# VLBI Measurements for Frequency Transfer

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*Abstract*: We carried out the intercomparison experiment between VLBI and GPS to show that VLBI can measure the correct time difference. We produced an artificial delay change by stretching the Coaxial Phase Shifter which was inserted in the path of the reference signal from Hydrogen maser to the Kashima 11m antenna. Concerning the artificial changes, VLBI and the nominal value of Coaxial Phase Shifter show good agreement, i. e. less than 10ps. Thus it is concluded that the geodetic VLBI technique can measure the time differences correctly.

## 1. Introduction

As one of the new frequency transfer technique to compare the next highly stable frequency standards, we proposed the geodetic VLBI technique [1], [2]. Previously, we evaluated the ability of VLBI frequency transfer by comparison with GPS carrier phase frequency transfer at Onsala-Wettzell baseline using data from the International VLBI Service for Geodesy and Astrometry (IVS) and the International GNSS Service (IGS). We achieved a frequency stability of $2 \times 10^{-11}$ at an averaging time of 1 sec following a $1/\tau$ trend. Over the averaging time of 1000 sec, it surpassed the frequency stability of a typical atomic fountain. These results showed that geodetic VLBI technique has the potential for precise frequency transfer [3], [4], [5], [6].

Furthermore, to show the capability of VLBI, we carried out the intercomparison experiments between VLBI and GPS at Kashima 34m - Kashima 11m baseline. In this paper, we describe the comparison with VLBI and GPS carrier phase for that experiment.

## 2. The intercomparison between VLBI and GPS carrier phase

### 2.1 Outline of the experiment

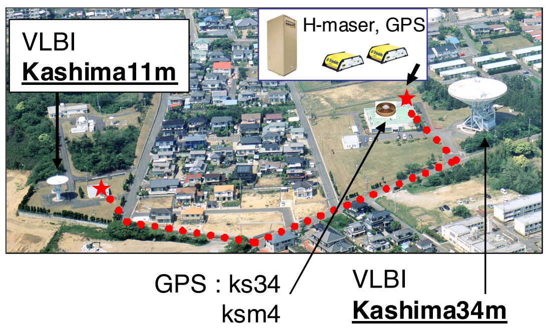


*Figure 1. The experimental setup at Kashima station. The baseline length of Kashima 34m - Kashima 11m is about 239m.*


*Figure 2. The Coaxial Phase Shifter (trombone type) which was made by NIHON KOUSHUHA Co., Ltd. The maximum time change at frequency of 10MHz is 333.7ps.*

Figure 1 shows the experimental setup at Kashima station. The baseline length of Kashima

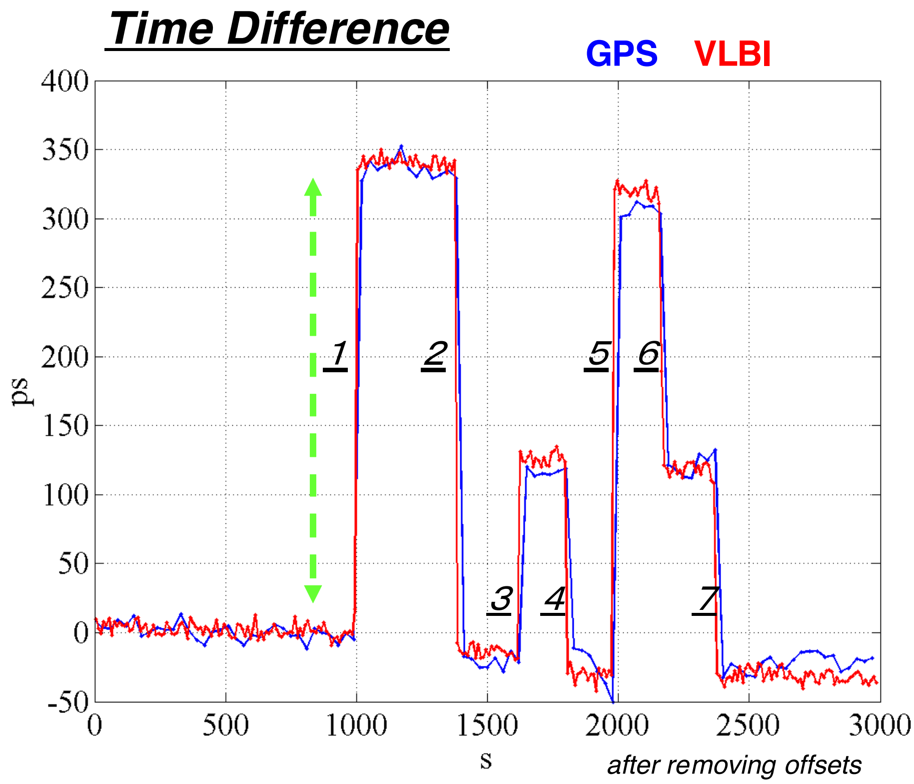


*Figure 3. Time difference calculated from VLBI and GPS. The large steps were artificial delay change parts by trombone.*

