AN OPINION ON RADIO TIME SIGNALS

by Dr. Akira M. SINZI,
Hydrographic Department of Japan

SUMMARY

Due to the irregularity of the Earth's speed of rotation, the rate of UT (*) (GMT) is not uniform. The unit of time by which frequencies are measured is formally defined as 1 atomic second. The current system of radio time signals in the UTC (**) scale is a result of compromise since it attempts to meet the requirements of users of UT as well as of frequencies. The rate of UTC is based strictly on the atomic time scale, and an instant expressed in UTC is an approximation of UT for various purposes in navigation and civil life. It is specified that the departure of UTC from UT shall normally be restricted to a maximum of 0.7 sec. In order to keep within this limit, one "leap" second can if necessary be introduced once or twice a year, preferably at the end of June and/or December.

For navigation a departure of less than 1 sec between UTC and UT1 (***) can be tolerated in most cases.

On the other hand, UTC, which is an approximation to UT, can scarcely be used in surveying, even if the disseminated coded correction DUT1 is applied. Moreover, in surveying UT is not required at the actual moment of observation. In 1973 the International Astronomical Union (IAU) adopted a recommendation that the current UTC system be amended to increase the maximum tolerance limit to 0.950 sec, with the possibility of introducing a leap second in March and/or September besides June and/or December.

In a questionnaire on the UTC time signals about 50 % of navigators responding supported a maximum limit for UT1 - UTC of less than 1 sec, 30 % advocated larger values, and 20 % would have preferred a smaller limit.

Since the time system — which is at the very basis of all human activity — should be both simple and logical, I have considered it worthwhile to investigate the possibility of the introduction of International Atomic Time for all general uses in place of UTC.

(*) Universal Time.
(**) Coordinated Universal time.
(***) Universal Time corrected for polar motion.

PREFACE

Many human activities — not only in the domains of science and of engineering but also in ordinary daily life — are dependent on the time signals emitted by radio, usually on the carrier waves of the standard broadcast frequencies. These radio time signals are especially indispensable for navigation and surveying. The time system must be both basically simple and scientifically logical. Compromise should be avoided so far as possible. All time signals are at present emitted in the UTC system, with the exception of the Shanghai signal. The present system of time dissemination is, however, a compromise, since the standard broadcasts have two functions : to provide the frequency standard and also the time epoch.

At the IAU's 15th General Assembly held in Sydney in 1973, Commission 31 (Time) and Commission 4 (Ephemeris) met jointly to amend the UTC specification. After much discussion the following resolution was adopted and subsequently endorsed by the General Assembly.

The IAU, *considering :*

(a) that present procedures governing the insertion of leap seconds have been variously interpreted and,

(b) that if the present trend of the rotation of the earth continues it will become impossible to maintain UTC within the present limits by the insertion of leap seconds on two preferred dates only, and

(c) that it is important for many users to have UT1 minus UTC remain within a *fixed* limit;

recommend :

(1) that the *maximum* limit of UT1 minus UTC be set at ± 0.950 second,

(2) that the maximum deviation of UT1 from UTC plus DUT1 be ± 0.100 s,

(3) that, when necessary, leap seconds may be introduced at the end of any month, but that first preference be given to the end of June and December, and the second preference be given to the end of March and September.

This resolution is being forwarded to the International Radio Consultative Committee (CCIR) for consideration at its 13th Plenary Assembly in 1974 so that a new specification for dissemination of UTC may be adopted.

The text of Part II and a fuller version of the Questionnaire analysis were originally presented to the 15th General Assembly of the IAU and may thus be regarded as a background paper to the above resolution. Part I expounds the problem briefly and Part II has now been rewritten to take account of the discussions and resolution of the above meeting. The Annex summarises the answers to the questionnaire sent out to ocean-going vessels.

PART I

TIME SYSTEMS AND TIME SIGNALS

1) Universal Time, Ephemeris Time and Atomic Time.

There are three basic time systems : Universal Time, Ephemeris Time, and Atomic Time. The first two essentially provide chronological epochs of time, whilst the third provides intervals of time.

Universal Time (UT), popularly called Greenwich Mean Time, was originally defined as the "Greenwich hour angle of the mean sun + 12 h", and directly reflects the Earth's diurnal rotation. Due to secular deceleration, seasonal changes, and irregular variations in the speed of the Earth's rotation, the rate of UT is not uniform and has recently retarded by over 1 sec per year (see figure 1).

