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Wide-band High-temperature Superconductor Filter on 2.2GHz RFI Mitigation

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

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

1. Introduction

To remove radio frequency interference (RFI), a new High-Temperature Superconductor (HTS) band-pass filter is developed for radio-astronomy geodesy and astrometry reception in S-band. The filter has sharp frequency cut-off and wide band-pass characteristics. We have installed the filter into the Kashima 34-m antenna interfered by local mobile phone base station. As the result the telescope recovered its wide band-pass and the interferences were totally attenuated. We already reported use of an Ambient Temperature Cavity (ATC) filter against the severe interference [*Kawai et al.*, 2002]. In this report, the HTS filter produces very good results in the S-band reception.

2. RFI from IMT-2000 and other radio services

The Kashima 34-m antenna S-band receiver frequency is 2150-2350 MHz. From their historical background most of the VLBI telescopes are receiving the bandwidth. Though, officially there is no radio astronomical frequency allocation in this range by the ITU. Thus, without the authority, radio telescopes can not take strong stand point to the other radio services. Recently IMT-2000 mobile phones are appears between 2110-2170 MHz and 2.4-GHz radio LAN system started in many areas. As a consequence, severe RFI in the S-band receiving system occurred in telescopes. Typically the strong RFI causes saturation of down converter system in telescope and occasionally with heavy inter modulations (Figure 1). Still the spectrum between 2110-2170MHz are clean, we have to develop techniques to live together these new radio applications.

3. HTS filter

The experimental receiver installation diagram of HTS and ATC filters is shown in Figure 2. They are currently installed between the LNA and down converter. The receiver output when using an ATC filter is shown in Figure 3. By this ambient filter we realized sufficient -60dB attenuation at 2170 MHz, where the upper end frequency assigned for IMT-2000. For this case cut-off frequency of the filter was set to 2250 MHz. Though the reception ranges was narrowed between 2250-2350 MHz, receiving spectrum was recovered. The signal of IMT-2000 is still obvious in the spectrum. The strength of the IMT-2000 signal is varied by communication traffic, enough margin up to 11dB should be considered. By the characteristic of the ATC filter shape, the receiving range cannot be extended from this range. With the filter range, we had problems in international VLBI experiment frequency assignment. In addition, there is a possibility of saturation in the front-end LNA in the strong RFI case. ATC can not be installed ahead of the cooled

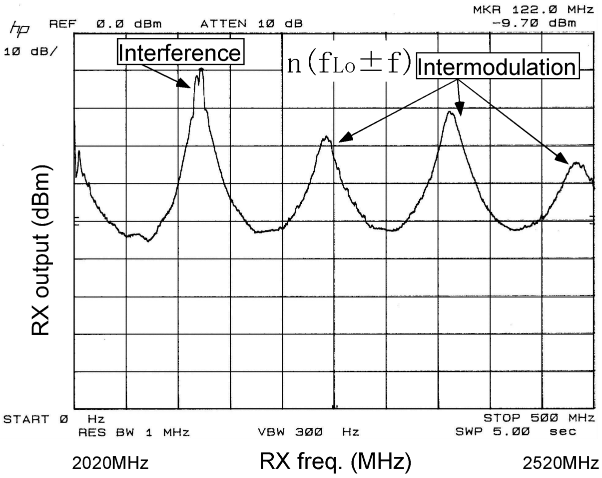

Figure 1. Saturated S-band receiver output just after IMT-2000 started. The base station signal and local frequency are inter modulated. Under this condition observations were impossible.

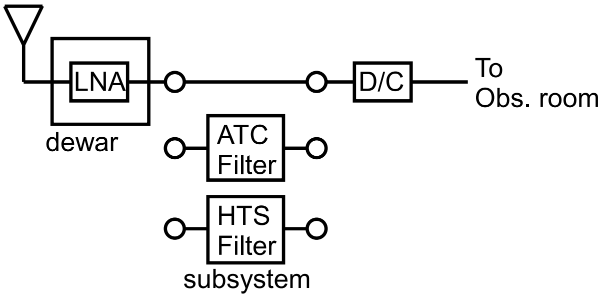

Figure 2. A schematic block diagram of S-band receiver. In this experiment the HTS filter is installed at the output of the LNA to compare ATC filter.

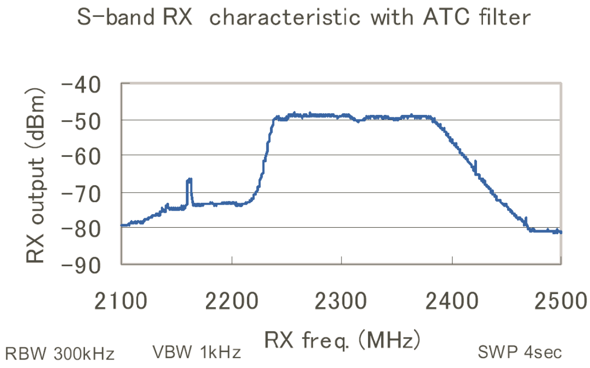

Figure 3. Receiver spectrum with started from 2250MHz when using ATC filter. IMT2000 signal is remaining 2160MHz.

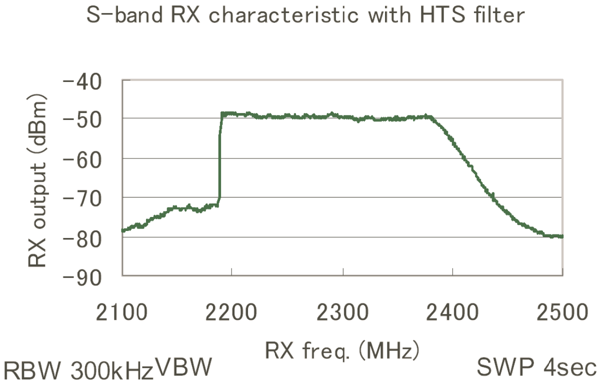

Figure 4. Receiver spectrum with started from 2193MHz when using HTS filter. It is remarkable that the filter increased the bandwidth and the interference is disappeared.

