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

**Ronald L Beard**[1]

ITU-R Working Party 7A, US Naval Research Laboratory, Washington, DC 20375, USA

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**Abstract**
The International Telecommunications Union (ITU) is the leading United Nations agency for Radio and Telecommunications coordination worldwide. The process of managing overall frequency spectrum utilization is through Worldwide Radio Conferences, associated radiocommunication conferences and the activities of the Radiocommunication Study Groups. These 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 the world known as Coordinated Universal Time (UTC). UTC is defined by the International Telecommunication Union (ITU-R) and is maintained by the International Bureau of Weights and Measures (BIPM) in cooperation with the International Earth reference and Rotation Service (IERS). Contributed measurements from timing centres around the world are used in the determination of UTC, which is adjusted to within 0.9 s of Earth rotation time (UT1) by IERS-determined values of the Earth rotation. The adjustments, made in one second steps known as leap seconds, were implemented in 1972 to permit UT1 to be recovered from broadcast values of UTC for celestial navigation. Current telecommunications and navigation systems utilize continuous timing for their data transmissions; consequently, deliberations have been ongoing within the ITU-R on the issue of modifying the definition of UTC to a continuous time scale.

## 1. Introduction

Before 1955 time was determined exclusively by astronomical observations that were the concern of the International Astronomical Union (IAU). Concurrently, radio broadcasts of time were beginning to find coordination across international boundaries necessary. This started to become a problem in that the time being broadcast had multiple users and international implications. Since then atomic time has been born and merged with astronomical time so that now atomic time is the primary international time scale and astronomical time is a measure of the rotation of the Earth determined by Very Long Baseline Interferometry measurements of selected astronomical radio point sources, satellite laser ranging and tracking of Global Positioning System (GPS) satellites. International coordination is the concern of the International Telecommunications Union—Radiocommunications (ITU-R) Sector. Developments of new observational techniques based on Global Navigation Satellite Systems (GNSS) and other satellite based technology have almost completely replaced astronomical techniques for the international determination and coordination of time.

The measure and dissemination of time is becoming an increasingly more important issue in today's electronic era. The profusion of electronic devices, cell phones, personal computers and GPS receivers that have become an essential part of our lives are all controlled by clocks and oscillators. These same devices then control and regulate, though perhaps only indirectly, our daily lives. These devices all measure time and time intervals that must be coordinated in order to function properly. How they measure time and are coordinated is the purpose behind the establishment of Coordinated Universal Time (UTC) and maintenance of that time both nationally and internationally by the ITU-R.

[1] Chairman.

  

## 2. The International Telecommunications Union (ITU)

The ITU is the leading United Nations agency for radio and communication technology issues, and the global focal point for governments and the private sector in developing networks and services. For 145 years, ITU has coordinated the shared global use of the radio spectrum, promoted international cooperation in assigning satellite geostationary orbits, worked to improve telecommunication infrastructure in the developing world, and established the worldwide standards to foster seamless interconnection of the vast range of communications systems. Based in Geneva, Switzerland, the ITU membership includes 192 Member Nations and more than 700 Sector Members and Associates from the international commercial and scientific communities. Managing the international radio-frequency spectrum and geostationary satellite orbit resources is a primary concern of the ITU Radiocommunication Sector (ITU-R).

The ITU-R is mandated by its Constitution to allocate spectrum and register frequency assignments, geostationary orbital positions and other parameters of satellites, 'in order to avoid harmful interference between radio stations of different countries'. The international spectrum management system is therefore based on regulatory procedures for frequency notification, coordination and registration.

Major tasks of ITU-R also include developing standards for radiocommunication systems, ensuring the effective use of the radio-frequency spectrum and studies concerning the development of radiocommunication systems. The ITU Radio Regulations is an international treaty and its Table of Frequency Allocations is revised and regularly updated to keep pace with the enormous demand for spectrum utilization. The ITU World Radiocommunication Conference (WRC), which convenes every three to four years, is central to the international spectrum management process and constitutes the starting point for national practices. The WRC reviews and revises the Radio Regulations that establish the framework for the utilization of radio frequencies and satellite geostationary orbits among ITU member countries, and considers any question within its purview.

