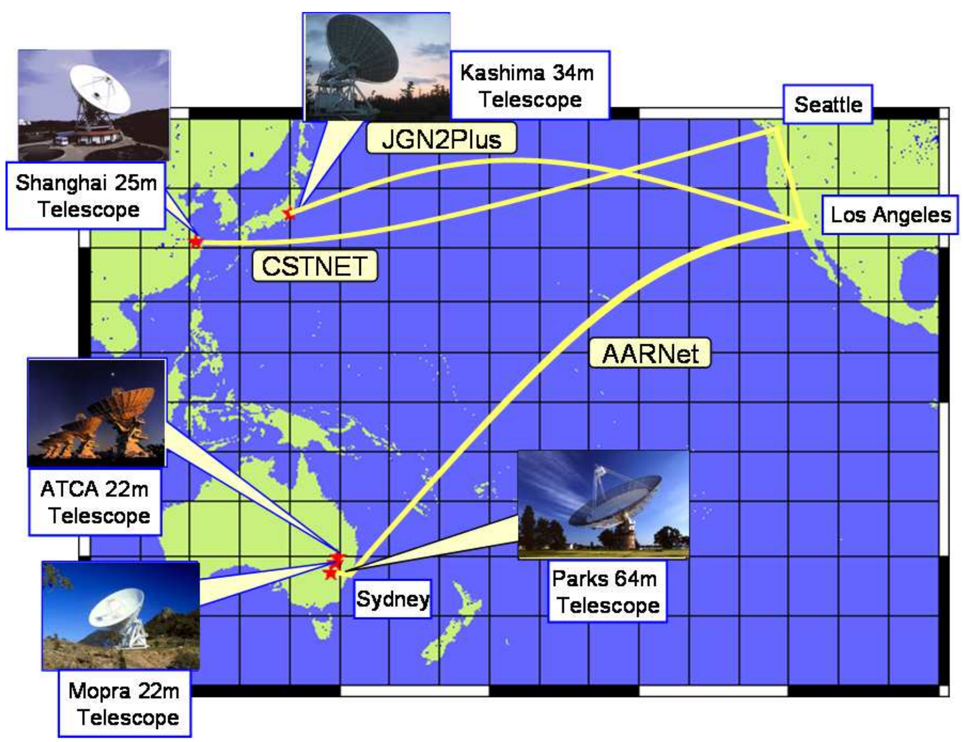

Figure 1. The first real-time eVLBI observation at Asia Pacific region. Observed data at the rate of 512Mbps at each stations were transmitted to Sydney in real-time via high speed network in Mark5B data format. Kashima, Shanghai, and Australian radio telescopes have participated the observation. The data streams were processed by DiFX software correlator developed by Swinburne University of Technology.

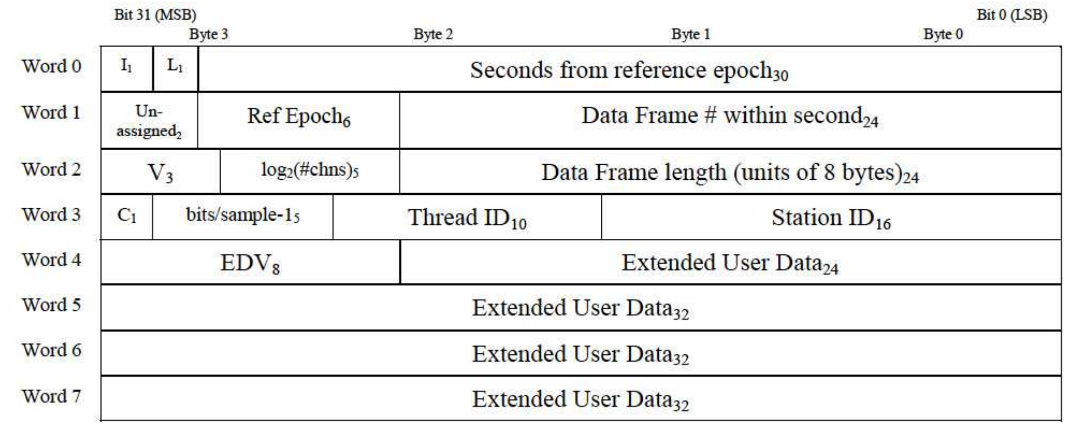

Figure 2. VDIF frame header format. Subscription number of each term indicates the number of bits for that data. I_1:Invalid flag, L_1:16 Byte Legacy Header flag, Data epoch is expressed by a combination of "Ref Epoch", and "Seconds from reference epoch". "Ref Epoch" is half year counter from Jan. 1st 2000. V_3:Version number. Number of channels contained in the data is expressed by $\log(nch)$. C_1: Complex flag. The VDIF allows transmitting data not only real data, but also complex data composed of real and imaginably data. Refer to the VDIF specification[5] for more detail.

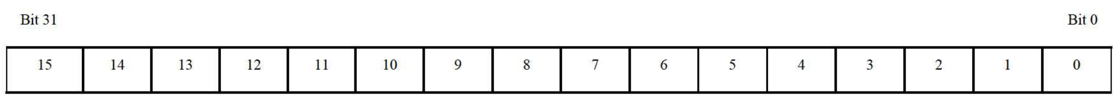

Figure 3. An example of 2bit/1ch assignment format in payload data. Numbers in the boxes indicate sample numbers in time order.

the difficulty of VLBI data translation from one format to the other. A need of common data format has arisen, and a task force group to discuss about common data format was organized in the 7th international eVLBI workshop held at Shanghai Observatory in 2008. After a year of discussion, draft specification of VLBI Data Interchange Format (VDIF) was proposed by the task force, and finally it was ratified at the 8th international eVLBI workshop. This paper describes the overview of the VDIF specification.

2. A Brief History on VLBI Compatibility

Compatibility among the different kinds of data acquisition system(DAS)s in the international VLBI community has been a issue for along time. Several kinds of VLBI data acquisition systems (DAS) such as Mark3/4/5, VLBA, S2, and K3/4/5 have been used in the world. There have been efforts to take compatibility among those systems[3]. One of the big success was the establishment of VLBI Standard Interface (VSI) specification, which is composed of description on connector's electrical specification (VSI-H) and software specification (VSI-S) on control protocol for DASs[1]. A specification for data transportation on the network has been proposed as VSI-E by Lapsley and Whitney[4]. Although it has not been widely adopted in the VLBI community because of complexity of the protocol.

Four years after since then, global eVLBI observations have become active. Productive real-time eVLBI observations project 'EXPReS' for radio astronomy have been operated by the European VLBI Network (EVN). Some eVLBI demonstration experiments of streaming the observation data from observatory to correlation center have been performed among Europe, Australia, US, China, and Japan. In the 7th e-VLBI workshop held in Shanghai observatory in China, a demonstration of the first international real-time e-VLBI observation in Asia-Pacific region was conducted by ATNF(Fig.1). In that workshop, a session for discussion on data compatibility was organized. After a enthusiastic discussion in the session, four people, M.Kettenis (JIVE), C.Phillips (ATNF), M.Sekido (NICT), and A.Whitney (MIT) were nominated for

[1] These specifications are available on the web. http://www.vlbi.org/

a task force to make a draft proposal of a common data format. Discussions among the task force members and several key developers of eVLBI systems was made mainly via E-mails. One year later, finally the VDIF specification[2] version 1.0 has been proposed, and it was ratified in the 8th international e-VLBI workshop held at Madrid in June 2009.

3. Specification of the VDIF and Some Use Cases of It

One of the important aspects of VDIF is that it was designed to be independent from transport method. It can be transported either via network or in the form of file on a recording device of computer. This gives an advantage of keeping the data contents invariant with respect to the change of transportation protocol.

The VDIF specify to write the VLBI data in a frame form. A set of frame header and data payload are repeated. The frame length is specified in the description in the frame header and it can be chosen flexibly by the need of user. A ristriction is it must be constant for that data and have to be multiple of 8 bytes. Any frame should not cross over of second tic. The data at 1PPS tick must be at the beginning of a frame. Frame header format is indicated in Fig.2.

The VDIF header contains all the necessary information for computing frequency spectrum of the data and for identification of the data source (observation station). Representation of time tag in the header is designed to be tolerant for introducing leap second. It is intended to avoid mistake and complexity in setting time tag for the case of leap second.

Sixteen bytes of remaining space in the header is left for extension of header information. This 'Extended User Data' (EUD) area will be used to include additional information defined by implementer of VDIF data. And 'EDV'(Extended User Data Version) number will be assigned for a specific EUD format by submission registration of the data format to the VDIF task force web page[3]. The registered EUD formats will be available from the web, and the EDV number will be useful for automatic identification of the header format. The data allocation on the memory is Little Endian (Intel byte order).

Offset binary encoding is specified in the VDIF for expression of sampled value of the signal. For example in case of 4 level expression with 2 bit, 00, 01, 10, and 11 are the codes for values in the order of large negative to large positive.

Allocation of data time series is specified in the

[2]http://www2.nict.go.jp/w/w114/stsi/research/e-VLBI/VSI/VDIFspecificationRelease-1.0.pdf

[3]http://www.vlbi.org/

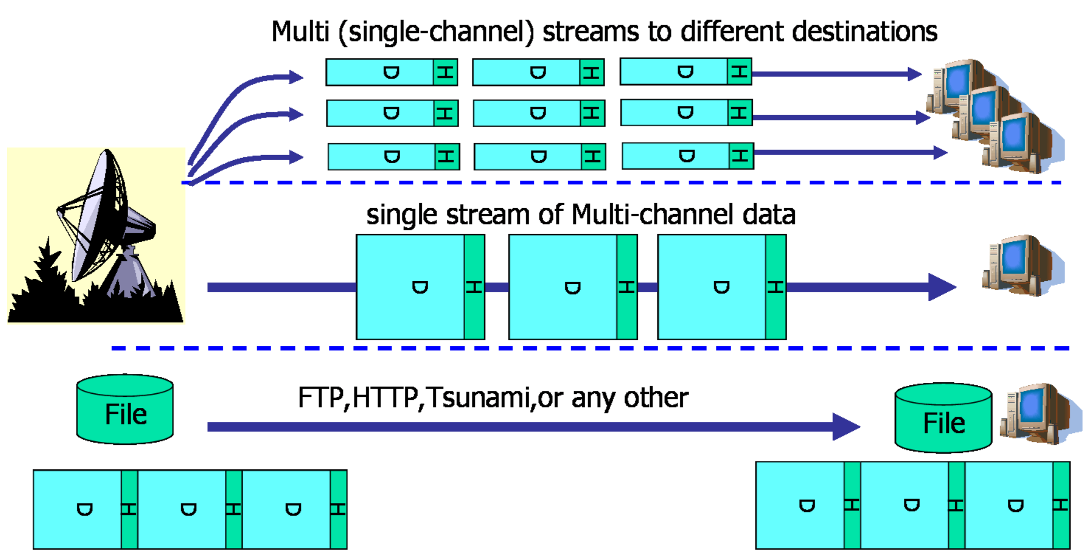

Figure 4. Examples of VDIF use cases. The VDIF concept supports network data transportation via 'Data Thread', which contain sub-group of channels. Data streams may direct to single destination, or to different destinations by each thread. The latter case may be useful for distributed computing. Since VDIF concept is independent from transportation method, thus data can be transported not only by data stream on the network, but also by the form of data file. In the latter case, either any kinds of file transport protocol over the network or physical trasnport of the memory device can be chosen.

order from Least significant bit (LSB) to most significant bit (MSB). Example of the data format in case of 2bit/1ch mode is indicated in Fig.3.

