Comparison Study of VLBI and GPS Carrier Phase Frequency Transfer - Part II -

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Abstract: To show the frequency stability of local baseline, we carried out long term VLBI experiment together with GPS and DMTD measurement. And, we compared the results provided from these three techniques. The results are strongly correlated at long term period. The frequency stability of VLBI is surpassing the stability of atomic fountain at \(10^5\) seconds or longer.

1. Introduction

In several institutes including NICT (National Institute of Information and Communications Technology) push forward to develop the atomic fountain frequency standards and the optical frequency standards. The atomic fountain frequency standards have already achieved the uncertainty of \(1.9 \times 10^{-15}\) [5]. And optical frequency standards are aiming to achieve the uncertainty on a \(10^{-16}\) to \(10^{-17}\) level [6]. In order to compare such precise standards by the current time transfer techniques like two-way satellite time and frequency transfer (TWSTFT) or GPS carrier phase, it is necessary to average over long periods. Since these techniques are not sufficient to compare next standards improvements of high precision time transfer techniques are strongly desired.

Recent years, we are suggesting the geodetic VLBI technique as a one of the new time and frequency transfer technique [4], [7]. To show superiority of the VLBI, we are evaluating the ability of VLBI frequency transfer by comparison with GPS carrier phase frequency transfer at the Kashima-Koganei baseline. Results showed VLBI is more stable than GPS. Also, we compared VLBI and GPS using data from the International VLBI Service for Geodesy and Astrometry (IVS) and the International GNSS Service (IGS) for the same purpose. The results of the VLBI frequency transfer show that the stability follows a \(1/\tau\) law very closely and it’s surpassing the stability of atomic fountain at \(10^3\) seconds or longer. And that shows the stability has reached about \(2 \times 10^{-11}\) (20ps) at 1 sec. These results show that geodetic VLBI technique has the potential for precise frequency transfer [8], [9].

Figure 1. The frequency stability of VLBI. Large dot is Onsala-Wettzell baseline. Dot is Kashima34-Koganei baseline. Also, it shows the normal frequency stability of TWSTFT, atomic fountain and optical clocks.

Figure 1 shows the frequency stability of International baseline (Onsala-Wettzell) and local baseline (Kashima34-Koganei). As described before, we could showed the international baseline was surpassing the stability of atomic fountain at \(10^3\) seconds or longer. However we can’t show about that at local baseline yet. So we performed long term (over a week) VLBI experiment at Kashima34-Kashima11 baseline, to show the long term frequency stability.

In this paper, we describe the comparison with VLBI and GPS carrier phase about that experiment. Also, we performed frequency transfer by the dual mixer time difference (DMTD) [2]. We also describe that result.
2. The intercomparison between VLBI, GPS carrier phase and DMTD

2.1 Outline of the experiment

Figure 2 is the layout map of Kashima station. The baseline length of Kashima34m-Kashima11m is about 239m. The outline of the experiment are described to Table 1.

Table 1. Outline of this experiment.

<table>
<thead>
<tr>
<th>VLBI</th>
<th>KASHIM34, KASHIM11</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS</td>
<td>ks34, ksmv</td>
</tr>
<tr>
<td>DMTD</td>
<td>1ch: to 34m ETR and back, 2ch: to KSP room and back</td>
</tr>
<tr>
<td>duration</td>
<td>12days (from 01 to 12 Aug)</td>
</tr>
</tbody>
</table>

Figure 3 is the reference signal setup diagram at Kashima station.

Figure 4 shows the time difference calculated from three techniques (VLBI, GPS and DMTD).

Figure 5 is the variations of temperature at Kashima 11m antenna observation room and outside.

2.2 Results

Figure 4 shows the time difference calculated from three techniques (VLBI, GPS and DMTD). Figure 5 is the variations of temperature at Kashima 11m antenna observation room and outside. It is clearly visible that the variations of time difference and temperature are strongly correlated (The time difference and temperature are inverse correlation). At 3rd August (day of year 216), we changed the definition temperature of air conditioner of Kashima 11m antenna observation room. We couldn’t turned off the air conditioner, because of summer season at that time. So, the influences of room temperature change still remained of the time differences.

Table 2. The details of estimated parameters.

<table>
<thead>
<tr>
<th>symbole</th>
<th>estimated parameter ( per minutes)</th>
</tr>
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<tbody>
<tr>
<td>*</td>
<td>180</td>
</tr>
<tr>
<td>×</td>
<td>10</td>
</tr>
<tr>
<td>◇</td>
<td>30</td>
</tr>
<tr>
<td>+</td>
<td>10</td>
</tr>
</tbody>
</table>
As for the result of the VLBI, the variation of around several days agree with a result of DMTD well. However it doesn’t agree with DMTD, when the variation is beyond 500 ps in several hours (day of year from 214 to 216). Contrastively, as for the result of the GPS, the variation of several hours agree with a result of DMTD well. However due to the code noise, the clock offsets of the GPS solutions show discontinuities at the day-boundaries. It seems that the reason why the result of VLBI doesn’t agree with DMTD when the variation of DMTD is beyond 500ps at the short period are analysis strategy and schedule of scan time. Figure 6 and Table 2 show the result of VLBI approach the result of DMTD by changing a analysis strategy of VLBI.

Table 3. The correlation coefficient of the time difference between three techniques.

<table>
<thead>
<tr>
<th></th>
<th>VLBI-GPS</th>
<th>VLBI-DMTD</th>
<th>GPS-DMTD</th>
</tr>
</thead>
<tbody>
<tr>
<td>12days</td>
<td>0.87</td>
<td>0.94</td>
<td>0.91</td>
</tr>
<tr>
<td>1day</td>
<td>0.46</td>
<td>0.51</td>
<td>0.73</td>
</tr>
<tr>
<td>6hours</td>
<td>0.45</td>
<td>0.38</td>
<td>0.60</td>
</tr>
<tr>
<td>2hours</td>
<td>0.51</td>
<td>0.36</td>
<td>0.59</td>
</tr>
</tbody>
</table>

We calculated the correlation coefficient of the time difference between three techniques for the following four cases: (1) whole days, (2) 1 day, (3) 6 hours, and (4) 2 hours. The results show on Table 3 and Figure 7. In the case (1), the results from three techniques are strongly correlated each other. Also, in the case from (1) to (4), the correlation coefficient between GPS and DMTD are keep high correlation up to about 0.6. However, the correlation coefficient between VLBI and GPS/DMTD become small as the calculation period shortens. The correlation coefficient is about 0.4 and the differences of time difference are about ±50 ps at the short term period. However, the clock estimate precision of GPS analysis by using PPP (Precise Point Positioning) is about 100 ps [1], and it is larger than above difference.

We calculated frequency stability of VLBI using the data from 220 to 225 day of year. Figure 8 shows the results together with past results. This result is not stable than the past result of international baseline. It’s surpassing the stability of atomic fountain at $10^5$ seconds or longer.

3. Summary and Outlook

To show the frequency stability of local baseline (Kashima34m-Kashima11m), we carried out long term VLBI experiment together with GPS and DMTD measurement. And, we compared the time difference calculated from these three techniques (VLBI, GPS and DMTD). The results are strongly correlated at long term period (correlation coefficient about 0.9).

The frequency stability of VLBI is surpassing the stability of atomic fountain at $10^5$ seconds or longer. This result is unstable in comparison with the stability of the international baseline. And, as for the cause to fall stability at local baseline, the influence of the temperature change is large. In the future, the effort to reduce the influence of temperature change is necessity.

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References

Figure 8. The frequency stability of VLBI together with past results.