34m - Kashima 11m is about 239m. To produce the artificial delay change, we inserted the Coaxial Phase Shifter (hereafter trombone) (Figure 2) in the signal path of the reference signal from the Hydrogen maser to the Kashima 11m antenna (Figure 4). The trombone can introduce delays in the electrical signal when propagating through the coaxial cable. Thereby, the maximum time change at frequency of 10MHz is 333.7ps.

The outline of the experiment is described in Table 1. We carried out this experiment with a special strategy. Usually, geodetic VLBI observe multiple sources that uniformly cover the sky. And usually clock, atmosphere and station coordinates are estimated with in analysis. However in this experiment, we observed only one source (3C84), and we estimated only clock parameters. We used CALC/SOLVE and Natural Resources Canada's PPP to analyze VLBI and GPS respectively. The details of the data analysis of VLBI and GPS are described in [2].

### 2.2 Results

Figure 3 shows the time difference calculated from VLBI and GPS. The large steps were arti-

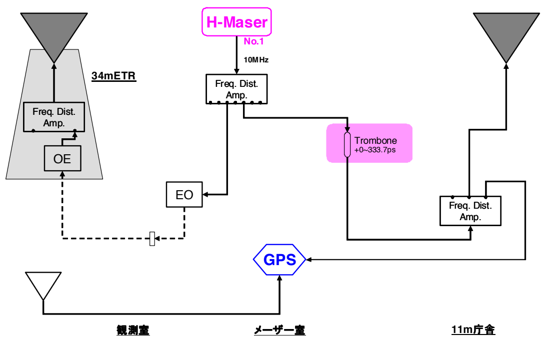


*Figure 4. The reference signal setup diagram at Kashima station.*

*Table 1. Difference with the normal geodetic observation*

| | |
|---|---|
| **Normal Geodetic VLBI** | |
| Observation | multiple sources |
| | antenna slew time |
| | different scan time |
| | 24 hours |
| Data Analysis | estimate |
| | clock parameter |
| | atmosperic delay |
| | station coordinates |
| **This study** | |
| Observation | one source : 3C84 |
| | no antenna slew time |
| | same scan time |
| | a few hours |
| Data Analysis | estimate only clock parameter |
| | station coordinates : |
| | fixed to a-priori coordinates |

ficial delay changes introduced by the trombone. Large differences are not seen when comparing in the results between VLBI and GPS.

Table 2 summarizes the differences between nominal value and VLBI, GPS at the artificial delay changes. According to this table, VLBI yields result slightly close to the nominal value than GPS. The results of VLBI and the nominal value of Coaxial Phase Shifter show good agreement, less than 10ps. Anyway, the result of our experiment clearly show that the geodetic VLBI technique can measure the correct time difference.

As already mentioned, this experiment observed only one source continuously. So, we obtained the time difference every 10 seconds from VLBI. Figure 5 shows the frequency stability of VLBI that was calculated from that time difference. The frequency stability reached about the $1 \times 10^{-11}$ at an averaging time of 1 sec which has an $1/\tau$ trend as in our past research. Also at the averaging time of 500 sec, it surpassed the frequency stability of typical atomic fountain. This averaging time is shorter than our past research.

## 3. Summary and Outlook

We carried out the intercomparison experiment between VLBI and GPS in order to show that VLBI can measure the correct time difference. We produced artificial delay changes by stretching the trombone which was inserted in the path of the reference signal from Hydrogen maser to Kashima 11m antenna. At the artificial changes, VLBI and the nominal value of trombone show good agreement, less than 10ps. Consequently, the geodetic VLBI technique can measure the correct time difference.