LNA due to its insertion loss. For these reason we developed HTS filter and installed to the system. The receiver output when using the HTS filter subsystem is shown in Figure 4. It is remarkable that the signal of IMT-2000 in 2160MHz is completely attenuated and reception range is lowered to 2193MHz. The receiving frequency band was expanded 57MHz. In this experiment both higher end of receiving range is limited by a filter in the down converter. In future it is possible to locate the HTS filter ahead of the LNA. The HTS filter subsystem is shown in Figure 5. A small cryostat is used and the filter unit is cooled at 70K to sustain superconductivity. The compact HTS filter unit is shown in Figure 6.

The characteristics of the ATC filter and the HTS filter unit are summarized in Table 1. As seen in the Figure 4, the HTS filter can set the cut-off frequency of 23 MHz separation from the interference. In addition by its low insertion loss, this is a hopeful device for front-end. If an ambient temperature filter of 1dB attenuation inserted in front of the LNA, increase system temperature (Tsys) 62K, but if the cooled HTS filter of insertion loss 0.5dB is used, the Tsys increase is remained 8K. Tsys is affected by slightly.

Figure 5. HTS filter subsystem installed at LNA output.

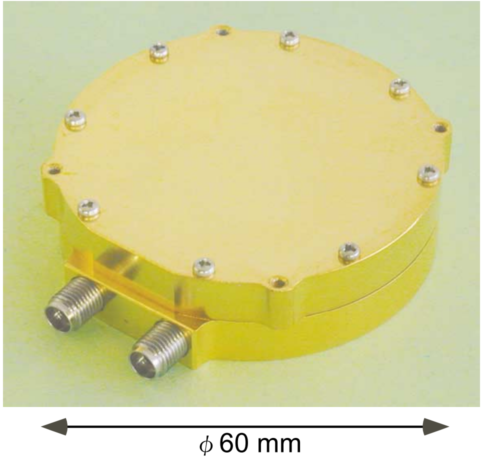

Figure 6. HTS filter unit.

4. Conclusions

Severe radio frequency interference occurred at S-band receiver of Kashima 34-m antenna by the IMT-2000 mobile phone and other radio service were solved by the HTS filter installation. Compared to ATC filter, the HTS filter can extend receiver range 57MHz (57%). Since IMT-2000 and other radio services are increasing year by year. This will be a remedy against the severe interfer-

Table 1. The characteristics of filter.

	ATC filter (19 section)	HTS filter (32 section)
Passband	2250–2450 MHz	2193–2473 MHz
Attenuation	>60 dB at 2170 MHz	>80 dB at 2170 MHz
Insertion Loss	<1dB	<0.5dB
Dimension (mm)	260 × 42 × 27	ϕ 60 × 14

ence in other telescope sites.

Acknowledgement: We wish to thank Dr. Nobuyoshi Sakakibara, Mr. Akito Torii, and Mr. Shunji Okemoto of DENSO CORPORATION Research Laboratories for their contribution to develop an HTS filter adapted for an S-band radio astronomical receiver.

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Kashima 34m Radio-telescope 2003 Annual Maintenance

34m radio-telescope maintenance group

Annual maintenance of the Kashima 34-m radio telescope started 1st July. Every year, the maintenance is carried out during July thorough August, the fist half of the period is used by regular maintenance and then additional repair continues. The operation of the improved 34m telescope will start in September again. To cut a huge summer maintenance work short, followings are main headings to keep the telescope in good condition.

The mechanical maintenance includes six motors overhaul, back structure rust removals, main-reflector support fixture replacement, and azimuth wear-strip clean up. Most of the safety related components are replaced. Electronics components including antenna controller, DC power amps and high precision encoder units are re-checked and part of instruments are replaced to prevent failures in future. Receiver cooling cryogenics are stopped and send back to factory to replace wearing components. They are re-installed as completely new. This year, especially we disassemble sub-reflector unit. The huge complex 5-axies unit located in severe weather environment is removed by dual crane tucks from top of the antenna. It needs special consideration to work properly.

In recent year, observations in higher frequency on 22/32/43 GHz are increasing. In addition special demands like spacecraft monitoring are frequently programmed. To accomplish these tasks successful, the telescope maintenance becomes important year by year.

Though its maintenence budget is limited, local companies which consider the symbolic telescope in this area provide us their best effort. Occasionally affected by weather conditions, often these contractors had to give up their summer vacation. But still they are zeal for job completion before the first observation deadline. In the CRL side, two staffs are newly joined the telescope maintenance group. Hiromitsu Kuboki is a specialist of 34m operation and maintenance. Hiroshi Takeuchi is a researcher and he also take a part of engineering issue. Since they joined the 34m group, numerous part of the telescope are already modified or improved. The details of these will be reported in a separate issue of TDC news.

(*see page 15 for a picture*)

First Detection of 2-Gbps Wide-band Fringes between two PC-based VLBI Systems

Moritaka Kimura[1] (*mkimura@crl.go.jp*),
Junichi Nakajima[1], **Jouko Ritakari**[2], **and**
Ari Mujunen[2]

[1]*Kashima Space Research Center*
Communications Research Laboratory
893-1 Hirai, Kashima, Ibaraki 314-8501, Japan
[2]*Metsähovi Radio Observatory, Finland*

1. Introduction

2-Gbps (1-Gsps/2-bit/1-ch) wide-band e-VLBI observations between Communications Research Laboratory (CRL) and Metsähovi Radio Observatory succeeded 17th June 2003. First 2-Gbps fringes were detected by high-speed CRL multi-baseline software correlation system [*Kimura and Nakajima,* 2002]. This 2-Gbps observation is placed as final goal of a series of observations in October 16, 2002 and February 7, 2003 reported in the previous issue [*Koyama et al.,* 2002].

2. 2Gbps e-VLBI observation

Two different PC systems adapted to VSI-H (VLBI Standard Interface Hardware) were used to carry out the 2Gbps e-VLBI. These are named as 'PC-VSIB' in Finland [*Ritakari and Mujunen,* 2002] and 'PC-VSI' in Japan. Though these systems are developed independently, raw data of the VLBI bit stream stored to PC standard file format has a compatibility. CRL G-bps AD sampler, ADS-1000 [*Nakajima,* 2000] had been installed at Metsähovi Radio Observatory and the unit is connected to the PC-VSIB. Wide-band IF of telescope, converted from 22.020GHz to 22.532GHz are connected.

