

INITIAL TESTING OF A NEW GPS RECEIVER, THE POLARX2, FOR TIME AND FREQUENCY TRANSFER USING DUAL-FREQUENCY CODES AND CARRIER PHASES

P. Defraigne, C. Bruyninx, and F. Roosbeek
Royal Observatory of Belgium

Abstract

To contribute to TAI, the Royal Observatory of Belgium (ROB) routinely performs all-in-view time transfer using an Ashtech Z-XII3T GPS receiver and the in-house-developed RINEX-CGGTTS conversion software. In order to anticipate the renewal of that kind of time transfer equipment, the ROB started to test a new geodetic GPS receiver, the PolaRx2, developed by Septentrio (Belgium), for suitability for time transfer applications. Our results, obtained using codes as well as carrier phases, show that this receiver is very promising, with a 1 pps input port, and a very low noise level on the codes. However, we proposed and started to evaluate some hardware and firmware adaptations to improve its performances for continuous and precise (sub-ns) time transfer. The present firmware release indeed introduces clock discontinuities at each receiver reset, and produces variations at the level of tenths of nanosecond due to internal temperature variations related to changes in the processor load (depending on the number of used channels).

INTRODUCTION

The time lab of the Royal Observatory of Belgium (ROB) presently uses the geodetic Ashtech Z-XII3T receiver and the in-house-developed RINEX-CGGTTS conversion software to contribute to TAI. This equipment replaces the previously used single channel C/A code GPS receiver (type NBS, decommissioned in April 1999), and the 12-channel GPS/GLONASS receiver (type R100-30T from 3S Navigation, decommissioned in November 2001). The Ashtech Z-XII3T is steered by an active H-maser CH1-75, which is used to generate the local realization of UTC, UTC (ORB). The receiver participates in BIPM campaign TAIP3 (TAI time links with geodetic receivers using the ionosphere free combination P3; see [1]), and it also belongs to the International GPS Service IGS (station BRUS); the H-maser is consequently also included in the IGS time scale.

The production of the Ashtech Z-XII3 (the core of the Ashtech Z-XII3T) has ended some time ago and repair services will only be available for the Z-XII receivers for as long as replacement parts are available, with end-of-life estimated to occur in October 2004. For this reason, we are presently investigating the use of a new geodetic receiver, the PolaRx2 (see Figure 1), developed by Septentrio (Belgium). This receiver provides dual-frequency tracking of the GPS signal and simultaneous tracking of up to six Space-Based Augmentation System (SBAS) satellites. Its raw measurements and navigation data can be converted into the RINEX format using a conversion utility provided by Septentrio. Furthermore, the receiver accepts a 10 MHz external frequency and an associated 1 pps input, which makes it suited for

time transfer applications. The internal clock is obtained from a multiplication by 6 of the external frequency, followed by a division by 2; this division consists of taking one from two positive (or negative) zero-crossings of the 60 MHz frequency. The first one being chosen arbitrarily, this induces an ambiguity of a multiple of 8.33 ns in the delay between the 1 pps input and the latching of the observations. Septentrio is aware of this effect and states that this ambiguity will be eliminated in next versions of its receiver. The relation between the latching of observations and the external clock can, however, be obtained from the 1 pps output, which is synchronized with the internal clock, or from postprocessing. This allows, by differential analysis of the code measurements, one to determine the internal hardware delays of the receiver.



Figure 1. PolaRx2 receiver (Septentrio)

As the ROB is strongly involved in the EUREF Permanent Network (EPN), we are routinely computing the time link between all the EPN stations equipped with an Ashtech Z-XII3T receiver and USNO, also equipped with a Z-XII3T receiver, connected to the H-maser MC #3, which is steered to the realization of

UTC (USNO). Two separate analyses are performed: a RINEX-CGGTTS analysis using ionosphere-free code P3 and rapid IGS orbits [2] and a Bernese-based combined code carrier-phase analysis [3]. In order to investigate their ability to participate in time transfer studies, two PolaRx2 receivers were installed at the Royal Observatory of Belgium and were introduced in the analyses. The first section of the paper describes the setup of the experiments; the numerical results obtained from a combined code/carrier-phase analysis are presented in the second section; the determination of the hardware delays and the possibility of using the PolaRx2 receiver within the TAIP3 project are investigated in Section 3; and the conclusions are discussed in the last section.

