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VLBI Observation Systems Based on the VLBI Standard Interface Hardware (VSI-H) Specifications

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Abstract. The VLBI Standard Interface Hardware (VSI-H) specifications have been designed to allow easy interconnectivity between various components of the VLBI observations and correlation processing systems. Since the signal handling has been standardised with a simple architecture and the electrical and physical requirements have been distinctly defined, VLBI observation systems based on these specifications are potentially able to be used by various scientific fields which require high speed time series of digital data with accurate time stamping to each data stream. In this report, various system components developed by the Communications Research Laboratory based on the VSI-H specifications will be introduced. In addition, results of initial test experiments and discussions about the future prospects will be given.

1. Introduction

VLBI Standard Interface Hardware (VSI-H) specifications were discussed by representatives from broad community of VLBI research and developments. The first official version of the specifications was agreed and published in August 2000, and was accepted as the standard to be followed by International VLBI Service for Geodesy and Astrometry (IVS) and Global VLBI Working Group (GVWG).

In precise, the VSI-H specifies electrical and physical requirements, and internal functions of Data Input Module (DIM) and Data Output Module (DOM). The concept is to make the Data Transport System (DTS) to be transparent as much as possible. The DTS is a conceptual device which has DIM and DOM, such as a data recorder or an optical fiber transmission device. To achieve this concept, the signal streams into DIM and from DOM are defined symmetrically. As the results, the data stream coming from the DOM become identical replica of the input data stream into the DIM. Then the DOM output data stream may be connected to a correlator system (Data Processing System : DPS) for correlation processing or another DTS to copy recorded data to convert recording media. Ideally, same correlator system should be able to correlate data from differently designed DTS systems. From this point of view, the VSI-H can be seen as an 'intersection' of data streams between various components. Here, the various components are A/D samplers (Formatter), data recorders, optical

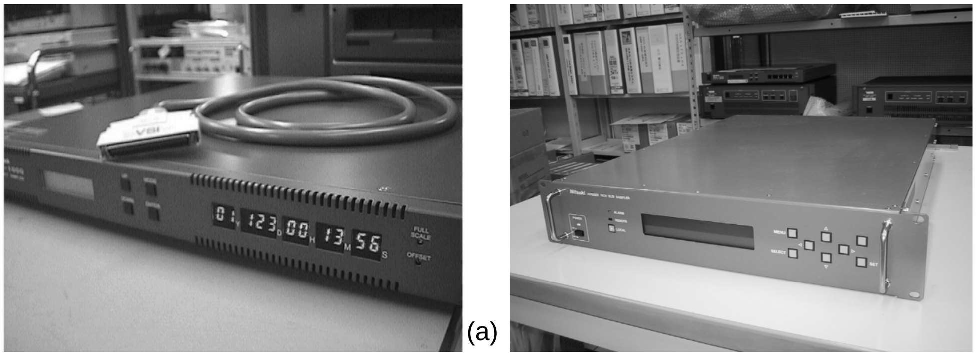

Figure 1. (a) ADS1000 A/D sampler unit. (b) ADS2000 A/D sampler unit.

fibers, correlators, and so on. In the past, there was no standard specifications and the interface between one component and the other component was independently designed. As the result, differently designed components were not compatible with each other. However, if all devices are designed with VSI-H, it become possible to connect differently designed components, ideally speaking. For example, it become possible to choose an A/D sampler from variety of available A/D samplers, and the output data from the A/D sampler will be recorded by one of the available data recorders. Or instead, the same data can be transferred by optical fibers to a correlator system in realtime.

This situation is our goal to achieve. But, on the other hand, this goal is not easy to achieve. We can not expect that the use of VSI-H automatically assures the inter-changeability like just mentioned above. Therefore, it is important to make every efforts to ensure the inter-changeability between different systems and make necessary revisions to the current VSI-H specifications by using actual experiences in the future. This paper will introduce various component systems developed based on the VSI-H specifications first. Then we will describe about our recent efforts to assure the compatibility between different systems and present a few actual examples which demonstrated the use of VSI-H based components.

