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COMMISSION 31 TIME

L'HEURE

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TRIENNIAL REPORT 2006-2009

1. Introduction

The realization and dissemination of the international time scales is the responsibility of the Time, Frequency and Gravimetry Section of the BIPM. Commission 31 supports and coordinates investigations associated with Time definitions, realizations, astronomical data relevant to atomic timekeeping, such as pulsar data. The major developments achieved during the period 2005-2008 in that domain are reported here.

2. Consultative Committee for Time and Frequency

The CCTF held its 17th meeting on 14 and 15 September 2006. Following the discussions, six Recommendations were adopted and submitted to the Comite International des Poids et Mesures (CIPM). The list is the following:
Recommendation CCTF 1 (2006): Recommended values of standard frequencies for applications including the practical realization of the metre and secondary representations of the second;
Recommendation CCTF 2 (2006): Concerning secondary representations of the second;
Recommendation CCTF 3 (2006): Concerning the use of measurements of the International Atomic Time (TAI) scale unit;
This Recommendation specifies the role of the Working Group on Primary Frequency Standards in evaluating new PFS and their use for the steering of TAI;
Recommendation CCTF 4 (2006): Concerning the use of Global Navigation Satellite System (GNSS) carrier phase techniques for time and frequency transfer in International Atomic Time (TAI);
This Recommendation promotes the development of GNSS carrier phase techniques both for the laboratories equipment and for the BIPM to generate solutions and prepare their use in TAI computation.
Recommendation CCTF 5 (2006): Improvement to Global Navigation Satellite System (GNSS) time transfer;
Recommendation CCTF 6 (2006): Coordination of the development of advanced time and frequency transfer techniques;
This Recommendation promotes the activity of a recently created Working Group on Coordination of the Development of Advanced Time and Frequency Transfer Techniques,

with the aim that time and frequency transfer techniques match the progresses in primary frequency standards.

Additionally discussed were the present form of UTC and the interest of preserving the leap second. The work of the ITU-R Special Rapporteur Group (SRG) was reviewed and a new CCTF working group was created to express a view of the CCTF regarding this issue.

3. Computation and Dissemination of TAI and UTC

Reference time scales TAI and UTC have been computed regularly and published in the monthly Circular T. Definitive results have been available in the form of computer-readable files on the BIPM home page and on printed volumes of the Annual Report of the BIPM Time Section for 2005 (Volume 18) and of the BIPM Annual Report on Time Activities for 2006 and 2007, Volumes 19 and 20. Since January 1st, 2006, BIPM Time activities have been incorporated in the Time, frequency and gravimetry section, a new organization which is reflected in the BIPM publications on time.

Research concerning time-scale algorithms includes studies to improve the long-term stability of the free atomic time scale EAL and the accuracy of TAI. The number of laboratories participating to TAI steadily increases and is about 65 in 2008. The number of clocks participating in the ensemble time scale EAL also increases to about 350, among them more than 80% are either commercial caesium clocks of the HP5071A type or active, auto-tuned hydrogen masers. About 15% of the clocks reach maximum weight and they provide nearly 50% of the total weight. The medium-term stability of EAL, expressed in terms of an Allan deviation, is estimated to be 0.4×10^{-15} for averaging times of twenty to forty days over the period 2006-2008.

To characterize the accuracy of TAI, estimates are made of the relative departure, and its uncertainty, of the duration of the TAI scale interval from that of Terrestrial Time TT, as realized by primary frequency standards. Over 2006-2008, individual measurements of the TAI frequency have been provided by twelve primary frequency standards including nine Cs fountains. Detailed reports on the operation of primary standards are published in the Annual Report. Over 2006-2008, the global treatment of individual measurements has led to a relative departure of the duration of the TAI scale unit from that of TT ranging from 2×10^{-15} to 4×10^{-15}, with a standard uncertainty of order 0.5×10^{-15} to 1×10^{-15}. The steering procedure has been changed in 2006, to allow more frequent steerings in the aim of providing a more accurate TAI without impeding its stability.

4. The future of UTC

The ITU-R Special Rapporteur Group (SRG), created withing the ITU Working Party 7a to study the question ITU-R 236/7 "The Future of the UTC Time Scale", presented its report to the Working Party 7A in 2007. Several documents have been studied by the SRG, coming from countries members of the ITU, from organisations (like the BIPM), from laboratories providing with experiences during past leap seconds etc... Due to the difficulties induced by a non-continuous UTC in some applications requiring a time scale without jumps (GNSS, tlcoms, newtworks, etc...), and as the IERS is able to provide a way to get UT1 in real time with a precision better than UTC, the present opinion is in favour of a new definition of UTC. There remains however still opposition from some national delegation. During its last meeting in April 2008, the WP7A decided to prepare a complete report of the content of the discussions since 2000; this report will be attached to the recommandation which should progress, after approbation by the Study

Group 7, up to the World Radiocommunication Conference to be validated as official recommandation. The new definition could be in use 5 year after the approbation by the WRC, i.e. not before 2017.