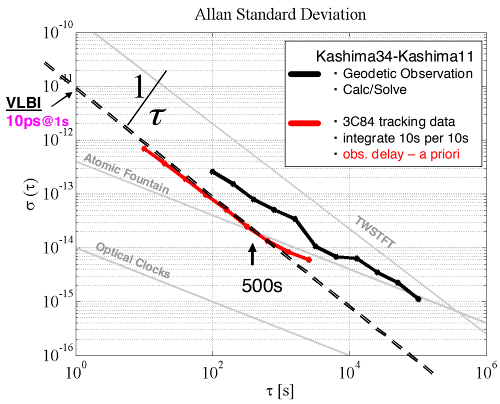


*Figure 5. The frequency stability of VLBI that was calculated from the time difference every 10 seconds.*

*Table 2. The summary of the difference between nominal value and VLBI, GPS at the artificial delay change parts.*

| | Nominal Value | Nominal-GPS | Nominal-VLBI |
|---|---|---|---|
| 1 | 333.7 | 3.6 | 2.8 |
| 2 | 333.7 | 16.5 | 15.2 |
| 3 | 147.2 | 12.8 | 0.0 |
| 4 | 147.2 | 17.0 | 4.6 |
| 5 | 333.7 | 11.6 | 19.5 |
| 6 | 186.7 | 0.6 | 9.8 |
| 7 | 147.0 | 9.2 | 7.3 |
| | mean | 10.2 | 8.5 |
| | | | ps |

NICT has several T&F transfer techniques (Figure 6) other than VLBI such as using GPS and telecommunication satellites at NICT Koganei Headquaters. We set up the TWSTFT (Two-Way Satellite Time and Frequency Transfer) antenna and the Time Comparison Equipment (TCE) ground station of the satellite ETS-VIII (Engineering Test Satellite -VIII) at NICT Kashima Space Research Center (KSRC). KSRC has GPS and VLBI sites. We finished the preparations for exact intercomparison between VLBI and other techniques on the Kashima-Koganei baseline. In the near future, we are going to carry out these intercomparison experiments.

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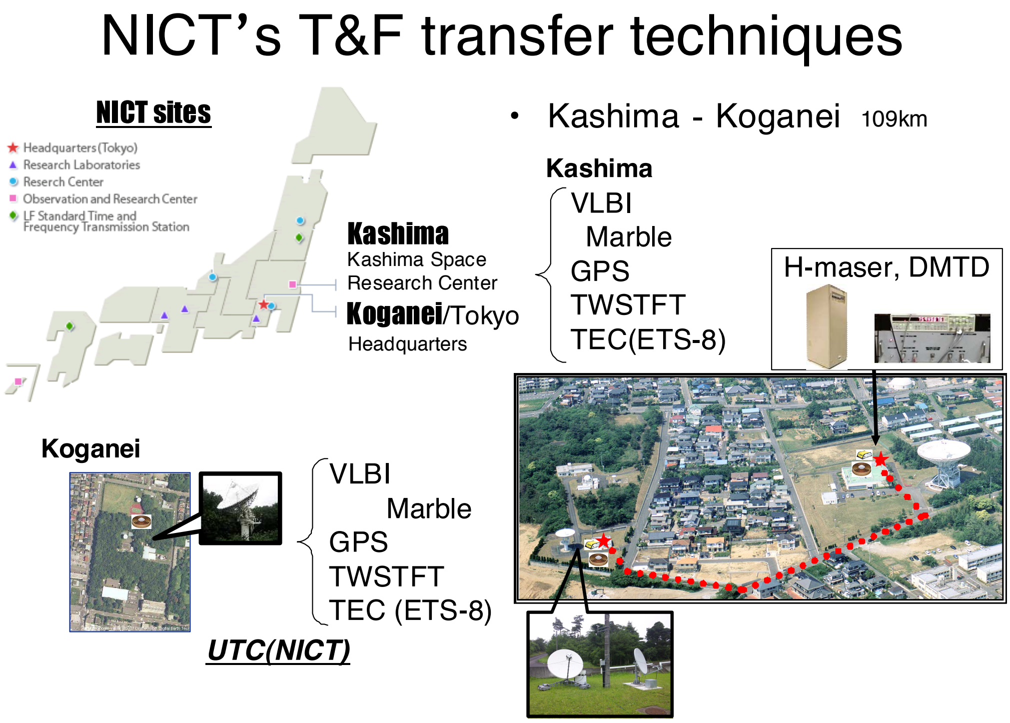


*Figure 6. The list and disposition of NICT's T&F transfer techniques.*

ity products. We are grateful that GSFC and NR Canada provided the VLBI and GPS analysis software (CALC/SOLVE and NRCan's PPP). The VLBI experiments were supported by M. Sekido and E. Kawai of the Kashima Space Research Center.

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