The wide-band IF signals were sampled at base-band is now extended to 2bit quantization (MSB and LSB: Most and Least Significant Bit) fully utilizes ADS-1000 performance and 2048- Mbps VSI data is recorded to RAID disks. Two continuum sources and a maser source were observed automatically during 2 hours session. All observation data files recorded at Metsähovi station were transferred to Kashima site by using multi-thread FTP.

After obtained the first requested file, cross correlation were carried out by software correlator immediately. Using the popular high performance personal computers which has some CPUs. The first 2Gbps fringe of NRAO150 integrated 16 seconds presented in Figure 1. SNR of the 2-bit correlation is 39.5% higher than that of 1-bit (only MSB) correlation (Table 1)

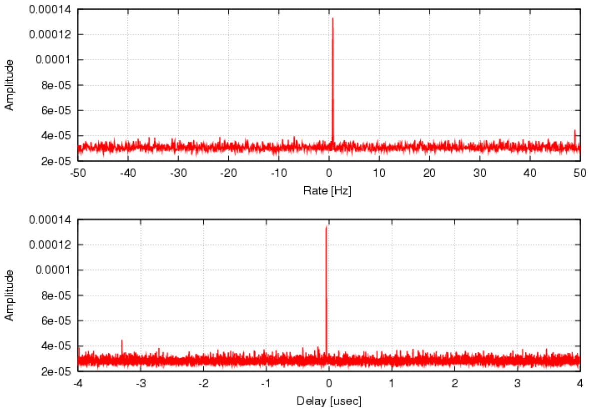

Figure 1. The first 2-Gbps e-VLBI fringe between Metsähovi and Kashima. The fringe is projected in rate and delay windows.

Table 1. Improvement of the SNR in 2-bit correlation of NRAO150. SNR were measured with same integration time (16 sec).

	Metsähovi 1bit	Metsähovi 2bit
Kashima 1bit	22.8	27.4
Kashima 2bit	27.2	31.8

From this SNR increase, expanded lower bit acquisition in both 2-Gbps systems worked perfect. Further K-band wide-band G-bps observation will continues between the Finnish-Japanese 7400-km baseline.

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Rapid UT1-UTC estimation from Westford-Kashima e-VLBI experiment

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

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

1. Introduction

Currently, minimum delay time to obtain results from IVS global sessions is about two weeks for IVS-R sessions and about one week for intensive sessions. As it is pointed out by the report of the IVS Working Group 2 for Product Specification and Observing Program (Schuh, et al., 2002), it is very important to shorten this processing time delay to improve the products of the IVS. The report set the goal of the IVS observing program to make the time delay from observing to product less than one day by the year 2005. To achieve this goal, it is necessary to transfer observation data electrically over the high speed global communication network by replacing the current magnetic tape recording system at the observing sites and correlator sites with the e-VLBI systems.

Figure 1. K5 VLBI system (Versatile Scientific Sampling Processor)

IVS Technology Development Centers including Haystack Observatory and Communications Research Laboratory have been concentrating their efforts to realize the e-VLBI in the global geodetic VLBI observations. At Communications Research Laboratory, the K5 VLBI system (Figure 1) has been developed based on the UNIX PC systems. The K5 VLBI system, or also called as Versatile Scientific Sampling Processor, is consist of four UNIX PC systems. Each UNIX PC system has one IP-VLBI data sampling board on its PCI interfacing bus. The board can sample 4 channels of baseband signals at various sampling rates ranging from 40kHz to 16MHz. Quantization bits can be set from 1, 2, 4, and 8. The maximum data rate from one IP-VLBI board is 512Mbps, but the actual usage is limited by the data transfer speed of the PCI bus of the UNIX PC system. The current prototype system has achieved data recording at the data rate of 128Mbps by one PC system. As the results, the K5 VLBI system (VSSP) can be used up to the data rate of 512Mbps as the whole. The sampled data can be recorded to internal hard disks as ordinary data files and softwares to transfer and receive observation data in real-time are under developments.

In this report, the results of the test observations performed between Kashima and Westford VLBI stations on March 25 will be presented.

2. Experiment

The test e-VLBI session was performed for two hours from 16:00 UT on March 25, 2003 with the Kashima-Westford baseline. The 34m antenna VLBI station at Kashima and 18m antenna station at Westford were used for the observations (Figure 2). This was the fourth test in the series of e-VLBI test observations. During the previous tests, successful detections of the fringes from the e-VLBI observations were demonstrated and the software developments have been continued with the obtained data sets.

At the Kashima station, K5 VLBI system was used to record observed data. At the Westford station, Mark5 VLBI system developed by Haystack Observatory was used to record observed data. The observed data were recorded to internal hard disks at each site and transferred to Kashima and Heystack Observatory after the observations by using FTP. For this purpose, a program was executed to extract the data from the Mark5 and to generate data files. At Haystack Observatory, K5 data files were converted their format and recorded to Mark5 system. After the conversion, both data recorded at Kashima and at Westford were processed for cross correlation processing using the

Figure 2. 34m antenna VLBI station at Kashima (left) and 18m antenna VLBI station at Westford (right).

Mark-4 correlator. At Kashima, Mark5 data files were converted to K5 file format and then both data recorded at Kashima and at Westford were processed for cross correlation processing by using the software correlator on the K5 VLBI system. After the cross correlation processing, bandwidth synthesis processing was done and database files (one for X-band and another for S-band) for data analysis. Table 1 lists the observed radio sources and the sizes of the data files. The total data volume was hence 56Mbps. The observations were performed with 14 channels (8 for X-band and 6 for S-band) and 2MHz for each channel. The file size of the Mark5 system was checked from the extracted files from the Mark5 disks. The extracted file contains 36 channels for data space and the parity bits and therefore the file size is larger than the actual data volume. File size of the K5 VLBI system is the total of the four data files recorded at four UNIX PC system of the K5 VLBI system. In this case, data space for the two channels were redundant.

