Toward new procedures in TWSTFT and GNSS delay characterization for UTC time transfer ?

Z. Jiang, F. Arias, W. Lewandowski and G. Petit

Time, Frequency and Gravimetry Section, Bureau International des Poids et Mesures (BIPM)
Pavillon de Breteuil F-92312, SEVRES CEDEX, France, zjiang@bipm.org

Abstract

UTC generation includes the computation of *UTC-UTC*(*k*) and its uncertainty estimation. A significant part of the uncertainty of the *UTC* approximations *UTC*(*k*) in national contributing laboratories is based on accurate metrological measurement of time transfer equipment delays (so called "equipment calibration"). Organizing and maintaining the calibration of the time transfer facilities contributing to *UTC* is among the responsibilities of the BIPM.

At present, the time transfer techniques used for UTC generation are based on the two-way satellite time and frequency transfer (TWSTFT or TW) and the global navigation satellite systems (GNSS), i.e. GPS and GLN (Glonass). They are used for calculating the differences [*UTC*(*k*) – *UTC* (*l*)] between any participating laboratory and that chosen as a pivot (at present the PTB). In the 1980s, GPS C/A technique dominated the *UTC* time transfer. Since 2000, TW and GPS MC, P3 and PPP techniques as well as GLN have been successively introduced in the UTC generation. In consequence, the calibrations of the different time transfer equipment were introduced and are performed separately. Today, there are four parallel types of independent calibrations based on different strategies that can be defined either as site-based or link-based. The BIPM has assigned values of u_B of about 1 ns for the link-based TW calibrations, based on the values reported by those performing the calibration. However, for the sited-based GNSS calibrations, a conventional value of 5 ns has generally been assigned. This choice has been motivated by studies which found that values of [*UTC*(*k*) – *UTC* (*l*)] bigger the respective u_B may exist when the link as calculated by different techniques, and because long-term instability of the standard receivers may cause inconstancy in individual calibrations carried out in different periods.

On the other side, due to the development in technology, the statistical uncertainty u_A has been reduced by a factor of 10 since a dozen of years. The state of the art of u_A is 0.5 ns for TW and 0.3 ns for GPS PPP. The u_B calibration uncertainty is dominant in the total uncertainty of [*UTC-UTC*(*k*)], and several authors have investigated how to improve the calibration of time transfer equipment to decrease its value.

Also the BIPM has undertaken studies for improving the current calibration policy. The goal of this studies are: 1) to reduce the inconsistency between different techniques by making a combined use of the respective calibrations; 2) to reduce influence of the long-term instability of the BIPM standards by a special designed schedule; 3) to obtain more realistic u_B values than the conventional 5-ns and, in consequence, to reduce the total uncertainty of *UTC-UTC*(*k*); 4) to easy the calibration organization and reduce its cost; 5) to simplify the calibration monitoring and the combination of different time transfer techniques. Uncertainty estimation is an important part of the UTC computation and hence carefully discussed.

We present hereafter a study, which in no way means the adoption of a new calibration policy at the BIPM.

I. Introduction

The current time transfer calibration policy for *UTC* has been gradually established with the development of the time transfer techniques. In the 1980s and 1990s, the dominating technique was that of single frequency single channel GPS C/A code. The statistical uncertainty u_A of a time link was about ten ns in order. Consequently u_B, the uncertainty of the calibration was then not a critical issue. Since 1986, the calibration uncertainty of GPS reported at calibration dates has usually been below 5 ns [1,2,3].

However, in the last decade, due to the rapid progress in hardware and software, the new techniques that have been applied to the generation of *UTC* brought down the measurement (statistical) uncertainty of the time links by a factor of 10. As it has been published in the Section 6 of BIPM Circular T of April 2010 [1], the typical value of u_A for the TW links is 0.5 ns, for GNSS C/A, GPS P3 and GPS PPP are respectively 2 ns, 0.7 ns and 0.3 ns.