SETUP OF THE EXPERIMENT

Our initial tests have been obtained with two PolaRx2 receivers (named PLB1 and PLB2) and two Ashtech Z-XII3T receivers (named ZTBR and BRUS). Three receivers (PLB1, PLB2, and ZTBR) are connected to the same Ashtech antenna (type Dorne Margolin, ASH701945B_M) with a one-input, four-output GPS splitter (type S14, from GPS Source, Inc.); the RGB233 antenna cable is about 50 m long. The BRUS receiver is connected to a similar Ashtech antenna (using the low-loss 85 m heliax LDF250A cable from the Andrew Corporation), but located on the IGS reference marker about 53 m from the other antenna. All receivers are located in the same laboratory, where temperature variations are limited to 0.1°C. All receivers are driven by a multiple (x2 or x4) of the 5 MHz frequency provided by ROB's active hydrogen maser CH1-75 (KVARZ). The 1 pps is obtained from the same 5 MHz frequency using a frequency divider developed in-house, and amplified with a distribution amplifier DATUM (see Figure 2). This signal corresponds to our local realization of UTC as time laboratory: UTC (ORB).

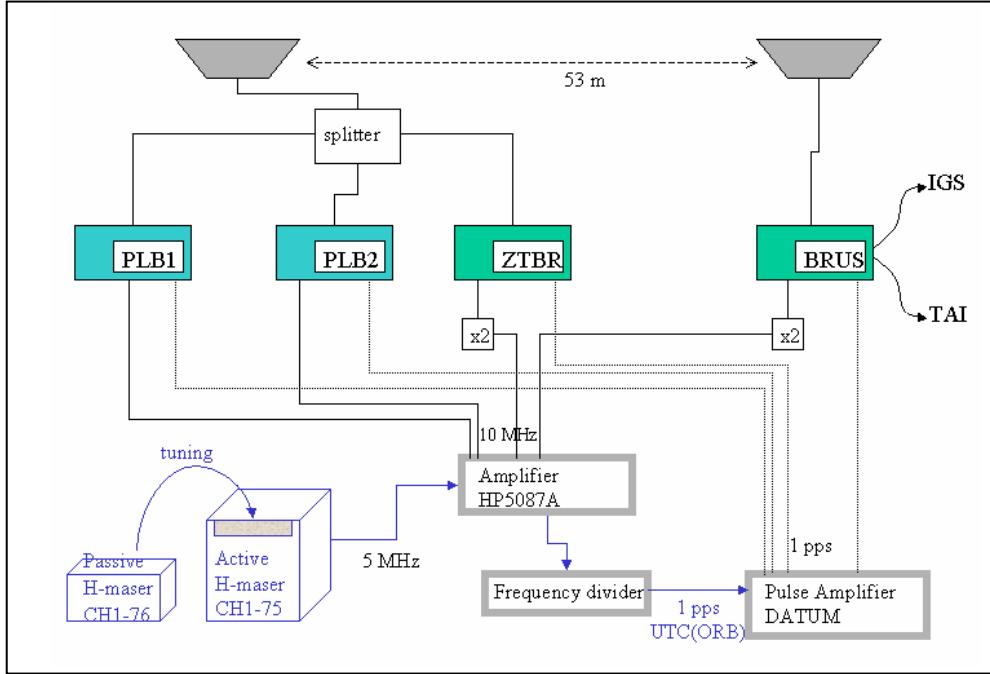


Figure 2. Setup of the experiment.

TIME TRANSFER USING A COMBINED CODE AND CARRIER-PHASE ANALYSIS

Using a combined code and carrier-phase analysis with the Bernese V4.2 analysis software, we have computed the time link between Brussels and USNO for all of our four receivers. The results show significant discrepancies (below the 1 ns level) between the signals obtained with the Z-XII3T or the PolaRx2 receivers, as well as between the signals obtained with the two PolaRx2's, while there is a very good agreement between the signals obtained with the two Z-XII3T's, although they track on separate antennae. This is illustrated in Figure 3.

From discussions with Septentrio, and from the observed daily repeatability of the variations obtained with PLB1 and PLB2, emerged the hypothesis that the variations obtained with the PolaRx2 could be due to temperature variations associated with the variable load on the receiver's channels when tracking different amounts of satellites. These temperature changes induce variations of the internal hardware delays and, hence, of the determination of the time signal. This hypothesis was tested and validated using an option of the PolaRx2 receiver to limit the number of used channels (to eight in our case), which stabilizes the internal temperature of the receiver. We introduced this modification on PLB1 only. The results obtained with the receivers BRUS and ZTBR and those obtained with PLB1 coincide now very well, while PLB2, still tracking variable number of satellites, carry on giving the same variations. This is illustrated in Figure 4. A special firmware version, currently under test at the ROB, should remedy the problem without having to limit the number of channels.

