Absolute Calibration of GPS Time Transfer System at NTSC

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***Abstract*—GNSS time transfer is the main technology currently used in UTC generation. GNSS reception chains need to be calibrated for ensuring accuracy and long-term stability of time links. This paper presents the recent absolute calibration at NTSC. The receiver is calibrated using a satellite simulator, and the antenna calibration is done using a specific anechoic chamber with Vector Network Analyzer (VNA) signals. The results show that the calibration uncertainty is 2.4 ns. We use another receiver, NTP3, was relatively calibrated in 2018 to evaluate the calibrated results. The calibration uncertainty of NTP3 is 3.2 ns from BIPM website. We obtain the common clock difference (CCD) between NTP3 and NT06, and the mean of GPS P3 CV result is 3.95 ns, within the total uncertainty of 4 ns.**

Keywords—GNSS, time transfer, absolute calibration

I. INTRODUCTION

Nowadays, GNSS time transfer is widely used for remote clock comparisons, in particular by the Bureau International des Poids et Mesures (BIPM) for Coordinated Universal Time (UTC) calculation [1]. In order to ensure the accuracy and long-term stability of time transfer links, GNSS reception chains need to be calibrated periodically [2]. Relative calibration and absolute calibration are currently the two main methods used. Relative calibration uses a travelling calibrator to calibrate the total delay of the entire link, but the reference receiver of travelling calibrator must be absolute calibrated [3]. Absolute calibration is determining the time delay of each component of the GNSS reception chain (antenna, cable, receiver), which has higher accuracy and lower calibration uncertainty than relative calibration [4]. At present, BIPM mainly uses relative calibration method to calibrate the UTC link. All laboratories contributing to UTC are divided into Group 1 and Group 2 according to different Regional Metrology Organizations (RMOs). The BIPM will organize the calibration of Group 1 in each RMO, and these Group 1 laboratories will organize calibration campaigns for the Group 2 laboratories of their region [5]. Considering economy and convenience, calibration campaigns will not be carried out frequently. To evaluate the accuracy and stability of GNSS time transfer, the Consultative Committee for Time and Frequency (CCTF) recommends competent laboratories to operate absolute calibration for their GNSS time transfer system.

Recently, we firstly calibrate of the GPS P1 and P2 reception chain of NT06 receiver using absolute calibration at National Time Service Center (NTSC). In this paper, we first briefly describe the basic principle of absolute calibration. Then, the procedures and results of the receiver calibration and the antenna calibration are presented. Finally, the two different GNSS reception chains with common-clock configuration are compared.

II. PRINCIPLE OF ABSOLUTE CALIBRATION

A. Receiver Calibration

The internal delay of the receiver is calibrated using a satellite simulator, which is equal to the time difference between the pseudoranges measured by the receiver and generated by the simulator after deducting other time delays. The calibration method involves simultaneously connecting the receiver and simulator to the same frequency reference [6]. The GNSS simulator generates GNSS signals and 1PPS signals to connect to the receiver to be calibrated, obtaining pseudorange measurements. After deducting the internal delay of the simulator, the difference in delay between the RF link and the 1PPS link, the internal delay of the receiver can be obtained at different frequency. The calibration principle is shown in Fig. 1.

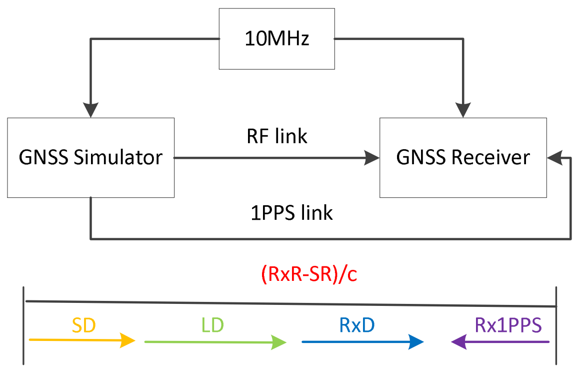

Fig.1. Principle of receiver calibration

The delay at different frequency of the receiver to be calibrated can be given by:

$$RxD = (RxR - SR)/c - LD - SD + Rx_{1pps} \quad (1)$$

where RxD is the receiver delay; $RxR - SR$ is the pseudoranges difference between the receiver and simulator; c is the light speed; LD is the time delay difference between the RF link and 1PPS link; SD is the simulator internal delay and Rx_{1pps} is the delay between the internal reference and the external reference of receiver.