A new technique of time transfer introduced in the calculation of *UTC* is usually associated to a related calibration method. This explains why there exist 4 types of independent calibrations. Two of the very first calibrations [2,3] were made for single frequency single channel GPS C/A code equipment at OP, USNO and VSL, traceable back to the NIST NBS by a calibration tour dated in 1984 and 1986. The GPS P code calibration was also a differential calibration with BIPM standard equipment which was absolutely calibrated in 2001 [4]. The first TW calibrations for 3 European laboratories (TUG, DTAG and PTB) were made in 1997 [5] and the latest for 7 European laboratories (CH, IT, OP, NPL, PTB, SP, VSL) [6] and for USNO-PTB were carried out in 2008. These calibrations were performed with traditional methods. The GPS link between BEV and PTB constitute a special case; it was calibrated by a portable TW station following the method described by Niessner at al. [7]. In addition to these independent equipment calibrations, the BIPM applies, whenever necessary the so called alignment correction. By doing so, we align a non-calibrated link to a calibrated one that needs to be replaced. A dozen of TW, GPS and GLN calibrations were made by this procedure.

Some questions arise: 1) cross calibrations have never been organized. Hence, the independent calibrations are not traceable to a unique standard. In the following section, we show that differences beyond the u_B values may exist between links performed with different techniques; they could be originated in these calibrations; 2) roughly speaking, the *UTC* calibrations can be grouped into link-based (like TW) and site-based (like GPS). The calibration uncertainty u_B is about 1 ns for the link-based TW and conventionally 5 ns for the sited-based GNSS. This situation is different from that of u_A, especially for GNSS; 3) the conventional values u_B take into account the long-term instability of the equipment involved in the calibrations, which is the BIPM standard equipment and that in the laboratories. Comparison between GPS and TW results for the same baselines shows that the discrepancy can be up to 6 ns, probably provoked by long-term variations; 4) for some inter-continental TW links, the only way of calibration is by alignment to the co-located GNSS links. In these cases the u_B vales is large due to the GNSS uncertainty of 5 ns assigned according to current calibration policy, and the degradation of its value follows that of GNSS links.(case of NIST-PTB).

In the following sections, we revisit the present BIPM calibration policy for *UTC* time transfers; we analyze its advantages and disadvantages. We present numerical examples of the differences between some time links calculated with different techniques independently calibrated, and we later discuss possible strategies for reduce the inconsistencies. Finally we discuss some practical issues.

II. Current *UTC* calibration policy

The four types of *UTC* equipment calibration in participating laboratories are 1) GPS C/A code receiver calibration with travelling GPS C/A code standard equipment; 2) TW link calibration with a portable TW station; the calibration campaigns are entirely organized by the TW laboratories 3) GPS P code receiver calibration with a BIPM P code standard [4]; since 2001 the GPS P code receiver calibrations have been performed with the same methodology; 4) the unique calibration of the GPS C/A code link between BEV and PTB using a TW portable station in 2007 [7]. In addition to these four types of independent calibrations, non-independent calibrations are realized at BIPM with the so called alignment operation. The TW links between PTB and AOS, NICT, NIST, ROA, NTSC, NPL, TL and the GLN links between PTB and AOS, NIS, OP, SG, SU, UME were aligned to exiting calibrated GPS links; a few GPS links were aligned to TW. A couple of timing laboratories calibrated individually (either absolute or relative calibrations) their back up GPS receivers [10,11,12].

Changes in the satellite occur rather frequently, provoking frequently loses of calibration. The last TW calibrations were performed in 2008 [6], and they were lost because of the change in satellites in July 2009. The calibrations were restored with the help of bridges made at the BIPM with the respective GPS PPP links with one exception (NPL) due to equipment failure [8].

Section 6 of BIPM Circular T gives the values of the u_B for the links used in the monthly calculation. Conventional values of u_B are assigned to different calibration types [1,7,9,13]: 20 ns for the cases of non-calibrated equipment; 1 ns for a TW link calibrated with a TW portable station; 5-7 ns for a GNSS link; Finally 3 ns has been assigned to u_B for the unique GPS link BEV-PTB at the moment of the calibration in 2008. As discussed below, it will be proposed to degrade this value in order to account for possible long-term instability of the GPS equipment.

