VLBI MEASUREMENTS FOR FREQUENCY TRANSFER

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Abstract

We compare the frequency transfer precision between VLBI and GPS carrier phase using IVS and IGS observation data in order to confirm the potential of VLBI time and frequency transfer. The results of the VLBI frequency transfer show that the stability follows a 1/tau law very closely. And that shows the stability has reached about 2 x 10^{-11} at 1 sec. In this study, the results show that VLBI frequency transfer is more stable than GPS on the same baseline and same period. These results show that geodetic VLBI technique has the potential for precise frequency transfer.

1. Introduction

Modern cold-atom-based frequency standards have already archived the uncertainty of 10^{-15} at a few days. Moreover cold-atom-based optical clocks have the potential to realize the uncertainty on a 10^{-16} to 10^{-17} level after a few hours (Takamoto et al., 2005). On the other hand, time transfer precision of two-way satellite time and frequency transfer and GPS carrier phase experiments have reached the 10^{-10}@1sec level (Ray and Senior, 2005 etc.). In order to compare such modern standards by these time transfer techniques, 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.

Very Long Baseline Interferometry (VLBI) is one of the space geodetic techniques measures the arrival time delays between multiple stations utilizing radio signals from distant celestial radio sources. In the usual geodetic VLBI analysis, clock offsets and their rates of change at each station are estimated with respect to a selected reference station. The averaged formal error (1 sigma) of the clock offsets is typically about 20 picoseconds when analyzing geodetic VLBI experiments which are regularly conducted by the International VLBI Service for Geodesy and Astrometry (IVS). This precision is nearly one order better than other techniques like GPS or two-way satellite time transfer. It is feasible to use geodetic VLBI for comparison of primary frequency standards when radio telescopes are deployed at time and frequency laboratories. For this purpose, we have started to develop a compact and transportable VLBI system (Ishii et al.,

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2007).

To confirm the potential of the current VLBI time and frequency transfer aiming at the practical use in the future, we have compared the results of the VLBI and GPS carrier phase frequency transfer using Kashima-Koganei baseline (Takiguchi et al., 2007). That study showed that VLBI is more stable than GPS between 2000 seconds to 6000 seconds. In this study, we mainly compared VLBI and GPS carrier phase frequency transfer using data from the IVS and the International GNSS Service (IGS) by the same purpose.

2. The comparison experiments between VLBI and GPS carrier phase

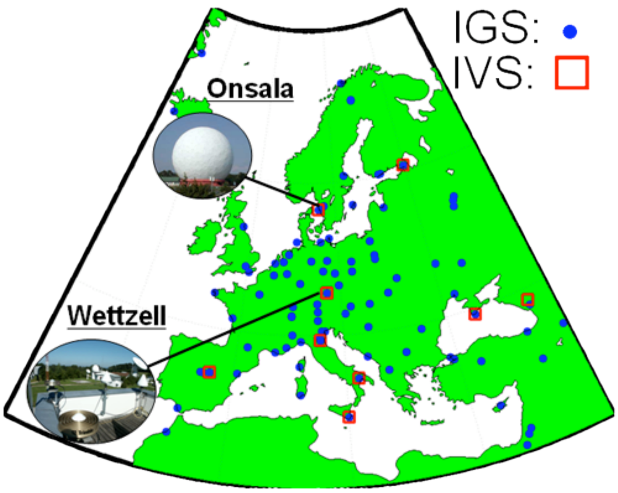

Figure 1. Map of IVS and IGS stations in Europe.

We checked the ability of time transfer of VLBI and GPS carrier phase using IVS and IGS data. We selected two stations (Onsala, Wettzell) which belong to IVS and IGS network. These two stations have in common that at each site VLBI and GPS are sharing the hydrogen maser (Figure 1). Table 1 shows a list of the data used for this study. The IVS has 12 kinds of regular sessions, and IVS conducts about 180 sessions every year. We selected R1 session which is conducted at every Monday. This session is dedicated to provide weekly EOP results. Basically, R1 sessions are observed 24 hours, starting from UTC 17 o'clock. From the pool of available session, we analyzed those 23 sessions in which both Wettzell and Onsala stations had participated. As for GPS, we analyzed 2 day's data including the IVS session. We didn't use site "wtzr" after the receiver was changed in January, 2008, since it's stability was not good.

