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## First Phase Development of Korea-Japan Joint VLBI Correlator and Its Current Progress

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### Abstract

The first phase of the Korea-Japan Joint VLBI Correlator (KJJVC) development has been completed and installed to correlate the observed data from KVN (Korean VLBI Network) and VERA (VLBI Exploration of Radio Astrometry) in October 2009. KJJVC is able to process 16 stations, a maximum of 8 Gbps/station, and 8,192 output channels for VLBI data. The system configuration, the experimental results, and future plans are introduced in this paper.

### 1. Introduction

Recently, it has been suggested to continue the research in close cooperation with East-Asian region research group using the VLBI network. Especially in the case of Korea and Japan, a Memorandum of Understanding (MOU) has been signed between Korea Astronomy and Space Science Institute (KASI) and National Astronomical Observatory of Japan (NAOJ) to build a Korea-Japan Joint VLBI Network (KJJVN) and to perform joint observation research using the Korean VLBI Network (KVN) and the VLBI Exploration of Radio Astrometry (VERA). KVN has three stations with 21-m diameter antennas and has been operating at 22 and 43 GHz since 2008. VERA has four stations with 20-m diameter antennas and has been operating at 2, 8, 22, and 43 GHz since 2002. KVN plans to extend the observation frequency to 86 and 129 GHz by 2011 [1]. Including VSOP-2 after 2012, the East-Asian VLBI Network (EAVN) [2] will obtain the effectiveness of a ground-based 6,000 km diameter VLBI radio telescope. To process the observation data of EAVN, the need for a new correlator has been strongly considered. The new correlator development project for KVN was begun in 2004. The VERA also needs to develop a substitute correlator for the Mitaka FX correlator as a back-up. Therefore, a MOU was signed between KVN and VERA in 2005 to jointly develop a new correlator and to extend the number of stations of the EAVN. The Korea-Japan Joint VLBI Correlator (KJJVC) development project was started in 2006.

In this paper, the specification and technical design of each component will be introduced briefly. The paper is organized as follows: In Section 2, we briefly introduce the East-Asian VLBI Network. In Section 3, each component of KJJVC is introduced. Finally, the current progress and future plans are summarized in Section 4.

## 2. East-Asian VLBI Network

Radio interferometers get good quality observation data in proportion to the square of the number of stations observing at the same time. So it is better that Korea and Japan cooperate rather than independently operate in order to get good science research.

KVN, which has been operated by KASI since 2008, consists of three radio telescopes with 21-m diameter dishes and baseline lengths of about 500 km, which is half the size of the Korean Peninsula. The KVN will employ a unique multi-frequency band receiver system which is able to achieve simultaneous observations at up to four frequencies (22, 43, 86, and 129 GHz). The phase of a source at 22 GHz can be used to calibrate the phase of the same source at higher frequency bands. To do this, the KVN Data Acquisition System (DAS) [3] was developed and installed at each site for measuring simultaneously four frequencies.

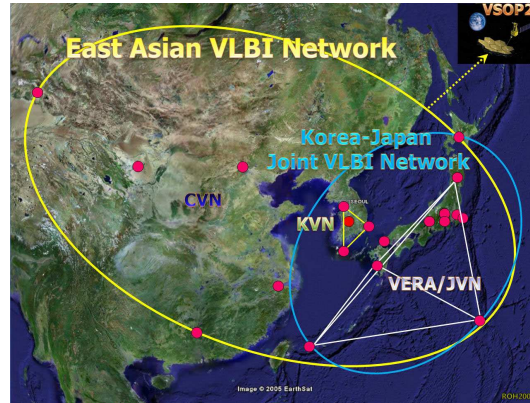


Figure 1. East-Asian VLBI Network with KVN, VERA/JVN, KJJVN, and CVN including VSOP-2.

In the case of Japan, VERA is also operated by using a unique dual beam system at four stations of NAOJ since 2002. VERA plans to improve the DAS in order to be able to process at maximum 8 Gbps for LHCP and RHCP observation simultaneously including the 86 GHz frequency band. As shown in Figure 1, the EAVN, which is based on the KJJVN in connection with the Chinese VLBI Network (CVN), will be realized in 2011. The next generation space VLBI satellite (VSOP-2) will be launched after 2012, so it will be a huge size radio telescope of 36,000 km. It is necessary to build a correlation Data Center for providing large capacity correlation, as 16 stations will be operated simultaneously according to the new VLBI network expansion plan.

