IMPLEMENTATION AND COMPARISON OF TIME AND FREQUENCY TRANSFER METHODS BY GPS CARRIER PHASE

Kun Liang and Aimin Zhang
National Institute of Metrology (NIM)
Beijing 100013, P.R. China
E-mail: *Liangk@nim.ac.cn*

Abstract

Nowadays, GPS carrier-phase time and frequency transfer methods are applied more and more in the timing area because of their high ranging resolution, which corresponds to high time and frequency transfer precision. In this paper, we have built a GPS carrier-phase time and frequency transfer system preliminarily at the National Institute of Metrology (NIM). Several different time and frequency transfer experiments, including zero-baseline and long-baseline experiments with the same reference or the different references, conducted using GPS carrier phase with the GPS carrier-phase time and frequency transfer system by two different solution methods, were implemented and the experimental results are compared.

INTRODUCTION

Now GPS carrier-phase time and frequency transfer is more and more important for clock comparison. The precision of GPS carrier-phase time and frequency transfer is much better than that of GPS Common View and all-in-view time and frequency transfer based on C/A or P3 code measurement and is comparable with that of two-way satellite time and frequency transfer. The potential capability and application using GPS carrier phase with the Common View technique to transfer precise time and frequency has been recognized, described, and discussed in the Reference **[1]**. It can be implemented by the different solution methods. In this paper, GPS carrier-phase time and frequency transfer was implemented by two different methods, differential solution and Precise Point Positioning. Some experiments by GPS carrier-phase time and frequency transfer methods were conducted and the experimental results are compared.

1. EXPERIMENT SETUP

The experiment setup is shown in Figure 1. As the figure shows, in the experiments, we used several devices, including the geodetic receivers, atomic clocks, and so on. These receivers can acquire phase and code observations from all satellites in view, at both *L1* and *L2* frequencies. The receivers are connected to the atomic clock generating a 1pps signal and a 5 MHz frequency signal.

