ESTIMATING THE RECEIVER DELAY FOR IONOSPHERE-FREE CODE (P3) GPS TIME TRANSFER

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Abstract

The ionosphere-free code (P3) GPS time transfer uses dual-frequency measurements from GPS geodetic receivers to minimize the errors in the ionospheric delay correction. The P3 GPS time transfer requires knowledge of the receiver delays on both the L1 and L2 frequencies (P3 receiver delay). Very few receivers used for P3 GPS time transfer are absolute calibrated, due to the complexity of the calibration. The BIPM has started regular calibration campaigns to determine the delay of the P3 receivers around the world against an absolute calibrated BIPM receiver. This paper presents a method to estimate the P3 receiver delay that uses a calibrated conventional GPS common-view receiver. The uncertainty of the estimated P3 receiver delay is about the same as that obtained by the differential calibration between two P3 receivers. Each timing laboratory with a calibrated common-view receiver can apply this method to estimate the delay of an on-site P3 receiver. This method can also be used to simplify the differential calibration of both the common-view receiver and the P3 receiver with one traveling common-view receiver.

INTRODUCTION

The GPS common-view method **[1]** has been used to compare remote clocks for more than 20 years. Many national timing centers around the world use GPS common-view to contribute their clock data to the computation of International Atomic Time (TAI) and Coordinated Universal Time (UTC). Most of the conventional common-view receivers are the single-frequency, C/A code, single- or multi-channel receivers designed specifically for time and frequency transfer applications. The receivers are installed in stationary locations with known coordinates to track the same satellites at the same times. The receivers make the time of arrival measurements between the local reference clock and the received GPS time. The measurements are corrected with the delays in the signal path to produce the difference between the local reference clock and the GPS time (REFGPS) **[2]**. By exchanging data from the remote receivers and differencing the two sets of REFGPS data, the GPS time drops out, and we obtain the time difference between two remote clocks. In recent years, the Bureau International des Poids et Mesures (BIPM) and many laboratories apply the measured ionospheric delay (MSIO) and the precise ephemeris provided by the International GPS Service (IGS) to the common-view measurements to reduce the error in propagation delay corrections.

The ionosphere-free code (P3) technique has been developed in the past few years to use the dual-frequency measurements from geodetic receivers for GPS common-view time and frequency transfer applications **[3]**. The P3 common-view has three advantages over conventional common-view. First, the P3 ionospheric delay correction is more accurate than the broadcast modeled ionospheric delay (MDIO) and the IGS MSIO correction. This is especially true for receivers located in areas where the ionosphere changes rapidly. Second, most geodetic receivers produce the P-code measurements, which have higher resolution than the C/A code measurements. Third, the geodetic receivers make the code/carrier phase measurements many times in 1 second, as opposed to the time of arrival measurements made every second by the conventional common-view receivers. As a result, the P3 measurements contain less short-term measurement noise.

Because the P3 data involve the measurements on both the L1 and L2 frequencies, it is necessary to determine the receiver delay on both frequencies in order to compare the time of remote clocks. Procedures have been developed for absolute calibration of several different types of geodetic receivers **[4]**. The BIPM has begun a yearly differential calibration using a calibrated geodetic receiver **[5,6]**. The purpose of the regular differential calibration is to determine the delay of the uncalibrated receivers and to evaluate the long-term stability of the geodetic receivers used for time and frequency transfer applications.

This paper presents a method to estimate the P3 receiver delay with a calibrated conventional single frequency GPS common-view receiver.

ESTIMATING THE P3 RECEIVER DELAY

Geodetic receivers make measurements between a local reference signal and the received GPS signals on both the L1 and L2 frequencies. The measurements are recorded in the Receiver Independent Exchange Format (RINEX) files. Since the delay through the dispersive ionosphere is proportional to TEC/f^2, where TEC is the total electron content over the signal path and f is the frequency of the GPS signal, the impact of the ionospheric delay can be cancelled by the linear combination:

$$P3 = \frac{f_1^2}{f_1^2 - f_2^2} P1 - \frac{f_2^2}{f_1^2 - f_2^2} P2 = 2.54 \cdot P1 - 1.54 \cdot P2 \,. \qquad (1)$$

In Equation (1), P1 and P2 are the code measurements with the GPS signal's propagation time on the frequencies f_1 = 1575.42 MHz, f_2 = 1227.60 MHz, and P3 is the ionosphere-free code measurements. For time transfer applications, the receiver hardware delays on L1 and L2 frequencies (INT_{L1} and INT_{L2}) must be removed from the P1, P2 measurements to generate the P3 data. During the absolute or differential geodetic receiver calibration, INT_{L1} and INT_{L2} can be individually determined. Because conventional common-view receivers make measurements only on the L1 frequency, the P3 receiver delay (INT_{L1} and INT_{L2}) cannot be obtained directly from the comparison between the conventional common-view data and the P3 data.

