Metrologia Special Issue

Modern applications of timescales

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BIPM Time Department

14 papers related to redefinition of UTC

✓One is opposing change

Foreword
F Arias, W Lewandowski

- In the middle of 1960s at the moment of the discussion on the adoption of an atomic timescale to replace ephemeris time, the possibility of having both an astronomical time and an atomic time to serve different purposes was discussed. In the words of Louis Essen, this 'would cause endless confusion as well as involving duplication of equipment'.

- Forty years after the adoption of the definition of Coordinated Universal Time at the International Telecommunication Union (ITU), we are close to the moment of making a decision on whether or not to decouple UTC from its tight link to the rotation of the Earth embodied in UT1.

Time, the SI and the Metre Convention
Terry Quinn

Since 1954 when the definition of the second first came under the authority of the intergovernmental organization of the Metre Convention, the range and complexity of time metrology have increased far beyond anything envisaged in those days. Today, the essential international coordination of this domain of metrology is through the organs of the Convention with the exception of the definition of Coordinated Universal Time, UTC. In his short article Terry Quinn, Emerytous Director of the BIPM, suggests that this also should now come under the authority of the Metre Convention.

Role of the ITU-R in time scale definition and dissemination
Ronald R Beard

- The International Telecommunications Union (ITU) is the leading United Nations agency for Radio and Telecommunications coordination worldwide.
- ITU Study Groups and their Working Parties, devoted to specialized technical areas, provide the mechanism for Member Nations to participate, study and recommend standards and practices to ensure equitable utilization and interference-free operation within the radio spectrum.
- An important underlying aspect of spectrum utilization is the facilitation of the determination and coordination of the international time scale. The international time scale is an atomic time scale used by broadcast services throughout

Evolution of timescales from astronomy to physical metrology

Dennis D McCarthy

- Astronomy has provided a means to mark the passage of time throughout history. One of the repeating phenomena that makes this possible is the Earth's rotation.
- The basic variability in its rotational speed, however, makes astronomical techniques unsuitable for timekeeping with the precision required for modern applications.
- Physical metrology from the first mechanical clocks to the most sophisticated atomic standards of today has assumed a growing role in timekeeping.
- Along with this progress in technology, more sophisticated concepts of timescales have appeared to take advantage of those improvements.

Timescales at the BIPM
E Arias, G Panfilo and G Petit

- The paper reviews the present status of the timescales established at the International Bureau of Weights and Measures (BIPM).

- It focuses our attention on the calculation and the characteristics of Coordinated Universal Time (UTC) and present its applications.

Local representations of UTC in national laboratories

Peter B Whibberley, John A Davis and Setnam L Shemar, NPL

- In this paper, authors examine the rationale and requirements for maintaining a local representation of UTC. Its applications might range from underpinning the reference time scale of a Global Navigation Satellite System to providing traceability for frequency and time dissemination services.
- They address the practical aspects of setting up and operating a UTC(k) time scale, including the equipment and algorithms that generate the time scale.
- Local representations of the international time scale, Coordinated Universal Time (UTC), are maintained by approximately 69 national laboratories.
- They conclude by considering briefly some future developments that may have an impact on the laboratories operating local representations of UTC.

Earth rotation monitoring, UT1 determination and prediction

D Gambis and B Luzum

- Monitoring the Earth's rotation angle is essential in various domains linked to reference systems such as space navigation, precise orbit determinations of artificial Earth satellites including the Global Navigation Satellite Systems (GNSS), positional astronomy and for geophysical studies on time scales.
- Universal Time UT1 is based on the rotation of the Earth on its axis.
- Historically it was related to mean solar time on the meridian of Greenwich, sometimes known as Greenwich Mean Time.
- Monitoring Earth orientation, and in particular UT1, is the primary task of the International Earth Rotation and Reference Systems Service (IERS).

Relativistic time transfer in the vicinity of the Earth and in the solar system

Robert A Nelson

- The algorithms for relativistic time transfer in the vicinity of the Earth and in the solar system are derived.
- The concepts of proper time and coordinate time are distinguished.
- The coordinate time elapsed during the transport of a clock and the propagation of an electromagnetic signal is analysed in three coordinate systems: an Earth-Centred Inertial (ECI) coordinate system, an Earth-Centred Earth-Fixed (ECEF) coordinate system and a barycentric coordinate system.
- The timescales of Geocentric Coordinate Time (TCG), Terrestrial Time (TT) and Barycentric Coordinate Time (TCB) are defined and their relationships are discussed.

- The International Conference held in 1884 at Washington defined a universal time as the mean solar time at the Greenwich meridian (GMT).
- Now, the Universal Time, version UT1, is strictly defined as proportional to the angle of rotation of the Earth in space.
- In this evolution, the departure of UT1 from GMT does not exceed one or two seconds. This is quite negligible when compared with the **departure between the solar time and the legal time of citizens, which may exceed two hours without raising protests.**

- The halt of future leap seconds from UTC would not necessarily diminish the use of existing timescales.
- Reinstating intercalary adjustments will be difficult if they are retired for any length of time, and **there are long-term consequences of breaking civil timekeeping from the heavens that have not been satisfactorily assayed**.
- Yet *status-quo* UTC requires no changes to most operations and would provide a minimum of concerns to those relying on it as a realization of UT1.
- Because UTC without leap seconds is no more precise than UTC with leap seconds, it seems that there is still a strong case to prefer leap seconds.

Time references in US and UK astronomical and navigational almanacs

C Y Hohenkerk and J L Hilton

- An astronomical or navigational almanac can best be thought of as a device for connecting an observer with celestial objects.
- For an observer with a known position and time the almanac allows the observer to identify the celestial objects.
- However, the wide variety of users of our almanacs and products need to be aware of the different time scales that are employed.
- It is particularly important that the user understand the relationship between UT1 and other time scales.

Software for timescale applications

P T Wallace

- Correct handling of UTC leap seconds was a particular challenge in transformation software provided by the International Astronomical Union.
- Although UTC leap seconds deliver precision timekeeping perfectly well, they are a perennial source of difficulties for the software developer. There are two reasons for this. Firstly, they are unpredictable, and software somehow has to be able to react to the announcement of new ones. Secondly, having a 61st second in the final minute of a given day is an awkward special case, affecting every calculation in which UTC times appear.

Timing in telecommunications networks
Judah Levine

- Paper describes the statistical considerations used to design systems whose clocks are compared by the use of dial-up telephone lines or the Internet to exchange timing information.
- The comparison is usually used to synchronize the time of a client system to the time of a server, which is, in turn, synchronized to the time scale of a national timing laboratory.
- The design includes a dynamic estimate of the system performance and a comparison between the performance and a parameter that specifies the required stability based on external considerations.

GNSS times and UTC

W Lewandowski and E F Arias

- Global Navigation Satellite Systems (GNSSs) use *internal* reference time scales: *GPS Time*, *GLONASS Time, Galileo System Time* and *BeiDou System Time*.
- Constructed from a clock ensemble, they are designed for internal system synchronization, necessary to produce a navigation solution.
- To achieve safe operation of a GNSS, a system time should preferably be a uniform time scale not affected by the leap seconds of Coordinated Universal Time (UTC).
- But this is not compatible with international recommendations that radio broadcast time signals should conform as closely as possible to UTC.
- This paper also explains why, on some occasions, GNSS *system times* play a role of alternative time scales with the consequent risk of confusion.

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