III. Consistency of the *UTC* time transfer links

The *UTC* time transfer calibrations are parallel and independent for the different techniques. Although a considerable number of links can be performed by more than one technique and they have all been calibrated, no cross calibrations have been formally organized yet. To asses the consistency between the different techniques applied to a time link, and later study the influence of the various calibrations, we make use of the comparisons between different links of a baseline. In these cases the common clocks are cancelled, so that the discrepancy between two links indicates their consistency. To reduce the influence of the measurement noise and the short-term biases like the diurnals in TW and multi-paths in GNSS, we compare the monthly mean value of the links. On average, there are more than 360 measured TW points per month and more than 2000 for GNSS. According to the availability of the data set, the comparisons are made for a period of 5 to 14 months back up from February 2010. All the link statistic data are collected from the BIPM ftp site on the monthly *UTC* time link comparisons (ftp://tai.bipm.org/TimeLink/LkC/). Three statistical estimators are used in the following analysis: the mean (Mean), standard deviation (StdD) and the root mean square (RMS) of the differences between two techniques on the same link to describe the characteristics of the inconsistency. RMS gives its total absolute amplitude; StdD gives its variation against the Mean; and Mean indicates the degree of deviation (negative or positive). If the RMS is close to the Mean and both are bigger than u_B and StdD << RMS and less than u_B, we know that some inconsistency may exist. In other cases, an inconsistence may present as a slow drift. All the statistics in this paper are based on the data of *UTC* baselines.

We have chosen as a first example 14 months of results of the baseline USNO-PTB calculated with TW Ku and X bands and GPS PPP. Table 1 and Fig. 1 show the differences of the monthly averages. The TW Ku link was calibrated through X band in 2008; the GPS PPP equipment at the USNO was absolutely calibrated by USNO/NRL in 2002 and the GPS PPP equipment at the PTB was differentially calibrated by BIPM in Aug. 2004. There is a clear tendency: in January 2009, close to the TW Ku link calibration, the three links agreed within 0.5 ns. Until July 2009, the TW X band and PPP links agreed within 1 ns and then separated each other. The maximum difference (1.9 ns) is found November 2009. USNO reported that both the TW links X and Ku bands were disturbed during the winter 2009. The Mean of the differences between TW X and PPP is 0.9 ns with the StdD 0.5 ns and the RMS 1.0 ns; the Mean of the differences between TW Ku and X bands and TW Ku and PPP are respectively in ns -2.7 and -1.8 with StdD 1.4 and 1.0 and RMS 3.0 and 2.1. We may conclude that the TW X agrees well with PPP within 1 ns and that inconsistencies of 2 to 3 ns exist between TW Ku-band and both TW X and PPP. The inconsistency is two or three times the value of u_B; a drift of the Ku-band link is observed (the yellow line in Fig. 1) since last May 2009; this is the primary link for the computation USNO-PTB in *Circular T*.

Table 1 Consistency of European-American links (USNO-PTB) over last 14-months in ns

YYMM	TW KU-PPP	WT X-PPP	TW KU-X
1002	-2.3±2.3	1.2±0.7	-3.2±3.0
1001	-2.4±1.1	0.4±0.4	-2.9±1.5
0912	-3.1±1.2	1.4±0.7	-4.8±1.8
0911	-1.6±0.9	1.9±0.4	-3.5±0.9
0910	-2.4±1.1	1.5±0.3	-4.2±0.9
0909	-2.6±0.7	1.1±0.3	-3.8±0.9
0908	-3.0±0.7	1.2±0.2	-4.2±0.8
0907	-2.7±0.4	0.8±0.5	-3.5±0.5
0906	-1.9±1.1	0.4±0.2	-2.3±1.0
0905	-0.9±1.0	0.2±0.?	-1.1±1.0
0904	-1.1±1.0	0.1±0.?	-1.2±1.6
0903	-0.5±0.6	0.8±0.?	-1.3±0.8
0902	-0.5±0.7	0.6±0.?	-1.1±1.0
0901	-0.1±0.6	0.4±0.?	-0.5±0.7
Mean	**-1.8**	**0.9**	**-2.7**
StdDev	**1.0**	**0.5**	**1.4**
RMS	**2.1**	**1.0**	**3.0**

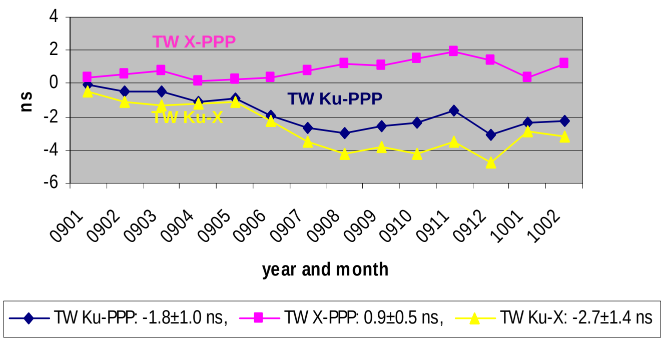

Fig. 1 Consistency USNO-PTB links: 14 months between January 2009 and February 2010