Equitable access to spectrum and orbital resources is of special concern, given the uneven needs of developed and developing countries. As a consequence, the principle of *a priori* planning of spectrum and orbit resources is considered in conjunction with a series of plans established by radiocommunication conferences. Through its various activities covering the implementation of Radio Regulations to the establishment of recommendations and guidelines on the usage of radio systems and spectrum/orbit resources, the ITU-R plays a vital role in the global management of radio-frequency spectrum and satellite geostationary orbits. The demands for these limited natural resources are increasingly from services such as fixed, mobile, broadcasting, amateur, space research, meteorology, global positioning systems and environmental monitoring that all depend on radiocommunication to ensure safety of life on land, at sea and in the skies.

**Table 1.** ITU-R Study Groups.

| |
|---|
| SG 1—Spectrum Management |
| SG 3—Radiowave Propagation |
| SG 4—Satellite Services |
| SG 5—Terrestrial Services |
| SG 6—Broadcasting Service |
| SG 7—Science Services |
| CCV—Coordination committee for Vocabulary |

The management process is implemented through the establishment and activities of the Radiocommunication Study Groups. Table 1 lists the current Study Groups. These groups establish a formalized series of questions, recommendations, reports, handbooks and opinions relevant to the technology and operation in the radio spectrum and satellite transmission parameters.

## 3. Time and frequency services

Working Party 7A (WP7A), Broadcast Time and Frequency services, of ITU-R Study Group 7, Science Services, is responsible for Standard Time and Frequency Signal (STFS) services, both terrestrial and satellite. The scope includes the dissemination, reception and exchange of STFS services and coordination of these services, including satellite techniques, on a worldwide basis.

The WP7A develops and maintains Questions, ITU-R Recommendations in the TF Series, Reports, Opinions and Handbooks relevant to STFS activities, covering the fundamentals of the STFS generation, measurements and data processing. The ITU-R Recommendations are of importance to telecommunication administrations and industry. They also have important consequences for other fields, such as radio navigation, electric power generation, space technology, scientific and metrological activities and cover the following topics: terrestrial SFTS transmissions, including HF, VHF, UHF broadcasts; television broadcasts; microwave links; coaxial and optical cables; space-based SFTS transmissions, including navigation satellites; communication satellites; meteorological satellites; time and frequency technology, including frequency standards and clocks; measurement systems; performance characterization; time scales; time codes. The current questions being maintained by WP 7A are listed in table 2, and the current recommendations are listed in table 3. A major recommendation administered by ITU-R WP7A is the definition of UTC in ITU-R TF.460 [1].

The ITU-R then plays a central role in the definition, determination and maintenance of UTC as one of the international organizations involved in the dissemination and coordination of time and frequency services and standards development [2]. These organizations are described in figure 1. They are categorized into those organizations that deal primarily with 'standards', such as the definition of the second; those that deal with scientific aspects, such as observing the rotation of the Earth; and those involved with the regulatory aspects involving time and frequency dissemination services.

**Table 2.** Current questions assigned to WP 7A.

| Question ITU-R | Title |
|---|---|
| 110-2/7 | Time codes |
| 111-1/7 | Signal delays in antennas and other circuits and their calibration for high-accuracy time transfer |
| 152-2/7 | Standard frequencies and time signals from satellites |
| 207-2/7 | Time and frequency transfer using digital communication links |
| 236/7 | The future of the UTC time scale |
| 238/7 | Trusted time source for time stamp authority |
| 239/7 | Instrumentation time codes |
| 244/7 | Interference between standard-frequency and time-signal services operating between 20 kHz and 90 kHz |
| 245/7 | Interference to the standard-frequency and time-signal service in the low-frequency band caused by noise from electrical sources |
| 248/7 | Timing Information from Global Navigation Satellite Systems (GNSS) and their augmentations |
| 249/7 | Time and frequency information from 'enhanced' LOng Range Aid to Navigation (eLORAN) |
| 250/7 | Application and improvement of two-way satellite time and frequency transfer (TWSTFT) |

**Table 3.** Current STFS recommendations.

| Rec. ITU-R | Title |
|---|---|
| TF.374-5 | Precise frequency and time-signal transmissions |
| TF.457-2 | Use of the modified Julian date by the standard-frequency and time-signal services |
| TF.460-6 | Standard-frequency and time-signal emissions |
| TF.486-2 | Use of UTC frequency as reference in standard-frequency and time-signal emissions |
| TF.535-2 | Use of the term UTC |
| TF.538-3 | Measures for random instabilities in frequency and time (phase) |
| TF.583-6 | Time codes |
| TF.686-2 | Glossary and definitions of time and frequency terms |
| TF.767-2 | Use of global navigation satellite systems for high-accuracy time transfer |
| TF.768-6 | Standard frequencies and time signals |
| TF.1010-1 | Relativistic effects in a coordinate time system in the vicinity of the Earth |
| TF.1011-1 | Systems, techniques and services for time and frequency transfer |
| TF.1153-3 | The operational use of two-way satellite time and frequency transfer employing PN codes |
| TF.1876 | Trusted time source for time stamp authority |