## 3. Korea-Japan Joint VLBI Correlator

Figure 2 (a) is the conceptual configuration of KJJVC. There are several VLBI data playback systems which will be used in our combined VLBI network, such as Mark 5B, VERA2000, K-5/OCTA DISK and some kind of optical fiber which will be introduced in the near future. Some of them have the VSI-H compatible interface, but others use a different interface for data transmission. Furthermore they have their own maximum data recording/play back rates, respectively. To absorb all of these differences and in homogeneity among these existing VLBI data playback systems, the Raw VLBI Data Buffer (RVDB) was introduced, which is in fact a big data server with many large RAID disks and several kinds of VLBI data interfaces. The VLBI Correlation Subsystem (VCS) will receive the VLBI data from the RVDB system, will calculate the correlation between every possible pair of data inputs with proper control parameters given from the correlator control and operation computer, and then will dump the correlation results into the data archive system. The data archive system is also a kind of data server, which is used to capture the correlated data

output from the VCS, to save them in a structured file system. Finally there is also the correlator control and operation software for the overall system. KJJVC development is a joint project in close collaboration with KASI and NAOJ based on the MOU in 2005. NAOJ is responsible for the VERA2000 and other playback systems and RVDB development. KASI is responsible for the Mark 5B, VCS, and data archive system development. The control and operation software development is done jointly by KASI and NAOJ.

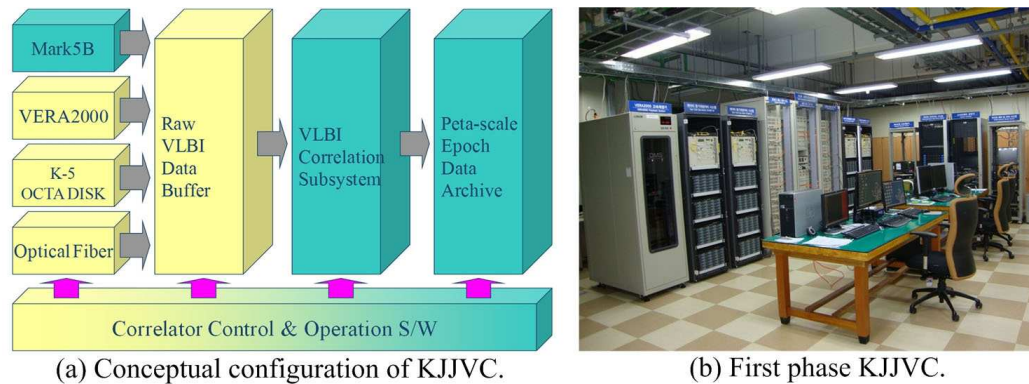


Figure 2. Conceptual configuration of KJJVC and the first phase implementation of KJJVC.

### 3.1. Playback System

KVN is now using the Mark 5B system [4] for recording and playing back the observed data. KASI participated in Mark 5B development with Haystack Observatory as a member of an international consortium. It can support the VSI compatible and RAID-based HDD storage system. Recording and playback speed is 1 Gbps. VERA is now extensively using the DIR2000 system for recording and playback with 1 Gbps. Recently the manufacturer of DIR2000 discontinued the production, so NAOJ developed a new playback system called VERA2000, which is a version of the DIR1000H system for playback only.

### 3.2. RVDB System

The RVDB system [5], which is developed by NAOJ, consists of a Data Input Output (DIO), a 10GbE switch, and a Disk Data Buffer (DDB). It is able to record the data with a maximum speed of 2 Gbps and to play back the data to the correlator with a nominal speed of 2 Gbps. So, RVDB has 2-Gbps recorder and playback functions. As shown in Figure 2 (a), KJJVC uses different types of playback systems. So, the purpose of the RVDB system is to adjust the data format, to easily synchronize the data during playback, and to maintain the buffering between recorder speed and correlation speed.

### 3.3. VLBI Correlation Subsystem

The main specifications of the VCS are described in Table 1. The VCS has the capability of processing a total of 120 cross-correlations and 16 auto-correlations intended for a maximum of 16 stations and 8 Gbps (4-streams  $\times$  1 Gbps/2-bit/64 MHz clock) input data rate per station.

The correlation architecture is FX-based, and it will use the variable length of FFT (Fast Fourier Transform) to maintain the 0.05 km/sec velocity resolution at 22 GHz. The maximum delay rate (maximum baseline velocity) is 7.5 km/sec, and the maximum fringe tracking is 1.075 kHz. The number of frequency channels per correlation output is 8,192.