The three European links CH-PTB, OP-PTB and VSL-PTB have been chosen to compare over a five-month interval the differences between TW and GPS PPP, and over a 14-month interval for TW and GPS P3.. The results are presented in Tables 2 and 3; PPP is more precise than P3 in the sense of measurement noise but in both cases the calibrations are based on the P codes. We notice that all the Mean and RMS are bigger than 1 ns while the StdD are lower than or equal to 1 ns. The biggest RMS is 4.3 ns. This implies that some inconsistency may exist. If we subtract OP-PTB from CH-PTB resulting link is CH-OP. The corresponding Means are: -6.3 ns for TW-PPP and -5.9 ns for TW-P3. I.e. if we make a time transfer between CH and OP, by GPS PPP and by TW, we will have a 6.3 ns difference in the results, most probably from the calibrations or their variations. This differences are beyond the uncertainty combination, $u_B^2(\text{GPS})+u_B^2(\text{TW})=5.1^2$ ns.

Table 4 gives the difference between TW and GPS C/A code links. C/A code is much noisier than the P code, but in the Mean calculated over a month the noise is greatly reduced. The European link OP-PTB shows a difference of 3.8 ns while the European-American link USNO-PTB agrees well.

Table 2 Consistency of European links over last 5 months between TW and GPS PPP in ns

YYMM	CH-PTB	OP-PTB	VSL-PTB
1002	-4.3±0.9	2.6±0.7	-1.8±0.7
1001	-3.6±1.0	2.7±0.7	-1.1±0.9
0912	-3.3±0.9	3.3±1.1	-0.9±0.9
0911	-3.0±0.6	2.4±0.7	-1.3±1.2
0910	-3.4±1.1	2.9±0.6	------
Mean	**-3.5**	**2.8**	**-1.3**
StdDev	**0.5**	**0.3**	**0.4**
RMS	**3.5**	**2.8**	**1.3**

Table 3 Consistency of intra-Europe and Europe-American links over last 14 months between TW and GPS P3 in ns

YYMM	CH-PTB	OP-PTB	VSL-PTB	USNO-PTB
1002	-4.7±1.0	2.3±1.2	-1.9±0.8	1.0±0.9
1001	-4.1±1.0	2.6±1.3	-1.3±1.0	0.2±0.6
0912	-3.8±0.9	3.1±1.6	-1.2±1.4	1.0±0.9
0911	-3.7±0.8	2.2±1.0	-1.6±1.3	1.4±0.7
0910	-4.0±0.7	2.4±1.0	-2.0±1.0	1.0±0.7
0909	-4.2±0.7	2.6±0.8	-------	0.6±0.7
0908	-4.8±0.8	------	-3.2±1.1	0.5±0.7
0907	-5.3±0.6	1.4±0.8	-3.3±2.0	0.4±0.7
0906	-5.2±0.5	0.6±1.1	-3.5±2.0	------
0905	-5.2±0.6	1.5±2.2	-3.7±2.0	------
0904	-4.9±0.6	2.0±1.1	-3.5±1.9	1.2±1.6
0903	-3.6±0.5	1.2±1.1	------	------
0902	-3.4±0.5	0.6±0.6	------	------
0901	-3.2±0.5	0.6±0.6	------	------
Mean	**-4.2**	**1.7**	**-2.5**	**0.8**
StdDev	**0.7**	**0.8**	**1.0**	**0.4**
RMS	**4.3**	**1.9**	**2.7**	**0.9**

Table 4 Consistency of TW-GPS C/A links over last 14 months in ns

YYMM	OP-PTB	USNO-PTB
1002	4.0±2.3	-0.8±1.6
1001	3.9±2.3	-0.9±1.4
0912	3.2±2.6	0.0±1.6
0911	3.5±2.5	0.6±1.7
0910	4.6±2.4	-0.2±1.8
0909	5.1±2.5	-0.6±1.5
0908	-----	-0.8±1.4
0907	4.5±2.4	-0.9±1.3
0906	4.1±2.3	-1.2±1.4
0905	3.6±2.5	-1.5±1.4
0904	3.7±2.2	-0.5±2.5
0903	3.0±2.4	------
0902	2.9±2.3	------
0901	2.4±2.2	------
Mean	**3.7**	**-0.6**
StdDev	**0.8**	**0.6**
RMS	**3.8**	**0.8**

