# Calibration of time transfer systems in time and frequency laboratories

C.L. de la Pina[1], A. Pasquaré[1], D.A. Luna[2], F. Arias[3], C. Brunini[1] & R. Galván[1]

[1] *Observatorio Argentino-Alemán de Geodesia, CONICET-AGGO, Argentina*
[2] *Instituto Nacional de Tecnología Industrial, INTI, Argentina*
[3] *Observatoire de Paris, SYRTE, Francia*

*Contact* / carladelapina@gmail.com

**Resumen** / El siguiente trabajo aborda la calibración de dos institutos argentinos que participan del cálculo del Tiempo Universal Coordinado (UTC) en el Bureau International des Poids et Mesures (BIPM). Las medidas de tiempo y frecuencia son parámetros indispensables para la astronomía y la geodesia y como tales requieren de una completa caracterización de la incertidumbre.

**Abstract** / The following work addresses the calibration of two Argentine institutes that participate in the calculation of Coordinated Universal Time (UTC) at the Bureau International des Poids et Mesures (BIPM). Time and frequency measurements are essential parameters for astronomy and geodesy and as such require a complete characterization of the uncertainty.

*Keywords* / time — reference systems — astrometry

## 1. Introduction

Coordinated Universal Time (UTC) is the practical world time reference. It serves as a reference for diverse activities, from legal time in countries to specific applications including astronomical navigation, geodesy, telescope settings, space navigation, satellite tracking, etc. UTC is computed as a weighted average of about 420 free-running atomic clocks distributed over the Globe and designed to approximate UT1 (a timescale derived from the rotation of the Earth). Thus, the realization of UTC by the International Bureau of Weights and Measures (BIPM), relies on remote time comparisons of clocks. Among several techniques, GNSS common-view time transfer is the technique most widely employed by the laboratories that participate in the computation of UTC. It is a one-way method, in which the signal emitted by a satellite is received by a specific equipment operated in a laboratory. In this sense, the local representation of UTC by each laboratory (called UTC(k)) needs a clock and a time transfer method to compare the clock's time to the rest of the participant clocks.
The dissemination of UTC is done by the monthly publication of results in BIPM named Circular T. This document depicts the time offsets between UTC and UTC(k) together with their respective uncertainties. This uncertainty in the difference UTC - UTC(k) is affected by three major elements: clock's stability, time transfer and the time-scale algorithm. Thus, an accurate characterization of the time transfer system is crucial in the quality of the UTC(k) representations. That means that, the signal delays in the receiving equipment (antenna, cable, and receiver) of the GNSS stations must be determined and accounted for.(Panfilo & Arias, 2019)

Between September 2021 and February 2022 a calibration campaign of GNSS receivers took place in Argentina. In this occasion, receivers at INTI (Instituto Nacional de Tecnología Industrial), AGGO (Observatorio Argentino-Alemán de Geodesia) and ONBA (Observatorio Naval de Buenos Aires) were calibrated by means of a traveling system. The calibration trip was organized by NIST (National Institute of Standards and Technology).

The present work shows the measurement results of the campaign together with independent validations of the results and further aspects to explore in the characterization of GNSS receivers.

## 2. Relative calibration procedures

NIST manages the campaign calibration of the time transfer systems to the laboratories members to the Inter-American Metrology System (SIM). In this particular case, AGGO and ONBA where also invited to participate. Together with INTI, these three laboratories contribute to UTC. The BIPM calibrates the regional nodes (NIST in this case) and each node calibrates the laboratories in its region. From September 2021 to February 2022, the calibration trip conducted by NIST in AGGO and INTI was performed. The NIST traveling calibration equipment consists of a Septentrio PolaRx3eTR PRO GNSS receiver unit identified as NB05, a Novatel pin-wheel antenna and antenna cable, a laptop, a time interval Counter (TIC) and auxiliary cables.

It is a relative calibration, with measurements made in situ. The traveling system and the system that operates the laboratory receive simultaneously signals from the same satellites (this technique is called Common

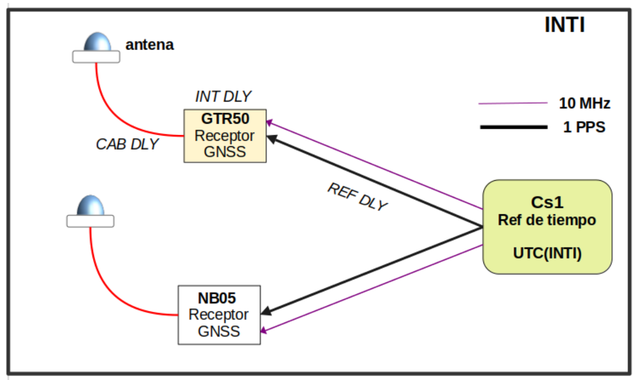


Figure 1: Calibration principle: Local and travelling receiver are referenced to the same clock and zero-baseline common view measurements are performed.

View: CV(Costa et al., 2004)), see Fig.1.

