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The 2nd CRL TDC Symposium

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As a Technology Development Center (TDC) of the IVS, Communications Research Laboratory (CRL) had held IVS Technology Development Center Meeting twice every year until March 2001. The laboratory has executed a transition from an agency belonging to the Japanese government to Independent Administrative Institution on April 1, 2001. After the transition, the IVS Technology Development Center Meeting was reformed to make it a symposium and we started to call for contributed papers from broader community. Originally, the second symposium was to be held in March 2002, but was postponed until this time because there was the Second IVS General Meeting in February 2002. The second IVS Technology Development Center Symposium was then held on September 20, 2002 at the large conference hall of the main research building in the Kashima Space Research Center. At the symposium, 17 oral presentations and 4 poster presentations were given and during the day.

On the same day, the farewell ceremony of the 26m antenna in the Kashima Space Research Center was held since it will close its history soon. The antenna had been a symbol of the geodetic VLBI research in Japan. Motions of the plates around Japan and inter-plate deformations were actively investigated by using the antenna. The position of the reference point of the antenna based on the International Terrestrial Reference Frame was used as the essential reference to establish Geodetic Coordinates 2000 which was officially adopted as a national coordinate system of Japan. Contrastively, the importance of the geodetic VLBI has been gradually changing from positioning capability to the unique ability to determine Earth's orientation independently from any other space geodetic techniques. Reflecting this fact, many presentations given in the symposium were related with the developments of the e-VLBI systems and PC based observation/correlation systems which are expected to improve the current turn around time of the geodetic VLBI data processing to determine Earth Orientation Parameters, especially UT1-UTC. There were also many presentations about the application of the e-VLBI to determine precise orbit of planetary space-crafts in near real-time.

The symposium was coincidently held just when the old symbolic antenna is closing its history (*see page 41 for details*), but it certainly opened a new window for future directions of the geodetic VLBI research and developments.

Pictures taking on the second CRL Technology Development Center symposium held on September 20, 2002. The picture at the top is at the aural session. At the middle, symposium participants, and the bottom, at the poster presentations.

An Evaluation of Positioning Error Estimated by the Mesoscale Non-Hydrostatic Model –Preliminarily report–

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We are now evaluating atmospheric parameters (equivalent zenith wet delay and linear horizontal delay gradients) derived from slant path delays obtained by ray-tracing through the non-hydrostatic numerical weather prediction model (NHM) with 1.5 km horizontal resolution. Our ultimate purpose is to establish a new method for reducing atmospheric effects on geodetic positioning. We first seek to establish the level of positioning error due to intense mesoscale phenomena such as the passing of cold fronts, heavy rainfall events, and severe storms. The NMH provides temperature, humidity and pressure values at the surface and at 38 height levels (which vary between several tens meters and about 35 km), for each node in a 1.5 km by 1.5 km grid that covers Izu peninsula of the central Japan and surrounding ocean.

We performed ray tracing experiments for the entire grid of the NHM at one epoch of the 1200 UT 3/7/1997. For each station we invert the simulated data set, consisting of 52 slant delays, using an isotropic and an anistropic delay model. The isotropic model has only one parameter – the zenith wet delay (ZWD). The anisotropic delay model of Chen and Herring (1997) has two additional lateral gradient parameters. We compare the 'true' ZWD, computed by directly integrating the wet refractivity field of NHM, with the ZWD estimated by least squares inversion of the 'observed' slant delays obtained by ray tracing. We did this using the isotropic and the anistropic delay models.

Figure 1 shows the zenith wet delays (ZWDs) computed using ray tracing based on the vertical profile of the NHM. Gradient vectors estimated using least squares inversion of ray-traced slant delays are also indicated (white allows). A characteristic ZWD pattern caused by the mountain lee waves is presented in this figure. At the east of the Izu peninsula ZWDs are lying in a north-south band about 10km in width and about 50km in length. This ZWD pattern is consistent with the observed

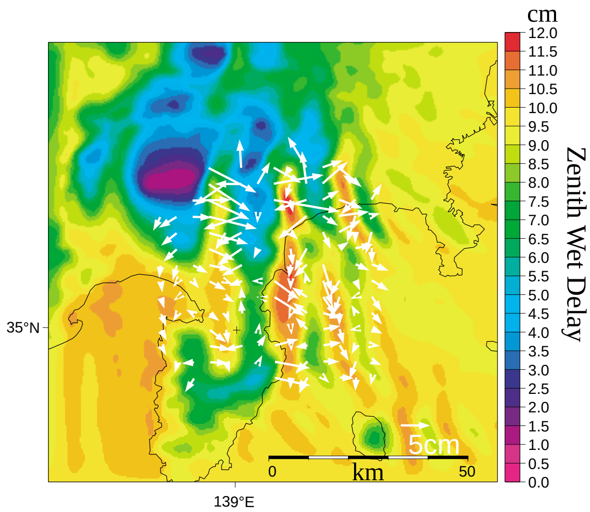

Figure 1. Zenith wet delay retrieved by the 1.5km NHM at the 1200UT of March 7, 1997. Arrows indicate gradient vectors estimated by the best-fit anisotropic model to the slant delays using ray tracing through the NHM.

GMS cloud image [*Shimada et al.*, 2002]. Large gradient vectors are perpendicular to the north-south ZWD band. In addition the biggest gradients occur at the northern part of the peninsula where topographic variations produce a much more complex distribution of water vapor.

We are now numerically examining positioning errors calculated from the slant delays through the NHM, assuming realistic GPS and VLBI positioning. In the another paper we will present the behavior of the positioning errors under the atmospheric disturbance in local scale, the relation between the ZWD errors and the vertical positioning errors, and the efficiency of the reduction of the azimuthal anisotropy of the atmosphere using the anisotropic mapping function [e.g. *MacMillan*, 1995; *Chen and Herring*, 1997].

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Holographic measurement of Kashima 34-m radio telescope surface accuracy –Preliminary report–

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1. Introduction

We have planned to measure surface accuracy of Kashima 34-m antenna using a microwave holographic technique. It had been difficult to carry out holographic measurement, because there was no reference antenna exists near Kashima 34-m antenna site. To realize a holographic measurement we adopted CARAVAN 0.65-m antenna [*Yonezawa et al.,* 2002] as a reference antenna. A geostationary satellite, N-star b, was used as a reference radio source in a far-field region.

Only a few satellites are matched with a frequency and AZ/EL position requirement of our measurement system. We are working on data analysis and have not reached result yet. In this report, we will introduce a measurement system and a result of experimental observation briefly.

2. Measurement

2.1 Theory

A microwave holography is technique to measure a far-field pattern of test antenna using a reference antenna. Then applying the Fourier Transform to far field pattern to get aperture distribution of amplitude and phase of test antenna. Aperture distribution of phase error is considered to represent surface error of reflector. Figure 1 shows relationship between near-field aperture phase distribution pattern and far-field phase pattern.

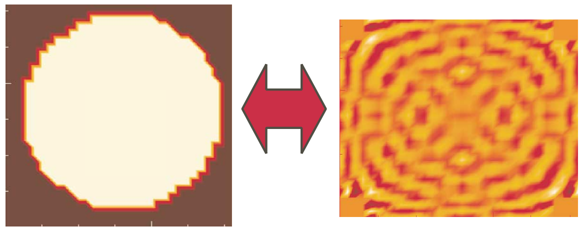

Figure 1. Near-field(Left) and Far-field (Right) phase pattern.

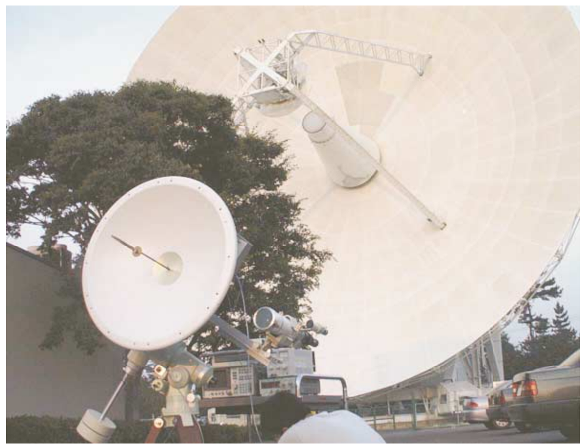

Figure 2. Kashima 34-m antenna and CARAVAN 0.65-m antenna are used to receive the geostationary sattelite N-star b.

2.2 Measurement system

During measurements, the Kashima 34-m and the CARAVAN 0.65-m antennas observe signal from the geostationary satellite N-star b (see Figure 2). Elevation of satellite from Kashima site is 48.02 deg.

Figure 3 shows a diagram of holographic measurement data acquisition system. RF signals at Kashima 34-m and CARAVAN 0.65-m station are fed to down converters and each 0-2GHz IF signal are fed to video converter. Outputs of video converters, 2 channel 2MHz video signals, are finally fed to the VSSP (Versatile Scientific Sampling Processor) [*Osaki et al.,* 2002], then sampled and stored on HDD. Sampling rate is 4MHz 4bit 1ch for each station. Data are stored in HDD, then processed by software correlator.

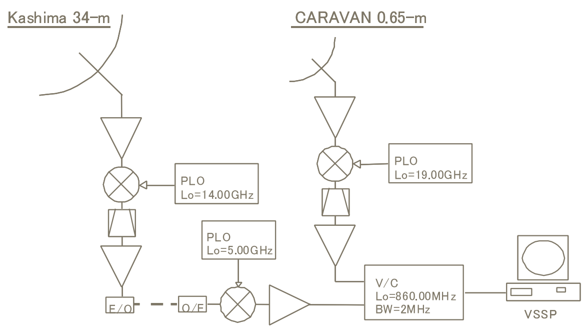

Figure 3. Microwave holographic measurement data acquisition system.

2.3 Antenna maneuver

On the first attempt of our measurement, we acquired data at each 1024 (32×32) points. After

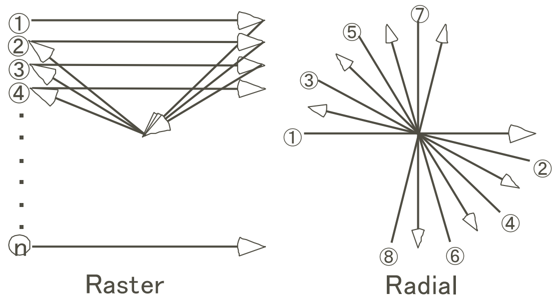

Figure 4. Antenna maneuver.

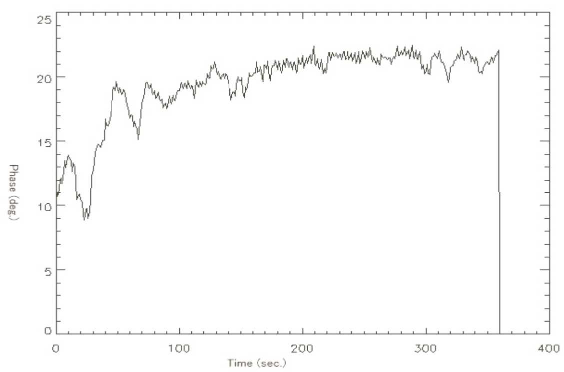

Figure 5. Phase fluctuation of measurement system.

data processed, we found that phase connectivity between each observation is not good. Thus in the second attempt, we changed antenna scan pattern. Using radial and raster scan (Figure 4), data was acquired continuously during a scanning process. Radial scan is thought to be shorter observation time because beam center is measured at each scan. Although raster scan consumes observation time, the data processing will be easier. At this moment we took data of both scan pattern.

3. System error estimation

Figure 5 shows correlated phase during experimental observation. During this observation test antenna received signal from the satellite in center of beam. From this result, phase stability of the system is measured to 0.028 degree/sec. This antenna scanning process takes about 16 minutes. Hence phase fluctuation of measurement system will contribute measurement error of 1.1 mm. Previously we estimated that local oscillator phase error contributed as large as 0.85 mm.

4. Conclusion

The holographic measurement of the Kashima 34-m antenna is in progress. Antenna scan pattern was improved but estimated phase error of the system is still large. Main reason comes from due to a local oscillator phase error of the reference telescope. Now we are improving the system and we will present the results of holographic measurements to improve system.

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Dependence of Correlation Dimension of QSO Radio Wave Intensity Time Series on Red Shift

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Summary: The variation of the radio wave intensity with time from the quasars (QSOs) at cosmological distance are unpredictable because of unknown dynamical structures of the radio sources and the external factors effected on the path of wave propagation. In this paper, the preliminary analysis results of the time series data of the quasars of S band (2 GHz) and X band (8 GHz) are presented.

The purpose of our study is to calculate the degree to which the presumed dimension of the dynamical system are limited from the Grassberger-Procaccia (GP) method by correlation integration.

1. Introduction

In our previous study, time series data of QSO radio wave flux density were analyzed on the stand point of Higuchi's fractal dimension, Hurst exponent, power spectrum etc. Khan et al. [1]. The calculated results were plotted and compared with respect to red shift. In that results, we did not get any information about the effect of external noise. In the present analysis, a convolution time series has been calculated from the original radio wave time series. Then the correlation dimensions for both time series have been calculated and plotted with respect to red shift. In these results, a new notion has been probed that inevitable external noise may be accumulated on the original radio wave at the time of the wave passing through the space from the cosmological distance.

2. Analysis Methods

2.1 Convolution Time Series

To calculate the convolution time series, we have processed the convolution operation on the microwave time series data with some *kernel* values. For example, let us consider, "$list1$" is the kernel values, "$list2$" is the time series data, then the resulted values of convolution operation is shown in "$result$" list.

$list1$ = {A, B, C, D, E}
$list2$ = {a, b, c, d, e, f, g, h, i, j, k, l, m, n}
$result$ = { (Aa + Bb + Cc + Dd + Ee), (Ab + Bc + Cd + De + Ef), (Ac + Bd + Ce + Df + Eg), (Ad + Be + Cf + Dg + Eh), (Ae + Bf + Cg + Dh + Ei), (Af + Bg + Ch + Di + Ej), (Ag + Bh + Ci + Dj + Ek), (Ah + Bi + Cj + Dk + El), (Ai + Bj + Ck + Dl + Em), (Aj + Bk + Cl + Dm + En) }

If the length of original data is x and the length of kernel is y, then the length of convolution data will be (x - y + 1). For example, here the lengths of "$list2$" is 14 and length of "$list1$" is 5. So, the length of "$result$" is (14 - 5 + 1) = 10.

In our analysis, we have used the kernel values, Wolfarm [2] as follows

$$\frac{1}{6.1\sqrt{2\pi}}\mathrm{Exp}(-\frac{n^2}{100}) \tag{1}$$

where n = - 10 to 10, which gives us the folloing list of kernel values.
$kernel$ = {0.0240595, 0.0290939, 0.0344851, 0.040066, 0.0456283, 0.0509339, 0.0557305, 0.0597714, 0.062836, 0.0647496, 0.0654004, 0.0647496, 0.062836, 0.0597714, 0.0557305, 0.0509339, 0.0456283, 0.040066, 0.0344851, 0.0290939, 0.0240595}
and

$$\sum(kernel) = 1 \tag{2}$$

2.2 Correlation Dimension and Multidimensional Embedding Spaces

We have used the Grassberger-Procaccia (GP) method to calculate correlation dimension for multi-dimensions, Hilborn [3]. We have calculated the correlation sum by

$$C^{(m)}(r) = \frac{1}{N^2}\sum_{i,j=1\&i\neq j}^{N}\theta(r- \mid \vec{x}_i - \vec{x}_j \mid) \tag{3}$$

where $\theta(t)$ is the Heavicide step function and $\theta(t)$ = 0 if $t < 0$ and $\theta(t) = 1$ if $t \geq 0$, and m denotes the dimensions. m-dimensional vector is the collection of m components

$$\vec{x}_i = (x_i, x_{i+\tau}, x_{i+2\tau}, ..., , x_{i+(m-1)\tau}) \tag{4}$$

here τ is the time lag and it represents the time interval between the successively data values that we have used to construct the vector $\vec{x}_i$.

The "$length$" of the difference between the two vectors is usually taken to be the "Euclidean length"

$$\mid \vec{x}_i - \vec{x}_j \mid = \sqrt{(\sum_{k=0}^{m-1}\{x_{i+k\tau} - x_{j+k\tau}\}^2)} \tag{5}$$

Finally, we have calculated the correlation dimension from the following equation for some range of r values which is called the scaling region.

$$C^{(m)}(r) = kr^{-D_c(m)} \tag{6}$$

2.3 Embedding Theorem

Given a dynamical system with a m-dimensional solution space is $x(t) = f_s(x(t))$. Let, $y(t)$ be some observation and $y(t) = g(x(t))$, and $v(x) = (g(x), g(f_s(x)), ..., g(f_s^{m-1}(x)))$ be the lag vector.

The embedding theorem states that if the system produces orbits in the original state space that lie on a geometric object of dimension D_c (which need not be integer), then the object can be seen without any spurious intersections of the orbit in another space of integer dimension m and

$$m > 2D_c \tag{7}$$

that is also known as Fractal time delay embedding prevalent theorem, Abarbanel [4].

3. Result and Discussion

The original time series, after primary noise elimination and compensating missing values, is shown in Fig. 1, Khan et al. [1] and the convolution time series is shown in Fig. 2 of source 0336-019 at 2 GHz of GBI observation. Fig. 3 and 4 show the three dimensional state space map for original and convolution time series respectively at time lag 5 days.

Table 1 shows the list of sources observed by Key Stone Project (KSP), Koyama et al. [5], [6]. Table 2 shows the list of sources observed by Green Bank Interferometer (GBI) [7]. Column 1 through 4 show IAU source designation, red shift, correlation dimension (S & X band) and % of missing value (S & X band).

Fig. 5 shows the relationship between correlation exponents and phase space dimension for original and convolution time series. In this figure, the correlation dimensions (about 2.5) for convolution time series clearly satisfy the embedding theorem (equ. 7). But for original time series, the correlation dimension (about 5 - 6) do not satisfy the embedding theorem all time.

Fig. 6 shows the relationship between redshift and correlation exponents at 10^{th} dimension, which we defined here the correlation dimensions of the systems' dynamics, of GBI observation. This figure shows us an important information that, for the case of original data, the correlation dimensions have apparent dependence on redshift except the squired one[1] ; in case of convolution data, it seems there is less dependence of correlation dimensions on red shift.