The VDIF specification allows transporting data either by frames which contains data of single channel, or by frames which contains a sub group of channels among a set of many. In those cases, multiple sub-groups of data will be transported in parallel. Each stream is named 'Data Thread' and it is identified by 'Thread ID' in the header. Streaming data to multiple destinations by using the mutile threads will be usefule for distributed computing of cross correlation. Fig. 4 indicates some examples of use cases of VDIF data.

4. Summary

Enhancement of international eVLBI activities among Europe, Australia, USA, China, and Japan increases a chances to exchange the VLBI data obtained by their own DAS. Such global VLBI collaborations have been rising the motivation to make global standard data format for VLBI. Finally VDIF specification as the standard VLBI data format has ratified at th 8th international eVLBI workshop in 2009. The VDIF specification was designed with keeping in mind the separation of layers: application, and transportation. That will bring easiness in maintenance of the data format and data transport protocol. Also representation of time tag is designed with intension to avoid mistakes in treatment of leap second at observatory. The VDIF specification will become common for all of the VLBI DASs in world soon. Resolution of the compatibility issue is an important event in the history of VLBI technology. It will boost international collaboration and productivity of VLBI.

References

[1] Phillips, C. "eVLBI developments on the LBA", Proceedings of the 8th International e-VLBI workshop (22-26 June at Madrid),to be published, 2009.

[2] Dhawan, V. "NRAO VLBA Upgrade Plans and Prospects", Proceedings of the 8th International e-VLBI workshop (22-26 June at Madrid),to be published, 2009.

[3] Hama, S., Y. Takahashi, H. Kiuchi, M. Imae, R. Wietfeltdt, N. Kawaguchi, "Compatibility of International VLBI Systems", Proceedings of the International workshop for Reference Frame Establishment and Technical Development in Space Geodesy (Jan. 18-21 at Tokyo), pp.49-52, 1993.

[4] Lapsley, D., and A. Whitney, "VSI-E Software Suite", Proceedings of the 7th European VLBI Network Symposium (Oct. 12-15, 2004),

[5] Kettenis, M., C. Phillips, M. Sekido, A. Whitney, "VLBI Data Interchange Format (VDIF) Specification Release 1.0", http://www2.nict.go.jp/w/w114/stsi/research/e-VLBI/VSI/VDIFspecificationRelease-1.0.pdf.

First Fringe Detection with Next-Generation A/D Sampler ADS3000+

Kazuhiro Takefuji (*takefuji@nict.go.jp*)[1], **Yasuhiro Koyama**[1], **and Hiroshi Takeuchi**[2]

[1] *Kashima Space Research Center, National Institute of Information and Communications Technology, 893-1 Hirai, Kashima, Ibaraki 314-8501, Japan*
[2] *Institute of Space and Astronautical Science (ISAS)*
Japan Aerospace Exploration Agency (JAXA) 3-1-1 Yoshinodai, Sagamihara, Kanagawa 229-8510, Japan

Abstract: A high-speed A/D sampler, we called the ADS3000+, has been developed in 2008, which can sample one stream analog signal up to 4Gbps to Linux PC. Furthermore, the ADS3000+ equipped two FPGAs it can be possible such as real-time DBBC (Digital Base Band Conversion) and other signal processing. The ADS3000+ will not be used for only VLBI, but also other versatile purposes. Consequently various sample modes of ADS3000+ was evaluated from 128Msps to 4096Msps (sampler per second). Based on these examination, first fringe test at 2Gsps has been carried out on13 Feb 2009. After success of the fringe test, 4Gsps fringe test with the ADS3000+ has been performed and obtained 4Gsps fringe finally. Here, we will describe the result of fringe test and more details in this article.

1. Introduction

National Institute of Information and Communications Technology (NICT) is one of the technology development centers of the International VLBI Service for Geodesy and Astrometry (IVS), and we have been developing VLBI observation systems and data processing systems to improve the capabilities of the existing systems.

2. A next-generation A/D sampler ADS3000+

A next-generation A/D sampler, The ADS3000+ has been developed in 2008 The ADS3000+ is newly-extend A/D sampler from the ADS3000 system by adopting supporting various sampling mode[Koyama, et al., 2008]. faster A/D sampler chip and two new FPGA chips replacing one FPGA chip[Takeuchi, et al., 2006]. It has a capability to sample analog data up to 5GHz at the highest speed. However one VSI-H (VLBI Standard Interface) interface is connected with PC up to 2Gbps (Giga bit per second), the maximum sampling speed of one channel with the ADS3000+ becomes 4Gbps via two VSI-H connection.

The ADS3000+ already fulfills VLBI2010 requirements which digitizes analog signal 2Gsps X 2ch, 1Gsps X 4ch. Moreover, various signal processing such as DBBC (Digital Base-Band Converter) can be performed with FPGA chips in the ADS3000+. Table.1 shows the major specifications of the ADS3000+ system.

A/D chip	e2V EV8AQ160
Size	EIA 2U (480 x 88 x 430 mm)
Sampling Modes	4096Msps x 1ch
	2048Msps x 2ch
	1024Msps x 4ch (option)
FPGA chip 1	Xilinx Virtex5 XC5VLX110
FPGA chip 2	Xilinx Virtex5 XC5VLX220

Table 1. Specifications of the ADS3000+ unit.

3. Evaluation of each mode

The ADS3000+ has a several sample mode, 128Msps to 4Gsps mode, Test Vector output mode, and DBBC mode (see Table.2). Firstly standard sample mode (ex 128Msps to 2048Msps) was evaluated. Figure.1 shows a result of 128Msps to 2048Msps. A 1.5GHz CW signal from signal generator was inputted into ADS3000+. When sample rate is lower than frequency of this signal, A frequency of signal is folded to lower frequency as expected. Then, a folded frequency was used for identifying to detect CW signal correctly. In Figure.1 some harmonic signals can be seen. This occurs due to low bit quantization. However, it is less affected using eight bit quantization.

4. Evaluation of 4Gsps

Next, 4Gsps (more concretely 4096Msps) was evaluated. 4Gsps data was simply obtained via ADS3000+ buffer memory. From 100MHz to 3GHz signals generated by signal generator stepping 100MHz. Then they were digitized and stored ADS3000+ buffer memory. Figure.2 shows a result

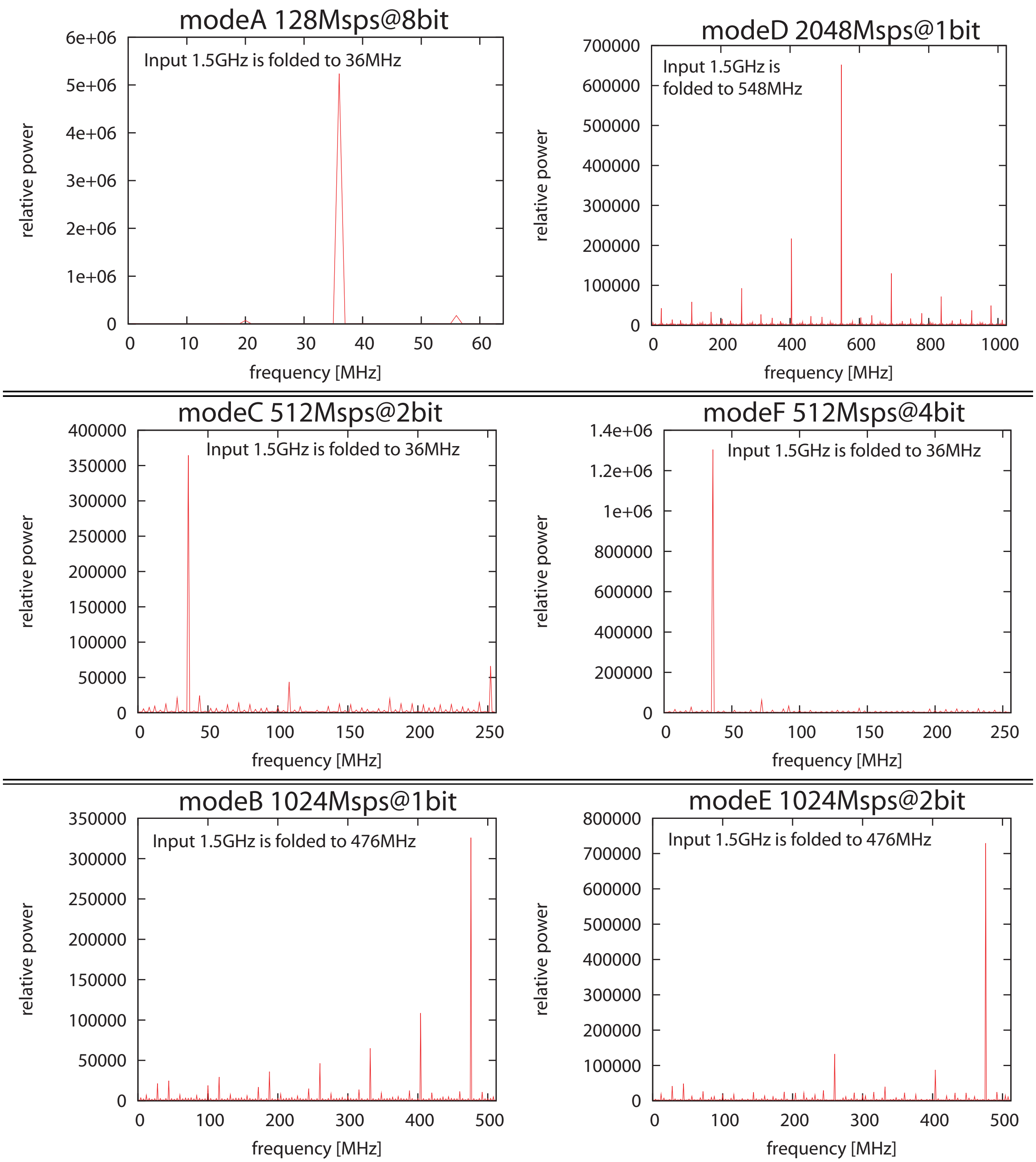

Figure 1. Evaluation of standard sample mode from 128Msps to 2048Msps. A 1.5GHz CW signal from signal generator was inputted into ADS3000+. An expected folding frequency was measured. Folding frequency could be identified in all standard mode. The evaluation uses only single VSI port, output is half quantization from mode B to mode F . Upper two figures is 128Msps (mode A) and 2048Msps (mode D). 2048Msps mode is the fastest sampling mode with using single VSI port. Middle figures and lower figures show 512Msps and 1024Msps mode. Right side figures are so large number of bit quantization that harmonics waves become smaller than left side figures.

