THE IMPROVED UTC SYSTEM TO BE INTRODUCED ON 1 JANUARY 1972

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1.1 Introduction

Following the introduction of the system of Coordinated Universal Time (UTC) the majority of time signal emissions throughout the world have operated on an atomic basis for the past ten years. However the stations participating in this system do not radiate Atomic Time (AT) but an approximation to Universal Time (UT2) achieved by applying an offset to the time signal generator. This compromise arrangement will shortly be replaced by an ' improved UTC system ' (*) in which the offset will be eliminated and the interval between successive pulses will truly represent the basic unit of time, the second of the ' Système International d'Unités ', commonly called the SI system in English. Overall agreement with astronomical time will now be maintained by step adjustments of amount exactly one second applied, when necessary, once or twice per year. These will restrict the excursion between UTC and the time scale UT1 to less than 0.7 second and the magnitude and sense of the difference (UT1 — UTC) will be indicated by means of a coded announcement radiated with the time signals.

2.1 Development of the UTC System

The first steps towards the coordination of national time and frequency broadcasts were taken in 1959 when the United States and the United Kingdom agreed to coordinate their respective emissions. The basis of the agreement was the use of caesium atomic standards to regulate the emitted signals and to maintain uniform time and frequency. However the experiments conducted in the period 1955-58 to determine the frequency of the

(*) This has been in existence since 1 January 1972.

caesium resonance in terms of the second of Ephemeris Time (ET) had shown a considerable difference between the atomic unit and the current value of the second in the UT2 time scale. It was decided, therefore, to apply an offset to the caesium reference which would bring the radiated time scale into approximate agreement with UT2. In 1960 the International Astronomical Union (IAU) recommended that the amount of the offset for each year should be announced by the ' Bureau International de l'Heure ' (BIH) after consultation with the appropriate laboratories and observatories. During the period 1961 to 1965 the offset fluctuated between the values — 130 parts in 10^{10} and — 150 parts in 10^{10}; in 1966 it was changed to — 300 parts in 10^{10} and remained at this figure up to and including 1971. In addition to the choice of offset at the beginning of each year the coordinated system contained provision for step adjustments of amount 100 ms, to be applied to the emitted signals should they depart from UT2, for any reason, by more than 100 ms. During the period 1963 to 1968 six such adjustments were made to correct an existing divergence between UTC and UT2. It is notable that only one step change, of + 100 ms, has been necessary since the offset was altered to — 300 in 10^{10} indicating that the Earth's rate of rotation has been sensibly constant during the past five years, the departure between astronomical and atomic time scales increasing at the rate of about 1 second per year.

2.2 The coordinated system now extends to the large majority of standard-frequency and time-signal stations and the operation of the system is governed by the Recommendations of Study Group 7 of the International Radio Consultative Committee (CCIR), an organ of the International Telecommunications Union. In the field of time and frequency the CCIR receives advice from the international scientific unions, the IAU and the URSI (International Union for Radio Science). In addition, the CCIR functions through national Study Groups and these provide a focus for the efforts in various countries to extend and improve the service of standard-frequency and time-signal emissions. Plenary assemblies of the CCIR are held at three-yearly intervals and those in 1963 and 1966 introduced modifications to the relevant recommendations arising from operational experience and the rapid developments in the techniques of precise time and frequency generation. At the most recent Assembly in 1970 the CCIR approved a Recommendation which gives effect to the improved UTC system on 1 January 1972.

3.1 Revision of the UTC System

The UTC system as originally conceived represented a useful compromise between the need to make available a uniform time scale (uniform, at least, over the period of a year) and simultaneously provide a time scale related to the Earth's motion. It was evident in the first few years of operation that difficulties might arise in reconciling these aims. Thus the change in offset from — 150 to — 300 in 10^{10} in 1966 had been postponed for a year because of the difficulty in accommodating existing standards to such a

large adjustment. Consequently during 1965 the relation of UTC and UT2 was maintained by means of the combination of an offset of — 150 in 10^{10} and four step adjustments, each of — 100 ms.