Fig. 7 shows the relationship between red shift and correlation dimension and Table 1 shows the values of correlation dimensions of KSP observation. In this case, we have used about 1000 day's data on daily basis and for most of the sources we got 50% or more missing values. On observation, some portions of data are observed on daily basis and other portions are observed on every after one day basis. If we take the data on every after one day basis, the data range is about 500 or less, which is very few data to get effective result. In this analysis, about 50% data are compensated by the average of neighbour values. As a result, for most of the sources we got the correlation dimensions lie between 3 to 5.

4. Conclusion

The difference between the correlation dimension of the original time series and the convolution time series increases as the red shift increases (as shown in Fig. 6). The difference of their dependence on the red shift might be concluded alternatively as follows:

1. The original time series data is superimposed by external noise on passing through the wave propagation media. The result of the convolution may reflect the source dynamics in a higher manner.
2. The original time series data reflects directly the source dynamics, if there is negligible effect on the wave through its propagation.

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[6] http://ksp.crl.go.jp/index-j.html

[7] http://www.gb.nrao.edu/fgdocs/gbi/gbint.html [2]

[1] Most of the sources, we have analyzed about 1000 days data. But for the squired source as shown in Fig. 6, we have analyzed only 300 days data which we can ignore.

[2] The Green Bank Interferometer is a facility of the National Science Foundation operated by the NRAO in support of NASA High Energy Astrophysics programs.

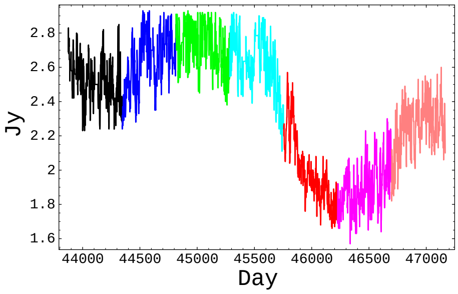

Figure 1. Original time series.

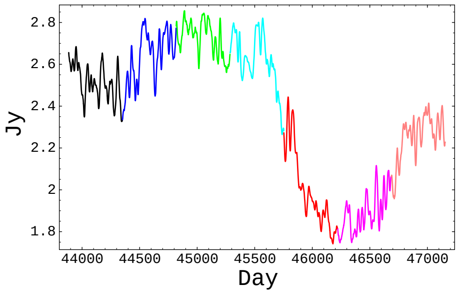

Figure 2. Convolution time series.

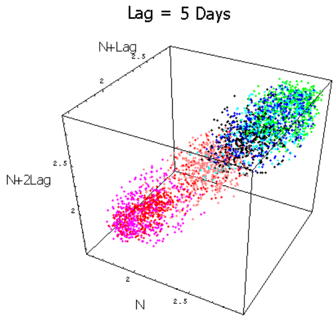

Figure 3. 3D phase space map for original time series.

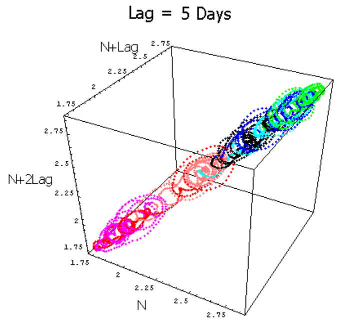

Figure 4. 3D phase space map for convolution time series.

Table 1. KSP Observational Data

Source Name	Red shift	Correlation S Band	dimensions X Band	% of Missing S Band	values X Band
0059+581	...	2.741	2.843	53.12	59.18
0727-115	...	2.603	3.915	51.27	52.73
0316+413	0.017	3.966	5.512	50.39	51.37
1226+023	0.16	3.970	4.965	50.78	51.86
1921-293	0.35	3.841	3.010	51.56	53.32
1253-055	0.54	3.230	4.848	51.56	52.64
1334-127	0.54	4.618	3.880	51.76	52.83
1641+399	0.59	3.736	3.508	50.68	51.17
0923+392	0.70	4.444	4.135	50.59	51.66
2251+158	0.86	3.365	3.057	50.29	51.07
1730-130	0.90	1.882	2.180	79.98	82.42
0420-014	0.92	3.963	5.311	50.78	52.05
2145+067	0.99	4.816	4.792	50.39	50.88
1308+326	1	4.780	5.483	50.78	52.25
2134+004	1.93	7.217	7.181	50.39	50.98
0552+398	2.37	4.531	3.657	60.74	62.01

Table 2. GBI Observational Data

Source	Red		Correlation	dimensions		% of Missing	values
Name	shift	Origina	Data	Convolution	Data		
	z	2 GHz	8 GHz	2 GHz	8 GHz	2 GHz	8 GHz
0300+470	0.475	2.33	5.60	1.14	1.14	2.66	2.66
0133+476	0.86	3.50	4.15	2.20	2.15	21.96	17.38
0235+164	0.94	3.85	2.24	1.69	1.65	7.52	7.52
0333+321	1.26	3.87	2.62	2.69	1.40	18.33	17.70
0202+319	1.47	2.56	4.52	1.30	2.71	21.50	20.24
0215+015	1.715	4.85	6.82	2.55	2.04	13.90	14.36
0237-234	2.225	7.20	8.55	3.15	2.48	16.68	16.68

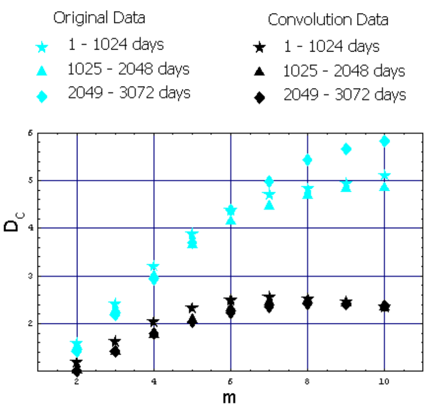

Figure 5. Correlation exponents vs phase space dimension of 0336-019 at 2 GHz of GBI observation.

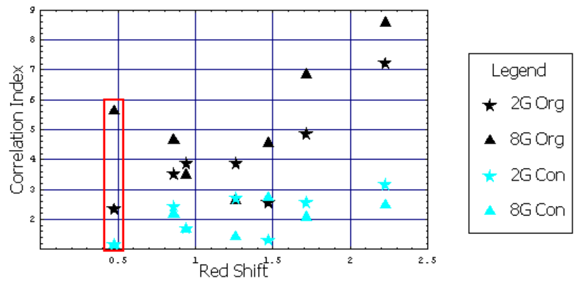

Figure 6. Relationship between red shift and correlation dimensions for GBI observational Data, in legend, Org for original time series and Con for convolution time series.

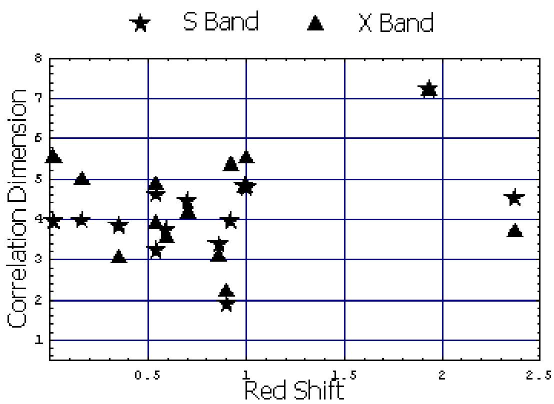

Figure 7. Relationship between red shift and correlation dimensions for KSP observational Data

S-band RFI problems at Kashima 34-m antenna and a passive filter for mitigation

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1. Introduction

Severe RFI at an S-band due to a third-generation mobile phone system (IMT-2000)[1] occurred at Kashima 34-m antenna in December 2001. KSP-VLBI observations had been interfered at Koganei since July, 2001 due to a nearby transmitting station [*Amagai et al.*, 2001]. Fortunately we could mitigate RFI by inserting a passive filter to an LNA output in both Koganei and Kashima cases. However the third-generation system is the worldwide standard, so that geodetic VLBI receiving dual S and X bands may be seriously affected by this system in near future.

2. RFI due to IMT-2000

Figure 1 shows an example of spectra at the S-band IF signals of Kashima 34-m antenna after the IMT-2000 service started. An IF amplifier was saturated due to strong signals transmitted from an IMT-2000 base station located several kilometers apart from Kashima 34-m antenna. An example of base stations is shown in Figure 2. As a frequency band assigned to the IMT-2000 is partly overlapped with that of Kashima 34-m antenna (Figure 3), it was essentially impossible to avoid severe interferences. To investigate a way to mitigate RFI problems, firstly we checked up whether an LNA was saturated or not. The linearity of the LNA was measured by switching a noise diode power on/off with receiving maximum RFI signals (Figure 4). Results were compared with those measured for a cold load input, then it was confirmed that the LNA was not yet saturated. Followed by, necessary attenuation to prevent an IF amplifier from a saturation was determined as follows. An IF output was monitored with changing the attenuation value of the LNA output. When we inserted 42.7 dB attenuation in total to the LNA output, saturation of IF output disappeared (Figure 5). Necessary attenuation is, hence, estimated to be 60 dB taking into account an 11 dB margin that is expected under more crowded traffic condition.

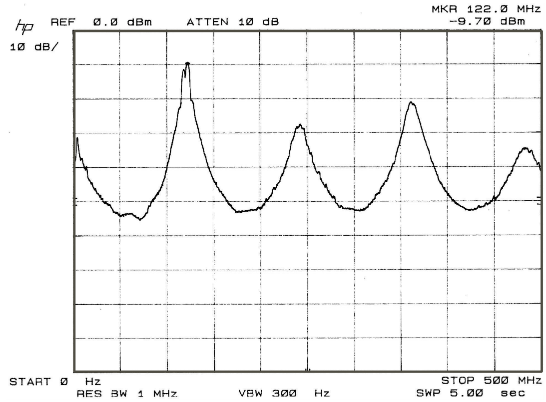

Figure 1. An example of RFI spectrum at the S-band IF of Kashima 34-m antenna. Frequency of O Hz corresponds to 2020 MHz in the sky.

Figure 2. A top portion of a typical base station for the mobile phone system.

[1]IMT-2000 (International Mobile Telecommunications-2000) is the ITU (International Telecommunication Union) globally coordinated definition of the next generation of mobile service covering key issues such as frequency spectrum use and technical standards (see *http://www.imt-2000.org/portal/index.asp* for details).

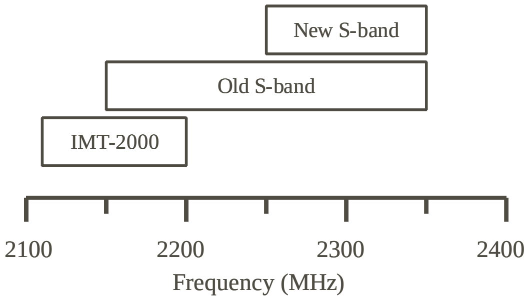

Figure 3. Frequency allocation of IMT-2000.

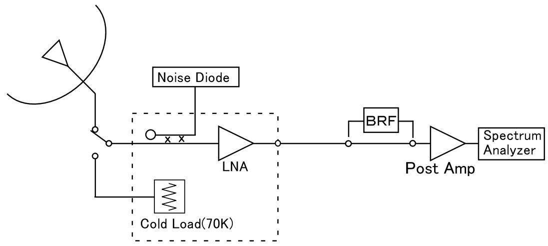

Figure 4. A schematic block diagram of S-band receiving system of Kashima 34-m antenna on a linearity measurement.

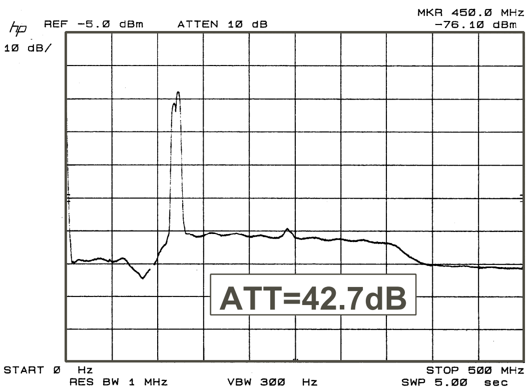

Figure 5. An S-band IF spectrum when the LNA output attenuation is 42.7 dB.

3. A passive band pass filter

We ordered a band pass filter (BPF) that has characteristics shown in Figure 6. The BPF has a sufficient attenuation value at RFI frequencies. We put the BPF between the LNA output and the IF input (see Figure 7). Figure 8 shows an IF spectrum after the BPF was installed. As a result the bandwidth of S-band has become narrow by 100 MHz as compared with before, we can make an S-band observation again. Now frequency range available to use for an S-band observation is 2250–2350MHz.

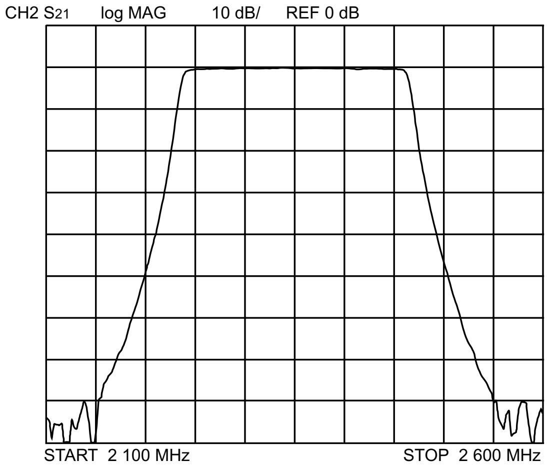

Figure 6. The characteristics of filter inserted to LNA output.

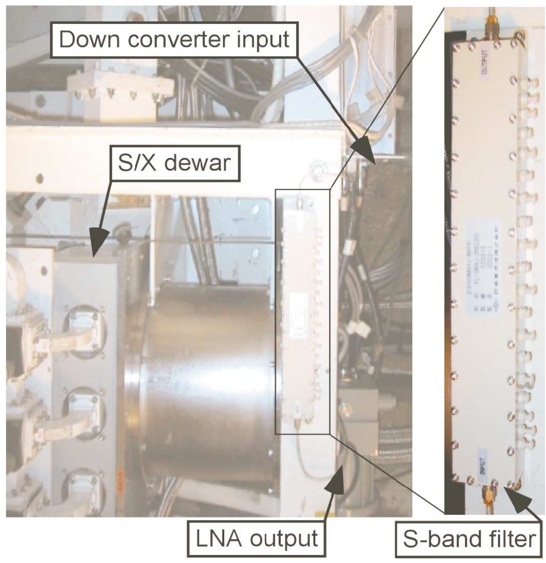

Figure 7. An Filter inserted to LNA output.

4. Concluding remarks

We experienced a severe RFI at the S-band of Kashima 34-m antenna. Fortunately we could mitigate RFI by installing a passive band-pass filter to an LNA output. However, it is expected to increase the number of IMT-2000 user year by year. Moreover it is also supposed that another mobile phone company will start an IMT-2000 service at Kashima in the near future. If RFI becomes stronger than the present situation, it will result in

Table 1. The characteristics of filters

	Existing Filter	HTS Filter (70K operation)
Passband	2250–2450 MHz	2200–2400 MHz
Attenuation	>60 dB at 2170 MHz	>80 dB at 2170 MHz
Insertion Loss	<1 dB	<0.5 dB
Tsys when setting at LNA input	72K+62K(at 296K)=134K	72K+8K(at 70K)=80K
Dimensions (mm)	260×42×27	ϕ60×14

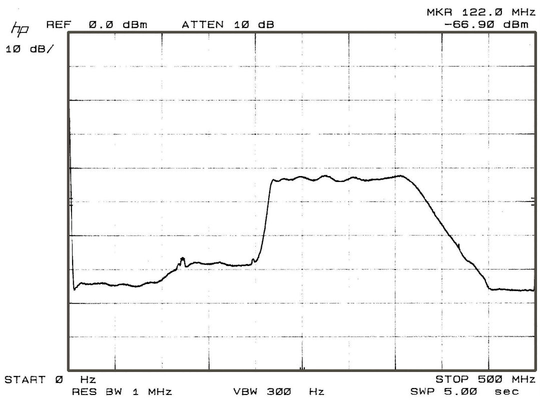

Figure 8. An S-band IF spectrum after filter insertion.

the saturation of LNA. If it occurs, we have to insert any filter in front of the LNA, which causes a system temperature increase. To reduce the system temperature as small as possible, we are investigating the feasibility of the use of a high-temperature-superconductor (HTS) filter that has a low loss and low noise features. Table 1 summarizes the characteristics of conventional filter and those of HTS filter. We are planning to test an HTS filter using Kashima 34-m antenna. If it shows a good performance, we will replace the current filter to the HTS one.

Acknowledgement: We wish to thank NTT DoCoMo Inc. for their helpful cooperation to carry out RFI measurements before regular IMT-2000 service started. We also would like to thank DENSO CORPORATION Research Laboratories for their aggressive contribution to develop an HTS filter worked at an S-band.

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Measurements of Harmful Interferences in the HF-UHF Bands Caused by Extension of Power Line Communication Bandwidth

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1. Extension of the PLC Bandwidth

Power line communication (PLC) has become available for a low bit rate network which is permitted to use the frequency range from 10 kHz to 450 kHz. Due to the limited bandwidth for the current PLC system, maximum data rate is limited. Recently, the fast power line telecommunication equipments to archive data rates of several Mbit/s are developed, and the broadband PLC system by extending the available frequency bandwidth up to 30 MHz is proposed. However, because power lines are designed not for telecommunication line but 50 Hz power distribution, high power transmission is required and the power lines emit substantial level of electromagnetic noise in HF. In HF band, there are a lot of radio stations for broadcasting, amateurs, air-traffic control, and so on. If the PLC using HF band becomes operational, large portion of HF spectrum may become unusable for them. HF band is also worth for scientific observations of earth's ionosphere, planets in the solar system, and astronomical objects. These observations have significantly contributed to understand the environment of the earth and scientific truth. Because the received signal level is usually very weak in the case of the scientific observations, it is feared that interferences from the power lines disable scientific observations.