No.	Mode	Record	Rate	Quantization	Clock	Output Port
0	MODE A	1Gbps	128 Msps	8bit	32MHz	VSI 1ch
1	MODE B	2Gbps	1024 Msps	2bit	32MHz	VSI 2ch*
2	MODE C1	2Gbps	512 Msps	4bit	32MHz	VSI 2ch*
3	MODE C2	2Gbps	512 Msps	4bit	32MHz	VSI 2ch*
4	MODE D	4Gbps	2048 Msps	2bit	64MHz	VSI 2ch*
5	MODE E1	4Gbps	1024 Msps	4bit	64MHz	VSI 2ch*
6	MODE E2	4Gbps	1024 Msps	4bit	64MHz	VSI 2ch*
7	MODE F	4Gbps	512 Msps	8bit	64MHz	VSI 2ch*
8	TVG1	non	non	non	32MHz	
9	TVG2	non	non	non	64MHz	
10	BBC	variable	4/8/16/32Msps	2bit	32MHz	VSI 1ch
11	MODE G1	4Gbps	4096 Msps	1bit	64MHz	VSI 2ch†
12	MODE G2	4Gbps	4096 Msps	1bit	64MHz	VSI 2ch†

*Table 2. Each sample mode of ADS3000+. 4Gsps mode (mode G1 and G2) is the highest sampling mode of ADS3000+. Difference of C1 and C2, E1 and E2 is to support downward compatibility of ADS1000 and ADS2000 or not. *: Two VSI output to sample. First VSI channel sends upper half bit of mode, also Second VSI channel sends lower half bit. †: G1 and G2 is irregular mode because of up to 2Gbps VSI output. Two VSI outputs have to be combined in software after sample. These modes has a difference of separation length, in case of G1, sample data separated one byte sequentially to two VSI. Similarly G2 is four byte.*

of 4Gsps. Bottom axis means frequency, left axis is decibel. A loss of cable was measured by a spectrum analyzer before evaluation, also 4Gsps result was already corrected this cable loss. Higher frequency than Nyquist-rate of 4096MHz (2048MHz) is folded to lower frequency . 4Gsps can conversely be checked this folded signal. From this result, a -3dB level (half power) was determined 2.6GHz.

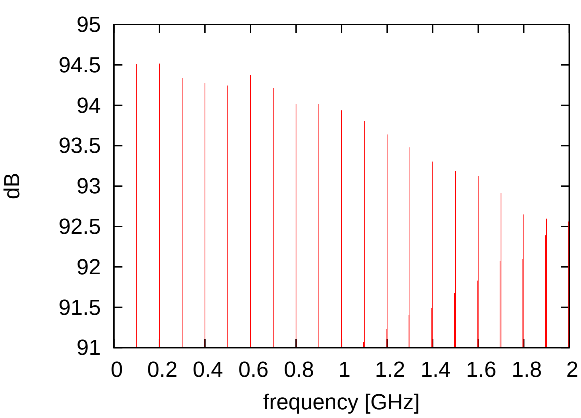

Figure 2. Result of 4Gsps with ADS3000+. 4Gsps was identified with folded signal that is higher than 2GHz signal. Furthermore, a -3dB level was measured 2.6GHz. A cable loss was corrected before 4Gsps evaluation. Signals from 100MHz to 3GHz CW stepping 100MHz were input to ADS3000+.

5. First Fringes Detection with ADS3000+ in MARBLE experiment

MARBLE experiment is performed on 9 Feb 2008 [Ichikawa, et al., 2009]. Kashima 34m antenna and MARBLE 1.6 antenna were used. A IF signal (efficient bandwidth is 450MHz) was divided two streams. One was recorded in standard geodetic VLBI sampler the K5/VSSP. The other simultaneously recorded for first fringe detection with two ADS3000+s at two stations. A configuration of ADS3000+ was 2Gsps at 1bit quantization. After recorded with ADS3000+, a simple FX correlation (complex multiplication of two streams in frequency domain) was performed. Then first fringe could be successfully obtained. Figure.3 shows results of fringe detection that target source is 3C84, Tau-A and Ori-A. Fringes are clearly seen in this figure. Peaks of three fringes were also consistent with a-priori expectancy.

6. First Fringe Detection at 4Gsps speed

Before 4Gsps fringe experiment, VSI-H limitation (connection between ADS3000+ and PC) has to be considered. A VSI-H data rate is 2Gbps at a maximum, so that 4Gsps@1bit experiment is not possible with one port output. Then using two VSI-H port trick has been applied to ADS3000+. Concretely speaking, digitized data is sequentially

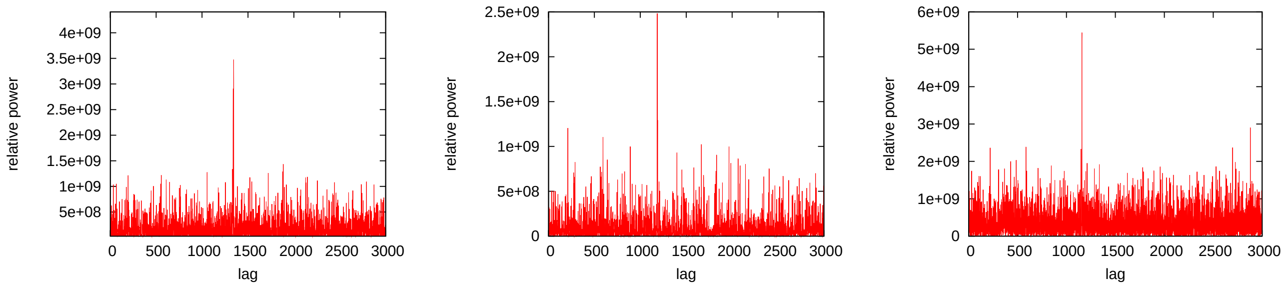

Figure 3. First fringe detection @ 2Gsps with ADS3000+ (left: fringe of 3C84, middle: fringe of Tau-A, right: fringe of Ori-A). Peak positions of these three fringes was consistent with a-priori expectancy.

station	34m	11m
frequency	X-wH:8180-9080MHz	X-H:8100-8600MHz
polarization	RHCP	RHCP
First PLO	8080MHz	7680MHz
After down convert	100-1000MHz	420-920MHz

Table 3. Specifications of 4Gsps fringe test.

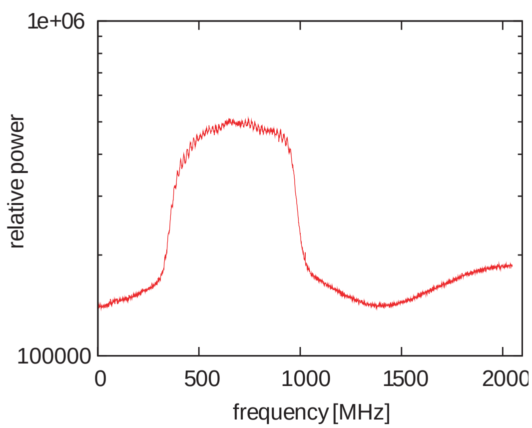

Figure 4. A spectrum of X-band Kashima 11m antenna. A bandwidth the X-band is 500MHz wide, however 4Gsps mode detects up to Nyquist-rate 2GHz. Whole bandwidth spectrum of X-band can be obtained at one time.

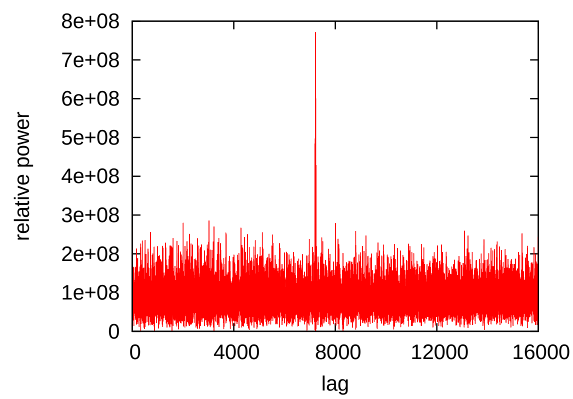

Figure 5. A first fringe of 3C273B at 4Gsps speed with ADS3000+ in 8 ms integration time with Kashima 34m and 11m antenna on 27 Apr 2009. The 4Gsps fringe is a fastest record in NiCT now.

divided each one byte or four byte sample and allocated two VSI-H output. After sampled two VSI-H output, two digital data assemble in software side to obtain 4Gsps data. This software adopts an algorithm of look-up-table method to get high performance.

A fringe test was carried out on 27 Apr 2009. Kashima 34m antenna and 11m antenna were used with setting ADS3000+ at two stations. Phase calibration signal was shut off to detect fringe correctly. A specification of fringe test is shown in Table.3. After sample at 4Gsps speed with 1bit quantization, whole bandwidth spectrum of X-band is fully shown in Figure.4. a first fringe of 3C273B at 4Gsps could be successfully detected after correlation process . This is shown in Figure.5. A signal-noise-ratio (SNR) of the 3C273B fringe is estimated about 8.6 at 8ms integration. The 4Gsps fringe is a fastest record in NiCT now.

7. Summery and Outlook

We identified standard sampling mode from 128Msps to 2Gsps (2048Msps) and 4Gsps mode correctly. On the basis of this evaluation, we have detect a first fringe with ADS3000+ at 2Gsps speed within MARBLE experiment, Furthermore we could obtain the fastest record of 4Gsps fringe in 2009. ADS3000+ will not only be powerful converter for current receiver system but also suitable for a wide-band receiver of next-generation VLBI (VLBI2010). A SNR is proportional to bandwidth, and more finely phenomena can be captured with high-speed sampling, so that the ADS3000+ would be hopefully broken new ground in the VLBI, astronomy and science.

Acknowledgments: Developments of the ADS3000+ system cooperative efforts between NICT, JAXA/ISAS, and COSMO RESEARCH Corp. The authors would like to thank for cooperation of the Kashima VLBI team.

References

[1] Koyama, Y., T. Kondo, M. Sekido, and M. Kimura, Developments of K5/VSI System for Geodetic VLBI Observations TDC News, IVS NICT-TDC News, **No.29**, pp.15-18, 2008.

[2] Takeuchi, H., M. Kimura, J. Nakajima, T. Kondo, Y. Koyama, R. Ichikawa, M. Sekido, and E. Kawai, Development of 4-Gbps Multi-functional VLBI Data Acquisition System, Publications of the Astronomical Society of the Pacific, **Vol.118**, pp.1739-1748, 2006.

[3] Ichikawa, I., A. Ishii,. H. Takiguchi, Y. Koyama, T. Kondo, K. Kokado, S. Kurihara, M. Matsuzaka, Present Status and Outlook of Compact VLBI System Development for Providing over 10km Baseline Calibration, TDC News, IVS NICT-TDC News, **No.30**, this issue, 2009.

Present Status and Outlook of Compact VLBI System Development for Providing over 10km Baseline Calibration

ICHIKAWA Ryuichi[1] (*richi@nict.go.jp*),
ISHII Atsutoshi[1,3,5],
TAKIGUCHI Hiroshi[1],
KOYAMA Yasuhiro[2],
KONDO Tetsuro[2,4],
KOKADO Kensuke[3],
KURIHARA Shinobu[3],
MATSUZAKA Shigeru[3]

[1] *Kashima Space Research Center, National Institute of Information and Communications Technology, 893-1 Hirai, Kashima, Ibaraki 314-8501, Japan*
[2] *Space-Time Standards Group,National Institute of Information and Communications Technology, 4-2-1, Nukui-Kitamachi, Koganei, Tokyo 184-8795, Japan*
[3] *Geographical Survey Institute, Tsukuba, Japan*
[4] *Department of Space Survey and Information Technology, Ajou University, Republic of Korea*
[5] *Advanced Engineering Services Co.,Ltd. 1-6-1 Takezono, Tsukuba, Ibaraki 305-0032, Japan*

Abstract: We are developing a compact VLBI system with 1.6 m diameter aperture dish in order to provide reference baseline lengths for calibration. The reference baselines are used to validate surveying instruments such as GPS and EDM and maintained by the Geographical Survey Institute (GSI) of Japan. The compact VLBI system is designed to be assembled with muscle power simply in order to perform short-term (about one week) measurements at several reference baselines in Japan islands. We have successfully detected the first fringe between the new compact VLBI system and Kashima 34 m on February 9, 2009. We are now planning to perform the first geodetic experiment using the new VLBI system.