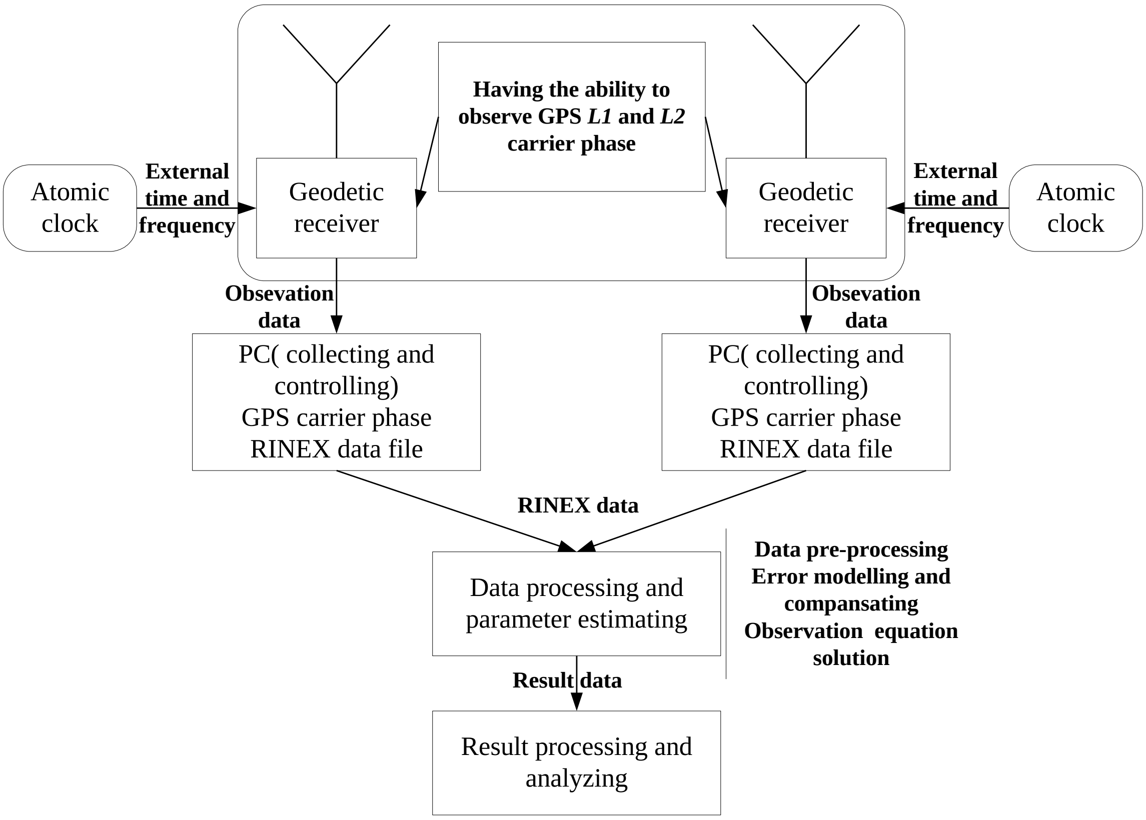


Fig. 1. Experiment setup of time and frequency transfer by GPS carrier phase.

The GPS carrier-phase observation equation is:

$$\phi_{r,1}^{s}\lambda_1 = \rho_g + c\,(\delta_r - \delta^s) + \rho_{trop} + \rho_{ion}^{\phi_1} + \rho_{multi}^{\phi_1} + b_{r,1}^{s} + \varepsilon^{\phi_1}$$
$$\phi_{r,2}^{s}\lambda_2 = \rho_g + c\,(\delta_r - \delta^s) + \rho_{trop} + \rho_{ion}^{\phi_2} + \rho_{multi}^{\phi_2} + b_{r,2}^{s} + \varepsilon^{\phi_2}$$

where

ρ_g is the geometric range

ρ_{trop} is the propagation delay due to the troposphere

ρ_{ion} is the propagation delay due to the ionosphere

ρ_{multi} is the multi-path error

b_r^s is the carrier-phase integer ambiguity

δ_r and δ^s are the offsets from the reference time for the receiver and satellite clocks

ε represents the unmodelled bias and receiver noise

c is the speed of light in the vacuum

λ is the carrier wavelength.

First, we did the zero-baseline experiment with the same reference, which allowed us to identify the contribution of each hardware component (receiver, antenna, cable, clock) to GPS carrier-phase time and frequency transfer in the system. Then, we conducted the zero-baseline experiment with the different references to check the ability of the frequency standards comparison without the baseline influence. Herein, the same reference was UTC (NIM) steered by a cesium (Cs) clock, and the different references were a hydrogen maser and

UTC (NIM). And since both receivers, “IMPR,” a 12-channel Septentrio Polarx2, and “IMEU,” a Javad GGD-16T, were located in the same laboratory, they were subject to identical temperature variations which were recorded during the experiments. Finally, we finished two long-baseline experiments with the different references. One had a more than 2000-kilometer baseline between NICT and NIM, and the two receivers SEPA and IMPR, whose models were both 12-channel Septentrio Polarx2TR, with the different references UTC (NICT) and UTC (NIM) located separately at NIM and NICT, were used. The other had about a 700-kilometer baseline; the different references were UTC (NIM) and a 5061B cesium clock; and the receivers used were the same as those in the zero-baseline experiments. Precise orbital data and the modeling of troposphere obtained from IGS (International GNSS Service) Web site were used in order to obtain high-precision corrections to time and frequency transfer. The data used in these experiments were the RINEX files generated by the geodetic GPS receivers.

The code and phase measurements recorded by these three receivers were saved in daily RINEX data files. The decimation interval was 30 seconds, which is standard for normal IGS operations. The coordinates of both antennas were known to cm accuracy in the ITRF96 reference frame. All tests were done using daily data sets where satellite tracking was not interrupted, nor did spontaneous clock resets occur.

