PERFORMANCE EVALUATION OF NIM GPS RECEIVERS IN USE FOR TIME TRANSFER WITH PTB

Kun Liang(1),(2), Thorsten Feldmann(2), Andreas Bauch(2), Dirk Piester(2), Aimin Zhang(1), Xiaoxun Gao(1)

(1)National Institute of Metrology (NIM), Bei San Huan Dong Lu 18, 100013 Beijing, P.R.China

liangk@nim.ac.cn

(2)Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig, Germany

ABSTRACT: Two self-developed GPS receivers of NIM (National Institute of Metrology), which are based on a Javad E_GGD receiver and a NovAtel OEMV3 receiver, respectively, have been installed and operated at PTB (Physikalisch-Technische Bundesanstalt) for a time transfer link calibration between both institutes. During the operation of the traveling receivers at PTB for several weeks, their performances have been thoroughly evaluated. A subset of the results of general interest is presented. From the results we decided on the most suitable mode of operation of the NIM GPS traveling receivers. The uncertainty of the link calibration will potentially be influenced by the temperature sensitivity of the receivers, which was thus investigated. Finally, we studied the receiver internal delay as a function of time and its installation in the host laboratory.

INTRODUCTION

At present, GPS time transfer is a very popular and a widespread means to compare remote atomic clocks all over the world. There are many kinds of GPS receivers for geodetic applications, but there are only a few types of GPS receivers dedicated for time transfer, such as AOA TTR6 and TTR12, AOS TTS3 and TTS4, Dicom GTR50, Ashtech Z12-T, and Septentrio PolaRx2eTR and PolaRx3TR. NIM uses two other geodetic receiver boards in their new timing receivers IMEU, a Javad E_GGD board with JNSMARANT_GGD antenna, and IMNV, a NovAtel OEMV3 board with 702GG antenna, shown in Fig.1, and this is the first report of their performance. The TWSTFT (Two-Way Satellite Time and Frequency Transfer) link to be officially started soon between NIM and PTB is initially not calibrated, so we are motivated to implement the link calibration using GPS preferably in the way as it was demonstrated for the links ROA-PTB [1] and METAS-PTB [2]. Portable TWSTFT stations [3] are expensive and barely available whereas the method using a traveling GPS receiver costs much less. Moreover, some TWSTFT links can not be calibrated only by one portable TWSTFT station [4]. For a link calibration using GPS in general, one GPS traveling receiver (TR) needs to be used to do CCD (Common Clock Difference) measurements at the two timing labs. Before using IMEU and IMNV, their performances should first be tested to verify their suitability for this purpose.

Fig.1. IMEU and IMNV

IMEU and IMNV can both be synchronized to an external clock via 1PPS and frequency inputs, and they output a 1PPS signal, representing the internal time base. IMNV can output the internal frequency signal no matter whether it is synchronized to the external clock or not. In IMEU the input pin for the external clock frequency is the same one as the internal frequency output pin, so it outputs the internal frequency only when it is not synchronized to the external clock. IMNV does not provide P1 data. More details about the two geodetic GPS boards can be found in [5] and [6]. We studied important performance parameters for time transfer, such as receiver operating mode, temperature impact, and stability of the receiver internal delays. Some other PTB receivers have been involved in the related experiments: PTB7 (Dicom GTR50, NovAtel 702GG antenna), PTBB and PTBG (Ashtech Z12-T, ASH700936E SNOW antenna).

OPERATION MODE FOR TIME TRANSFER RECEIVERS

There are two kinds of operation modes for GPS timing receivers, usually dual frequency geodetic receivers. In mode 1, the GPS receiver, e.g. a Polarx2TR or Z12-T, is operated with time and frequency (1PPS and 20 MHz) synchronized to the local reference time scale by a phase lock loop. In mode 2, the GPS receiver, e.g. a TTR6 or GTR50, is operated in a free running status without synchronization, and the link between the receiver time scale and the local reference time scale is established with a time interval counter (TIC).