## 4. Origins of UTC

UTC originated as a result of the need to coordinate time being kept at the different timing centres throughout the world and coordinate the time broadcasts that they originated [3]. The rotation of the Earth was the basis for the definition of time scales until the mid-1960s. The Length of the Day (LOD) traditionally determined the length of the second and it was well known by that time that the LOD was irregular. A more stable definition first sought was based on the orbital motion of the Earth around the Sun. That time scale was known as Ephemeris Time and promised a more stable definition but the advent of atomic standards rapidly overcame that definition. Atomic clocks operating in the timing centres offered a more stable and easily realizable method of generating and maintaining time.

Atomic time quickly became the basis of all modern time scales and has been maintained continuously in various laboratories since 1955, although not formally adopted until 1971 as an international time scale [4]. The advent and operation of caesium atomic standards in the 1950s, and broadcast systems such as LORAN which enabled accurate international comparison of these standards, led to the initial form of Atomic Time (AT) generated at the UK and US national timing centres. The formation of International Atomic Time (TAI) was recommended by the International Astronomical Union (IAU) in 1967, the International Union of Radio Science (URSI) in 1969 and the International Radio Consultative Committee (CCIR) of the ITU in 1970. The 14th General Conference on Weights and Measures (CGPM) approved the establishment of TAI in 1971 as the coordinate time scale whose unit interval is the second of the International System of Units (SI) as realized on the rotating geoid [5].

Direct comparison of timekeeping worldwide by means of radio transmissions became available in about 1961 by means of long range navigation systems and Earth orbiting satellites. The Bureau International de l'Heure (BIH), which was responsible for maintaining the international common time known as Universal Time (UT), began taking measurements from long range navigation systems and other systems to 'coordinate' time between timing centres. When TAI was established as a continuous time scale, decoupled from the rotation of the Earth, it was related to the coordination of UT. The initial coordination was agreed through the CCIR in 1962 as 'Coordinated Universal Time' for broadcast time comparisons and regulation of broadcast time signals [3, 6]. The name 'Coordinated Universal Time (UTC)' was accepted by IAU in 1967. The initial coordination of timekeeping by broadcast time signals from 1961 to 1972 attempted to maintain UTC to within 0.1 s of UT2 by both frequency offsets and sub-second steps. Close agreement was considered necessary because celestial navigation users required access to a time scale related to rotational time with an uncertainty of less than one second [3].

## 5. Coordinated Universal Time

The present UTC system adopted by the ITU-R was defined in 1972 [3]. The definition specifies UTC $=$ TAI $+\ n$ seconds, where $n$ is an integer number of seconds known as leap seconds and adjustments of the predicted differences of $\mathrm{UT1} - \mathrm{UTC} < 0.9\,\mathrm{s}$, and $\mathrm{DUT1} = \mathrm{UT1} - \mathrm{UTC}$ [1, 3]. It is in effect a 'stepped' atomic time scale. The rate of UTC is determined by TAI so that the basic time interval is the