There are three kinds of UT. UTO is the raw value of UT obtained at a national observatory directly from observations of fixed stars whose position in relation to the mean sun is accurately known by means of a transit circle, photographic zenith tube or astrolabe. UT1 is obtained by applying the correction $\Delta\lambda$ to UTO. $\Delta\lambda$ is a longitudinal displacement due

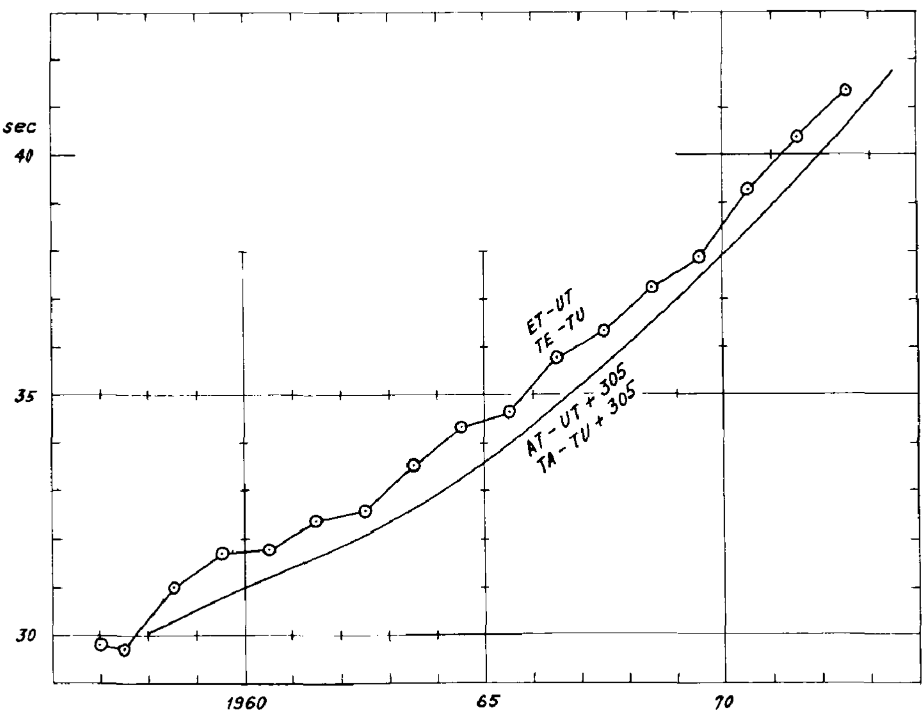

Fig. 1. — ET-UT and AT-UT.

ET-UT : Obtained from photoelectric observation of occultations made by the Japanese Hydrographic Department.

AT-UT : Determined by the Bureau International de l'Heure.

to the movement of the Earth's axis of rotation with respect to the Earth's mass (the polar motion). UT2 is obtained by applying to UT1 a further correction, ΔS, which compensates for the annual and semi-annual changes in the Earth's speed of rotation and is expressed as an empirical formula (seasonal variation).

UT1 indicates the actual state of the Earth's rotation, and hence should be used for calculating the hour angle of a heavenly body. The term GMT when used in navigation and surveying should be understood to mean UT1. UT2 takes into account the effect of seasonal changes in the Earth's rotation in order to make the rate of UT more uniform. It is clear that the UT time interval cannot be used to define a unit of time, i.e. a period, and thus cannot be used as the base for a frequency standard.

In 1956, the General Conference of Weights and Measures (CGPM) adopted a resolution to define the unit "an interval of 1 sec" by reference to Ephemeris Time (ET) instead of to UT. ET is defined by reference to the revolutional motion of the Earth around the Sun. Thus, theoretically, ET is a dynamic time system and is the independent variable t in the equation of motion in Newtonian mechanics. In practice, ET is determined by comparison of the Moon's observed positions with the positions shown in the Ephemeris under the time argument ET, the Earth's motion around the Sun and the Moon's motion around the Earth being governed by the same law of celestial mechanics.

It is of interest that among the classic navigational methods the method of lunar distance needs ET whilst the longitude by chronometer method and the so-called "new navigation" (i.e. post Marcq St. Hilaire) employ UT.

Further, in 1967 the CGPM adopted a new definition for the time unit, the SI (Système International) second : the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium atom 133. With a time epoch as reference origin, it was possible to construct an Atomic Time (AT) system on the basis of accumulated SI seconds. The current reference origin of AT was UT2 at 00 h 00 m 00 s on 1 January 1958.

