TIME SCALES: STATE OF THE ART

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Progress in realization of the time unit and scales

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Abstract - The establishment of the TAI is done in two steps: the construction of the EAT from clocks in laboratories, then its steering by primary frequency standards. Great progress in the precision and stability of EAL was made by the generalized use of GPS time transfer and by the introduction of hydrogen masers and new very performant clocks. Only two primary frequency standards are sufficiently accurate to steer the frequency of TAI, but new standards are now being assessed. The present stability of TAI is 5.10^{-15} and the accuracy 2.10^{-14}. Improvements should occur in the years to come.

The establishment of the International Atomic Time (TAI) and the resulting Coordinated Universal Time (UTC) by the time section of BIPM is done in two steps (Guinot and Thomas, 1988). At first, a free atomic scale, EAL (Echelle atomique libre) is built in two month blocks combining data from about 200 atomic clocks kept by 60 laboratories and regularly reported to the BIPM by 45 centres which maintain a local coordinated universal time, UTC(k). Then, the duration of the scale interval of EAL is compared with data from primary caesium standards producing the SI second which, in turn, is converted on the rotating geoid as the unit scale of TAI. A linear function of time with the necessary slope is added to EAL to ensure the accuracy of the TAI scale interval.

1. Construction of EAL

In the recent years, major progress has been realized in the construction of EAL. Two factors have contributed to this.
- First, the extensive use of GPS time transfer technique has greatly increased the quality of the links between the local UTC(k) and BIPM. The accuracy is now of several nanoseconds. The precision is enhanced when observations are made simultaneously on the same GPS satellites. For this reason, BIPM issues every six months common view tracking schedules in order to interconnect ten geophysical areas in the world.
- The second factor is the availability of new industrial clocks, HP5071A whose stability performance is one order of magnitude better than older clocks. About 50 such clock now contribute to EAL. In addition, since 1991, 15 hydrogen masers were introduced in the computation of EAL for their short term stability.

The basic tool for constructing EAL is the ALGOS software (Guinot, 1987) which uses the time differences between clocks at 10 day intervals. Since the establishment of this algorithm, the stability of clocks and the quality of the comparisons have improved by orders of magnitudes, and some amendment to take this into account is under consideration. In particular, the interval between comparison times could easily be

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reduced to 5 days. One should take a better account of the short term stability of hydrogen masers. Finally, one should prevent a single type of clocks to have a strong predominant influence.

2. Construction of TAI

Since several years, two primary standards, both in Physikalisch Technische Bundesanstalt, PTB (Cs1 and Cs2), are so much more accurate and stable, that no other standard can contribute to the transformation of EAL into TAI. The two clocks are in the same environment and give very similar results. There is however no way to check whether these remain some systematic errors. Now, three laboratories have developed instruments which have reached the stage of systematic experimentation and preliminary assessment, but none has contributed as yet to TAI.

- NIST whose NIST7 standard has an accuracy presently evaluated to be of the order of 10^{-14}, a little better than PTB standards.
- Two new clocks, both mounted vertically have been built in PTB. No accuracy evaluation has yet been publicized.
- LPTF in Paris has built a caesium frequency standard based upon optical pumping technique. The first evaluation, in May 1993 gave only a $1.1.10^{-13}$ accuracy, but improvement are undertaken. In parallel, a cold caesium fountain clock is experiencing its first tests.

Until these new developments reach a routine operation stage, TAI will continue to be controlled by the PTB standard Cs2 with some weight allocated to Cs1.

3. Present achievements and prospects

The stability of TAI has benefited from the improvement of EAL. It is estimated now to be 5.10^{-15} to be compared to its 2.10^{-14} accuracy. Some statistical tests (Allan variances) with the major local times in laboratories have shown that at 2-3 months interval, EAL behaves better than TAI. This is probably a consequence of the last frequency steering correction of 5.10^{-15} made in April 1993. Future steering should be made in smaller steps.

New frequency standards, together with the increased availability of high stability clocks and an updating of the computing procedures, should lead TAI towards accuracies and stabilities of the order of a few 10^{-15} in a few years. The 10^{-16} accuracy is no more a dream. But it is also a limit at which the present relativistic treatment of synchronisation and the theoretical interpretation of various time scales will no more be adequate. Second order relativistic terms will become significant. A working group of the CCDS, under the leadership of B. Guinot has been set up to examine the problems of general relativity theory in connection with time.

References

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