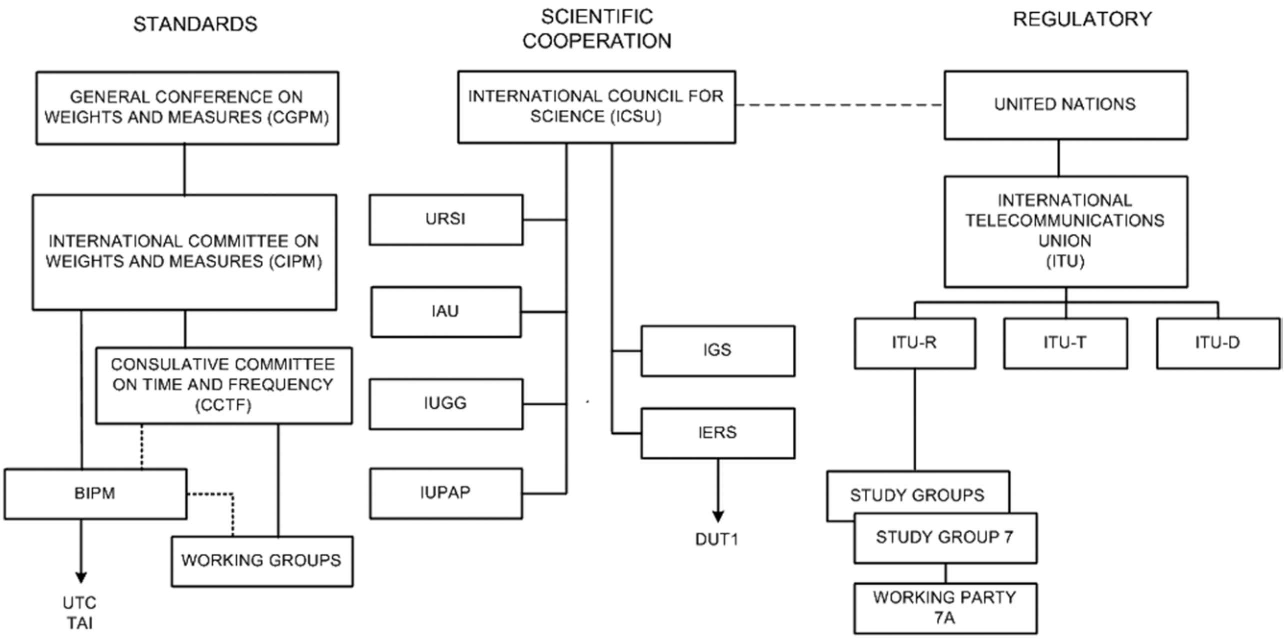


**Figure 1.** Relationship of agencies involved in time and frequency.

SI second. One second steps, either positive or negative, are then applied to maintain the difference from UT1 within 0.9 s. Producing UTC this way is a compromise in providing both the SI second and an approximation to UT1 for celestial navigators to access by radio transmissions. Among the astronomical time scales only UT1 is actively maintained by the International Earth Rotation and Reference Service (IERS) as a difference value (UT1 − UTC). The International Bureau of Weights and Measures (Bureau International des Poids et Mesures (BIPM)) assumed responsibility for maintaining TAI and consequently UTC, from the BIH in 1988.

International Atomic Time (TAI) is the primary metrologic time scale from which all the other time scales are derived, in particular the relativistic time scales for scientific and astronomical references [7, 8]. To maintain accurate time on the Earth and solar system the celestial mechanics used to determine the position and motion of the planets and stars must take the theory of relativity into account. Consequently there are several relativistic time scales defined for this purpose. Terrestrial Time (TT) is the relativistic coordinate time scale derived from TAI as the fundamental time scale with the SI second as the scale unit on the Earth's rotating geoid [9]. The fact that TAI or TT should be considered a coordinate time scale was determined by the Consultative Committee for the Definition of the Second (the predecessor to the Consultative Committee for Time and Frequency (CCTF)) in 1980, as well as providing the necessary correction information for the establishing TAI/TT in relativistic terms and for use in non-terrestrial reference frames. UTC is derived from TAI as a compromise approximation of Universal Time (UT1). For practical everyday use UTC is considered adequate for general system use as a broadcast standard and has been adopted by many nations for civil timekeeping.

## 6. The question of UTC

From issues raised within the ITU-R and a letter on behalf of the CCTF from the Director of the BIPM, a new question, ITU-R 236/7 (2000) 'The Future of the UTC Timescale', was established by ITU-R WP7A. The question considers the future definition and use of UTC. With a possible significant change to the definition of the UTC timescale there could be a significant impact on synchronization of communications networks, navigation systems and time distribution performance. Due to this potential impact and to focus on the issues, WP7A established a Special Rapporteur Group (SRG) to specifically address the question of the future of UTC and related issues.

## 7. Special Rapporteur Group (SRG)

The SRG was established and announced to the community by a letter from the ITU-R Radiocommunication Bureau (BR) on 8 Jan 2001. The letter invited participation in the SRG and outlined the plan of action of the group. It was distributed to the BIPM, CCTF, International Committee for Weights and Measures (CIPM), Committee on Space Research (COSPAR), IAU, International Civil Aviation Organization (ICAO), International Council of Scientific Unions (ICSU), International Maritime Organization (IMO), International Union for Geodesy and Geophysics (IUGG), International Union of Pure and Applied Physics (IUPAP), URSI and World Metrological Organization (WMO). As a result participants from the CCTF, IAU and IUGG joined the SRG.

Coordination and technical exchange meetings were held to gather data on UTC utilization, to analyse usage, and to examine alternative approaches to reduce or eliminate any operational impact of UTC adjustments. Meetings were held in conjunction with international conferences dealing with time and frequency as well as special presentations to the Institute of Navigation and the Civil GPS Interface Committee [10–12]. Several bodies in the international community conducted surveys and information fact-finding independently from the SRG but the results did not provide any clear resolution [10].