Table 1. Specifications of the VCS.

Items	Contents
# of stations	16
# of inputs/station	Max. 4 inputs
Max. # of correlations/Input	120 Cross + 16 Auto
Observation frequency	(VSOP-2) 45 GHz, 130/86/43/22 GHz
Largest baseline length	36,000 km(0.12 sec)
Max. data output rate	1.4 GBytes/sec
Digitization for each input	1 Gbps by 2-bit/sample
Quantization levels	4 levels as 00 01 10 11
Interface	VSI-H
Input data rate	2 Gbps/1 Gbps
Architecture	FX type, with FPGA and DSP chips
FFT points	256k/128k/64k/32k/16k/8k Adjustable
Word length in FFT	16 + 16-bit
Integration period	25.6 msec - 10.24 sec
Frequency binning	1-256 channels bin (powers of 2)
Correlation output data interface	10 Gbit Ethernet

### 3.4. Data Archive System

The basic architecture is infiniband. For KVN and KJJVN, the first phase of data archive system with about 100 TB capacity was implemented. It has four 10-Gbit-Ethernet input ports to connect with VCS output, and one 10-GbE-Ethernet port is connected to the data file system to share the disk. We plan to increase the system capacity corresponding to the EAVN including VSOP-2. The CODA file system [6] will be used in the data archive system, which is a modified Mitaka FX correlator file system. A new version of the CODA file system is expected to be completed in September 2010.

## 4. Current Progress and Future Plans

The first phase of the KJJVC hardware development has been completed, and all of the components were installed in October 2009. Field performance tests of the correlator hardware were successfully completed using VERA observation data which had already been verified with the Mitaka FX correlator. Then a test correlation experiment was conducted using KVN observation data at 22 GHz of the W49N spectral-line source between the KVN stations Yonsei and Ulsan. The correlation result is shown in Figure 3 as real and imaginary spectrum shape, phase, and

cross-spectrum. This result is just correlation spectrum without any other data processing such as global fringe search. The correlation post-processing software for KJJVC, including the CODA file system and the ability to perform a global fringe search, is now being developed jointly by KASI and NAOJ through 2010. After that we will employ the KJJVC operationally starting in 2011.

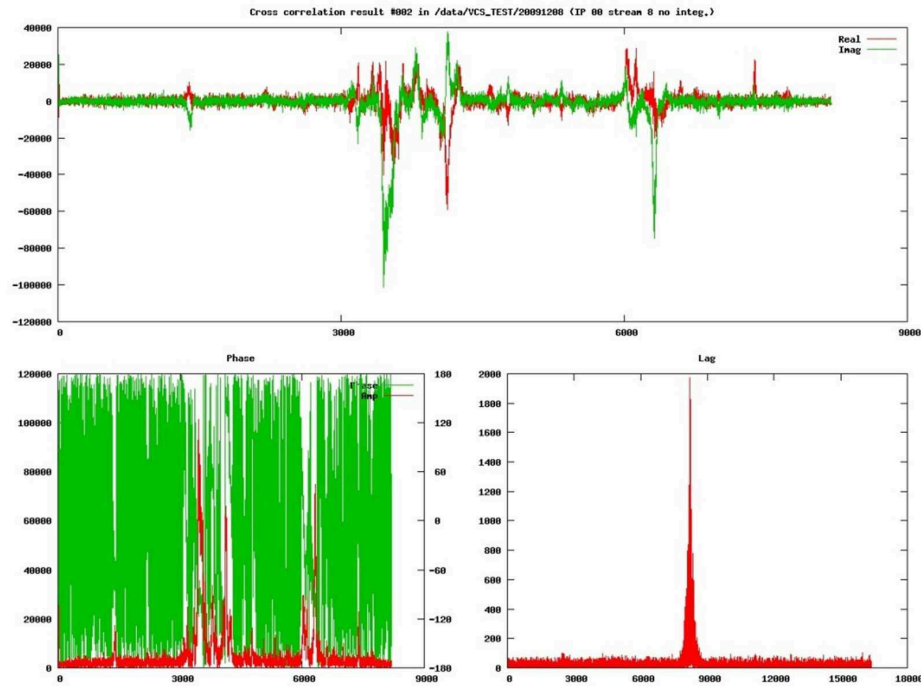


Figure 3. Spectral-line correlation result (cross spectrum, phase, lag) for W49N of a 22 GHz observation on the KVN baseline Yonsei to Ulsan.

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