3.2 Other factors have contributed to dissatisfaction with the present form of coordinated system. The use of atomic frequency and time standards has greatly extended over the past decade and they now provide the essential elements in large and complex systems of navigation and position finding which operate on a world-wide scale. Such systems are dependent on precise synchronisation between remote stations and the disturbance resulting from a change in the value of the offset can no longer be accepted where the service must be maintained. The position is further complicated by the fact that the offset has remained constant since 1966 and this may have lulled the user into a false sense of security and led to the acceptance of offset frequency and time as invariant quantities. There is the related difficulty that although the atomic definition of the SI second was confirmed by the 13th General Conference of Weights and Measures in 1967 this basic interval of time is not made available directly by any of the coordinated stations. In addition to the more technical considerations there remains the very considerable logical difficulty in supporting a system in which the internationally accepted unit of time, which can be realised with an uncertainty of 1 in 10^{12}, is intentionally offset by several parts in 10^8 to agree with an inconstant astronomical interval.

3.3 One of the earliest meetings which gave consideration to an alternative UTC system was called by URSI in 1967 to discuss coordination of standard-frequency and time services in the European area. It recommended the future operation should be on a strictly atomic basis without frequency offset or step adjustments. If that were not possible immediately then steps of amount 1-second should be used to maintain conformity with UT2. In the following year, at its Interim Meeting in Boulder, Colorado, CCIR Study Group 7 set up an International Working Party to consider the implications of the non-offset system combined with 1 s step adjustments. After wide consultations and as a result of the generally favourable response of administrations and organisations it was possible for the Working Party to recommend the adoption, in principle, of such a system as from 1 January 1972. Consequently at its 12th Plenary Assembly the CCIR approved Recommendation 460 (see Appendix I) in which the principal features of the new system are embodied.

3.4 The International Working Party under its chairman, Mr. Humphry SMITH of the Royal Greenwich Observatory, engaged in a further round of consultation to determine the detailed form in which the new system of UTC should take. The same topic was also considered by the IAU at its 14th General Assembly in 1970. As a result of these preliminary exchanges and discussions broad agreement was obtained on the following points.

(a) The deviation between emitted signals and the astronomical time scale UT1 should not exceed ± 0.7 s.

(b) The magnitude of the step adjustment would be exactly 1 s.

(c) Step adjustments would be made, when necessary, at fixed dates spaced six months apart, the BIH to be responsible for promulgating the changes.
(d) The accuracy required in the relation to UT1 was 0.1 s.

In addition the IAU gave consideration to a number of detailed questions particularly the designation of events in the vicinity of a step change and the nomenclature to be adopted for the improved system.

3.5 The definitive discussions on the implementation of the UTC system took place at the Interim Meeting of Study Group 7 in Geneva in February 1971. The full operational specification of the new UTC system is contained in Report 517, attached as Appendix II, and represents the agreement reached by the 12 countries participating in the Geneva meeting.

4.1 The Improved UTC System

As has been indicated Study Group 7, when it met, had the benefit of previous discussion and consultation at both national and international level. However several matters of substance remained to be decided at Geneva. Of these perhaps the most important were the form of the coded announcement giving the time difference between the radiated signal and the astronomical reference, the incidence of step adjustments, and questions of nomenclature.

4.1.1 Code Announcement

It was a condition of acceptance of a non-offset system by navigators and surveyors that, as indicated in paragraph 3 of Recommendation 460, the information giving the difference (UT — signal) should be radiated in the form of a simple code along with the time signals. There was early agreement that UT1 should be the astronomical reference but it was only after considerable discussion that a generally acceptable system of coding was evolved. This is described in Annex I to Report 460. As will be seen it gives the difference DUT1 where :

$$\mathrm{DUT1} = \mathrm{UT1} - \mathrm{UTC}$$

and the value is restricted to integral multiples of 0.1 s. Capital 'D' was chosen to denote the difference in preference to the more usual Greek 'Δ' for ease of transmission by telegram or Telex.