Firue 3 and Figure 4 show the schematic route of the high speed network used in the e-VLBI tests. Kashima is connected to the Galaxy network under the collaboration with NTT cooperations at the maximum bandwidth of 2.4Gbps. The Galaxy network is then connected to Abilene network in the United States by Super-SINET route (622Mbps) and GEMnet route (20Mbps) for trans-Pacific connection. The maximum bandwidth of the GEMnet trans-Pacific connection was upgraded to 150Mbps, but there is still a bottleneck between Galaxy network and connecting point in Tokyo which limits the effective bandwidth to 20Mbps. During the test session on March 25, the route of Super-SINET was used. The Haystack Observatory is connected to Abilene network via BOSSNET and GLOWNET at the maximum bandwidth of 1Gbps.

3. Results

After the data processing, CALC and SOLVE softwares were used to perform data analysis. In the estimation process, positions of both Kashima and Westford stations were fixed to the ITRF2000 values and the UT1-UTC was estimated along with the clock offset, clock rate, and the atmospheric zenith delay. The estimated UT1-UTC value is shown in the Table 2 as well as the values published in the Bulletin B of the IERS (IERS Bulletin B 183, May 2, 2003).

Table 3 shows the required time for various processing steps. As shown in the table, the file transfer and the correlation processing are dominating the time. But it is also shown that the time delay from the observations to obtain results can be shorten to less than two days. At the time of the test, the file transmission speed was not as fast as expected from the network capacity. The speed was only about 2.4 Mbps while the overall network capacity was 100Mbps which was limited by the network interface card of the K5 system. The reason of the slow traffic was found to be the small transmission buffer for the TCP/IP connection (64kBytes) and the large transmission time delay (more than 200 milli-seconds). By adjusting the buffer size larger, the file transmission speed is expected to be improved and hence the time required for the file transmission will become much shorter. The correlation processing also can be shorten by using more CPUs to process the data. By combining these efforts, it will become feasible to estimate UT1-UTC within one day after the observations.

Table 1. List of observed radio sources and the sizes of the data files.

No.	Source Name	Duration (sec)	File Size Mark5 (MB)	File Size K5 (MB)
1	4C39.25	90	1,620	720
2	1736+455	200	3,600	1,600
3	1357+769	90	1,620	720
4	0059+581	250	4,500	2,000
5	2234+282	310	5,580	2,480
6	1300+580	140	2,520	1,120
7	0955+476	90	1,620	720
8	2113+293	300	5,400	2,400
9	1739+522	500	9,000	4,000
10	1357+769	90	1,620	720
11	0059+581	270	4,860	2,160
12	2234+282	510	9,180	4,080
13	1044+719	784	14,112	6,272
14	1128+385	180	3,240	1,440
15	1300+580	130	2,340	1,040
16	0955+476	90	1,620	720
17	2113+293	390	7,020	3,120
18	1739+522	530	9,540	4,240
19	1357+769	90	1,620	720
Total		5,034	90,612	40,272

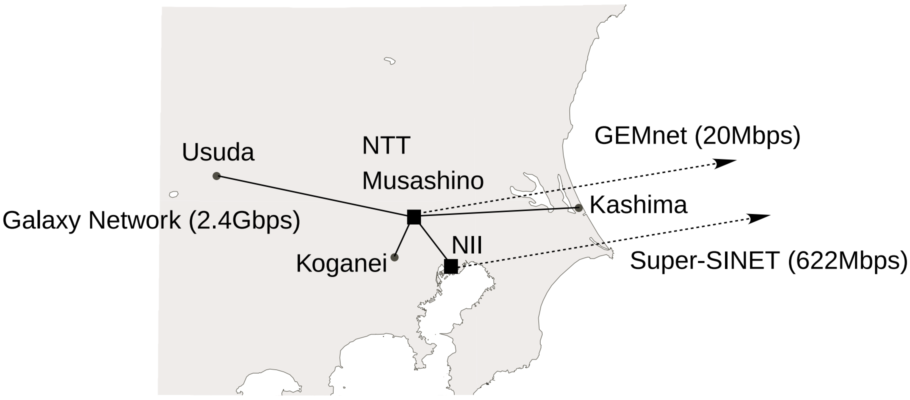

Figure 3. The logical configuration of the high speed network in Japan. The location of the NTT Musashino R&D center and National Institute for Informatics (NII) are not accurate.

Table 2. Estimated results of UT1-UTC from the test e-VLBI session and values from IERS Bulletin B.

UT1-UTC (epoch)	microseconds
Estimated Value (at 20:00 UT on March 25, 2003)	-338727.0 ± 23.9
Bulletin B (at 00:00 UT on March 25, 2003)	-337951
Bulletin B (at 00:00 UT on March 26, 2003)	-338610

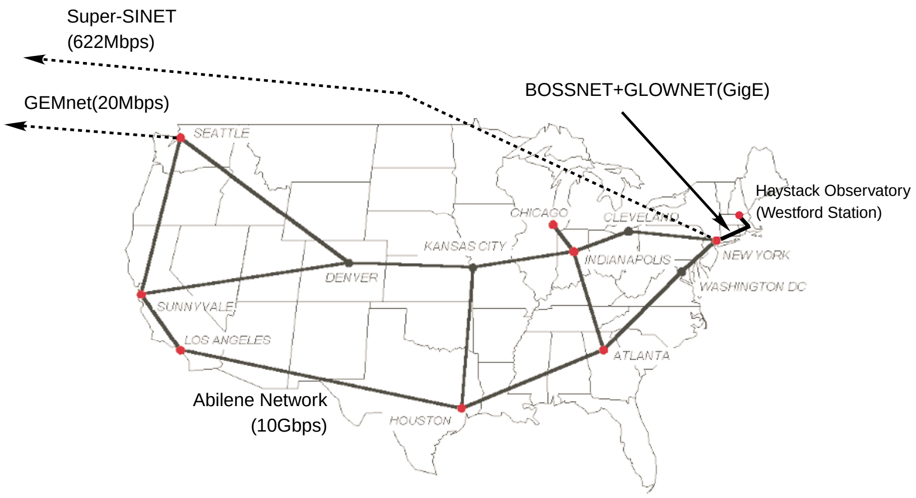

Figure 4. The logical configuration of the high speed network in the United States.

