Stability of Hardware Delays of GNSS Signals

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***Abstract*— The goal of this study is to analyse the stability of the hardware delays of GPS and Galileo signals in multi-GNSS stations dedicated to time transfer. We first demonstrate a significant sensitivity of these delays to external environment (multipath, weather), up to 2 ns in case of snow when the antenna is not protected by a radome. Furthermore, we notice that the long-term stability of the Galileo E5a code and GPS C5 code measurements is poorer than for the other code measurements.**

Keywords—GNSS; Hardware delay; stability

I INTRODUCTION

The reception of Global Navigation Satellite Systems (GNSS) signals in a time laboratory plays an important role in time transfer activities. The ability to measure accurately GNSS time scales with dedicated receiving equipment requires the knowledge of hardware delays in the antenna, cables and receivers involved, but requires also that these delays remain constant with time.

To date, the calibration activities coordinated by the Time Section of the Bureau International des Poids et Mesures (BIPM) and by the Regional Metrology Organizations concern both GPS and Galileo signals, and are further used for the time transfer links contributing to the computation of the Coordinated Universal Time (UTC). The guidelines for these calibration exercises are provided in [1]. In order to characterize the uncertainties associated with calibration for the different signals, as well as with the stability of the hardware delays, it is important to study their observed behavior for the different GNSS signals, and for different station setups.

Using data from pairs of GNSS stations connected to a common clock, we compute the time stability of the Common-View pseudorange differences for different stations. These are located at the Royal Observatory of Belgium (Brussels) where they are connected to UTC(ORB), and at the laboratory Systèmes de Références Temps-Espace (SYRTE) of Observatoire de Paris[1], where they are connected to UTC(OP). From this, we compare the stability of the different code pseudoranges and their respective sensitivity to weather conditions. The first section of the paper describes the station setups, the two following sections describe the frequency-dependent variations observed in case of antenna not protected by a radome, as well as a comparison of the long-term instabilities of the different GNSS codes pseudoranges.

[1] This laboratory is designated by the French National Metrology Institute (NMI) Laboratoire National de Métrologie et d'Essais (LNE) for time and frequency metrology activities.

II STATION SETUP

A common clock setup consists in two separate GNSS stations, i.e. two different receivers driven by the same clock, and connected either to two separate antennas or to a common antenna (see Figure 1). As the two receivers are running with the frequency of the same external clock, the pseudorange differences (also called Common-View results) between these two stations, once corrected for the antenna differential position in case of separate antennas, only contain the noise and multipath of the measurements, plus a bias associated with the different hardware delays of the two stations. This bias should be constant if the hardware delays are constant with time.

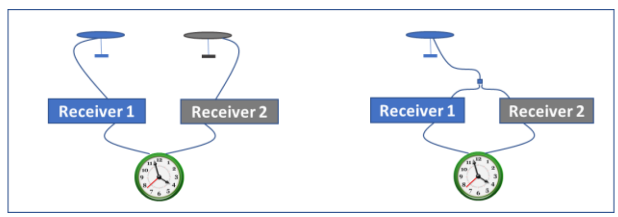

Fig. 1. Common Clock setup with separate antennas or with common antenna

Different common clock setups are used in this study. At ORB, four multi-GNSS stations are connected to the realization UTC(ORB), which is the output of a H-maser steered on UTC. These four stations have each a separate antenna. Three of these stations are using a receiver Septentrio PolaRx5TR, while the last one (ORBA) is using a PolaRx4TR. A summary of these four stations is given in Table 1. The four stations have been calibrated following the BIPM calibration guidelines, with the calibration ID 1011-2020 [2]. Note that among these four stations, some are equipped with a radome, while not all of them. In particular the station BRUX, which is participating in the International GNSS Service (IGS) network of permanent stations, was set up with no antenna radome. This was in line with the IGS guidelines [3]: "*Unless absolutely necessary for environmental or animal protection, using a radome over the station's GNSS antenna should be avoided." "There are still* *concerns over the use of a radome over the antenna. The concerns include uncharacterized effects such as weathering, possible radome orientation issues, and the repeatability of the absolute calibration using different radome batches.”* However, in view of the results shown in this paper, it was decided to put a radome on the antenna, which was done in April 2021 (see Figure 2).