Table 5 presents the difference between the C/A code links of GPS All in View (AV) and GLN Common View (CV). The data are collected from the same type of receivers (TTS3). Both of the raw data are corrected using the IGS precise ephemeris and ionosphere maps. GLN links were calibrated and aligned to GPS in May 2009 [14]. The calibrations of GPS and GLN links are consistent due to the fact that both share almost the same hardware: antenna, cable and receiver. While the contribution of the satellites (either GPS or GLN), the data processing methods (AV or CV) and the IGS corrections as well as the measurement noises are different, but they do not affect the calibration. The consistency between GPS and GLN does not asses the long-term stability of the equipment but shows the agreement between them.

Table 5 Consistency of GPS vs GLN C/A links over last 10 months in ns

YYMM	AOS-PTB	SU-PTB	UME-PTB
1002	-0.6±1.6	-0.2±1.4	0.0±1.4
1001	-1.4±1.6	-0.3±1.6	-0.4±1.4
0912	-1.0±1.5	-0.2±1.6	-0.4±1.4
0911	-0.7±1.6	-0.4±1.6	-------
0910	-0.9±1.4	-0.3±1.6	-0.4±1.3
0909	-0.4±1.6	-0.4±1.6	-0.0±1.4
0908	-0.4±1.6	-0.4±1.6	-0.6±1.4
0907	-0.3±1.6	-0.7±1.6	-0.6±1.4
0906	-0.2±1.6	-0.3±1.6	-0.7±1.4
0905	-0.0±1.6	-0.0±1.6	-0.0±1.4
Mean	**-0.6**	**-0.3**	**-0.3**
StdDev	**0.4**	**0.2**	**0.3**
RMS	**0.7**	**0.4**	**0.4**

Table 6 Summary of the consistence between the UTC calibrations in ns

Link Comparison	u_B	Min	Max	Mean	StdDev	RMS
TW-TW(X-KU)	1	-4.8	-0.5	-2.7	±1.4	±3.0
TW-GPS(P3/PPP)	5	-4.2	2.8	-0.9	±0.3~1.0	±0.1~4.3
TW-GNSS(C/A)	5	-0.6	3.7	1.6	±0.6~0.8	±0.8~3.8

Table 6 is a summary of the differences between *UTC* links. We can draw out that:

1. Inconsistency does not come from the measurement uncertainty u_A or biases of the techniques (diurnals in TW, ionosphere in GNSS etc.)
2. Inconsistency may partially be originated on:
   - the different types of independent calibrations
   - in the case of a single type of calibration, the cause could be the long-term variation of the standards
3. Long-term variation of time transfer equipment in the time laboratories

Item 2 calls for unification of *UTC* link calibrations and item 3 indicates a need for more frequent calibrations.

IV. Unifying calibrations of *UTC* links

Esteban et al.[12] made experimental work to jointly calibrate the TW and GPS time links for the baseline ROA-PTB. A dual frequency multi-channel GPS carrier phase receiver GTR50 was employed as the travelling standard receiver. Measurements took place at first at ROA, then at the PTB concluded at ROA to have the closure. The C/A codes, P1, P2 and P3 (PPP) codes of 8 GPS receivers as well as the TW link were calibrated as a whole. As reported by the authors the result was encouraging: the u_B of TW was below 2 ns and sub-nanosecond uncertainty is potentially achievable. This suggests, if the uncertainty is proven, that generalizing this experience to unify *UTC* TW and GNSS link calibrations allows expecting a lower u_B globally in the *UTC* time transfer network. We discuss a scheme adapted to the *UTC* generation through a unified calibration.

For different sections of *Circular T* computation, the calibrations are used differently: site-based calibrations for the computation of the values of [*UTC* − *GPS Time*] and [*UTC* − *GLONASS Time*] published in Section 5; and link-based calibrations for the values of [*UTC* − *UTC*(*k*)] published in Section 1. More exactly, for *UTC* generation, we need the calibration of the links Lab(*k*)-PTB and the associated Type B uncertainty, u_B. As presented in the previous section, differences between results of *UTC*(k) comparisons for the same baseline using various available techniques can be larger than the respective u_B values. These differences could arise from the calibrations, that is, degradation of the calibration with time, change of set-up in the laboratory, lost of calibration provoked by satellite changes (case of TW). For the maintenance of the system of time links at the BIPM, the ideal situation should be to repeat regularly the calibration of all links and all techniques, and to check that after each exercise the results are consistent. We are aware that this procedure would be very heavy in cost and manpower for the contributing laboratories and also for the BIPM.