4.1.2 In agreement with the earlier concepts the interpretation of the code requires no additional instrumentation. The magnitude of the difference is obtained by counting the number of emphasised seconds markers, up to a maximum of seven (see Annex II, fig. 3). The sign depends on their relation to the minute marker, being positive when the emphasised pulses coincide with seconds markers 1 to 7 and negative when they fall on seconds markers 9 to 15. The absence of emphasised signals denotes a zero value for

the difference DUT1. It is an advantage of the agreed system that the coding is confined to the first 15 seconds in each minute and, moreover, it need not interfere with the normal processes of time signal reception and measurement.

4.1.3 Any suitable means may be chosen of emphasising the appropriate seconds markers. In the case of the U. K. emissions of GBR and MSF it is intended to transmit double pulses for emphasised markers, the first pulse being a normal seconds pulse and the second a delayed version of the first separated from it by 100 ms. The necessary code generators have now been constructed and test transmissions will begin in August 1972.

4.2.1 Nomenclature

The name Coordinated Universal Time and the abbreviation UTC have been retained for the non-offset system. Although alternative names were suggested it was the majority opinion that there would be less possibility of confusion if the former description were continued. There will be a large change in rate between the UTC of 1971 and the UTC of 1972, amounting to 2.59 ms/day, but this will be very soon apparent to users equipped with a precise time reference.

4.3.1 Leap Seconds

A new concept which has been introduced is the leap second, considered positive when it is a second additional to, and negative when it is omitted from, an otherwise uniform atomic time scale. There is, of course, a close correspondence between the positive leap second and the leap or intercalary day which is introduced periodically to maintain the Gregorian calendar in agreement with the tropical year. A leap second will be inserted or omitted as required on 31 December and/or 30 June. A positive leap interval will begin at 23 h 59 m 60 s delaying the start of the following day by 1 second : a negative leap second will begin at 23 h 59 m 58 s and will advance the start of the following day by 1 second. Thus in the neighbourhood of a leap second there will be leap minute with 61 (or 59) seconds and conventions have been agreed for the designation of events in this interval. Examples are given in Annex I to Report 517.

4.3.2 The incidence of leap seconds will be announced by the BIH at least eight weeks in advance of the proposed adjustment but it should also be clear from the general trend of the difference (UT1 — UTC) when such changes will be necessary. The possible course of the change in the difference during 1972 is shown in figure 1 on the assumption that there is no major alteration in the Earth's present rate of rotation. A special adjustment will be made on 1 January 1972 to set the zero of the UTC scale in agreement with a time of 0 h 0 m 10 s on the AT scale of the BIH. On this

date, if the present trend continues, the value of (UT1 — UTC) will be in the region of + 50 ms. Starting from this figure the differences will follow the heavy line and it is evident that the introduction of a positive leap second will become necessary on 30 June if the allowable limits to the time difference are not to be exceeded. A leap second of the appropriate sign can always be applied when the difference (UTC — UT1) falls within the shaded regions in figure 1 and no difficulty will arise in making the change on 30 June.

4.3.3 The code announcement will naturally record the change in the difference following a leap second and this information will be radiated by all primary time signal stations. However, there are many secondary sources of time signals (e.g. general broadcast services) which have no provision for dissemination of the code and it will be important in each country to devise suitable safeguards to ensure that such stations and indeed any other source of precise time, such as the telephone system, adjust their reference clocks to be in agreement with a primary time standard.

4.4.1 Positional Tolerance

The limits of ± 0.7 s on the departure between UT1 and UTC correspond to a variation in equivalent longitude of ± 10 seconds of arc. Changes of this magnitude are not significant for general navigation at sea and will be largely ignored by the navigator. However they are important in precise topographic or hydrographic survey work where it is desired to carry out some on-site reduction of the observations and the reception and interpretation of the coded difference will enable the longitude as derived from UTC to be corrected to better than 2 seconds of arc. This should be adequate for all immediate purposes in the field.

5.1 Conclusions

The revised UTC system has been designed to provide a uniform time reference for general scientific use combined with the dissemination of UT1 for those observations necessarily made from the Earth's rotating frame of reference. The success of the system will depend to some extent on the unpredictable variations in the Earth's rate of rotation but the provision for two leap seconds in each year should accommodate all the changes in rate which have been recorded over the past 150 years. When sufficient experience has been gained with the improved system it may be possible to relax further the limits on the difference (UT1 — UTC) and ultimately consider the possibility of an atomic time scale without step adjustments. However progress in this direction will depend on achieving a greater understanding of the causes of the variations in the Earth's motion and in particular acquiring the ability to predict changes in the rate of rotation at least a year in advance.

