# Long-Term Stability of GPS Time Transfer Link

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***Abstract*—The techniques of GPS Common-View (GPS CV) and GPS Precise Point Positioning (GPS PPP) are widely used in the computation of Coordinated Universal Time (UTC) for major international time-keeping laboratories. Long-term stability of the link is an important factor that affects the accuracy of time comparison at present. In order to ensure the long-term stability of time transfer, the link must be calibrated. However, in many cases, due to limited costs and lack of appropriate calibration equipment, frequent calibration is not possible. Instead of repeated calibration, some information about the long-term stability of these links can be obtained by comparing the two links. In this paper, the data of two years after the GPS travelling calibrator of the Bureau international des poids et mesures (BIPM) is used to perform the calibration measurement of the comparison link of the National Time Service Center (NTSC), based on the GPS receivers that use common reference signals from the same clock to carry out the zero-baseline common clock comparison. Then take the national standard time maintained by the NTSC and Physikalisch-Technische Bundesanstalt (PTB) as comparison objects, a long baseline GPS CV and PPP comparison test was carried out to directly investigate the long-term stability. The results show that the long-term stability of GPS time comparison is 1.88ns, which can meet the international time comparison requirements.**

***Keywords—Common-View (CV); Precise Point Positioning (PPP); stability; time link***

## I. INTRODUCTION

The high precision time comparison link is an important part of keeping time measurement between more than 80 time-keeping laboratories around the world, and it is the necessary mean to generation the international standard time Coordinated Universal Time (UTC)[1]. At present, the main comparison methods used by the time-keeping laboratories include two-way satellite time and frequency transfer (TWSTFT) and time comparison technology based on the global navigation satellite system (GNSS).

The time comparison accuracy is an important index to measure the performance of time synchronization. Generally, the uncertainty is selected as the main indicator to evaluate the comparison accuracy. Since 2005, the Bureau international des poids et mesures (BIPM) has published the uncertainty of UTC(k) in Circular T every month. At present, the uncertainty of UTC(k) mainly comes from atomic clocks, atomic time algorithms and comparison links, 98% of the uncertainty comes from the impact of comparison links[2,3]. Therefore, calibration and link stability are key issues affecting UTC comparison. In recent years, international experts in the field of time and frequency have also done a lot of relevant research on the long-term stability of time comparison links. Z. Jiang of BIPM found that the results of some UTC time comparison links may experience drift over time, and the calibration uncertainty is only valid for a short period of time. This may be related to equipment aging or malfunction, changes of environmental factors, etc.[4]. Victor Zhang of the National Institute of Standards and Technology (NIST) proposes the necessity of frequent calibration, otherwise equipment aging or malfunction may increase uncertainty[5]. Therefore, carrying out the research on the long-term stability of time comparison links is of great significance for improving high-precision time comparison. In order to calibrate the time comparison links that participate in UTC comparison around the world, BIPM proposed a plan to use GPS mobile calibration station to regularly calibrate time comparison links in 2007. In 2016, NTSC successfully calibrated the GNSS international time comparison link between NTSC and PTB using the mobile calibration station of BIPM. This article is based on the national standard time maintained by the NTSC and PTB, selecting data from two years after calibration, conducting long-term stability analysis of GPS time comparison, and evaluating the uncertainty of the system. The analysis results indicate that the long-term uncertainty of the current link is 1.88ns, which can meet the current international time-keeping requirements and lay the foundation for further improving the performance of the time comparison link.

## II. GPS COMMON-VIEW TIME COMPARISON

GPS Common-View (GPS CV) time comparison means that atomic clocks of two time-keeping laboratories A and B on Earth observe one or more satellites synchronously by using GPS ground receivers, in order to obtain the time difference between the local reference time and the navigation system GPST. After correcting the errors of the ionosphere, troposphere, relativistic effect and multi path delay, the time difference between the two laboratories can be obtained. The principle is shown in Figure 1.