Mode 1

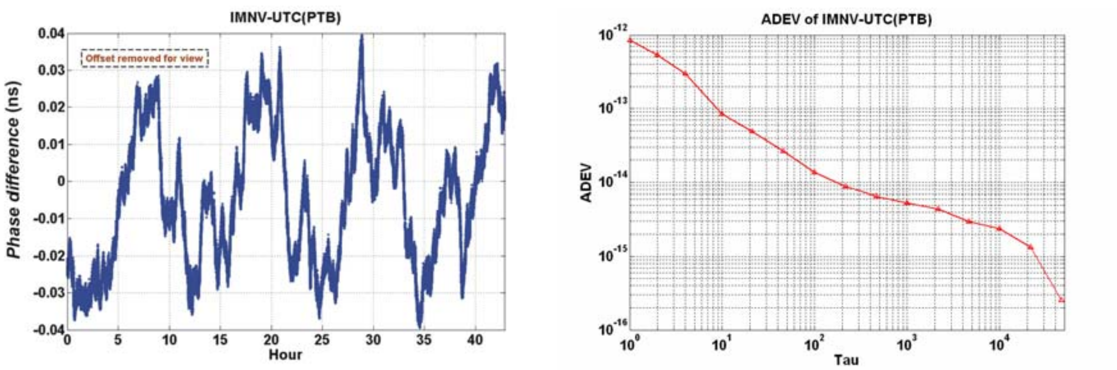


Fig.2. Phase difference (left) and ADEV (right) between 10 MHz signals UTC(PTB) (reference) and IMNV output

In mode 1, the receiver is directly synchronized to the local reference time scale. The receiver time scale is coherent with the local reference time scale. Its difference from GPS time or IGS time is obtained from GPS measurements using CGGTTS (CCTF Group on GNSS Time Transfer Standards) files for CA or P3 computation, or using RINEX (Receiver Independent Exchange Format) files for PPP (Precise Point Positioning) computation, respectively. For a study of the synchronization of the GPS receiver with the local reference we compared the IMNV internal frequency output after synchronization with the local reference frequency UTC(PTB) by a commercial high-resolution phase comparator of type VCH-312. The measured phase difference and ADEV (Allan deviation) are depicted in Fig.2. In addition, we used a SR620 TIC to measure the difference between UTC(PTB) 1PPS and IMEU 1PPS, but this was limited by the noise floor of the TIC. From Fig.2 we conclude that IMNV can be synchronized well enough for GPS PPP measurements whose precision is at the sub-nanosecond level, as well as all other kinds of GPS measurements.

Mode 2

In mode 2, the receiver is free running, and its 1PPS output is set to be synchronized to the receiver time scale. Then the difference $D1$ between the receiver time scale (1PPS) and the local reference time scale is measured using a TIC. At the same time, we get the comparison results $D2$ between the receiver time scale and GPS time or IGS time from the GPS measurements. Thus we calculate the difference DD between the local reference time scale and GPS time or IGS time as (1)

$$DD = D2 - D1. \qquad (1)$$

This is the basic principle of the method which we used in our experiments, but in commercially available time transfer receivers more elaborate routines could be used. The performance of the TIC will influence the final results. We found that a TIC of type SR620 TIC suits even regarding the precision required in the PPP analysis, which has been used in the following experiments.

Selection of the Operation Mode of the NIM GPS Receivers

To compare the two modes of IMEU and IMNV, CCD measurements between both receivers and PTB7 were performed. We combined RINEX files and the 1PPS measurements from a SR620 TIC. We used the NRCan-PPP software [7] for PPP computation and a homebuilt Matlab program for the combination. The final results are shown in Fig.3.