The details of the analysis of VLBI and GPS are listed as follows:

VLBI

- Software : CALC/SOLVE
- Strategy

GPS

- Software : GIPSY-OASIS II
- Strategy : Precise Point Positioning (PPP)

- multi baseline
- S/X ionosphere-free linear combination
- reference station: Wettzell

- estimate
  - station coordinates
  - atmospheric delay / 1h
  - clock offset / 1h

- clock offset + postfit residual / scan

- estimate
  - station coordinates
  - atmospheric delay / 5min
  - clock offset / 5min

- Time Difference
  - clock offset A – clock offset B

Table 1. The lists of the data used for this study.

VLBI				On: ONSALA60, Wz: WETTZELL		GPS				
Session	Date	DOY	Time	Duration	Stations	Date	DOY	Time	Duration	Stations
R1258	07JAN09	9	17:00	24	HhKkNyOnTsWfWz	07JAN09	9	-	-	-
R1260	07JAN22	22	17:00	24	KkNyOnTcTsWfWzZc	07JAN22	22	0:00	48	onsa, wtzr
R1262	07FEB05	36	17:00	24	HhKkNyOnShTsWfWz	07FEB05	36	0:00	48	onsa, wtzr
R1263	07FEB12	43	17:00	24	HhKkNyOnShTcWfWz	07FEB12	43	0:00	48	onsa, wtzr
R1265	07FEB26	57	17:00	24	KkMcNyOnTcWfWzZc	07FEB26	57	0:00	48	onsa, wtzr
R1270	07APR02	92	17:00	24	HhKkNyOnShTsWfWz	07APR02	92	0:00	48	onsa, wtzr
R1271	07APR10	100	17:00	24	KkNyOnTcTsWfWzZc	07APR10	100	0:00	48	onsa, wtzr
R1273	07APR23	113	17:00	24	KkMcNyOnTcTsWfWz	07APR23	113	0:00	48	onsa, wtzr
R1274	07MAY02	122	17:00	24	FtHhNyOnTcWzZc	07MAY02	122	0:00	48	onsa, wtzr
R1285	07JUL16	197	17:00	24	HhKkOnWfWz	07JUL16	197	0:00	48	onsa, wtzr
R1291	07AUG27	239	17:00	24	KkNyOnTcTsWfWz-Zc	07AUG27	239	0:00	48	onsa, wtzr
R1292	07SEP04	247	17:00	24	HoKkNyOnTcTsWfWz	07SEP04	247	0:00	48	onsa, wtzr
R1293	07SEP10	253	17:00	24	KkNyOnTcTsWfWz	07SEP10	253	0:00	48	onsa, wtzr
R1294	07SEP17	260	17:00	24	HhKkNyOnWfWz	07SEP17	260	0:00	48	onsa, wtzr
R1295	07SEP24	267	17:00	24	HhKkNyOnTcWfWz-Ho	07SEP24	267	0:00	48	onsa, wtzr
R1311	08JAN14	14	17:00	24	BdFtHhNyOnTcWfWz	08JAN14	14	-	-	-
R1312	08JAN22	22	17:00	24	FtHhNyOnTcWfWz	08JAN22	22	-	-	-
R1315	08FEB11	42	17:00	24	FtHhOnTcWfWz-Ny	08FEB11	42	-	-	-
R1316	08FEB19	50	17:00	24	FtHhNyOnTcWfWz	08FEB19	50	-	-	-
R1325	08APR22	113	17:00	24	BdFtHhOnTcWz-NyWf	08APR22	113	-	-	-
R1327	08MAY05	126	17:00	24	BdFtHhNyOnTcWfWz	08MAY05	126	-	-	-
R1334	08JUN23	175	17:00	24	FtHhMaNyOnTcWfWz	08JUN23	175	-	-	-
R1336	08JUL07	189	17:00	24	FtHhNyOnTcWfWz-Bd	08JUL07	189	-	-	-

Figure 2 shows one of the VLBI results of clock offsets (R1274 session). The lower plot of Figure 2 shows the formal errors, which have been estimated using clock offsets every 1 hour. This figure shows you that the formal errors were almost 20ps or less. Table 2 shows averaged formal errors for each session. The averaged formal errors (1 sigma) of the estimated clock offsets at Onsala station referred to Wettzell station was 15ps.

