Establishment of International Atomic Time and Coordinated Universal Time

1. Data and computation

International Atomic Time (TAI) and Coordinated Universal Time (UTC) are obtained from a combination of data from about 450 atomic clocks operated by more than 80 timing centres which maintain a local UTC, UTC(*k*) (see http://webtai.bipm.org/database/showlab.html). The data are in the form of time differences [*UTC*(*k*) - *Clock*] taken at 5-day intervals for Modified Julian Dates (MJD) ending in 4 and 9, at 0 h UTC; these dates are referred to here as "standard dates". The equipment maintained by the timing centres is detailed in Table 4.

An iterative algorithm produces a free atomic time scale, EAL (Échelle Atomique Libre), defined as a weighted average of clock readings. The processing is carried out and, subsequently, treats one month batches of data. The weighting procedure and clock frequency prediction [1, 2] are chosen such that EAL is optimized for long-term stability. No attempt is made to ensure the conformity of the EAL scale interval with the second of the International System of Units (SI).

2. Accuracy

The duration of the scale interval of EAL is evaluated by comparison with the data of primary frequency caesium standards and secondary frequency standards recommended for secondary representations of the second, correcting their proper frequency as needed to account for known effects (e.g. general relativity, blackbody radiation). TAI is then derived from EAL by adding a linear function of time with an appropriate slope to ensure the accuracy of the TAI scale interval. The frequency offset between TAI and EAL is changed when necessary to maintain accuracy, the magnitude of the changes being of the same order as the frequency fluctuations resulting from the instability of EAL. This operation is referred to as the "steering of TAI" and file feal-ftai gives the normalized frequency offsets between EAL and TAI. Measurements of the duration of the TAI scale interval and estimates of its mean duration are reported in Table 6 and Table 7.

3. Availability

TAI and UTC are made available in the form of time differences with respect to the local time scales UTC(*k*), which approximate UTC, and TA(*k*), the independent local atomic time scales. These differences, [*TAI - TA*(*k*)] and [*UTC - UTC*(*k*)], are computed for the standard dates including uncertainties of *[UTC – UTC*(*k*)] [3].

The computation of TAI/UTC is carried out every month and the results are published monthly in *Circular T*.

The BIPM pilots the key comparison in time CCTF-K001.UTC. Institutes participating in the key comparison are National Metrology Institutes and Designated Institutes; they constitute a sub-set of the participants in *Circular T*.

A rapid solution, *UTCr* has been published without interruption since July 2013. Regular publication of the values [*UTCr - UTC*(*k*)] allows weekly access to a prediction of UTC [4] for about fifty laboratories which also contribute to the regular monthly publication. However, the final results published in BIPM *Circular T* remain the only official source of traceability to the SI second for participating laboratories.

The difference between UTC and UTCr (calculated as a weighted average over the laboratories participating to UTCr) is reported in Figure (1) from August 2012 until August 2020.