Table 3. Evaluation of required time for various processing steps.

Processing	Required Time
File Transfer	20 hours
File Conversion	1 hour
Bandwidth Synthesis	1 hour
Correlation	20 hours
Data Analysis	1 hour
Total	< 2 days

Acknowledgement: The authors would like to appreciate many members of the Haystack Observatory for observations and data processing, Internet2 for the Abilene network, NTT corporations for GALAXY network, and National Institute for Informatics for Super-SINET network.

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VLBI Application for Spacecraft Navigation (NOZOMI) Part I – Overview –

ICHIKAWA, R.[1] (*richi@crl.go.jp*),
SEKIDO, M.[1], **OSAKI, H.**[1],
KOYAMA, Y.[1], **KONDO, T.**[1], **and**
NOZOMI VLBI group[2]

[1] *Kashima Space Research Center*
Communications Research Laboratory
893-1 Hirai, Kashima, Ibaraki 314-8501, Japan
[2] *ISAS, NAO, GSI, NASDA, Gifu Univ.,*
Yamaguchi Univ., Hokkaido Univ., and
SGL/CRESTech

Precise spacecraft positions can be obtained with differential spacecraft-quasar VLBI observations that directly measure the angular position of the spacecraft relative to nearby quasars. We performed more than 30 VLBI experiments for the NOZOMI spacecraft navigation from September 2002 until June 2003. NOZOMI, which means "Hope" in Japanese, is the Japan's first Mars probe developed and launched by the Institute of Space and Astronautical Science (ISAS) (see Figure 1). NOZOMI was originally scheduled to reach its destination in October 1998, but an earlier Earth swingby failed to give it sufficient speed, forcing a drastic rescheduling of its flight plan. According to the new trajectory strategy, NOZOMI's arrival at Mars is scheduled early in 2004 through two additional earth swingbys in December 2002 and June 2003 as shown in Figure 2 [*ISAS web site,* 2002].

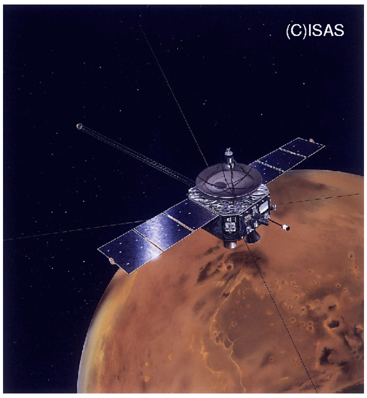

Figure 1. NOZOMI image.

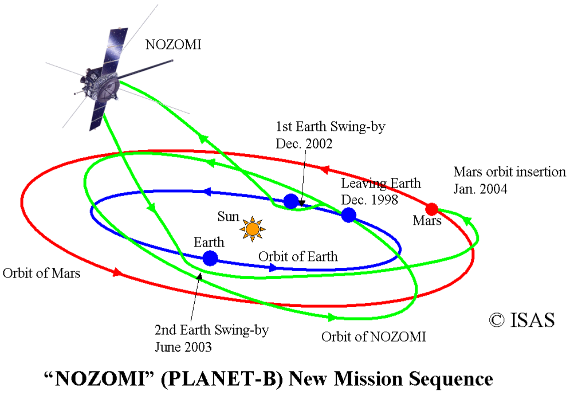

Figure 2. NOZOMI mission sequence toward Mars.

Our main concern was to determine the NOZOMI orbit just before the second earth swingby on June 19, 2003. It was significantly important to get the timing to maneuver the NOZOMI before the swingby. ISAS scientists were afraid that the range and range rate (R&RR) orbit determination might not be available because it was difficult to point the high-gain antenna mounted the spacecraft toward the earth during the period between two swingby events. So we started to support the orbit determination of the NOZOMI using VLBI technique since September 2002. These experiments are also aimed to establish the positioning technology for the interplanetary spacecrafts in realtime.

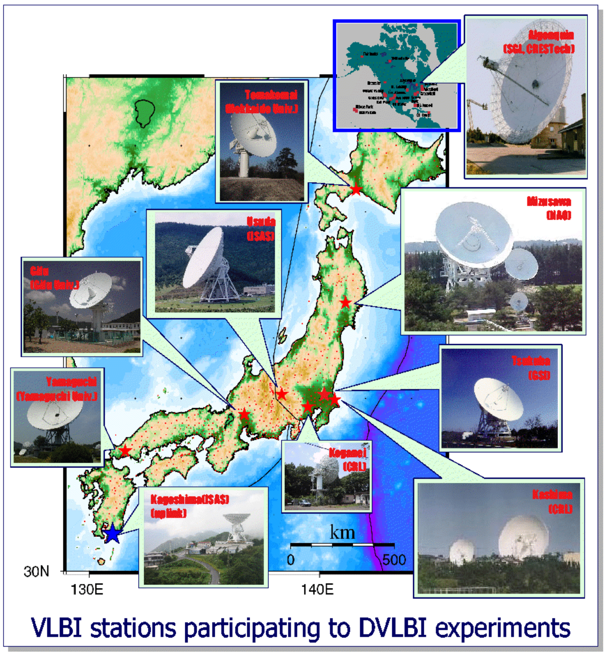

Figure 3. VLBI stations participating to NOZOMI experiments.

We use nine VLBI antennas in Japan to carry out the NOZOMI VLBI experiments at X-band.

Algonquin 46-m antenna operated by Natural Resource Canada and the Space Geodynamics Laboratory (SGL) of the CRESTech also participated in the several experiments. The VLBI stations are shown in Figure 3. In each experiment, several quasar VLBI obsevables are obtained in conjunction with NOZOMI VLBI observations in order to determine the clock offset. We equipped the state of the art "K5 VLBI system" to these stations. The K5 system is the multiple PC-based VLBI system equipped with a PCI-bus Versatile Scientific Sampling Processor (VSSP) board on the FreeBSD and Linux operating system [*Osaki,* 2002; *Kondo et al.,* 2002]. The K5 system includes the original software packages which are data sampling and acquisition, real-time IP data transmission, and correlation analysis. For the purpose of analyzing the VLBI observables we are developing the specific VLBI delay model for finite distance radio source [*Sekido and Fukushima,* 2003; *Sekido et al.,* 2003]. The model is already implemented in the VLBI software package. The package will include the VLBI observation scheduling to take account of the passage of the spacecraft near the quasar line of sight and the propagation delay estimating for the ionosphere and the neutral atmosphere.