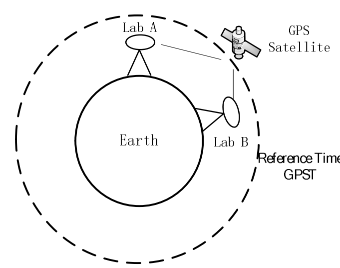


Fig. 1. The principle of GPS CV

According to the above principle, the formula for calculating the CV comparison results between two time-keeping laboratories is as follows:

$$\Delta t_{\mathrm{AGPST}} = (t_{\mathrm{A}} - \mathrm{GPST}) \quad (1)$$

$$\Delta t_{\mathrm{BGPST}} = (t_{\mathrm{B}} - \mathrm{GPST}) \quad (2)$$

Where $\Delta t_{\mathrm{AGPST}}$ is the time difference between the local reference time of laboratory A and the GPS system, $t_{\mathrm{A}}$ is the local reference time of laboratory A, $\Delta t_{\mathrm{BGPST}}$ is the time difference between the local reference time of laboratory B and the GPS system, $t_{\mathrm{B}}$ is the local reference time of laboratory B.

The time difference between two stations can be expressed by equation (1) minus equation (2):

$$\Delta T_{\mathrm{AB}} = \Delta t_{\mathrm{AGPST}} - \Delta t_{\mathrm{BGPST}} = (t_{\mathrm{A}} - \mathrm{GPST}) - (t_{\mathrm{B}} - \mathrm{GPST}) = t_{\mathrm{A}} - t_{\mathrm{B}} \quad (3)$$

The most important feature of GPS CV is that it can eliminate the influence of satellite clock error and effectively reduce the influence of satellite orbit error. In the process of correcting error, ionosphere delay is corrected by dual-frequency ionospheric combination model, troposphere delay is corrected by improved Hopfiled model, and earth rotation effect is corrected by Sagnac effect algorithm, hardware delay of ground receiving station is determined by mobile receiver closed-loop calibration. the principle of calibration.

# III. The Principle of Calibration and Uncertainty

## A. *The principle of calibration*

At present, the uncertainty of UTC-UTC(k) (k refers to the time-keeping laboratories participating in UTC calculation) mainly comes from the time comparison link. In the time comparison link, 60% of the Type A uncertainty ($u_a$) (statistical uncertainty) is less than 1ns and 93% of the Type B uncertainty ($u_b$) (calibration uncertainty) is greater than 5ns. Therefore, the calibration uncertainty is the main source of uncertainty in the time comparison link, and also the key factor limiting the high precision time comparison technology.In order to ensure the accuracy of the comparison link, since 2007, BIPM began to consider the calibration method of GNSS and proposed a new calibration method --METODE, that is, which uses GPS mobile calibration stations for link calibration. This calibration method directly calibrates the entire time comparison link, and the calibration value is the total delay from the antenna phase center to the UTC reference point[6].BIPM has also developed a standard calibration scheme, which uses a portable mobile calibrator stdB. It consists of a frequency distribution amplifier, a pulse distribution amplifier, and two GNSS geodetic devices, each of which includes an independent set of receivers, antennas, and cables[7].

The specific calibration method is to use a local GPS reference receiver with known time delay of BIPM to carry out the zero-baseline common view time comparison experiment with the GPS mobile calibration station firstly. Then, the mobile calibration station is transported to the laboratory that needs calibration and compared with the local timing receiver using the same reference source UTC(k) for a one week common clock zero baseline time comparison experiment, and compared with the reference station PTB for time comparison experiment. Finally, the mobile calibration station was returned to the BIPM, and then zero-baseline time was compared with the local GPS reference receiver of the BIPM, calculate the closure error and complete the whole circuit calibration.

## B. *Uncertainty*

When describing the uncertainty of measurement techniques, "random" and "system" are usually used to divide and express. Since the International Organization for Legal Metrology (OIML) requires BIPM to provide a unified method on the measurement of uncertainty, in 1993, according to the requirements of OIML, The International Organization for Standardization (ISO) issued the Guide to the expression of uncertainty in measurement (hereinafter referred to as the Guide). The "Guide" indicate that there are two methods for measuring uncertainty: statistical analysis and external calibration[8]. From the above evaluation methods of uncertainty, it can be mainly divided into the Type A uncertainty and Type B uncertainty.

