

NICT VLBI Analysis Center Report for 2015-2016

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Abstract VLBI Analysis activity of NICT is targeting for distant clock comparison with small diameter broadband stations. Broadband VLBI observation with the small stations and large diameter station have become available. Signal processing path has become available from VLBI observation, correlation processing, bandwidth synthesis, registration to Mk3DB, up to VLBI analysis with CALC/SOLVE. A series of broadband domestic VLBI sessions have been conducted in 2016. From these broadband data, we could show that broadband delay observable has sufficient precision even with small diameter stations. Further improvement of VLBI analysis will depend on how much we could reduce atmospheric excess delay uncertainty by observation strategy.

1 General Information

Space-Time Standards Laboratory (STSL) of National Institute of Information and Communications Technology (NICT) has been conducting broadband VLBI system development and observations with it. VLBI group is located at the Kashima Space Technology Center. Research subject of the VLBI group of NICT is application of VLBI technique for precision frequency comparison over intercontinental distance. Broadband VLBI system named GALA-V, which is compatible with VGOS specification[1], has been developed for this application. The VLBI observation scheme for

clock comparison is basically the same with that of standard geodetic VLBI session except for that session length is not limited to 24 hours, but it last as long as 48 - 62 hours or more. Since our VLBI analyses have been performed mainly for technology development, this report focuses on the analysis for geodesy and time and frequency transfer with the broadband VLBI system.

2 Component Description

VLBI application for frequency transfer is current mission of our project, and the clock parameters estimated by VLBI sessions are the products as the clock difference between two VLBI stations. The observation strategy of VLBI session for clock comparison is basically the same with standard VLBI session for geodesy. To get better separation of estimation parameters, observation is made for extragalactic radio sources with different directions on the sky by frequent switching. Broadband VLBI observation GALA-V[2] acquires 4 channels of 1 GHz bandwidth data. Cross correlation processing of the broadband VLBI data is made by GICO3[3] software correlator and results are stored to Mk3 database system through a data conversion with MK3TOOLS[4]. Then VLBI data analysis package CALC Ver.11.01 and SOLVE Ver.2014.02.21 developed by the NASA/GSFC has been used for this data analysis.

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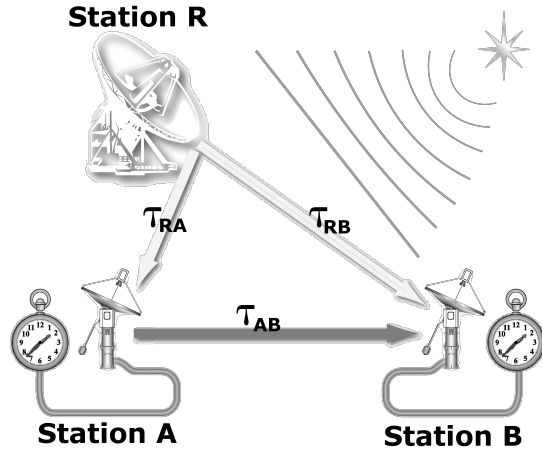


Fig. 1 The concept of the distant frequency comparison project GALA-V is composed of a pair of small-diameter antennas and a large-diameter antenna. Transportable small-diameter antennas are placed in laboratories, where the atomic frequency standards to be compared is located. Sensitivity of VLBI observation between a pair of small-diameter antennas is boosted by joint observation with large-diameter antennas.

3 Staff

Members who are contributing to the Analysis Center at the NICT are listed below (in alphabetical order):

- KONDO Tetsuro: Maintenance of correlation software K5VSSP and development of broadband bandwidth synthesis software.
- SEKIDO Mamoru: Coordinating of VLBI observation and making data analysis with CALC/SOLVE.
- TAKEFUJI Kazuhiro: Data processing of broadband data and development of broadband VLBI observation system.

4 Activities during the Past Year

4.1 Frequency Transfer by Means of VLBI

Space geodetic techniques such as GNSS have been proven to be a useful tool for time and frequency transfer purposes. VLBI is another space geodetic technique that can be utilized for frequency transfer. In contrast to GNSS, VLBI does not require any orbital information. It directly refers to an inertial reference frame defined by the location of the quasi-stellar objects. Free

from availability of communication satellite and from its transponder rental cost are another advantage of VLBI with respect to the two-way satellite time and frequency transfer (TWSTFT) technique.

The concept of our project (GALA-V) is displayed in Fig. 1. Transportable small-diameter antennas are placed in laboratories, where atomic frequency standards to be compared are located. Sufficient signal to noise ratio (SNR) is gained by joint observation with small and large-diameter antennas. By using closure relation of delay, VLBI delay for the pair of small diameter antennas are derived, and the delay data are stored in Mk3-database and analyzed.