The electromagnetic interference (EMI) problems described above had been investigated from April to July in 2002 by the PLC study group organized by the Ministry of Public Management, Home Affaires, Post and Telecommunications (MPHPT) in Japan. The study group held a working group on the field experiments and executed collaborated field experiments of the PLC facility. In July 8-9 and 23-24, field experiments were carried out at Mt. Akagi in Gunma Prefecture, Japan. In the experiments, we measured interferences leaked from the PLC facility in HF and UHF bands in order to evaluate influences of the expansion of PLC bandwidth on the radio astronomical observations and examine the presence of spurious emissions over higher frequency. In this paper, we report the experimental results in the field experiments, and compare the PLC noise with the galaxy background level and the limit of harmful interference for radio astronomical observation which is given in Recommendation ITU-R RA769-1.

2. Field Experiment of the PLC Facility

Figure 1 shows the configuration of the field experiment of the PLC facility at July 24. Power lines used for the experiment were extended between electric poles (poles #1, #2, and #3 in Figure 1) and a model house which was electromagnetically shielded by wire meshes. Table 1 shows a list of PLC modems tested in the experiment. The "in-house" PLC system was set up inside the model house. Three pairs of laptop-type personal computers were connected into wall sockets by way of the PLC modems (No. 5/6, 7/8, and 9/10 in Table 1). The "access" system was set up between the model house and the electric poles. Two pairs of modems were tested as the access system (No. 1/2 and 3/4). The modems and the computers connected at the outdoor side of power lines were set on the pole #2. All the experimental data shown in this paper are measured at July 24.

3. Interferences in HF Band

Purpose of the experiment in HF band is to measure the interference level emitted from the PLC facility and examine the propagation characteristics in order to evaluate safety distance between the PLC facility and a radio astronomical observatory. Two sets of equivalent T2FD antennas were set up at distances of 57 m and 180 m apart from the pole #2 (T2FD #1 and #2 in Figure 1, respectively). Height of each antenna from the ground was about 5 m. Outputs from the T2FD antennas were directly connected with spectrum analyzers and the radio spectra were measured in HF band.

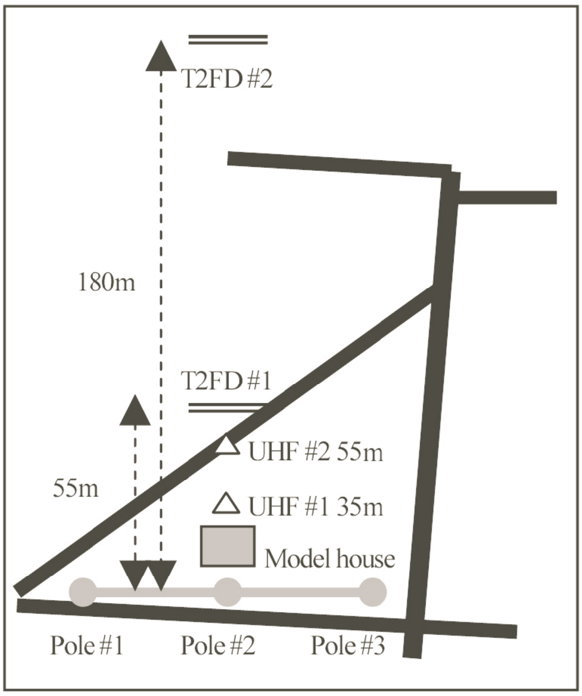

Figure 1. Map of the experiment site. Details are described in the text.

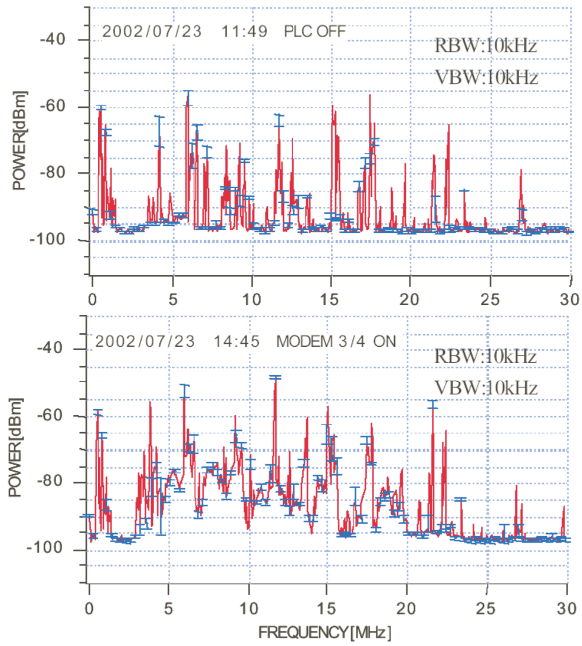

Figure 2. Typical HF spectrum measured by T2FD #1 when the PLC system was not in operation (top) and was running with the modem 3/4 (bottom). Error bars represent the standard deviation of signal intensity with the resolution bandwidth (RBW) of 10 kHz.

Table 1. PLC modems used for the field experiment.

No.	Modulation Principal	Freq. Range [MHz]	System Type
1/2	OFDM	4.3–20.9	access
3/4	SS	4.0–20.0	access
5/6	Multi-Carrier	2.622–11.202	in-house
7/8	OFDM	3.8–11.8	in-house
9/10	OFDM	7.9–22.8/3.8–17	in-house

For the quantitative measurements, we obtained 10 spectral traces for one spectrum measurement then evaluated the deviations of the measurements.

Figure 2 shows one of the results of the spectral measurements. When the PLC system was not in operation, a lot of broadcasting bands were appeared over flat noise floor which represented noise level of the spectrum analyzer. After the modem 3/4 which was tested as an access system was turned on, significant increase of the noise floor was observed in the frequency range from 4 to 20 MHz which was just used by the operational modem (see Table 1). There were some narrow drops in the increased noise floor at frequencies of 7, 10, 14, and 18MHz, which were identical with frequencies of notch filters in the modem unit. These characteristics indicated that increased noise level was caused by the PLC facility. As shown in the figure, many broadcasting signals were interfered and some of them were completely masked by the PLC noise. The increase of the noise floor was also identified in the case of the modem 1/2, but about 5 dB smaller than that of the modem 3/4. In the case of the other modems tested as the in-house system, distinct increases of the noise floor were not observed because the in-house system was set inside the shielding room.

Distance dependence of the PLC noise level was examined assuming that the leakage electric field E is proportional to the power low of distance r, that is, $E = E_0 r^{-\alpha}$. From the measurements using two T2FD antennas, the power index α distributed from 0.5 to 1.0 depending on frequency. The reason why the calculated index was smaller than that of the far field electric wave of 1.0 may be because the source of the PLC noise was distributed along the long power line cable.

In order to evaluate the interference level quantitatively, the T2FD antennas were calibrated. A standard loop antenna (Antitsu MP414B) was set just below the T2FD antenna, and we measured electric field intensity of some broadcasting frequencies simultaneously and calculated antenna

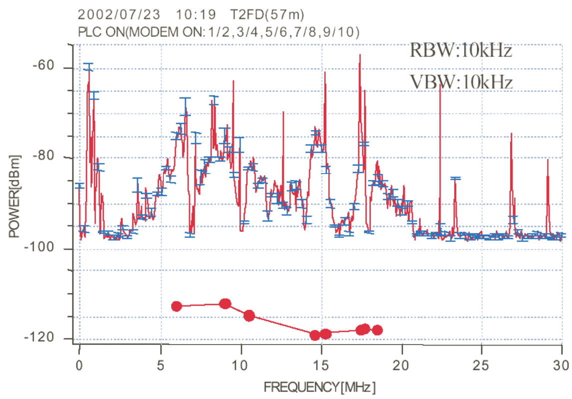

Figure 3. Comparison plot for a HF spectrum measured by T2FD #1 during all the PLC modems were running (upper line) and estimated galactic level (lower line).

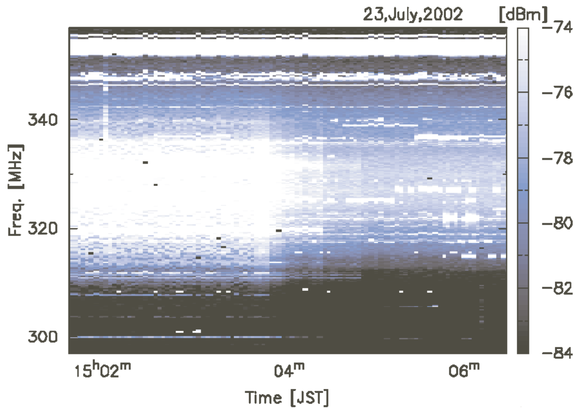

Figure 4. Dynamic spectrum around the frequency of 327 MHz. Corresponding to the turning off of the modem 3/4 at 15:04, the broadband noise and some narrow band emissions were disappeared.

factors of T2FD in HF range. Figure 3 shows a result of comparison between the PLC noise and galactic level calculated by referring known galactic spectra (Alexander et al, 1969; Hartz, 1969) and the calibrated antenna factors. The PLC noise exceeded the level of galactic noise with more than 30dB.

4. Spurious Emission in UHF Band

UHF band is an earth-based window for the radio astronomical observation and high sensitive measurements of weak radio sources are possible. Although the broadband PLC system dose not use such a higher frequency band, it is necessary to confirm the level of spurious emissions from the PLC facility because the system noise temperature in UHF band is very low in the radio astronomical observations. A log-periodic antenna (Create Design, CLP-5130-1) and a receiver were set up at a distance of 55 m apart from the pole #2 (UHF #2 in Figure 1), and sometimes moved at a distance of 35 m (UHF #1). The receiver consisted of a high pass filter, low noise pre-amplifier, and wide band amplifier. The pre-amplifier had a power gain of 40 dB at the center frequency of 327 MHz, the bandwidth of about 20 MHz, and the minimum noise figure of 0.8 dB. The high pass filter whose cut off frequency was 260 MHz prevented the saturation of the pre-amplifier by strong broadcasting signals in VHF range. Spectra around 327 MHz were measured by spectrum analyzers, and automatically recorded by a personal computer via GPIB interface. In order to check that the spurious emissions were actually originated from the PLC facility, we measured the HF spectra simultaneously and examined dependences of spurious emission on distance and direction from the PLC facility.

Figure 4 shows a dynamic spectrum in the frequency range from 297 to 357 MHz during an operation of the modem 3/4. When the modem was turned off at 15:04, disappearance of broadband noise and some narrow band emissions were clearly observed, which indicate the presence of spurious emissions in UHF band. Figure 5 shows dependence of the spurious level on the distance and direction of the antenna with respect to the PLC facility. When the all modems were turned off or the antenna did not direct to the PLC facility, no spurious emission was detected. On the other hand, stronger spurious emission was received when the antenna directed and was closer to the facility. Assuming that electric field intensity of the spurious was proportional to power low of the distance from the pole #2, the power index was calculated to be 1.3, which was close to but larger than the far field value of 1.0. We compared the intensity of spurious emission at the frequency of 327 MHz with a limit of harmful interference level for radio astronomical observation which was regulated in Recommendation ITU-R RA 769-1. Assuming a system noise temperature of 150 K at 327 MHz and a receiver band width of 120 kHz, the recommendation level was calculated to be -247 dBW/m^2/Hz. The detected intensity of the spurious emission at the position of 35 m was -206 dBW/m^2/Hz, which was greater than the recommendation level. The safety distance for the radio astronomical observation was calculated to be 4 km apart from the PLC facility assuming that the intensity of spurious electric field was anti-proportional to the distance from the source.

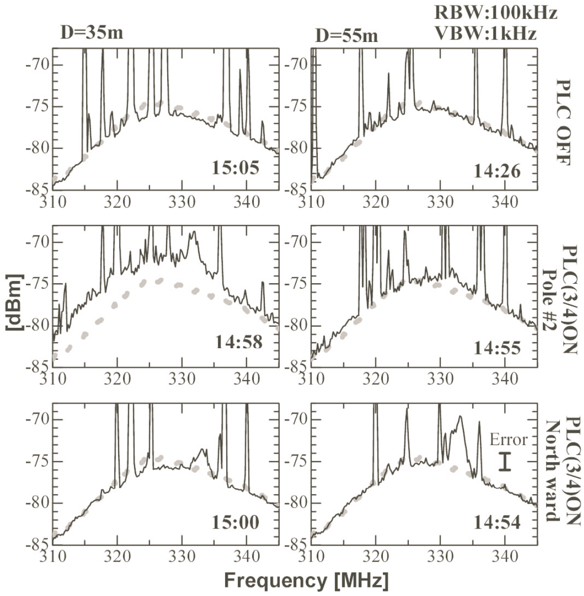

Figure 5. Dependence of spurious emissions on the distance and direction of the log-periodic antenna with respect to the PLC facility. Left: spectra measured at 35m point. Right: Same as left but at 55m point. Top: PLC was not operational. Middle: PLC modem 3/4 was running and the antenna was directed to the pole #2. Bottom: Same as middle panels but the antenna pointed the opposite direction. In each panel, solid lines are averaged spectra around the frequency of 327 MHz and gray dotted line shows a spectrum when input of the receiver was terminated. Some environmental noises which were not related to the PLC were also identified as narrow band emissions which were received when PLC was turned off and the antenna directed northward. A typical error bar in the measurements is indicated in right-bottom panel.

5. Discussion and Conclusion

From the spectral measurements in HF band, it was confirmed that the noise floor level significantly increased in the frequency range which was used by the operational PLC modem. The intensity of the interference was much stronger than that of radio astronomical signals as shown in Figure 3. From the experiments in UHF band, it was found that the spurious emissions were leaked from the PLC facility and the intensity was grater than the limit of interference level regulated in Recommendation ITU-R RA 769-1 at the experiment site. The safety distance for the radio astronomical observatory of 4 km is not short because a distance between a radio observatory and the closest residential area to the observatory will be generally less than 4 km in Japan.

PLC seems to be a harmful interference source for the radio astronomical observation in both HF and UHF bands. If PLC is widely operated, interference level will increase more and more and the safety distance will become larger. Furthermore, because the radio waves in HF band are reflected from the ionosphere and can propagate over long distance, it becomes difficult to prevent the harmful interferences of PLC.

Finally, it is noted that the measurements reported in this paper were carried out under a specific environment; only a few PLC modems were running in the rural area, the model house was electromagnetically shielded, and there was no home electronics plugged in the model house, which was quite different from that the general persons would use the PLC modems for actually. Both the quality and quantity of the experiments were also not enough for the quantitative discussion. For example, because there were only two data points to evaluate the propagation characteristics, the power index showed a large ambiguity from 0.5 to 1.3. A more realistic environment and elaborated measurements are necessary in the future experiment. Especially, far field measurements are important for the quantitative evaluation of the harmful effect on the radio astronomical observations.

The experiments reported in this paper contributed to the results of the working group on field experiments. At the end of July, the PLC study group concluded that the extension of the PLC bandwidth at current technical level was not permitted for commercial use based on results from working groups on hearing surveys and field experiments.

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Advancement of Versatile Scientific Sampling Processor (VSSP)

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1. Introduction

A personal computer (PC) based VLBI data acquisition system was developed by Communications Research Laboratory (CRL) and Nihon Tsushinki Co. Ltd. [*Osaki et al.,* 2002]. The system was called versatile scientific sampling processor (VSSP). This system adopted a PCI-bus VLBI data sampler board and was capable of recording 4-channel 64 Mbps data (16 Mbps for each channel). Using four VSSP PCs, a 16-channel 256 Mbps data recording/processing system was produced, which was called "K5". This system is expected to replace present tape-based VLBI observation system, because this system is less expensive and more convenient than present tape-based system. In this paper we will report the advancement of VSSP so far and introduce briefly about some experimental observations recorded using this system.

Figure 1. A prototype K5 data recording/processing terminal.

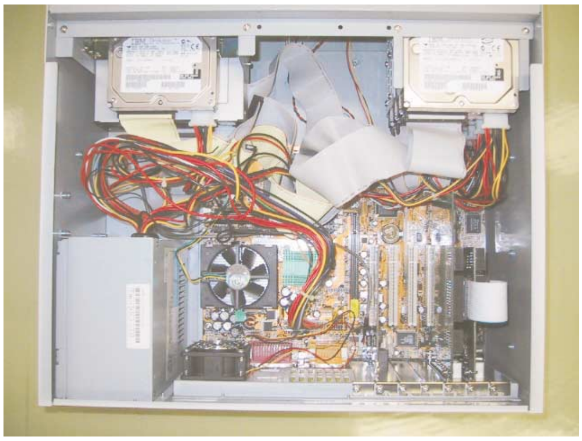

Figure 2. Inside of the VSSP PC used as one part of the K5 terminal.

2. Advancement of the VSSP

2.1 Software Environment of VSSP

At first VSSP and PC-VLBI sampler board was developed on FreeBSD and Microsoft Windows, because device driver software of the sampler board was developed only for these two operating systems (OS) [*Osaki et al.,* 2002]. Recently device driver for Linux was developed in order to fulfill the users' request. This driver was developed on Red Hat Linux 7.3/kernel 2.4.18. It is also tested on kernel 2.4.19 and works well. The development of the Linux driver must be good news for the VLBI sampler board users.

Several VLBI application softwares have been developed by CRL. They have been developed so as to be compliant with both FreeBSD and Linux systems. The applications may easily be compiled on some C compilers on Microsoft Windows system, but this compatibility is not tested yet. The development of the Linux-based VSSP as well as FreeBSD-based system will accelerate the development of the PC-based VLBI software. Moreover, the chance of the OS selection will prevent the users from being annoyed with some OS install troubles, such as compatibility problem between the OS's boot loader and the PC's BIOS, or some device recognition trouble used in one's PC.