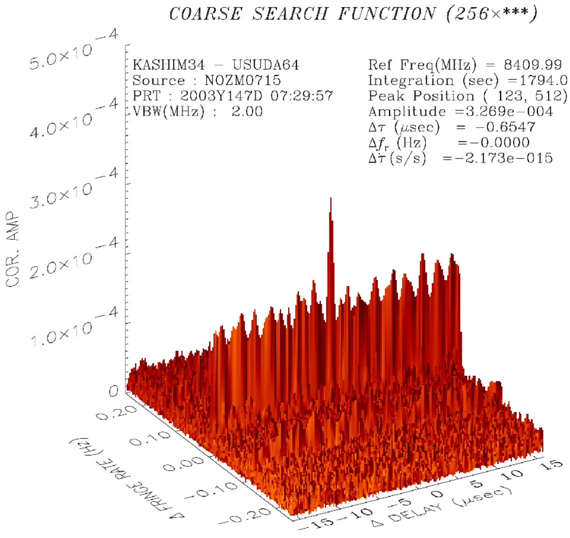

Figure 4. Detected fringe of NOZOMI range signal.

We could successfully detect fringes of NOZOMI range signal for several baselines using software correlation in spite of weak and narrow-bandwidth signal. An example of NOZOMI fringe is shown in Figure 4. We provided 15 VLBI group delay data sets to ISAS to support the orbit determination at the end of May 2003. On the other hand, ISAS scientists have fortunately succeeded to determine the NOZOMI orbit using R&RR observables at the end of May 2003. Preliminary results demonstrate that the VLBI delay residuals are consistent with R&RR observables. However, the rms scatter between them are relatively large up to several tens nanoseconds. We are now evaluating our VLBI data sets in more detail by comparing with the R&RR results.

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Sekido, M., R. Ichikawa, H. Osaki, T. Kondo, and Y. Koyama, VLBI application for spacecraft navigation (NOZOMI) part II –Delay model and analysis–, *TDC News No.22 (this issue),* pp12–15, 2003.

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VLBI Application for Spacecraft Navigation (NOZOMI) Part II
– Delay Model and Analysis –

Mamoru Sekido (*sekido@crl.go.jp*),
Ryuichi Ichikawa, Hiro Osaki,
Tetsuro Kondo, and Yasuhiro Koyama

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

1. Introduction

VLBI is one of the most precise technology to measure angular distance in the celestial sphere. It is not only tool for astronomy but also is quite useful in engineering application such as spacecraft navigation. VLBI is good at measurement in coordinates perpendicular to the line of sight. It has complementary sensitivity with that of range and range rate (R&RR) measurement, which is commonly used for spacecraft navigation in deep space. Thus a combined analysis is expected to increase accuracy of orbit determination of spacecraft.

Pioneering work in spacecraft navigation with VLBI has been performed by JPL [*Border et al.,* 1982] with group delay (Delta Differential One way Range). Institute of Space and Astronautical Science (ISAS) in Japan and CRL is collaborating to use VLBI for Japanese space mission. A spacecraft NOZOMI launched by ISAS was going to do two earth swingbys in the period of December 2002 and June 2003 [*Yoshikawa et al.,* 2001]. And a request for support the orbit determination with VLBI data arose. Orbit determination of NOZOMI has been performed by the ISAS and we provided VLBI data delay for supporting their work. On the other hand, our group is planning to develop a tool for spacecraft navigation with VLBI independently from the ISAS. Here we introduce some points in data reduction and analysis procedure of spacecraft coordinates estimation.

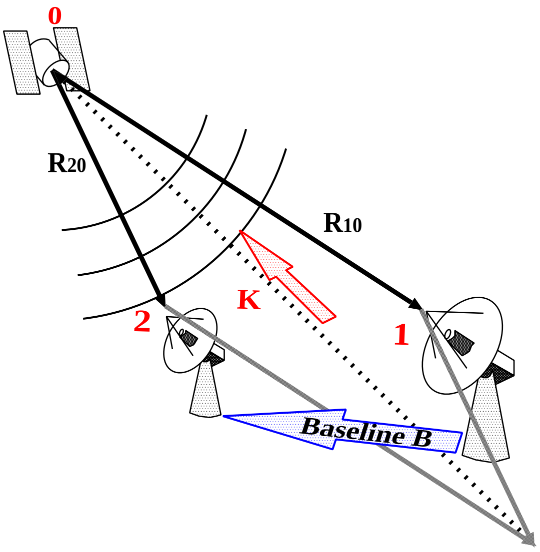

Figure 1. Schematic diagram of pseudo source vector $\vec{\mathbf{K}}$. *The vector* $\vec{\mathbf{K}}$ *is on the diagonal line of parallelogram composed from vector* $\vec{\mathbf{R}}_{10}$ *and* $\vec{\mathbf{R}}_{20}$.