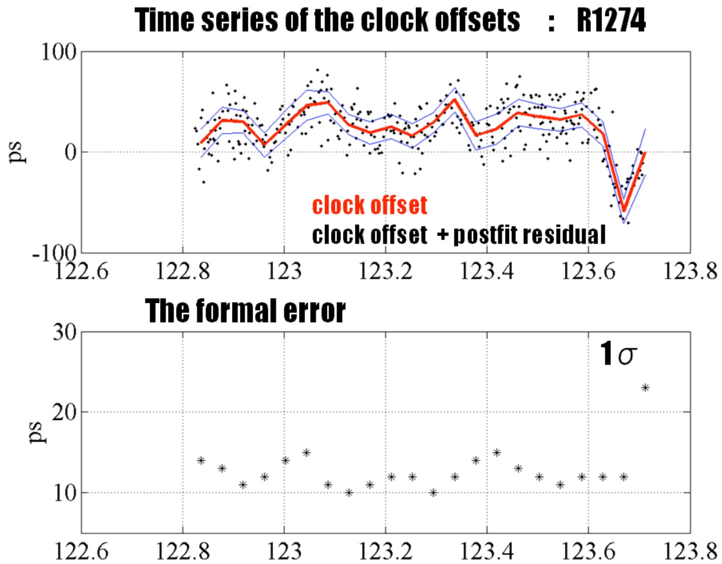

Figure 2. Time series of the clock offsets (upper) and the formal error (lower) at Onsala station referred to Wettzell station.

Table 2. The lists of formal errors at each session.

Session	1σ	Session	1σ
R1258	12	R1293	14
R1260	11	R1294	14
R1262	9	R1295	21
R1263	16	R1311	18
R1265	12	R1312	13
R1270	13	R1315	13
R1271	13	R1316	14
R1273	14	R1325	18
R1274	12	R1327	19
R1285	17	R1334	31
R1291	15	R1336	19
R1292	12	Average	15

Figure 3 shows that the time series of the clock difference between Onsala and Wettzell (session R1274) calculated from GPS and VLBI respectively (upper part: after subtracting an average, middle part: after removing a linear trend, lower part: the differences between GPS and VLBI). Due to the code noise, the clock offsets of the GPS solutions show discontinuities at the day boundaries. The averaged over all session's day boundary discontinuity was 94ps. The lower part of Figure 3 is the difference between GPS and VLBI clock offsets showing a good agreement within ±200ps.

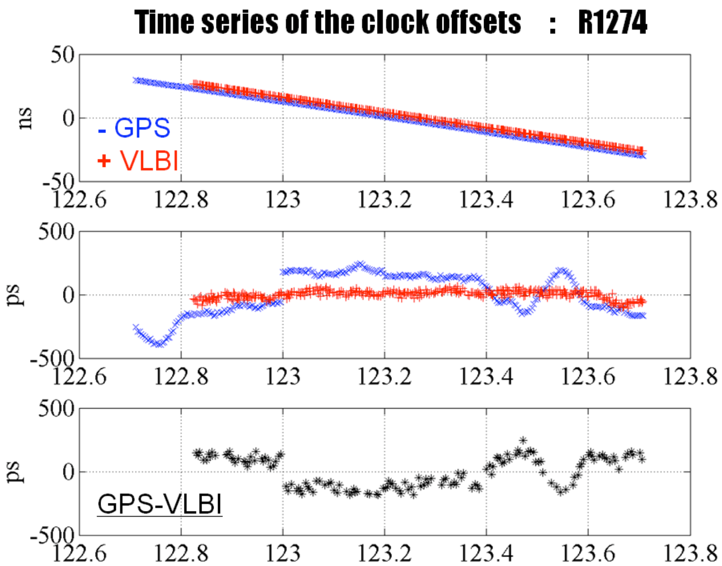

Figure 3. Time series of the clock difference (upper part: after subtracting an average, middle part: after removing a linear trend, lower part: the differences between GPS and VLBI) calculated from GPS (blue) and VLBI (red) respectively.

Figure 4 illustrates the frequency stability of clock difference as obtained from VLBI and GPS. The short terms stability of GPS carrier phase seems to be slightly better than those from VLBI for averaging periods up to 10^3s. However, VLBI is more stable at averaging periods longer than 10^3s in any sessions (Figure 5). Also, Figure 5 shows that the stability of VLBI is surpassing the stability of atomic fountain at 10^3s or more. In general, the VLBI frequency transfer stability follows a 1/tau law very close when averaging up to 10^4s. And that shows that the stability has reached about 2×10^{-11} (20ps) at 1 sec (Figure 5).