2. VSI-H based systems

2.1. A/D samplers

Figure 1 shows the pictures of two sampler units developed for VLBI observations. ADS1000 is a sampler unit which can sample single wide-band signal from 0Hz to 512MHz at the sampling rate of 1024MHz. The sampling level can be selected from 1 bit or 2 bits. ADS2000 is a multi-channel sampler unit which can sample 16 channels of baseband signals at the sampling rate of 64MHz. The sampling level can be selected from 1 bit or 2 bits. Thus, the highest data rate from these sampler units are both 2048Mbps. Under the VSI-H concept, slower sampling rate observations can be done by omitting a part of the sampled data stream periodically. For example, the sampling rate can be decreased by a

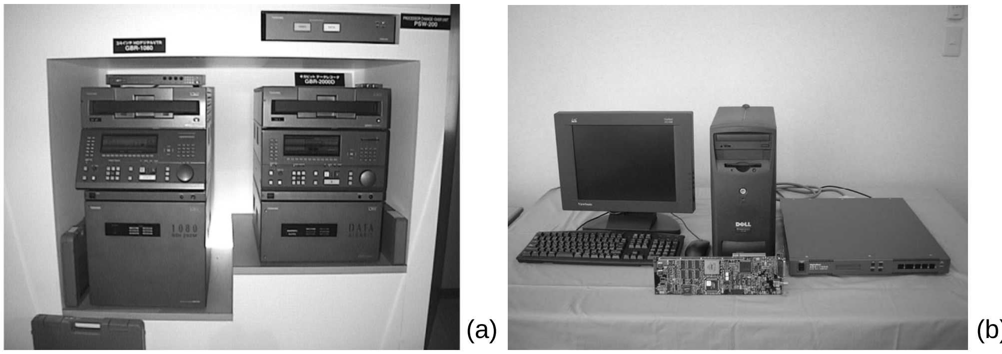

Figure 2. (a) GBR1000 (left) and GBR2000D (right) data recorder units. (b) PC-VSI system.

factor of two by skipping one sampling data alternatively. By using this mechanisms, ADS1000 and ADS2000 sampler units can be used for different sampling speeds. The ADS1000 sampler unit has been developed for astronomical VLBI observations which require high sensitivity with wide frequency bandwidth. The ADS2000 sampler unit, on the other hand, has been developed for geodetic and astrometric VLBI observations which require multi-channel observations for bandwidth synthesis.

2.2. Data recording systems

Figure 2(a) shows a picture of GBR1000 and GBR2000D data recorder units. Both recorder units can record VLBI data stream at the data rate of 1024Mbps. GBR1000 is the first model and was used in the initial 1-Gbps VLBI observations (Nakajima et al., 2001). GBR2000D has been developed by adding VSI-H compliant capabilities into GBR1000. The size of the transport unit was significantly decreased as shown in the figure. GBR1000 and GBR2000D employ D6 standard recording format using 3/4-inch magnetic cassette tapes which can record data for 62 minutes. Both recorders can be combined with a tape changer unit which enables 24 tapes to be used consecutively without manual operation and the observations can be automatically performed for more than one day unattended.

Figure 2(b) shows a picture of the PC-VSI system and the data input board. The system can record data stream through a VSI-H data input connector at the data rate of 1024Mbps. The recorded data are stored in a RAID disk array under the LINUX operating system.

Figure 3 shows pictures of two data interface units (VSI-K4-DIM and VSI-S2-DOM) and the K4 data recorder unit (DIR1000). The K4 data recorder was developed before the VSI-H specifications were discussed and was not compliant with VSI-H by itself. VSI-K4-DIM has been developed to make the K4 recorder equipped with the DIM capabilities of the VSI-H. By using the VSI-K4-DIM and the K4 data recorder, it becomes possible to record data stream through the VSI input connector. In the same manner, VSI-S2-DOM has been developed to make the S2 recorder equipped with the DOM capabilities of VSI-H. By using the VSI-S2-DOM and the S2 data recorder, it became possible to reproduce recorded

