Establishment of International Atomic Time and of Coordinated Universal Time

1. Data and computation

International Atomic Time (TAI) and Coordinated Universal Time (UTC) are obtained from a combination of data from more than 400 atomic clocks kept by more than 70 timing centres which maintain a local UTC, UTC(*k*) (see Table 3). 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 [1] and [2]. The weighting procedure and clock frequency prediction [3] 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.

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”. Table 5 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*)] [4].

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

After the successful closure of the Pilot Experiment, the rapid solution *UTCr* became an official BIPM publication from July 2013. Regular publication of the values [*UTCr - UTC*(*k*)] allows weekly access to a prediction of UTC [5] for about forty 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

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 geodetic-type receivers are regularly used in the calculation of time links, in addition to that acquired by a few single-frequency (single- or multi-channel) GPS time receivers. For those links realized using more than one technique, one of them is considered official for TAI 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” [6], with a network of time links that uses the PTB as a unique pivot laboratory for all the GPS links. Since September 2009, links equipped with geodetic-type receivers are computed with the “Precise Point Positioning” method GPS PPP [7].

Clock comparisons using GLONASS C/A (L1C frequency) satellite observations with multi-channel receivers have been introduced since October 2009 [8]. These links are computed using the “common-view” [9] method; data are corrected using the IAC ephemerides SP3 files and the CODE ionospheric maps.

Combination of individual TWSTFT and GPS PPP links and of individual GPS and GLONASS links were introduced in January 2011 and are currently used in the calculation of TAI [10, 11].

A figure showing the time link techniques in the contributing laboratories can be downloaded from the BIPM website. For more detailed information on the equipment refer to [Table 4] and to Section 6 of BIPM *Circular T* for the techniques and methods of time transfer officially used.

The uncertainty of [*UTC*(k_1) - *UTC*(k_2)], obtained at the BIPM with these procedures is given in *Circular T*, section 6. The BIPM publishes in *Circular T* an evaluation of [*UTC - GPS time*] based on GPS data provided by Paris Observatory (LNE-SYRTE), and also an evaluation of [*UTC - GLONASS time*] based on ongoing observations of the GLONASS system at the Astrogeodynamical Observatory (AOS), Poland.

The BIPM also 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 by USNO and SU; and broadcast by GPS and GLONASS.

International GPS tracking schedules have been published by the BIPM about every six months.

5. Time scales established in retrospect

For the most demanding applications, such as millisecond pulsar timing, the BIPM issues atomic time scales in retrospect. These are designated TT(BIPMxx) where 19xx or 20xx is the year of computation [12, 13, 14]. 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.xx

Notes

Tables 8 and 9 of this report give the rates relative to TAI and the weights of the clocks contributing to TAI in 2013.

A full list of time signals and time dissemination services is compiled by the BIPM from the information provided by the time laboratories. The report on the scientific work of the BIPM on time activities for the period January - December 2013 is extracted from the *Director's Report on the Activity and Management of the BIPM (1 January − 31 December 2013)*. All the publications mentioned in this report are available on request from the BIPM.

References

[1] Thomas C. and Azoubib J., TAI computation: study of an alternative choice for implementing an upper limit of clock weights, *Metrologia*, 1996, **33** (3), 227-240.

[2] Azoubib J., A revised way of fixing an upper limit to clock weights in TAI computation, Document CCTF/01-14 presented to the 15th meeting of the CCTF (2001).

[3] Panfilo G., Harmegnies A., Tisserand L., A new prediction algorithm for the generation of International Atomic Time, *Metrologia*, 2012, **49** (1), 49-56.

[4] Lewandowki W., Matsakis D., Panfilo G. and Tavella P., The evaluation of uncertainties in [UTC – UTC(*k*)], *Metrologia*, 2006, **43**, 278-286.

[5] Petit G., Arias F., Harmegnies A., Panfilo G., Tisserand L., UTCr: a rapid realization of UTC, *Metrologia*, 2014, **51**, 33-39.

[6] Petit G., Jiang Z., GPS All in View time transfer for TAI computation, *Metrologia*, 2008, **45** (1), 35-45.

[7] Petit G., Jiang Z., Precise point positioning for TAI computation, IJNO, Article ID 562878, http://dx.doi.org/10.1155/2008/562878, 2008.

[8] Lewandowski W. and Jiang Z., Use of GLONASS at the BIPM, *Proc. 41st PTTI Systems and Applications Meeting*, 2010, 5-14.

[9] Allan D.W., Weiss, A.M., Accurate time and frequency transfer during common-view of a GPS satellite**,** *Proc. 34th Ann. Symp. Frequency Control (1980)*, 1980, 334-346.

[10] Jiang Z., Lewandowski W., Use of GLONASS for UTC time transfer, *Metrologia,* 2012, **49** (1), 57-61

[11] Jiang Z., Petit G., Combination of TWSTFT and GNSS for accurate UTC time transfer, *Metrologia*, 2009, **46** (3), 305-314.

[12] Guinot B., Atomic time scales for pulsar studies and other demanding applications, *Astron. Astrophys.*, 1988, **192**, 370-373.

[13] Petit G., A new realization of Terrestrial Time, *Proc. 35th PTTI*, 2003, 307-317.

[14] Petit G., Atomic time scales TAI and TT(BIPM): present status and prospects, *Proc. 7th Symposium on frequency standards and metrology*, L. Maleki (Ed.), World Scientific, 2009, 475-482.