2.2 Examples of the VSSP PCs

As the VSSP is a flexible system developed on PC, it can be arranged according to the user's requirement. For an example, CRL and Nihon Tsushinki Co. Ltd. develop a system that will replace today's tape-based geodetic VLBI recorder system. This system, called "K5", is composed of four VSSP PCs. Figure 1 shows a prototype K5 system assembled by CRL. Each PC has 480 GB data storage area with 4-channel PC-VLBI sampler board. Practically one-day geodetic observation data can be stored on this system. Figure 2 shows inside of a VSSP PC used as one unit of the K5 terminal. The observed data is stored four HDDs seen on the upper-right part of the picture. The other HDD seen on the upper-left part is the system disk. For another example, a briefcase size 4-channel data recording/processing system is assembled by CRL. This system can be used as a mobile VSSP recording/processing terminal. Two 120 GB HDDs are installed on this system. 4 GB of one of the HDD is used as system area. The remaining 236 GB is used as data storage area. If a user has

Table 1. Specification sheet of the VSSP PCs

	K5: 16-channel VSSP for geodetic observation (composed of 4 PCs, followings are specs for each PC)	Mobile VSSP: Briefcase size 4-channel VSSP PC
CPU	Pentium III (1.2 GHz)	Pentium IV (2.53 GHz)
RAM	256 MB	512 MB
HDD	120 GB $\times$ 4 for data strage 60 GB $\times$1 for system (7200rpm, Ultra ATA/100)	120 GB $\times$ 2; 4GB for system and remaining 236GB for data storage (7200rpm, Ultra ATA/100)
Ether port	10/100 Base-T	on-board 10/100 Base-T
PCI bus	6	2

to carry recorder/processor system and if 4 channel sampling and 236 GB data storage area is enough for the purpose, this system may be an attractive selection. Another example shows that several universities and institutes that have purchased the IP-VLBI sampler board have assembled their own VSSP-like system in accordance with their needs. In order to exchange know-how to use the IP-VLBI sampler board and to support the users each other, a users' mailing list has been started by CRL. The specifications of the VSSPs assembled by CRL are shown on Table 1.

3. Experimental Observations by VSSP

Several experimental observation have been made using VSSP. In this section some of the experiments are introduced briefly.

CRL Kashima and Haystack observatory promoted electric transmission of VLBI data (e-vlbi) observation experiments. At CRL site the data was recorded using K5 system. On the contrary, the data was recorded using Mark-V system at Haystack site. Both systems recorded the data as files on HDDs. After the experiment the data was transmitted via FTP over GEMnet and GALAXY network. At Haystack K5 data was converted to be correlated with Mark-V data. At Kashima, on the other hand, Mark-V data was converted to be correlated with K5 data. The latter case the data was processed using a software correlator developed by CRL. Eventually both institutes found the fringes of the observation. This shows that PC-based VLBI data recording systems are flexible enough to convert one data format to another, using software. The data conversion process must be easier compared with those of the present tape-based data recorder system.

VSSP is also used for spacecraft observation experiment [Ichikawa et al., 2002]. This system is expected to play an important role in delta-VLBI observation of the Nozomi spacecraft, especially positioning before/after Earth swing-by [*Sekido and Yoshikawa,* 2002]. In order to prepare for the swing-by, test observation experiment was made using Kashima-34m, Kashima-11m, Koganei-11m, Usuda-64m, Gifu-11m, and Yamaguchi-32m antennas. These data were also processed with the software correlator. The data was also recorded by K4 systtem at the same time at Kashima-34m, Kashima-11m, Koganei-11m, Gifu-11m, and Tomakomai-11m antenna, to compare the result with VSSP. The fringes were successfully detected by both systems. Those results are being examined now.

4. Summary

Recently VSSP PC can be set up on Linux as well as FreeBSD. A PC-based geodetic VLBI reording system is produced by CRL by assembling four VSSP PCs. This system is called K5. Application softwares like data recording scheduler, manual data sampler, a software correlator, and some more are developed for VSSP. Several observation experiments like e-vlbi between Haystack Mark-V system and Kashima K5 system, and test observation preparing for delta-VLBI spacecraft positioning are made. These experiments showed the flexibility and effect of the PC-based VLBI system, especially in such process as data recording, data transportation, data convertion, and data processing compared to those of the present tape-based VLBI systems.

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VLBI observations using IP-VLBI system for orbit determination of deep space spacecraft – Group delay measurements of GEOTAIL and NOZOMI telemetry signals –

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1. Introduction

Communications Research Laboratory has promoted a research on the spacecraft positioning technology by using a delta VLBI technique. A general-purpose VLBI system using the Internet and a personal computer has been developed as a part of this project and it is called an IP-VLBI system [*Kondo et al.,* 2000; *Kondo et al.,* 2002] or a VSSP system [*Osaki et al.,* 2002]. The IP-VLBI system aims at a real-time VLBI system, and off-line observations and correlation processing are possible at present. Delta VLBI test observations of "GEOTAIL"[1] were carried out using the IP-VLBI system in collaboration with the Institute of Space and Astronautical Science of Japan (ISAS) and the National Astronomical Observatory of Japan (NAO) to check automatic observation software and to evaluate the accuracy of observed delay obtained by the IP-VLBI system. We intend to utilize the delta VLBI observation data for the orbit-determination of "NOZOMI" (PLANET-B), which is a Japanese spacecraft launched in 1998 to explore Mars [*Yamamoto and Tsuruda,* 1998], during the period just before the last earth swing-by planned in June 2003 toward Mars. Recently we made test observations for "NOZOMI" to evaluate the feasibility of actual orbit determination.

[1]The GEOTAIL satellite was launched on July 24, 1992, from Cape Canaveral, Florida, U.S.A. by the Delta II launch vehicle, and it is a joint program of the Institute of Space and Astronautical Science (ISAS) of Japan and the National Aeronautics and Space Administration (NASA) of U.S.A to investigate near-earth space. ISAS developed the spacecraft and provided about two thirds of the science instruments, while NASA provided the launch and about one third of the science instruments. The spacecraft is operated from ISAS but the telemetry is received by both agencies [*Nishida,* 1994].

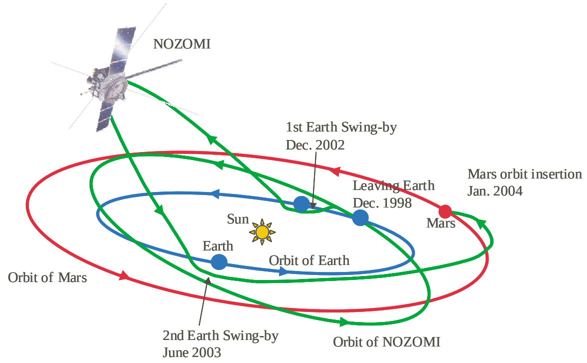

Figure 1. Trajectory of NOZOMI (after http://www.isas.ac.jp/e/enterp/missions/nozomi/traject.html).

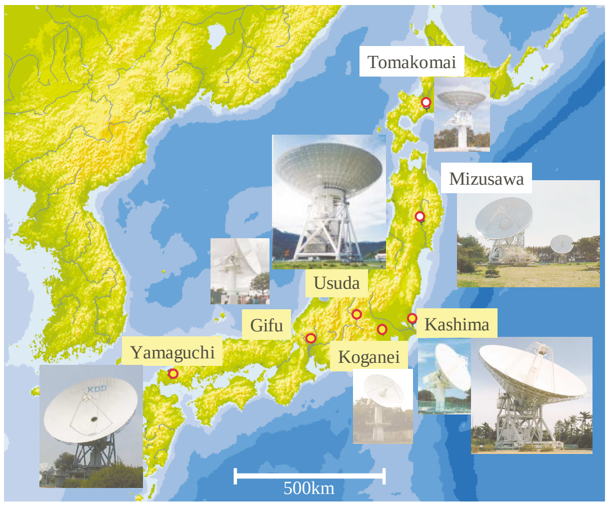

Figure 2. The location of staions participated in GEOTAIL and NOZOMI VLBI observations.

2. Why Delta-VLBI?

The NOZOMI is the first Japanese Mars orbiter, and was launched on July 4, 1998. It was planned to arrive Mars in 1999 by using two-times lunar swing-bys and a powered earth swing-by. However due to malfunction of a thruster valve during the powered earth swing-by and maneuvers to recover the right trajectory to Mars, enough fuel is not left to inject NOZOMI into a Mars orbit. The NOZOMI team found a new trajectory to Mars available to inject NOZOMI into a Mars orbit. Hence the orbit insertion scheduled in 1999 was abandoned, and it is now scheduled early in 2004 after two more earth swing-bys (Figure 1). The determination of spacecraft position is usually made on the basis of range and range rate measurements using a telemetry link. However range measurement is supposed to be difficult during several months

Table 1. GEOTAIL test observation schedule

Date(YYYY/MM/DD)	Time(UT)	Stations (name with antenna diameter in meter)
2002/06/04	06:49-14:00	Usuda64, Kashima34, Kashima11 Mizusawa10*1, Yamaguchi32*2
2002/06/25	08:30-14:38	Kashima34, Kashima11, Koganei11
2002/06/28	01:58-03:00	Kashima34, Kashima11, Koganei11
2002/07/20	01:05-04:16	Kashima11, Koganei11, Gifu11

*1: unable to observe due to a thunderbolt damage
*2: undetect correlation due to a clock problem

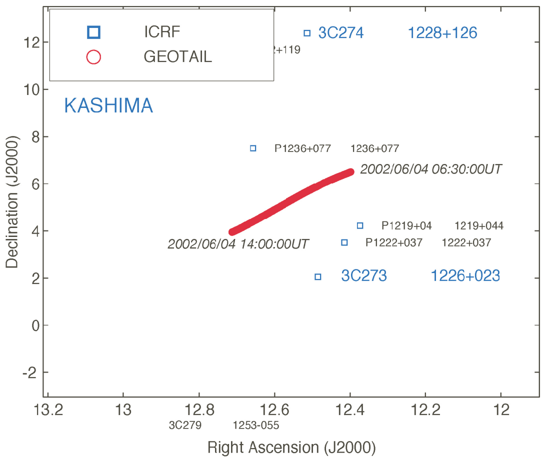

Figure 3. The position of GEOTAIL on the equatorial coordinates on June 4, 2002.

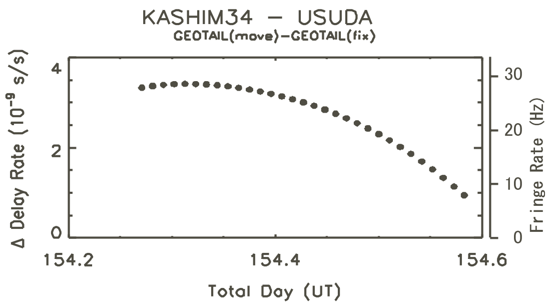

Figure 4. The difference of delay rates between that calculated for the position of GEOATIL fixed at the middle of each scan (i.e., only diurnal motion is considered) and that calculated taking the motion in the equatorial corrdinates into account.

before the last earth swing-by planned on June 19, 2003 to cruise to Mars, due to a bad geometrical relation between spacecraft attitude and earth position, i.e., the high-gain antenna of NOZOMI does not point the Earth during this period. However it is very important to navigate the NOZOMI precisely during this period to succeed in the last earth swing-by. CRL and ISAS started collaboration to determine NOZOMI orbit using a delta VLBI technique and to lead a NOZOMI mission to a success [*Yoshikawa et al.*, 2001].

A test VLBI observation was planned in June 2002 at first. Unfortunately NOZOMI had some problems at that time caused by the large solar flare occurred on April 21, 2002. Thus we had carried out a series of test VLBI observations using GEOTAIL instead of NOZOMI until it was recovered in August 2002.

3. "GEOTAIL" Observations

VLBI observations were carried out for GEOTAIL to learn the characteristics of telemetry down-link signals and to investigate the feasibility of group delay measurements. We made observations using the IP-VLBI system. Test observations were conducted several times (see Table 1) and data reduction software was developed for a preliminary analysis. Two of four-channel inputs of the IP-VLBI system are used for S and X band signals of which base band signal frequencies are 2258.90 MHz and 8473.60 MHz, respectively. Observations were made with a sampling frequency of 4 MHz and an A/D resolution of 4 bits. The location of stations participated in the observations is shown in Figure 2.

The GEOTAIL moves so fast in the sky (see Figure 3) that a priori values calculated by using software developed for geodetic processing have insufficient accuracy, in particular in delay rate that is necessary for fringe stopping, so that we developed new a-priori calculation software for correlation processing, in which the motion of GEOTAIL is interpolated by using a spline interpolation method. Figure 4 shows the difference between delay rate calculated using the conventional a priori

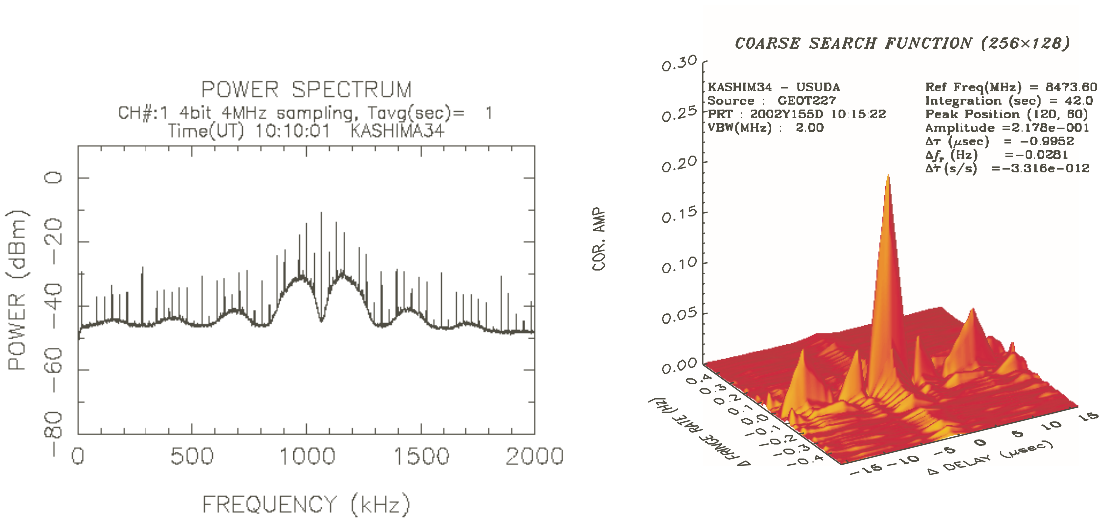

Figure 5. A spectrum of X-band telemetry signals from GEOTAIL observed at Kashima34 (left panel) and coarse delay search function calculated from correlated data on Kashima34-Usuda64 baseline (right panel). Observation date is June 4, 2002.

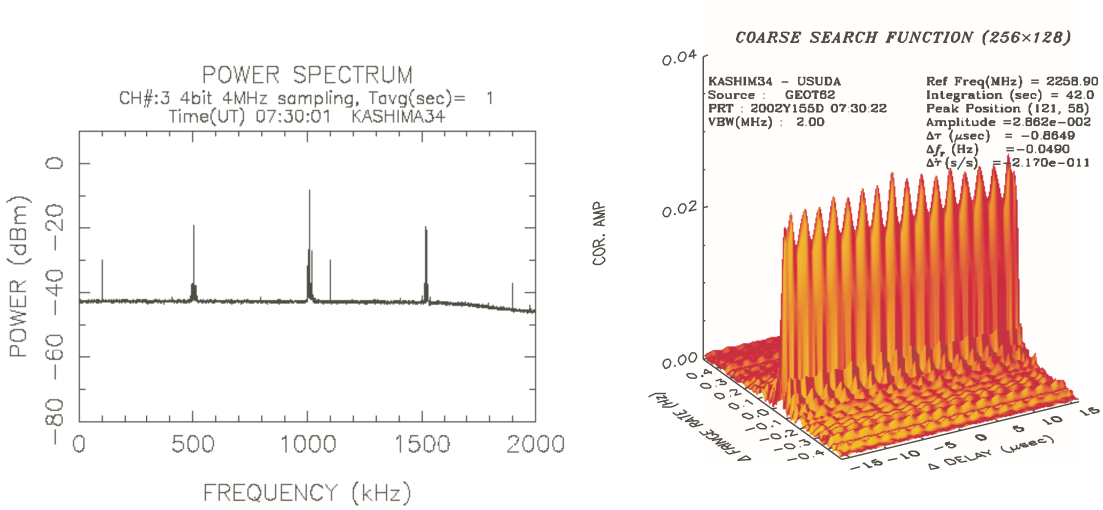

Figure 6. A spectrum of S-band telemetry signals from GEOTAIL in a range measurement mode observed at Kashima34 (left panel) and coarse delay search function calculated from correlated data on Kashima34-Usuda64 baseline (right panel) observed on June 4, 2002. Two micro sec ambiguities arising from 500 kHz spacing between carrier and subcarrier frequencies can be seen in the coarse delay search plot.

calculation software and that using the newly developed software. In a former calculation the position of GEOATIL in the equatorial coordinates is fixed at the middle point of each scan, while actual motion in the celestial position is considered in a latter one. Maximum discrepancy reaches about 3.5×10^9 s/s in this case. It corresponds to 28 Hz fringe frequency at 8 GHz, and this will result in loss of correlation amplitude for 1 sec integration period, which is typical period for a conventional correlator. Correlation processing is carried out by software able to run at any PC without any dedicated hardware for correlation processing.

A spectrum at X-band telemetry signals and

Table 2. NOZOMI test observation schedule

Date(YYYY/MM/DD)	Time(UT)	Stations (name with antenna diameter in meter)
2002/09/17	12:39-18:23	Kashima34, Koganei11
2002/10/17	17:54-19:33	Kashima34, Kashima11, Koganei11
2002/10/18	17:54-19:34	Kashima34, Kashima11, Koganei11
2002/10/21	16:54-20:04	Kashima34, Kashima11, Koganei11, Usuda64 Gifu11, Tomokomai11, Ymaguchi32, Mizusawa20
2002/10/21	16:54-20:03	Kashima34, Kashima11, Koganei11, Usuda64 Gifu11, Tomokomai11, Ymaguchi32, Mizusawa20

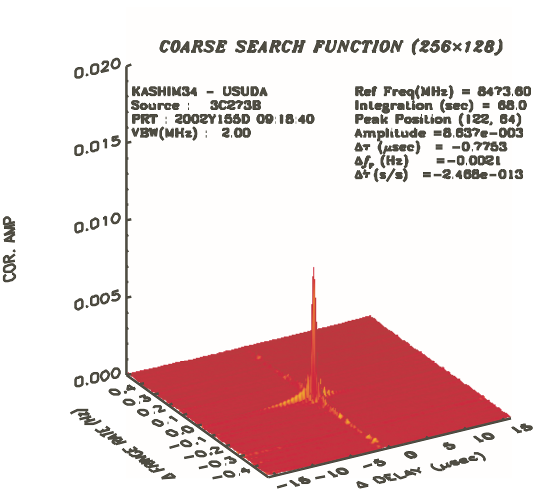

Figure 7. An example of X-band coarse search functions for a quasor (3C273B) on Kashima34-Usuda64 baseline. Observation date is June 4, 2002.