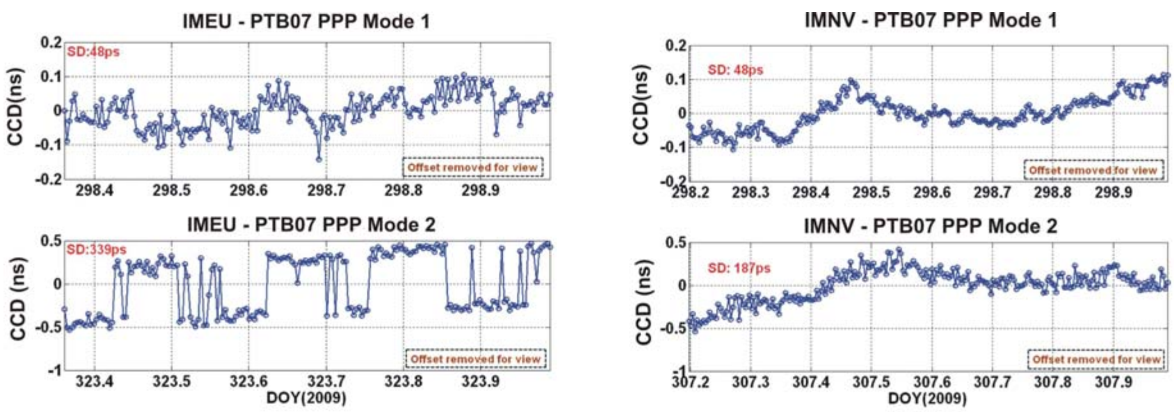


Fig.3. CCD results between IMEU (left) and IMNV (right) and PTB7 for both modes of operation of the NIM receivers

In Figure 3, we notice some significant step-wise fluctuations in IMEU results in mode 2, which are not understood yet. In general, it seems clear that for GPS PPP time transfer using NIM receivers, mode 2 is not bad, but mode 1 provides a lower noise level. Therefore only mode 1 has been used further on.

TEMPERATURE SENSITIVITY OF THE GPS RECEIVERS

Temperature is known to influence the measurement results of time transfer GPS receivers. Until now there have been many efforts to characterize the temperature impact on GPS receivers' internal delays [8-11]. Unfortunately, in all of these experiments other receiver types than ours were used. We were thus inspired to test our GPS receivers using a temperature chamber and get delay variations as a function of temperature. We put IMNV and a temperature logger that is set to 10-min sampling interval into the temperature chamber as shown in Fig.4, whose temperature inside can be controlled and stabilized. The chamber is unfortunately too small to accommodate IMEU.

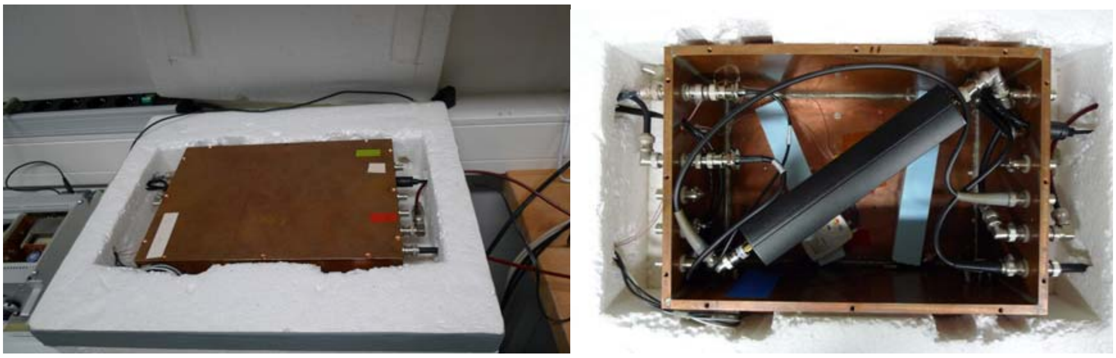


Fig.4. Temperature test chamber, outside view left, inside view right, consisting of a heated massive copper box with many cable feedthroughs, enclosed by 5 cm thick Styrofoam