2. VLBI Delay Model for Finite Distance Radio Source

The standard VLBI delay model so called 'consensus model' [*Eubanks,* 1991] uses plane wave approximation based on a assumption that a radio source is at infinite distance from observer. When the distance is less than 30 light years, however, curvature of wavefront of the signal from radio source is not negligible as pointed out by Sovers and Jcobs [*Sovers and Jacobs,* 1996]. They and Fukushima [*Fukushima,* 1994] argued about finite distance VLBI model, but an expression including coordinates transformation of general relativity have not been given. Sekido and Fukushima [*Sekido and Fukushima,* 2003] have derived a expression of VLBI delay for finite distance radio source corresponding to the 'consensus model' by taking into account relativistic effects. That form is

$$\begin{aligned}\tau_2 - \tau_1 & \\ = (1+\beta_{02})^{-1} & \\ \Bigg\{ \Delta t_g - \frac{\vec{\mathbf{K}}\cdot\vec{\mathbf{b}}}{c}\left[1-(1+\gamma)U-\frac{V_e^2+2\vec{\mathbf{V}}_e\cdot\vec{\mathbf{w}}_2}{2c^2}\right] & \\ -\frac{\vec{\mathbf{V}}_e\cdot\vec{\mathbf{b}}}{c^2}\left(1+\beta_{02}-\frac{\vec{\mathbf{K}}\cdot(\vec{\mathbf{V}}_e+2\vec{\mathbf{w}}_2)}{2c}\right)\Bigg\}, &\end{aligned} \tag{1}$$

where valuable in large capital indicates quantity in barycentric reference frame and that in small capital is that of geocentric frame. $\vec{\mathbf{R}}_{ij} = \vec{\mathbf{X}}_i - \vec{\mathbf{X}}_j$ and $\vec{\mathbf{X}}_i$ is position vector in barycentric reference frame. Suffix 0,1, and 2 respectively indicate radio source, station 1, and 2. $\vec{\mathbf{b}}$ is baseline vector on the geoid, $\vec{\mathbf{V}}_e$ and $\vec{\mathbf{w}}_2$ are barycentric velocity of geocenter and geocentric velocity of station 2, respectively. And pseudo source vector $\vec{\mathbf{K}}$ and parameter β_{20} are defined as :

$$\beta_{02} = \hat{\vec{\mathbf{R}}}_{02}\cdot\frac{\vec{\mathbf{V}}_2}{c} \tag{2}$$

$$\hat{\vec{\mathbf{R}}}_{02} = \frac{\vec{\mathbf{R}}_{02}}{R_{02}} \tag{3}$$

$$\vec{\mathbf{K}} = \frac{\vec{\mathbf{R}}_{02}(T_1)+\vec{\mathbf{R}}_{01}(T_1)}{R_{02}(T_1)+R_{01}(T_1)}. \tag{4}$$

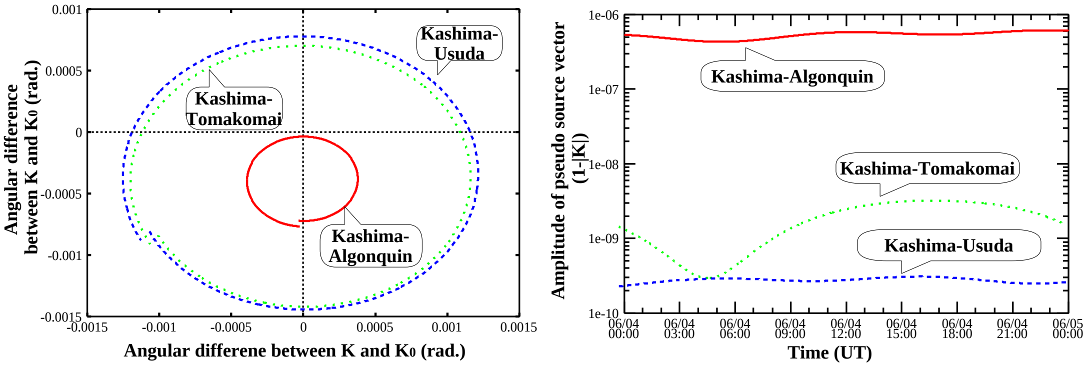

Figure 2. Behavior of pseudo source vector $\vec{\mathbf{K}}$ *in comparison with geocentric source unit vector* $\vec{\mathbf{K}}_0$*. Left panel shows changes of the direction of* $\vec{\mathbf{K}}$ *vector during 24 hours. The origin of the plot is the direction of* $\vec{\mathbf{K}}_0$ *vector. Right panel shows change of the magnitude of* $\vec{\mathbf{K}}$ *vector. Three lines on both two panels correspond to Kashima-Algonquin, Kashima-Tomakomai, and Kashima-Usuda baselines. Predicted orbit of NOZOMI on 4th-5th June 2003 was used for computation of the vectors here. Distance to the NOZOMI was* $4. \times 10^9$ *m from the geocenter in this period.*

The formula of (1) is very similar with that of 'consensus model' and both formulae become identical when the radio source is at infinite distance from observer. In this sense, our formula (1) will be regarded as expansion of 'consensus model'. The main difference between them comes from definition of source vector $\vec{\mathbf{K}}$. Actually, that vector must be called as pseudo source vector, and is neither unit vector nor constant vector as defined in equation (4). The schematic view of pseudo source vector $\vec{\mathbf{K}}$ is displayed in Figure 1. It changes the magnitude and direction with baselines and with time. Figure 2 demonstrate the behavior of $\vec{\mathbf{K}}$ vector during 24 hours in comparison with geocentric source vector to the spacecraft (NOZOMI) on Kashima-Algonquin (9109 km), Kashima-Tomakomai (750 km), and Kashima-Usuda (208 km) baselines. The $\vec{\mathbf{K}}$ vector was computed with based on predicted coordinates of NOZOMI in 4th-5th June 2003. Left panel in the figure shows deviation of the pseudo source vector from the direction to the source from geocenter. The deviation is larger as baseline is shorter. It is because parallax affect more directly to $\vec{\mathbf{K}}$ vector on shorter baseline. Since the NOZOMI is moving, the track of the vectors are not closed curves in 24 hours. Right panel indicate magnitude of the vector $\vec{\mathbf{K}}$. In contrast to the direction of $\vec{\mathbf{K}}$ vector, the magnitude deviates from unity more significantly as baseline becomes longer. Since the (pseudo) source vector affects directly to VLBI delay, change of its direction and magnitude cause change of delay in the same order. We implemented this model in our software by modification of CALC ver.9. Apriori delay, delay rate, and partial derivatives computed by this software was used in correlation processing and astrometric analysis of the spacecraft.