APPENDIX I

RECOMMENDATION 460

Standard-frequency and time-signal emissions

The CCIR,

Considering

(a) the desirability of eliminating all offsets from nominal values in the carrier frequencies and in the time signals;

(b) the desirability of disseminating on a world-wide basis precise time intervals in conformity with the definition of the second (SI), as adopted by the 13th General Conference of Weights and Measures (1967);

(c) the continuing need of many users for Universal Time (UT).

Unanimously recommends

1. that, from a specified date, carrier frequencies and time intervals should be maintained constant and should correspond to the adopted definition of the second;
2. that the transmitted time scale should be adjusted when necessary in steps of exactly one second to maintain approximate agreement with Universal Time (UT);
3. that the standard-frequency and time-signal emissions should contain information on the difference between the time signals and Universal Time (UT);
4. that detailed instructions on the implementation of this Recommendation be adopted by Study Group 7 after consideration of the report of Interim Working Party 7/1;
5. that the standard-frequency and time-signal emissions should conform to paragraphs 1, 2, 3 and 4 above from 1 January 1972, 0000 h UT;
6. that this document be transmitted by the Director CCIR to all Administrations Members of the ITU, to the Scientific Unions (IAU, IUGG, URSI, IUPAP), and other organizations such as BIH, CIPM, ICAO and IMCO.

APPENDIX II

REPORT 517

Standard-frequency and time-signal emissions

Detailed instructions by Study Group 7 for the implementation of Recommendation 460 concerning the improved Coordinated Universal Time (UTC) System, valid from 1 January 1972.

1. The XIIth Plenary Assembly of the CCIR adopted unanimously Recommendation 460. According to paragraph 4 of this recommendation, Study Group 7 was entrusted with the task of formulating the detailed instructions for its implementation on 1 January 1972.

Study Group 7 met from 17 - 23 February 1971 and adopted the following text for this purpose.

2.1 A special adjustment to the standard-frequency and time-signal emissions should be made at the end of 1971 so that the reading of the UTC scale will be 1 January 1972, 0 h 0 m 0 s at the instant when the reading of Atomic Time (AT) indicated by the Bureau International de l'Heure (BIH) will be 1 January 1972, 0 h 0 m 10 s. The necessary adjustments to emissions which are in accordance with Recommendation 374-2 will be specified and announced in advance by the BIH.

2.2 The departure of UTC from UT1 should not normally exeed 0.7 s (*).

2.3 Inserted seconds should be called positive leap seconds and omitted seconds should be called negative leap seconds.

2.4 A positive or negative leap second, when required, should be the last second of a UTC month, preferably 31 December and/or 30 June. A positive leap second begins at 23 h 59 m 60 s and ends at 0 h 0 m 0 s of the first day of the following month. In the case of a negative leap second 23 h 59 m 58 s will be followed one second later by 0 h 0 m 0 s of the first day of the following month (See Annex I).

(*) Universal Time.

In applications in which errors of a few hundredths of a second cannot be tolerated, it is necessary to specify the form of Universal Time (UT), referred to in Recommendation 460, which should be used.

UT1 is a form of UT in which corrections have been applied for the effects of small movements of the Earth relative to the axis of rotation.

UT2 is UT1 corrected for the effects of a small seasonal change in the rate of rotation of the Earth.

UT1 corresponds directly with the angular position of the Earth around its axis of rotation, and is used in this document. GMT may be regarded as the general equivalent of UT1.

2.5 The BIH should decide upon and announce the occurrence of a leap second; such an announcement is to be made at least eight weeks in advance.

2.6 The time signals of standard-frequency and time-signal emissions should be kept as close to UTC as possible, with a maximum deviation of one millisecond.

3.1 The approximate value of the difference UT1 minus UTC, as disseminated with the time signals should be denoted DUT1, where DUT1 $\approx$ UT1 — UTC.

