COORDINATED UNIVERSAL TIME (UTC)

1. HISTORY

Details of the history of UTC can be found in Nelson, *et al*. (2001) from which much of this document is taken.

1.1. HISTORY BEFORE 1960

In the 19th century the words "universal time" were used typically to refer to the concept of time that would read the same everywhere in the world and be used as a conventional, or "universal," time standard as opposed to the common practice in which many "local" times referred to many local meridians. The phrase did not necessarily refer to a particular time scale such as Greenwich Mean Time (GMT). Although the subject of time was not covered originally in the Treaty of the Meter that was signed on May 20, 1875, (Bureau International des Poids et Mesures, 2006) it has since become part of the mission of the organizational structure put in place by the Treaty.

The most precise determinations of time in the 19th century were accomplished using astronomical observations of star transits of the observers' meridians. Consequently, the development of the concept of universal time was related directly to the acceptance of the idea of a standard meridian to which those astronomical observations could be referred. Although maritime charts were available using other "standard" meridians including Christiania (Oslo), Copenhagen, Naples, Paris, and Stockholm, the commencement of the British *Nautical Almanac* in 1767 caused users to be predisposed to the Greenwich meridian. In August, 1871, the first International Geographical Congress met in Antwerp and passed a resolution expressing the opinion that the Greenwich meridian should be used as the zero of longitude for all passage charts and that this should be obligatory within 15 years (Howse, 1997). The second International Geographical Congress met in Rome in 1875 producing further discussion without definitive results. At this meeting, however, the proposition was first suggested that France might consider adopting the Greenwich meridian, if Great Britain were to adopt the metric system.

In 1876 Sandford Fleming, the engineer-in-chief of the Canadian Pacific Railway published an article promoting the concept of a universal time. This was followed in 1879 by two papers outlining his ideas regarding time (Fleming, 1879a; 1879b). In these works he proposed what he first called "cosmopolitan" time. However, he states that "For this purpose either of the designations, 'common,' 'universal,' 'non-local,' 'uniform,' 'absolute,' 'all world,' 'terrestrial,' or 'cosmopolitan,' might be employed." (Fleming, 1879a). The words "cosmic time" were also used. Although Fleming suggested the use of a prime meridian, he did not propose the use of Greenwich, because he apparently felt that this would be too politically sensitive (Blaise, 2002). He eventually favored the adoption of a meridian situated 180 degrees from that of Greenwich corresponding loosely to the current "date line."

In 1880 GMT did become the legal time in Great Britain and in 1883, the U. S. and Canadian railways adopted a system of time zones based on the Greenwich meridian to facilitate scheduling. The U. S. government did not implement a time zone system officially until 1918 (Bartky, 2000). Meanwhile, the Third International Geographical Congress met in 1881 in Venice to discuss the zero meridian and a standard time, among other issues. The participants voted to appoint an international commission to consider the problem, but no action was taken (Wheeler, 1885). In 1883 the issues were taken up at the Seventh General Conference of the International Association of Geodesy held in Rome. There, the delegates adopted resolutions that, among other things, (1) suggested Greenwich as the initial meridian, (2) recommended that longitude be measured from west to east, (3) recognized the usefulness of adopting "une heure universelle" in addition to "heures locales," (4) recommended that Greenwich noon, which corresponds with midnight on the meridian situated 12 hours from Greenwich in longitude, be the beginning of the cosmopolitan date, and (5) noted the convenience of measuring time from 0h to 24h. They also noted the special conference that had been proposed by the U. S. government regarding the standardization of longitude and time (Hirsch and von Oppolzer, 1883).

The International Meridian Conference held in Washington in October 1884 settled the matter by proposing "the meridian passing through the center of the transit instrument at the Observatory of Greenwich as the initial meridian for longitude." Participants in that conference also took on the issue of an international convention for time by proposing "… the adoption of a universal day for all purposes for which it may be found convenient, and which shall not interfere with the use of local or other standard time where desirable." They further proposed that "…this universal day is to be a mean solar day; is to begin at the moment of mean midnight of the international meridian, coinciding with the beginning of the civil day and date of that meridian; and is to be counted from zero up to twenty-four hours." (*International Conference held at Washington for the purpose of fixing a Prime Meridian and a Universal Day, October 1884 – Protocols of the Proceedings*)

Despite the recommendations of the 1884 International Meridian Conference, astronomers continued to measure days from noon to noon. Following that tradition, the mean solar time measured from mean noon at Greenwich was designated as Greenwich Mean Time (GMT). In 1925, however, the situation was changed in the astronomical almanacs, by introducing a 12-hour discontinuity whereby the date previously referred to as 31.5 December 1924 was now to be known as 1.0 January 1925. The British *Nautical Almanac* continued to call this time Greenwich Mean Time, but *The American Ephemeris* referred to this new time scale, measured from midnight to midnight, as Greenwich Civil Time. To avoid confusion, the name "Greenwich Mean Astronomical Time" (GMAT) was used to designate the time measured from noon to noon.

In 1928, The International Astronomical Union (IAU) recommended using the name "Universal Time" to replace GMT or GCT in astronomical almanacs. This was the first "official" designation of Universal Time. The actual determination of this time continued to rely on astronomical observations of star transits that were used to set mechanical, and later, electronic clocks. Beginning in 1956 the IAU recognized three versions of

Universal Time. The Greenwich Mean Solar Time as observed at any location on the Earth, without regard for the location of the Earth's rotation axis with respect to the observing site, was designated "UT0." If we also know the position of the pole with respect to the observing location small corrections can be applied to produce a time scale, "UT1" that is free of the local effects of the station's geography. Finally, a third version was designated "UT2," that was obtained by applying a conventionally adopted seasonal variation to UT1 to account for the observed seasonal variation in the Earth's rotational speed. This time was generally regarded in the early 1950s as being the best representation of a uniform time scale, and radio time signals of that time were based on UT2.

