TIME TRANSFER WITH GEODETIC GPS RECEIVERS

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ABSTRACT. The classical time transfer method used to realize the TAI (International Atomic Time) is based on the common view technique, with GPS observations collected by C/A (Course Acquisition) code receivers. However, the geodetic GPS receivers have the advantage of providing additionally P (Precise) code and carrier phase data, which can be used to compare the internal receiver clocks with a very high precision. This paper presents the possibilities and limitations of the geodetic GPS receivers for time and frequency transfer applications.

1. INTRODUCTION

The International Atomic Time scale (TAI) is computed by the Bureau International des Poids et Mesures (BIPM) from a set of atomic clocks distributed in about 40 time laboratories over the world. Each laboratory 'k' maintains a local realization of UTC called UTC(k), to which all the clocks of the laboratory are reported. In order to compare remote clocks for the computation of TAI, time receivers (which are C/A code receivers) are installed in the time laboratories. These receivers are connected to the 1 pps (pulse per second) signal delivered by UTC(k), and an internal software computes, following a given procedure as recommended by the CCTF (Allan and Thomas, 1994), the clock offsets between UTC(k) and GPS time as realized by each satellite for conventional tracks appearing in the international BIPM tracking schedules. When comparing clocks located at several thousands km from each other, the precision of this technique is of a few nanoseconds.

Geodetic GPS receivers have the advantage of providing additionally P code and carrier phase data, with a noise level significantly smaller than the noise on the C/A code. However, most of these receivers do not allow a direct link between their internal clock signal and the external clock used to steer the receiver frequency. These receivers resynchronize their internal clock on GPS time after each tracking interruption, and this with an uncertainty of 1 microsecond. This induces a clock discontinuity at each tracking interruption. Some geodetic receivers, especially designed to be also suitable for time transfer, like the Ashtech Z-XII3T, are steered by an external clock frequency and synchronize their internal clock on the 1pps signal provided by the same external clock, so that the receiver internal clock is directly a mirror of the external clock. In this way, there are no clock discontinuities associated with tracking interruptions as is the case with classical geodetic receivers.

The use of geodetic receivers for time and frequency comparisons fits with the main goals of the IGS-BIPM pilot project (Ray, 1999). These are, first, to allow a comparison of frequency standards ("clocks") with higher stability than the classical common view with C/A code. A

second objective is to use GPS in order to get an improved availability of accurate time and frequency comparisons. On the one hand, the TAI has a very good long term stability, but is available only after several weeks. On the other hand, the IGS can provide with a 2-day delay a time scale with a very good short-term stability. This will be steered to TAI in order to ensure the long-term stability. This IGS time scale is realized from the IGS clock combinations, i.e. satellite and receiver clock offsets (Kouba and Springer, 2001; Senior et al., 2001), based on time transfer between IGS receiver and/or satellite clocks, and it is computed from the combination of code and phase observations. In the present study, we show the advantage of using geodetic GPS receivers like the Ashtech Z-XII3T, involved in IGS, to establish the link between the IGS clock combinations (satellite and receiver clock offsets) and TAI.

2. FREQUENCY TRANSFER USING GPS CARRIER PHASES

The noise level of the carrier phase observable is about 100 times smaller than the corresponding noise level on the code observable. For this reason, the carrier phases have been used since '80 for different geodetic applications requiring very high precision. During the last years, the potential of GPS carrier phases for time transfer was recognized and demonstrated by different authors (Overney et al., 1998, Larson et al., 1999, Bruyninx et al., 2000). The phase observable is given as

$$P_p^i = -f(\tau_p^i + \Delta t_p - \Delta t^i) + (\Phi_0^i - \Phi_{0p}) + N_p^i \tag{1}$$

where τ_p^i is the travel time (including the atmospheric effects), Δt_p and Δt^i are the receiver and satellite clock offsets, Φ_{0p} and Φ_0^i are the receiver and satellite initial phases, and N_p^i is the phase ambiguity, which is constant during one track if there is no tracking interruption. The clock offset between two receivers p and q, written as Δt_{pq}, is obtained from the single difference

$$P_p^i - P_q^i = -f(\tau_p^i - \tau_q^i + \Delta t_{pq}) + (\Phi_{0p} - \Phi_{0q}) + N_p^i - N_q^i \tag{2}$$

