Bureau International des Poids et Mesures

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EXPLANATORY SUPPLEMENT OF BIPM *CIRCULAR T*

This document describes the contents of the sections in BIPM *Circular T* updated in June 2024 (Cirt.437, based on May 2024 data).
For automatic data extraction, a *Circular T* format description file is available at https://webtai.bipm.org/ftp/pub/tai/other-products/notes/cirt_format_v0.3.txt .
The issues of BIPM *Circular T* are available at the BIPM website at https://www.bipm.org/en/time-ftp/ ; data used in the calculation of each *Circular T* are available at https://www.bipm.org/en/time-ftp/data .

In *Circular T*, all uncertainties are expressed with a coverage factor k = 1.

Section 1
Difference between UTC and its local realizations UTC(k) and corresponding uncertainties

This section gives the values of [*UTC*-*UTC*(*k*)] (in ns) at five-day intervals on MJD ending by 4 and 9, at 0 h UTC for local realizations of UTC maintained at contributing laboratories "*k*" and their respective uncertainties, valid for the month.
A complete description of the method of UTC calculation is available in [1].
The algorithm for the uncertainty evaluation is based on [2].
Notes on this section provide relevant information relating to a result.

Section 2
Difference between the normalized frequencies of EAL and TAI

This section gives the values of the difference between the normalized frequencies of EAL (free atomic time scale) and TAI for the interval covered by the current *Circular T* as well as those for the following two months. They indicate if a steering correction of the frequency of EAL has been applied and/or is foreseen necessary for preserving the accuracy of TAI.

Section 3
Duration of the TAI scale interval *d*

TAI is a realization of coordinate time TT (in practice, the SI second on the geoid). The tables give the fractional deviation *d* of the scale interval of TAI from that of TT , In Table 1 *d* is the normalized difference between the frequency of the single PSFS with respect to the frequency of TAI ($d = y_{PSFS} - y_{TAI}$) and Table 2 is the estimated normalized frequency difference of TT with respect to TAI ($d = y_{TT} - y_{TAI}$), i.e. the fractional frequency deviation of TAI with the opposite sign: $d = -y_{TAI}$. To obtain these data, the PSFS is measured versus a clock or UTC(k) participating to UTC acting as intermediate reference. The frequency of that intermediate reference versus TAI, for the purpose of this section, is evaluated by the ratio of the end-point phase difference to the duration of the interval [3].

For each month yymm, the instability of EAL and the list of primary and secondary frequency standards measurements used in the evaluation of *d* may be found in the file etyy.mm in https://webtai.bipm.org/ftp/pub/tai/other-products/etoile .

In the first table, *d* is obtained, on the given periods of estimation by comparison of the TAI frequency with that of the given individual Primary and Secondary Frequency Standards (PFS/SFS).
In this table:

- $\boldsymbol{u_A}$ is the uncertainty originating in the instability of the standard,
- $\boldsymbol{u_B}$ is the combined uncertainty from systematic effects,
- $\boldsymbol{u_{A/lab}}$ and $\boldsymbol{u_{B/lab}}$ represent the uncertainty in the link between the standard and the clock participating to TAI, respectively from statistical fluctuations including the uncertainty due to the dead-time for $\boldsymbol{u_{A/lab}}$, and from systematic effects for $\boldsymbol{u_{B/lab}}$,
- $\boldsymbol{u_{l/TAI}}$ is the uncertainty in the link to TAI,
- $\boldsymbol{u}$ is the quadratic sum of all five uncertainty values,
- ***Ref*($\boldsymbol{u_B}$)** is a reference giving information on the values of u_B or is the *Circular T* where the reference was first given,
- $\boldsymbol{u_B}$***(Ref)*** is the u_B value stated in this reference,
- ***Uptime*** is the percentage of the period of estimation when the frequency of the standard is actually used to obtain the reported frequency; it is the complement of the dead-time used for $\boldsymbol{u_{A/lab}}$,
- ***Lastrep*** is the Circular T number where the standard was last reported in the preceding 36 months,
- ***Nrep3y*** is the number of reports of the standard published in the preceding 36 months,
- ***Steer*** indicates whether the standard has been approved for TAI steering by the CCTF working group on primary and secondary frequency standards.

Note that all uncertainties may vary over time and that the current u_B values are generally not the same as the peer reviewed values given in Ref(u_B).

See https://www.bipm.org/en/time-ftp/ for previous issues of *Circular T* and individual Reports of Evaluation of Primary and Secondary Frequency Standards that explain changes in uncertainties.

For the SFS, $\boldsymbol{u_S}$**rep** represents the recommended uncertainty of the secondary representation of the second and ***Ref*($\boldsymbol{u_S}$)** provides the reference for the frequency of the transition and its uncertainty $u_S$rep, these two fields are not applicable to PFS.

All values are expressed in 10^{-15} and are valid only for the stated period of estimation.

The second table gives the BIPM estimate of *d*, based on all available PFS and SFS measurements over the indicated period, taking into account their individual uncertainties and characterizing the instability of EAL as noted above. *u* is the computed standard uncertainty of *d*.

Note that a plot summarizing all PFS and SFS evaluations since Circular T190 may be found at https://webtai.bipm.org/database/show_psfs.html and https://webtai.bipm.org/database/d_plot.html .

Section 4
Relations between UTC and predictions of UTC broadcast by GNSS

This section informs on the relations between UTC and predictions of UTC broadcast by GNSS. To this aim, the BIPM Time department selects a pool of calibrated, multi-constellations receivers hosted by G1 UTC laboratories, combines their results to estimate the values UTC-bUTC$_{GNSS}$, where bUTC$_{GNSS}$ represents the prediction of UTC broadcast by an individual GNSS, named GPS/GLO/GAL/BDS respectively.