The Type A uncertainty: Statistical uncertainty refers to the uncertainty that can be measured using statistical analysis methods, including the uncertainty of observation column statistical analysis and the internal uncertainty of measurement equipment. The Type A uncertainty is generally considered to follow the normal distribution and can be calculated by range method, maximum deviation method, least square method, Bessel formula method, etc.

The Type B uncertainty: mainly refers to calibration uncertainty, which is usually evaluated using methods other than statistical analysis and external calibration. For the evaluation of Type B uncertainty, the "calibration" method is currently commonly used internationally.

In order to reduce the uncertainty of the time comparison link, from July 19 to July 31, 2016, the NTSC used BIPM's GPS mobile calibration station to directly calibrate the GNSS time comparison link of NTSC-PTB, reducing its total uncertainty to 1.7ns[9]. In 2018, NIM calibrated NTSC again, and the calibration report showed that the hardware delay changes for two times were completely within the range of uncertainty, indicating that the link was stable for a long time within the two years. Now, an analysis is conducted on the long-term stability of the NTSC time comparison link.

# IV. Results and Analysis

## A. *Zero-baseline common clock comparison*

The zero-baseline common clock comparison (CCD) experiment was carried out on two receivers of the same type of NTSC, NTP1 and NTP3, using the common view method to directly study the long-term relative instability of a single P3 link technology. Through CCD, we found that the current GNSS receivers of NTSC were relatively stable to each other during the two years from 2017 to 2018, and the noise level fluctuated within ±5ns, the average value of zero-base line comparison results is 0.36ns, and STDEV is 0.63ns.

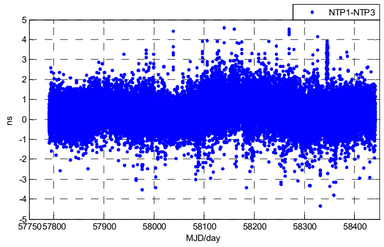


Fig. 2. The result of CCD

### B. *Analysis of uncertainty*

- The Type A uncertainty

The long-term changes studied in this article mainly come from: (1) changes in the total delay of the receiving system: signal delay from the antenna phase center to the UTC(k) reference point; (2) The instability of the local frequency and time distribution system connected to the receiving system. The long baseline comparison experiment was established in the NTSC and PTB, and the data of nearly two years after calibration (MJD 57790-58440, i.e. February 6, 2017 to November 18, 2018) were selected. This time period was selected because NTSC successfully calibrated the GNSS international time comparison link of NTSC-PTB using the GPS mobile calibration station stdB of BIPM from July 25 to July 31, 2016; from December 21, 2018 to December 25, 2018, NTSC used the NIM calibrator to calibrate the link again, and the delay changes in the two calibration results were completely within the calibration uncertainty range. The article obtains the time difference between two places based on the relevant CV algorithm, and selects the PPP link result as the reference value, as shown in Figure 3-8. The configuration of GPS dual frequency time comparison equipment of each ground station is shown in Table 1.

TABLE I. THE CONFIGURE OF GPS CV RECEIVERS

| **Laboratories** | **Receiver code** | **Receiver type** | **Antenna type** |
|---|---|---|---|
| NTSC | NTP1 | SEPT POLARX5TR | SEPCHOKE_MC |
| NTSC | NTP3 | SEPT POLARX4TR | SEPCHOKE_MC |
| PTB | PT02 | SEPT POLARX5TR | LEIAR25.R4 |

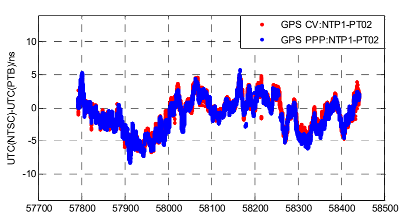


Fig. 3. The CV and PPP results between NTSC and PTB（NTP1-PT02）

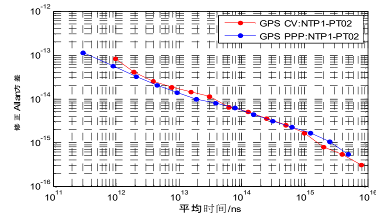


Fig. 4. The Allan variances of two methods

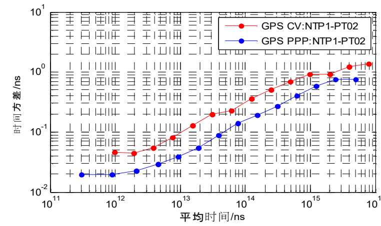


Fig. 5. The Time variances of two methods

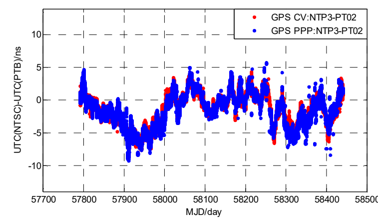


Fig. 6. The CV and PPP results between NTSC and PTB（NTP3-PT02)