1. Introduction

The GSI has a responsibility to calibrate and maintain a 10 km reference baseline for validating surveying instruments such as GPS and EDM. We are developing a compact VLBI system with 1.6 m diameter aperture dish to certificate the length of the reference baseline based on a collaboration

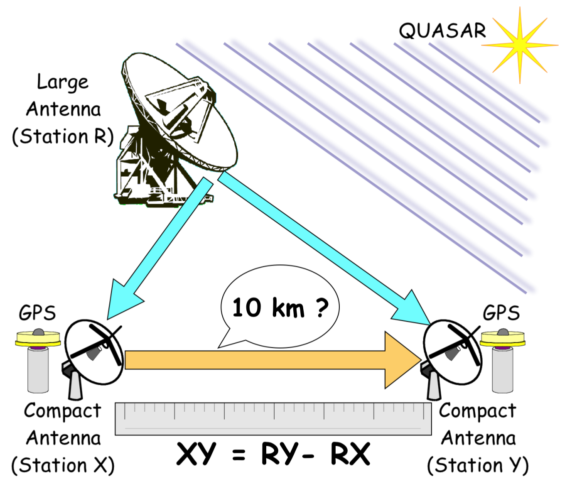

Figure 1. The MARBLE (Multiple Antenna Radio-interferometer for Baseline Length Evaluation) system.

between GSI and NICT. The operational calibration by GSI needs 2 mm RMS of baseline length accuracy. However, since it is too long to get a line of sight from the end to the other end by EDM at the actual reference baseline, calibration works at present are only performed at the shorter baseline in stead of a measurement of whole 10 km length.

On the other hand, Geodetic VLBI technique can give an independent measurement to examine the baseline length with a millimeter accuracy using the hydrogen-maser. Moreover, the hydrogen-maser frequency standard can be considered as the traceable technique to the national standard. Thus, we started to develop a compact VLBI system with 1.6 m diameter aperture antenna in order to measure the accurate length of the reference baseline. In this short article, we describe a present status and outlook of the compact VLBI system dedicated to 10 km measurement.

2. MARBLE concept

The two compact VLBI systems will be installed at both ends of the baseline. However, it is too insensitive to detect fringe between both stations using such compact dish. Thus, we have designed a new observation concept including one large dish station into the baseline observation as shown in Figure 1.

We can detect two group delays between each compact VLBI system and the large dish station

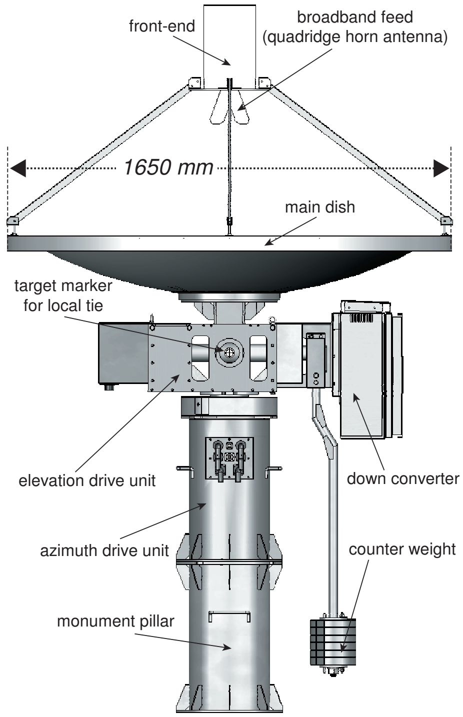

Figure 2. Schematic image of the MARBLE compact VLBI system.

based on conventional VLBI measurement. A group delay between the two compact dishes, ΔXY, can be indirectly calculated using a simple equation as follows.

$$\Delta XY = \Delta RY - \Delta RX \quad (1)$$

where ΔRX and ΔRY are two group delays obtained by a conventional way (see Figure 1). We named the idea '**M**ultiple **A**ntenna **R**adio-interferometer for **B**aseline **L**ength **E**valuation (MARBLE)'.

The compact VLBI system is designed to be assembled with muscle power simply in order to perform short-term (about one week) measurements at several reference baselines in Japan islands. The compact VLBI system is also capable to be used as a fiducial station of a local geodetic observation network at remote locations.

3. First Prototype of the Compact VLBI System

In the fiscal year of 2007 the first prototype of the compact VLBI system had been completed and in the last fiscal year the second prototype in the fiscal year of 2008 so far[5]. The first prototype consists of a 1.65 m diameter aperture antenna, a new front-end system with a wide-band quad-ridged horn antenna (QRHA), an azimuth drive unit, a elevation drive unit, an IF downconverter unit, an antenna control unit (ACU), a counterweight and a monument pillar (see Figure 2). Each drive unit is equipped with a zero-backlash harmonic drive gearing component. The new front-end system with a QRHA is based on VLBI2010 concept[2] (Figure 3).

On December 9, 2008, we installed the first prototype of the compact VLBI system on the top of the building nearby the Kashima 34 m antenna (Figure 4). We have successfully detected the first fringe between the new compact VLBI system and Kashima 34 m on February 9, 2009 (Figure 5).

4. Second Prototype of the Compact VLBI System and Outlook

At present, we are now developing the second compact VLBI system to realize the MARBLE concept. The 1.5 m dish size of the second one is smaller than the first one by choosing a suitable f/D ratio for X-band. We will finish to install the second one in the GSI, Tsukuba until this summer season. In this fiscal year, we are planning to perform the first geodetic VLBI experiment using the two compact VLBI system with the Tsukuba 32 m of GSI. In addition, we are also planning to apply our system into the precise time and frequency comparison experiment between a separated locations.

References

[1] Ishii, A., Ichikawa R., Takiguchi H., Kuboki H., Kondo T., Koyama Y., Machida M., and Kurihara S., Current Status of a Compact VLBI System for Providing over 10 km Baseline Calibration, *IVS NICT-TDC News* **No.29**, pp.19–22, October 2008.

[2] VLBI2010: Current and Future Requirements for Geodetic VLBI Systems, Report of Working Group 3 to the IVS Directing Board, http://ivs.nict.go.jp/mirror/about/wg/wg3/IVS_WG3_report_050916.pdf, 2005.

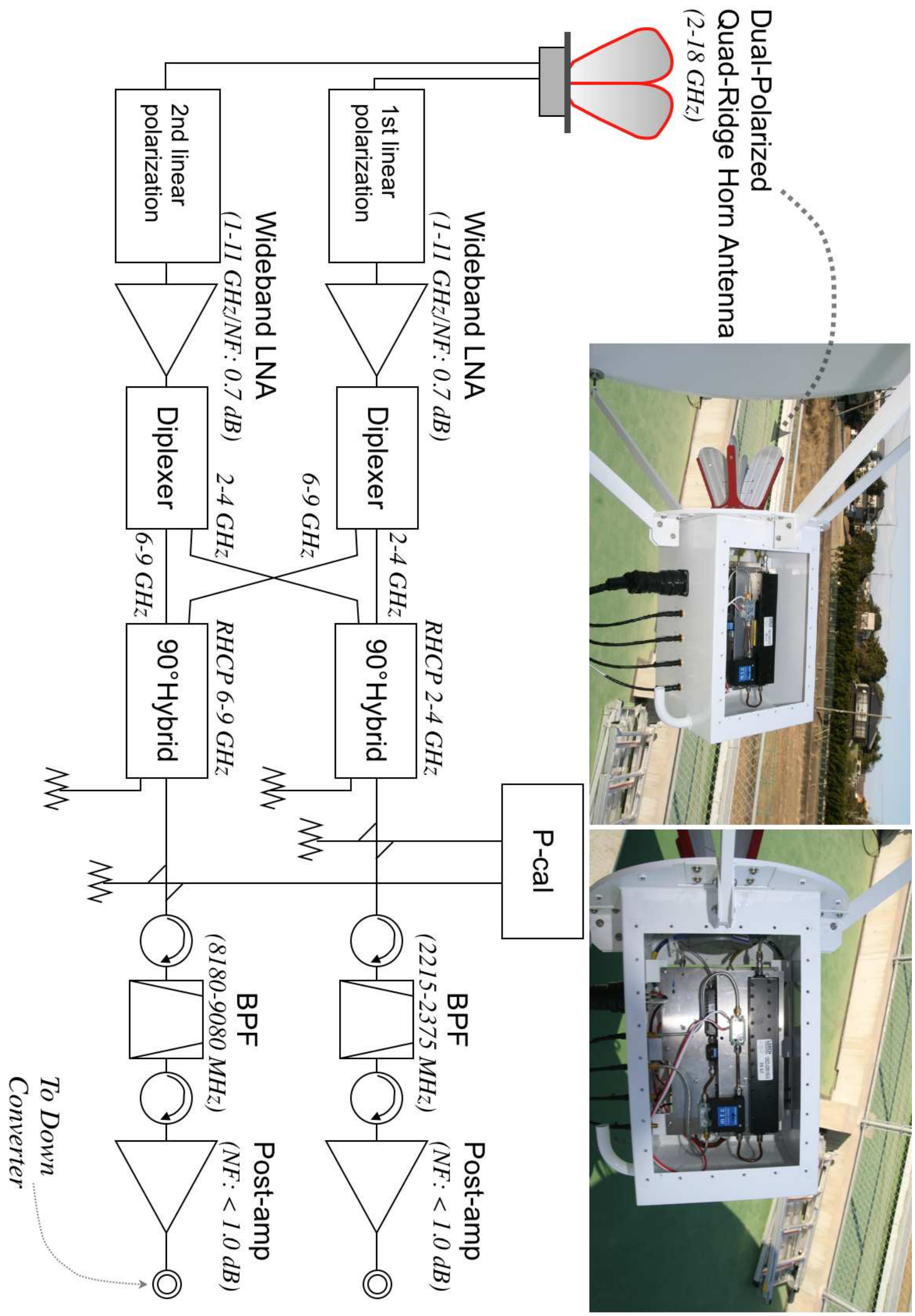

Figure 3. Front-end using a wideband LNA was equipped on the first prototype of the compact VLBI system.

Figure 4. Installation of the first prototype of the compact VLBI system on the top of the 34 m antenna building on December 9, 2008 at Kashima.