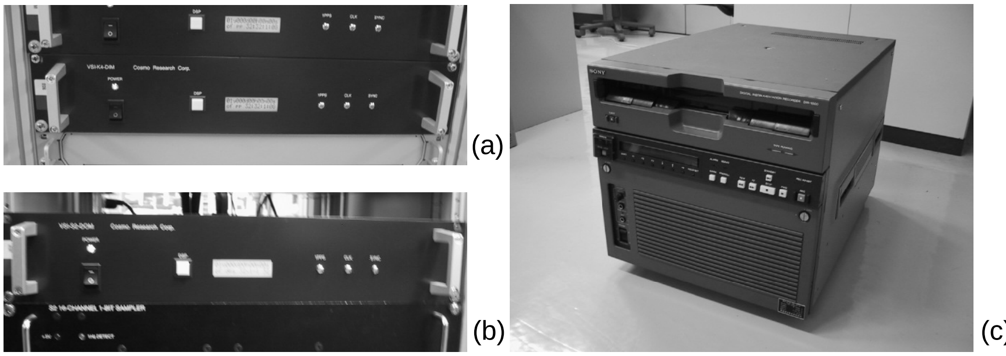

Figure 3. (a) VSI-K4-DIM. (b) VSI-S2-DOM. (c) K4 data recorder unit DIR1000.

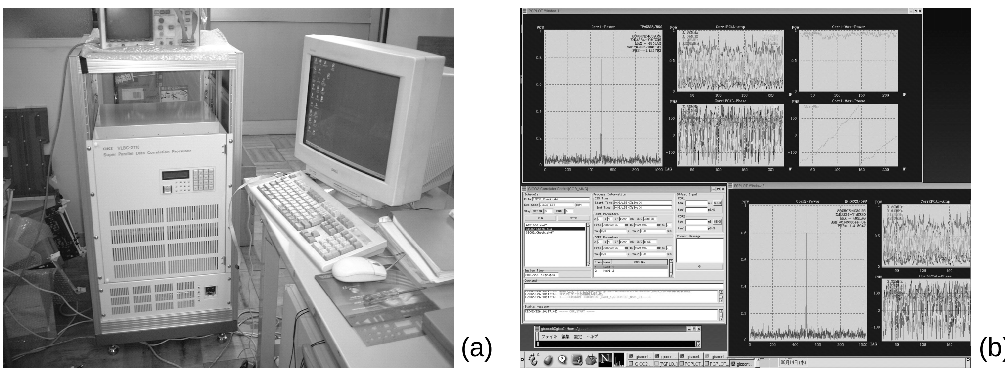

Figure 4. (a) GICO-2 correlator system. (b) A snapshot of the display of the control PC.

data through the VSI output connector. By using these systems together, S2 data tapes can be copied to K4 data tapes through the functions of VSI-H. Developments of these units demonstrated the actual examples to achieve VSI-H compliances with conventional systems developed before the VSI-H specifications were discussed.

2.3. Correlators

Figure 4 shows a picture of the GICO-2 correlator system and a snapshot of the display of the control PC. The correlator system can process two pairs of 1024Mbps data streams with a lag length of 512bits, or one pair of 1024Mbps data streams with a lag length of 1024bits. 2-bits sampling data at 1024Msps can also be processed by using the correlator by processing twice for each scan. The correlator has been developed by expanding the design of original GICO correlator which can process one pair of 1024Mbps data streams recorded with GBR1000 data recorders. While the original GICO correlator does not support VSI-H specifications, the GICO-2 correlator has been designed based on the VSI-H specifications.

