Shanghai VLBI Correlator 2013 Annual Report

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Abstract This report summarizes the activities of the Shanghai VLBI Correlator during 2013. We have improved the delay model accuracy and real time processing capability. We also managed to develop an offline software function to convert the correlator output into FITS-IDI format. Furthermore, we obtained some experience in operating an ad hoc DiFX correlator and HOPS software.

1 Introduction

The Shanghai VLBI Correlator is hosted and operated by the Shanghai Astronomical Observatory, Chinese Academy of Sciences. It is dedicated to the data processing of the Chinese domestic VLBI observing programs, inclusive of the CMONOC project for monitoring the Chinese regional crustal movement, and the Chinese deep space exploration project for spacecraft tracking.

As shown in Figure 1, the VLBI stations near Shanghai, Kunming, and Urumqi participate in some domestic geodetic sessions on an annual basis, while the Beijing station is mainly used for spacecraft data downlink and VLBI tracking. In 2013, we began to process the VLBI data from the Shanghai 65-m antenna, namely the Tianma Radio Telescope. A few fringe tests with Chinese deep space stations Kashi and Jiamus were also performed.

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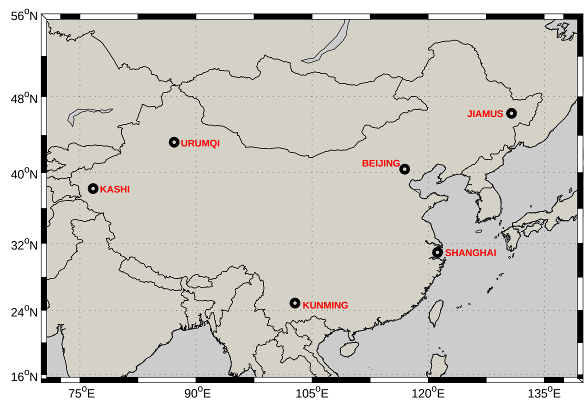

Fig. 1 Distribution of the VLBI stations in China.

2 Component Description

Based on the FX type VLBA correlator, we have been designing two correlators since 2003. One is the hardware correlator using the FPGA technology. The other one is the software correlator. The first version of our software correlator has been operational since 2006 and was installed on AMD Opteron 2200 CPU computers and later on Intel X5400 CPU computers. Because the software correlator was much easier to modify, we adopted the second version of the software correlator for geodetic applications. By using Message Passing Interface (MPI) and the POSIX threads APIs, the software correlator was migrated to a computer cluster based on blade servers to get better performance since 2010. It was formally accepted as an IVS correlator in March 2012.

In 2013, the Shanghai VLBI data processing center was moved to the Sheshan area, just a few kilometers from Tianma65 and Seshan25. A new hardware platform was installed at the new VLBI center. Features of the software correlator cluster are listed below.

- DELL M1000e Blade Server with 32 computing nodes
- Computing node configuration: a two-socket Intel E5-2640 CPU (2.5 GHz, six cores) with 24 GB of memory
- Five I/O nodes with 264 TB raw storage capacity
- Two redundant administration nodes with BCM cluster management software
- 40 G Infiniband for blade internal computing network connection
- 10 G Ethernet for blade internal and external data network connection

A summary of the capabilities of the software correlator is presented in Table 1.

3 Staff

The people involved in the development and operation of the Shanghai Correlator are listed below.

- Weimin Zheng: group head, software correlator development
- Xiuzhong Zhang: CDAS and other technique development
- Fengchun Shu: scheduler, experiment oversight, CDAS evaluation
- Zhong Chen: e-VLBI, cluster administration
- Weihua Wang: lead correlator operator, automatic correlation process development
- Juan Zhang: correlator software development and maintenance
- Yun Yu: operator, experiment support
- Wu Jiang: operator, experiment support
- Wenbin Wang: media library, computer services
- Renjie Zhu: CDAS development
- Zhijun Xu: FPGA programming, hardware correlator development
- Yajun Wu: FPGA programming
- Li Tong: postdoctor, correlator software development and maintenance

4 Summary of Activities

4.1 Correlator Software

In order to improve the accuracy of differential VLBI observations to the level of better than 0.1 ns, we have incorporated more corrections such as tidal station motion and gravitational delay in the correlator model. We compared the time series of geometric delays with those calculated by VieVS and DiFX-Calc. Our software results agree with DiFX-Calc at the level of 50 ps and agree with VieVS better than 15 ps.