Both systems are operated in common clock configuration: one commercial cesium clock provides the time reference of 1 PPS (Pulse Per Second) and the 10 MHz reference frequency.

The purpose of this campaign was to measure the internal delay (INT DLY) of the local (visited) receivers and thereby calibrating the time links with traceability to the BIPM's reference receiver. This calibration has to be done for the three GPS observables:

- **C1**: C/A-code modulated onto the L1 carrier.
- **P1**: P-code modulated onto the L1 carrier.
- **P2**: P-code modulated onto the L2 carrier.

Where C/A: Coarse/Acquisition, P: protected, $L1 = 1.57542$ GHz y $L2 = 1.2276$ GHz (El-Rabbany, 2002).

The travelling receiver and the receivers of INTI and AGGO are all dual-frequency receivers.

The concept of relative calibration is to measure delays with respect to a single reference that does not travel. A travel equipment is used as intermediate to determine its status with respect to the reference before and after the calibration campaign.

### 2.1. Calibration model

The difference of the total delay for a pair of co-located receivers is the sum of the delays incurred in the antenna cable (CAB DLY) and the internal delay (INT DLY), minus the time offset at the latching point of the receiver as referenced to a fixed point, usually UTC(k)(REF DLY). The internal delay is comprised of both code- and frequency-dependent delays in the antenna and the receiver. After accounting for the baseline geometry, the difference in pseudoranges between a pair of receivers, for each code, is given by Eq.1

$$RAWDIF(code)_{T-V} = \Delta CABDLY_{T-V} + \Delta INTDLY_{T-V} - \Delta REFDLY_{T-V} \quad (1)$$

where T = Traveling, V = Visited and $RAWDIF(code)_{T-V}$ is the raw difference of pseudorange measurements of two receivers. Following the BIPM recomendation, the median value of the measurements is used to represent $RAWDIF(code)_{T-V}$ *.

### 2.2. Uncertainty estimation

The Allan time deviation, TDEV is a measure of time stability based on the modified Allan variance. It is used to characterize the time dispersion of a time source (clock) or distribution system. (Riley, 2008).

The Guide to the expression of uncertainty in measurement, defines the uncertainty as a *parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand* (Joint Committee for Guides in Metrology, 2008).

The uncertainty components are classified into two categories based on their method of evaluation, "a" and "b". Both are added in quadrature to obtain the combined uncertainty:

- **Uncertainty type a, $u_a$:** method of evaluation of uncertainty by the statistical analysis of series of observations. For example, TDEV for temporal data series.
- **Uncertainty type b, $u_b$:** method of evaluation of uncertainty by means other than the statistical analysis of series of observations. Eq.2. **

$$u_b = \sqrt{\sum_{i=0}^{n} u_{b,n}} \quad (2)$$

- **Combined uncertainty:** is given by Eq.3.

$$u_{CAL} = \sqrt{u_a^2 + u_b^2} \quad (3)$$

In this case, $u_a$ is estimated by the value of TDEV($\tau = 1$ *day*). In order to fully characterize the visited receiver, the calculation of Eq.1 in each code is repeated to determine the respective INT DLY and their combined uncertainty.

## 3. Results

Figures 2 and 3 depict time differences for C1, P1 and P2 codes. Similar results are obtained in both laboratories. As expected, P1 and P2 codes generate more stable readings. It can be seen that some periodical gaps appear in the measurements. It has been noted that the gaps disappear when operating the receiver in a single-constellation mode. So it is recommended to further perform separate calibrations for each constellation, at least for this receiver model.

Figures 4 and 5 show the estimation of the type a uncertainty. It can be seen that minimum values are reached for different averaging times ($\tau$) for C1 and P1.

*https://webtai.bipm.org/ftp/pub/tai/publication/gnss-calibration/guidelines/annex-3_computation-procedure-rinex_v32.pdf

**https://webtai.bipm.org/ftp/pub/tai/publication/gnss-calibration/guidelines/annex-4_template-calibration-report_v31.pdf

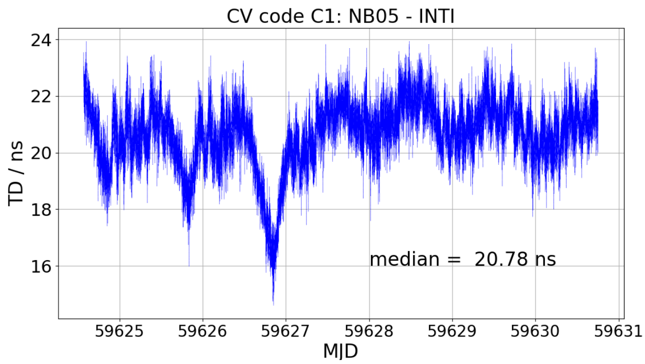


Figure 2: Time differences (TD) between NB05 and INTI through CV.