1.2. RADIO TIME SIGNALS

In the 19th century time dissemination by telegraph had become widespread, and in 1904 the first regular repeated radio time signals were begun. In 1919, the International Research Council established the Bureau International de l'Heure (BIH) at the Paris Observatory to coordinate the transmission of radio time signals through routine publication of the differences between the broadcast radio signals and the astronomically determined time. The early 20th century saw the proliferation of radio time signals from various countries. They were so loosely controlled that a listener monitoring several stations could hear the pulses arriving at different times.

The World Administrative Radio Congress of 1959 recognized that different countries were sending inconsistent time signals, and they asked the International Radio Consultative Committee, abbreviated "CCIR" to study the problem. The UK and the US had already decided in 1957 to combine Nautical Almanacs beginning with the 1960 edition, and in 1959, they also agreed to coordinate their time and frequency transmissions by making the same adjustments, at the same time, to their Caesium-based time scales to stay close to UT2. In 1959 the Royal Greenwich Observatory, the National Physical Laboratory in England, and the U. S. Naval Observatory agreed to coordinate their time and frequency transmissions, which were based on UT2 and the atomic frequency. Based on a comparison of UT2 and the rotation rate of the Earth during the previous year, a factor S was determined and the actual frequency of transmission would be $F_0 (1 + S)$, where F_0 is the nominal atomic frequency. The time between pulses was 9192631770 (1-S) cycles of the cesium resonance. When the rotation of the Earth departed unpredictably from this offset atomic scale, step adjustments were introduced in the time scale in multiples of 50 milliseconds. The purpose of this cooperation was to avoid diverse time scales and to provide the same time and frequency from multiple sources. This coordination began on January 1, 1960, and the resulting time scale began to be called informally "Coordinated Universal Time." Timing laboratories from other countries also began to participate over time, and in 1961 the BIH began to coordinate the process internationally.

1.3. HISTORY AFTER 1960

Details of the UTC system were formalized by CCIR Study Group 7 in Geneva in 1962 and were adopted by the CCIR in its Recommendation 374 of 1963 (*Documents of the Xth Plenary Assembly*, 1963). In 1965 the BIH started calculating UTC based on the atomic time scale A3 that would eventually evolve into TAI. Each year, the BIH would, after consulting other observatories, announce an offset in the atomic frequency in order to match UT2 as closely as possible. They would also announce 100 ms adjustments in UTC as required in order to maintain UTC with 0.1s of UT2. In 1967 the CCIR adopted the names *Coordinated Universal Time* and *Temps Universel Coordonne* for the English and French names with the acronym UTC to be used in both languages The name "Coordinated Universal Time (UTC)" was approved by a resolution of IAU Commissions 4 and 31 at the 13th General Assembly in 1967 (*Trans. IAU*, 1968).

As UTC included rate offsets to reduce the need for step adjustments, the broadcast time signals indicated neither the SI second nor the mean solar second, but rather variable intervals to stay in step with UT2, from which the SI second could be obtained by applying a known correction. Attempts to follow these fluctuations necessitated revisions in complex equipment on a frequent basis and risked temporary interruptions of service. At an interim session in Monte Carlo during March 1965, Study Group 7 suggested that experimental broadcasts and studies should be made to investigate how to provide both the epoch of Universal Time and the international unit of time interval in the same emission (Hudson, 1965). The revised CCIR Recommendation 374-1 (*Documents of the Xth Plenary Assembly*, 1967) of 1966 allowed for the limited and provisional use of an experimental "Stepped Atomic Time (SAT)", in which the broadcast time rate was the atomic time rate, with no carrier deviation, but in which frequent step adjustments of 200 ms were applied to match UT2 to within 0.1 s. The existence of two parallel systems, UTC and SAT, was regarded as a phase in the evolution and adoption of a single, practical and internationally acceptable system (Hudson, 1967).

The resulting UTC time scale broadcast worldwide, with its seconds of variable length and potential "jumps" in time, began to cause concerns among users that needed stable time scales. There was an increasing need for precise frequencies for practical applications. Radio and television stations needed precise frequency standards to calibrate their transmitters so they could stay within their assigned places in the overcrowded frequency spectrum. Precise calibration of oscillators was also required for navigation systems such as Loran, Loran C, and Omega. Thus, the changing offset frequency was becoming a nuisance, and an attempt was made to maintain the same frequency for several years at a time. The proposed introduction of an air collision avoidance system in the early 1970s, based on precise frequency, made the use of frequency offsets intolerable. These concerns drove the acceptance of a new UTC, adopted in 1970 and implemented in 1972.

At the 15th General Assembly of the International Union of Radio Science (URSI) in Munich in 1966, Commission 1 expressed the opinion that all proposed methods of operating standard time and frequency services contained defects and that these services must inevitably develop towards a system of uniform atomic time and constant frequency. For those requiring astronomical time, some form of correction would be necessary (*Progress in Radio Science 1963-1966*, 1967; *Trans. Int. Astron. Union*, 1967). In 1967, at a meeting held in Brussels under the auspices of the URSI to consider frequency coordination in Europe, it was unanimously agreed that both rate offsets and step adjustments should be discontinued. It was suggested that the deviations of UTC from UT2 would have no significance for civil purposes, but could be disseminated to navigators in tables or in the transmissions themselves (Essen, 1967).