The early efforts did not identify clearly defined user group(s) using UTC time information nor a consensual opinion on future utilization. Consequently, the SRG organized a special colloquium on the future of UTC for deliberating and exploring possible recommendations with representative organizations and contributing parties. At the Colloquium, representatives in the areas of International Timekeeping, Navigation, Earth Rotation, Telecommunications and Internet Timing were invited to deliver presentations pertinent to the issues and to engage in discussion [13].

During the colloquium, analyses presented of deceleration of the Earth's rotation indicated that the possibility of multiple leap seconds per annum may be needed in the future to maintain the currently defined tolerance between UT1 and UTC [14]. If valid, these projections would indicate the probability of multiple leap seconds per year being introduced in order to maintain the current tolerance between UTC and UT1 of 0.9 s. It was generally agreed this will be the case but how soon this might happen is in question. Should multiple leap seconds be necessary, the existing definition allows for the insertion or deletion of a second at the end of any UTC month even though the preferred times are at the end of December or June [1].

Some members of the astronomical community have expressed great concern over any change to the current system. These concerns appear to stem from the use of UTC *in lieu* of UT1 in various applications of embedded software. Software incorporated into telescope pointing systems and other equipment controlling software which has become too old to be readily modified, or expensive to change, appears to be one of the primary concerns. Similarly, the astrodynamic community concerned with the determination of orbital parameters of artificial satellites and other celestial bodies utilize UTC as an approximation of the Earth's Rotation Angle in much the same way for the same purpose. It is unclear how much or how little of this problem exists in currently operating systems.

The other concern expressed was the divergence between a continuous time scale and solar time producing an increasing error that may be an issue in 'civil' timekeeping. The magnitude of the divergence has been estimated on the average as a few seconds over three years accumulating to an error of approximately one hour by the year 2600, as shown in figure 7 of [13]. One hour was considered significant since that is the interval used in adjusting to daylight saving time which is currently accommodated in 'civil' timekeeping. The impact of this divergence on general purpose 'civil' timekeeping is difficult to estimate.

Advances in telecommunications, navigation and related fields are moving towards the need for a single internationally recognized time scale to regulate and provide uniformity to these systems. The global nature of these systems providing omnipresent precise service is requiring increasingly precise time and frequency coordination. Their services are becoming integrated international services which could produce the need for even more precise systems by requiring universal synchronization and increased bandwidth. The increasing number and interdependence of these systems will likely result in an ever increasing number of independently maintained global time references as each system seeks to have its own continuous reference time. This will create a growing number of *de facto* global time scales. Such independently maintained reference time as GPS Time represents a continuous internal system time that has in many ways become an external time scale because of its availability, continuity and precision. A multiplicity of these 'pseudo-time scales' could lead to confusion and potentially disastrous consequences [15].

## 8. Alternatives to modifying UTC

Several alternatives have been investigated concerning UTC. Some of the more significant ones are briefly discussed below.

Creation of another time scale, to be known as International Time (TI), was suggested to form the continuous time scale that would be a continuation of UTC only under a new name. This new time scale could then provide continuity without any major time step that might be necessary if another time scale were to be used. Although sound in principle, a name change could cause confusion and complications for systems attempting to implement the new standard. The use of the term Greenwich Mean Time (GMT) is a prime example of the difficulties which arose when the astronomical community changed its definition. Creation of a new name was therefore not recommended.

The use of TAI was suggested since it is an existing continuous time scale. Although UTC uses the rate of TAI in SI seconds to determine its rate, TAI itself is not disseminated. TAI is primarily maintained as a metrologic time scale; the means of dissemination would need to be made available and standardized. To change the basis of broadcast time and frequency services to TAI would require existing timekeeping systems to adjust to that scale, and incorporate a significant initial time step. Changing to TAI would have all the complications of a name change, as previously mentioned, as well as a major time step and dissemination aspects. Of the defined time scales in the literature, in fact only UTC is maintained and distributed for international timekeeping purposes.

The necessity of continuing to broadcast DUT1 was also considered, but was largely unsupported. From the results of the independent surveys and investigations it appears that users apparently needing UT1 use UTC directly as an approximation of UT1. The broadcast of DUT1 was recommended to be discontinued, especially since a more precise value of UT1 is available via the IERS Website and BIPM *Circular T* for orbit determination software and astronomical instruments. The IERS makes available a more accurate and precise value of the LOD and UT1 than could be derived from a broadcast value of UTC and DUT1.

