NICT Technology Development Center 2019+2020 Biennial Report

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Abstract The National Institute of Information and Communications Technology (NICT) is developing and testing VLBI technologies and conducts observations with this new equipment. This report gives an overview of the Technology Development Center (TDC) at NICT and summarizes recent activities.

1 NICT as IVS-TDC and Staff Members

The Communications Research Laboratory (CRL), which is former name of current National Institute of Information and Communications Technology (NICT), was designated as IERS VLBI Technology Development Center (TDC) from the International Earth Rotation Service (IERS) in 1990. Since then, we have been continuously engaged in VLBI technology development over 30 years including the transition of designation name from IERS-TDC to IVS-TDC in 1999. As one of the activities of the IVS-TDC, we publish the newsletter "IVS NICT-TDC News (former IVS CRL-TDC News)" at least once a year in order to inform about various VLBI related technology development in Japan. The series of newsletters are available at a following URL https://www2.nict.go.jp/sts/stmg/ivstdc/news-index.html. Table 1 shows the list of staff members contributing to this component.

1. Kashima Space Technology Center, National Institute of Information and Communications Technology
2. Usuda Deep Space Center, Japan Aerospace Exploration Agency

Table 1 Staff Members of NICT TDC as of January, 2019 (alphabetical).

HASEGAWA, Shingo	KAWAI, Eiji
KONDO, Tetsuro	MIYAUCHI, Yuka
SEKIDO, Mamoru	TAKEFUJI, Kazuhiro
TSUTSUMI, Masanori	UJIHARA, Hideki

2 General Information

The main topic of the 2019-2020 period is an intercontinental VLBI experiment for the precise frequency comparison between Italy and Japan. The scientific result is reported by Pizzocaro et al. [1] and its analysis was reported by Sekido et al. [2]. Here we focus on a technical side about the experiments.

3 VLBI between Japan and Italy

We have carried out a series of geodetic VLBI experiments in 2018-2019 on approximately 9000 km baseline between 2.4 m diameter radio telescopes installed in Medicina, Bologna, Italy and in Koganei, Tokyo by using a 34 m diameter radio telescope in Kashima as a reference station. We installed vertical polarization receivers at two 2.4 m diameter telescopes and vertical and horizontal polarization receivers to the Kashima 34-meter telescope. Four 1 GHz frequency bands specified within the total receiving range of 3.2 GHz to 14.4 GHz were simultaneously extracted, then we observed 21-25 quasars repeatedly for about 30 hours in a single session. After the observation, linear polarization correction considering the parallactic angle and dispersive delay correction due to the ionospheric effect were applied. As the results, we have successfully performed the bandwidth synthesis over the frequency range of 9.0 GHz from 4.8 GHz to 13.8 GHz with the effective bandwidth of 3.1 GHz.

4 The candidate radio sources

Correlated fluxes of most quasars are weak due to the 9000 km long baseline between Japan and Italy. In a first test experiment, we chose good candidates from the radio catalogue of the Astro-geocenter[1]. We picked up the 115 radio sources, which have over 1.0 Jy of the total flux, from -10 deg to 90 deg declination, the 35 % from the top in terms of total flux. In the series of frequency transfer sessions, about 27 sources are selected from ICRF sources by considering detected correlated flux in the observations.

5 Data transfer and Correlation

Single session of the frequency comparison experiment lasted about 30 hours, and the amount of data volume of 3 stations was 240 TB (60TB for the single polarization). We transferred these data from Medicina to Kashima via UDT/IP protocol with jive5ab[2] at average data rate at 5 Gbps. Then, correlation processing was performed by software correlator GICO3 as soon as the transfer finished. It took about 1 week for processing all the scans of single session. We routinely performed such sessions about 20 times.

6 Polarization synthesis after the correlation

The large parallactic angle difference between Japan and Italy causes misalignment of linear polarization angle, consequently it leads to degradation of signal to noise ratio (SNR). We need synthesize two polarization outputs to compensate the loss of SNR. The pseudo-Stokes-I observables is given by following form[5]:

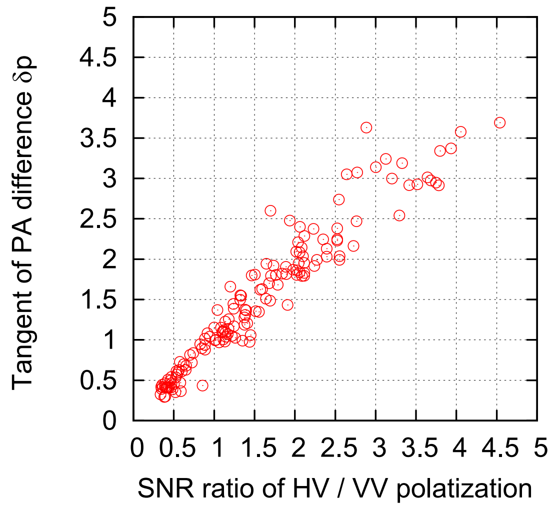

Fig. 1 A comparison of SNR ratio of the polarization pair of Kashima 34 m and Medicina 2.4m radio telescope and their tangent of parallactic angles difference in a session.