To avoid or minimize any inconsistency among the *UTC* calibrations, several options could be envisaged tempting to "unify" the TW and the GNSS calibrations by making them traceable to a unique standard. [15,16]. There is already experience [13] in calibrating a GPS link via TW with a portable TW station as a standard. The GNSS equipment calibrated in this way could be used for regional calibrations in other laboratories. Disadvantage of this approach is the cost and the difficulty in the organization. A more feasible strategy that has been recently discussed and agreed with European laboratories is to circulate GNSS receivers following a specially designed programme to fully profit of the short-term stability and avoid the long-term instability. Two GNSS dual-frequency, multi-channel carrier-phase receivers with proven short and long terms stability are necessary, one at the pivot laboratory (today PTB), the other visiting *UTC* contributing laboratories. Absolute calibration of the two receivers is desirable to further investigate their behavior and better monitoring their long-term stabilities.

Meanwhile, other independent calibrations should also be maintained, e.g. the repeated GNSS absolute calibrations provide information on the long-term stability of equipment and the portable TW stations provide good accuracy.

To simplify the discussion, we may call "Total Delay" the result of a GNSS link calibration, which is in fact the alignment correction in *UTC* computation at BIPM. As illustrated in Fig. 2, the Total Delay is the differential delay of the ground systems at the two ends of a link, i.e. (antenna1+cables1+receiver1) - (antenna2+cables2+receiver2). It is quite like the CALR in TW except that the later contains the delay of the satellite segment.

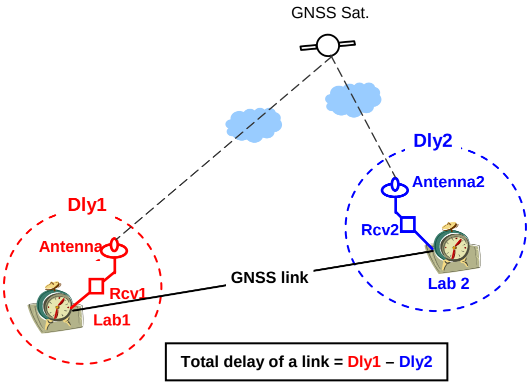

Fig. 2 Total Delay of a GNSS link

A scheme of 3 steps for unifying GNSS and TW using two receivers Std1 and Std2 could be as follows:

1) Initial relative calibration by the side-by-side installation of Std1 and Std2, we determine the Total Delay = Dly1(Std1) – Dly2(Std2) then we adjust the Total Delay = 0 for Std1 and Std2, i.e., Dly1(Std1) = Dly2(Std2) (Fig. 3a).

2) A typical calibration tour is illustrated as in Fig. 3b: Std1 stays at the reference laboratory (possible the pivot) and Std2 visits other contributing laboratories to calibrate together the TW and GNSS links. The key of the calibration quality is the instability of Std2 which travels among the laboratories.

3) The process concludes with the closure measurements respecting the initial calibration set up.

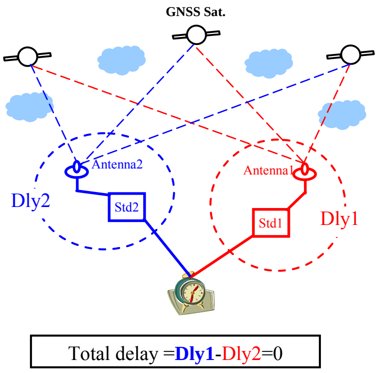

Fig. 3a Side-by-side installation of Std1 and Std2

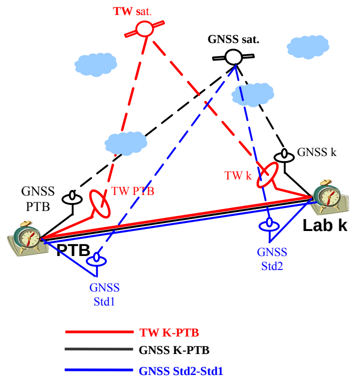

Fig. 3b Installation of an integer calibration TW and GNSS links for baseline Lab(*k*)-PTB through Std1 and Std2