The GPS code and carrier-phase data processing and analyzing was done partially with NRCAN_PPP software or GAMIT software and partially with a self-developed software based on MATLAB at 5-minute or 1-minute intervals. The processing intervals of the two kinds of software are different. The processing interval of NRCan_PPP software is 5 minutes and that of GAMIT software is 1 minute.

Data processing and parameter estimating consists of the following parts:

[1]. Pre-processing of raw data
[2]. Acquisition of IGS final ephemeris
[3]. Observation equation solution and clock bias estimation by GAMIT or NRCan_PPP.

In the paper, we call the GPS carrier-phase method using NRCan_PPP software the GPSPPP method; the GPS carrier-phase method using GAMIT software the GPSCP method; and the time and frequency method by GPS P3 code the GPSP3 method.

2. NUMERICAL RESULTS

In the section, we describe the time and frequency performance from the time difference and Allan deviation (ADEV).

From Figure 2, the standard deviation of time difference can reach at 100 picoseconds, which means the noise floor of GPS carrier-phase time and frequency transfer, excluding the baseline influence.

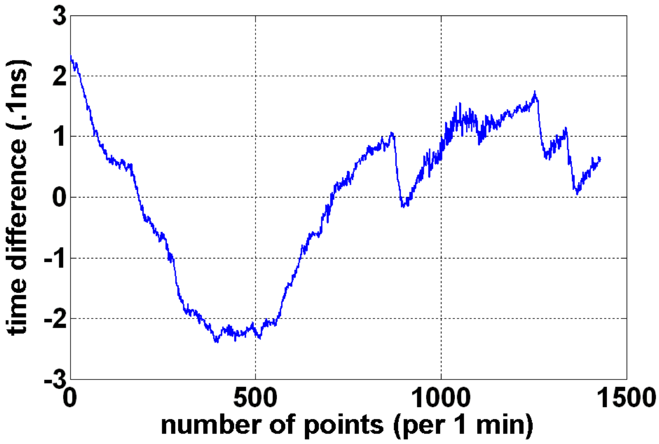


Fig. 2. Time difference by GPSCP in the zero-baseline experiment with the same reference.

From the zero-baseline experiment with the same reference, GPS carrier-phase time and frequency transfer based on RINEX files has the time stability of 100 picoseconds, which translates into a frequency transfer uncertainty of about two parts in 10^{15} for an averaging time of 1 day from random effects. ADEV results of the experiment are shown in Figure 3. If the averaging time is 5 days, the frequency transfer uncertainty will reach at eight parts in 10^{15}.

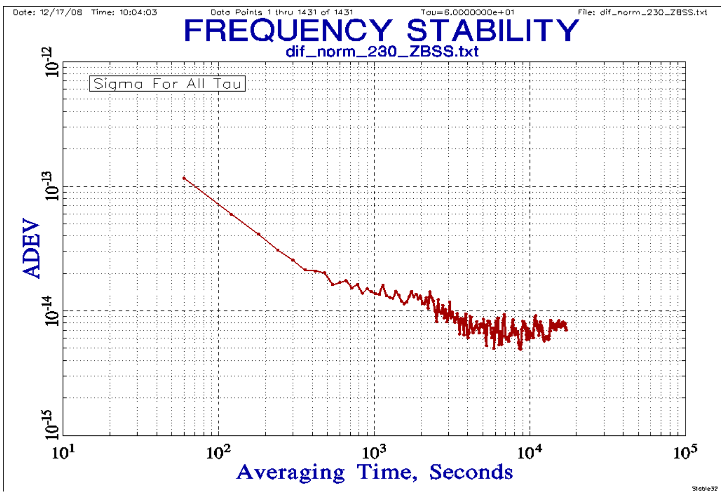


Fig. 3. ADEV by GPSCP in the zero-baseline experiment with the same reference.

In the zero-baseline experiment with the different references, we used the dual-mixer time difference (DMTD) measurement method, the GPSP3 method, and the GPS carrier-phase methods to implement the time and frequency transfer experiments at the same time. The results as follows were achieved. Figure 4 shows that the results by GPSCP method are very similar to those by DMTD. Herein, the sampling interval of DMTD is 1 second.