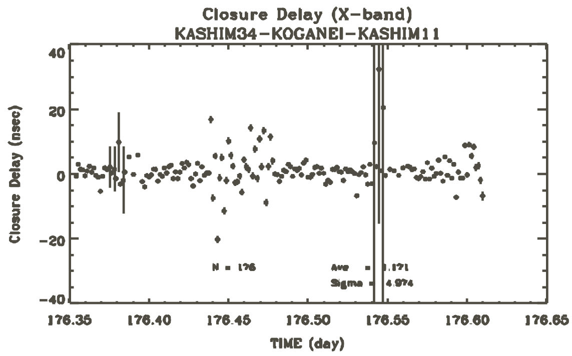

Figure 8. An example of closure delay test for GEOTAIL observations. Observations were carried out on June 25, 2002 at three stations, Kashima34, Kashima11, and Koganei11. Data with large error bars represent quasor observations. Although data are lagely scattered aroound 176.45 days, standard deviation of total data is wel less than 10 nsec (∼5 nsec).

coarse delay search function calculated from correlated data are shown in Figure 5. As shown in the figure, group delay can be obtained without any ambiguities. Figure 6 shows an S-band power spectrum and coarse delay search function when telemetry mode is in a range measurement mode. In this case 2 μsec ambiguities appeared in the delay direction. Figure 7 is an example of coarse delay search function for a quasor (3C273B).

A closure delay test was carried out to check the accuracy of observed group delays. It is confirmed that an rms error of a few nsec was attained with coarse delay measurements (Figure 8).

4. “NOZOMI” Observations

As NOZOMI recovered from a trouble, a VLBI observation became possible late August 2002. Since then we have carried out VLBI observations using a NOZOMI telemetry signal siveral times (Table 2). Only X-band signals were observed because NOZOMI’s S-band telemetry was already malfunctioned on July 5, 1999 The set-up of IP-VLBI system is as same as that for GEOTAIL except for a base band signal frequency (8410.00MHz). Examples of fringes observed for NOZOMI telemetry signals are shown in Figure 9. Figure 10 also shows fringes for NOZOMI but in a very weak telemetry signal case. It is thought to simulate the case when actual delta VLBI is necessary. In any case, we succeeded in determining group delay without ambiguities.

5. Conclusions

We have carried out a series of delta-VLBI observations of GEOTAIL and NOZOMI using IP-VLBI system for several months to learn characteristics

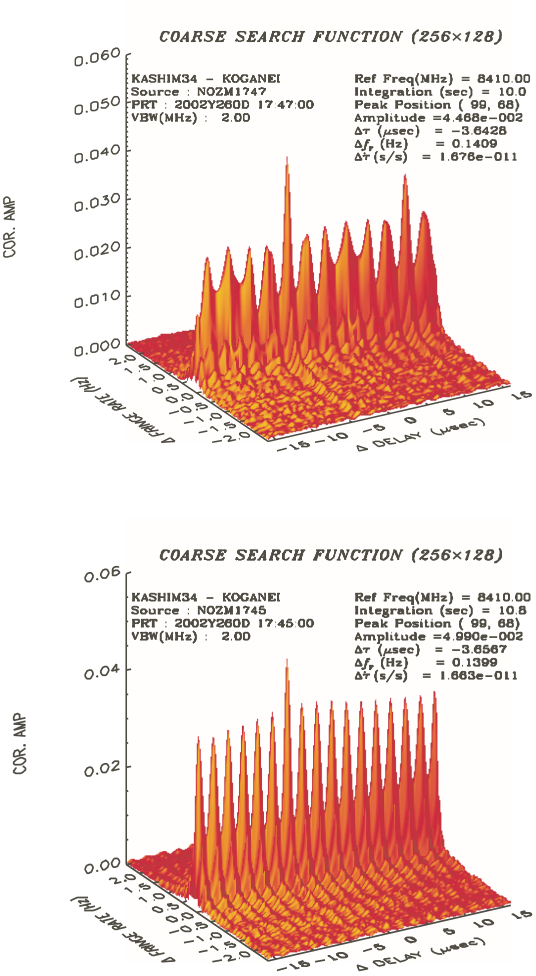

Figure 9. NOZOMI fringes for two different epochs. Telemetry mode changed slightly between two epochs, however group delay without ambiguity is easily determined for both cases.

of satellite downlink signals and to investigate the feasibility of delay measurements. Preliminary results show that most of the cases we can determine group delays for telemetry signals without any severe ambiguities. Now an attempt to reflect VLBI data to an orbit determination is carried out by an ISAS team. Next VLBI observations will be performed several months before the last earth swing-by scheduled on June 19, 2003 to determine orbit and to lead a Mars exploring project to a success.

Acknowledgement: We would like to thank “NOZOMI” VLBI collaboration team members of ISAS, NAO, Yamaguchi University, Gifu University, and Hokkaido University for their kind observational supports. A part of NOZOMI VLBI data

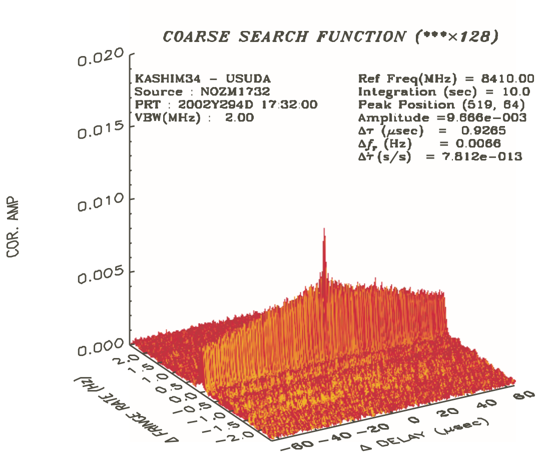

Figure 10. NOZOMI fringes for very weak signal case detected on Kashima34-Usuda 64 baseline.

are transferred through GALAXY network maintained by the NTT in collaboration with CRL and NAO. We also would like to express our appreciation to all GALAXY collaboration team members for their helpful technical assistance.

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International e-VLBI experiments

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1. Introduction

Communications Research Laboratory and NTT Laboratories are collaborating together to develop hardware and software systems for e-VLBI observations using high speed IP based shared networks. A series of test experiments using the newly developed systems were carried out in September and October 2002. Two baselines were selected for these test experiments. One is the Kashima-Westford baseline. The 34m antenna station at Kashima and 20m antenna station at Westford, Massachusetts, USA were used. The other is the Kashima-Metsähovi baseline. The 34m antenna at Kashima and 14m antenna at Metsähovi, Finland were used. The details of the test experiments are introduced in the following sections.

2. Kashima-Westford Experiments

Three sessions were scheduled with the Kashima-Westford baseline. The dates and time of these sessions are shown in Table 1. In evlbi1 and evlbi3 sessions, K5 VLBI observation system was used at Kashima and Mark-5 VLBI data recording system was used at Westford. Eight frequency channels were assigned to X-band and six frequency channels were assigned to S-band. Sampling rate of each channel was 4MHz and the total data rate was 56Mbps. Frequency assignment was same with the conventional geodetic VLBI experiments performed under the Crustal Dynamics Project in the past. In the evlbi2 session, K5 VLBI observation system was used at Kashima and the 4 channels configuration of the K5 VLBI observation system was used at Westford. The latter system is consist of a PC system running on the FreeBSD operating system and an IP-VLBI board which can sample 4 channels of video signals at various sampling speed from 40kHz to 16MHz. Only the X-band signals were recorded with the observation system both at Kashima and at Westford. The full set and the subset of the K5 VLBI observation system used for the Kashima-Westford e-VLBI test experiments are shown in Figure 1. The 4-channel set of the system was small enough to be stored in a suitcase and was transported in a check-in baggage of airline between Japan and the USA.

Figure 2 illustrates the high speed network route used in the test e-VLBI experiments. To prepare the international e-VLBI experiments, the

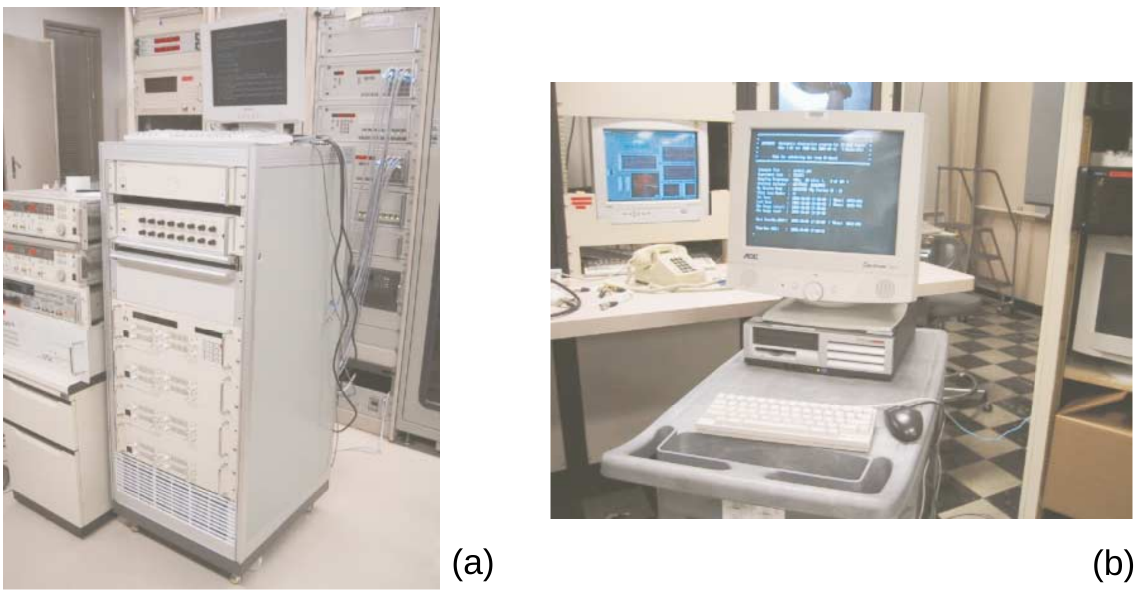

Figure 1. K5 VLBI observation system. The full set of the system (a) can record 16 channels of data while the subset of the system (b) can record 4 channels of data.

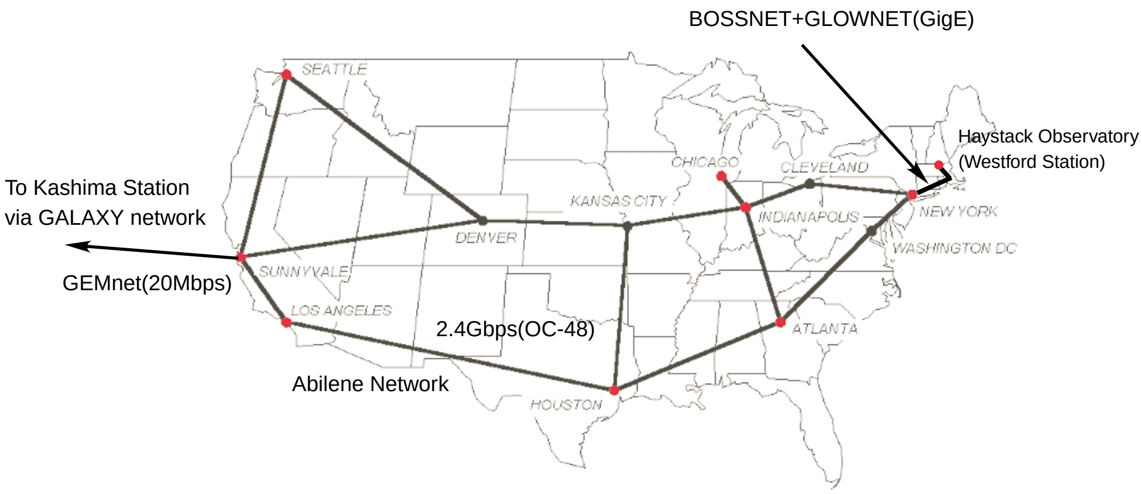

Figure 2. High speed network which was used in the experiment between Kashima and Westford stations.

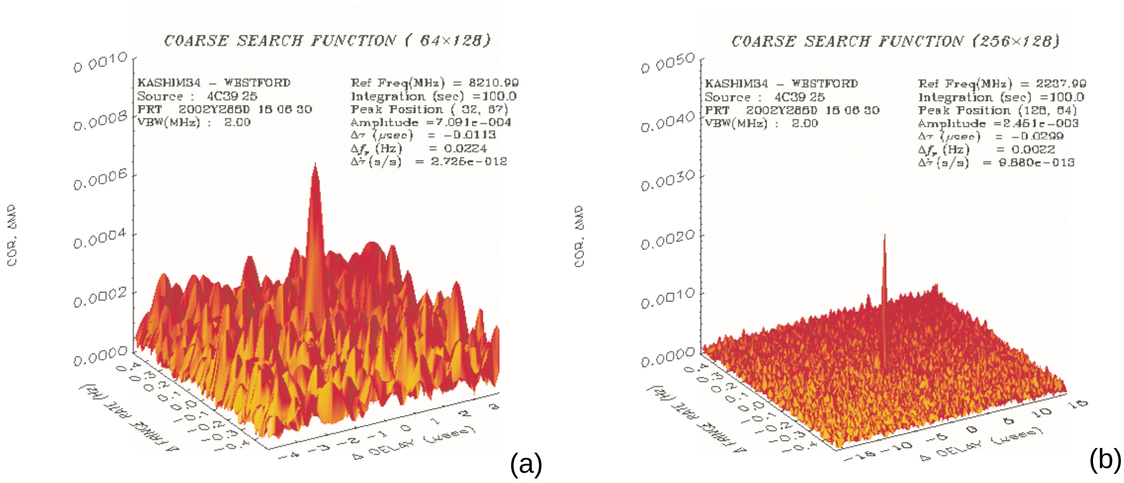

Figure 3. Detected fringes at X-band (a) and S-band (b) observations towards 4C39.25. The PC software correlator was used to correlate Mark-5 data recorded at Westford station and K5 data recorded at Kashima station.

Table 1. Three sessions done with the Kashima-Westford in October, 2002.

Exp. Code	Date	Time
evlbi1	October 8, 2002	17:30UT-19:30UT
evlbi2	October 9, 2002	12:00UT-15:00UT
evlbi3	October 15, 2002	17:30UT-18:40UT

GALAXY network was connected to the GEMnet network which is the high speed research network of the NTT Service Integration Laboratories. The GEMnet has an international link between Japan and the USA at the data rate of 30Mbps. 20Mbps of the bandwidth is assigned to the connection to the Abilene network which are used by universities and institutions along the USA. Haystack Observatory has been connected to the Abilene network by using BOSSnet and GLOWnet. At the time of the e-VLBI experiments, the BOSSnet was not available, and the alternative route was used. The backbone of the Abilene network has a capacity of 2.4Gbps (OC-48). In total, the expected limit of the data rate was 20Mbps which was restricted at the transpacific connection provided by GEMnet.

After evlbi1 and evlbi3 sessions, the data recorded by the Mark-5 system at Westford station were converted to transferable files and transfered to Kashima by using the high speed network

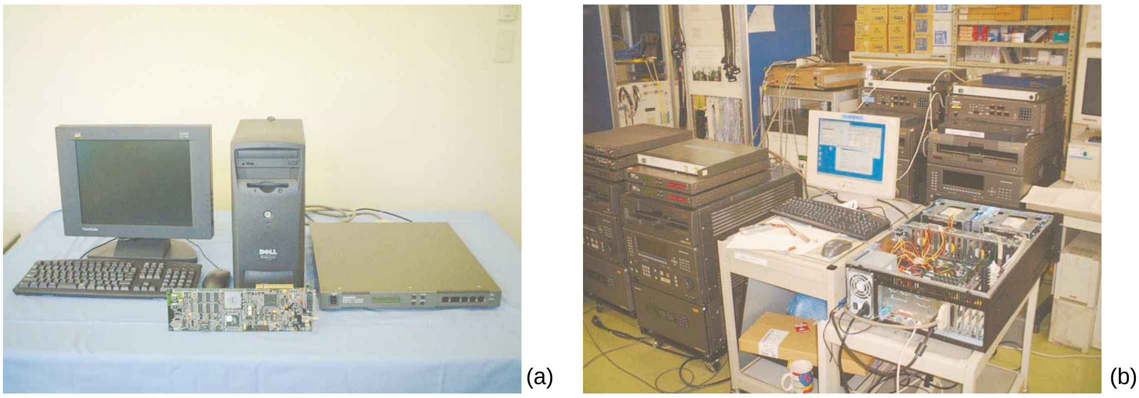

Figure 4. The observation system used at Kashima station for the Kashima-Metshähovi experiments. (a) The ADS1000 sampler unit (right) is connected to the PC-VSI2000-DIM board (front) installed in the Linux PC system (behind). (b) The actual configuration during the experiments.

and FTP protocol. The data files were then converted to K5 compatible format and processed with the data recorded with the K5 system at Kashima for correlation processing. Software correlator programs of the K5 system were used for the correlation processing. On the other hand, the data recorded with the K5 system at Kashima were transfered to Haystack Observatory by using the high speed network. The data files were then converted to Mark-5 disk system and processed with the data recorded with the Mark-5 system at Westford station. The Mark-4 hardware correlator system was used for the correlation processing. Although evlbi1 session was not successful, fringes were successfully found from the evlbi3 session by both of the correlators. Figure 3 shows the detected fringes at X-band and S-band for the radio source 4C39.25.

The evlbi2 session was performed to evaluate the current performance of the realtime data transmission between K5 VLBI observation systems over the intercontinental distance. The K5 system is capable of transmiting observed data in realtime to the network by using IP protocol. The realtime transmission was tried at various data rate from 40kbps to 2Mbps from Westford station to Kashima station. As the results, the transmissions were successful up to the data rate of 1Mbps, while the 2Mbps data transmission could not be succeeded.

