# Precise Frequency Transfer Experiments using VLBI and other Techniques

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## Abstract

We carried out inter-comparison experiments between VLBI, GPS, TWSTFT and DMTD in order to demonstrate that VLBI can measure the correct time difference between Koganei and Kashima, Japan (about 109 km) on August and October of 2010. The frequency stability of VLBI reached up to $5\times10^{-14}$ at an averaging time of several hundreds seconds and the value surpassed the frequency stability of GPS. In the experiments, we also evaluated the accuracy of each technique by inserting an artificial delay change into the path of the reference signal cable using a coaxial phase shifter. The results reveal that the artificial delay changes measured by VLBI and DMTD show good agreement (within 10 picoseconds). In general the VLBI results match the DMTD results better than GPS does. From these experiments, we confirmed the capability of the geodetic VLBI technique for time transfer application.

## 1 Introduction

We proposed Very Long Baseline Interferometry (VLBI) technique as a new frequency transfer technique which enables the comparison of highly stable frequency standards. In our first feasibility studiy [1,2] it could be demonstrated that the frequency stability of $2 \times 10^{-11}$ at an averaging time of 1 sec is reached using VLBI data sets from the International VLBI Service for Geodesy and Astrometry (IVS). The stability is consistent with that from GPS carrier phase frequency transfer. This suggests that geodetic VLBI has the potential of precise frequency transfer.

The National Institute of Information and Communications Technology (NICT) has several T&F transfer techniques beside VLBI such as GPS and TWSTFT (Two-Way Satellite Time and Frequency Transfer). Based on the previous result, we carried out inter-comparison experiments between VLBI, GPS, TWSTFT and DMTD (Dual Mixer Time Difference) on the local Kashima 34m - Kashima 11m baseline in order to evaluate the actual performance of our VLBI equipment for precise frequency transfer.

## 2 Facilities and experiments

We operate three VLBI stations, i.e. a 11 m antenna station at NICT Koganei (headquarter), a similar one at Kashima (KSRC/Kashima Space Research Center), and a 34 m antenna station at Kashima. We carried out inter-comparison experiments one the Koganei 11 m– Kashima 11 m baseline (about 109 km) on August and October of 2010. Before the experiments, we prepared state-of-the-art equipment such as a wide-band analog digital sampler, a processing software for high speed correlation, and a coherent frequency transfer system to deliver UTC(NICT) by using optical fibers. The stability of the latter system reached $10^{-16}$ over 1000 seconds. In addition, we equipped a thermally regulated rack to keep the temperature stable for the data acquisition system.

We installed a TWSTFT antenna next to the each VLBI site and we also installed a Time Comparison Equipment (TCE) ground station for the satellite ETS-VIII (Engineering Test Satellite VIII) at Koganei

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and Kashima. A geodetic GPS station has been operated at each site since 1999. These facilities are shown in Figure 1.


Figure 1: NICT facilities for precise time transfer at Kashima Space Research Center, NICT, Japan.
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The experiment also included a proof-of-concept test which measures the capability to determine clock differences, whereby the length of a reference signal transmission cable was artificially changed by using a coaxial phase shifter (hereafter trombone)[3]. Such an instrument can introduce delays in the electrical signal path when propagating through the coaxial cable. The maximum time change at a frequency of 10 MHz could be set to 333.7 picoseconds.

## 3 Results

Figure 2 shows the time difference between Koganei and Kashima obtained from VLBI, GPS, TWSTFT and TCE/ETS-VIII. Linear and second order trends were already subtracted from the time series prior to the comparison. The time difference from the TCE/ETS-VIII is most stable. It suggests that the satellite-onboard atomic clock on the ETS-VIII has a good performance. The time series from VLBI and that from GPS agree well in both amplitude and phase throughout the experiment period. Since these temporal variations are almost identical to that of zenith path delays caused by water vapor changes, it implies that the variation is caused by atmosphere changes. The frequency stability from each technique is shown in Figure 3. The frequency stability of VLBI reaches up to $5 \times 10^{-14}$ at an averaging time of several hundreds seconds and surpasses the frequency stability of GPS. As for the artificial delay change experiments, VLBI and DMTD show good agreement. The root mean square of time differences is less than 10 picoseconds.

## 4 Summary and outlook

We performed inter-comparison experiments of time transfer using four techniques such as VLBI, GPS, TWSTFT and DMTD between Koganei and Kashima, Japan (about 109 km) on August and October of 2010. We also performed an experiment by inserting an artificial delay into the path of the reference signal from the Hydrogen maser to the Kashima 11m antenna. Both experiments demonstrate that VLBI time transfer surpassed the one obtained from GPS.