Great effort was made to shorten the data latency for the navigation of spacecraft. For the navigation of the Chang'E-3 lunar mission, we have improved the realtime ability, and the total data turnaround time can be shorter than one minute.

We also managed to develop an offline software function to convert the correlator output into FITS-IDI format. Thus we can make a comparison of correlation results between our own correlator and DiFX in AIPS. The average fringe phase difference for a two-minute scan is about 0.1 degree.

4.2 Development of Hardware Correlator

We have built a new hardware correlator which has performed well for the Chang'E-3 lunar mission. The hardware correlator can perform real time correlation at 128 Mbps per station. It includes five FPGA boards. Each board has the same hardware, one Xilinx Virtex-4 FX60 and four LX160 FPGAs. A new hardware correlator based on Uniboard was also under design. It can perform real time correlation at 2 Gbps per station for a maximum of eight stations.

4.3 Performance of CDAS

The Chinese VLBI Data Acquisition System (CDAS) is a type of digital backend designed to replace the traditional analog BBCs. The new digital system has better bandpass and wider bandwidth. In order to demonstrate the capability of CDAS, we used 1 Gbps (16 x 32 MHz, 1bit sampling, S/X) recording mode and de-

Table 1 Correlator capabilities.

Number available	5 Mark 5B
Playback speed	1.8 Gbps
Input data formats	Mark 5B
Sampling	1 bit, 2 bits
IF channels	≤ 16
Bandwidth/channel	(2, 4, 6, 8, 32) MHz
Spectral points/channel	≤ 65536
Geometric model	supports plane wave front and curved wave front
online averaging time	0.1s$\sim$4s
Phase Cal extraction	yes
Output	CVN matrix format, FITS-IDI format, or NGS card file

tected 18 weak sources at the level of 0.1 Jy with the VLBI method for the first time.

In addition to the DDC version currently being used, we are also developing a PFB version of CDAS with much more compact design. It contains two Xilinx K7 FPGAs for data processing. The input signals are from two IFs with 512 MHz bandwidth each or one IF with 1024 MHz bandwidth. Comparing with the previous platform which consists of four Xilinx V4 FPGAs, the new one not only updated the key chips for DSP but also added two TenGiga Ethernet SFP+ ports for data transmission. For the application, the PFB version can be configured with 32 MHz bandwidth x 16 channels and 64 MHz bandwidth x 16 channels.

4.4 e-VLBI

The data link between the Shanghai VLBI center, Seshan25, and Tianma65 was upgraded to 10 Gbps. The data link to other stations is 155 Mbps for domestic e-VLBI observations. In the Chang'E-3 lunar mission, the data transfer performed well at 64 Mbps for each station.

4.5 DiFX Operation

We installed the DiFX 2.1 in an ad hoc 36 Intel X5650 (2.67 GHz) core cluster. With the help of the Bonn correlator and the GSFC group, we have obtained some experience in using DiFX, HOPS, and DBedit to generate FITS-IDI data and Mark IV database files.

4.6 Experiments Correlated

In 2013, four domestic geodetic VLBI experiments were carried out using 16 channels allocated at S/X band, three experiments recorded at a data rate of 256 Mbps, and one at 1024 Mbps with a 32 MHz bandwidth in each channel. After the Mark 5 modules were shipped to the Shanghai VLBI center, the data correlations were done by both the domestic correlator and the DiFX correlator. The output of the DiFX correlator was further processed with HOPS. Meanwhile, two milli-second pulsar astrometric observations with the Chinese VLBI network were successfully correlated with the DiFX correlator.

The differential VLBI observations continued to support the navigation of the Chang'E-3 spacecraft from the trans-lunar orbit to soft landing on the moon. The DOR (Differential One-way Range) signals transmitted from the spacecraft were received and processed. Data processing was performed largely in e-VLBI mode. The post-fit RMS delay residuals of orbit determination were as good as 0.5 ns.

5 Future Plans

We will continue to support the data correlation of Chinese domestic VLBI observations and make comparisons of correlation results between our own correlator and DiFX at different levels of data products. A hardware platform dedicated to DiFX correlation will be installed to meet the requirements of more astronomical VLBI experiments and VGOS technique development in China. We will also make some efforts to provide service for international VLBI experiments.