3. Kashima-Metsähovi Experiments

A series of test e-VLBI experiments were performed with Kashima-Metsähovi baseline from the end of September. The 34m antenna at Kashima and 14m antenna at Metsähovi Radio Observatory in Finland were used for these experiments. The RF frequency from 21.98GHz to 22.48GHz were received by both antennas and converted to the baseband. The baseband signals were then sampled with ADS1000 sampler units. The ADS1000 sampler is capable of sampling analog signal at the rate of 1024Msps with one or two bits per each sample. In the test e-VLBI experiments, one bit sampling mode was used. The sampled digital data is generated based on the VLBI Standard Interface Hardware (VSI-H) specifications. At Kashima station, the PC-VSI disk based recorder system equipped with PC-VSI2000-DIM board was used to record the data. At Metsähovi station, two Linux PC systems each equipped with VSIB VSI-H PCI data acquisition board were used to record the data. Both systems are capable of recording digital data through VSI-H interface connectors. These systems are shown in Figure 4.

The data recorded at Metsähovi station were transfered to Kashima by using FTP protocol after observations and processed for correlation processing on a Linux PC system using software correlator programs. The first successful fringe was detected from the observation towards the W3OH maser source made on October 16, 2002. Figure 5 shows the cross power spectrum after 15 seconds of integration time.

4. Significance of the Test Experiments and Future Prospects

The successes of the international e-VLBI experiments have many important meanings. The success of the Kashima-Westford experiments demonstrated that the PC disk based recording systems are flexible enough and it is possible to achieve compatibility between one system and the other by software programs. It also demonstrated that the

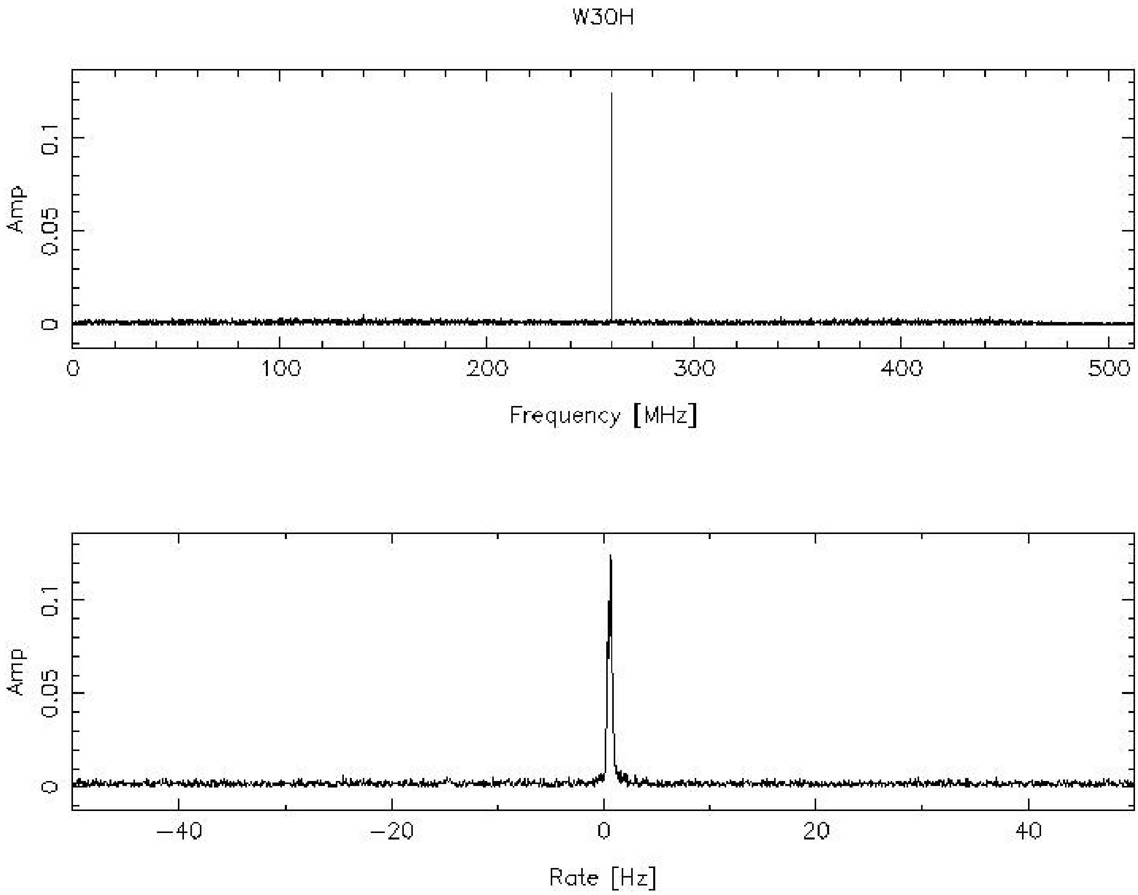

Figure 5. The first fringe detected with the Kashima-Metsähovi baseline from the observation towards W3OH.

international network connection has been drastically improved recently and the e-VLBI observations with intercontinental baselines are becoming realistic. The success of the Kashima-Metsähovi baseline experiments have an additional meaning. Two different VSI recording systems have been developed by two independent teams and these two systems were used with the same sampler unit interfaced with the VSI-H specifications. The successes to exchange data recorded by different recording systems demonstrated the intended results of the standardization of the interface by VSI-H.

One of our purposes of the e-VLBI system developments are to achieve minimal turn around time to process international geodetic VLBI sessions. The current speed of the network demonstrated with the test e-VLBI experiments are not yet satisfactory for this purpose. The speed of the transpacific network could be improved if we can use a faster transpacific network route. There seems to be a few possibilities and we are currently investigating these possibilities to expand the network capacity for the Kashima-Westford baseline e-VLBI experiments in the future.

Meanwhile, we are planning to improve hardware systems and develop software systems to make the entire system robust and routine processing become possible. We are also planning to test a high-speed VLBI data transmission system which has the maximum speed of 256Mbps using multiple IP streams. We would like to perform these test e-VLBI experiments in the future and continue efforts to realize routine e-VLBI experiments with international and intercontinental baselines.

Acknowledgement: The authors would like to appreciate many members of the Haystack Observatory and Metsähovi Radio Observatory who jointly participated in the test experiments.

Yamaguchi 32m Radio Telescope and an On-line Observation System

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1. Introduction

National Astronomical Observatory of Japan was given a 32m radio antenna from KDDI corporation in 2001, and has made use it as a radio telescope (Yamaguchi 32m telescope) under collaboration with Yamaguchi university and other institutes. The telescope is planned to use as a powerful element of VLBI network as well as a large single dish telescope. In this article, we describe the current status and scientific targets of this telescope. A special feature of network-oriented observation is also mentioned.

2. The Telescope

The antenna (Figure 1) was constructed in 1979 for tracking, telemetry and command to a telecommunication satellite (INTELSAT) for the first time. The mount is Azimuth-Elevation type covering the full sky. The diameter of the main reflector is 32m and the cassegrain optics system with focused-beam reflector assembly is equipped. The antenna finished its role of telecommunication in 2001, then we have started to modify it to a radio telescope.

The feed horn was changed from corrugate (4-6 GHz) to straight horn with 8 GHz dual-channel circular polarization feed for astronomical observation. A cooled dual-channel 8 GHz HEMT receiver is mounted. The system noise temperature is about 50 K at 8 GHz. A 6.7 GHz feed and room temperature receiver is also available although it is exclusive use with the 8 GHz system.

A simple tracking system (PC base) has been developed by NAO and Yamaguchi university. Encoded angle values (Az and El) from the existing antenna control unit (ACU) was detected by the PC, then the PC output the error voltage to the ACU in real-time. The error voltage is proportional to the angle between the current angle and the target one. The maximum speed is 0.25 deg/sec, and the angular resolution is 0.01 degree that is enough for observation at 8 GHz. For 22 GHz observation in future, the upgrade of the angular resolution to 0.001 degree is planned.

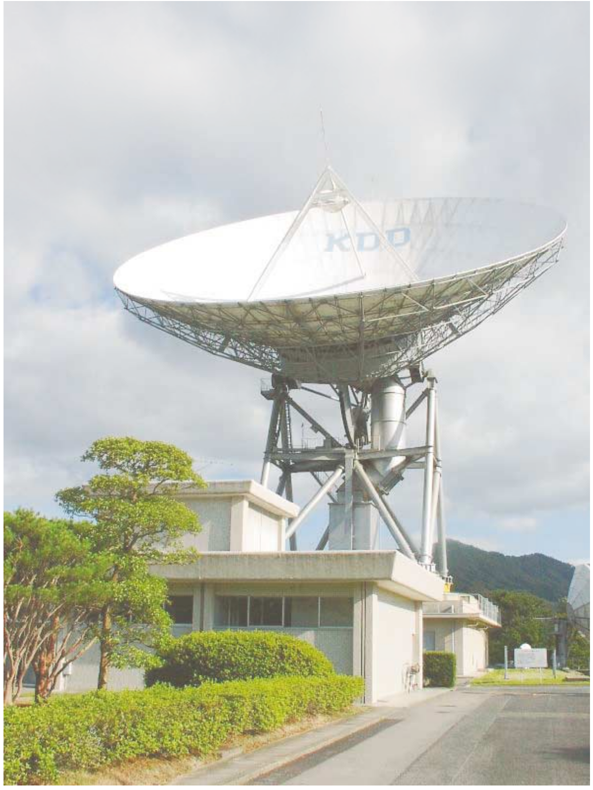

Figure 1. Yamaguchi 32m telescope at the KDDI Yamaguchi Satellite Earth Station. The telescope is on a building where the receiver and tracking systems are installed.

A preliminary result of the aperture efficiency measurement is 65 % at 8 GHz, which is sufficient for astronomical observation, also suggesting a potential up to 22 GHz observation (surface accuracy of lesser than 1.0 mm rms is inferred). Back-end systems, e.g. VLBI terminal, line observation system, and observation system software are also under development. Along with completion of these astronomical observation systems, test observations including VLBI will be started by the end of this year.

3. Purposes

The Yamaguchi 32m telescope will be used mainly for VLBI observation. We are planning to organize some 8 GHz telescopes in Japan and make VLBI observation of variable active galactic nuclei and radio active stars. Frequent VLBI observations by taking advantage of the much observing time would give a chance to investigate those short time-scale variables. We expect to expand this 8 GHz VLBI network to other countries in future. Yamaguchi 32m is also expected to be a co-observing telescope with VERA and future space VLBI project (VSOP2).

A technical study of spacecraft navigation by VLBI has been carried out in Japan under collaboration of ISAS, CRL, NAO, NASDA and Yamaguchi university. The Yamaguchi 32m telescope would be used as an element of this navigation network. We have succeeded in a VLBI observation of downlink signal of a spacecraft NOZOMI in October 2002.

4. On-line Observation

Yamaguchi 32m telescope is going to have a special feature of 'network based observation' system. According to the rapid expansion of information network and increasing potential of personal computer (PC), studies of new VLBI system based on the network have been started in the world. One of them is the GALAXY project that is collaboration among NAO, CRL, ISAS, and NTT since 1998. Large telescopes (Usuda 64m, Kashima 34m, and some other telescopes) around the Kanto area are connected by high-speed dedicated network in the GALAXY project to achieve real-time VLBI observation. The GALAXY project has been achieved 1 Gbit/sec observation between Usuda 64m and Kashima 34m telescopes resulting 2 mJy detection sensitivity.

Yamaguchi 32m telescope is being planned to join such real-time VLBI network via Super-SINET operated by the National Institute of Informatics (NII). The high sensitivity and the distant location (800 km west to Kanto) of the telescope would provide not only the high sensitivity but also the high resolution for the real-time VLBI observation.

Figure 2. A small radio telescope mounted on an equatorial for amateur astronomer. Broadcasting satellite system is used for the dish and receiver.

Not only the dedicated high-speed network, we are planning to connect the telescope to the Internet for a new way of VLBI observation fully based on the PC and the internet. Process of VLBI observation, e.g., observation, data archiving, data transsion, and correlation are all done on PCs. A small radio telescope (Figure 2) for this internet VLBI system is being constructed in Yamaguchi university.

Acknowledgement: We thank colleagues of KDDI for supporting the Yamaguchi 32m project.

Development of compact VLBI system

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1. Introduction

We have developed the compact VLBI system for network based VLBI observation. This system is named as the "Compact Antenna of Radio Astronomy for VLBI Adapted Network (CARAVAN)". A low noise LNA in normal temperature, a wide bandwidth Giga-bit AD sampler, and inexpensive PC data recording system enabled VLBI observation with the small antenna. The CARAVAN is integrated as portable telescope site. Followings are the advantages. At the large telescope site which can use high-speed network, the CARAVAN is dedicated to network experiment before telescope time allocated to large dish. In observation sites where the network backbone are not reachable and universities where they are not to afford to operate large dish, the CARAVAN will provide an environment of VLBI experiment at their closely located network nodes. Since the CARAVAN uses commercial products, the price of the observation package is reduced drastically. Network observations with high-speed optical fibers realize VLBI observation without storage media. Furthermore, observation data are processed immediately. Details of the CARAVAN and initial operation results are reported in this paper.

2. CARAVAN

The prototype CARAVAN consists of an equator mounted prime focus 65-cm parabolic antenna, an optical guide telescope, and a receiver. A handy controller with optical object database can track sources automatically by entering Right Ascention and Declination of radio star. In other case, the telescope can be programmed from a scheduling PC. The entire view of the CARAVAN is shown in the Figure 1. The price the CARAVAN telescope is less than ten thousand US dollars. The receiver and down converter are assembled in the aluminum container and they are operated in normal temperature. Observation frequency is 22GHz. Receiver noise temperature is 140K. System noise temperature is 210K.

Figure 1. Left: The dish front view of CARAVAN. Prime focused horn is connected to the receiver by waveguide. Right: The side view of CARAVAN. Low noise Amplifier is located behind the small dish. Optical telescope is mounted beside the dish. Right Ascention and Declination axis are balanced by counter weight.

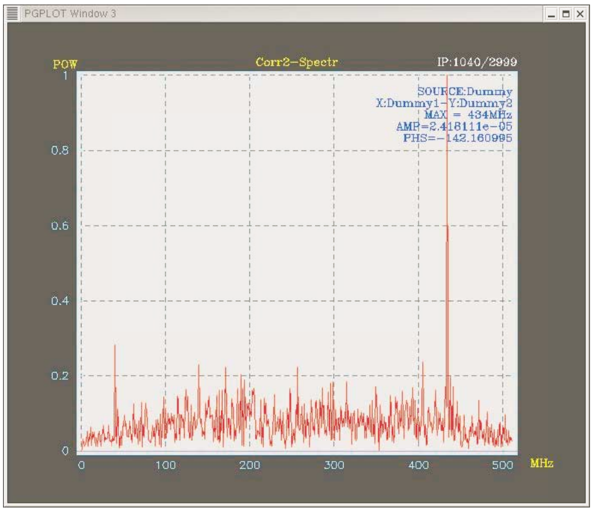

Figure 2. Cross-power spectrum of between CARAVAN and Kashima 34m. The feature of water maser is visible at telescope IF baseband 430MHz.

3. Observation

Single dish observations were made for confirmation of basic parameter. From the astronomical measurement, HPBW of 1.5°and aperture efficiency of 0.5 were obtained. Then an interferometeric observation was carried out. We observed NSTAR-B (geo-stationary satellite) with CARAVAN as a reference antenna of holography observation to measure Kashima 34m surface accuracy. On October 2nd, 2002, we observed water maser source W49N with CARAVAN and Kashima 34m antenna. We have detected W49N fringes (Figure 2). This observation was performed with 1Gbps AD sampler and Gbps real time Correlator (GICO). VLBI preparation is in progress (Figure 3). It is expected that radio source stronger than 20Jy is detectable by CARAVAN and the 34m antenna for integration time of 1 second.

4. Operation scheme

The ubiquitous (anywhere, anytime) VLBI package consists of 4 components, sampler, i.e., small telescope, Giga-bit AD portable reference, and PC based observation system (PC-VSI). The system is simple so that these units are carried by a car. Installation of the equator mount is straightforward. Electric axis of 65cm parabolic antenna is collimated by an optical guide scope. Then the antenna is set up using the polar star and major bright stars. Even without optical stars in clear sky, the wide beam dish allows the set up using the sun.

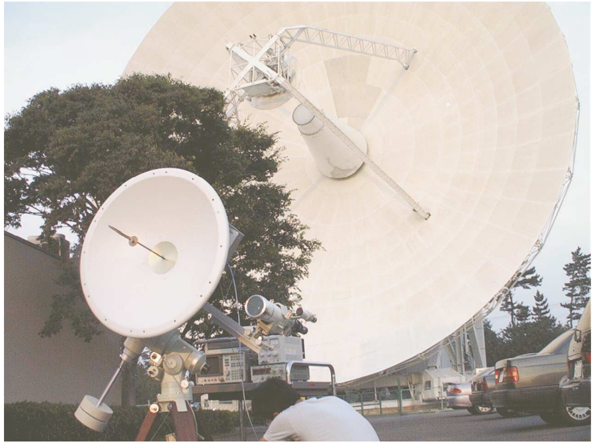

Figure 3. View of the CARAVAN and Kashima 34m antenna toward a same object.

5. Future plan

The CARAVAN will be moved to Ibaraki University and VLBI observation is planned with 50km baseline. This observation is scheduled in December 2002. We will carry the CARAVAN to high-speed network nodes and VLBI observation will be performed for further study of small telescope VLBI.

The implementation of the PC based Giga bit VLBI system

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1. Introduction

We are developing new Giga bit VLBI system integrated around personal computer (PC). The performance of personal computers is increasing quickly every year, it can replace almost part of the VLBI back-end system. The PC based system has several advantages. These advantages are flexible data analysis, the low cost and the good compatibility to other PC-VLBI. The PC-VLBI utilizes high performance CPUs for software correlaton. It can be used for real-time fringe test via Internet data transfer during observation[1]. The PC correlator can switch the algorithm XF and FX. It provides high frequency resolution for maser observation by FX and high correlation speed for geodetic or continuum observations by XF. The cost of PC-VLBI is inexpensive, it is two order lower than former back-end systems. The low price will spread VLBI research to many applications. Universities in Japan started VLBI study and PC-VLBI software development. Since, the sampling data of PC-VLBI is written on hard disk as standard file system, any PC-VLBI systems employ the file system can read another PC-VLBI data and correlate between heterogenous systems[2]. The data compatibility between PC-VLBI systems is no longer severe problem between systems. We report our PC-VLBI system and performance of the software correlation toward future.