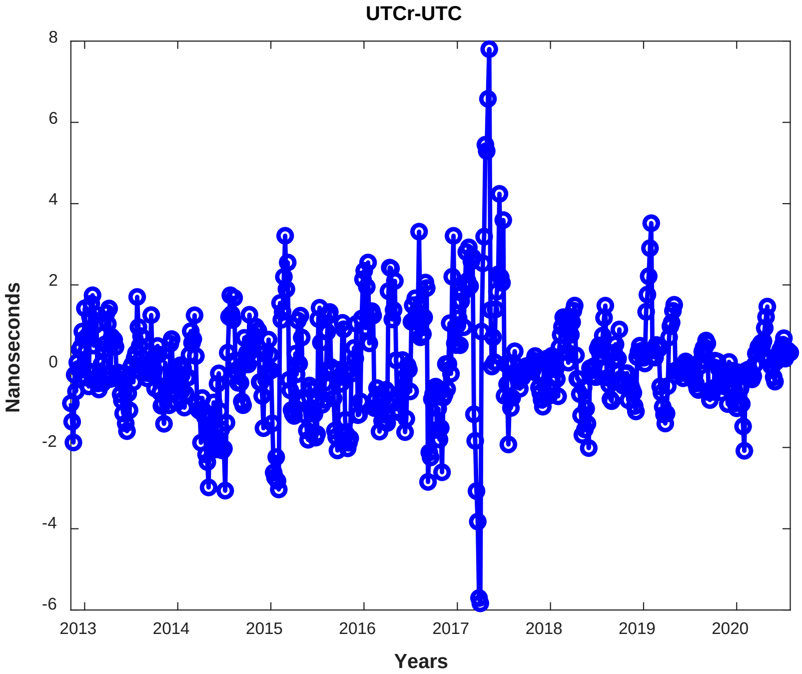

Figure 1. Difference between UTC and UTCr until May 2020.

4. Time links

The BIPM organizes the international network of time links to compare local realizations of UTC in contributing laboratories and uses them in the calculation of TAI. The network of time links used by the BIPM is non-redundant and relies on observation of GNSS satellites and on two-way satellite time and frequency transfer (TWSTFT).

Most time links are based on GPS satellite observations. Data from multi-channel dual-frequency GPS receivers are regularly used in the calculation of time links, in addition to that acquired by a few multi-channel single-frequency GPS time receivers. For those links realized using more than one technique, one of them is considered official for UTC and the others are calculated as back-ups. Single-frequency GPS data are corrected using the ionospheric maps produced by the Centre for Orbit Determination in Europe (CODE); all GPS data are corrected using precise satellite ephemerides and clocks produced by the International GNSS Service (IGS).

GPS links are computed using the method known as “GPS all in view” [5], with a network of time links that uses the PTB as a unique pivot laboratory for all the GPS links. Links between laboratories equipped with dual-frequency receivers providing Rinex format files are computed with the “Precise Point Positioning” method GPS PPP [6].

Clock comparisons using GLONASS C/A (L1C frequency) satellite observations with multi-channel receivers have been in use since October 2009 [7]. These links are computed using the “common-view” [8] method; data are corrected using the IAC ephemerides SP3 files and the CODE ionospheric maps. They can also be used in a combination of GPS and GLONASS links [9].

Finally, a combination of individual TWSTFT and GPS PPP links [10] are currently used in the calculation of TAI. The figure showing the time link techniques in the contributing laboratories can be downloaded from the BIPM website and is also reported below as “*Geographical distribution of the laboratories that contribute to TAI and time transfer equipment*”. For more detailed information on the equipment refer to [Table 4], and to BIPM *Circular T* for the techniques and methods of time transfer officially used and for the values of the uncertainty of [$UTC(k_1)$ - $UTC(k_2)$], obtained at the BIPM with these procedures.

New or improved time transfer system measures are evaluated and used as back up. These include the SDR (software defined radio receiver) [11], the preliminary use of the Galileo and Beidou GNSS [12, 13], IPPP (integer precise point positioning) [14].

The BIPM publishes in *Circular T* daily values of [*UTC – UTC(USNO)_GPS*] and [*UTC – UTC(SU)_GLONASS*] where *UTC(USNO)_GPS* and *UTC(SU)_GLONASS* are respectively, UTC(USNO) and UTC(SU) as predicted and broadcast by GPS and GLONASS. Evaluations of [*UTC - GPS time*] and [*UTC - GLONASS time*] are provided only through the ftp server of the Time Department. These tables are based on GPS data provided by the Paris Observatory (LNE-SYRTE), France, and on GLONASS data provided by the Astrogeodynamical Observatory (AOS), Poland.

5. Time scales established in retrospect

For the most demanding applications, such as millisecond pulsar timing, the BIPM retrospectively issues atomic time scales. These are designated TT(BIPMxx) where 19xx or 20xx is the year of computation [15, 16, 17]. The successive versions of TT(BIPMxx) are both updates and revisions; they may differ for common dates.