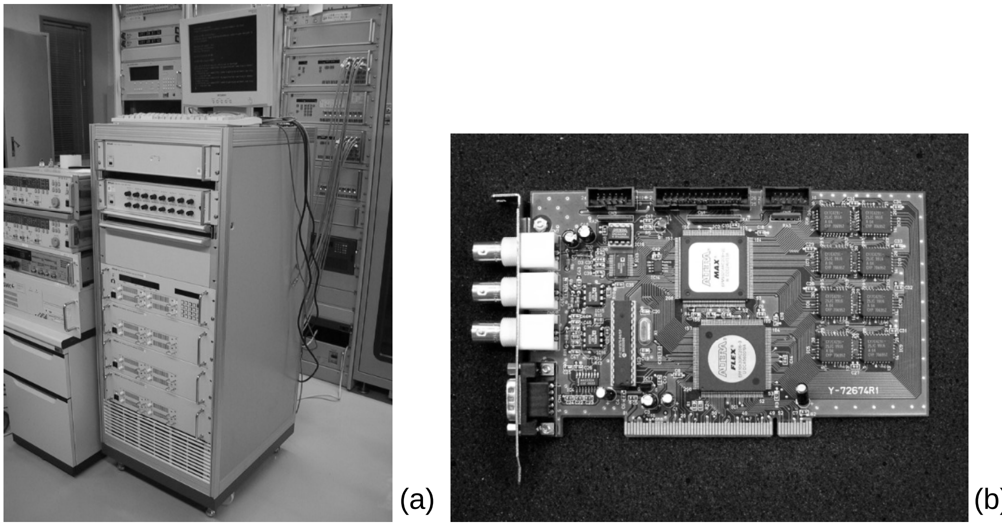

Figure 5. (a) K5 data acquisition system. (b) Main board of the IP-VLBI boards.

2.4. PC based systems

In addition to the PC-VSI system previously described in this report, CRL is also developing K5 PC based VLBI system. The system is also called as PC-VSSP (Versatile Scientific Sampling Processor) (Kondo et al., 2002). The K5 data acquisition system is consist of four PC systems each equipped with a main board and an auxiliary board of the IP-VLBI boards. The IP-VLBI boards can sample baseband signals at various sampling rates selectable from 40kHz, 100kHz, 200kHz, 500kHz, 1MHz, 2MHz, 4MHz, 8MHz, and 16MHz. The sampling level can be selected from 1, 2, 4, or 8-bits. The PC systems run on the LINUX, FreeBSD, and MS-Windows operating systems. Figure 5 shows pictures of the K5 data acquisition system and the main board of the IP-VLBI boards. Each PC system is equipped with four hard disk drives of 120GBytes each. The maximum recording speed is currently restricted by the speed of the CPU motherboard and the speed of the PCI internal bus, but the 128Mbps with each PC system has been achieved which corresponds to 512Mbps recording in total. It can be expected to record data up to 1024Mbps by using faster PCI bus and faster CPU motherboard within a year or two years. To process the data stored with the K5 data acquisition system, software correlation programs are under developments on the same PC architecture.

3. Experiments

By using the new VLBI observation and data processing systems described in the previous section, a series of test experiments have been carried out. Three baselines were selected for these test experiments. One is the Kashima-Koganei baseline. The 11-m antenna stations at Kashima and at Koganei, Tokyo were used. The second baseline was the Kashima-Westford baseline. The 34-m anten-

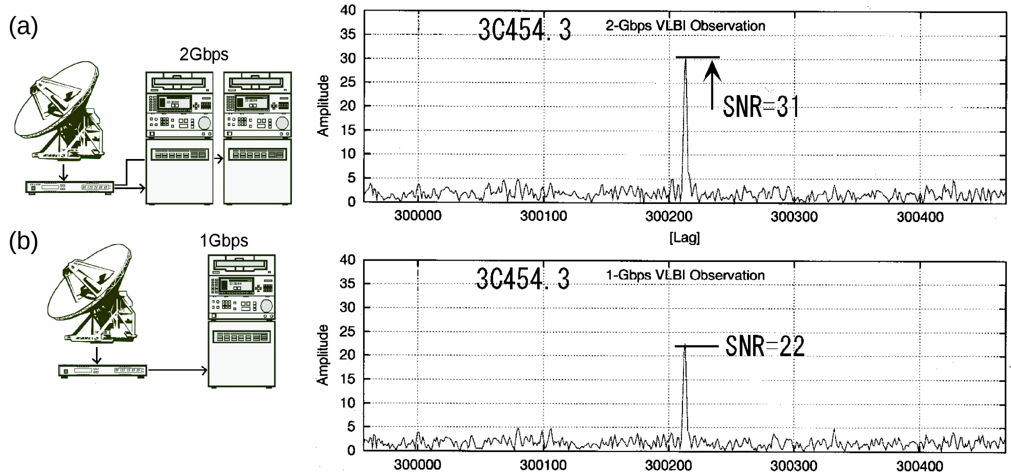

Figure 6. Cross correlation function processed with the 2-bits processing (a) and 1-bit processing (b).

na station at Kashima and 20-m antenna station at Westford, Massachusetts, USA were used. The third baseline is the Kashima-Metsähovi baseline. The 34m antenna at Kashima and 14m antenna at Metsähovi, Finland were used.