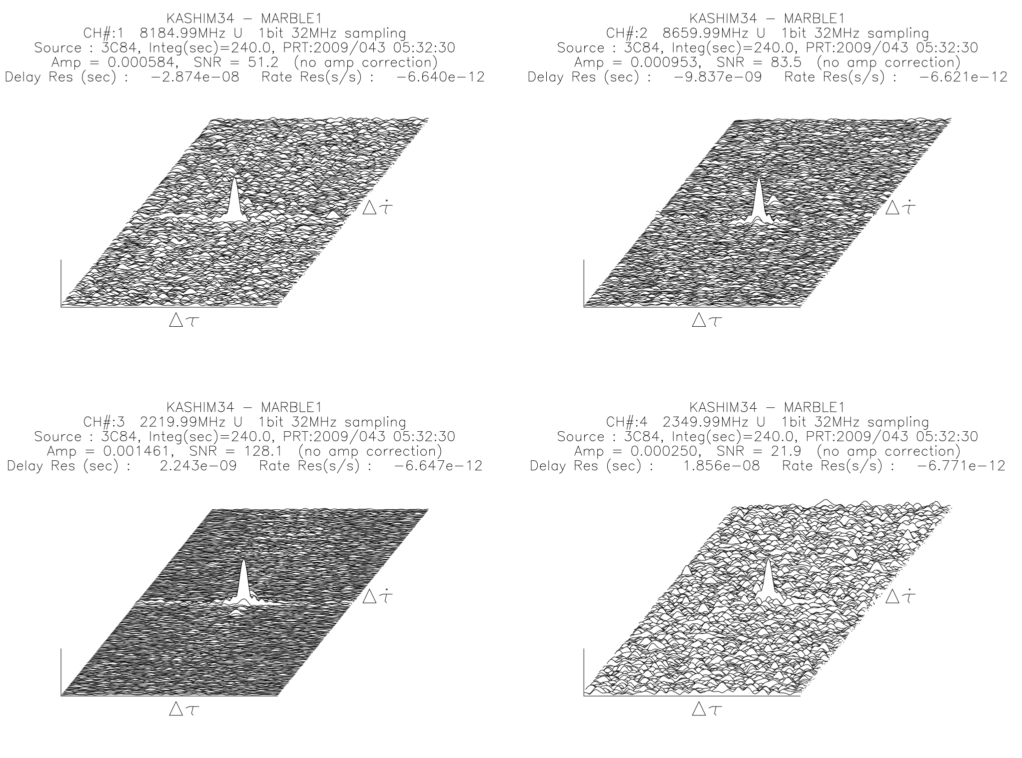

Figure 5. The first fringe test between the new compact VLBI system and Kashima 34 m antenna was successfully performed on February 9, 2009.

Comparison Study of VLBI and GPS Carrier Phase Frequency Transfer - Part II -

Hiroshi Takiguchi[1] (*htaki@nict.go.jp*), **Yasuhiro Koyama**[2], **Ryuichi Ichikawa**[1], **Tadahiro Gotoh**[2], **Atsutoshi Ishii**[1,3,4], **and Thomas Hobiger**[2]

[1] *Space-Time Standards Group, Kashima Space Research Center, National Institute of Information and Communications Technology, 893-1 Hirai, Kashima, Ibaraki, 314-8501, Japan*

[2] *Space-Time Standards Group, National Institute of Information and Communications Technology, 4-2-1 Nukui-Kitamachi, Koganei, Tokyo, 184-8795, Japan*

[3] *The Geographical Survey Institute, 1 Kitasato, Tsukuba, Ibaraki, 305-0811, Japan*

[4] *Advance Engineering Services Co., Ltd 1-6-1 Takezono, Tsukuba, Ibaraki, 305-0032, Japan*

Abstract: To show the frequency stability of local baseline, we carried out long term VLBI experiment together with GPS and DMTD measurement. And, we compared the results provided from these three techniques. The results are strongly correlated at long term period. The frequency stability of VLBI is surpassing the stability of atomic fountain at 10^5 seconds or longer.

1. Introduction

In several institutes including NICT (National Institute of Information and Communications Technology) push forward to develop the atomic fountain frequency standards and the optical frequency standards. The atomic fountain frequency standards have already achieved the uncertainty of 1.9×10^{-15} [5]. And optical frequency standards are aiming to achieve the uncertainty on a 10^{-16} to 10^{-17} level [6]. In order to compare such precise standards by the current time transfer techniques like two-way satellite time and frequency transfer (TWSTFT) or GPS carrier phase, it is necessary to average over long periods. Since these techniques are not sufficient to compare next standards improvements of high precision time transfer techniques are strongly desired.

Recent years, we are suggesting the geodetic VLBI technique as a one of the new time and frequency transfer technique [4], [7]. To show superiority of the VLBI, we are evaluating the ability of VLBI frequency transfer by comparison with GPS carrier phase frequency transfer at the Kashima-Koganei baseline. Results showed VLBI is more stable than GPS. Also, we compared VLBI and GPS using data from the International VLBI Service for Geodesy and Astrometry (IVS) and the International GNSS Service (IGS) for the same purpose. The results of the VLBI frequency transfer show that the stability follows a $1/\tau$ law very closely and it's surpassing the stability of atomic fountain at 10^3 seconds or longer. And that shows the stability has reached about 2×10^{-11} (20ps) at 1 sec. These results show that geodetic VLBI technique has the potential for precise frequency transfer [8], [9].

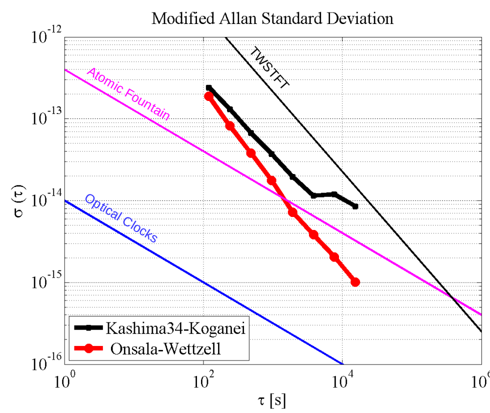

Figure 1. The frequency stability of VLBI. Large dot is Onsala-Wettzell baseline. Dot is Kashima34-Koganei baseline. Also, it shows the normal frequency stability of TWSTFT, atomic fountain and optical clocks.

Figure 1 shows the frequency stability of International baseline (Onsala-Wettzell) and local baseline (Kashima34-Koganei). As described before, we could showed the international baseline was surpassing the stability of atomic fountain at 10^3 seconds or longer. However we can't show about that at local baseline yet. So we performed long term (over a week) VLBI experiment at Kashima34-Kashima11 baseline, to show the long term frequency stability.

In this paper, we describe the comparison with VLBI and GPS carrier phase about that experiment. Also, we performed frequency transfer by the dual mixer time difference (DMTD) [2]. We also describe that result.

2. The intercomparison between VLBI, GPS carrier phase and DMTD

2.1 Outline of the experiment

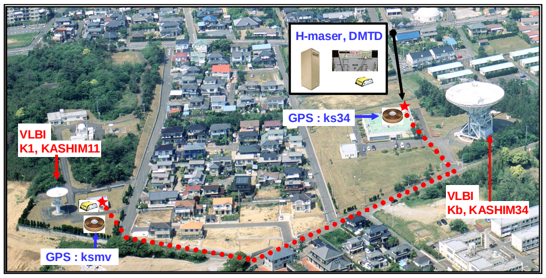

Figure 2. Layout map of Kashima station

Figure 2 is the layout map of Kashima station. The baseline length of Kashima34m-Kashima11m is about 239m. The outline of the experiment are described to Table 1.

Table 1. Outline of this experiment.

VLBI	KASHIM34, KASHIM11
GPS	ks34, ksmv
DMTD	1ch: to 34m ETR and back, 2ch: to KSP room and back
duration	12days (from 01 to 12 Aug)

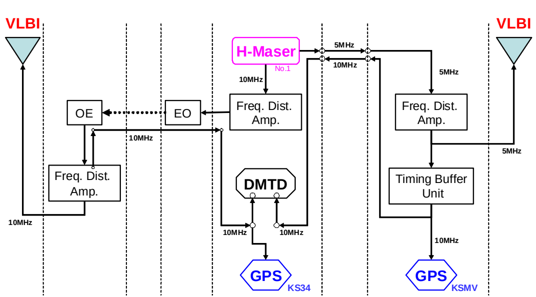

Figure 3. The reference signal setup diagram at Kashima station

Figure 3 is the reference signal setup diagram. In this experiment, we used one hydrogen maser and we transferred the reference signal by coaxial cable and optical fiber to VLBI and GPS antennas. We analyzed the data using CALC/SOLVE and GIPSY-OASIS II [3] for VLBI and GPS respectively. The details of the analysis of VLBI and GPS were described at [7].

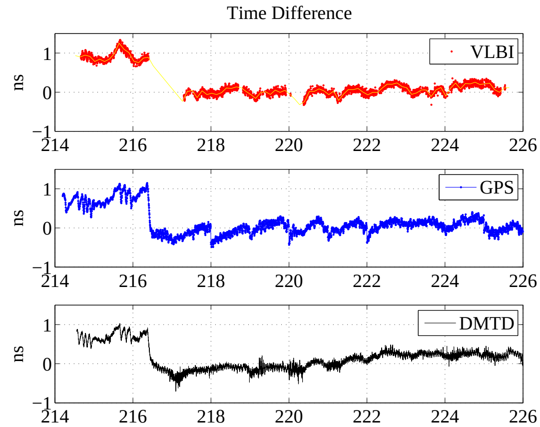

Figure 4. Time difference calculated from VLBI, GPS and DMTD.

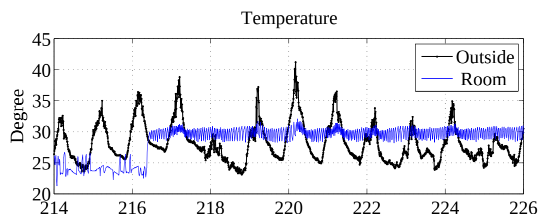

Figure 5. Variations of temperature at Kashima 11m antenna observation room and outside.

2.2 Results

Figure 4 shows the time difference calculated from three techniques (VLBI, GPS and DMTD). Figure 5 is the variations of temperature at Kashima 11m antenna observation room and outside. It is clearly visible that the variations of time difference and temperature are strongly correlated (The time difference and temperature are inverse correlation). At 3rd August (day of year 216), we changed the definition temperature of air conditioner of Kashima 11m antenna observation room. We couldn't turned off the air conditioner, because of summer season at that time. So, the influences of room temperature change still remained of the time differences.

Table 2. The details of estimated parameters.

	estimated parameter (per minutes)	
symbole	clock offset	atmospheric
$\star$	180	180
$\times$	10	10
$\diamond$	30	60
$+$	10	300

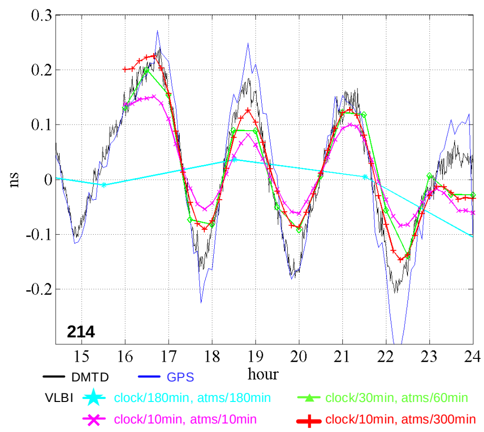

Figure 6. Time difference calculated from VLBI. The analysis strategy is described in Table 2.

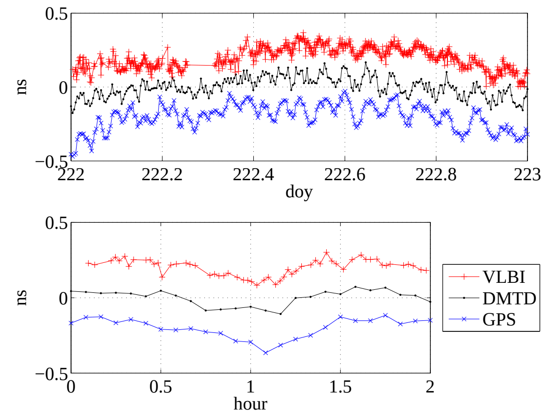

Figure 7. Time difference calculated from VLBI, GPS and DMTD.