The sensitivity to internal heating is also observed in the case of a receiver reset: the signal shows a small drift during the first minutes after the restarting, but this has also been observed with the Ashtech receiver Z-XII3T, as illustrated in Figure 5. Note that the jumps associated with the interruptions in Figure 5 are due to changes of antenna splitter (plus the clock ambiguity for PLB1).

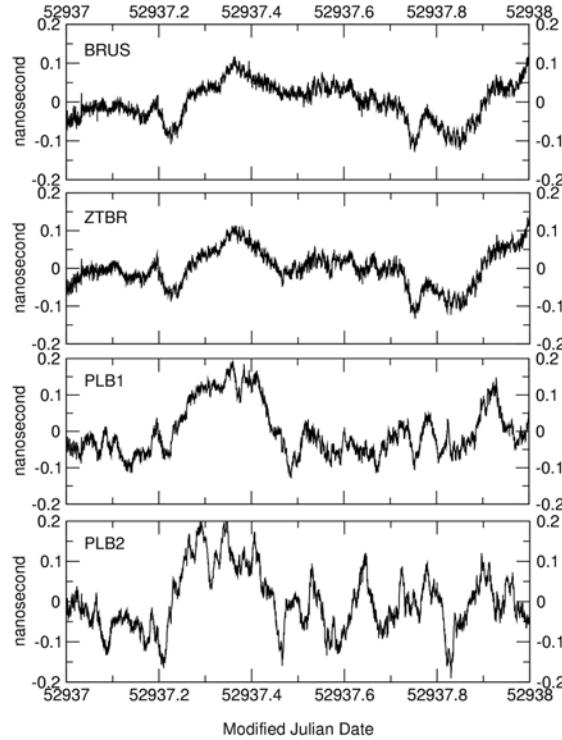


Figure 3. Time link (detrended) between USNO and each of the four receivers installed at ROB, based on a combined code and carrier-phase analysis.

TIME TRANSFER USING A CODE-ONLY ANALYSIS

Before analyzing the RINEX data in terms of time synchronization, we first compared the noise level of the code measurements from the PolarRx2 and the Ashtech Z-XII3T. The different specifications provided by Septentrio and Ashtech concerning the noise are given in Table 1. We investigated the effect of these noise levels on our time transfer results by performing two zero-baseline tests: ZTBR (Z-XII3T) – PLB1 (PolarRx2) and PLB1 (PolarRx2) – PLB2 (PolarRx2).

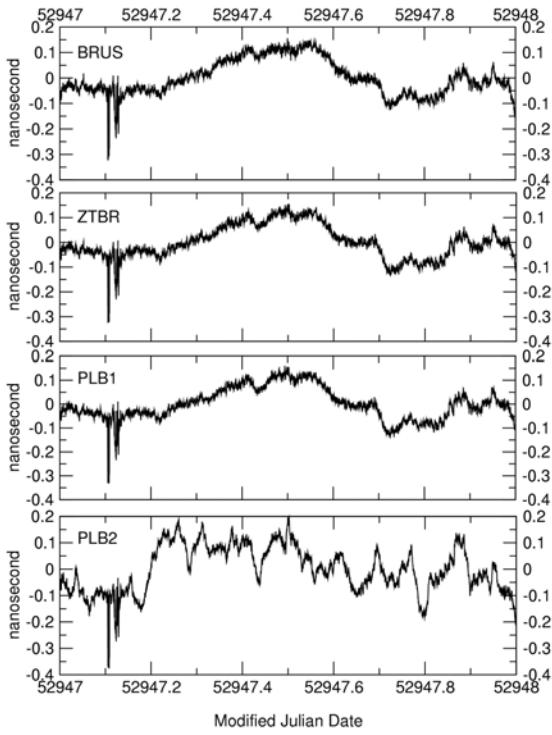


Figure 4. Time link (detrended) between USNO and each of the four receivers installed at ROB, based on a combined code and carrier-phase analysis. PLB1 is set on an eight-channel option, while PLB2 tracks variable number of satellites.