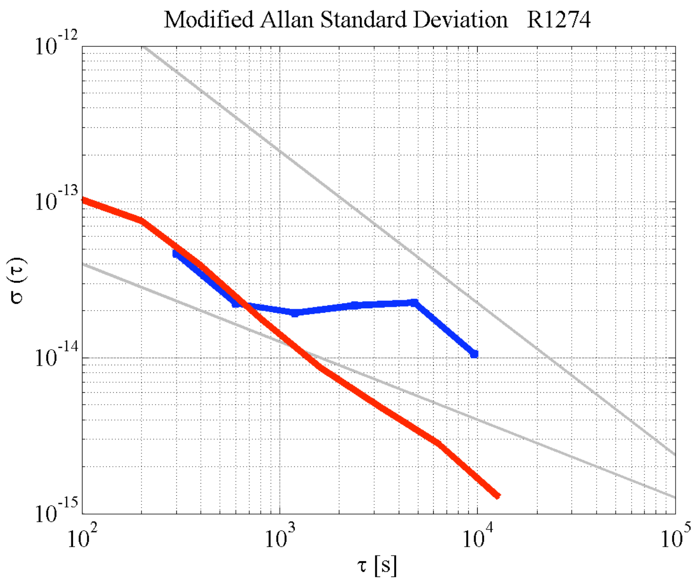

Figure 4. Modified Allan deviation of VLBI and GPS carrier phase results from R1274 session.

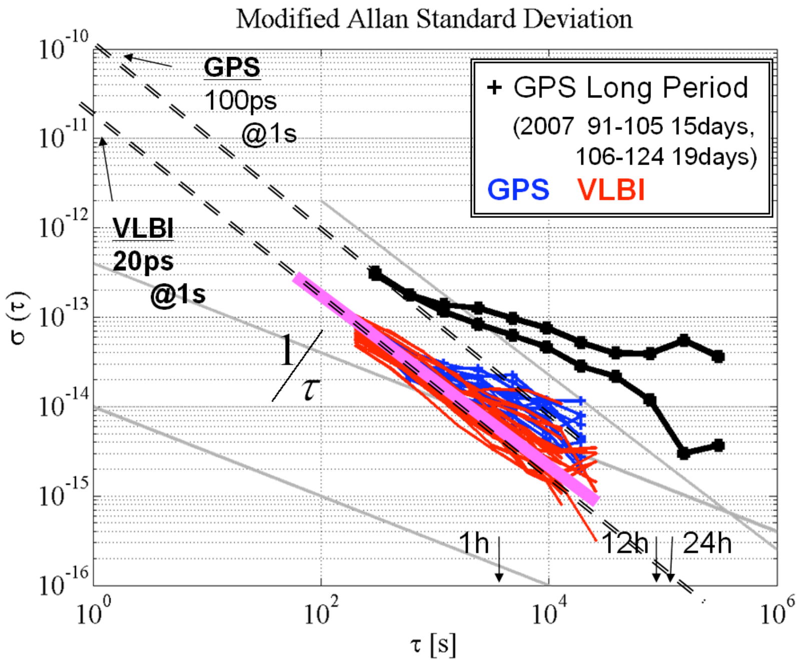

Figure 5. Modified Allan deviation of VLBI and GPS carrier phase results from all sessions.

3. Conclusion

To compare the results of VLBI and GPS (carrier phase) frequency transfer, we have analyzed IVS and IGS data. The results of the VLBI frequency transfer show that the stability follows a 1/tau law very closely (phase noise dominant). And that shows the stability has reached about 2 x 10^{-11} (20ps) at 1 sec. In this study, the results show that VLBI frequency transfer is more stable than GPS on the same baseline and same period. These results show that geodetic VLBI technique has the potential for precise frequency transfer.

Figure 6 shows the future image of the time transfer by the compact VLBI system and high speed networks.

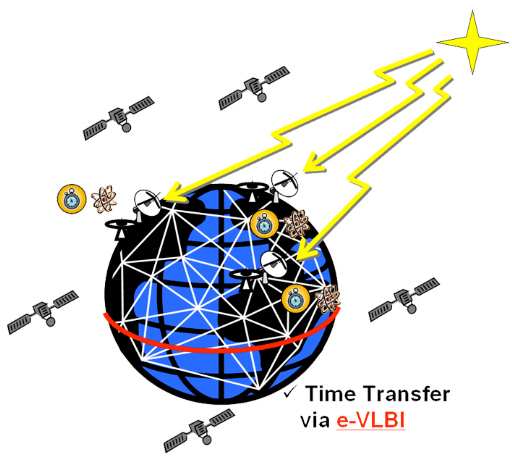

Figure 6. Future image of the time transfer by the compact VLBI system and high speed networks.

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