IAG Scientific Services

International Bureau on Weights and Measures
Bureau International des Poids et Mesures (BIPM)
– Time Department –

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http://www.bipm.org/metrology/time-frequency/

The Time Department is one of the four scientific departments of the BIPM. The activities at the Time Department are focused on the maintenance of the SI second and the formation of the international reference time scales.
The BIPM provides, together with the US Naval Observatory, the IERS Conventions Centre, with the responsibility of the establishment and publication of the IERS Conventions, providing standards and models for applications in the fields of geodesy, geophysics and astronomy.

The establishment and maintenance of the International System of Units (SI) at the BIPM constitutes a fundamental contribution to the activities relating to the IAG.

International Time Scales at the BIPM

The BIPM Time Department maintains the atomic time scales Coordinated Universal Time (UTC); the UTC rapid solution (UTCr); and the realization of Terrestrial Time TT(BIPM).

Coordinated Universal Time (UTC) is computed every month and published *BIPM Circular T*. It is identical in rate to International Atomic Time TAI, their difference is the integral number of (leap) seconds inserted in UTC to approximate Earth's rotation time UT1. The frequency stability of UTC, expressed in terms of an Allan deviation, is estimated to 3×10^{-16} for averaging times of one month. About 500 industrial clocks located in more than 70 national laboratories contribute to the calculation of the timescales at the BIPM. Some of these laboratories develop and maintain primary frequency standards – among them caesium fountains – that contribute to the improvement of the accuracy of TAI. Twelve primary frequency standards contributed to improve the accuracy of TAI in 2015, including ten caesium fountains developed and maintained in metrology institutes in China, France, Germany, India, Italy, the Russian Federation, the United Kingdom and the USA. Measurements of a French rubidium secondary frequency standard have been also regularly reported and included for improving the accuracy of TAI. The scale unit of TAI has been estimated to match the SI second to about 2×10^{-16} in average over the year.

The laboratories contributing to the formation of UTC maintain representations of the international time scale denominated UTC(k). Routine clock comparisons of UTC(k) are undertaken using different techniques and methods of time transfer. All laboratories contributing to the calculation of UTC at the BIPM are equipped for GNSS reception. GPS C/A observations from time and geodetic-type receivers are used with different methods, depending on the characteristics of the receivers. Dual-frequency receivers allow performing iono-free solutions. Also combination of code and phase measurements of GPS geodetic-type receivers (GPS PPP) is used in the computation of UTC. The observations of GLONASS are regularly used for the computation of UTC, combined with GPS links. Some laboratories are equipped of two-way satellite time and frequency transfer (TWSTFT) equipment allowing time comparisons independent from GNSS through geostationary communication satellites. Combinations of TWSTFT and GPS PPP links are computed whenever possible. The statistical uncertainty of time comparisons is at the sub-nanosecond level for the best time links. In the frame of the cooperation between the BIPM and the RMOs, the BIPM is implementing frequent campaigns for characterizing the delays of GPS equipment operated in a group of selected laboratories distributed in the metrology regions with the aim of decreasing the calibration uncertainty. The first campaign including nine institutes in three regions concluded at the end of 2015.

The result is an improvement of the calibration uncertainty in a factor of about 3 with respect to the previous 5 ns value conventionally assigned to calibrated equipment (http://www.bipm.org/jsp/en/ TimeCalibrations.jsp). The second campaign will start beginning of 2016, and we expect to confirm that this uncertainty agrees with the time stability of the equipment. Results of campaigns organized by the regions will maintain the calibration of all equipment used for clocks comparison in UTC. TWSTFT links have been calibrated in Europe confirming nanosecond order uncertainty.

Research on time and frequency transfer techniques resulted in the achievement of 1 × 10-16 frequency transfer by GPS PPP with integer ambiguity resolution.

Since 1 July 2013 the Time Department has been publishing the rapid solution UTCr every Wednesday (ftp://62.161.69.5/pub/tai/publication/utcr/). About 50 laboratories contribute to UTCr, representing 70% of the clocks in UTC; in consequence the frequency stability of the rapid solution is similar to that of UTC.

Because TAI is computed on a monthly basis and has operational constraints, it does not provide an optimal realization of Terrestrial Time (TT), the time coordinate of the geocentric reference system. The BIPM therefore computes an additional realization TT(BIPM) in post-processing, which is based on a weighted average of the evaluation of the TAI frequency by the primary frequency standards. The last updated computation of TT(BIPM), named TT(BIPM14) has an estimated accuracy of order 3×10^{-16}. The monthly extension of TT(BIPM) can be directly derived from TAI (ftp://tai.bipm.org/TFG/ TT(BIPM)/TTBIPM.14).