DUT1 may be regarded as a correction to be added to UTC to obtain an approximation of UT1.

3.2 The values of DUT1 should be given in integral multiples of 0.1 s. The BIH is requested to determine and to circulate one month in advance the value of DUT1. Administrations and organizations should use the BIH value of DUT1 for standard-frequency and time-signal emissions whenever possible, and are requested to circulate the information as widely as possible in periodicals, bulletins, etc.

3.3 Where DUT1 is disseminated by code, the code should be in accordance with the following principles :

— the magnitude of DUT1 is specified by the number of emphasized seconds markers and the sign of DUT1 is specified by the position of the emphasized seconds markers with respect to the minute marker. The absence of emphasized markers indicates DUT1 = 0;

— the coded information should be emitted after each identified minute.

Full details of the code are given in Annex II.

3.4 Alternatively DUT1 may be given by voice announcement or in morse code.

3.5 In addition, UT1 — UTC may be given to the same or higher precision by other means, for example, in morse or voice announcements, by messages associated with maritime bulletins, weather forecasts, etc.; announcements of forthcoming leap seconds may also be made by these methods.

3.6 The BIH is requested to continue to publish in arrears definitive values of the difference UT1 — UTC, UT2 — UTC and AT(BIH) — UTC.

Extract from

ANNEX I

Dating of events in the vicinity of a leap second

. . . . . .

The dating of events in the vicinity of a leap second shall be effected in the manner indicated in the following figures :

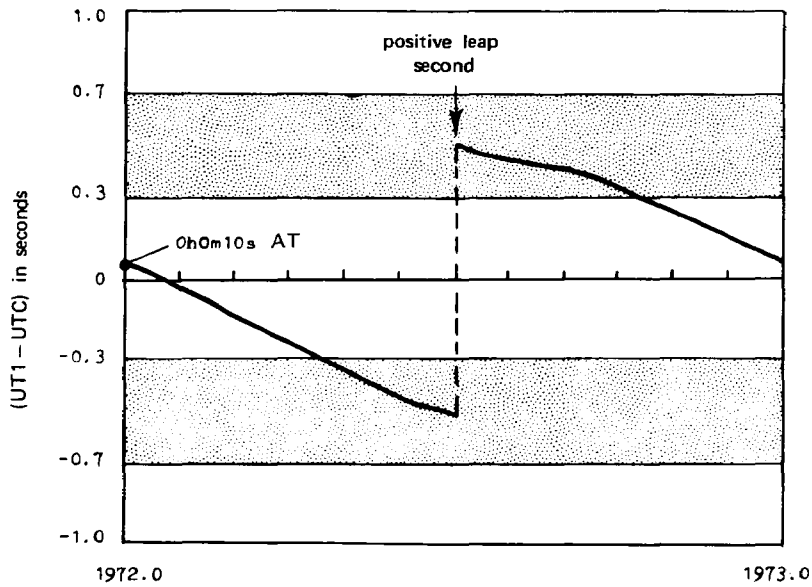

FIG. 1. — Suggested variation in the difference (UT1 — UTC) during 1972.