Dissatisfaction with the existing form of UTC and the need to study the implications of the new definition of the second adopted in 1967 prompted discussions by the International Committee for Weights and Measures (CIPM) and the CCIR. Following a recommendation of the Consultative Committee for the Definition of the Second (CCDS), the CIPM formed a preparatory commission for the international coordination of time scales. The concept of the leap second, analogous to the leap day in the calendar, was proposed independently by G. M. R. Winkler (1968) and Louis Essen (1968) at a meeting of the commission held at the BIPM in May 1968 (Commission Préparatoire pour la Coordination Internationale des Échelles de Temps, 1968; Chadsey & McCarthy, 2001). It was proposed that integer steps of seconds replace the steps of 100 ms or 200 ms then being used because they were too frequent and too small. Consideration of possible modifications to UTC was also given by CCIR Study Group 7 in Boulder in August, 1968 (Smith, 1972). The view was expressed that the best system would be one with 1 s steps without rate offsets, so that equipment generating a pulse train would not require a change in frequency. To meet the needs of navigators, it was suggested that coded information might be incorporated in the emission to indicate the difference between UTC and UT2 to higher resolution. An Interim Working Party, IWP 7/1, was formed to investigate requirements, submit proposals, and fix a date for the introduction of the new system. The options under consideration at this time were summarized as follows (*Trans. Int. Astron. Union*, 1970):

> "Discarding the suggestion (for practical reasons and to avoid confusions) of two time scales, one approaching UT (the present UTC) and the other without offsets and adjustments, only three alternatives remain: (a) step adjustment of 0.1 s or 0.2 s to maintain the UTC sufficiently near to UT2 to permit to ignore the difference in most of the applications; (b) complete disuse of UTC system, replacing it with a coordinated uniform time scale without offsets and steps and therefore not approaching UT; (c) step adjustment of 1 s exactly."

Specific proposals were made by Study Group 7 in Geneva in October 1969, which were approved by the CCIR XIIth Plenary Assembly in New Delhi in January 1970. In its Recommendation 460 (International Radio Consultative Committee, 1970), the CCIR stated that (a) carrier frequencies and time intervals should be maintained constant and should correspond to the definition of the SI second; (b) step adjustments, when necessary, should be exactly 1 s to maintain approximate agreement with Universal Time (UT); and (c) standard signals should contain information on the difference between UTC and UT. The CCIR also decided to begin the new UTC system on 1 January 1972.

At the IAU's 14th General Assembly in Brighton, UK, in August 1970, the chairman of CCIR IWP 7/1, H. M. Smith, sought the views of Commissions 4 (Ephemerides) and 31 (Time). The appropriate method of providing both precise Earth orientation to navigators and uniform time to time and frequency laboratories was discussed. As the navigator requires knowledge of UT1 rather than UT2, it was recommended that radio time signals should disseminate differences in the form of [*UT1 – UTC*]. Several astronomers emphasized that visual observers in astronomical and related fields require UT1 to a precision of 0.1 s, as this is about the limit of human time discrimination. In addition, the almanacs were designed to permit a determination of position to 0.1 minute of arc, and for this a comparable precision in time of 0.25 s was required. At Brighton, Commission 31 adopted recommendations similar to those of the CCIR. Also, the IAU General Assembly resolved that adequate means should be provided to ensure that the difference [*UT1 – UTC*] would be available before permitting UTC to depart from UT1 by more than about 0.1 s (*Trans. Int. Astron. Union*, 1971).

Detailed instructions for the implementation of CCIR Recommendation 460 were drafted at a further meeting of Study Group 7 that was held in February 1971 (International Radio Consultative Committee, 1974). The defining epoch of 1 January 1972, 0 h 0 m 0 s UTC was set 10 s behind TAI, which was the approximate accumulated difference between TAI and UT1 since the inception of TAI in 1958, and a unique fraction of a second adjustment was applied so that UTC would differ from TAI by an integral number of seconds. The recommended maximum departure of UTC from UT1 was 0.7 s. The term "leap second" was introduced for the stepped second. An additional correction DUT1 was introduced, having integral multiples of 0.1 s, to be embodied in the time signals such that, when added to UTC, they would yield a better approximation to UT1. For example, this second level of correction was achieved by U. S. National Bureau of Standards (NBS) radio stations WWV and WWVH by using double ticks or pulses after the start of each minute in its UTC broadcasts (Howe, 1979).

The recommendations of the IAU were formalized by resolutions of Commissions 4 and 31 at the 15th General Assembly in Sydney in 1973 and, after further discussion, the name UTC was retained (*Trans. Int. Astron. Union*, 1974). UTC was recommended as the basis of standard time in all countries, the time in common (civil) use as disseminated by radio signals. The limit of [*UT1 – UTC*] was set at ±0.950 s, as this is the maximum difference that can be accommodated by the code format. The maximum deviation of UT1 from [*UTC* + *DUT1*] was set at ±0.100 s. In 1974, the CCIR increased the tolerance for [*UT1 – UTC*] from 0.7 s to 0.9 s. The present UTC system is defined by ITU-R (formerly CCIR) Recommendation ITU-R TF.460-5 (1974):

> "UTC is the time scale maintained by the BIPM, with assistance from the IERS, which forms the basis of a coordinated dissemination of standard frequencies and time signals. It corresponds exactly in rate with TAI but differs from it by an integral number of seconds. The UTC scale is adjusted by the insertion or deletion of seconds (positive or negative leap seconds) to ensure approximate agreement with UT1."

The interval between time signals of UTC is thus exactly equal to the SI second.

Study Group 7 then formulated specific proposals that were approved in January 1970 at the CCIR XIIth Plenary Assembly in New Delhi. The recommendation adopted there provides the current definition of the world's civil time. It specified that (a) radio carrier frequencies and time intervals should correspond to the atomic second based on the Caesium atom; (b) step adjustments should be exactly one second to maintain approximate agreement with UT; and (c) standard time signals should contain information on the difference between UTC and UT. The new system was to begin on 1 January 1972. In February 1971 Study Group 7 specified more details regarding the implementation of the 1970 recommendation 460. The predicted difference DUT1= UT1-UTC was to be coded into the broadcast time signals and DUT1 was not to exceed 0.7 s. A special offset of –0.1077580 second was given to UTC at the end of 1971, so that TAI – UTC was exactly 10 seconds. Since then the UTC scale has been based on TAI with leap seconds added to keep UTC within less than a second of UT1.

The CCIR failed to send an official letter concerning the change to the IAU in time for its 1970 General Assembly. Hence, the IAU could not respond until the 1973 General Assembly, which was after the introduction of the change. In 1973 the IAU recognized that UTC provided mean solar time, recommended it for civil time, and suggested modifications to the leap second rules. In 1974 the CCIR revised recommendation 460-1 based on the input from the IAU, and raised the maximum difference between UTC and UT1 to 0.9 second. In 1975 the General Conference on Weights and Measures (CGPM) stated that UTC provided both atomic frequency and UT and endorsed it for civil time. On 1979 January 1 the rate of TAI was reduced by one part in 10^{12}, to better approximate the SI second. Thus, the UTC rate was also changed. The CCTF determined that the TAI second was longer than the SI second, because the time standards were not being corrected for the effects of blackbody radiation. So from 1996 to 1998 the TAI was steered to reduce the length of the second by two parts in 10^{14}. This also had a corresponding effect on UTC.