The process of improvement of the algorithm for UTC has concluded in the period of this report. After the implementation of the quadratic model for the clock frequency prediction, fundamental changes were made in the algorithm for the clock weighting. We have introduced a new concept where the clock weight is based on its frequency predictability, instead of using the frequency stability as an estimator; these changes positively impact the clock weight distribution and the stability of TAI in the short and long terms.

Radiations other than the caesium 133, most in the optical wavelengths, have been recommended by the International Committee for Weights and Measures (CIPM) as secondary representations of the second. These frequency standards are at least one order of magnitude more accurate than the caesium. Their use for time metrology is conditioned by the progress in very accurate frequency transfer, allowing comparisons of these standards at the level of their performances. Substantial progress has been made in the use of optical fibres for frequency comparisons over up to 1000 km, but still work is to be done for extending these comparisons to time and for the implementation of permanent fibre links between UTC contributing laboratories. Intercontinental comparisons are still under study using space techniques. The time and frequency metrology community is engaged in a collective effort for solving this issue, since one of the interests is the redefinition of the SI second.

The computation of TAI is carried out every month and the results are published monthly in *BIPM Circular T*. When preparing the *Annual Report*, the results shown in *Circular T* may be revised taking into account any subsequent improvements made to the data. Results are also available from the BIPM website (www.bipm.org), as well as all data used for the calculation. The broad real-time dissemination of UTC through broadcast and satellite time signals is a responsibility of the national metrology laboratories and some observatories, following the recommendations of the International Telecommunication Union (ITU-R).

Conventions and references

Research work is also dedicated to space-time reference systems. The BIPM provides, in partnership with the US Naval Observatory, the Conventions Product Centre of the International Earth Rotation and Reference Systems Service (IERS). The last version of the IERS Conventions (2010) has been published in the IERS Technical Note N°36, also at http://www.iers.org/nn_11216/IERS/EN/ Publications/TechnicalNotes/tn36.html). Regular updates are published on the internet (last one on 19 June 2015) (http://62.161.69.131/iers/convupdt/convupdt.html). In the frame of the International Astronomical Union (IAU) activities, and in cooperation with the IERS Centre for the International Celestial Reference System, staff of the Time Department contributes to the elaboration of the third version of the International Celestial reference Frame (ICRF3).

On the adoption of a continuous reference time scale (without leap seconds)

The BIPM has actively participated to the work of the International Telecommunication Union (ITU) in the discussions on the adoption of a continuous time scale as the world reference that involves interrupting the introduction of leap seconds in UTC. The decision by the World Radiocommunication Conference 2015 (WRC-15) calls for further studies regarding current and potential

future reference time-scales, including their impact and applications. A report will be considered by the World Radiocommunication Conference in 2023. Until then, UTC shall continue to be applied as described in Recommendation ITU-R TF.460-6 and as maintained by the BIPM. WRC-15 also calls for reinforcing the links between ITU and the International Bureau of Weights and Measures (BIPM). ITU would continue to be responsible for the dissemination of time signals via radiocommunication and BIPM for establishing and maintaining the second of the International System of Units (SI) and its dissemination through the reference time scale.

Activities planned for 2016-2018

- Calculation and dissemination of UTC through the monthly publication of *BIPM Circular T*; computation and improvement of the rapid UTC; computation of TT(BIPM)
- Improvement of techniques of time and frequency transfer, in particular
  - Studying some observed effects increasing the noise in some time transfer techniques (diurnals in TWSTFT, drift between TWSTFT and GPS links, etc.);
  - Comparison of optical frequency standards requiring an accuracy at the level of $10^{-17} – 10^{-18}$;
- Testing novel statistical tools for clock noise characterisation in view of their application in the construction of the reference time scale;
- Continuing operating in cooperation with the USNO the IERS Conventions Centre;
- Supporting the organization of the next comparison of absolute gravimeters in 2017;
- Continuing the cooperation with the IERS for the establishment of space references;
- Liaising with the relevant organizations, such as: IUGG, IAG and GGOS, IERS, IAU, ITU-R, IGS, and the International Committee for GNSS (ICG).