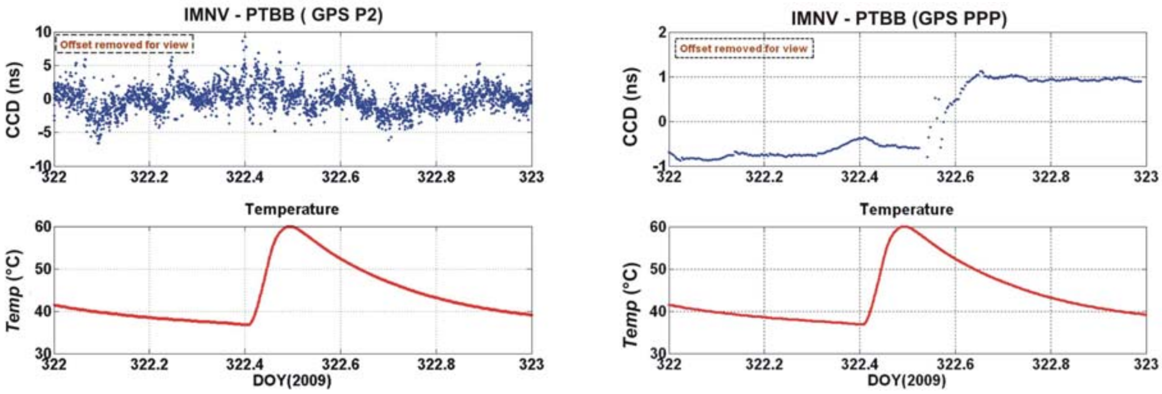


Fig.5. Variation of IMNV GPS P2 (left) and PPP (right) measurement with temperature

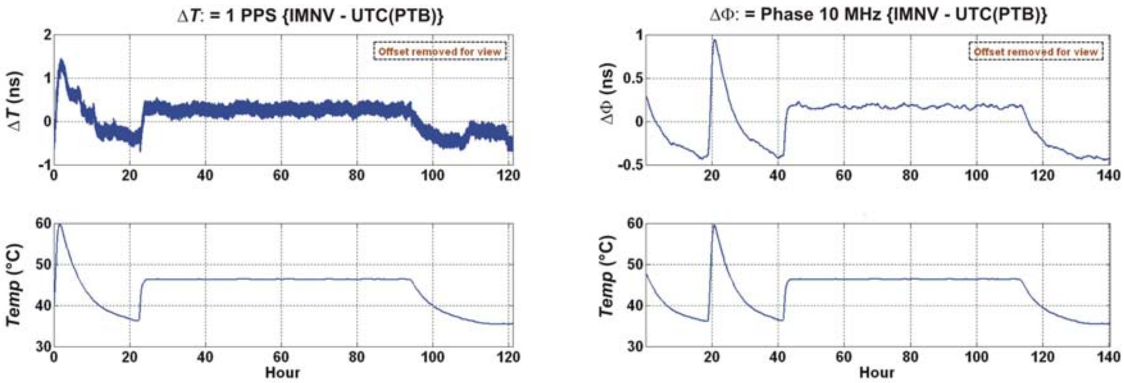


Fig.6. Variation of IMNV 1PPS output (left) and frequency output (right) with temperature

In Fig.5, P2 and PPP CCD results between IMNV and PTBB were used to show some relation between GPS receiver measurements and temperature around IMNV. All the devices except the GPS antennas and antenna cables were in the measurement room that was temperature stabilized. Fig.5 does not reveal any correlation between the temperature and

P2 measurements, but some influence of the temperature on PPP measurement might exist, even if it does not coincide with the temperature change very well. Likewise we measured the 1PPS output and the frequency output of IMNV with respect to UTC(PTB), and get a strong correlation as illustrated in Fig.6. Similarly, the temperature effect on the delay of RG58 cable has been tested in the chamber as this type of cable was used for connections inside the box.