Due to the unknown phase ambiguities, it is not possible to determine the absolute value of Δt_{pq}. The carrier phase observable can thus only be used for frequency transfer, i.e. for the determination of the time evolution of Δt_{pq}. The absolute value of the clock offset will be determined using the code observables. A combined analysis using both carrier phase and code observations is necessary to obtain both the absolute value of the clock offset, with a precision limited by the code noise level (some nanosecond), and a very precise determination of the frequency transfer.

The comparison of very stable frequency standards over short time intervals using code observables does not give sufficiently precise results. Consequently, the stability of the frequency standards is deteriorated by this comparison technique. Recent tests have shown that the carrier phase frequency transfer allows to compare clocks with a stability of some parts in 10^{16} at a period of 1 day. This is illustrated in Figure 1 where the frequency transfer has been performed between two Hydrogen masers located in Brussels and Westerbork (about 290 km far from Brussels). The modified Allan deviation of this frequency transfer is reported in the right part of Figure 1; it corresponds exactly to the Allan deviation characterizing the Hydrogen masers. This indicates that the carrier phases are a very powerful tool for the frequency transfer between stable frequency standards because their noise level is smaller than the noise level of the clocks compared. This fits perfectly within the first goal of the IGS-BIPM pilot project as described in the introduction.

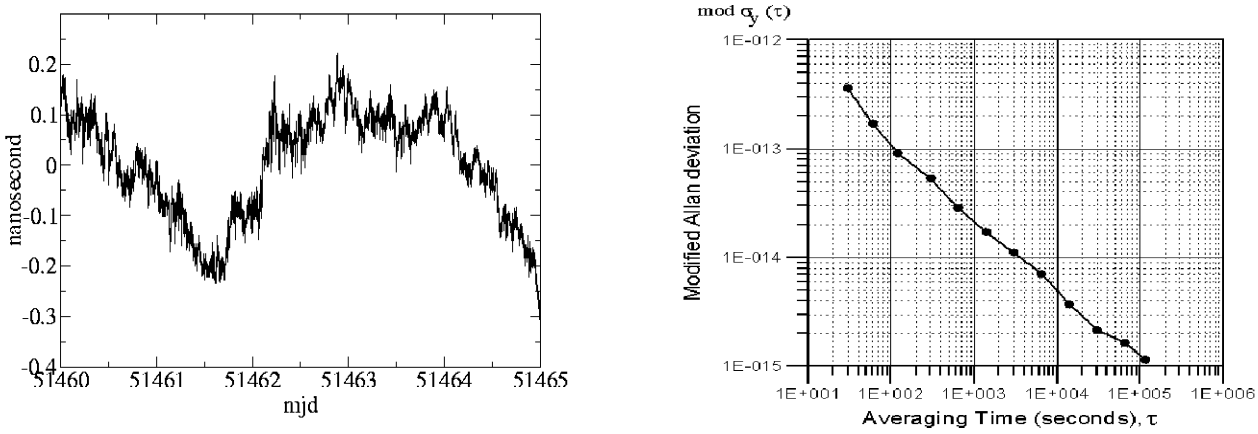

Figure 1: (left) Frequency transfer between the two Hydrogen masers located in Brussels and Westerbork, computed from carrier phase analysis. (right) Stability of the signal presented in the left part of the figure, as given by the modified Allan deviation, as a function of the averaging time.