In 1988 the responsibility for TAI was transferred to the BIPM from the BIH and the responsibility for determining the rotation of the Earth, and UT1, was transferred to the IERS. Thus, both the BIH and the International Latitude Service (ILS) ceased to exist at that time. In a 1992 reorganization, the International Telecommunications Union-Radiocommunications Sector (ITU-R) replaced the CCIR, and the UTC recommendation became ITU-R TF 460.

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2. INTERNATIONAL ORGANIZATIONS

2.1. TREATY OF THE METER

The Treaty of the Meter is also known as the Meter Convention or in French as the Convention du Mètre. Written in the French language, it was signed originally in 1875 by 17 countries at the International Metric Convention that was called to organize formally the means to maintain the metric standards. The number of signatories increased to 21 in 1900, 32 in 1950, 44 by 1975, 48 by 1997, and 49 by 2001. As of 2005, there were 51 signatories and 30 states with associate status. The treaty was revised in 1921, and the system of units it established was renamed the *Système international d'unités* (SI) ("International System of Units") in 1960. To carry out the intentions of the treaty, three organizations were created: the Conférence Générale des Poids et Mesures (CGPM), the Comité International d Poids et Mesures (CIPM), and the Bureau International des Poids et Mesures (BIPM). The resposibility for an international standard time was taken on by the CGPM in 1985 (Guinot, 2000).

General Conference on Weights and Measures (CGPM)

Delegates from each of the signatories along with observers from each of the associates comprise the General Conference on Weights and Measures (Conférence Générale des Poids et Mesures, CGPM). The CGPM meets every four years at the BIPM where it receives the official report of the CIPM, discusses possible improvements in the SI units, and endorses new metrological results and international scientific recommendations regarding the fundamental units. It also makes decisions regarding the future direction of the BIPM. The Système International d'Unités or the International System of Units, abbreviated "SI" was established in 1960 by the 11th CGPM and it is modified by the CGPM as required to reflect the latest advances.

International Committee on Weights and Measures (CIPM)

Eighteen individuals, each from a different member state, comprise the International Committee on Weights and Measures (Comité International des Poids et Mesures, CIPM). Its mission is to promote uniformity in the international measurement units principally by submitting draft resolutions to the CGPM for its approval. It discusses the work of the BIPM and issues an annual report on the operations of the BIPM to the governments of the member states. Its members discuss and coordinate current metrological activites and prepare other reports including the SI Brochure.

The CIPM has created a number of Consultative Committees (in French: Comités Consultatifs) to provide technical information on a wide range of metrological activities. Each committee is composed of technical experts from national metrology institutes and the chair of each committee usually serves on the CIPM. These committees discuss scientific and technical advances related to metrology and formulate recommendations for the CIPM. They also advise the CIPM on the work of the BIPM. The committees with titles current as of 2008 are:

- Consultative Committee for Acoustics, Ultrasound and Vibration (CCAUV)
- Consultative Committee for Electricity and Magnetism (CCEM)
- Consultative Committee for Length (CCL)
- Consultative Committee for Mass and Related Quantities (CCM)
- Consultative Committee for Photometry and Radiometry (CCPR)
- Consultative Committee for Amount of Substance - Metrology in Chemistry (CCQM)
- Consultative Committee for Ionizing Radiation (CCRI)
- Consultative Committee for Thermometry (CCT)
- Consultative Committee for Time and Frequency (CCTF)
- Consultative Committee for Units (CCU)

The CIPM meets annually at the BIPM to discuss the reports of the Consultative Committees. The CCU assists in the preparation of the SI Brochure. Suggested modifications of the SI are submitted to the CGPM by the CIPM for formal adoption. On matters relating to interpretation or usage of the SI the CIPM may also adopt its own resolutions and recommendations.

BIPM

The third organization created by the Meter Convention is the Bureau International des Poids et Mesures (International Bureau of Weights and Measures, BIPM). It is located in Sèvres, a suburb of Paris. Its status is that of an intergovernmental organization that is financed by the member states of the Meter Convention. Its operations fall under the supervision of the CIPM. The staff of the BIPM, which numbers about 70, carries out its mission to ensure international unification of physical measurements. It is to provide the basis for a single, coherent system of measurements traceable to the SI.

The BIPM is currently organized in five sections:

- Mass
- Time, Frequency and Gravimetry
- Electricity
- Ionizing radiation
- Chemistry

These carry out a variety of tasks including maintaining the kilogram, coordinating international measurement standards, and in the case of time, providing the actual SI unit, the second.

2.3. INTERNATIONAL TELECOMMUNICATIONS UNION (ITU)

The International Telecommunications Union is a United Nations organization that deals with information and communications technologies. Based in Geneva, Switzerland, the ITU has 191 member states and more than 700 sector members and associates. Sector members are recognized operating agencies, scientific or industrial organizations, and financial or development institutions, and organizations of an international character representing them. The ITU is comprised of three sectors:

- Radiocommunication (ITU-R)
- Standardization (ITU-T)
  ITU's standards-making efforts are its best-known — and oldest — activity.
- Development (ITU-D)
  Established to help spread equitable, sustainable and affordable access to information and communication technologies (ICT).

The ITU-R manages the international radio-frequency spectrum and satellite orbit resources and is the primary sector of the ITU dealing with issues of time and frequency. The ITU-T deals with setting technical specifications so that elements of communications systems can interoperate seamlessly, and ITU-D creates policies and regulations and provides training programs and financial strategies in developing countries. ITU also organizes TELECOM events that bring together leading elements of the information and communication technologies (ICT) as well as ministers and regulators for exhibitions, and high-level forums.