2. PC-VLBI System: Hardwares

Figure 1 shows the PC-VLBI system. This system is consist of the A/D sampler based on VSI standardization[3] and a PC. We have two type samplers named ADS1000 and ADS2000. The specification of the ADS1000 was introduced by Nakajima et al.[4]. It has 1-channel of 1024Msps with 2-bit quantization. Another A/D sampler ADS2000 has 16-channels of 64Msps with 2-bit quantization. The targets of ADS1000 and ADS2000 are high sensitive astronomical VLBI and geodetic VLBI respectively. The VSI data generated from the sampler are introduced to PC through a PCI-bus by PC-VSI2000DIM board shown in Figure 2. This interface board is full compatible with VSI standardization and maximum performance is 2048Mbps. The major specifications of the PC is described in Table 1. This PC has two 64bit/66MHz PCI interfaces for the PC-VLBI capture board and IDE-RAID board. The normal recording rate is 1024Mbps using 4-IDE hard disks with RAID-0 mode. The total recording time is 96 minutes with four 180GB disks under 1Gbps. It can extend recording time with more capacity disks or using software data re-sampling. The recording time is shown in Table 2. This system has four removal IDE hard disk cases, the media is changed when the data reached maximum. Hot swap is possible by the RAID card selection.

Figure 1. The PC-VLBI system: PC with PC-VSI board, display and a giga-bit A/D sampler (ADS1000). In PC-VLBI observation whole telescope IF sampling is accomplished by this combination.

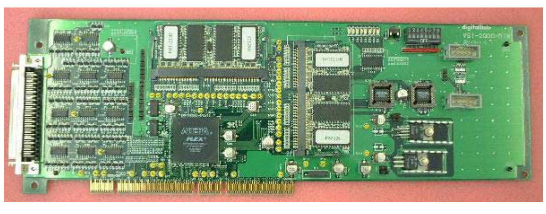

Figure 2. The PC-VSI data capture board. The 1024/2048Mbps VLBI data is transferred to PCI-bus continuously.

3. PC-VLBI Software and Further Ability

The software correlation is utilized in PC-VLBI. It provides new ability at fringe test. The software correlator enables near real-time correlation

Table 1. Specifications of PC for the PC-VLBI

CPU	AMD Athlon 1.6GHz dual
Memory	4GByte
HDD	IBM Deskstar 180GXP(7200rpm/ATA100) × 4
Ether card	Intel Pro 1000/XT Server Adapter
RAID card	Promise Fasttrek SX4000

Table 2. The recording time with four-180GB hard disks

sampling mode	total data rate [Mbps]	recording time [minute]
1024Msps/1bit/1ch	1024	96
512Msps/2bit/1ch	1024	96
512Msps/1bit/1ch	512	192
256Msps/2bit/1ch	512	192
256Msps/1bit/1ch	256	384
128Msps/2bit/1ch	256	384
128Msps/1bit/1ch	128	768
64Msps/1bit/16ch	1024	96
32Msps/2bit/16ch	1024	96
32Msps/1bit/16ch	512	192
16Msps/2bit/16ch	512	192
16Msps/1bit/16ch	256	384

via Internet data transfer transportaion. In this correlation, the required dataset for the fringe test is relatively small. It can detect calibration sources (> 1Jy) within 1-second sampling data (128Mbyte) between medium sized telescopes. Since, this correlator has large lag and rate windows, the fringe finding is straightforward even with large clock offset. Since, a performance of nominal Internet transfer rate is not reached 1-Gbps, disk transportation will need a while for the correlations.

Once data is available, the software correlator speed does not requires the observation speed of exactly 1Gbps. It is able to complete correlation in reasonal period by shareing data in the network. CRL had been used the software correlation up to 3-base line in practice. Here we present that software can correlate multiple telescopes observation more than three. In this method PCs correspond to number of telescopes are working with giga-bit-ether (GbE) connection. The correlation PCs have same specification as observation PCs. The flow of VLBI sampling data is shown in Figure 3 as the case of 4-telescopes A, B, C, D observation. Each PC read sampling data from own disks and send a part of the data to other PC. The four station data

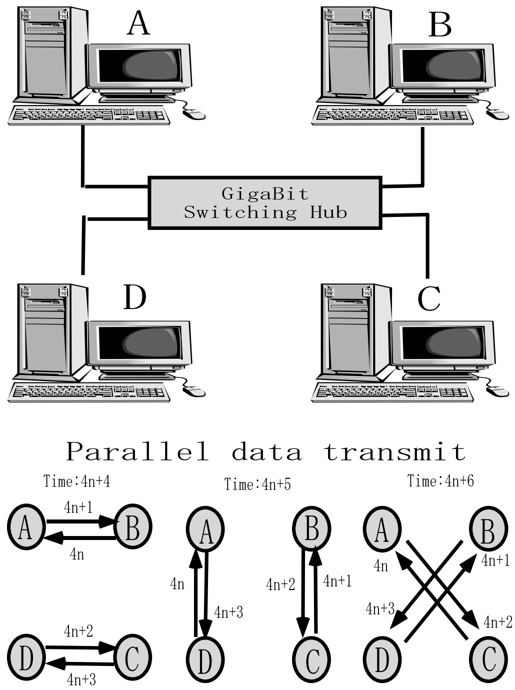

Figure 3. The concept of the network distributed computing. PCs A,B,C and D have a dataset of stations A,B,C and D. In first step, PC-A and PC-B exchange observation data 4n and 4n+1 second, the PC-C and the PC-D exchange 4n+2 and 4n+3. In second and third step, the similar exchanges are done at each pairs. After three steps, correlated result of 4n, 4n+1, 4n+2, 4n+3 seconds are in respectively in PC-A, PC-B, PC-C and PC-D.

is correlated at each PC in three steps in time sequence. This data transfer are executed in parallel. After correlation at each PC, the correlation data are gathered. Typical ability of the GbE network is around 800Mbps. Even at the GbE network below the Gbps, above three steps finish correlation within 4-seconds. The data switching distribution is effective at multi baselines and high speed correlation. In this case, the software correlation is four

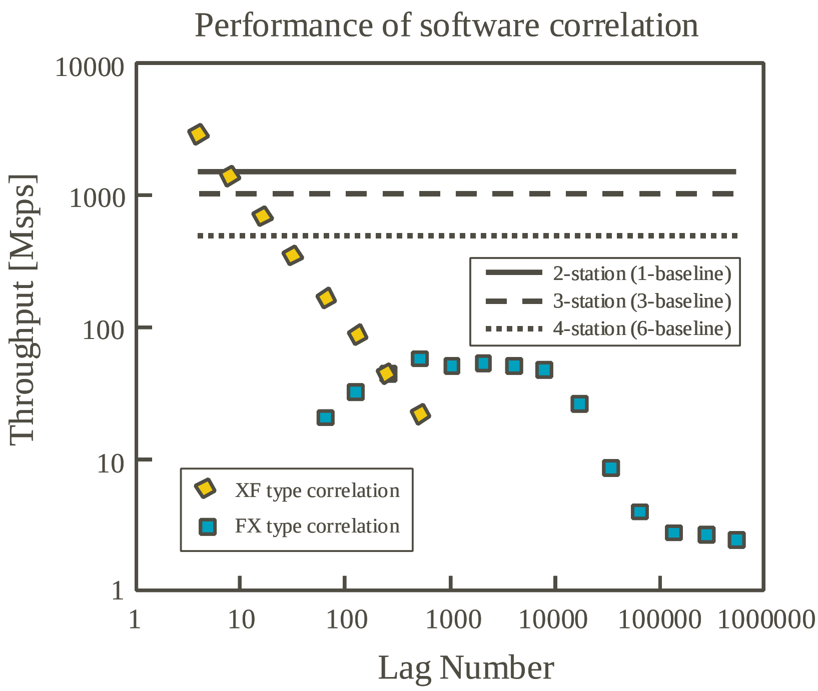

Figure 4. The XF and FX cross correlation performance evaluation using one PC. CPU cash memory size affect the performance loss at large lag.

times faster than one PC, thus this will enable real-time correlation between high speed linked telescope even with software correlator of limited CPU performance. This processing scheme is able to apply to N-telescopes observation with N-port switching hub.

As for each PC programming, correlation speed was considered as the first priority. Numerical codes are written in Single Instruction Multiple Data (SIMD) instructions and multi threading for multi-way proseccers are employed. The results of performance test of software correlation in XF and FX using one PC are shown in Figure 4. The PC specification used for this evaluation is also an ordinary one in Table 1. Three lines indicated in Figure 4 are requirement for 1Gbps real-time correlation with station number 2,3 and 4. Already the Gbps performance is achieved at small lag number by XF correlation. It is enough for geodetic VLBI which uses small lag window. The FX correlation dose not reach real-time processing speed at present, The correlation speed is expected to be achieved by simply using multi-way processors PC in near future, for example AMD hammer 8-way processors[5].

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VLBI development merge into to PC commodity

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1. Introduction

PCs on the market integrated around high performance CPU with high-speed bus have reached ability to carry out normal VLBI observation and correlation data rate up to 1Gbps. The VLBI data rate had been categorized as extreme high speed application which require specially integrated recorders. So far the sophisticated systems developed in laboratories are operated in telescope networks. But it caused incompatibility between the different systems, especially in their media. Currently, a typical telescope data rate of 1-Gbps, corresponding to a bandwidth of 500MHz sampled at 2-bit level, is handled by ordinary PCs and the part of the VLBI system formally called "backend" are replaced to widely used PCs.The PC backend is expected to dissolve the incompatibility by its file system. CRL have developed variety of the VLBI interface boards enable conjunction of the tape-VLBI and PC-VLBI. These are the PC-VSSP which substitute current moderate speed VLBI including AD and the PC-VSI which enables high-speed data acquisition beyond the Gbps.

2. PC-VSSP, PC Versatile Sampling Processor

PCs with 4-channel analog input boards, the name commonly known as the "IP-VLBI", the system aim replacement of the VLBI system up to 256Mbps. In the PC-VSSP, AD samplers are integrated into the board. Analog inputs, reference signal and 1-pps signals are connected to the board through BNC receptacles and all VLBI components except BBC (baseband converter) are disappeared in observation site. The data rate of the PC-VSSP is variable to 1-Mbps to adapt available network to put real-time VLBI into practice. Spectroscopy up to 16MHz bandwidth using 4-bit quantization extend its application. VLBI softwares in observation, correlation and bandwidth synthesis are put together in the PC. Software for this board are intensively developed by VLBI users and evaluated through the mail reflector.

3. PC-VSI, PC VSI interface board

Aim the data acquisition over 1-Gbps, PC-VSI2000-DIM board had developed. Different from the PC-VSSP, the interface to outside PC is a digital. Here, internationally agreed VSI-H interface is employed and the connector is MDR-80. Using this PC-VSI board, currently two samplers ADS1000 and ADS2000 are connected. The ADS1000 is 1Gsps (1024Msps) extremely low jitter high speed 1-ch AD sampler. The sampler enables direct telescope IF sampling. This is used for high sensitivity observation. The other ADS2000 supports 16-channels 64Msps for future geodetic VLBI. As well as the samplers, VSI connector enables the connection of other VSI instruments. For example, a MMM converter released from Metsahovi observatory, Helsinki University of Technology, will enable the VLBA/Mk-V type data converted VSI. Another PC-VSI2000-DOM board can outputs the VSI data from PC side when the VSI raw data is needed.

4. Conversion of VLBI Development

These two developments are related in their software development. Hardware controls usually done by RS232 and GPIB are confined to device drivers. A simple scheduling software or a commonly used FS/9 field system can control these boards using VSI-S (software) protocols. The correlation software is not hardware dependent too. Hence, all VLBI researchers can participate the correlation programming for the desired purpose as well as the successive analysis on the PC. Opportunities to touch radio telescopes raw data will enable interference removal technique and other interests to the data.

In Figure 1, we can perceive that the there are development part and commodity part in the PC-VLBI. The PC related technologies are rapidly improving at huge commercial demand. We will make full use of these available products. Bottleneck of the recent PC technology is the PCI-bus limitation of 64bit/66MHz. This will be increased several times in its alternated generation.

As for the removable media, we can expect optical RAID storage and holographic disc in near future. The kind of media does not have much importance in the PC-VLBI system, and only separated telescopes in remote islands will need them. From a engineering point of view, the VLBI researcher had been captivated the hardware compatibility. The VSI-H standard established this compatibility. The VLBI data rate is adapted to common PC and the file system handles them as data set. Further point, less difficult data file compatibility is re-

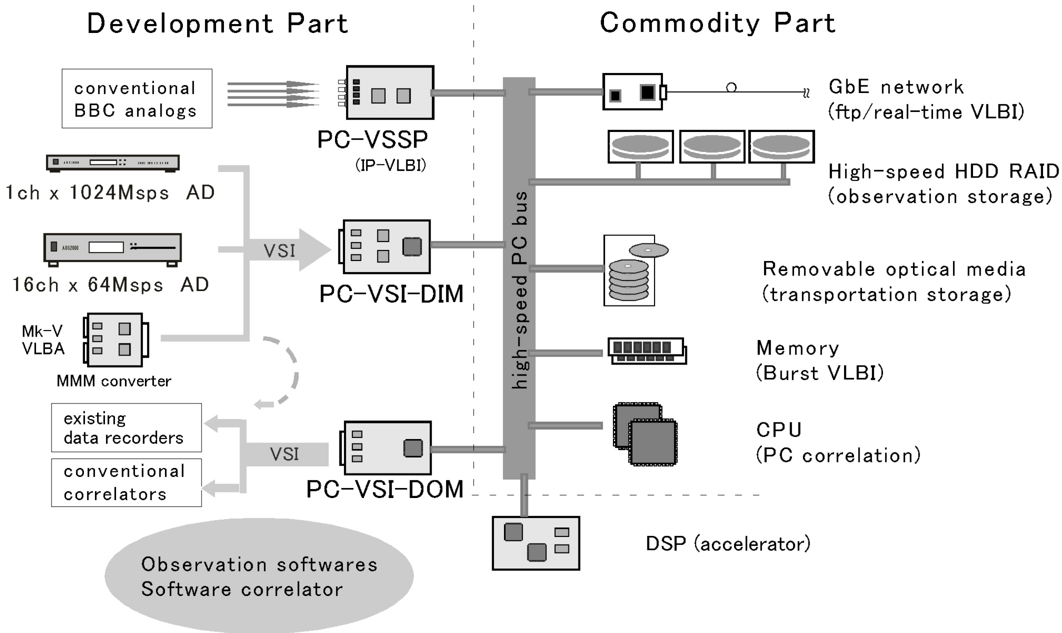

Figure 1. PC-VLBI configuration keep up with emerging PC hardwares. Rationalized back-end by PC commodity will decrease the load of back-end development work in VLBI. Conjunction to existing recorder systems are used as the data backup.

maining between researchers. In the development part, AD converters are still important as study. In higher band we have to increase the sensitivity of telescope by the AD speed. With the higher sensitivity, small telescope can participate VLBI and this will increase the range of VLBI users toward temporal communication dishes to high skilled amateurs.

Communications Research Laboratory continues these development to expand the VLBI field. We encourage universities and observatories participate with their unique idea to activate the community.

Current Status of the VERA

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National Astronomical Observatory Japan

Abstract: VERA (VLBI Experiment of Radio Astrometry) has finished construction in 2002 March, and test observations of it are under going.

1. Introduction

The VERA system consists of four VLBI stations at Mizusawa, Iriki, Ogasawara (Chichi-jima), and Ishigakijima. The maximum baseline (Mizusawa,Ishigaki-jima) is 2300 km. Construction of the former three stations of VERA started in 2000, and finished in 2001. The construction of the fourth station at Ishigaki-jima started in 2001 and finished in 2002 March.

The VERA is a newly developed VLBI system, which is dedicated to the differential VLBI. We have succeeded to obtain not only the first lights of all stations but also first fringes between them (Figure 1). We have also succeeded simultaneous VLBI observations using the 2 beam systems(Figure 2).

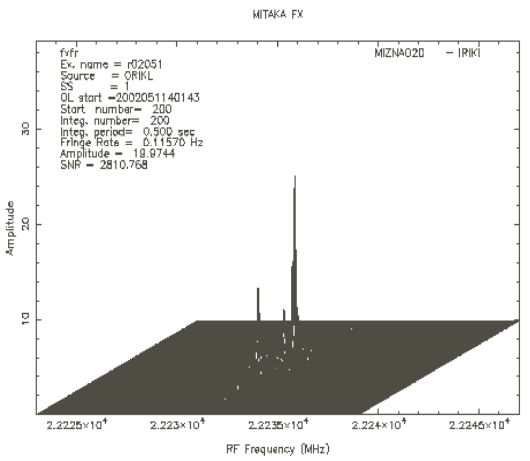

Figure 1. VERA first fringe between Mizusawa and Iriki stations.

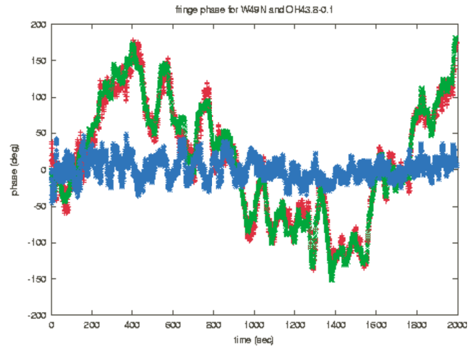

Figure 2. Resutls of 2beam simultaneous observation between Mizusawa and Iriki stations.

2. Scientific goal

The scientific goal of theVERA is mainly measurements of the proper motion and parallax of masers in the Galaxy (Figure 3). 3D map and velocity field of the Galaxy will be clear by using the results. Additionally, there are some other interesting scientific goals: detailed velocity structure of molecular gas around evolved stars and star forming regions; mass including dark matter distribution in the Galaxy; and phase referencing to improve sensitivity with long integration; precise measurements of moon satellites.