3. LINK BETWEEN TAI AND IGS CLOCK PRODUCTS

The link between TAI and the IGS clock products can be established from time transfer between atomic clocks operating within both the IGS and time communities. Furthermore, we developed the idea to use the same GPS receiver for both applications, TAI and IGS. As explained in the introduction, most of the geodetic GPS receivers used with IGS synchronize their internal clock on GPS time, and provide a discontinuous time scale in case of tracking interruption. However, when using the Ashtech Z-XII3T, of which the internal clock is driven by an external clock frequency and is synchronized on its 1pps signal, the receiver clock will be continuous and directly linked to the external clock. So, using this receiver for time transfer applications allows a direct time transfer between the external clocks, which is not the case for the classical geodetic receivers for which the link between the receiver clock and the external clock is not constant, or even cannot be precisely determined.

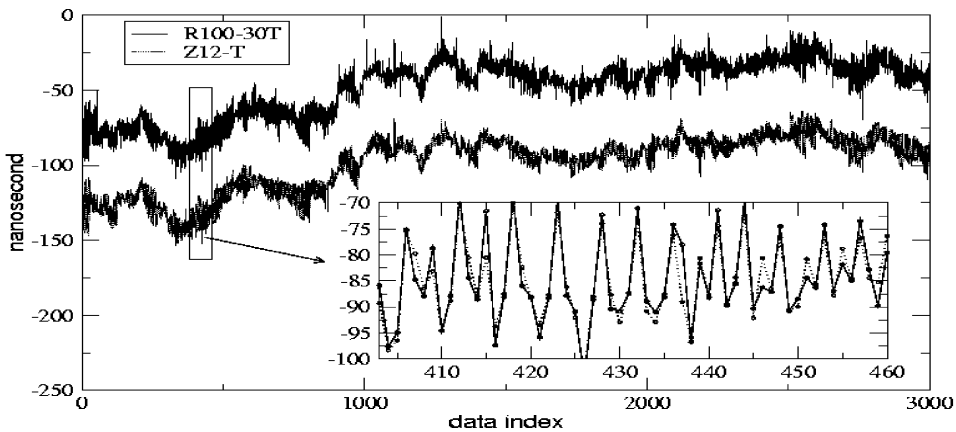

Figure 2: Figure 2. Figure 2. Comparison between the CCTF results (UTC(ORB)-GPS time) computed by the R100-30T receiver and the RINEX-based CCTF deduced from the Ashtech Z-XII3T receiver after shifting one curve by 50 ns for better visibility (only in the zoom).

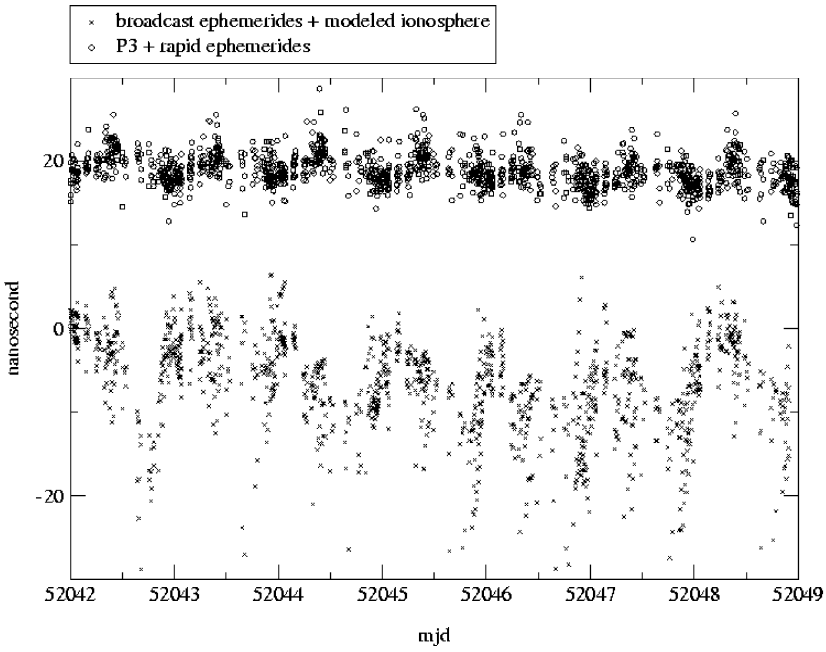

Figure 3: Figure 3. Time transfer between two hydrogen masers, located in Brussels and second at USNO (Washington), when using the classical CCTF procedure (i.e. broadcast ephemerides and broadcast ionospheric model) and when using the modified CCTF procedure, (i.e. using the P3 code and the IGS rapid orbits). The offset between the two signals has been introduced to allow better visibility.