As for the result of the VLBI, the variation of around several days agree with a result of DMTD well. However it doesn't agree with DMTD, when the variation is beyond 500 ps in several hours (day of year from 214 to 216). Contrastively, as for the result of the GPS, the variation of several hours agree with a result of DMTD well. However due to the code noise, the clock offsets of the GPS solutions show discontinuities at the day-boundaries. It seems that the reason why the result of VLBI doesn't agree with DMTD when the variation of DMTD is beyond 500ps at the short period are analysis strategy and schedule of scan time. Figure 6 and Table 2 show the result of VLBI approach the result of DMTD by changing a analysis strategy of VLBI.

Table 3. The correlation coefficient of the time difference between three techniques.

	VLBI-GPS	VLBI-DMTD	GPS-DMTD
12days	0.87	0.94	0.91
1day	0.46	0.51	0.73
6hours	0.45	0.38	0.60
2hours	0.51	0.36	0.59

We calculated the correlation coefficient of the time difference between three techniques for the following four cases: (1) whole days, (2) 1 day, (3) 6 hours, and (4) 2 hours. The results show on Table 3 and Figure 7. In the case (1), the results from three techniques are strongly correlated each other. Also, in the case from (1) to (4), the correlation coefficient between GPS and DMTD are keep high correlation up to about 0.6. However, the correlation coefficient between VLBI and GPS/DMTD become small as the calculation period shortens. The correlation coefficient is about 0.4 and the differences of time difference are about ±50 ps at the short term period. However, the clock estimate precision of GPS analysis by using PPP (*Precise Point Positioning*) is about 100 ps [1], and it is larger than above difference.

We calculated frequency stability of VLBI using the data from 220 to 225 day of year. Figure 8 shows the results together with past results. This result is not stable than the past result of international baseline. It's surpassing the stability of atomic fountain at 10^5 seconds or longer.

3. Summary and Outlook

To show the frequency stability of local baseline (Kashima34m-Kashima11m), we carried out long term VLBI experiment together with GPS and DMTD measurement. And, we compared the time difference calculated from these three techniques (VLBI, GPS and DMTD). The results are strongly correlated at long term period (correlation coefficient about 0.9).

The frequency stability of VLBI is surpassing the stability of atomic fountain at 10^5 seconds or longer. This result is unstable in comparison with the stability of the international baseline. And, as for the cause to fall stability at local baseline, the influence of the temperature change is large. In the future, the effort to reduce the influence of temperature change is necessity.

Acknowledgments: The authors would like to acknowledge the IVS and the IGS for the high quality products. We are grateful that JPL provided the licenses of GPS analysis software (GIPSY OASIS II). We used CALC/SOLVE made by GSFC

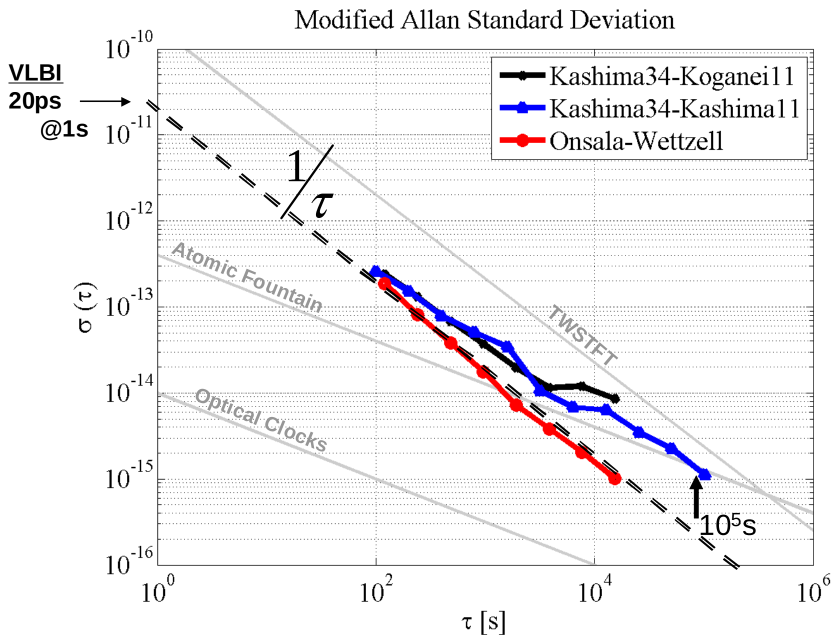

Figure 8. The frequency stability of VLBI together with past results.

for VLBI analysis. The VLBI experiments were supported by M. Sekido and E. Kawai of Kashima Space Research Center.

References

[1] Heroux, P., and J. Kouba, GPS precise point positioning using IGS orbit products, *Physics and Chemistry of the Earth*, 26, 6-8, 573-578, 2001.

[2] Komiyama, B., Frequency and time measurement methods, *Radio Lab Bull*, Vol. 29, 39–53, 1983.

[3] Kouba, J., and P. Heroux, Precise Point Positioning using IGS orbits and clock products, *GPS Solutions*, No. 5, 12–28, 2001.

[4] Koyama, Y., H. Takiguchi, T. Hobiger, and R. Ichikawa, Precise Time Transfer by Means of Geodetic VLBI Technique, *JPGU Meeting 2007 Abstract*, D106-002, 2007.

[5] Kumagai, M., H. Ito, M. Fujieda, and M. Hosokawa, Evaluation of caesium atomic fountain NICT-CsF1, *Metrologia*, 45, 139-148, 2008.

[6] Takamoto, M., F.-L. Hong, R. Higashi, and H. Katori, An Optical Lattice Clock, *Nature*, 435, 321–324, 2005.

[7] Takiguchi, H., T. Hobiger, A. Ishii, R. Ichikawa, and Y. Koyama, Comparison with GPS Time Transfer and VLBI Time Transfer, *IVS NICT-TDC News*, No.28, 10–15, 2007.

[8] Takiguchi H., Y. Koyama, R. Ichikawa, T. Gotoh, A. Ishii, T. Hobiger and M. Hosokawa, Comparison Study of VLBI and GPS Carrier Phase Frequency Transfer using IVS and IGS data, *IVS NICT-TDC News*, No.29, 23-27, 2008.

[9] Takiguchi H., Y. Koyama, R. Ichikawa, T. Gotoh, A. Ishii, T. Hobiger and M. Hosokawa, VLBI MEASUREMENTS FOR FREQUENCY TRANSFER, *ATF 2008 Proceedings*, 2008.

Geodetic VLBI Experiments by a Small VLBI Antenna with a Broad-band Feed

Atsutoshi Ishii (*ishii@nict.go.jp*)[1,2,3], **Ryuichi Ichikawa**[2], **Hiroshi Takiguchi**[2], **Kazuhiro Takefuji**[2] , **Yasuhiro Koyama**[2], **Shinobu Kurihara**[1], **Kensuke Kokado**[1], **and Daisuke Tanimoto**[3]

[1] *Geographical Survey Institute*
1 Kitasato, Tsukuba, Ibaraki 305-0811, Japan
[2] *Kashima Space Research Center, National Institute of Information and Communications Technology, 893-1 Hirai Kashima, Ibaraki 314-8501, Japan*
[3] *Advanced Engineering Services Co.,Ltd. 1-6-1 Takezono, Tsukuba, Ibaraki 305-0032, Japan*

Abstract: We are developing a compact VLBI system with 1 m class diameter antenna. The purpose of this development is to provide precise length of baseline of around 10 km. The developing system is called MARBLE (Multiple Antenna Radio-interferometer for Baseline Length Evaluation). We plan to use a broad-band antenna for feed of this VLBI antenna. One of the proposed antenna is a quad-ridge horn antenna (QRHA). The QRHA have multi-octave band width and dual linear polarization. To confirm the performance of the QRHA on geodetic VLBI, it was installed on existing VLBI antenna with 2.4 m diameter dish (CARAVAN2400) in Kashima. Original 2.4m antenna had been able to receive only X-band. After having installed the QRHA, it have been able to receive S-band too. Geodetic VLBI experiments were performed using the new 2.4 m antenna and 32 m antenna in Tsukuba. The error (1 sigma) of the estimated of the baseline lengths by the experiments were 6mm. The baseline lengths estimated were coincident within 10 mm compared with the past results.

1. Introduction

Geographical Survey Institute (GSI) and National Institute of Information and Communications Technology (NICT) are developing a compact VLBI system with an antenna of around 1.5m diameter by the collaboration. The purpose of this development is to provide precise length of baseline of around 10 km [4][5]. One of the main equipments of the compact VLBI system is a small and transportable antenna. A general geodetic VLBI observation requires the receiving of two frequency

Figure 1. The Quad Ridge Horn Antenna (ETS 3164-05).

bands of X-band and S-band simultaneously. It is one of the problem how to achieve this on such small antenna. A feed generally used in a large Cassegrain type VLBI antenna is a corrugated horn. This horn antenna have an axisymmetric beam and a low cross-polarization over a octave bandwidth[1]. However, expanding the band more than it is difficult. On the other hand, there is a method of installing the feed separately for each band by using frequency selective surface (FSS). The one example of practical use is Nobeyama Radioheliograph[7]. However, the receiving system becomes complex in this case, it is not suitable for transportable system.

Recently, a broad-band antenna called quad ridge horn antenna (QRHA) was commercialized. The main usage of QRHA is an Electro-magnetic compatibility (EMC) examination. The QRHA have multi-octave bandwidth, and the size is small[6]. If this antenna can be used as feed of the small parabolic antenna, simple and transportable VLBI antenna becomes feasible.

Figure 2. The remodeled 2.4 m antenna (CARAVAN2400).

Table 1. The conditions of geodetic VLBI experiments

	Experiment Name			
	CA6264	CA7032	CA8175	CA8184
Date	9/21/2006	2/1/2007	6/23/2008	7/2/2008
Using stations	Old 2.4 m - Tsukuba 32 m		New 2.4 m - Tsukuba 32 m	
Band and channels	X-band 8 ch		X-band 10 ch, S-band 6 ch	
Sampling rate	16 MHz / ch, 1 bit (2 level)			
Number of observations	275	375	220	188
Actual duration	24.0 h	24.2 h	24.0 h	24.0 h

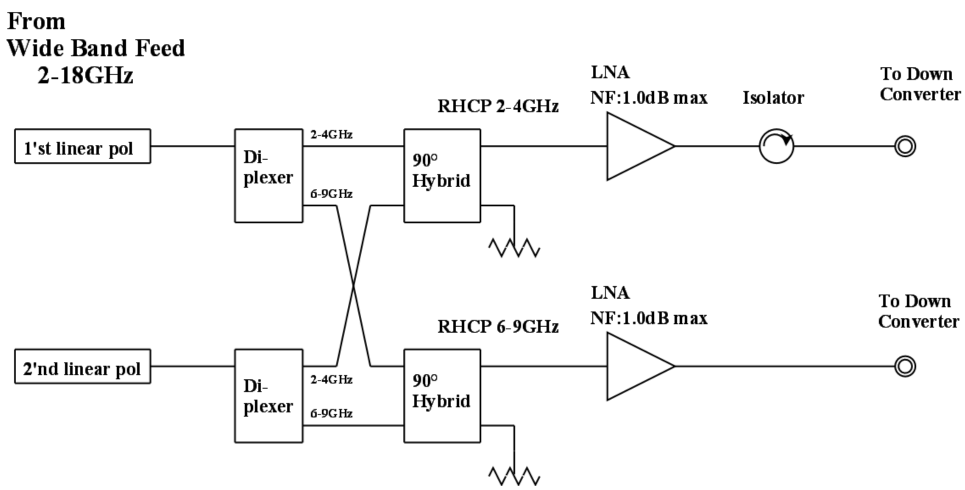

Figure 3. The block diagram of new receiver.