B. Antenna Calibration

The GNSS antenna calibration refers to estimating the time delay between the antenna phase center and the antenna access connector, and is related to the frequency of the GNSS signal. The Vector Network Analyzer (VNA) is used to calibrate the GNSS antenna. One end of the VNA is connected to the transmitting antenna, and the other end is connected to the receiving antenna to be calibrated. The system delay is directly measured by the VNA, then subtracting the delay of the transmitting antenna, free-space propagation delay and cable delay, we can obtain the antenna delay at different frequency. In order to limit the impact of multipath effects, calibration should be performed in a specific anechoic chamber. The calibration principle is shown in Fig. 2.

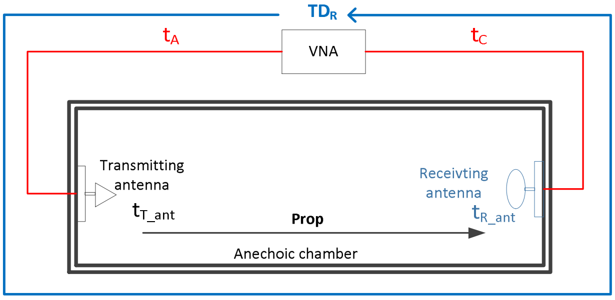

Fig.2. Principle of antenna calibration

$$t_{R\_ant} = TD_R - t_A - t_{T\_ant} - Prop - t_C \quad (2)$$

where t_{R_ant} is the delay of the receiving antenna; TD_R is the system total system delay; t_A and t_C is the delay of cables; t_{T_ant} is the delay of transmitting antenna; $Prop$ is free space propagation delay.

III. CALIBRATION IMPLEMENTATION AND RESULTS

A. Antenna Calibration

Two identical double ridge horn antennas were used as the transmitting antenna in this experiment. The receiving antenna to be calibrated is SEPCHOKE_B3E6 and the VNA that we used is ROHDE&SCHWARZ ZVB14. Cable A and Cable C used in this study are identical. The reference point for the transmitting antenna is at the center of the antenna's radiation aperture, and the reference point for the receiving antenna is at the center of the antenna's base. The actual antenna calibration in the anechoic chamber is shown in Fig. 3.

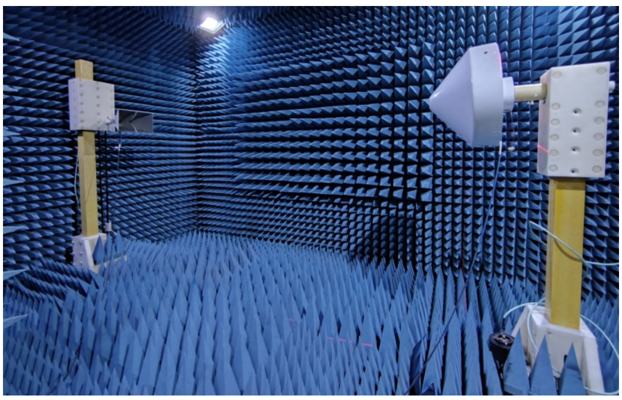

Fig.3. Antenna calibration in the anechoic chamber

The results of antenna calibration with a center frequency of 1227.6 MHz and a bandwidth of 50 MHz are shown in Fig. 4 and the results with a center frequency of 1575.4 MHz are shown in Fig. 5. We use a bandwidth of 10MHz at the center frequency for averaging, and calculate the antenna delay of GPS L1 and L2 band according to equation (1). The antenna phase center correction relative to the antenna reference point is determined using the igs14.atx file.

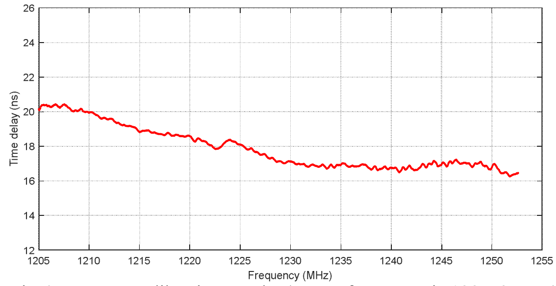

Fig.4. Antenna calibration results (center frequency is 1227.6 MHz)

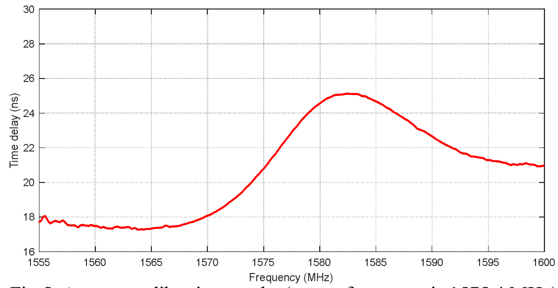

Fig.5. Antenna calibration results (center frequency is 1575.4 MHz)

B. Receiver Calibration

We use Spirent GSS9000 GNSS simulator to calibrate the Septentrio PolaRx5TR receiver. The 1PPS cable and GNSS signal cable used in this experiment are the same 2 m TCOM240 cables, so the time delay difference between the two is 0. The simulator has been calibrated. The auto-calibration of the PolaRx5TR receiver is enabled, so the delay between the PPS IN connector and internal receiver time reference is 0. The actual receiver calibration is shown in Fig. 6.The calibration results of GPS P1 and P2 are shown in Fig. 7 and Fig. 8. Receiver and antenna calibration results of GPS P1 and P2 are shown in Table 1.