The Bureau International de l'Heure (BIH) in Paris is charged with the task of setting up the International Atomic Time (TAI) system by a comparison of the various local ATs kept by a frequency standard (i.e. by atomic clocks) in laboratories throughout the world. It should be noted that Loran C and Omega provide important means for making accurate comparisons between the various local AT. The U.S. Naval Observatory in Washington, D.C., keeps yet another scale, designated A.1. Emissions of Loran C, NNSS (*) and Omega systems are accurately synchronized with A.1. In 1972 and 1973 the difference TAI minus A.1 was — 0.03440 sec.

2) Coordinated Universal Time (UTC).

In order that standard radio broadcasts may supply both frequency standards and UT there are two possibilities, both compromises. The

(*) Navy Navigation Satellite System.

emission frequencies could be adjusted according to the actual rate of the Earth's rotation : this procedure is termed a *frequency offset.* Alternatively, the approximate time in UT could be disseminated in the AT time scale; when divergence from UT becomes significant, the time origin must be shifted : this procedure is called a *step adjustment.* The time system in which a frequency offset and/or a step adjustment is applied is called Coordinated Universal Time (UTC).

The specifications for time signal dissemination are the responsibility of the ITUs International Radio Consultative Committee (CCIR) who take into consideration the opinions of scientific unions, especially those of the IAU and the International Union of Radio Sciences (URSI).

Until the end of 1971 these two methods were used in conjunction to maintain UTC. The frequency offsets were maintained constant throughout one calendar year at least, and step adjustments were made in order that the difference UT2 — UTC should remain smaller than 0.1 sec. However, both physicists and engineers protested at the inconveniences of the frequency offset, whilst many users — particularly navigators and surveyors — requested continued dissemination of the UT signals.

Then in 1970 the CCIR adopted Recommendation 460 (*) to amend the UTC system as from the beginning of 1972 by discontinuing the frequency offset and by making a step adjustment of exactly 1 sec in UTC in order to maintain approximate agreement with UT. Detailed instructions on the implementation of this Recommendation were given in Report 517 (**) drafted by the Interim Working Party 7/1 of Study Group 7, CCIR.

The main features of this new UTC system are that : (1) the difference between UTC and TAI is kept to integral multiples of a second; (2) the departure of UTC from UT1 should not normally exceed 0.7 sec; (3) in UTC the step adjustment, i. e. the insertion or omission of 1 sec — called a *leap second* — is made at the very end of a month, preferably 31 December and/or 30 June; and (4) the approximate value of the difference UT1 minus UTC, given in integral multiples of 0.1 sec, is denoted DUT1 and will be disseminated with the time signals by either emphasized seconds markers, voice announcement or morse code. Annex 1 to Report 517 indicates the method for dating of events in the vicinity of a leap second, and Annex 2 specifies the CCIR code to emphasize the seconds markers for DUT1.

In this connection the Bureau International de l'Heure was charged with : (1) deciding and promulgating at least 8 weeks in advance the date when a leap second is to be introduced; (2) determining the value of DUT1 and disseminating it one month in advance; and (3) publishing in arrears definitive values for the differences UT1 - UTC, UT2 - UTC and TAI - UTC.

The CCIR transmitted its Recommendation 460 and Report 517 to IMCO (MSC XXIII/18/2Add. 1), and at its 24th Session in September 1971 the IMCO Maritime Safety Committee concluded that the new system of UTC time signals would not cause any difficulties in navigation and that Member Governments could accordingly issue the necessary Notices to Mariners (MSC XXIV/19, Paragraph 90 : Time signal emissions for shipping).

(*) Reprinted in the *International Hydrographic Review*, July 1972, page 143.
(**) *Ibid.*, pages 144-145.

The emissions in the Loran C, NNSS, and Omega systems cannot be adjusted to take automatic account of the introduction of a leap second. However, the emission times of all 8 Omega stations will be shifted by exactly 1 second of theoretic UTC whenever a leap second is introduced.

3. Present status of UTC dissemination.

At present the time signals for the UTC system are emitted by more than 40 stations throughout the world. In about half these cases the signals are on carrier waves of standard frequencies whose accuracies vary between 0.1 and 1×10^{-10}. Errors in the time signals themselves are in most cases of under 0.0002 sec. Since the new UTC system was put into operation three leap seconds have been inserted : on 30 June 1972, 31 December 1972, and 31 December 1973. DUT1 is usually disseminated in the CCIR code. However, some of the time signals originating in the U.S.A., France and Australia disseminate DUT1 in morse code. In Russia and East Germany the signals disseminate DUT1 + dUT1 down to integral multiples of 0.02 second.