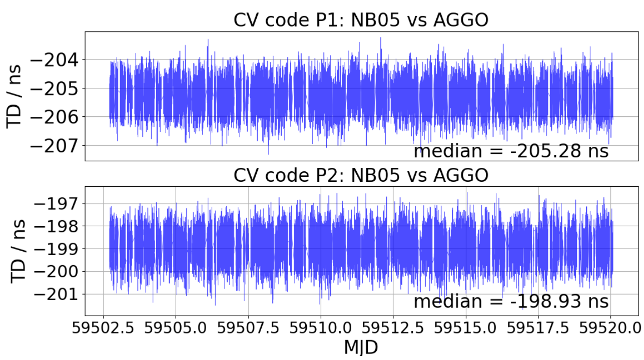


Figure 3: Time differences between NB05 and AGGO through CV.

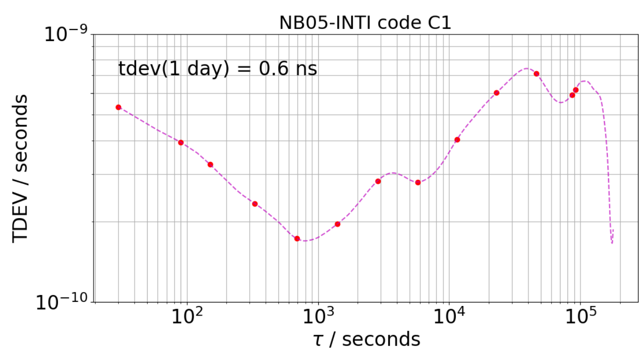


Figure 4: Uncertainty $u_a(C1)$ of INTI.

Tables 1 and 2 shows the values of INT DLY in each code plus its uncertainty. In the first row we see the value achieved by our own method and analysis, and in the second row we see the values reported by NIST*** as a validation of our estimation.

## 4. Conclusions

Participation in the UTC - UTC(k) comparison organized by the BIPM gives traceability to the SI second to institutes that perform local atomic time scales. Such

***https://webtai.bipm.org/ftp/pub/tai/publication/gnss-calibration/group2/2021/1014-2021/report_cal_id_1014-2021.pdf

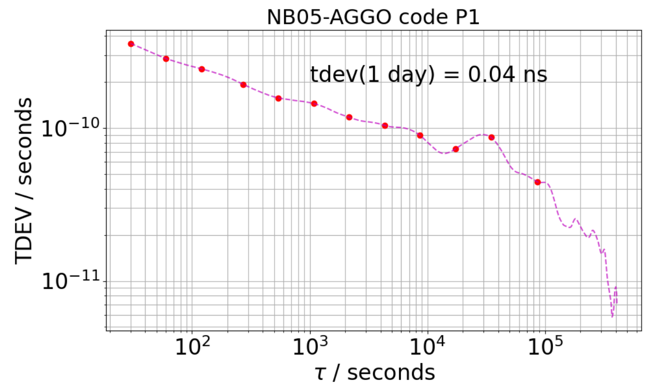


Figure 5: Uncertainty $u_a(P1)$ of AGGO.

Table 1: Results of the Calibration Campaign at INTI, from February 14 to 21, 2022

| DICOM GTR50 | INT DLY(C1) ns | INT DLY(P1) ns | INT DLY(P2) ns |
|---|---|---|---|
| OUR report | $-37.2 \pm 0.7$ | $-38.6 \pm 0.5$ | $-23.1 \pm 0.5$ |
| NIST report | $-37.3 \pm 0.5$ | $-38.0 \pm 0.5$ | $-23.0 \pm 0.5$ |

Table 2: Results of the Calibration Campaign at AGGO, from October 15 to November 2, 2021

| Septentrio PolaRx5TR | INT DLY(C1) ns | INT DLY(P1) ns | INT DLY(P2) ns |
|---|---|---|---|
| OUR Report | $31.7 \pm 0.4$ | $29.2 \pm 0.4$ | $27.8 \pm 0.4$ |
| NIST report | $31.9 \pm 0.4$ | $30.1 \pm 0.4$ | $28.3 \pm 0.4$ |

participation is possible only if the uncertainty of access to UTC(k) is fully characterized.

The Argentine institutes that maintain representations of UTC recently participated in a BIPM calibration campaign organized at the regional level by NIST. At INTI and AGGO, measurements for a relative calibration of two GPS receivers were carried out and values of the delays and their uncertainties were obtained.

The results of this calibration are satisfactory, but at the same time open perspectives to develop current lines of research: i.e. study the origin of different values of the internal delay in the different frequencies in which a receiver operates; design better uncertainty evaluation criteria of $u_a$; etc.

## References

Costa R., et al., 2004, IEN Technical Repport
El-Rabbany A., 2002, *Introduction to GPS: the global positioning system*
Joint Committee for Guides in Metrology, 2008, *Evaluation of measurement data—Guide to the expression of uncertainty in measurement*
Panfilo G., Arias F., 2019, Metrologia, 56, 042001
Riley W.J., 2008, *Handbook of frequency stability analysis*