TABLE I. STATION SETUP AT ORB

Station	Receiver	Antenna
BRUX	PolaRx5TR	Javad JAVRINGANT / Dome installed on April 21, 2021
ORBA	PolaRx4TR	SEPCHOKE + radome
RTBS	PolaRx5TR	Javad JAVRINGANT without radome
GRCB	PolaRx5TR	Leica AR20 + radome

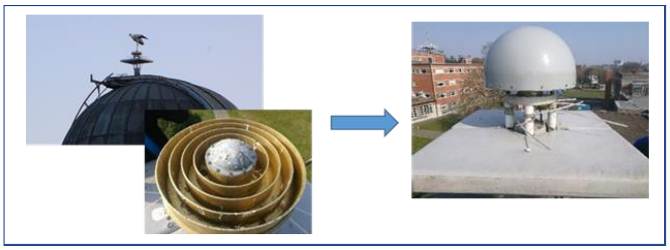

Fig. 2. Change of the antenna setup for the IGS station BRUX.

The second set of stations used in this study is located in the LNE-SYRTE in OP. The reference station OP71 is made of a Septentrio PolaRx4TR receiver connected to a Leica AR25 choke-ring antenna with a radome. OP71 is also part of the IGS network of fixed stations. We used another station OPM3 made of a PolaRX4TR receiver usually connected to a small size NovAtel 703-GGG antenna. This ensemble is part of the traveling equipment used by LNE-SYRTE for relative calibration campaigns. For the purpose of that study, OPM3 was temporarily also connected to a second AR25 antenna with radome too. In addition, we also used two Septentrio PolaRx5TR receivers called OP73 and OP75, connected to a single geodetic choke-ring antenna Septentrio PolaNt B3/E6 that has a radome, too. All OP stations were in common clock setup during this experiment, the source signal being UTC(OP), the realization of UTC in OP [4].

TABLE II. STATION SETUP AT OP

Station	Receiver	Antenna
OP71	Septentrio PolaRx4TR	Leica AR25 with radome
OPM3	Septentrio PolaRx4TR	NovAtel 703-GGG or Leica AR25 with radome
OP73	Septentrio PolaRx5TR	Septentrio PolaNT B3/E6
OP75	Septentrio PolaRx5TR	Septentrio PolaNT B3/E6

III IMPACT OF AN ANTENNA RADOME

The pseudorange differences (or Common View, CV) between the station GRCB (equipped with a radome) and the three other stations have been computed for the first five months of 2021. Figure 3 presents the moving 1-hour average of these CV results obtained for each of the GPS and Galileo code pseudoranges.

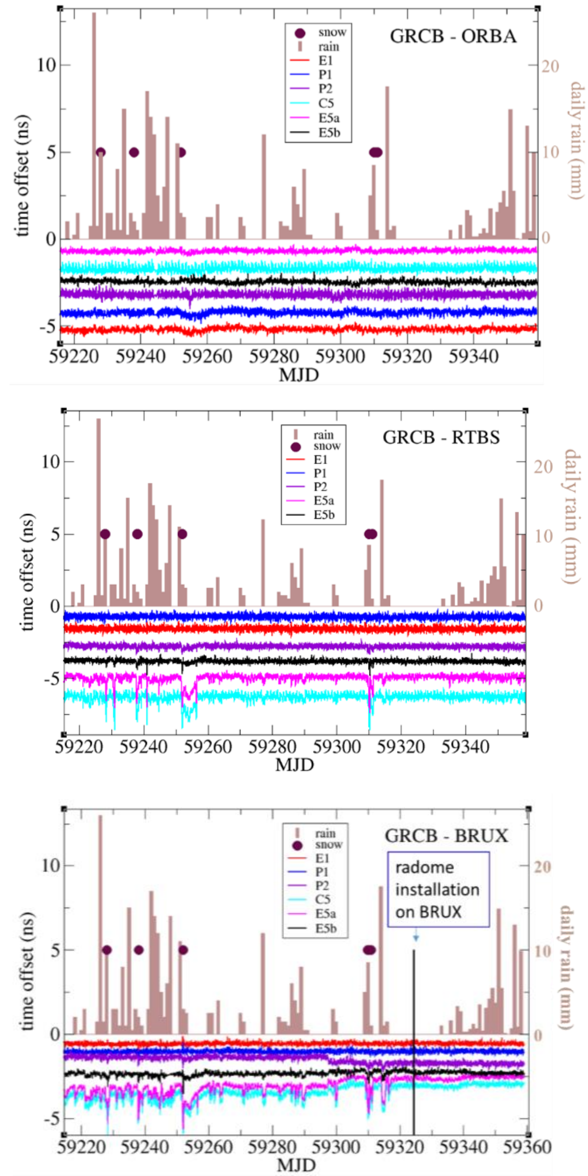

Fig. 3. Common-Clock differences between the stations at ORB plotted in parallel with rain and snow falls.