2. Geodetic VLBI Experiments

To confirm the performance of QRHA on geodetic VLBI, the QRHA was installed on small VLBI antenna with 2.4 m diameter dish (CARAVAN2400) in Kashima. The installed QRHA has the bandwidth of 18 from 2 GHz (ETS 3164-05, Figure 1). The 2.4 m antenna had been originally Cassegrain type antenna, and it had been able to receive only X-band[3]. First of all, the existing sub reflector and the corrugated feed horn were detached from the 2.4 m antenna, and the QRHA was installed in the prime focus. Moreover, we made a new receiver, and it installed in the back of the QRHA (Figure 2). This receiver plays not only amplification but also the role of the conversion to the circular polarization (Figure 3). After installing the QRHA and the new receiver, the 2.4 m antenna has been able to also receive S-band.

We performed geodetic VLBI experiment twice with the new 2.4 m antennas and Tsukuba 32 m antenna in 2008. Table 1 shows the conditions of these experiments. To comparison, Table 1 also contain past experiments using the original 2.4 m antenna.

3. Results

We successfully got good fringes in the most of scans in the experiments CA8175 and CA8184. We could also estimate the length of the baseline. The estimated lengths agree with the results of a past experiments within 10 mm. (Figure 4). The estimation errors (1 sigma) of baseline length were about 6 mm in the experiments. This errors were larger than the errors of the experiments using the old 2.4m antenna. The reason is a high system noise temperature and the low aperture efficiency of the new 2.4 m antenna. The system noise temperature of the old 2.4 m antenna is about 120 K for X-band, and the new one is 250 K. The aperture efficiency of the old 2.4 m antenna is about 40 % for X-band, and the new one is only 6 %.

However, such low performance doesn't matter in the viewpoint of the evaluation of the broadband feed and the receiver. Moreover, such a low performance can be evaded as follows. We will be able to obtain a high aperture efficiency if there is a new reflector optimized for the feed not such the 2.4m reflector. For this receiver, if the amplifier with a wide-band can be put ahead of the diplexer,

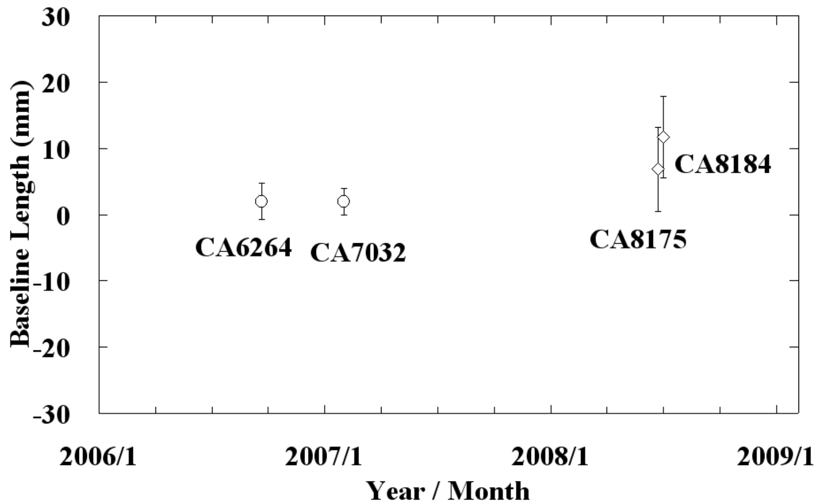

Figure 4. The baseline length estimated. The 0 mm of the baseline length in the vertical line corresponds 53800 m.

a low system noise temperature can be obtained. We actually designed the prototype of a compact antenna of MARBLE based on such ideas[2].

4. Conclusion

We performed remodeling of installing QRHA and a new receiver to the 2.4 m VLBI antenna in Kashima. By the remodeling, the 2.4 m antenna have been able to receive S-band and X-band simultaneously. Using the new 2.4 m antenna, the geodetic VLBI experiments were performed. We successfully got good fringes and results of baseline length. The errors (1 sigma) of estimated baseline length were about 6 mm. The baseline lengths estimated are coincident within 10 mm compared with past results. By these facts, it was proven that this antenna was able to be enforceable of the geodetic VLBI experiment for 24 hours, and to measure the baseline length.

Acknowledgments: We wish to express our gratitude to Teruaki Orikasa, Yoshiyuki Fujino, Tetsuro Kondo, Jun Amagai, Mamoru Sekido, Eiji Kawai, Moritaka Kimura and Junichi Nakajima of NICT by a lot of advices for this research. We are very grateful for cooperation in the experiments by Hiromitsu Kuboki, Masanori Tsutsumi and Shingo Hasegawa of NICT.

References

[1] Johnson, Richard C. (1993), Antenna Engineering Handbook Third Edition, 15-42.

[2] Ichikawa, R., A. Ishii, H. Takiguchi, Y. Koyama, T. Kondo, K. Kokado, S. Kurihara and S. Matsuzaka, Present Status and Outlook of Compact VLBI system Development for Providing over 10-km Baseline Calibration. *IVS NICT-TDC News No.30*, pp.TBD, TBD 2009.

[3] Ishii, A., R. Ichikawa, H. Kuboki, Y. Koyama, K. Takashima, and J. Fujisaku, VLBI Experiments Using CARAVAN2400. *IVS NICT-TDC News No.27*, pp.9-13, Aug 2006.

[4] Ishii, A., R. Ichikawa, H. Takiguchi, H. Kuboki, M. Kimura, J. Nakajima, Y. Koyama, J. Fujisaku, and K. Takashima, Development of a compact VLBI system for an length examination of a reference baseline. *IVS NICT-TDC News No.28*, pp.2-5, Aug 2007.

[5] Ishii, A., R. Ichikawa, H. Takiguchi, H. Kuboki, T. Kondo, Y. Koyama, M. Machida, and S. Kurihara, Current Status of Development of a Compact VLBI system for Providing over 10-km Baseline Calibration. *IVS NICT-TDC News No.29*, pp.19-22, Oct 2008.

[6] Rodriguez, Vincent., A Multi-octave Open-boundary Quad-ridge Horn Antenna for Use in the S- to Ku-band, Microwave Journal, 49, 84-92.

[7] T. Takano, H. Nakajima, C. Trii, H. Sekiguchi, Y. Shiomi, S. Kawashima, T. Bushimata, N. Shinohara, S. Enome, K. Shibasaki, M. Nshio, Y. Hanaoka, Y. Irimajiri, Radio Interferometer for Solar Radio Observations using Dual-Frequency Receiving Antennas at 17/34 GHz, A·P96-12, TECHNICAL REPORT OF IEICE (In Japaneses).

Data processing and analysis tools for ultra-rapid UT1 measurement

Kentarou Nozawa[1,2], Hiromi Shigematsu[1], Kensuke Kokado[1], Shinobu Kurihara[1]

[1] *Geographical Survey Institute*
[2] *Advanced Engineering Services Co., Ltd.*

Abstract: The Tsukuba VLBI Correlator performs the correlation processing and the primary analysis of the INT2 session (Tsukuba-Wettzell baseline) by e-VLBI on the weekend. We obtain the UT1 automatically by using the data processing tool and the analysis tool of "OCCAM". The feature of this automatic processing is to be able to perform the correlation processing of the observational data almost in real time. As a result, we were able to shorten the processing after the end of the session, and we obtained the UT1 value about 36 minutes after the end of the session by automating the primary analysis.

1. Introduction

To examine a continuous change in irregular rotation of the earth, the VLBI observation that is called Intensive Session for one hour is regularly done(INT1: Kokee-Wettzell baseline, from Monday to Friday; INT2:Tsukuba-Wettzell baseline, Saturday and Sunday; INT3:NyÅlesund-Tsukuba-Wettzell baseline, Monday). The data is recorded on the magnetic disk, and transferred to correlators by using the network. The UT1 is obtained within three days after the end of the session.

The high-speed network has enabled of the transfer of the data almost in real-time in recent years. We performed the Ultra-rapid dUT1 experiments to obtain the UT1 as quick as possible[1]. The stations that participated in the experiments were Tsukuba, Kashima, Onsala and Metsahovi. We performed the experiments Jul. 14, 2007, Sep. 4, 2007, Oct. 29, 2007, Nov. 22, 2007 and Feb. 21, 2008. We could obtain the UT1 result within 3 minutes 45 seconds after the end of the last scan of the session on Feb. 21, 2008[2].

With this success we have applied this technology to the processing of INT2 session. It is necessary to automate processing, because Tsukuba correlator is unattended weekends. We created the environments for automatic rapid UT1 measurement with "Cor_mgr"[1][3] and "MK3TOOLS"[4] developed at NICT(National Institute of Information and Communications Technology).

2. Environmental considerations for rapid UT1 measurement

We get Wettzell data through the high-speed network by using UDP-based data transfer protocol "Tsunami".

For data recording and the correlation processing, we use K5/VSSP software packages[4] developed by NICT are employed. Tsukuba data is in K5 format, on the other hand data from Wettzell is Mark5 which is necessary to be converted to K5 format.

Two or more computers perform the correlation processing by multitasking. "Cor_mgr" manages this multitasking.

We use analysis tools "OCCAM" because "CALC/SOLVE" can't solve ambiguities automatically. We use "MK3TOOLS" to run "OCCAM". "MK3TOOLS" are a collection of programs which allow to read/write MK3 databases without binding the CALC/SOLVE libraries. It uses the NetCDF format to store the data before MK3 databases are created. "MK3TOOLS" run "OCCAM" to obtain the UT1 values and ambiguities resolution. MK3 databases are created from the NetCDF files that contain the ambiguities resolution.

3. Flow of rapid UT1 measurement

3.1 Data transfer and conversion

Figure1 shows the outline of the data transfer. Tsukuba correlator gets Wettzell data as soon as one observation is finished. The observation data is recorded by sampling rate 256Mbps. The transfer rate of 200Mbps that is fast enough to transfer the data. It takes about 80 seconds to transfer the data (about 1.8GByte).

The program "m5tok5" converts Mark5 format of Wettzell data to K5 format. It takes about two minutes for one data conversion. If there are no data, it sends an error message to Tsukuba correlation staff by e-mail.

3.2 Fringe search, Correlation processing and Bandwidth synthesis

1. Fringe search

   The program "cor" performs the fringe search as soon as the first scan data conversion is finished. The program "apri_calc" creates a priori file before the fringe search. The clock offset and rate are of the previous values of fringe detection. If the fringe is detected, the value of the clock offset and rate are corrected, and the program "apri_calc" creates a priori file again. If the fringe is not detected, it

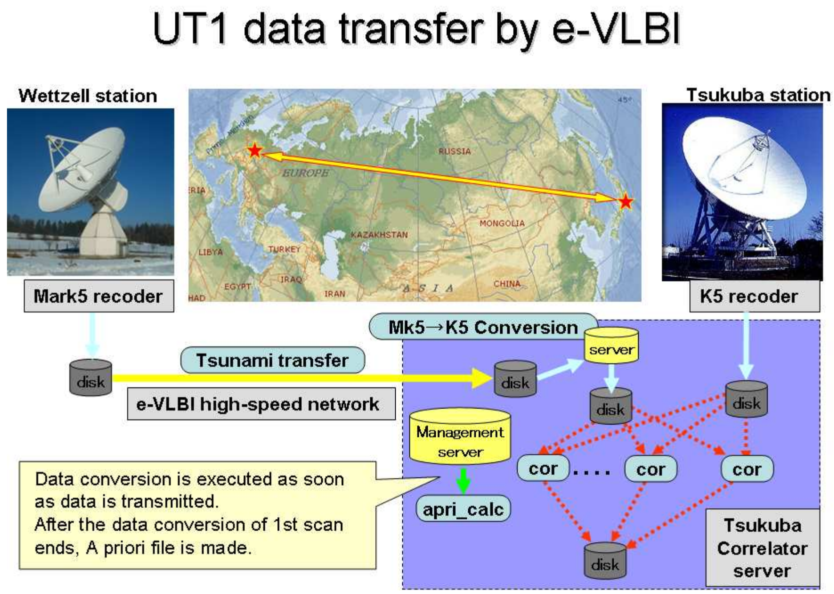

Figure 1. the outline of the data transfer

sends an error message to Tsukuba correlation staff by e-mail.