5. Pulsars and time scales

Pulsars, especially those with periods in the millisecond range, are extraordinarily good clocks and have the potential to establish a new timescale. Pulse times of arrival can be determined with a precision of a few tens of nanoseconds at best, so an averaging interval of a year or more is required to obtain rate measurements to a precision comparable to that of atomic frequency standards. A pulsar timescale will therefore be useful only for detecting long-term variations in the atomic-clock-based timescales. However, a pulsar timescale is essentially independent of terrestrial effects, is based on an entirely different physical principle, namely rotation of a macroscopic body, and is potentially continuous for billions of years.

Just as existing timescales are based on a statistical average of data from an ensemble of atomic clocks, the best pulsar timescale will be based on measurements of an ensemble of pulsars. Significant progress has been made in the past few years in establishing such ensembles, known as pulsar timing arrays. The Parkes Pulsar Timing Array (PPTA) has been timing 20 millisecond pulsars every 2-3 weeks since 2004 (Manchester et al., 2006) and similar timing arrays are being established in Europe (EPTA) and in North America (NANOGrav). With such measurements, variations in atomic timescales over intervals of a month or two can be investigated. Techniques for analysis of such data are currently under development: Rodin (2006) uses a Wiener filter approach, whereas Zhong & Yang (2007) advocate the use of a wavelet transform method to isolate variations having different timescales.

6. Laboratory reports

USNO

To provide accurate and precise time, the USNO currently maintains an ensemble of 73 cesium-beam frequency standards and 32 cavity-tuned masers in three buildings in Washington, DC and at the Alternate Master Clock (AMC), at Schriever Air Force Base in Colorado. A non-operational cesium-based atomic fountain has reached stabilities of 1.E-15 at one day, and one rubidium-based fountain has reached stability better than 5.E-16 at two days. An improved timescale algorithm involving Kalman-based hourly characterization and steering of the Master Clock against the USNO ensemble was installed in 2004. Since September 1, 2006 UTC(USNO) stayed within 3 ns RMS of UTC. USNO has participated in Two Way Satellite Time Transfer (TWSTT) for the generation of TAI, and has calibrated its transatlantic timing link with the PTB in Germany on a biannual basis. It has participated as a contributor of clock information to the International GPS Service (IGS) via time-stable Ashtech Z123Ts at all three of its buildings, and contributes to two real-time GPS networks.

USNO serves as the timing reference for GPS, and has also been designated to serve in the role of measuring the GPS-Galileo Time Offset (GGTO). With the advent of GPS III, the stability and robustness requirements for the USNO Master Clock will become more stringent. In order to prepare for this, the USNO has embarked upon an ambitious campaign of infrastructure improvement. One aspect is the constructing of a new clock building, with a temperature stability spec of 0.1 degrees C and 3% relative humidity at each interior point, at all times. The second is the construction of 6 operational rubidium fountains, 3 of which will be located at the AMC and all of which are designed to operate continuously. We anticipate that the new building will be ready for operations in test-mode by September 30 of 2008, along with two rubidium fountains. A third aspect is the design of new timescale algorithms which incorporated the superior performance of atomic fountains. Of equal importance is improved time transfer, and the USNO is therefore giving heavy emphasis to GPS receiver development, GPS calibration, and also to operational improvements for Two Way Satellite Time Transfer (TWSTT). While the design goals of these innovations are often expressed in terms of accuracy or precision, the explicit motivation behind many of the specifications is to guarantee robustness at the required levels.

Royal Observatory of Belgium

The ROB presently maintains 3 Cesium clocks HP5071A with standard tubes, and two active H-maser (CH1-75 and CH1-75A). The time scale UTC(ORB) is generated from the frequency of the active H-maser, of which the auto-tuning is performed using the second active maser CH1-75A. The steering of UTC(ORB) is performed only using the circular T, but UTC(ORB) is also monitored on a daily basis using a comparison with the IGS time scale and with several UTC(k)s produced by time laboratories collocated with IGS stations. This last comparison is done using a self-developed software named Atomium, using a combination of GPS code and carrier-phase measurements and the IGS products for satellite orbits and clocks. The ROB also developed during this triennium some methods for the combination of time transfer data (GNSS and TWSTFT).

7. Workshops, colloquia and conferences

Various meetings relating to the scope of Commission 31 were held. In addition to the usual meetings (see http://www.astro.oma.be/IAU/COM31/) of the time and frequency community , the fifth International Symposium on time scale algorithms, sponsored by the ROA, the USNO, the BIPM and the INRIM, was held in San Fernando (Spain) on 28-30 April 2008. A special issue of *Metrologia* will publish the Proceedings. Commission 31 also organizes a Joint Discussion at the Brazil IAU General Assembly in 2008, named Time and Astronomy. This JD will provide a forum for discussion of recent work on UT1 determination as well as UT1 modeling and prediction, on the recent developments in precision pulsar timing and its application to time scales, planetary ephemerides, detection of gravitational waves and tests of gravitational theories and on the present realizations and performance of atomic time scales and time transfer techniques.

Pascale Defraigne
president of the Commission

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