$$I = \left(\overline{H_a \star H_b} + \overline{V_a \star V_b}\right)\cos(\delta p) + \left(\overline{H_a \star V_b} - \overline{V_a \star H_b}\right)\sin(\delta p).$$

Here, V and H indicate linear polarization with their suffixes correspond to station (a,b). δp is difference of parallactic angle between two stations. Since the compact radio telescopes installed in Medicina has single vertical polarization receiver, data of H_b is not available. Hence, we used the half of pseudo-Stokes-I obtained with synthesizing two polarization cross products by following form:

$$I/2 = \left(\overline{V_a \star V_b}\right)\cos(\delta p) + \left(\overline{H_a \star V_b}\right)\sin(\delta p).$$

Figure 1 shows a plot of tangent of parallactic angles between Kashima 34 m and Medicina 2.4m radio telescope versus SNR ratio of two polarization pairs in a session. The plot clearly indicates linear slope, and it gives a good validation of the polarization synthesis. Moreover one more process was required before the polarization synthesis. Signal paths for two polarizations (V and H) of Kashima 34 m are slightly different. Thus, their correlation results involving the different delay had to be corrected. Figure 2 and figure 3 show the comparison of group and phase delay between $\overline{V_a \star V_b}$ and $\overline{H_a \star V_b}$. Firstly the group-delay was

[1] http://astrogeo.org/vlbi/solutions/

[2] https://github.com/jive-vlbi/jive5ab

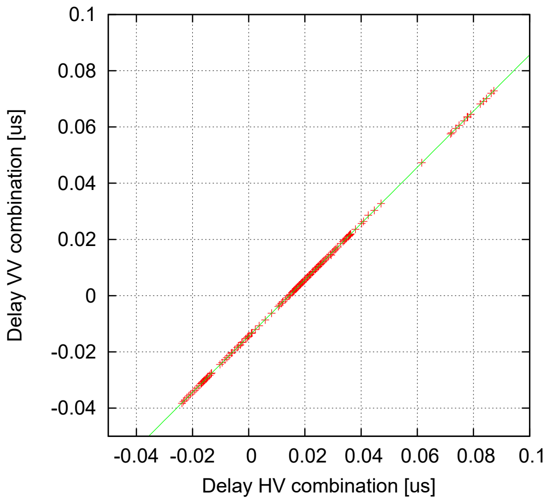

Fig. 2 A comparison of group delay of the polarization pair of Kashima 34 m and Medicina 2.4m radio telescope.

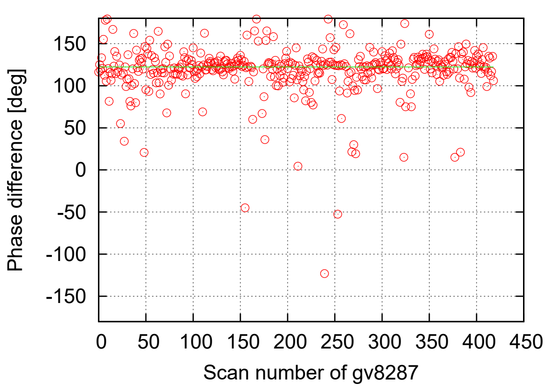

Fig. 3 Difference of phase delay between two sorts of the polarization pairs for Kashima 34 m and Medicina 2.4m baseline. The phase offset is empirically determined within 1 degree.

corrected, then the phase-delay (or phase offset) had to be corrected. These processes were performed for all four 1 GHz bands correlation outputs to recover the efficiency. The phase offset was determined within 1.0 degree. Figure 4 shows an example of improvement of fringe amplitudes by this polarization synthesis procedure. Thanks for the direct sampling system, no delay changes did happen during the series of observations. Once the delay difference between $\overline{V_a \star V_b}$ and $\overline{H_a \star V_b}$ were determined, then it could be used for a few months (We have not evaluated how long it can keep the same state.) and it was really helpful for our precise frequency comparison.

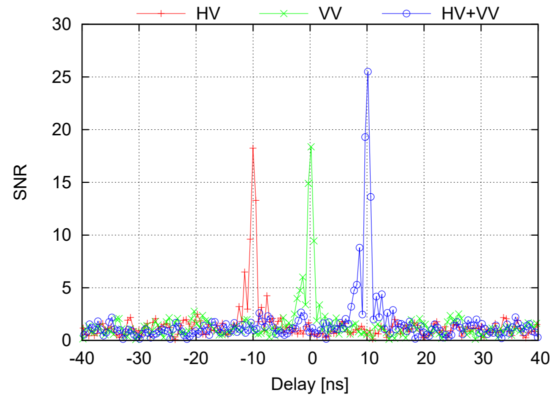

Fig. 4 An example fringe amplitude plots before and after the polarization synthesis for Medicina 2.4m and Kashima 34 m baseline. The SNRs are improved from 18.3 and 18.7 for HV and VV to 25.7 of HV+VV after the polarization synthesis.