The delay observable (τ_{AB}) between the small diameter antenna pair (AB) is computed by linear combination of those (τ_{RA} , τ_{RB}) of the small and large diameter baselines (RA, RB) as follows:

$$\begin{aligned} \tau_{AB}(t_{\text{prt}}) &= \tau_{RB}(t_{\text{prt}} - \tau_{RA}(t_{\text{prt}})) - \tau_{RA}(t_{\text{prt}} - \tau_{RA}(t_{\text{prt}})) \quad (1) \\ &\cong \tau_{RB}(t_{\text{prt}}) - \tau_{RA}(t_{\text{prt}}) - \frac{d}{dt} \tau_{AB}(t_{\text{prt}}) \times \tau_{RA}(t_{\text{prt}}), \end{aligned}$$

where t_{prt} is the reference epoch of the observation. Radio source structure affecting to the closure relation is subject to be investigated, and that is in the scope of our research.

One of the small-diameter antennas equipped with a broadband feed and high speed data acquisition system has been installed at the National Meteorology Institute of Japan (NMIJ) in Tsukuba since 2014. Another small antenna is located at NICT Headquarters in Koganei, Tokyo. Both NMIJ and NICT are the national institutes engaged in the development of atomic frequency standards and are keeping the time series of UTC(NMIJ) and UTC(NICT), respectively.

By development of original broadband feeds: IGUANA-H[6] and NINJA feed, two small antenna and Kashima 34m antenna were upgraded to enable broadband observation, and have been improved their sensitivity step by step. Broadband bandwidth synthesis software has been developed[7] to derive precise delay observable from four 1 GHz width data.

In 2016, four bands of 1 GHz width of data acquisition became ready at our three stations, and signal path from observation to data analysis has become available. A series of test VLBI sessions conducted in 2016 are listed in Table 1. Differently from standard VLBI sessions, session length is as long as 48 - 62 hours be-

Table 1 Broadband VLBI Experiments conducted in 2016. Abbreviation of station names are as follows: Kas34: Kashima 34m antenna, MBL1: MARBLE1 1.6m diameter antenna at NMIJ, MBL2: MARBLE2 2.4 m diameter station at NICT Koganei.

| Session Date | Stations | No.Scans (Used/Total) | Session Length |
|--------------|-----------------|--------------------------|-------------------|
| 26-27 Jan. | Kas34-MBL1-MBL2 | 1330/1500 | 46 hours |
| 12-13 Feb. | Kas34-MBL1-MBL2 | 1250/1600 | 47 hours |
| 28-29 Feb. | Kas34-MBL1-MBL2 | 1050/1450 | 49 hours |
| 16-17 May | Kas34-MBL1-MBL2 | 1220/1410 | 31 hours |
| 24-25 Jun. | Kas34-MBL1-MBL2 | 1800/1850 | 49 hours |
| 10-11 Jul. | Kas34-MBL1-MBL2 | 1960/2003 | 48 hours |
| 23-24 Aug. | Ish13-MBL1-MBL2 | 1372/1385 | 43 hours |
| 12-13 Sep. | Ish13-MBL1-MBL2 | 1600/1640 | 35 hours |
| 25-28 Nov. | Kas34-MBL1-MBL2 | 2193/2237 | 62 hours |
| 09-12 Dec. | Kas34-MBL1-MBL2 | 2022/2063 | 62 hours |

cause of project target is monitoring of clock difference.

Post-fit residual and histogram of the residuals of VLBI session at 25-28th Nov. are displayed in Fig. 2. Residual plot in the panel (a) was made by analysis of A(NMIJ)-B(NICT) baseline, whose delay data were derived by equation (1) from delay data of R(Kashima34)-A and R-B baseline. Weighted RMS of the residual was 14.2 pico sec. in this case. Fig. 2 (b) shows the histograms of residuals for AB baseline and those of RA, RB baselines. Since delay observable of AB baseline is computed by linear combination of delay observable for RA and RB, thus error of delay observable is root-sum-square of that of RA and RB baseline by error propagation law. However, the histogram plot show the error residual distribution of AB baseline data does not extend with respect to those of RA and RB baselines. This suggesting that the broadband delay observable is sufficiently precise and residual as indicator of error of analysis is dominated by other cause, which is thought to be uncertainty of atmospheric delay.