From these Figures, we can observe jumps in the pseudoranges, associated with rain or snow falls, in both RTBS and BRUX, i.e. for the antennas not covered by a radome. The magnitude of these pseudorange variations increases with decreasing frequency, and grows up to 2 ns in E5a and C5 for BRUX. We see that the impact of snow is similar for both stations, while the rain is affecting BRUX more seriously. The reason for this is not yet fully understood. It could be explained by the presence of an absorbing material under the BRUX antenna, of which the goal is to reduce the near field multipath. Figure 3 clearly shows that the radome installation over the BRUX antenna has suppressed the pseudorange variations due to rain falls, improving the stability of the pseudorange measurements especially in the L5 frequency band.

Furthermore, note that Figure 3 shows that the radome installation did not create any jump in the code measurements.

IV CODE MEASUREMENT INSTABILITY

In order to get insight on the GPS and Galileo code stabilities under quiet conditions, we carried out Allan Time deviation (TDEV) computations in different common clock setups. The TDEV of the common clock code differences at ORB were computed over a dry period of 10 days (MJD 59317-59326), and are presented in Figure 4. The TDEV of the common clock code differences at OP for two different seasons (MJD 59229-238 and MJD 59293-300) are shown in Figure 5.

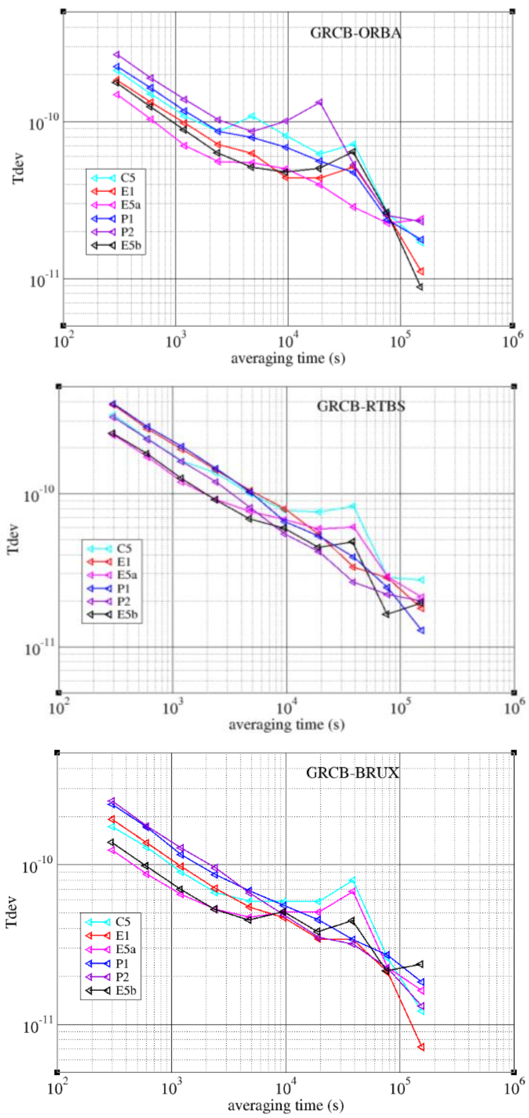

Fig. 4. TDEV of the Common-Clock differences between the stations at ORB during a dry period of 10 days (MJD 59317-59326).