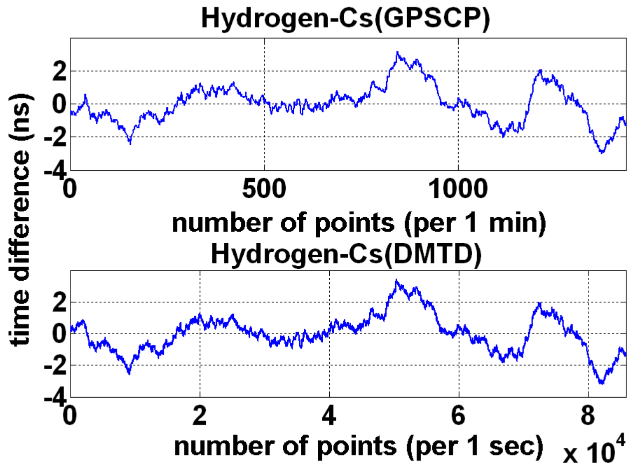


Fig. 4. Comparison of time differences by GPSCP and DMTD.

We can see that the results of the two GPS carrier-phase methods in Figure 5 are very similar and consistent.

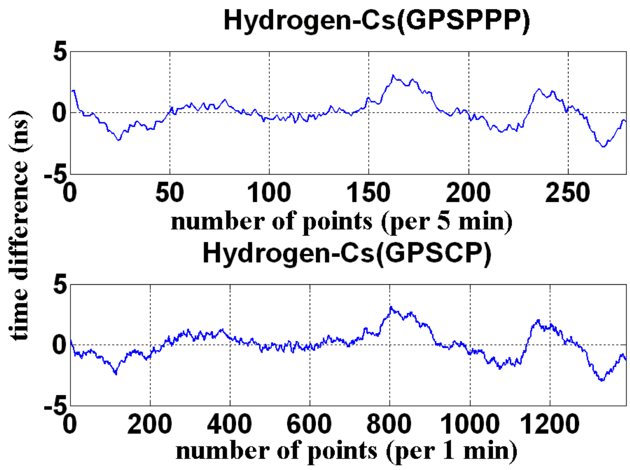


Fig.5. Comparison of time differences by GPSPPP and GPSCP.

In Figures 6-8, we see the comparison of the time difference and the frequency stability results by GPSP3, GPSCP, and DMTD methods. Herein, the processing interval of GPSP3 method is 16 minutes. Thus, the data generated by the GPSP3 method are not enough to get the good and detailed frequency stability results shown in Figure 8. The data generated by the GPSCP method are enough to evaluate the frequency stability as shown in Figure 7. And the time difference results by GPSP3 are much noisier than those by the GPSCP and DMTD methods, which are similar in Figure 6.

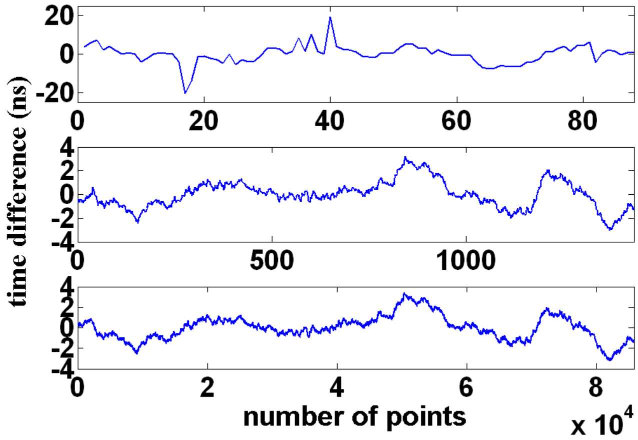
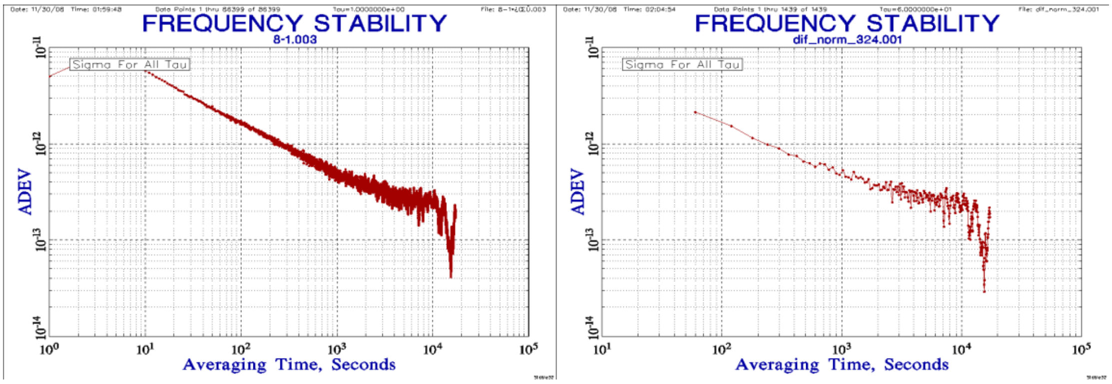