3. Correlation Processing and Difference from Normal VLBI

Observation and correlation processing of the VLBI data has been performed with PC-based system [*Osaki*, 2002; *Kondo et al.*, 2002]. We are seeking for better approach in both group delay and phase delay. In case of group delay, we used range signal to measure group delay for NOZOMI. Since the bandwidth of signal from the spacecraft is in order of 1 MHz when it is modulated, the delay resolution of group delay is in order of one nano second. To increase the spatial resolution of VLBI observation, we have asked to Algonquin observatory to join NOZOMI observations sometimes besides Japanese domestic VLBI stations [*Ichikawa et al.*, 2003]. The delay model for spacecraft is different from normal VLBI observation even on domestic baseline in Japan, since the radio source changes its position in the celestial sphere during observation. Moreover curvature of wave front affect significantly to the delay especially in intercontinental baseline. Figure 3 shows the delay rate derived from observation data and that of VLBI delay model of equation (1). We used following way to get continuous fringe rate for comparison here. We observed NOZOMI for almost 24 hours in the experiment of 4 June. Frequency of tone signal from NOZOMI was extracted every 2 seconds with 1 Hz resolution from observed 2bit-4MHz sampling VLBI data of each station via Fast-Fourier Trans-

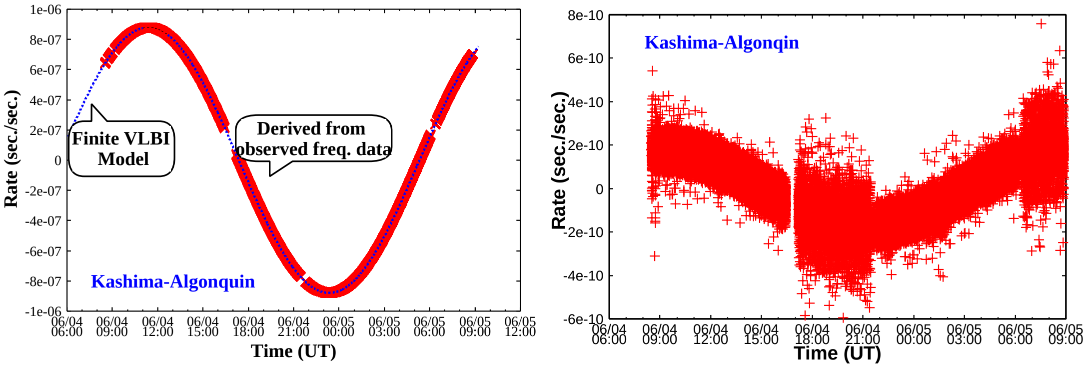

Figure 3. Delay rate derived from Doppler frequency (left) and Residual of delay rate(right) on Kashima-Algonquin baseline. In the left panel, × mark indicates derived delay rates and broken line indicate VLBI delay model of finite distance radio source. Plot in the right panel indicates residual of (observed) - (delay rate model).

form (FFT). Then delay rate including clock rates of VLBI stations was derived by a relation

$$\frac{d\tau}{dt} = \frac{f_x - f_y}{f_x}, \tag{5}$$

where f_x, and f_y is frequency of tone signal of NOZOMI observed at x and y station. Plot in Figure 3 scattered in range of $\pm 10^{-10}$ (sec/sec) because precision of frequency measurement was 1 Hz, then resolution of delay rate measurement here was 1(Hz)/8.4 (GHz) $\sim 1.2 \times 10^{-10}$. This order of delay rate resolution was not enough to compare rate residual precisely, but increasing the frequency resolution was limited due to some technical reasons (Number of FFT points, drifting frequency with time, and etc...). Delay rate resolution is low though number of data points is huge, so we can clearly recognize large systematic change of residual in Figure 3. It indicates apriori delay rate is not accurate enough, and consequently fringe rotates more than 1 turn in integration period (1 second was normal integration time in correlation process here). We think main reason of the rate residual may comes from difference between predicted coordinates and true ones of NOZOMI. Generally, this sort of error in predicted coordinates is supposed to be usual in also other spacecraft observation. Thus we need to establish stable procedure to detect fringe by searching wide range of fringe rate. One solution will be enlargement of rate window via decreasing integration period. Although increase of file size of intermediate correlation output (several tens of Mega Bytes to a few Giga Bytes per file) will accompany with it. The other solution will be searching fringe by repetition of correlation processing with changing rate parameter.

4. Analysis Software for Finite VLBI Astrometry

Observed VLBI delay data set obtained in series of NOZOMI VLBI observations [*Ichikawa et al.,* 2003] were submitted to ISAS for orbit determination analysis with joint data set with R&RR data. Independently from ISAS, we have been constructing our own software for coordinates estimation of spacecraft. Our analysis system is composed from two parts: precise apriori and partial derivative computation package ‘calc_skd’ and least square analysis package ‘lsq_src’, as similar with CALC/SOLVE system. We wanted to make platform independent system rather than using Mark-III database binded with HP computer, so most of the data used in the analysis are in form of ASCII text files. We may use PIVEX format [1] [*Gontier and Feissel,* 2002] as data system in future. The CALC version 9 was used as base to implement finite VLBI delay model. The analysis system runs on FreeBSD PC-unix system. The calc_skd computes apriori delay/rate and partials by following a file of scan list and with using a set of parameter files (planetary ephemeris DE405/DE406, EOP, and etc...) as the same with the CALC/SOLVE. The lsq_src is a simple multi-baseline least square analysis software with minimum functions. It use observed delay/rate, apriori delay/rate, partials, and constraints for estimating a subset of the parameters (source coordinates, proper motion, clock offset/rate, dry atmospheric zenith delay/rate, delay gradient of dry atmosphere, wet atmospheric zenith delay/rate). Since spacecraft may move rapidly on the celestial sphere, proper motion of the radio source may be included in estimation pa-

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[1] http://lareg.ensg.ign.fr/feissel/pivex.html

rameters.

5. Summary

We are investigating a VLBI technique for application of spacecraft navigation. As a first step, we have developed a finite VLBI delay expression with taken into account relativistic effects, and are developing analysis software packages. We will be able to report more detailed result of the analysis in future issue.

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Kashima 34m radio-telescope annual maintenance (*cont. from page 4*)

Photo. 34m telescope and a crane truck. Elevation motors are removed and sent back to the factory for overhawl. (see topics on page 4 for details)

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

VLBI Technology Development Center (TDC) at CRL is supposed

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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.

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