Fig.6. GNSS receiver absolute calibration

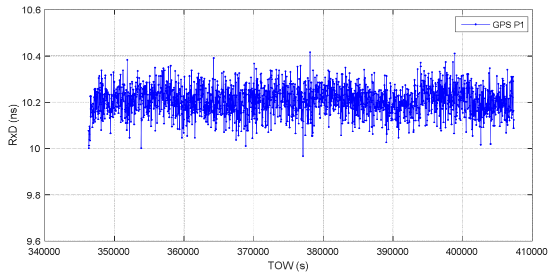

Fig.7. Receiver calibration results of GPS P1

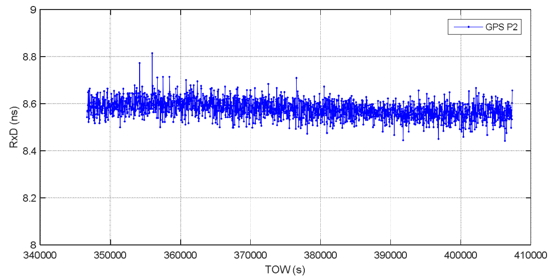

Fig.8. Receiver calibration results of GPS P2

TABLE I. CALIBRATED RESULTS OF NT06 GPS P1 AND P2

GNSS signals	Frequency (MHz)	Delay of SEPCHOKE_B3 E6 (ns)	Delay of PolaRx5TR (ns)
GPS P1	1575.42	21.3	10.2
GPS P2	1227.6	17.9	8.6

C. *Uncertainty budget*

The total uncertainty estimation of the absolute calibration takes into account the errors due to the receiver calibration, antenna calibration and cable calibration. the anechoic chamber, the cable C and the total delay measurement. The total uncertainty is the quadratic sum of these error sources. The uncertainty budget of this absolute calibration is shown in Table 2.

TABLE II. UNCERTAINTY BUDGET FOR THE ABSOLUTE CALIBRATION

	Uncertainty source	Uncertainty (ns)
Receiver calibration	Simulator calibration	2.0
	Pseudorange measurements	0.5
	PPS latching	0.2
	RF and 1PPS links measurements	0.2
Cable calibration	Cable measurements	0.2
Antenna calibration	Transmitting antenna calibration	1.0
	Anechoic chamber	0.5
	Cable measurements	0.2
	VNA	0.2
	Distance	0.1
Total uncertainty		2.4

IV. COMMON-CLOCK VALIDATION

In order to evaluate the accuracy of absolute calibraton, we compare NT06 with NTP3, which was relatively calibrated in 2018 by G1. The calibration uncertainty of NTP3 is 3.2 ns from BIPM website. We conducted a 7-day common clock experiment and obtained the time difference between NT06 and NTP3 using CGGTTS files, and the results are shown in Fig. 9. The CCD results of GPS P3 CV showed that the mean is 3.95 ns, within the total uncertainty of 4 ns.

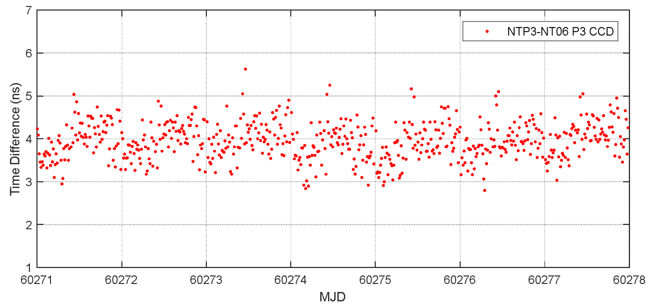

Fig.9. GPS P3 CV CCD results between NTP3 and NT06

V. CONCLUSION

We have completed the first absolute calibration of GPS P1 and P2 reception chains at NTSC. The reception chains are composed of a PolaRx5TR receiver and a SEPCHOKE_B3E6 antenna. The global uncertainty is 2.4 ns, which is dominated by the simulator uncertainty estimated to 2 ns. We performed a validation of the absolute calibration with two complete independent GNSS reception chains. The CCD results between the two receivers show a good consistency. Next, we will calibrate other receivers for comparison and carry out absolute calibration on the Galileo and BeiDou-3 signals.

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