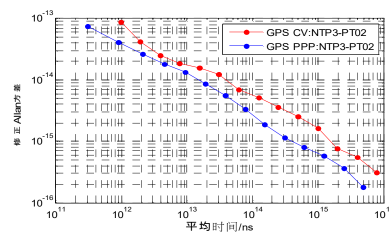


Fig. 7. The Allan variances of two methods

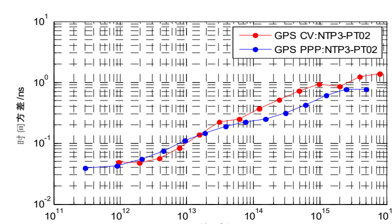


Fig. 8. The Time variances of two methods

The STDEV of GPS CV link comparison data relative to the PPP result is calculated by using NTP1 and PT02 receivers, and the result is 0.66ns and it is used to estimate the Type A uncertainty of the system, which is 0.66ns. The STDEV of GPS CV link comparison data relative to the PPP result is calculated by using NTP3 and PT02 receivers, and the result is 0.65ns and it is used to estimate the Type A uncertainty of the system, which is 0.65ns.

- The Type B uncertainty

The calibration uncertainty cannot be obtained by statistical methods, but is determined scientifically by all the information that affects the change of measurement results. Various error factors in the system measurement process will introduce the Type B uncertainty. Calibration uncertainty is the sum of various calibration uncertainty components, and its basic formula is as follows:

$$u_b = \sqrt{\sum_{i=1}^{n} u_{b,i}^2} \tag{4}$$

During the calibration process, the closed-loop measurement before and after calibration of GPS mobile calibration station, the instability between the reference source of the calibration station and the mobile calibration station, and the instability of the time delay measurement from the reference point to the calibration point will all bring uncertainty. In addition, the GPS receiver is sensitive to the temperature and humidity fluctuations in the laboratory, and small changes can cause the delay change of the receiver. At the same time, the power supply voltage of the receiver will also change the delay of the equipment to a certain extent, introducing uncertainty, and the unknown factors such as the change of antenna position and multi path effect will also introduce uncertainty. The estimated calibration uncertainty based on empirical values is shown in Table 2[10].

TABLE II. ANALYSIS OF TYPE B UNCERTAINTY

| **Type B uncertainty component $u_{b,n}$** | **Source** | **ns** |
|---|---|---|
| $u_{b,1}$ | Uncertainty of closed-loop measurement before and after calibration of GPS mobile calibration station | 1.0 |
| $u_{b,2}$ | Instability of local reference sources and mobile calibration stations | 0.7 |
| $u_{b,3}$ | Uncertainty of time delay measurement from reference point to calibration point | 0.5 |
| $u_{b,4}$ | Aging uncertainty | 1.0 |
| $u_{b,5}$ | Other unknown uncertainties | 0.6 |
| $u_b$ | $u_b = \sqrt{\sum_{i=1}^{n} u_{b,i}^2}$ | 1.73 |

The combined uncertainty is the geometric sum of the Type A and Type B uncertainties, which is 1.88ns.

$$u = \sqrt{u_a^2 + u_b^2} = 1.88ns \tag{5}$$

## V. CONCLUSIONS

In this paper, the principle and error processing of GPS common view are studied firstly. Then, based on the long-term measured data of nearly two years between the two calibration campaigns in NTSC, the Type A uncertainty and Type B uncertainty of the CV comparison link are analyzed. Finally, the combined uncertainty of the link is calculated. The results show that the long-term stability of the GPS time comparison link is completely within the uncertainty range, which is of great significance to the timekeeping work of the NTSC.

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