In the common-clock, common-view (short-baseline) setup, we can use the following three steps to estimate the P3 receiver delay with respect to a calibrated common-view receiver:

(1) Compute the common-view difference between the common-view receiver and the P3 receiver with the INT_{L1} and INT_{L2} for the P3 receiver set to zero. The P3 data contain no ionospheric delay. The data from the common-view receiver are corrected with the MDIO. To minimize the errors introduced by the

MDIO correction, the common-view data are post-processed with the IGS MSIO correction before computing the difference between the common-view data and the P3 data. Because both receivers are driven by the same reference signals, and the common-view receiver is calibrated, the GPS time and the local reference clock are canceled in the common-clock, common-view difference. The difference that remains is the composite delay of the P3 receiver:

$$INT_{L3} = 2.54 \cdot INT_{L1} - 1.54 \cdot INT_{L2} \,. \qquad (2)$$

(2) Estimate the INT_{L1} delay for the P3 receiver by computing the common-view difference using no ionospheric delay correction in both the common-view receiver data and the P3 receiver data. With the RINEX files, we can generate the REFGPS data based on only the P1 observations with no ionospheric delay correction for the P3 receiver. The REFGPS without ionospheric delay corrections for the common-view receiver can be obtained by removing the MDIO or the IGS MSIO corrections from the REFGPS data. By differencing the two sets of modified REFGPS data, the ionospheric delays are canceled. We obtain the INT_{L1} for the P3 receiver.

(3) With the composite P3 receiver delay, INT_{L3}, from Step 1, and the INT_{L1} from Step 2, we can obtain the INT_{L2} delay from:

$$INT_{L2} = \frac{2.54 \cdot INT_{L1} - INT_{L3}}{1.54} \,. \qquad (3)$$

UNCERTAINTY OF THE ESTIMATED P3 RECEIVER DELAY

The uncertainty of the estimated P3 receiver delay comes from the uncertainty of the calibrated common-view receiver delay and errors introduced by computing the composite P3 receiver delay in Step 1. For a high-quality common-view receiver, the uncertainty of the differential calibrated receiver delay is on the order of a few nanoseconds. This is about the same as the uncertainty of the differential calibration of the geodetic receivers **[7]**. To evaluate the uncertainty introduced by the composite P3 receiver delay, we compared the common-view differences between the receivers at the National Institute of Standards and Technology (NIST) and the receivers at the US Naval Observatory (USNO). The results are shown in Table 1, Fig. 1, Fig. 2, and Fig. 3.

The USNO receivers, USNO (common-view receiver) and USN3 (P3 receiver), have been absolute calibrated. The mean difference of the USNO - USN3 is -3.7 ns. The NIST common-view receivers, NIST and NISA, have also been differential calibrated with respect to an absolute calibrated common-view receiver. The P3 receiver delay for the NIST geodetic receivers, NISTP3 and NISAP3, are estimated with respect to the common-view receiver, NIST. By subtracting the difference between the P3 receivers from the difference between the common-view receivers, we should get the difference of USNO - USN3 plus the error in the estimate of the P3 receiver delay. The error is 0.2 ns for both the NISTP3 and the NISAP3 receiver delay estimates, which adds very little to the uncertainty of the common-view receiver delay. Although these results have not been compared to the results of the differential calibration between the geodetic receivers, the two examples suggest that the uncertainty of the estimated P3 receiver delay should be about the same as that obtained by differential calibration between two geodetic receivers.

CONCLUSION

We can estimate the P3 receiver delay using a calibrated conventional common-view receiver. The uncertainty of the estimated P3 receiver delay is about the same as that obtained by differential calibration between two P3 receivers. Each timing laboratory with a calibrated common-view receiver can use this method to estimate the P3 receiver delay. Instead of calibrating the common-view and the P3 receiver delays separately with two traveling receivers, this method can also be used to calibrate both delays with one common-view traveling receiver.

ACKNOWLEDGMENTS

I thank Pascale Defraigne of the Royal Observatory of Belgium for her source code of the P3 data program. I also thank Gerard Petit of the BIPM and Marc Weiss of NIST for the helpful discussions and advice about this method.