Another temperature logger was put just on IMEU at ambient temperature, together with several meters cable needed for the connections while the CCD experiments with PTB7 and PTBG were made. In PTB7, the receiver board is temperature-stabilized in an enclosure which is part of the instrument case. The IMEU 1PPS output and the GPS measurements are clearly dependent on the surrounding temperature as shown in Fig.7. The quite erratic temperature variations were caused by a malfunction of the air-conditioning system in these days. The small temperature effect on IMEU GPS measurement shown in the middle plot of Fig.7(b) may have been caused partially by PTBG. In general, we see small effects, but clearly correlated with the temperature changes. From all these results, some temperature sensitivity coefficients have been derived and are summarized in Table 1.

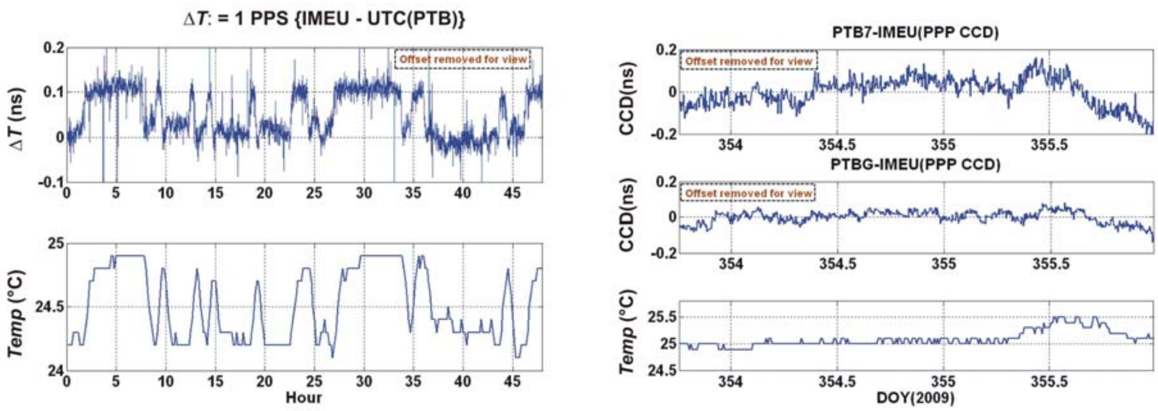


Fig.7. Temperature effect of IMEU 1PPS (left) and GPS measurement (right)

Table 1. Measurement sensitivity

Measurement object	Sensitivity factor(ns/℃)
IMNV internal frequency output	~0.058
IMNV 1PPS output	~0.098
IMEU 1PPS output	~0.200
IMNV GPS measurement	~0.083
IMEU GPS measurement	~0.240
RG58 Cable delay (time length: 41ns)	~0.010

Usually in many timing labs the variation of the temperature is being controlled at least within 2 degrees. From the temperature sensitivities of the internal frequency and 1PPS outputs and of the delay of the cable used either inside the GPS receiver or for external connections during the calibration, we can hardly see a significant uncertainty contribution of more than 200 ps. IMEU is much more sensitive than IMNV in GPS measurement, and such a sensitivity is more visible in PPP time transfer.