The ITU dates back to the days following the establishment of telegraph networks. To facilitate international communications countries gradually established regional agreements, and in 1865 the International Telegraph Convention was signed resulting in the formation of the International Telegraph Union. With the development of the telephone and wireless telegraphy it was necessary to establish international agreements regarding radiotelegraphy. The first International Radiotelegraph Conference was held in 1906 in Berlin resulting in the first International Radiotelegraph Convention and a set of regulations. These regulations, which have since been expanded and revised by following radio conferences, are now known as the Radio Regulations.

Within the ITU the International Telephone Consultative Committee (CCIF) was established in 1924, followed by the International Telegraph Consultative Committee (CCIT) in 1925, and the International Radio Consultative Committee (CCIR) in 1927. These organizations coordinated the technical studies, tests and measurements and drew up international standards to ensure international communications. The 1927 International Radiotelegraph Conference was the first to allocate frequency bands to existing radio services, including fixed, maritime and aeronautical mobile, broadcasting, amateur, and experimental.

In 1932 the International Telecommunication Convention was formed by combining the International Telegraph Convention and the International Radiotelegraph Convention. At the same time the name of the Union was changed to International Telecommunication Union to reflect its expanding scope. In 1947 it became a United Nations specialized agency and in 1956, the CCIT and the CCIF were merged to form the International Telephone and Telegraph Consultative Committee (CCITT). In 1992, a plenipotentiary conference, revised the structure of the ITU into the three sectors that integrated the functions carried out by the CCIR and the CCITT.

Some documents of the ITU have the status of international treaties. These are (1) the Constitution and Convention of the International Telecommunication Union originally signed in 1992 and subsequently amended in 1994, 1998 and 2002, and (2) the

Administrative Regulations, which include the Radio Regulations (http://www.itu.int/publ/R-REG-RR/en) and the International Telecommunication Regulations (http://www.itu.int/ITU-T/itr/), which complement the Constitution and the Convention. The last revision of the Radio Regulations was signed in 2003, and the International Telecommunication Regulations were signed in 1988. The Radio Regulations incorporate the decisions of the World Radiocommunication Conferences, including all appendices, resolutions, recommendations and ITU-R recommendations incorporated by reference. World radiocommunication conferences (WRC) are held every two to three years to review and, if required, revise the Radio Regulations. The general program of world radiocommunication conferences is established four to six years in advance and the final agenda set by the ITU Council two years before the conference, with the concurrence of a majority of Member States.

The Plenipotentiary Conference is held every four years to set the Union's general policies, adopt plans for the future and elect the management team. At this conference ITU member states decide on the future of the organization and sector members can attend as observers. The ITU Council, in the interval between Plenipotentiary Conferences, deals with broad telecommunication policies and prepares a report on the policy and strategic planning of the ITU. It is responsible for ensuring the smooth operation of the Union and facilitates the implementation of the provisions of the ITU Constitution, the ITU Convention, and the Administrative Regulations.

Within the ITU, matters relating to precise time and its dissemination fall within the tasks of the ITU-R, and within the ITU-R they are part of the agenda of Study Group 7. Study Group 7 is part of the structure of the Study Groups which includes:

- Study Group 1 (SG 1) - Spectrum management
- Study Group 3 (SG 3) - Radiowave propagation
- Study Group 4 (SG 4) - Satellite services
- Study Group 5 (SG 5) - Terrestrial Services
- Study Group 6 (SG 6) - Broadcasting service
- Study Group 7 (SG 7) - Science services

Within Study Group 7, issues related to precise time fall within the purview of Working Party 7A. Study Group 7 is structured as follows:

- Working Party 7A (WP 7A) - Time signals and frequency standard emissions
- Working Party 7B (WP 7B) - Space Radiocommunication Applications
- Working Party 7C (WP 7C) - Remote Sensing Systems
- Working Party 7D (WP 7D) - Radio astronomy

Issues related to precise time that might be expected to be included in the Radio Regulations would then be expected to be brought up first with Working Party 7A for discussion. They then would go to Study Group 7, then to ITU-R, before being accepted at a World Radio Conference.

2.3. INTERNATIONAL ASTRONOMICAL UNION

The International Astronomical Union (IAU) was founded in 1919 to promote the science of astronomy through international cooperation. It is made up of national and individual members. National members are organizations that represent national professional astronomical communities within their countries, and individual members are professional scientists whose research relates to astronomy. Individual members are elected by the Union's Executive Committee following the recommendation of a National Member.

The IAU is currently organized into 12 divisions. Each division is broken down further into commissions that deal with specific specialized topics. The number of commissions now totals forty. The organization also allows for any number of working groups that can report either to divisions or to commissions. As of 2008 there are 67 national members and over 9600 individual members. The Executive Committee sets and implements the overall policy, and the operations are overseen by a set of elected officers. The center for its business activities is the IAU Secretariat, which is currently hosted by the Institut d'Astrophysique de Paris in France.

In addition to sponsoring a number of symposia each year, the IAU holds a General Assembly every three years. The IAU defines fundamental astronomical and physical constants and astronomical nomenclature. It also promotes educational activities in astronomy and discusses future developments dealing with the science of astronomy. Matters related to the subject of time are discussed in Division 1 which has a number of associated Commissions:

- Commission 4. Ephemerides
- Commission 7. Celestial Mechanics and Dynamical Astronomy
- Commission 8. Astrometry
- Commission 19. Rotation of the Earth
- Commission 31. Time
- Commission 52. Relativity in Fundamental Astronomy