Fig.6. Comparison of time differences by GPSP3, GPSCP, and DMTD.



(a)DMTD (b)GPSCP

Fig. 7. ADEV in the zero-baseline experiment with the different references.

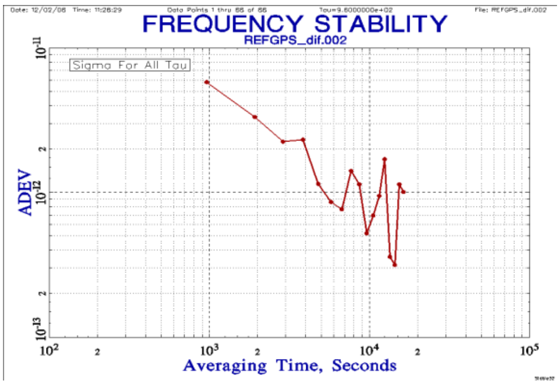


Fig. 8. ADEV by GPSP3 in the zero-baseline experiment with the different references.

In one long-baseline experiment with the different references, we compared the results of the day 172 of the year 2008 computed by GPSCP and TAIPPP. Figure 9 shows that the GPSCP results and the TAIPPP results (per 5 minutes) are very similar and comparable.

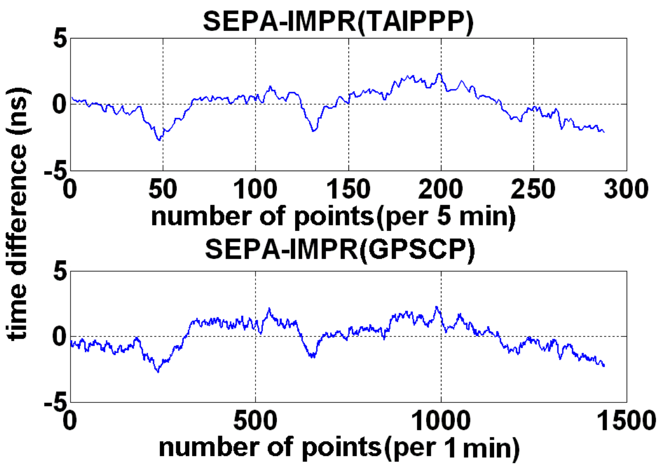
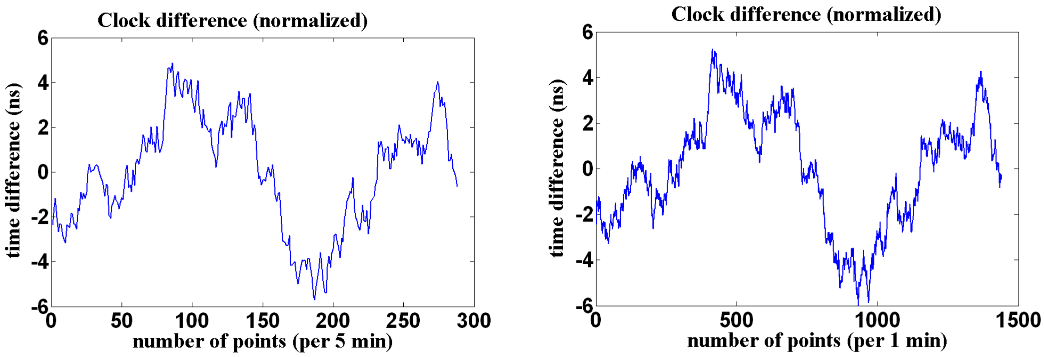