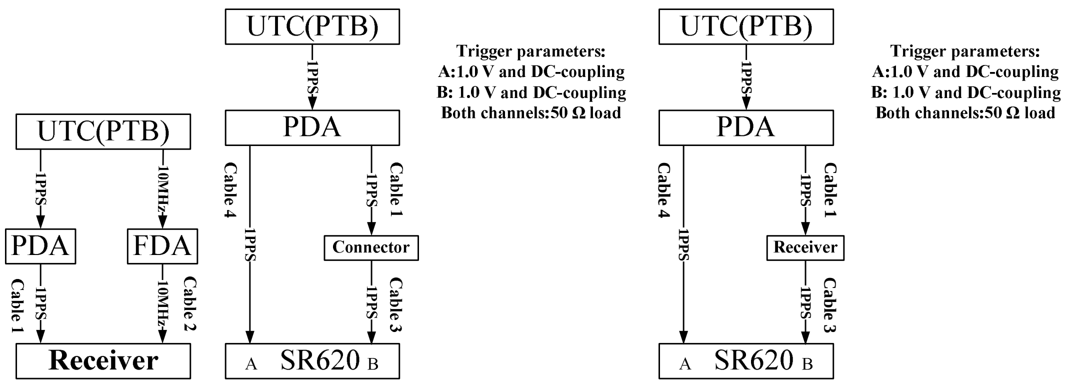
RECEIVER INTERNAL DELAY

We consider two aspects of the receiver internal delay. The first is the way an internal time base is derived from the external frequency reference. In some receivers the internal time base is fixed to a zero crossing of the external reference frequency, which is selected by the external 1PPS signal. Thus the phase relation between the external frequency and 1PPS inputs has an impact on the internal delay and is, e.g., routinely measured when using Z12-T receivers [12,13]. The other aspect is the reproducibility of time transfer results after receiver power off and power on sequences.

Effect of Receiver Internal Delay Changing on GPS Measurement

In mode 1, either of the two receivers' internal clocks is phase locked to the first zero crossing point of the reference frequency input after the rising edge of the reference 1PPS input. We define the 1PPS output socket as the receiver's internal time scale reference point and the receiver *internal delay* as (1PPS output - 1PPS input) that is measured by (setup3 – setup2) as shown in Fig.8 (setup 1). In setup 3, the receiver 1PPS output should be set to represent the receiver time scale, and UTC(PTB) is always used as external reference of the SR620 TIC. We report the *reference delay* as (UTC(PTB) - 1PPS input). From the combination we get the quantity *Cor* to correct the GPS measurements as (2)

$$Cor = -(reference\ delay + internal\ delay). \qquad (2)$$



(a) Setup 1 (b) Setup 2 (c) Setup3

Fig.8. Setups of the receiver delay change tests

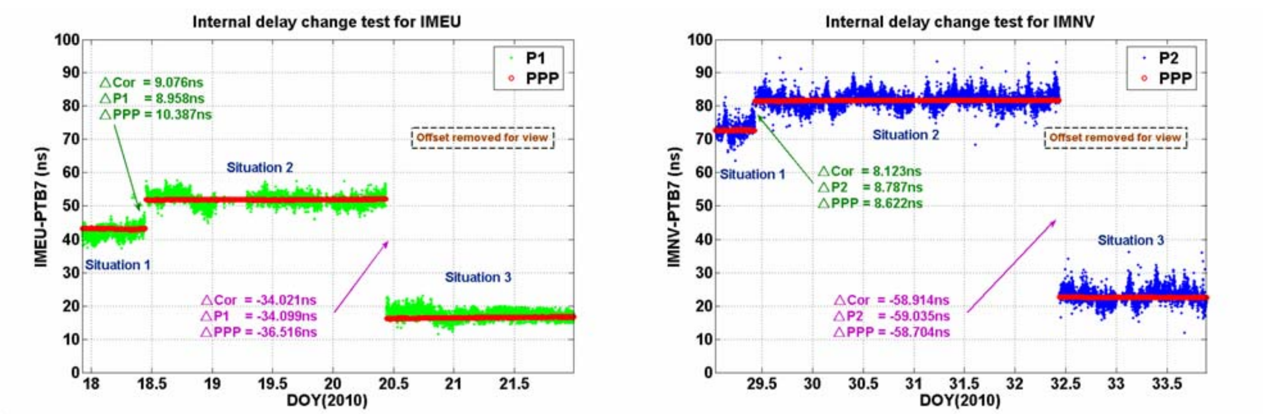


Fig.9. Relation between CCD result's change for IMEU (left) and IMNV (right) and internal delay change

In tests with the two NIM receivers, a cable 5 (delay = 41 ns) was added to cable 1 or cable 2 for all the three setups to check how the *internal delay* and the CCD result would change. In Fig.9 the original cable setting (shown in Fig.8) is called situation 1, cable 5 added to cable 2 by a BNC connector situation 2, and cable 5 added to cable 1 situation 3. In these three situations RINEX files of the receivers were recorded. From Fig.9 we can infer the changes in the P code and PPP CCD results compared with PTB7 when the cabling and thus the phase relation in the input were changed. Corrections calculated from (2) did agree with the observed steps in P1 or P2 CCD results. The PPP CCD results of IMEU did not reproduce *ΔCor* so well, probably due to the nonlinear processing involved in the software package [7].