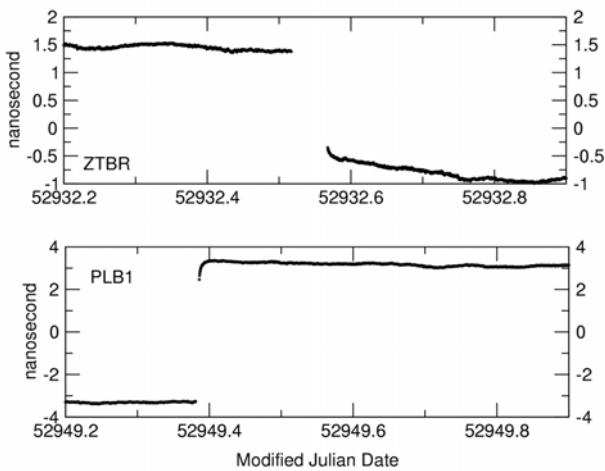


Figure 5. Time links between USNO and ROB using either ZTBR or PLB1. Small drifts during the first minutes after the restarting are observed.

Table 1. Noise specifications as indicated by the manufacturers.

receiver	C/A code	P code	L1-phase	L2-phase
Ashtech Z-XII3T	0.25 m	1.20 m (10°-30° elevation) 0.25 m (30°-50° elevation) 0.10 m (> 50° elevation)	1.4 mm	1.4 mm
Septentrio PolaRx2	0.15 m	0.10 m	0.2 mm	0.4 mm

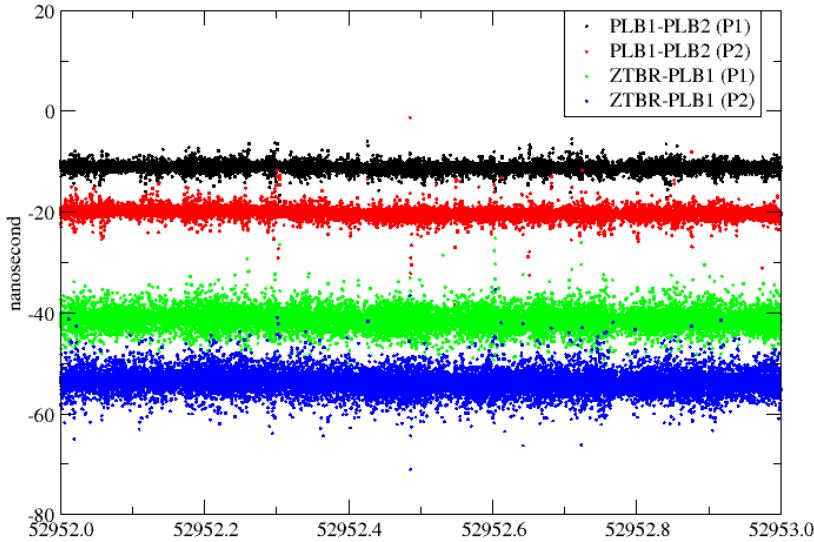


Figure 6. Difference of pseudoranges between two PolaRx2 receivers and between one PolaRx2 and one Z-XII3T, all connected to the same antenna.

The differences between the pseudoranges are shown in Figure 6. For the differences between the two PolaRx2, we got 0.6 ns (resp. 0.9) rms for the difference in P1 (resp. P2), and for the differences between the Ashtech receiver ZTBR and the PolaRx2 receiver PLB1, we got 1.7 ns (P1) and 1.9 ns (P2).

We also investigated the possibility of using the PolaRx2 receivers to perform time transfer suitable for TAI using the ionosphere-free code P3, and applying the procedure described in Defraigne and Petit [2]. The results of the transatlantic time link between Brussels and USNO with the two kinds of receivers – one Ashtech Z-XII3T (ZTBR) and one PolaRx2 (PLB2) – are presented in Figure 7. It appears clearly that both results are equivalent, as was confirmed also by the Allan deviations (not shown). However, in order to use the PolaRx2 for time links, it is still necessary to determine its internal hardware delays. This can be done by a differential calibration, as already proposed by Petit *et al.* [4]. While the link between the 1 pps input and the internal clock is not perfectly known for the PolaRx2, it is possible to have access to the internal clock using the 1 pps output that is synchronized to the internal clock (with a constant offset of 58±2 ns determined by the manufacturer). The clock synchronization error UTC (ORB) – GPS is obtained from the pseudoranges corrected for the delays of the receiver hardware, antenna, and cables. Both Z-XII3T receivers (BRUS and ZTBR) have been calibrated within the BIPM calibration campaign.

As ZTBR is connected to the same antenna as PLB1 and PLB2, we used ZTBR as a basis to determine differentially the hardware delays of the two PolaRx2 receivers. We measured the delay between the latching of observations (through the 1 pps output) and UTC (ORB), using a GT200 time interval counter.