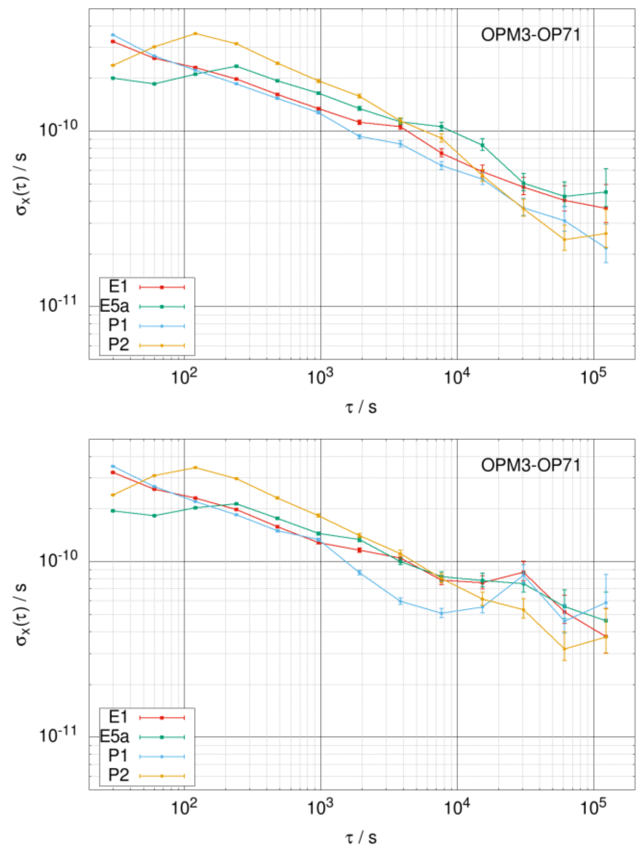

Fig. 5. Comparison between two PolaRx4 in common-clock set-up but two different antennas: NovAtel 703-GGG (OPM3) and Leica AR25 (OP71) during two different periods of time in 2021: (top) January (MJD 59229-238) and (bottom) March.(MJD 59293-300).

In all links between similar receiver types (i.e. all except GRCB-ORBA), we observe that the Galileo E5a noise is superior to the GPS P2 noise for analysis periods over 10^4 s. We furthermore observe a diurnal periodicity in the L5 frequency band, marked by the typical bump at half a day in the TDEV for both GPS and Galileo. In OP however, this periodic term does not appear in the analysed period of January 2021. We are having no explanation for this, except that it might be related to a very steady environment during this period of time with a diurnal temperature range of less than 4 degrees, while diurnal variations up to 9 degrees with sunny periods occur in the March period. We know that for GPS there is a period of one sidereal day in the repeated trace with respect to the Earth surface, which induces a diurnal repeatability of the multipath for GPS signals. However, this is not the case with Galileo satellites for which the periodicity of the trace with respect to the Earth surface is ten days. We therefore attribute the diurnal periodicity to some sensitivity of the hardware to environmental changes. External components (antenna or cable) should be probably the cause of this periodicity as the temperature in the ORB time lab and in LNE-SYRTE is maintained constant within ± 0.1 °C. This is also confirmed by the result in Figure 8 in common antenna setup (see section 5).

Higher instability is also found for the pseudoranges differences ORBA-GRCB than for the other cases. This can be explained by the fact that it is the only common-clock difference for which the receivers at both ends are different: GRCB is a PolaRx5TR while ORBA is a PolaRx4TR. The different correlators used in the receivers of ORBA and GRCB explain this higher instability in the code differences.

V Impact of the antenna on the long-term code stability

We have tested the impact of two different antenna types: a large geodetic choke-ring Leica AR25 and a small portable antenna NovAtel 703-GGG, both able to collect data from GPS and Galileo constellations. Long term trend shows that the Leica AR25 provides a better stability than the NovAtel 703-GGG above an averaging period of 1 d: down to about 10 ps at 10 d for the large geodetic antenna, where the small portable antenna seems limited to around 50 ps at 10 d. Here too, Galileo signal noise (E1/E5a) looks always higher than GPS signal noise (P1/P2 respectively) above an averaging period of 10^4 s. Nevertheless, we consider that the small portable antenna is qualified for GNSS station relative calibration campaigns: the resulting noise of the comparison due to this antenna does not seem higher than 50 ps at 1 d, and the small size of the antenna simplifies the implementation in different visited sites.