3.1. Kashima-Koganei experiment

The purpose of the first test experiment was to demonstrate high sensitivity VLBI observations by using ADS1000 A/D sampler units and GBR2000D/GBR1000 data recorders. At each station, two data recorders were used in tandem and 2-bits of sampled data from the sampler units were recorded. The experiment was performed on December 12, 2001. Single wide-band signal in the X-band with the bandwidth of 512MHz was sampled at the sampling rate of 1024MHz. Since the sampling level was 2-bits for each samples, total data rate recorded to the data recorders were 2048Mbps. The recorded data were reproduced and correlated by using GICO-2 correlator. Correlation processing was repeated twice to process all combinations of 2-bits at each station and the cross correlation function was combined. Figure 6 shows the comparison of cross correlation function processed with 2-bits processing and 1-bit processing. As mathematically expected, it was shown that the signal to noise ratio with the 2-bits processing was improved by the factor of $\sqrt{2}$ compared with the 1-bit processing. This result can be declared as the first detected VSI based fringes, because the fringes were obtained by recording data through VSI-H and the data were correlated through VSI-H.

3.2. 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

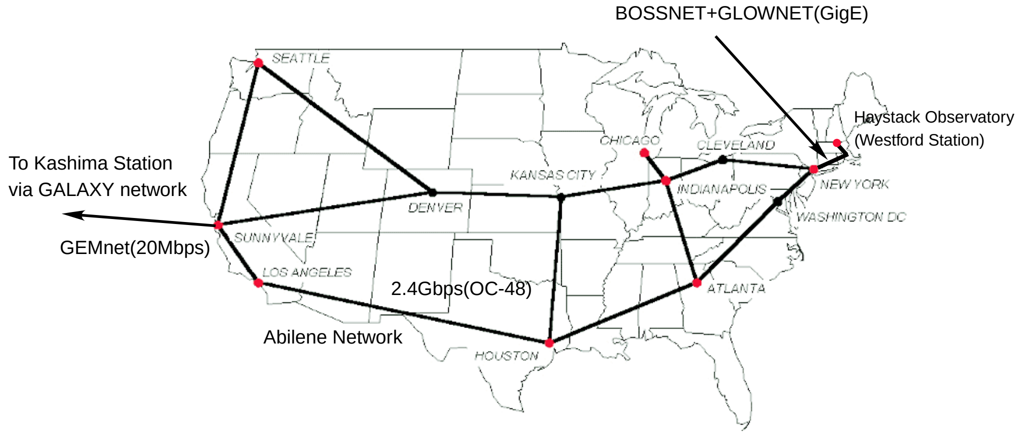

Figure 7. The high speed network route used in the Kashima-Westford test e-VLBI experiments.

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 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.

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

Figure 7 illustrates the high speed network route used in the test e-VLBI experiments. To prepare the international e-VLBI experiments, the GALAXY network was connected to the GEMnet network which is the high speed research network of the NTT 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

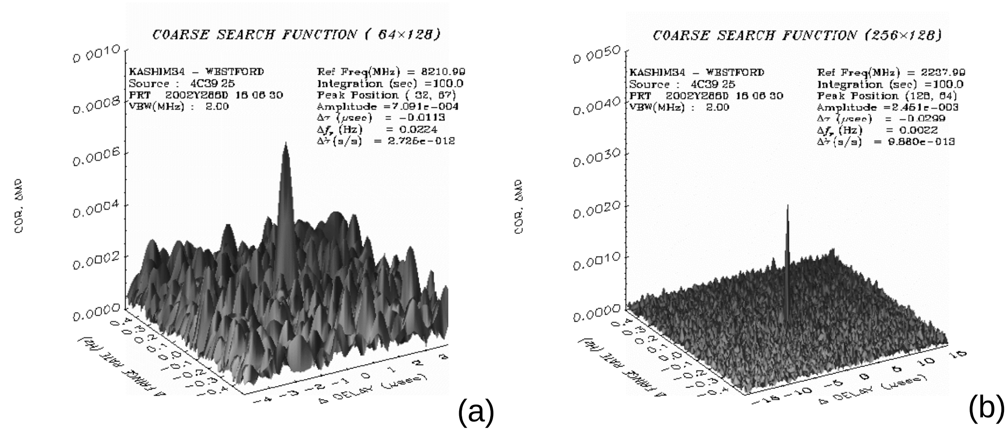

Figure 8. Detected fringes at X-band (a) and S-band (b) observations towards 4C39.25. The PC software correlator was used to correlate Mark-5 data recorded at Westford station and K5 data recorded at Kashima station.