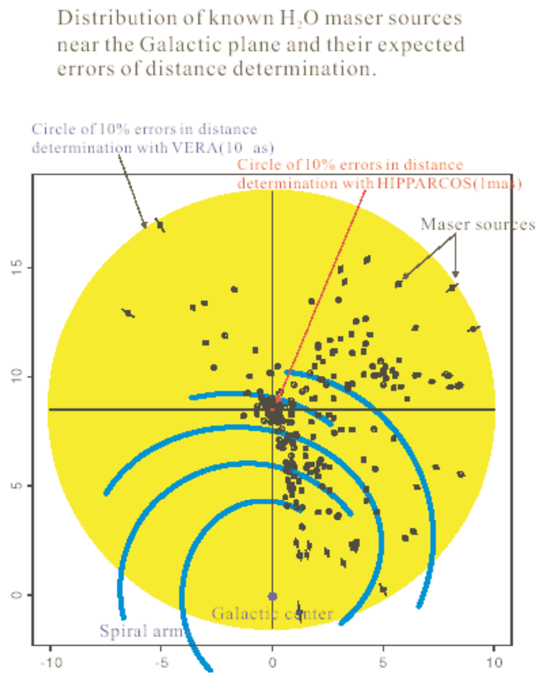

Figure 3. Expected circle of 10% errors in distance determination with VERA on the face on view of the Galaxy.

3. The VERA System

VERA antenna has dual-beam system with which we can observe two adjacent sources, simultaneously. Minimum and Maximum angular separation is 0.3 deg and 2.2 deg, respectively (see Figure 4). Amplified radio signals are digitalized and transmitted to the observation building by using

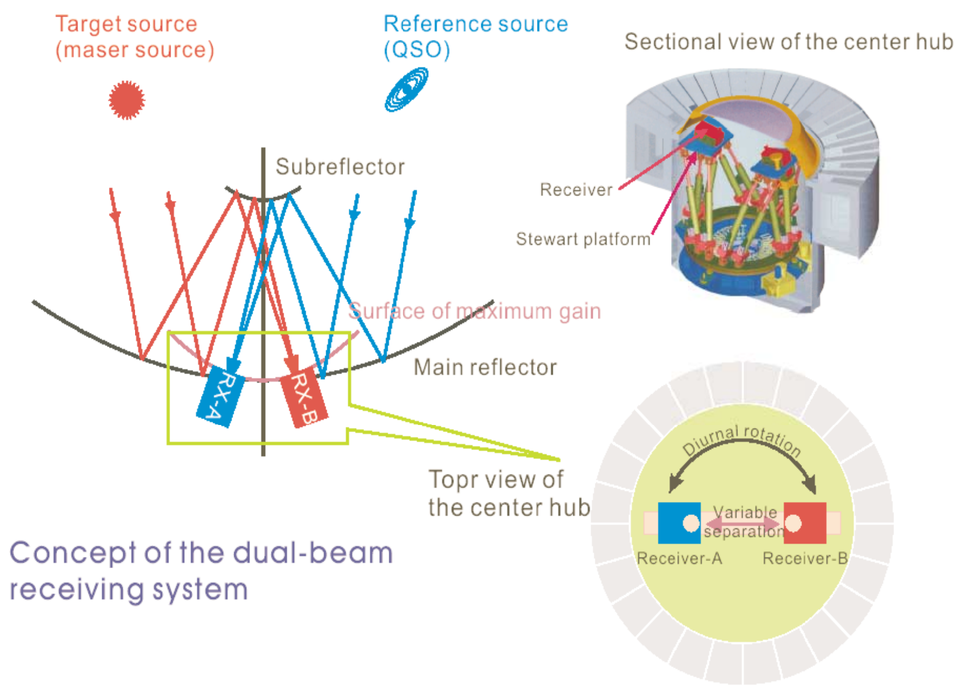

Figure 4. Concept of the dual beam receiving system.

optical fiber. The backend system, the frequency standard, and operation computer system are in the observation building of each VERA station. We can observe, S/X, 22GHz, 43GHz bands (Figure 5).

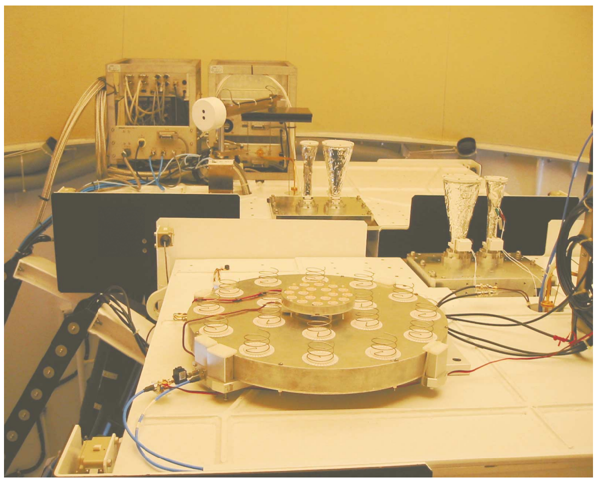

Figure 5. The real view of the receivers. S/X spiral horn is seen.

VSOP-2, a next generation space-VLBI mission

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Abstract: Following the success of the VLBI Space Observatory Programme (VSOP), a next generation space VLBI mission, dubbed VSOP-2, is being plannned in Japan. Higher observing frequencies, cooled receivers, increased bandwidths, dual-polarization capability, and a largere telescope diameter will result in gains in resolution and sensitivity by factors of about 10 over the VSOP mission. VSOP-2 science goals include studies of emission mechanisms in conjunction with X-ray ancl gamma-ray satellites, studies of magnetic field orientation and evolution in jets, and the highest resolution studies of spcctral line masers and megamasers. Here we describe the development of the space antenna, high speed sampler, and the satellite system.

1. Introduction

The successes of the VLBI Space Observatory Programme (VSOP) are described elsewhere [*Hirabayashi et al.,* 2000]. Planning for the next generation space VLBI mission VSOP-2 is well underway. The VSOP-2 spacecraft will have a 10 m class antenna with cryogenically cooled low- noise receivers and a downlink data rate of at least 1 Gbps, resulting in an improvement of an order of magnitude in sensitivity over the VSOP mission [*Hirabayashi et al.,* 2001]. Observing frequencies up to 43 GHz will allow high angular resolution observations of the optically thin emission in many AGN cores. An apogee height of at least 30,000 km will allow an angular resolution of 25 microarcseconds to be achieved at 43 GHz, correspnding to around 10 Schwarzchild radii at the distance of M87.

2. VSOP-2 mission

2.1 The satellite

The VSOP-2 spacecraft will, like HALCA, be three-axis stabilized. However, the VSOP-2 satellite will probably employ an off-axis paraboloid antenna, in contrast to the on-axis design of HALCA. One of the technical challenges is be the requirement placed on the surface accuracy of the mesh antenna by the highest observing frequency of 43 GHz (a wave length of 7 mm). A schematic view of VSOP-2 satellite is shown in Figure 1.

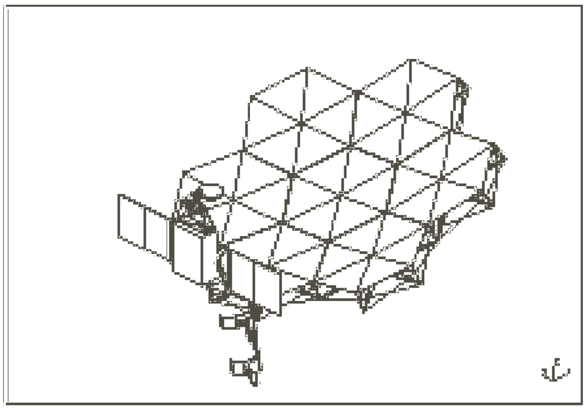

Figure 1. Possible appearance of the VSOP-2 satellite.

Due mainly to mass constraints, HALCA detected only Left-hand Crcular Polarization (LCP) radiation, and its front-end radio-astronomy receivers were not cooled. The VSOP-2 satellite will detect both LCP and RCP, and will use cryogenic cooler to reduce the system temperature of the receivers by a factor of around three. Sensitivity is ultimately limited by the coherence time, which becomes increasingly affected by atmospheric fluctuations above the ground telescopes at higher frequencies. Several posibilities for "phase-referencing" to improve sensitivity by extending the coherence time are under study.

Observing requires a two-way link between the satellite and a tracking station: a reference tone, derived from a hydrogen maser frequency standard is uplinked, and the science data down-linked from the satellite in real-time. HALCA used the 15 GHz band for uplink and a 128 Mbps downlink, but VSOP-2 will probably require a shift to the 37 GHz band for the 1-giga-bit-per-second tracking link. Testing of potential high-speed samplers for the on-board has been started.

The comparison of the specifications of the VSOP and VSOP-2 satellites is shown in Table 1.

2.2 Ground radio telescopes

Over 25 ground telescopes and arrays from 14 countries have participated in VSOP observations. By the time of the launch of the VSOP-2 spacecraft a number of new arrays and telescopes will also be operation. It is expected that upgrades of the sen-

Table 1. Comparison of the specifications of the VSOP and VSOP-2 satellites. The options column gives possible extensions of the baseline specification for the VSOP-2 satellite which are currently under discussion. In comparison, the VLBA has a resolution of 0.078 mas at 7 mm and a sensitivity of 4.9 mJy at 6 cm.

	VSOP	VSOP-2	(options)
Ant. Diameter	8 m	10 m	10∼15 m
Apogee Height	21,500 km	30,000 km	< 40,000 km
Period	6.3 hours	8.9 hours	
Polarization	LCP	LCP/RCP	
Downlink rate	128 Mbps	1 Gbps	1∼2 Gbps
Bands (GHz)	1.6, 5, (22)	5/8, 22, 43	5 to 8, 86
Resolution	0.3 mas	0.025 mas	
Sensitivity	140 mJy	12mJy (5 GHz, 25 m GRT)	
Launch	1997 Feb	2008	

sitivity of ground radio telescopes will further improve the VSOP-2 space-ground baseline sensitivity. The VERA array of the National Astronomical Observatory of Japan gives the possibility of phase referencing observations with the VSOP-2 spacecraft.

2.3 Scientific targets

The VSOP mission has produced astronomical results on AGN jet structure and evolution, high brightness temperature sources, and the plasma torus around the AGN, and so on.

The science goals of the VSOP-2 mission include: the stucly of emission mechanism in conjunction with the next generation of X-ray and gamma-ray satellites; full polarization studies of magnetic field orientation and evolution in jets, and measurements of Faraday rotation towards AGN cores; high linear resolution observations of nearby AGN to probe the formation and collimation of jets and the environment, around super-massive black holes; and the highest resolution studies of spectral line masers and mega-masers, and circum-nuclear diskd. Other non-thermal objects such as X-ray binaries, SNR, the Galactic Center, and gravitational lenses will also be able to be observed.

3. The activities of the development

3.1 Antenna development

A 7-segment, offset, 10-m class antenna (Figure 1) is under development. This antenna has a lighter weight, and easier adjustment mechanism, than that of HALCA. The basic concept of this type of antenna was developed by NASDA for the ETS-VIII mission, which will be launched in 2004. However, the planned surface accuracy of ETS-VIII is lower than that required for the VSOP-2 mission. We made the model of the central part of 1 segment (Figure 2) to evaluate how accurately the antenna surface can be adjusted. We succeeded to get an accuracy of less than 0.2 mm rms.

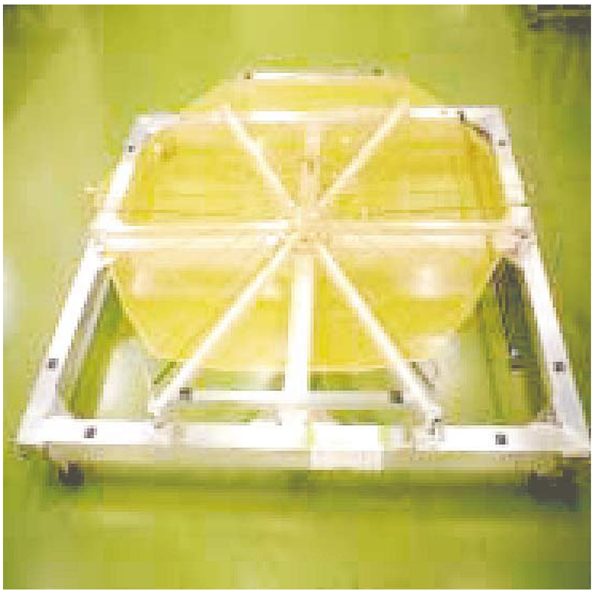

Figure 2. A model of the central part of a single antenna module to evaluate the adjustment of the surface accuracy. The size of the radial bars is 1/2 of the actual antenna module.

3.2 High speed sampler radiation test

One of the problems for VSOP-2 is how to sample the data on-board, if we follow the same approach as HALCA. We asume a giga-bit rate of data sampling to obtain the desired sensitivity. However, we can not find any A/D sampler LSI chips qualified for use in space. We tested a 10 Gbps, 1 bit sampler and a 1:16 demultiplexer, to demonstrate a possible solution for the on-board high speed sampler. We carried out a 1000 krad total dose test and a single event test. Figure 3 shows the LSI's on the test bench for the single event test. We confirmed we can use those LSI's on the VSOP-2 orbit.

3.3 On-board cooler and the LNA system study

We are now designing the front-end of the VSOP-2 observing system including the cooling system. We made a simulation of a single band obrserving system with an existing cooler rated for space use, and found we could cool to 30 K. We know that the temperature depends strongly on the design

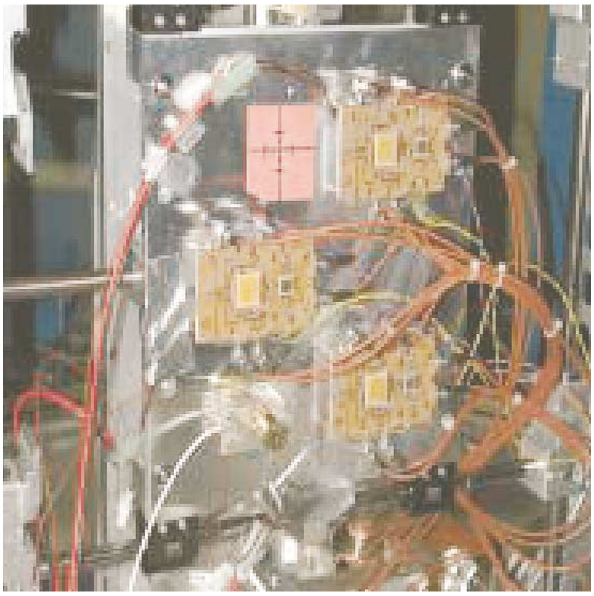

Figure 3. Three sets of the 10 Gbps sampler and the demultiplexer on the test bench for the single event test.

of the three-band observing system. Now we are designing the front-end feed. We are studying the use of a MMIC HEMT amplifier using chips sold by a Japanese LSI company.

3.4 Giga-bit data link

A giga-bit data transmission requires more than 1 GHz bandwidth frequency allocation. The only possible band based on frequency allocation regulations is 37–38 GHz. The uplink frequency will be moved to 40 GHz, so that we can use the same circuits for up- and down-link frequencies. We studied the link budget including signal transmission in bad weather. The detailed study of this issue is described by *Springett* [2002]. We also need to develop the modulator and demodulator for the giga-bit data transmission.

3.5 Possibility of the phase-referencing

Phase referencing observations are a powerful method to determine accurate relative positions of radio sources, and longer integration times for weaker sources. High speed switching between sources (or a multi-beam antenna like the VERA antenna) and a ~ 1 cm orbit accuracy are required. Both are very difficult. We are now studying the possibility of fast switching using the control moment gyro (CMG), which is a higher torque actuator. We are also studying the possibility of obtaining a higher orbit accuracy using an on-board GPS system and accelerometer.

3.6 System development

The total system design, including studies of the power, mass and thermal budgets, and compatibility with the rocket fairing is important. These developments have not yet progressed far, as we are now mainly working with the development of individual componentd. We will move on to the total system development in the near future.

4. Submission

There has been considerable activity within the USA recently, culminating in the submission of a white paper to NASA's Structure and Evolution of the Universe (SEU) roadmap committee. The white paper describes iARISE, an international future space VLBI mission involving two orbiting satellites, with nominally one of these being the VSOP-2 satellite and the other a US-funded satellite. The advantage of a two spacecraft mission is that by placing the two satellites in perpendicular orbits, a better all-sky coverage and more two-dimensional (u, v)-coverages can be obtained. The likelihood of a two spacecraft mission eventuating will be better known later this year.

The international cooperation and coordination required for VSOP observations make it one of the most complex space science missions undertaken, and similar level of collaboration between all mission elements — ground radio telescopes, tracking station, orbit determination teams, correlators etc. — will be required for VSOP-2. Submission of the VSOP-2 proposal will take place within the next year. Launch on an ISAS M-V rocket could be as early as 2008.

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

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Farewell ceremony of the Kashima 26m antenna

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On the day we had an IVS TDC symposium at Kashima, we had a small ceremony to say our farewell to the 26m antenna since it will be dismantled in the fiscal year of 2002. The 26m antenna was constructed in 1968 and has been used for the tests of satellite communications and pioneering VLBI work in Japan. In 1992, it was donated to Geographical Survey Institute (GSI) to continue global and domestic geodetic VLBI observations. It worked actively till the new 32m antenna construction in Tsukuba by GSI. This informal ceremony was held by CRL and GSI jointly. At the ceremony, Dr. Yukiyasu Suguri, who was a former director of Kashima Branch at the time of antenna construction, and six guests who worked with the 26m antenna attended the ceremony from the CRL side. And Dr. Kazuo Komaki, Director of Geodetic Department and GSI staff attended. The participants of the symposium also took part in the ceremony. On that day, we had a beautiful weather. After the final antenna tour, we thanked again to the 34 year's great activity of the 26m antenna.

Photo 1. The Kashima 26-m antenna and the participants of the farewell ceremony.

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

VLBI Technology Development Center (TDC) at CRL is supposed

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

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

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Summaries of VLBI and related activities at the Communications Research Laboratory are on the World Wide Web (WWW). The URL to view the home page of the Radio Astronomy Applications Section of the Kashima Space Research Center is : **"http://www.crl.go.jp/ka/radioastro/"**.

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