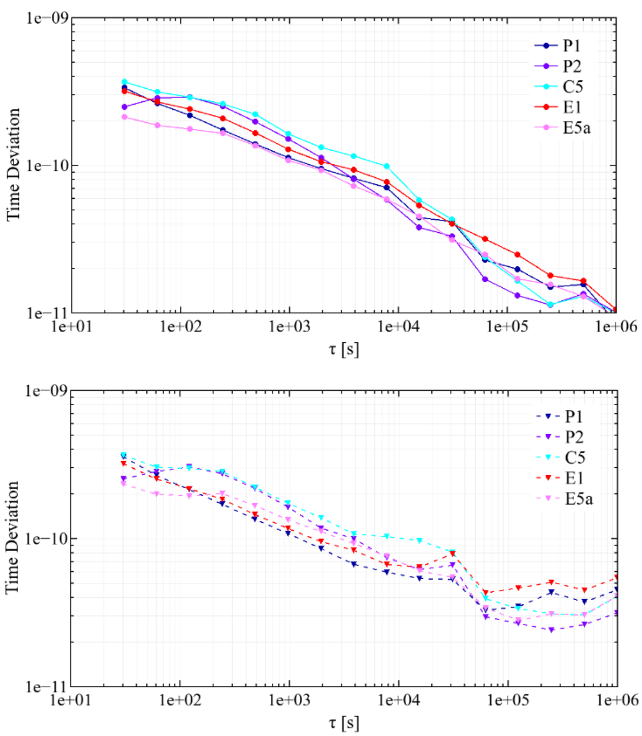

Fig. 7. Comparison between two PolaRx4 in common-clock set-up, but two different antennas: (top) two Leica AR25 (OPM3 and OP71), (bottom) NovAtel 703-GGG (OPM3) and Leica AR25 (OP71).

Fig. 6. Antennas considered in this study (not the same scale)

In the following setup, two PolaRx5 are connected to the same geodetic antenna PolaNT B3/E6. The antenna and most of the antenna cable contribution to the noise has disappeared, and we see that there is no more diurnal here. Galileo signal noise (E1/E5a) looks in line with GPS signal noise (P1/P2). E1 noise is slightly better than P1 up to an averaging period of about 2 x 10^4 s, where P2 noise remains better than E5a up to the same period, which might be explained by some kind of correlator bandwidth effect for such a computation period. At a 1 d analysis period, a TDEV of less than 7 ps for E1/P1 and of less than 3 ps for E5a/P2 is obtained from simple CV between RINEX files, which seems to be the bottom noise for these receivers types. The long-term trend shows that all noises are mixed up by some other effects.

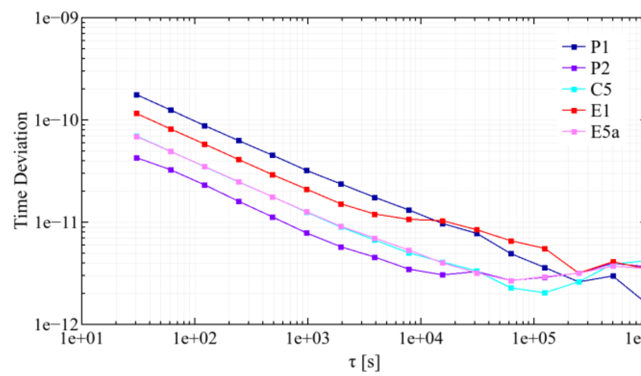

Fig. 8. Comparison between two PolaRx5 in common-clock and common antenna set-up: OP73 – OP75 + antenna PolaNT Choke-Ring B3/E6.

VI Conclusions

Our results indicate some instability of code measurements associated with the antenna, with a particular increase of the instability of Galileo E5a at averaging times longer than 10^4 s. The antenna is limiting the TDEV common clock comparisons at about 3 x 10^{-11} @ 1day, while the receiver contribution to the instability is about 5 times smaller.

We also noticed that the codes in the L5 frequency bands are affected by rain and snow when there is no radome on the antenna, with corresponding code variations observed up to 2 ns on Galileo E5a and GPS C5.

In addition to the associated instability of code-based time transfer, this can also have an impact on calibration as organised in the TAI network in case the traveling station is equipped with a choke-ring antenna: if there is no dome on this antenna, the HW delay can be different at the reference (G1/BIPM) location than at the station to be calibrated depending on the weather conditions, inducing calibration error. We therefore recommend to put a radome on the antenna on GNSS stations as well as on traveling equipment used for calibration, in case these antennas are choke-ring.

Finally, it turns out that the small portable pinwheel antenna NovAtel 703-GGG offers similar time stability as a choke ring antenna for averaging times up to 1 day, which is the typical period used for the noise contribution to the uncertainty budget in relative calibration campaigns. It therefore offers a good portable and compact alternative to choke ring antennas, hence circumventing the question of using a radome.

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