The commissions are composed of technical experts dealing with detailed aspects of the commission's tasks. Commissions 31 and 19 are of particular interest for those dealing with timekeeping. The activities of Commission 31 (Time) include maintaining cooperation with national and international institutions providing atomic timekeeping information, developing cooperation between observatories and other institutions providing and archiving astronomical data relevant to atomic timekeeping, such as pulsar data, developing methods of analyzing and evaluating astronomical data relevant to fundamental concepts of time, and publicizing astronomical data and results relevant to time. Commission 19 (Rotation of the Earth) supports and coordinates scientific investigations in Earth rotation and related reference frames. Its objectives include encouraging and developing cooperation in observation and theoretical studies of Earth orientation and serving as a link between the astronomical community and those organizations providing the International Terrestrial and Celestial Reference Systems/Frames (ITRS, ITRF, ICRS, and ICRF) and Earth orientation parameters, including the International Association of Geodesy (IAG), International Earth Rotation and Reference System Service (IERS), International VLBI Service for Geodesy and Astrometry (IVS), International GPS Service (IGS), International Laser Ranging Service (ILRS), and International DORIS Service (IDS). It also seeks to develop methods to improve the accuracy and understanding of Earth orientation and related reference systems/frames, ensure agreement and continuity of the reference frames used for Earth orientation with other astronomical reference frames and their densification, and provide the means to compare observational and analysis methods and their results to ensure the accuracy of data and models.

3. CCTF ACTIVITY REGARDING ELIMINATION OF LEAP SECONDS

The following sections are taken from the minutes of past CCTF meetings that have discussed the possible elimination of leap seconds. The series of discussions begins with the original proposal made in 1999.

3.1. 14th Meeting (April 1999)

The President invited Dr McCarthy to present this report (CCTF99-18).

Dr McCarthy began by reviewing the history of the SI second, noting that its duration has its origin in the ephemeris second, which is based on 19th century astronomical Observations. Slowing of the Earth's rotation rate since then results in the present need for the introduction of approximately one leap second into UTC every 1.5 or 2 years.

This convention results in several causes for possible concern:

1. increasing frequency of leap seconds in the future;
2. communications problems;
3. annoyance of people in charge of systems disseminating time;
4. and consequent proliferation of independent time scales, not including leap seconds, for specific purposes (e.g. GPS time).

Dr McCarthy listed some options for responding to these issues:

1. maintain the status quo;
2. discontinue leap seconds in UTC:
   Pro: would be supported by those in charge of disseminating time.
   Con: unlimited growth of [$UTC – UT1$].
3. redefine the second:
   Pro: fundamental solution;
   Con: would require redefinition of other physical units; the solution is only temporary and its efficiency is not certain
4. increase tolerance for [$UTC – UT1$]:
   Pro: easy to accomplish;
   Con: date of adjustment unpredictable, difficult to establish acceptable limit.
5. periodic adjustments of UTC at larger intervals:
   Pro: date of adjustment predictable;
   Con: number of leap seconds unpredictable, larger discontinuities.

Because none of these options is obviously satisfactory for the majority of users of UTC, Dr McCarthy suggested that a working group on this issue be formed, and that it should include representation from the IAU, IERS, ITU-R and navigation bodies.

The President thanked Dr McCarthy for the report, and called for discussion, which is summarized by the following points:

1. The CCTF, or a working group thereof, probably does not have the authority to recommend the cancellation of leap seconds (raised by Dr Guinot). However, there is a general consensus that leap seconds should be discontinued and that the CCTF should draw the attention of the IAU, ITU, URSI and other bodies to this issue via a letter written by Dr Quinn (raised by the President).

2. The use of TAI should be encouraged in applications where leap seconds cause problems (raised by Dr Bauch), such as Global Navigation Satellite Systems (GNSS), although for this to be generally feasible it would be necessary to make TAI more accessible (raised by Dr McCarthy). The letter mentioned in the previous point should recommend the use of TAI where a time scale without discontinuities is needed.

Dr Quinn agreed to write the above-mentioned letter, in collaboration with Dr McCarthy.

<u>3.2. 15th Meeting (June 2001)</u>

Mr Beard and Dr de Jong presented the reports from the ITU-R Special Rapporteur Group (SRG) 7a, “UTC time scale” (CCTF/01-17, CCTF/01-33). The SRG was created to study the question raised in ITU-R 236/7, “The future of the UTC time scale”.

At its May 2001 meeting, with regard to the use of time scales in satellite navigation systems, telecommunications systems, computer networking, broadcast services and scientific uses, the SRG categorized the options for the future of UTC and leap seconds as follows:

Option 1: Maintain the status quo
- recommend use of UTC as currently defined;
- clarify time scales available and considerations for use;
- more advanced notice and information availability;
- creation of a navigation time scale.

Option 2: Modify leap second procedures or occurrence
- increase tolerance of [*UTC – UT1*] and enable longer prediction interval and lower frequency of leap second occurrence;
- fixed-interval adjustment with multiple leap seconds possible;
- correction at predicted intervals based on a deceleration model of the Earth’s rotation, re-evaluated at fixed intervals.

Option 3: Use of, or transition to, another time scale

- existing TAI made more accessible;
- new navigation time scale may be needed for celestial users;
- new time scale based on redefinition of the SI second.

In order to gather information before developing its recommendations which are to be released at its meeting in October 2002, the SRG plans to release a general letter to both sectors of the ITU announcing the SRG and its objectives, and also plans to publish articles and notices in journals and newsletters.

The President asked Mr Beard if any of the SRG outcomes presently available require the attention of the CCTF. Mr Beard replied that at this stage the likely outcomes are unclear, since the SRG has received little feedback from interested groups.

Dr Levine pointed out that many organizations are required to time-stamp events (often using time disseminated on computer networks), and that there is no satisfactory way of time-stamping an event which occurs during a leap second using UTC as the reference time scale. One solution might be to transmit [*UTC – TAI*] on the computer network, and so effectively use TAI as the reference time scale, but this may raise legal issues, since TAI is not legally recognized in all countries. A solution which is both technically and legally acceptable must be found.

