

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

Hiroshi Takiguchi¹ (*htaki@nict.go.jp*),
 Yasuhiro Koyama², Ryuichi Ichikawa¹,
 Tadahiro Gotoh², Atsutoshi Ishii^{1,3,4},
 and Thomas Hobiger²

¹Space-Time Standards Group,
 Kashima Space Research Center,
 National Institute of Information and
 Communications Technology,
 893-1 Hirai, Kashima, Ibaraki,
 314-8501, Japan

²Space-Time Standards Group,
 National Institute of Information and
 Communications Technology,
 4-2-1 Nukui-Kitamachi, Koganei, Tokyo,
 184-8795, Japan

³The Geographical Survey Institute,
 1 Kitasato, Tsukuba, Ibaraki,
 305-0811, Japan

⁴Advance Engineering Services Co., Ltd
 1-6-1 Takezono, Tsukuba, Ibaraki,
 305-0032, Japan

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 1.9×10^{-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 fre-

quency 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 2×10^{-11} (20ps) at 1 sec. These results show that geodetic VLBI technique has the potential for precise frequency transfer [8], [9].

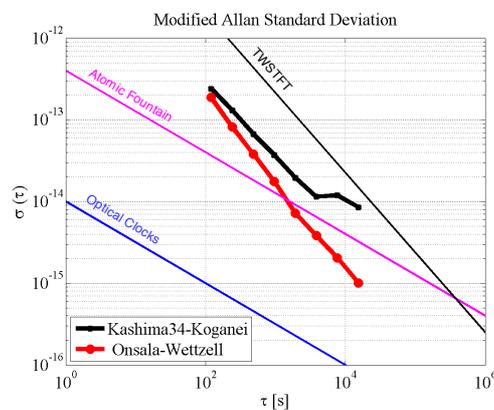


Figure 1. The frequency stability of VLBI. Large dot is Onsala-Wettzell baseline. Dot is Kashima34-Koganei baseline. Also, it shows the normal frequency stability of TWSTFT, atomic fountain and optical clocks.

Figure 1 shows the frequency stability of International baseline (Onsala-Wettzell) and local baseline (Kashima34-Koganei). As described before, we could show 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. Layout map of Kashima station

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.

VLBI	KASHIM34, KASHIM11
GPS	ks34, ksmv
DMTD	1ch: to 34m ETR and back, 2ch: to KSP room and back
duration	12days (from 01 to 12 Aug)

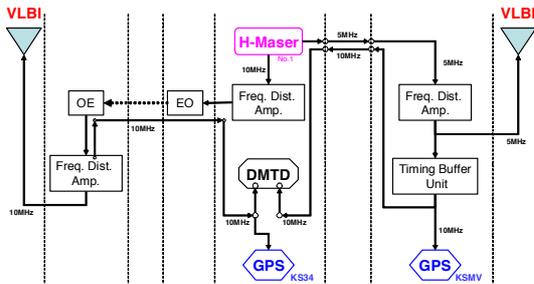


Figure 3. The reference signal setup diagram at Kashima station

Figure 3 is the reference signal setup diagram. In this experiment, we used one hydrogen maser and we transferred the reference signal by coaxial cable and optical fiber to VLBI and GPS antennas. We analyzed the data using CALC/SOLVE and GIPSY-OASIS II [3] for VLBI and GPS respectively. The details of the analysis of VLBI and GPS were described at [7].

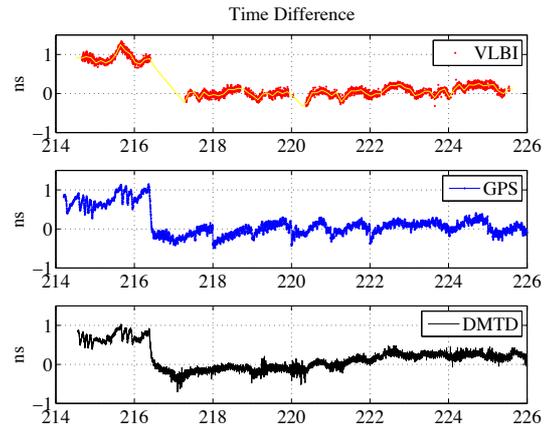


Figure 4. Time difference calculated from VLBI, GPS and DMTD.

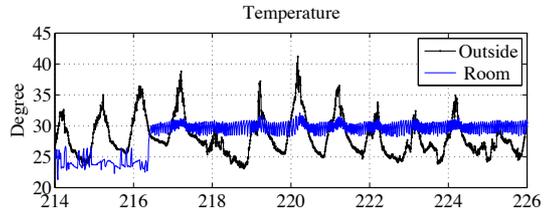


Figure 5. Variations of temperature at Kashima 11m antenna observation room and outside.

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.

symbole	estimated parameter (per minutes)	
	clock offset	atmospheric
★	180	180
×	10	10
◇	30	60
+	10	300

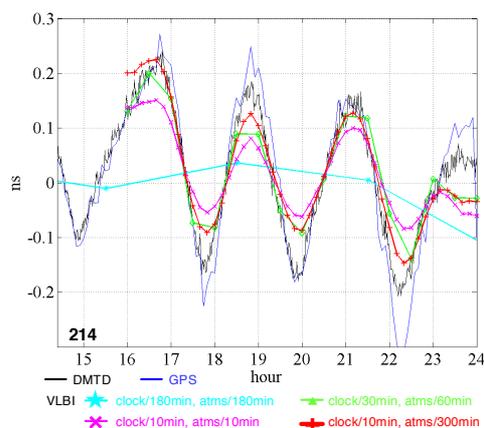


Figure 6. Time difference calculated from VLBI. The analysis strategy is described in Table 2.