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Table 1. Error in the Estimate of P3 Receiver Delay.

Difference Period	Common-view Difference	Mean / Standard Deviation
53736 – 54019	USNO – USN3	-3.7 ns / 0.7 ns
53886 – 54019	[USNO – NIST] – [USN3 – NISTP3]	-3.5 ns / 0.6 ns
53736 – 54019	[USNO – NISA] – [USN3 – NISAP3]	-3.5 ns / 1.5 ns

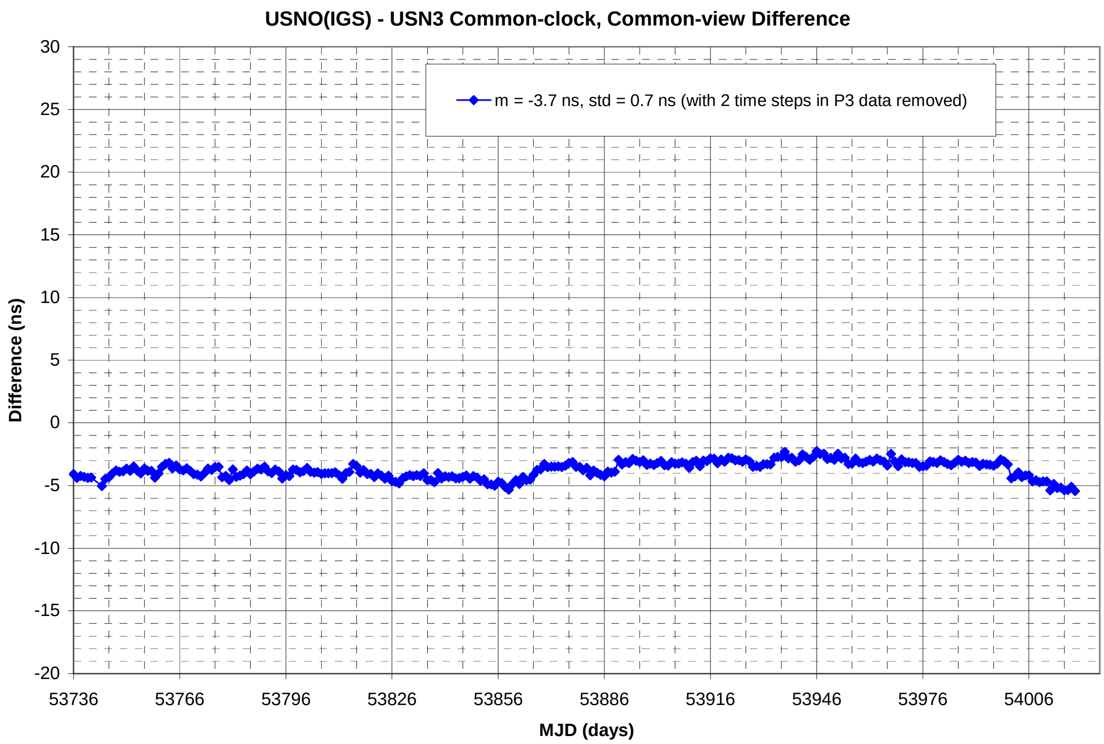

Figure 1. Daily averaged common-view difference between the USNO and USN3 receivers.