We then compared the pseudoranges with those obtained by the ZTBR receiver connected to the same antenna. We obtained the hardware delays from the following formula, which must be solved for P1 and P2 separately:

$$rec_i(P1, P2) = -A_i(P1, P2) + rec_{ZTBR}(P1, P2) + ref_i - ref_{ZTBR} - ant_i + ant_{ZTBR} \quad (1)$$

where i means one of the two PolaRx2 receivers (PLB1 and PLB2) to be calibrated, A_i is the mean difference between the pseudoranges of PLB1 or PLB2 and ZTBR, rec is the receiver hardware delay, ref is the delay between the latching of observations and UTC (ORB), and ant is the antenna + antenna cable delays. From this formula, and using 1 day of 30-second data, we got the receiver hardware delays for PLB1: 204.8 ns (P1) and 223.7 ns (P2), and for PLB2: 203.8 ns (P1) and 221.8 ns (P2). Note that in this determination, the values that can change in case of interruption are ref_b , which contains the ambiguity due to the frequency division, and A_i , the pseudorange affected by the same quantity; both cancel in equation (1).

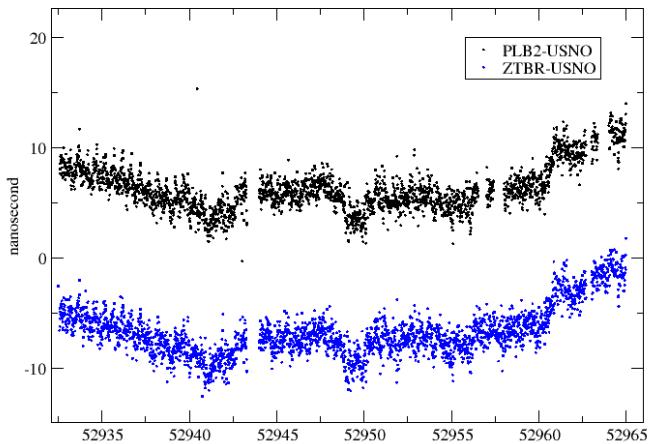


Figure 7. Time link between UTC (ORB) and USNO (MC #3) using two types of receivers in Brussels: one PolaRx2 and one Z-XII3T, and using the RINEX-CGGTTS conversion based on the ionosphere-free code P3 and rapid IGS orbits. A constant offset has been introduced between the two curves in order to allow better visibility.

CONCLUSIONS

Some preliminary tests have been presented to investigate the possibility of using the new PolaRx2 receivers from Septentrio for time and frequency transfer applications. Our results show that the PolaRx2 is very promising, thanks to its possibility of synchronizing the internal clock to an external clock, and thanks to the very low noise on the codes. Furthermore, it is possible to have access to the latching of

observations and, hence, to determine the receiver hardware delays differentially. However, one modification is still necessary before the PolaRx2 can be used for continuous time transfer: because the internal clock is defined with respect to the 1 pps input with an ambiguity multiple of 8.33 ns, jumps are introduced in the time links in case of a receiver reset.

We also demonstrated that the PolaRx2 can also be used for sub-nanosecond carrier-phase frequency transfer. However, the present receiver release requires fixing the number of channels in such a way that they are permanently occupied in order to avoid variations of the internal temperature that affect the hardware delays and, consequently, the signals at an observable level (some tenths of nanosecond). This will be solved in the upcoming versions.

REFERENCES

- [1] G. Petit, Z. Jiang, and P. Moussay, 2003, “*TAI time links with geodetic receivers: a progress report*,” in Proceedings of the 34th Annual Precise Time and Time Interval (PTTI) Systems and Applications Meeting, 3-5 December 2002, Reston, Virginia, USA (U.S. Naval Observatory, Washington, D.C.), pp. 19-28.
- [2] P. Defraigne and G. Petit, 2003, “*Time transfer to TAI using geodetic receivers*,” **Metrologia**, **40**, 184-188.
- [3] G. Beutler, H. Bock, E. Brockmann, R. Dach, P. Fridez, W. Gurtner, U. Hugentobler, D. Ineichen, J. Johnson, M. Meindl, L. Mervart, M. Rothacher, S. Schaer, T. Springer, and R. Weber, 2001, Bernese GPS Software Version 4.2, Astronomical Institute, University of Berne, Berne, Switzerland.
- [4] G. Petit, Z. Jiang, P. Uhrich, and F. Taris, 2001, “*Differential calibration of Ashtech ZXII-T receivers for accurate time comparisons*,” in Proceedings of the 15th European Frequency and Time Forum (EFTF), 6-8 March 2001, Neuchâtel, Switzerland (Swiss Foundation for Research in Microtechnology, Neuchâtel), pp. 164-166.