In order to use the geodetic GPS receiver Ashtech Z-XII3T for time transfer to TAI, we developed a software (Defraigne and Bruyninx, 2001) which constructs, from the RINEX observation files, the CCTF files needed for TAI. This software follows exactly the procedure recommended by the CCTF (Allan and Thomas, 1994) for the computation of the clock offsets between UTC(k) and GPS time as realized by each satellite for conventional tracks appearing in the international BIPM tracking schedules. This procedure uses the C/A code observations, and, in order to obtain the clock offset between the laboratory clock and GPS time, corrects them for the geometric delay (computed with antenna coordinates and broadcast satellite ephemerides), ionospheric and tropospheric delays, sagnac effect, periodic relativistic effect associated with the satellite orbit, L1-L2 group delay, satellite clock offset with respect to GPS time, receiver hardware delay, antenna and local clock cable delays. Figure 2 shows the comparison between the CCTF results (corresponding to UTC(ORB)-GPS time) obtained with a time receiver R100-30T from 3S-Navigation, and with our software applied to the RINEX observation files from the geodetic GPS receiver Ashtech Z-XII3T. The differences between both are at the noise level.

We also proposed to modify the classical CCTF procedure in order to use the additional observations provided by the geodetic GPS receivers. Firstly, the P codes which are given in the RINEX files for the two GPS frequencies L1 and L2, and which are called P1 and P2, can be combined into the so-called 'ionospheric-free' code observable P3. This combination exploits the frequency dependence of the ionospheric delay in order to cancel it out. In this P3 code, the ionospheric delay is therefore absent, while the ionospheric correction proposed in the CCTF procedure for the C/A code is based the Klobuchar ionospheric model which corrects only one part of the ionospheric delay, because it cannot represent and hence correct the effects of the random part of the ionospheric activity. Secondly, we also replace the broadcast ephemerides with the "rapid orbits" as computed by IGS in differate time (after a time delay of about 2

days). Figure 3 shows the time transfer between two Hydrogen masers, the first one located Brussels and the second one located at USNO (Washington), when using the classical CCTF procedure and when using the modified CCTF procedure, i.e. using the P3 code and the IGS rapid ephemerides.

If the same receiver is involved within both IGS and TAI, we have access to its clock offset with respect to the IGS clock products and with respect to TAI. In the case of the Ashtech Z-XII3T receiver, we have therefore simultaneously the clock offset of the external clock with respect to the IGS clock products and with respect to TAI. If we apply this setup in several stations we will finally be able to determine, with very high precision, the link between the IGS clock products and the TAI.

Note that in order to know the absolute offset between these clocks and the two time scales (IGS and TAI), all the delays due to propagation of the signal inside the GPS antenna, cables and receiver must be precisely determined. This stresses the need of perfectly calibrated installations. A calibration campaign for the determination of antenna and receiver hardware delays of receivers ZXII-T is presently organized under the initiative of the BIPM (Petit et al., 2001).

4. CONCLUSIONS

We have shown that the geodetic GPS receivers are very good tools for precise frequency transfer with GPS. However, in order to determine the absolute offsets, the frequency transfer obtained from carrier phase analysis must be complemented by the code observations. The IGS time products are based on a combined analysis of code and phase observations. The link between these IGS clock products and the international atomic time scale TAI requires several calibrated IGS receivers, driven by atomic clocks also contributing to TAI.

5. REFERENCES

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