7 Wideband Bandwidth Synthesis with a TEC searching

An algorithm using the least-squares estimation based on a phase model was developed for determining TEC in the wide-band bandwidth synthesis (WBWS) processing [3]. The algorithm works well. However, it was difficult to apply this algorithm for data of which SNR lower than 10. In order to improve a TEC estimation at lower SNRs, we developed a TEC search-function method in addition to the least-squares (LSQ) estimation method [4]. One sigma error when compared with GNSS was about 3 TECU on the Kashima-Medicina baseline (about 8700 km) (Fig. 5).

We have two strategies for TEC searching. One is above mentioned the LSQ search, and second is an iterative peak TEC search with applying several TEC values[5]. Even 1.0 TEC difference causes group delays deviation large as 17.2 ps ([2]). Thus, it is really important to pay attention to the TEC search.

Figure .6 shows the result of the iteratively searched TEC value on quasar 0133+476 in 110 sec integration on the Medicina-Kashima baseline. In the first step, we roughly apply TEC values from -50 to +50. Then, final peak value is determined around the tentative peak value by 2nd order polynomial fit (parabola fit). Figure 7 shows a nice fringe plot after wideband bandwidth synthesis obtained with this procedure.

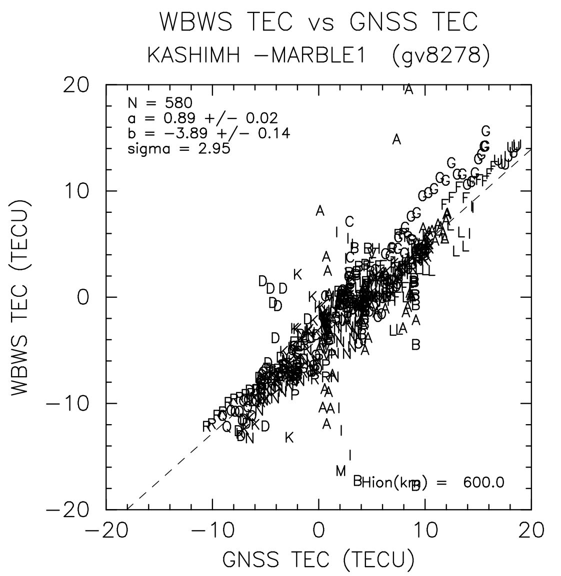

Fig. 5 A comparison of TECs (WBWS TEC) obtained by a TEC search function method and those (GNSS TEC) obtained from a TEC global map.

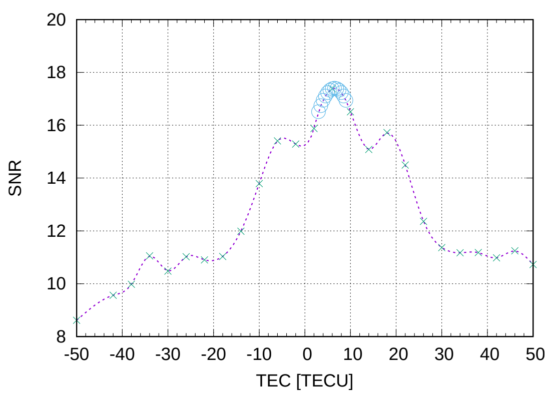

Fig. 6 Iteratively search TEC peak on quasar 1144+402 in 60 sec integration on the baseline of Medicina and Kashima.

8 Future of the geodetic VLBI

Since the aperture area of our compact telescopes is so small, the intercontinental baseline observations with Kashima 34 m telescope were initially pessimistic. However, even such small telescope could obtain nice results. Therefore, this approach may be a sustainable way for keeping on developing the large radio telescopes. If other large and highly sensitive telescopes join the observation, it greatly improves not only the number of scans of single session, but also the more

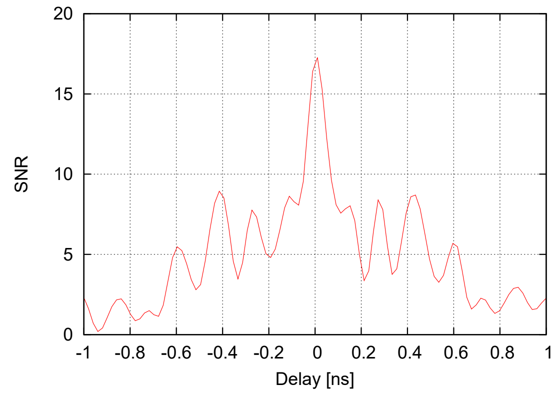

Fig. 7 A fringe plot of same radio source as figure. 6.

precise measurement can be expected on ionospheric TEC, consequently it leads to accurate results on long distance frequency comparison and geodesy. We believe this approach might become an option for the future of the geodetic VLBI.

References

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