We suppose that measurement data of clock difference is estimated clock parameter plus residual of VLBI analysis. The clock difference between UTC(NMIJ)-UTC(NICT) obtained by VLBI session of 25th - 28th Nov. is plotted in Fig. 3 (a). Clock difference measured by GPS observation provided from BIPM is over plotted. Absolute difference between clocks is difficult to measure for VLBI, then offset of vertical position of VLBI data in Fig. 3 (a) is adjusted to be appropriate for comparison with GPS data. Allan

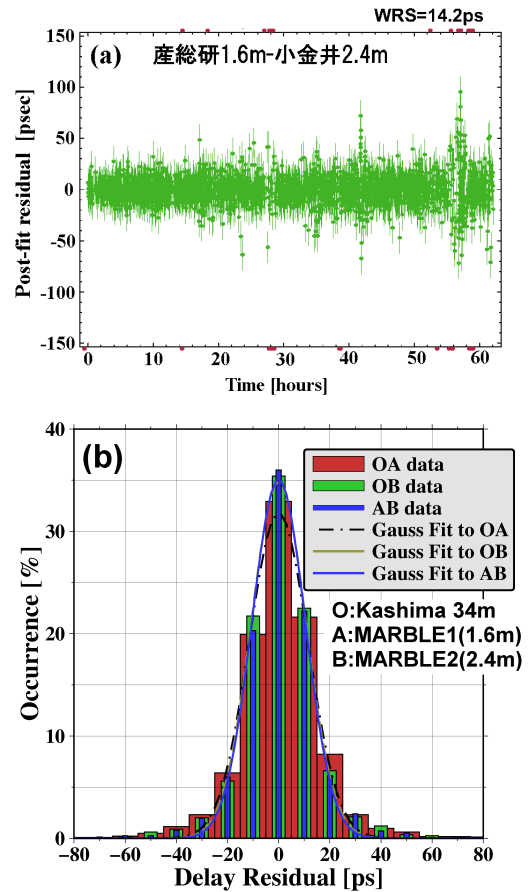


Fig. 2 (a) Post-fit residual of VLBI session of 25-28 Nov. for the NICT-NMIJ baseline. (b) Histograms of the distribution of residuals are over plotted for AB baseline and RA, RB baseline.

standard deviation computed from each of them and difference of the them are displayed in panel (b). Since true clock difference is not known, we cannot say which technique has better performance from the data. Though it is proven that VLBI observation between small diameter antenna pair works for clock comparison with performance no worse than GPS.

4.2 Other activities

Space Geodesy Software Package C5++ : The analysis software package for Space Geodesy (SLR, VLBI, and GNSS) “C5++” [5], has been conducted under multi-organization collaborations. NICT is

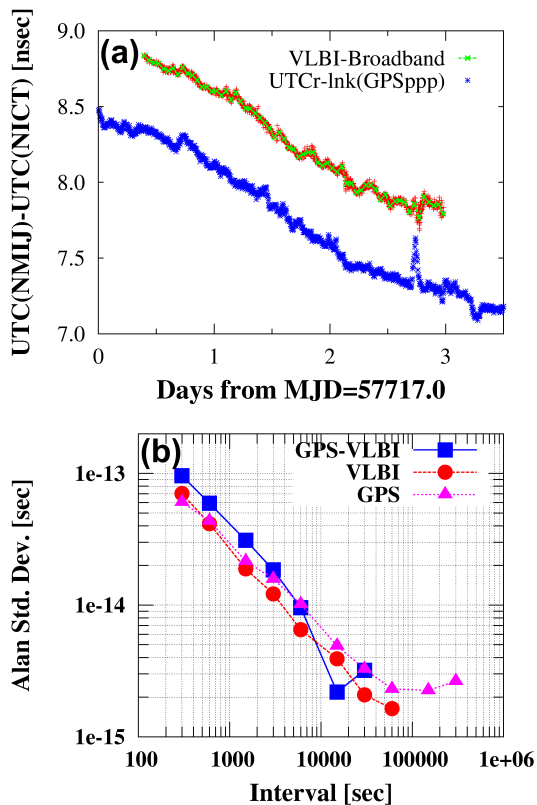


Fig. 3 The clock difference between NICT and NMIJ compared by VLBI('x') and GPS('*') observations are plotted in panel (a). Allan standard deviation of each time series and difference of them are plotted in panel (b).

taking a part of development and maintenance of the software.

MK3TOOLS: Software package MK3TOOLS, which is platform independent VLBI data base format with NetCDF, was originally developed by T. Hobiger during his stay at NICT. Currently T. Hobiger at Chalmers Univ. of Tech. of Sweden and M. Sekido of NICT are jointly maintaining the package.

5 Future Plans

We are going to continue broadband VLBI session in domestic baselines. After we could confirm the performance and stability of the system, we are willing to export one of the small VLBI station to foreign insti-

tute to test and evaluate the performance of GALA-V system for distant clock comparison.

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