Uncertainty of the "unified" calibration for the link Lab(*k*)-PTB can be estimated by:

$u_B^2(k\text{-PTB})=u_A^2(k\text{-PTB})+u_A^2(\text{Std2-Std1})+\boldsymbol{c}^2(\text{Std2-Std1})$

here $\boldsymbol{c}$ is the conventional short-term-link-instability of Std1-Std2 for a typical calibration tour that consists of at least three occupations: Reference lab→Lab(*k*)→Reference lab. If we set $\boldsymbol{c}$ = 2 ns (as is shown to be achievable by Esteban et al [12] and others), the u_B of the unified calibrations become: u_B(GNSS P) ≈ 2.23 ns (for u_A = 0.7); u_B(GNSS C/A) ≈ 2.60 ns (for u_A = 2.0) and u_B(TW) ≈ 2.17 ns (for u_A = 0.5). The above equation is conservative because the measurement uncertainty u_A should be averaged out, theoretically by a factor of the root of *n*, with *n* the number of the total measured points.

Advantages of the unified approach realized by the proposed schema are:

1. Provided that the calibration tours are short (around three months), the results will be affected only by the short-term instability of the equipment involved. (Note that the long term instability of the equipment at the laboratory k still needs to be addressed, see section V).
2. Improvement of the calibration uncertainty u_B for most *UTC* time links, and consequently reducing the uncertainty of [*UTC* – *UTC*(*k*)] in the *Circular T*;
3. Calibration of the TW links and in particular of inter-continental TW links becomes possible;
4. Simplifying the organization of *UTC* calibration campaigns;

5. Simplifying monitoring of these calibrations;

Nine contributing laboratories contribute half of the total clock weight in *UTC*. It is reasonable to think of closely monitoring the variation in the calibrations and establishing a program of calibrations in order of priority.

V. Evolution of u_B: increases with time

It is logic that without re-calibration or an independent check, the maximum life of a "*free running*" u_B is limited, saying about 10 years, e.g., for each of the techniques u_B(>10 year) = 10 ns. A "free running" u_B increases with time. For the purpose of automatic computation, it is useful to design an analytical model for u_B evolution. For example, a model based on a random walk phase noise or on a flicker phase noise (or on a combination of both) could be used. In the following, examples are shown for a random walk model, although the resulting values are probably overly pessimistic for the long-term

$$u_B^2(T - T_0)_{k\text{-PTB}} = u_B^2(T_0)_{k\text{-PTB}} + (T - T_0) \times u_A{}^2{}_{k\text{-PTB}}$$

Here T-T_0 is the time since calibration in months and u_A is the random walk part of the 1-month Type A uncertainty of the link taken to be: u_A(GNSS C/A code) ≈ 0.7 ns; u_A(GNSS P codes) ≈ 0.5 ns and u_A(TW) ≈ 0.3 ns. Based on above hypothesis, Table 7 demonstrates the evolution of $u_B(T - T_0)$ with time.

Table 7 Evolution of u_B (in ns) increasing with time as a random walk process

Link	$u_B(T_0)$	u_A	u_B(1yr)	u_B(3yr)	u_B(5yr)	u_B(10yr)	u_B(>10yr)
TW	1.0	0.3	1.4	2.1	2.5	3.4	10
GNSS P	2.0	0.5	2.6	3.6	4.4	5.8	10
GNSS C/A	3.0	0.7	3.9	5.2	6.2	8.2	10

VI. Conclusion

Following the technology progress and the upgrading of equipment in contributing laboratories, different time transfer techniques have been progressively introduced in the calculation of *UTC* time links, as well as the associated calibration methods. At present, different types of independent calibrations are organized for different types of *UTC* links. No cross calibrations have ever been organized, thus inconsistencies between the *UTC* links have not being studied.

In this study, we have investigated strategies for unifying TW and GPS calibrations of the same links to (a) monitor the long-term variations of the GNSS equipment, (b) enhancing the calibration of TW links faced to satellite changes, (c) allowing the calibration of TW intercontinental links by the corresponding GNSS link, (d) contributing to the monitoring of the stability of equipment calibration. We expect to obtain more realistic, and improved, values for the u_B and for the total uncertainty of *UTC-UTC*(*k*);

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