A complete description of the method and an assessment of the uncertainties are available in [4].

The sigma_GPS/GLO/GAL/BDS values, represent conservative monthly estimates of uncertainty based on the above mentioned article's calculations, and susceptible of being adjusted in case unexplained instabilities in the data are observed. It should be noted that this uncertainty corresponds to the uncertainty of the [*UTC – bUTC$_{GNSS}$*] values obtained with this method by the BIPM, and not to the uncertainty with which any user can link its local time scale to UTC using a GNSS receiver.

Then, for each day of the period covered by the Circular :

- Column 1: Calendar date
- Column 2: Modified Julian date
- Column 3: UTC-bUTC$_{GPS}$ value in ns
- Column 4: UTC-bUTC$_{GLO}$ value in ns
- Column 5: UTC-bUTC$_{GAL}$ value in ns
- Column 6: UTC-bUTC$_{BDS}$ value in ns

Missing data is indicated by the character "-"

Section 5
Time links used for the computation of TAI, calibrations information and corresponding uncertainties

This section provides information on the time links used in the elaboration of each *Circular T*, including equipment and calibration identifiers, uncertainties and alignment corrections applied by the BIPM, if any. Description of the plots content is available in section 2.3 of the document https://webtai.bipm.org/ftp/pub/tai/timelinks/lkc/ReadMe_LinkComparison_ftp_v11.pdf .

The first table includes links formed with station-based GNSS techniques indicated as follows:

- ***GPS MC*** for GPS all-in-view multi-channel C/A data,
- ***GPS P3*** for GPS all-in-view multi-channel dual-frequency P code data,
- ***GPSPPP*** for GPS Precise Point Positioning technique,
- ***GLN MC*** for GLONASS common-view multi-channel C/A data,
- ***GPSGLN*** for the combination of GPS MC and GLN MC.

The second table includes link-based techniques, indicated as:

- ***TWSTFT*** for two-way satellite time and frequency transfer,
- ***TWGPPP*** for the combined smoothing of TWSTFT and GPS PPP,
- ***TWSDRR*** for TWSTFT method involving Software Defined Radio receivers,
- ***SDGPPP*** for the combined smoothing of TWSTFT SDR and GPS PPP

For a link, the equipment at each laboratory is designated by its unique identifier (6-character for TWSTFT ground station).

- ***Cal_ID*** is the calibration identifier of the campaign where the equipment/link has been calibrated [5],
- ***NC*** stands for no calibration,
- ***NA*** stands for no availability of the calibration report,
- ***NC_Al*** indicates that a correction has been applied for aligning the current link to another link previously used, non-calibrated,
- ***NA_Al*** indicates that a correction has been applied for aligning the current link to another link previously used and calibrated, for which the calibration report is not available,
- ***NL*** indicates that no time transfer data was available for this *Circular T* period,
- ***uStb*** is the standard uncertainty representing the link instability and accounting for measurement noise and random effects with typical duration between 1 and 30 days,
- ***uCal*** represents the total uncertainty from calibration, derived from the original equipment/link calibration uncertainty and also including components for aging and for alignment when appropriate. In the case of links involving TWSTFT the standard measurement uncertainty of ESDVAR (ESIG) is also included, if applicable. In the case of uncontrolled events (affecting time links for 3 months) an additional component of uncertainty may be added.
- ***uAg*** is the uncertainty accounting for calibration aging [6] with the following rules applied:
  - until 10 years (0.4*sqrt(months)-1)
  - 10 years: u=20 ns
  - After 10 years: 20 ns per year
- ***Al*** is the link alignment correction applied if necessary by the BIPM on ***YYMM*** (year and month), the conventional uncertainty increment for an alignment is 1 ns.
- Validity of alignment: setting a 12-month time limit to the procedure of « alignment by the BIPM ». After this period, the calibration is considered invalid (NC).

For the calibration uncertainty of GNSS equipment prior to 2014, refer to the BIPM guidelines for GNSS calibrations [7], sub-section A1.

References

[1] G. Panfilo and F. Arias, 2019 Metrologia 56 042001
[2] G. Panfilo et al 2020 Metrologia 57 065011.
[3] G. Panfilo and F. Arias, 2019 Metrologia 56 042001, section 5.1.3.
[4] P. Defraigne et al., 2023 Metrologia 60 065010
[5] BIPM calibration information can be found in: https://webtai.bipm.org/database/calid_gnss.html
[6] Gérard Petit and Pascale Defraigne 2023 Metrologia 60 025009
[7] BIPM guidelines for GNSS calibration

Version history:

V0.3 (12 May 2020): Update of section 3.

V0.4 (11 Feb 2021):

- Update of ageing formula for all GNSS calibrations. The ageing coefficient to be applied following [2] is taken as 0.4 ns $yr^{-1/2}$. This follows from a decision of the WG on GNSS at its meeting of June 3, 2020.
- FTP file access modified from ftp://ftp2.bipm.org/... to https://webtai.bipm.org/ftp to adapt with web browser change of policy concerning ftp:// links.
- External access to EAL instability parameters values used in computations.

V0.5 (30 June 2021): Update of section 5 to add the SDGPPP combination.

V0.6 (12 July 2021): Update of section 3 to add the limitation of the last used report.

V0.7 (24 May 2024): Update of section 1 and 5 to apply the new rules for the uncertainties, of section 4 for including Galileo and Beidou
V0.8 (22 July 2024): Completion of references following QMS survey outcomes to provide more information to the users.