An alternative suggested was to simply adopt 'GPS Time' as the official international time scale rather than creating another time scale or revising UTC. Since 'GPS Time' is a continuous time and readily available, some have suggested it would be a better choice for a continuous time scale. GPS has also become the primary method for time dissemination and precise intercomparison of timing systems so adoption as the time standard would seem a logical alternative. However, although GPS is a highly precise synchronized system, 'GPS Time' is fundamentally an internal system synchronization time. Its purpose is to maintain the GPS satellite transmitters precisely synchronized to a common reference time so the relative error between the satellite signals is very small. This common reference time serves to synchronize the clocks within the GPS system, providing the reference against which GPS satellite corrections are broadcast. Consistency and relative synchronization between GPS satellites is essential for precise navigation. The internal determination, frequent adjustments and constant steering are suitable for system use, but produce a reference time that is not inherently accurate or suitable to reproduce fundamental metrological standards, such as the SI second. Consequently, GPS Time is not suitable as a replacement for UTC in the sense of an international standard for radiocommunication purposes.

Serious consideration was given to a contribution proposing that the maximum tolerance of DUT1, the difference between UT1 and UTC, be increased to one hour. This alternative was based on a similar concept of daylight saving time. This modification of standard time used by nations that is determined by national civil authority appeared to satisfy all civil requirements and concerns.

Considerations of other possible modifications in 2005 and 2006 have ranged from terminating the procedure of leap second adjustments to UTC altogether, some different alternatives for the tolerance and delaying the date suggested for application, to maintaining the status quo.

To gather additional information on the issues surrounding the application of a leap second a special request was made to the community on the leap second adjustment which took place prior to 1 January 2006. Another leap second was added on 1 January 2009. The 2005 event allowed the ITU-R to collect further documentation on leap second problems experienced in the areas of communication, navigation and other electronic systems.

A letter from the Director of the ITU-R requesting documentation on leap second experience was sent directly to all ITU sector members, twelve international bodies, and posted on websites of several international organizations. From the small number of responses collected from international bodies, timing laboratories, satellite agencies and network engineers, it appeared that only minor anomalies occurred, mostly on GPS driven equipment and on NTP time servers. At the same time, a few of the responses indicated their satisfaction with the present UTC system. It was noted by some that the early announcement of the leap second application by the IERS allowed them to avoid or fix any potential anomaly. In one case a computer network was shut down about an hour before the leap second occurred and brought back into operation an hour afterwards. The indications were that system operators using time information have learned to cope with the irregularities by one means or another, service disruption being one method. Should multiple leap seconds be required in the future such methods may not be an acceptable solution.

## 9. Summary

The definition of UTC is administered by the ITU-R as the common time reference for coordination of broadcast time and frequency services worldwide. Studies and information gathering on the potential future of the UTC time scale have been conducted over the past ten years by special groups from the ITU-R, the IAU, the IERS, URSI, the American Astronomical Society, and others. The issue of a continuous time scale for general usage has been pushed aside or generally ignored by the scientific societies at large. Consequently, special study groups have been faced with little interest from the parent bodies, which has resulted in an inability for some to make informed decisions.

The decision within the ITU-R to adopt a continuous time scale is still under consideration. A major issue has been when such a change should be effective. It was generally agreed that, should such a change be made, sufficient time should be allowed for any accommodation deemed necessary. Adoption of a revision to this recommendation will occur at a World Radio Conference since the UTC definition is incorporated by reference into the Radio Regulations and therefore has treaty status. Within the formal ITU-R procedures the effective date of the revision would be determined at the World Radio Conference.

To change the realization of UTC and forfeit its close agreement with UT1 would make it available to the many applications where a continuous time reference is required. The timekeeping elements within a given system could be configured to provide a realization of UTC within the system. In some cases where the system clocks are free running and not steered, the system internal timekeeping might also directly contribute to the formation of UTC. Such an approach could internalize the international standard rather than using it as an external 'steering' standard. Different systems could become inherently synchronized and thereby fundamentally compatible. A precise and accurate international time would no longer need to be external.

## Acknowledgments

The author would like to acknowledge the contributions and efforts of the members of Working Party 7A, the international timing community, and the members of the Special Rapporteur Group in particular in the pursuit of the issues concerning the future of the UTC time scale. This question has engaged many within the community who have expended considerable time and effort in attempting to resolve it.

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