Receiver Internal Delay Stability

We tested if there was a time step due to an internal delay change of IMEU after a power cycle on-off-on. About 10 minutes and 1 hour after shutting down IMEU, respectively, we restarted it and the CCD results with PTB7, PTBB, and PTBG before shutting down and after restarting were computed (see Fig.10). Some big variations which can be seen during the whole day are due to temperature effects

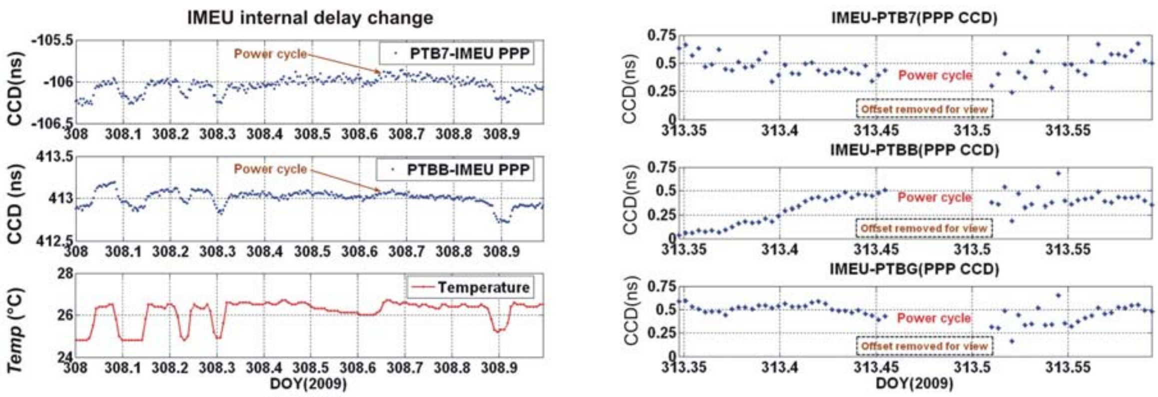


Fig.10. Receiver internal delay change after a power interruption of 10 min (left) and 1 hour (right)

When restarting IMEU or IMNV after a power off for around one day, some warm-up processes of the two receivers, lasting for several hours, caused some CCD variations which can be clearly attributed to temperature effects having the results shown in Fig.7 in mind. From the CCD results of twenty-one days, which is about the time span of the envisaged link calibration by GPS between IMEU and PTBG or PTB7, no obvious step or drift was noted which could be attributed to the function of IMEU.

CONCLUSIONS AND PERSPECTIVES

The receivers that will be used in the link calibration between NIM and PTB have been evaluated regarding three aspects, operation mode, temperature effect, and stability of the receiver internal delay. Conclusively, operation mode 1 should be chosen in IMEU or IMNV as TR for link calibration because of the lower time transfer noise level. IMEU and IMNV GPS measurements are sensitive to environmental temperature, 83ps/^{o}C and 240ps/^{o}C, respectively, were noted. There are also some noted sensitivities for 1PPS output, frequency output and cable delay. Thus the temperature around the receivers should be controlled as well as possible. There is a predictable change of the internal delay related to the relative phase between the frequency and 1PPS inputs of the receivers. Some variation of the receiver internal delay mostly due to the temperature effect may exist but neither a significant step after a power cycle nor a definite step or drift in the long term operations of IMEU internal delay have been observed. The results of this study will be applied to the evaluation of the link calibration between NIM and PTB in the near future.

DISCLAIMER

This paper shall not be understood as advertisement for any type of GPS receiver. The results are just from our specific measurements and the conclusions are suitable for our specific purpose and will be used for our specific application.

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