The President observed that the leap second issue is very important, and while noting that such an act was outside the terms of reference of the CCTF, conducted a poll of the CCTF on the three options for the future of UTC presented by Mr Beard. The results were:

Dr Sullivan: Option 1.
Dr Fisk: Option 1.
Dr Granveaud: Option 2, with TAI made more accessible.
Prof. Pâquet: Option 3.
Dr Matsakis: No further leap seconds.
Dr McCarthy: Option 3.
Dr Steele: Option 2, since UTC in its present form was defined more than thirty years ago, and is not necessarily appropriate now.
Dr Fukushima: (speaking for himself, not the IAU) Option 3.
Prof. Leschiutta: Option 3, but without redefining the SI second.
Dr Quinn: Expressed no preference, but agreed with the comment of Dr Steele.
Dr Arias: Option 1, with the introduction of a navigation time scale.
Dr Godone: Option 1, with the introduction of a navigation time scale.
Dr Palacio: Option 1, with TAI made more accessible.
Dr de Jong: Option 1, with TAI made more accessible.
Dr Imae: No further leap seconds.
Dr Hosokawa: Option 2.
Dr Ikegami: Option 3.

Dr Laverty: Expressed no preference, but emphasized the importance of maintaining the SI second as the scale unit.
Dr Henderson: No further leap seconds.
Dr Domnin: Option 3, but without redefining the SI second.

<u>3.3. 16th Meeting (April 2004)</u>

The President began the discussion by stating that it was not within the remit of the CCTF to agree a redefinition of UTC, as UTC is defined by the ITU (ITU Recommendation TF-460). However, the agenda item was included as the CCTF is an interested party to these matters. Dr Beard presented a report from the Special Rapporteur Group (SRG) on UTC of the ITU-R Working Party 7A. The issue arose from the problem caused to some timescale users, such as communications systems, by the discontinuity resulting from leap seconds. The working group has been asked to study the problem and suggest solutions. Dr Beard recalled that the definition of UTC was ITU-R TF460-6 and was one of the more fundamental recommendations of the ITU. He then listed the members of the study group. These were: Jacques Azoubib (BIPM), Thomas Bartholomew (USA), Francoise Baumont (France), Ronald Beard (USA, Chairman), Michel Brunet (France), Yury Domnin (Russian Fed.), Donald Hanson (USA) and William Klepczynski (USA, IAU). Other organizations were represented by: Felicitas Arias (BIPM), Dennis McCarthy (IAU), Daniel Gambis (IERS) and Sigfrido Leschiutta (CCTF).

The SRG has defined the questions to be answered:

What are the requirements of the time scale in terms of accuracy, stability, relation to the SI Second, uniformity, accessibility, reliability, and availability for civil and national timekeeping;

what tolerance could be accommodated in [UT1 - UTC];

does the current leap second procedure satisfy the needs of the users or should an alternative be developed?

In addition, other issues to be considered were: satellite systems utilizing independent system time; the use of TAI; and multiple systems with different timebases. The SRG planned to investigate possible changes in coordination with ITU-R Sector Members and CCTF and report results for consideration by ITU-R.

Dr Beard said that a special colloquium had been held at IEN in May 2003, where the SRG has reported its findings. He listed the subject matter of the contributions at that meeting and the issues addressed. These included the question: “Should UTC be decoupled from solar time”? It was noted that the IERS accepted the responsibility of continuing UT1 regardless of changes to UTC and also that astronomers may not have a need for a real time representation of UT1. The IEN meeting agreed that there were long-term deficiencies in UTC due, in part, to the increasing number of leap seconds.

The conclusion of the SRG was that the creation of a new time scale, to be known as "International Time", was not recommended, as a new name and scale would create confusion and complications. The necessity of broadcasting DUT1 was largely unsupported as most users were using UTC directly as an approximation to UT1. The broadcast of DUT1 should be discontinued; the IERS was assuming responsibility for maintaining UT1 and its dissemination. Redefinition of a new "UTC" was not necessary; rather there should be an adjustment to the current definition to continue the continuous broadcast of the time scale on the transition date. The approach would capitalize on what was current: organizational and systems support structure, and timing centres coordinating their real-time realizations. A long-term continuous timescale would be achieved. Gradual divergence from solar time might be an issue in low precision "civil" timekeeping; the increasing error has been estimated as a few seconds over three years growing to one hour not before year 2600.

The SRG was now working on a transition plan to be reported to the ITU-R in October 2004. Dr Beard said that 2010 was a possible date for the transition. The President thanked Dr Beard for his contribution.

Dr Boulanger observed that some groups, such as astronomers, would have to create a new timescale. It was not clear to him why those for whom leap seconds were a problem could not use TAI.

Dr Bauch asked for clarification on what was in the transition plan. Dr Beard explained that it meant that leap seconds would be discontinued and that UT1 would be disseminated for those who required correspondence with solar time. Dr McCarthy added that the IERS provided UT1 for those who needed a timescale with correspondence to solar time.

Dr Boulanger repeated his question regarding the alternative of some groups using TAI for a timescale devoid of leap seconds. Dr Beard explained that converting to the use of TAI was a more expensive step for these users.

The President recalled that the current recipe for UTC has been in place for 30 years (having been devised by Dr Steele and himself). At that time, ninety percent of the users needed UTC for navigation. His personal opinion was that the current UTC formula should be changed.

Dr Boulanger expressed the opinion that it was wrong to change the definition of the (UTC) timescale without changing its name as it could lead to a diminution of trust.

Dr McCarthy pointed out that there was a precedent for this. The frequency steps which were once part of UTC has been dispensed with.

Dr Arias said that the word "universal" would no longer be appropriate for UTC.

Dr McCarthy recalled that the word “coordinated” was chosen to reflect the coordinated change in the different timescales, then in use in the UK and the USA, to the (new) UTC.

Dr Arias clarified her earlier point; she believed that the word “universal” was appropriate only for a timescale that was “linked” to the rotation of the Earth.

The President, reiterating that it was not for the CCTF to make decisions on this matter, offered that the name of a unit was not always ideal; an example was the kilogram – it being a multiple of another unit. He could see the value in keeping the name the same because of its familiarity.

He continued by thanking Dr Beard for his efforts in seeking the input from so many organizations.

Dr Bauch sought further clarification on the timing of the abandonment of leap seconds; would it be 2010 or 2022?

Dr Beard explained that an earlier transition than 2022 was “preferred” and that 2010 was a suggestion.