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.

	VLBI-GPS	VLBI-DMTD	GPS-DMTD
12days	0.87	0.94	0.91
1day	0.46	0.51	0.73
6hours	0.45	0.38	0.60
2hours	0.51	0.36	0.59

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 corre-

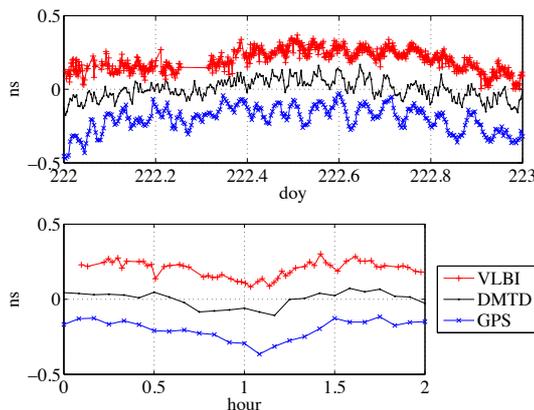


Figure 7. Time difference calculated from VLBI, GPS and DMTD.

lation 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.

Acknowledgments: The authors would like to acknowledge the IVS and the IGS for the high quality products. We are grateful that JPL provided the licenses of GPS analysis software (GIPSY OASIS II). We used CALC/SOLVE made by GSFC

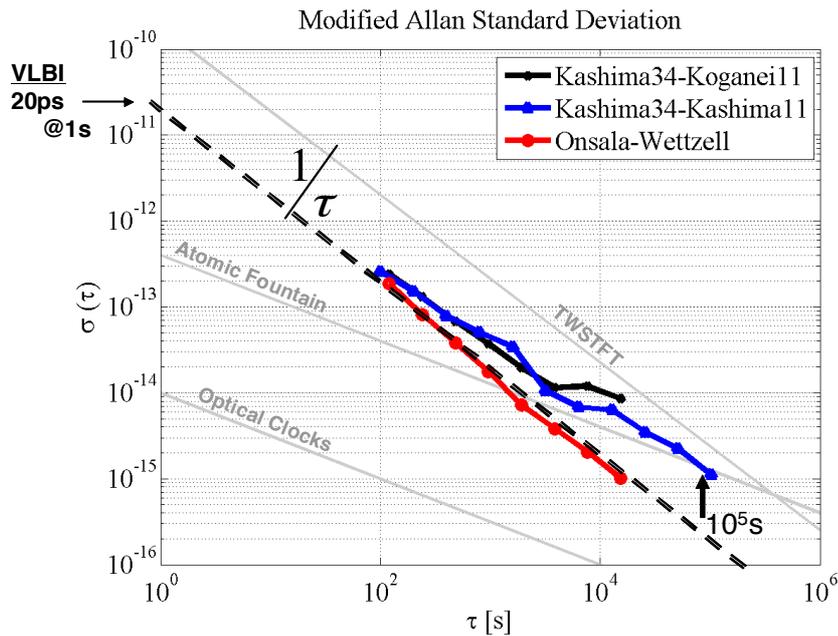


Figure 8. The frequency stability of VLBI together with past results.

for VLBI analysis. The VLBI experiments were supported by M. Sekido and E. Kawai of Kashima Space Research Center.

References

- [1] Heroux, P., and J. Kouba, GPS precise point positioning using IGS orbit products, *Physics and Chemistry of the Earth*, 26, 6-8, 573-578, 2001.
- [2] Komiyama, B., Frequency and time measurement methods, *Radio Lab Bull*, Vol. 29, 39-53, 1983.
- [3] Kouba, J., and P. Heroux, Precise Point Positioning using IGS orbits and clock products, *GPS Solutions*, No. 5, 12-28, 2001.
- [4] Koyama, Y., H. Takiguchi, T. Hobiger, and R. Ichikawa, Precise Time Transfer by Means of Geodetic VLBI Technique, *JPGU Meeting 2007 Abstract*, D106-002, 2007.
- [5] Kumagai, M., H. Ito, M. Fujieda, and M. Hosokawa, Evaluation of caesium atomic fountain NICT-CsF1, *Metrologia*, 45, 139-148, 2008.
- [6] Takamoto, M., F.-L. Hong, R. Higashi, and H. Katori, An Optical Lattice Clock, *Nature*, 435, 321-324, 2005.
- [7] Takiguchi, H., T. Hobiger, A. Ishii, R. Ichikawa, and Y. Koyama, Comparison with GPS Time Transfer and VLBI Time Transfer, *IVS NICT-TDC News*, No.28, 10-15, 2007.
- [8] Takiguchi H., Y. Koyama, R. Ichikawa, T. Gotoh, A. Ishii, T. Hobiger and M. Hosokawa, Comparison Study of VLBI and GPS Carrier Phase Frequency Transfer using IVS and IGS data, *IVS NICT-TDC News*, No.29, 23-27, 2008.
- [9] Takiguchi H., Y. Koyama, R. Ichikawa, T. Gotoh, A. Ishii, T. Hobiger and M. Hosokawa, VLBI MEASUREMENTS FOR FREQUENCY TRANSFER, *ATF 2008 Proceedings*, 2008.