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 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 8 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 transmitting 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.

3.3. 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 ex-

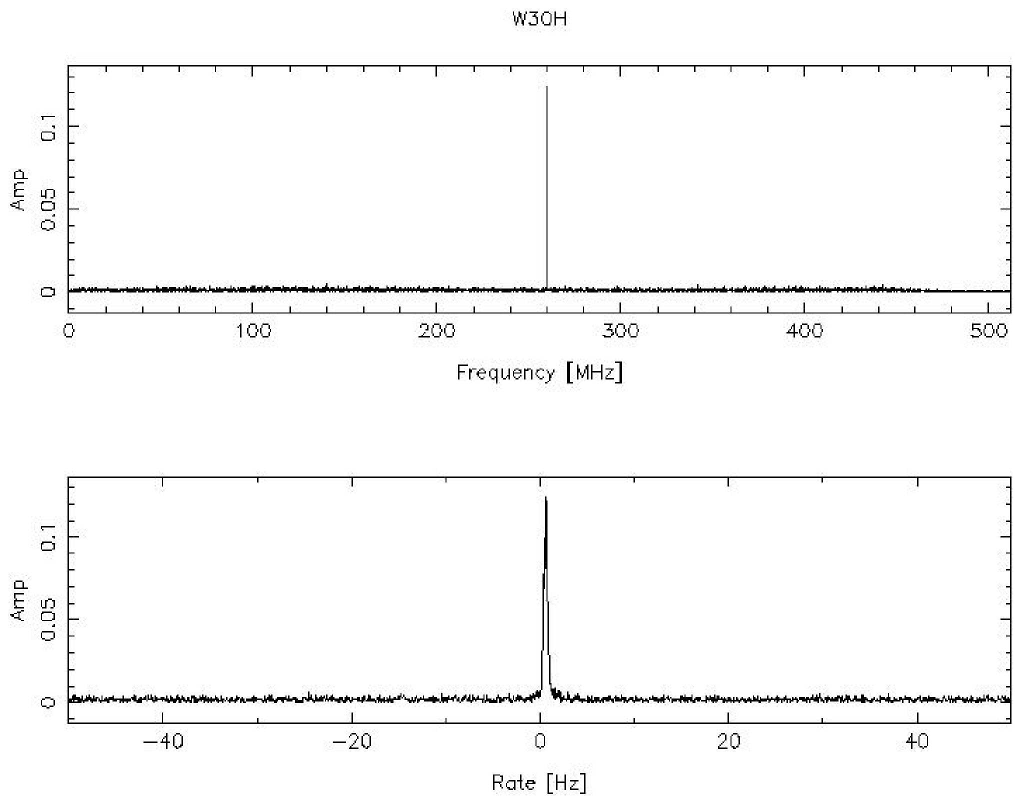

Figure 9. The first fringe detected with the Kashima-Metsähovi baseline from the observation towards W3OH.

periments. 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. In the test e-VLBI experiments, 1-bit sampling mode of the sampler unit was used. 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.

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 9 shows the cross power spectrum after 15 seconds of integration time.

4. Discussions and Future Prospects

The successes of the series of test experiments have many important meanings. The 2048Mbps Kashima-Koganei experiment demonstrated high sensitivity VL-

BI observations. The experiment also marked the first milestone of the VSI-H since the VSI-H architecture was first used in the actual VLBI observations and correlation processing.

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 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 standardisation of the interface by VSI-H.

The use of the VSI-H in the system design does not automatically ensure the connectivity between components. To make sure the VSI-H based components can be actually connected, it is important to accumulate experiences and feed back necessary improvements to the VSI-H specifications. By continuing efforts to make existing devices to comply with VSI-H specifications and to develop new devices based on the VSI-H specifications, we expect to realize hardware level compatibilities among different components.

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