The President then introduced the letter (CCTF/04-20) from Dr Jorg Hahn of the Galileo Project Office at ESA, addressed to Prof. Leschiutta and Dr Arias with regard to this meeting. The letter informed the meeting that the Galileo Project Office was aware of the discussions on the future of leap seconds. It added that the (GNSS system) Galileo intends to follow international standards and recommendations and that the Project Office would prefer that any decision to discontinue leap seconds (together with its implementation date) be made well before the Galileo system starts to operate. (The start of full operation is planned for 2008). The President noted the assurance that the Galileo system would follow international time. The intention stated in CCTF/04-20 is to steer Galileo's System Time (GST) towards TAI and to disseminate all information with respect to UTC to the users. He added that it was not for CCTF to act on this letter; rather it was for the ITU to do so.

<u>3.4. 17th Meeting (September 2006)</u>

The President invited Dr Beard to present this report.
Dr Beard said that in 2000 the ITU formed the Special Rapporteur Group on UTC (SRG) to address issues related to the definition and uses of UTC. The SRG considered a range of issues, including:

- proliferation of ad hoc system time as time scales (e.g.: GPS Time),
- use of TAI, and
- interfacing of multiple systems with different time scales.

The SRG compiled a report for publication on the ITU website in 2006 and, having completed its tasks, was disbanded in September 2006. The SRG sent a questionnaire to

12 international bodies in 2005 to obtain information related to the impact and implementation of leap seconds. It was expected that the insertion of a leap second in December 2005 would help bring these issues into focus. Ten responses were received, of which six were from timing laboratories and two were from agencies operating satellites. There was no response from the agency responsible for the Galileo GNSS system.
Of the responses received, only three expressed satisfaction with UTC in its present form. Some agencies also reported minor problems related to GPS-driven equipment, NTP time servers and related networking equipment.

The responses from timing centres regarding the implementation of the 2005 leap second indicated few or no problems. There was, however, a lack of uniformity in how the 2005 leap second was accommodated, with some agencies reporting that this was accomplished by effectively changing the length of a second at the time of the leap second. Media interest around the leap second highlighted the confusion of the general public regarding time scales and their purposes, and it appears that the purpose and utility of UTC has become unclear. Particular issues included confusion over the relationship between UTC and UT1, and the reasons for leap seconds.

The SRG concluded that the majority of system operators are coping with the time irregularities introduced by leap seconds, but that the elimination of leap seconds from UTC would facilitate many applications requiring a continuous time reference.
ITU Working Party 7A has confirmed that any changes in the definition of UTC would have to be accepted at the World Radio Conference (WRC), and that clarifying information would be required for the briefing of WRC delegates. Working Party 7A further determined, at its 2006 meeting, that further analysis and dissemination of information would be required before a formal recommendation on the subject of leap seconds in UTC could be agreed.

The points needing to be emphasized to the WRC included:

- the proliferation of internal time scales due to a lack of a standard continuous time scale,
- UTC is the only time realized in time laboratories and disseminated with time signals, and
- TAI is the basis for UTC and provides a frequency reference.

Dr Beard said that the introduction of a new continuous time scale as an alternative to removing leap seconds from UTC would be very disruptive and confusing. Furthermore, following this path would be inconsistent with the original motivation for the introduction of UTC, which was intended to be a common time scale for broadcast coordination. Finally, on behalf of the ITU, Dr Beard asked for the assistance of the CCTF in the following tasks:

- establishing how leap seconds are accommodated,
- providing clarification of time scales, their realization and their uses,
- clarification of the dangers of ad hoc system time scales,
- clarification of the relationship between UTC and UT1 and the definition of UT1,

- determination of the impact of the radiocommunications community transitioning to another time scale, and
- reviewing standards for timing systems and their use.

The President suggested that each member of the CCTF write to Dr Beard regarding these issues, and proposed to Prof. Wallard that the BIPM should express an opinion. The President then asked about the responses from the technical unions. Dr Steele said that URSI had not yet arrived at a formal view. Dr Boucher said that he was not aware of IUGG having formed a view. Dr McCarthy said that the IAU had written to the ITU in response to the request for organizations to report their experiences with the most recent leap second. The letter said that the IAU experienced no major problems, but was concerned about the effort required to accommodate the leap second.

Dr Boulanger suggested that TAI should serve the purpose of a continuous time scale, and noted that NRC broadcasts TAI via NTP servers.

Dr Arias responded that TAI is not a disseminated time scale, it is not defined or endorsed for broadcast by the ITU, and the ITU would need to take action to change this.

Dr Beard said using TAI as a new broadcast time scale would create difficulties and instead many organizations have established their own internal time scales (e.g.: IGS uses IGS time for data collection). Significant problems would arise if the ITU abandoned UTC because UTC was originally intended to be, and is widely accepted as, the timescale for broadcast purposes.

Dr McCarthy said that USNO is planning to establish an NTP server disseminating UT1. The server will become available in January 2007.

The President pointed out that TT is another candidate for a continuous time scale, and asked Dr Petit to comment. Dr Petit said that like TAI, TT is not a disseminated time scale, and that it is not yet used by the general public.

The President proposed that the CCTF should form a view on the issue of leap seconds, and that the BIPM should write to the ITU on this subject and that the content of the letter should be developed by a working group established for this purpose. Prof. Wallard agreed with the proposal, and added that the BIPM had received a formal request from ITU for information on this issue.
The President proposed that the working group should consist of:

- Dr Arias representing the BIPM,
- Dr Boucher representing the IUGG,
- Dr McCarthy representing the IAU,
- Dr Beard representing the ITU,
- Dr Koshelyaevsky representing the laboratories contributing to TAI,
- Dr Steele representing URSI, and
- Dr Boulanger.

The President requested that the draft letter be prepared for Prof. Wallard's consideration within one month.

Dr Levine pointed out that the issue of leap seconds is mainly political, not technical, and said that this should be taken into account. Prof. Wallard responded that he was well aware of the political issues, but he believes that a letter from the BIPM addressing the technical issues is nevertheless valid and useful.

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