The fringe search takes about five times as long as scan time, and it takes about one minute to create a priori file.

2. Correlation processing and Bandwidth synthesis

   Figure2 shows the outline of the correlation processing and the bandwidth synthesis. The correlation management tools "Cor_mgr" manage multitasking correlation processing. As soon as one scan data conversion is finished, "Cor_mgr" on the control server throw a job to correlation servers which are in standby status. We use ten correlation servers. The correlation processing takes about 1.3 times as long as a session time.

   The program "komb" on the control server performs a bandwidth synthesis after all correlation processing are finished. It takes about two minutes for a bandwidth synthesis.

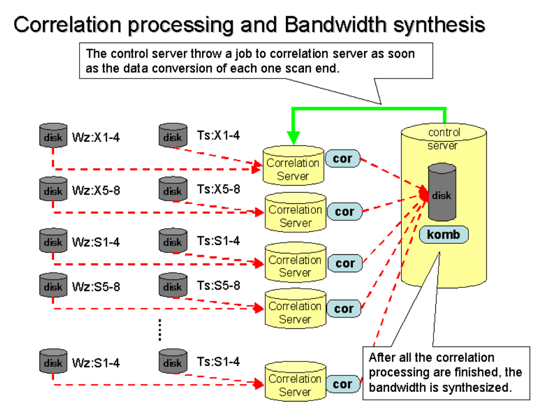

Figure 2. outline of the correlation processing and the bandwidth synthesis

3.3 Primary analysis

Figure3 shows the outline of primary analysis. "MK3TOOLS" on the analytical server creates a NetCDF file from the bandwidth synthesis files, and translates the NetCDF file into a NGS card. "MK3TOOLS" run "OCCAM" which calculates the UT1-UTC value and resolves the X- and S-band ambiguities. It finishes the UT1 caluclation within one minute, and sends the UT1 value to Tsukuba correlation staff by e-mail.

In addition, "MK3TOOLS" create MK3 databases from the NetCDF file containing the ambiguities resolved, and we obtain the UT1 values using "CALC/SOLVE" at the beginning of the week.

3.4 Processing time

The time for obtaining the UT1 value after the end of the last scan of the session becomes about 36 minutes. Figure4 shows the processing time of K09046(Feb. 25, 2009).

The most of the processing time are taken up by

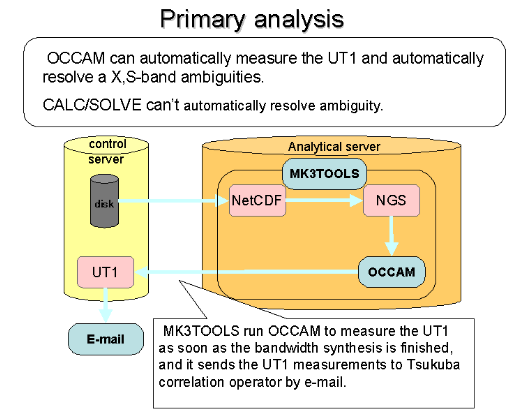

Figure 3. outline of primary analysis

the data conversion and the correlation processing . The correlation processing time becomes long as time of the data conversion increased. If we use two or more computers for a data conversion, the data conversion time will be shorter.

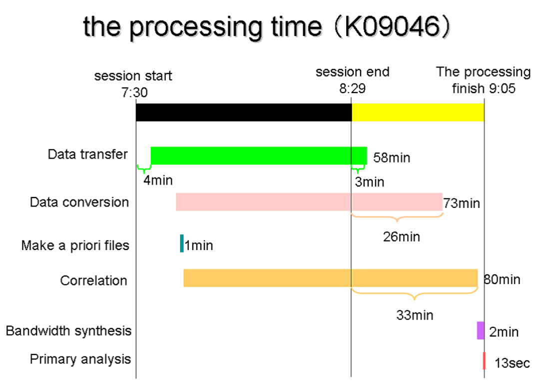

Figure 4. Processing time of K09046

3.5 Comparison of the UT1 measurement

Figure5 shows the UT1 measurement value difference between the value by "CALC/SOLVE" and "OCCAM".

The mean value of "CALC/SOLVE - OCCAM" is -7.9 microseconds, and standard deviation is 27.6 microseconds. As for the reason of the difference, the difference of analytical parameters of "CALC/SOLVE" and "OCCAM" is suspected. It needs further investigation.

4. Conclusion

We created the environments for the automatic rapid UT1 values of INT2 session and could obtain the UT1 result about 36 minutes after the end of the last scan of the session. We'd like to improve the environments for quick data conversion, and investigate the difference of the UT1 results between "CALC/SOLVE" and "OCCAM".

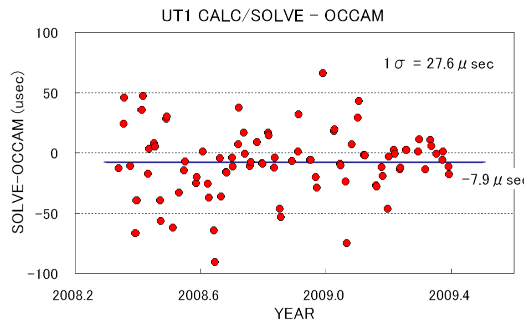

Figure 5. Difference of the UT1 measurement

Acknowledgments: We are deeply grateful to Dr.Sekido and Dr.Hobiger of NICT for helping us to use "Cor_mgr" and "MK3TOOLS".

References

[1] Sekido, M., Correlation Managemant Tools, https://www2.nict.go.jp/w/w114/stsi/research/e-VLBI/Soft/Cor_mgr/index.html

[2] Matsuzaka, S., et al. "Ultra Rapid UT1 Experiment with e-VLBI", The 5th IVS General Meeting Proceedings, 104-108, 2008

[3] Koyama, Y., et al. "Developments of Automated Data Processing System for Ultra Rapid dUT1 e-VLBI Sessions", The 5th IVS General Meeting Proceedings, 405-409, 2008

[4] Hobiger, T., et al. "MK3TOOLS - Seamless Interfaces for the Creation of VLIB Databases from Post-Correlation Output", The 5th IVS General Meeting Proceedings, 153-156, 2008

[5] Kondo, T., K5/VSSP VLBI SYSTEM, http://www2.nict.go.jp/w/w114/stsi/K5/VSSP/

Kashima 34m Antenna 20th Anniversary

Ryuichi Ichikawa (*richi@nict.go.jp*)

Professor Kawaguchi of National Astronomical Observatory gave the keynote presentation at the 20th anniversary ceremony of the Kashima 34 m antenna. The Kashima 34 m antenna was built to perform VLBI experiments 20 years ago. Professor Kawaguchi, who was belong to Radio Research Laboratory, was in full charge of all activities related antenna installation. In his presentation he revealed that he and his colleagues were confronted with great difficulties in order to proceed the project. The most severe problem was time. They had to finish to install the antenna within one year. However, they accomplished it eventually in the end of 1988. We greatly owe the recent progress in VLBI-related research at NICT to the 34 m antenna since then and we are deeply grateful to Professor Kawaguchi and his colleagues for their extraordinary efforts.

Figure 1. Keynote presentation by Professor Kawaguchi.

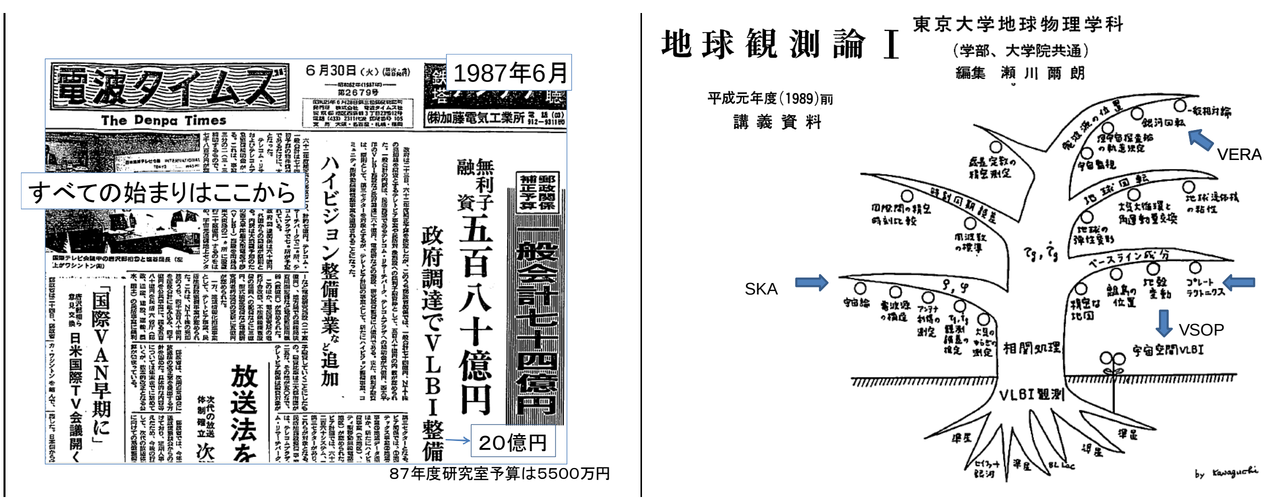

Figure 2. Some part of the presentation slide.

"IVS NICT Technology Development Center News" (IVS NICT-TDC News) published by the National Institute of Information and Communications Technology (NICT) (former the Communications Research Laboratory (CRL)) is the continuation of "IVS CRL Technology Development Center News" (IVS CRL-TDC News). (On April 1, 2004, Communications Research Laboratory (CRL) and Telecommunications Advancement Organization of JAPAN (TAO) were reorganized as "National Institute of Information and Communications Technology (NICT)".)

VLBI Technology Development Center (TDC) at NICT 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 NICT TDC newsletter (IVS NICT-TDC News) is published annually by NICT.

This news was edited by Yasuhiro Koyama and Hiroshi Takiguchi. Inquires on this issue should be addressed to H. Takiguchi, Kashima Space Research Center, National Institute of Information and Communications Technology, 893-1, Hirai, Kashima, Ibaraki 314-8501, Japan, TEL : +81-299-84-7133, FAX : +81-299-84-7159, e-mail : htaki@nict.go.jp.

Summaries of VLBI and related activities at the National Institute of Information and Communications Technology are on the Web. The URL to view the home page of the Space-Time Measurement Project of Space-Time Standards Group is : **"http://www.nict.go.jp/w/w114/stmp/index_e.html"**.

IVS NICT TECHNOLOGY DEVELOPMENT CENTER NEWS No.30, October 2009

International VLBI Service for Geodesy and Astrometry
NICT Technology Development Center News
published by
National Institute of Information and Communications Technology, 4-2-1 Nukui-kita, Koganei, Tokyo 184-8795, Japan

NiCT