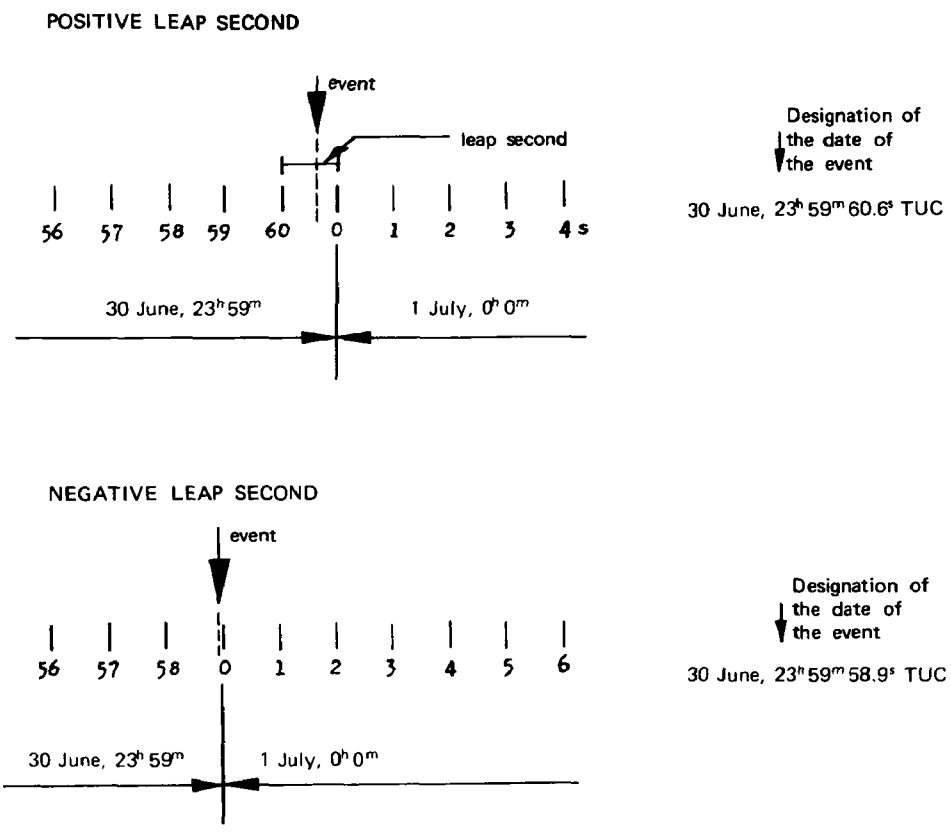

FIG. 2

ANNEX II

Code for the transmission of DUT1

A positive value of DUT1 will be indicated by emphasizing a number (n) of consecutive seconds markers following the minute marker from seconds markers one to seconds marker (n) inclusive; (n) being an integer from 1 to 7 inclusive.

$$\text{DUT1} = (n \times 0.1)\ \text{s}$$

A negative value of DUT1 will be indicated by emphasizing a number (m) of consecutive seconds markers following the minute marker from seconds marker nine to seconds marker (8 + m) inclusive; (m) being an integer from 1 to 7 inclusive.

$$\text{DUT1} = -(m \times 0.1)\ \text{s}$$

A zero value of DUT1 will be indicated by the absence of emphasized seconds markers.

The appropriate seconds markers may be emphasized, for example, by lengthening, doubling, splitting, or tone modulation of the normal seconds markers.

EXAMPLES

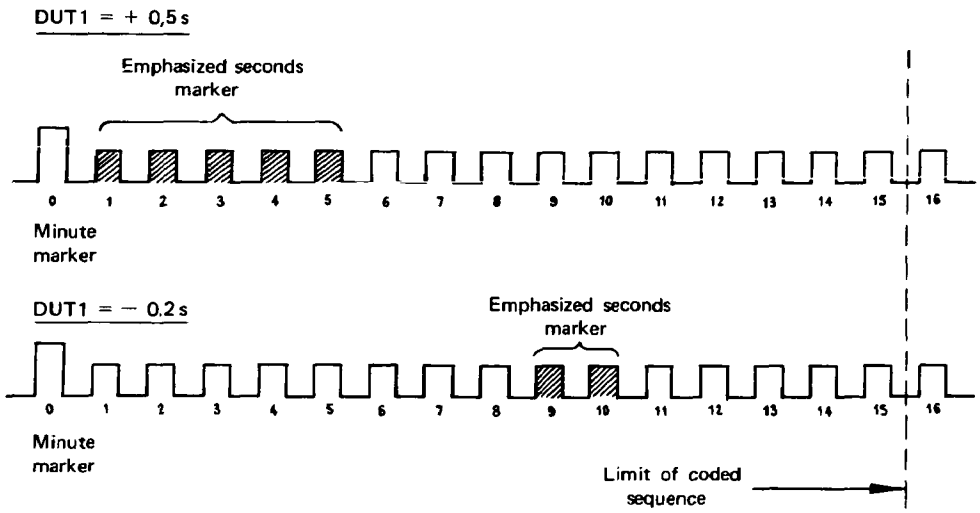

FIG. 3