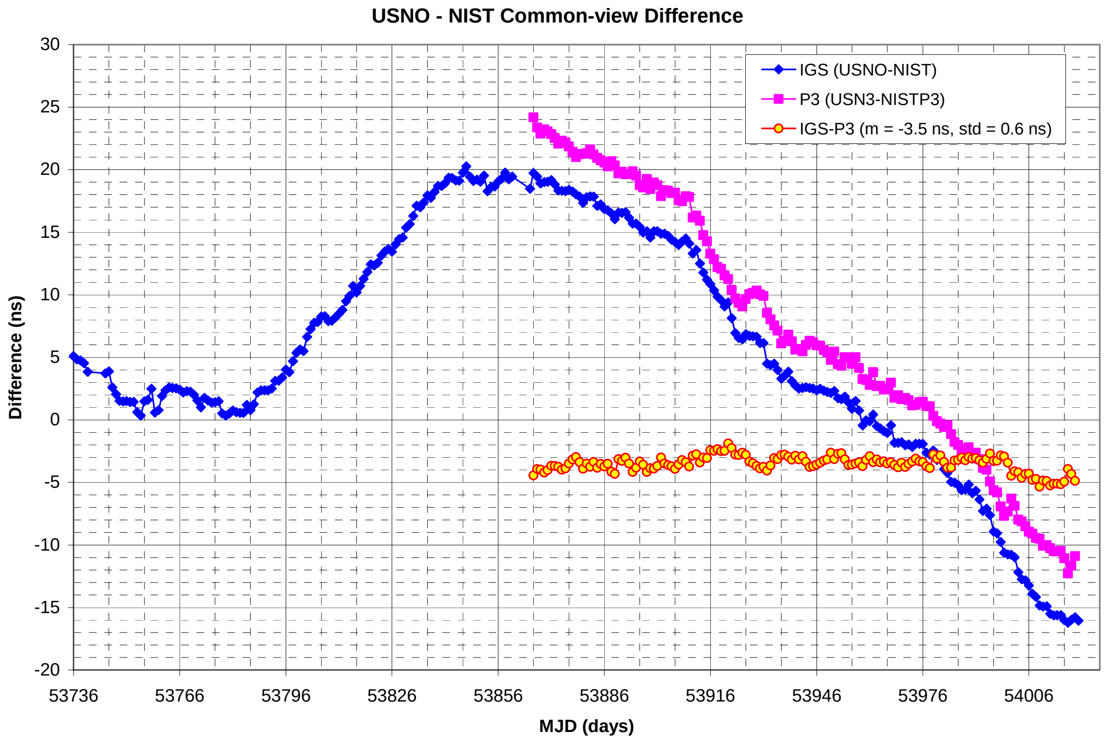

Figure 2. Daily averaged common-view differences between USNO and NIST and between USN3 and NISTP3 receivers.

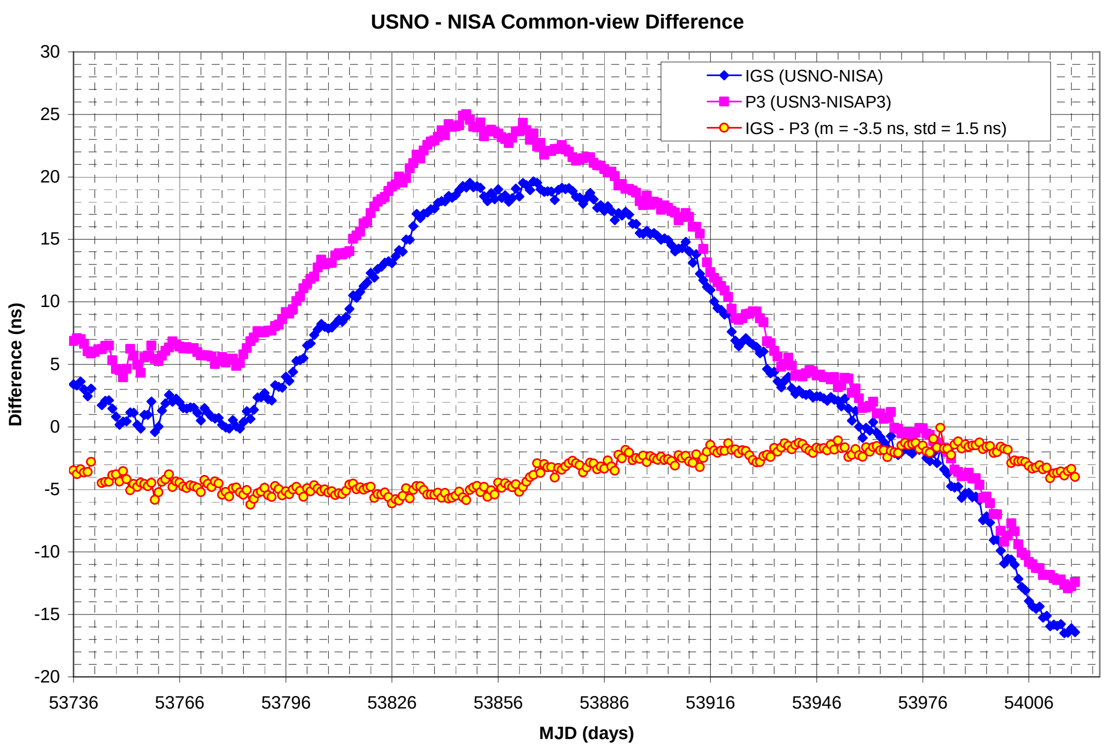

Figure 3. Daily averaged common-view differences between USNO and NISA and between USN3 and NISAP3 receivers.