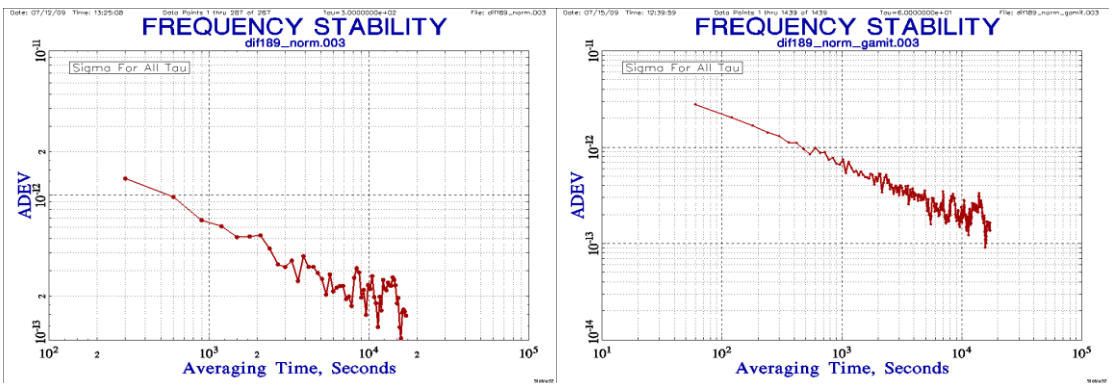
Fig. 9. Comparison of the results by TAIPPP and GPSCP.

In another long-baseline experiment, we compared a cesium clock of the Provincial Metrology Institute of Liaoning located in Shenyang with UTC (NIM), so the length of the baseline is about 700 kilometers. Because this cesium clock does not run continuously, we can only compare the frequency results of the two clocks as in Figures 10 and 11. In May 2009, this clock was verified with UTC (NIM) by the time and frequency group at NIM, and the results are shown in Table 1.



(a) GPSPPP (b) GPSCP

Fig. 10. Time difference in the long baseline experiment with the different references.



(a) GPSPPP (b) GPSCP

Fig. 11. ADEV in the long baseline experiment with the different references.

Because of the different processing intervals of the two GPS carrier-phase methods, we can see that the GPSCP method can get more and more detailed ADEV results, as shown in Figure 11.

Table 1. Direct comparison results using Symmetricom 5110A **[5]**.

Sampling time(s)	ADEV
100	2.7×10^{-12}
1000	7.9×10^{-13}
10000	2.1×10^{-13}

We can see that the frequency stability results obtained by the two GPS carrier-phase methods are consistent with the results shown in Table 1 on the whole.

3. CONCLUSIONS AND PERSPECTIVES

We can conduct the GPS carrier-phase time and frequency transfer by the two methods. GPS carrier-phase time and frequency transfer based on RINEX files can reach a time stability of 100 picoseconds, which translates into a frequency transfer uncertainty of about two parts in 10^{15} for an averaging time of 1 day. GPS carrier-phase time and frequency transfer based on RINEX files has the ability for precise time and frequency transfer basically. The experiments can be improved after removing some disadvantages better, such as receiver delay, antenna phase center, and so on. From the zero-baseline and long-baseline experiments, we can see the results by the two GPS carrier-phase methods are reliable, similar, and comparable with those by direct comparison. But some delays need be measured and calibrated precisely, for example receiver delay, and in the future our methods will be improved.

ACKNOWLEDGMENTS

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