Starting with TT(BIPM09), until TT(BIPM12) extrapolation for the current year of the latest realization TT(BIPMxx) had been provided in the file TTBIPMxx.ext. It had been updated each month after the TAI computation. Starting with TT(BIPM13), a formula for extrapolation is provided in the file TTBIPM.yyyy where yyyy is the year number.

In Figure (2) the difference between the frequency of PFS/SFS and TTBIPM is reported.

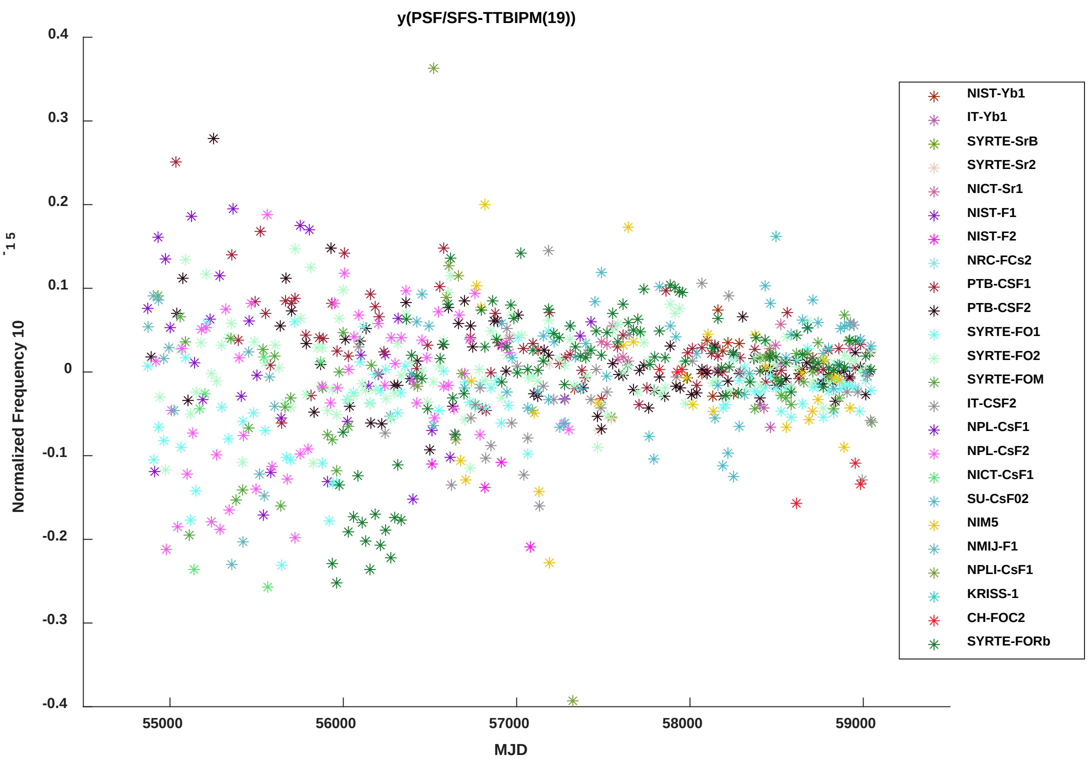

Figure 2. Difference between the frequency of PFS/SFS and TT(BIPM19).

Notes

Since January 2016 BIPM *Circular T* has been published in a new format with a different distribution of content in the sections. See
ftp://ftp2.bipm.org/pub/tai/publication/notes/explanatory_supplement_v0.3.pdf.

Since September 2016, a Time Department Database has been made accessible via the website at http://webtai.bipm.org/database/. It contains all relevant information relating to contributions to UTC and UTCr.

A full list of time signals and time dissemination services is compiled by the BIPM from the information provided by the time laboratories.

A recent overview of UTC computation and realization can be found here [18]. A formal definition of TAI and UTC can be found in Resolution 2 of the 26th CGPM.
https://www.bipm.org/utils/common/pdf/CGPM-2018/26th-CGPM-Resolutions.pdf .

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