We are now developing a compact and transportable VLBI system with 1.6 m diameter aperture dish to certificate the length of the geodetic reference baseline, based on a collaboration between Geospatial

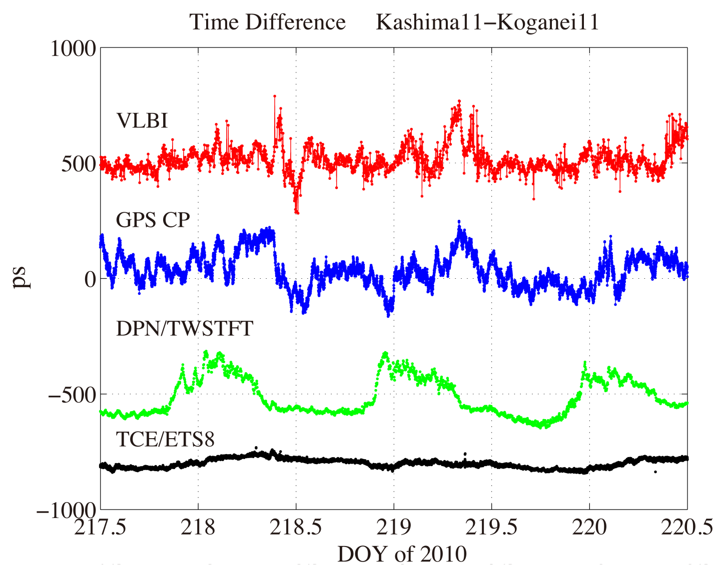


Figure 2: Time difference between Koganei and Kashima obtained from VLBI(red), GPS(blue), TWSTFT(green) and ETS-VIII/TCE(black).

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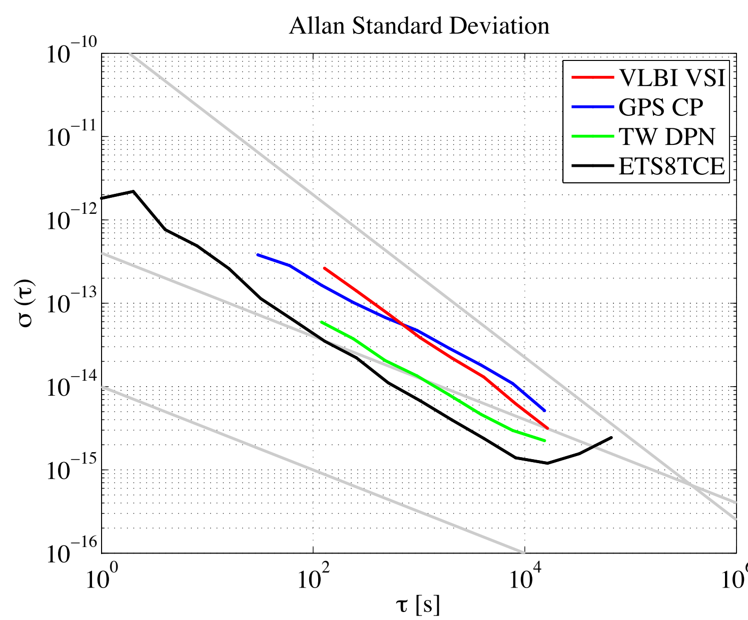


Figure 3: The frequency stability obtained from VLBI(red), GPS(blue), TWSTFT(green) and ETS-VIII/TCE(black).

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Information Authority of Japan (GSI) and NICT (see Figure 4)[4]. The compact VLBI system is easy transportable and its monument pillar is designed to install typical geodetic GNSS antennas easily and an offset between a GNSS antenna reference point and a location of the azimuth-elevation crossing point of the VLBI system is precisely collocated within less than 0.2 mm uncertainty. We named this system "Multiple Antenna Radio-interferometer for Baseline Length Evaluation (MARBLE)". Additionally to the MARBLE system a new analysis technique has been included. Since the compact VLBI system is not sensitive enough to detect fringes between these two compact dishes, we have designed a new observation concept including one large antenna which shares baselines with the smaller antennas. Thus we can detect two group delays between each compact VLBI system and the large dish station like a conventional VLBI measurement. Thereafter the group delay between the two compact dishes can be indirectly calculated using a simple equation. We expect that the MARBLE system will enable us to perform global VLBI T&F transfer with high speed networks.

Figure 4: The MARBLE compact VLBI system with 1.6 m dish at Kashima (left) and Tsukuba (right).

## 5 References


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