The Bureau International de l'Heure issues each month its *Circular D* which publishes : (1) the values for UT1 - UTC, UT2 - UTC, UT1 - TAI

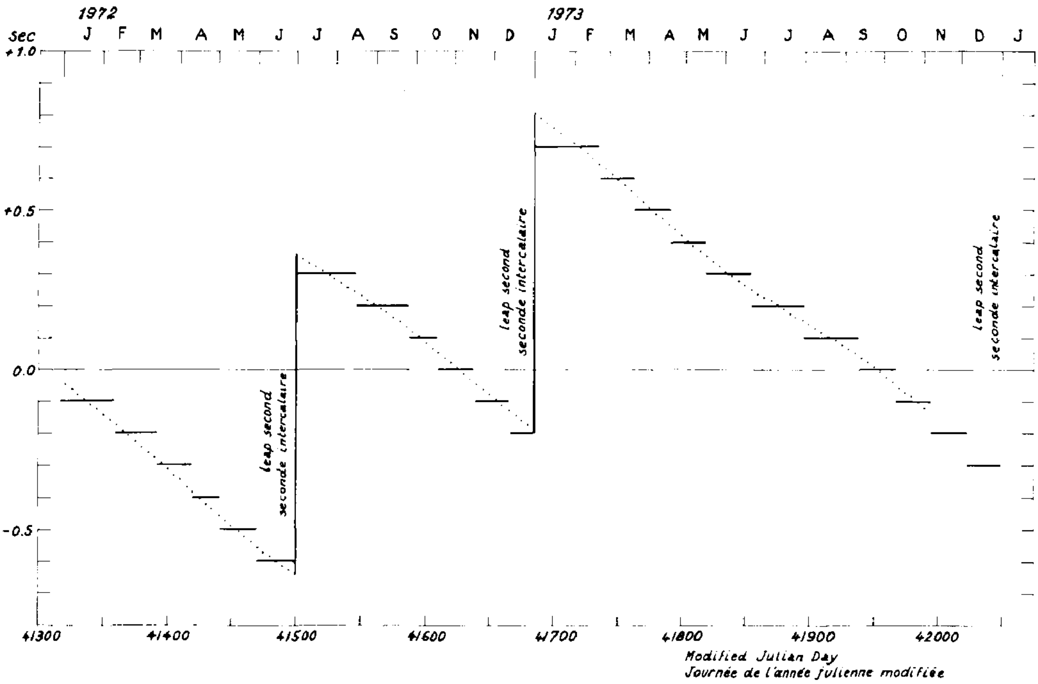

FIG. 2. — UT1-UTC in the years 1972 and 1973.
Dots : Smoothed values of UT1-UTC (Bureau International de l'Heure).
Horizontal Steps : DUT1.

and the x, y coordinates of the Earth's pole for every fifth day of the past two months; (2) the times of the time-signal emissions; (3) the difference between the values of local UTCs and that of the BIH; (4) the difference between the value of local ATs and TAI; and (5) any other information regarding time signals. The values for UT1 - UTC and the x, y coordinates are essential for all latitude and longitude calculations by astronomic observations. Predictions of UT1 - UTC are to be found in a leaflet entitled *Preliminary Times and Coordinates of the Pole, Series 7,* published weekly by the U.S. Naval Observatory: The leaflet also contains information regarding A.1, UTC (USNO), and the schedule for dissemination of DUT1.

The British "Notices to Mariners" give the dates for introduction of any leap seconds and the date and value of DUT1 in the form of corrections to the Admiralty List of Radio Signals, Volume V. Similar advance information is promulgated in other countries' Notices to Mariners.

The trends of UT1 - UTC and DUT1 in 1972 and 1973 are shown in figure 2. At the beginning of 1973 the deviation between UT1 and UTC exceeded 0.8 second, and was thus more than the normal limit specified in CCIR Report 517. Discussions regarding the necessity to amend the current UTC specifications were thus opened.

PART II

THE TOLERANCE LIMIT FOR UT1 - UTC

The crux of the UTC system problem is the extent to which its departure from UT1 may be tolerated. All considerations should therefore be made from the standpoint of users of UT1. As was frequently stated in the discussions on the UTC specifications navigators and surveyors are direct users of UT1; they make use of the Earth's rotation rate when determining the exact position of an observation site.

The various uses of UT in navigation and surveying are here considered in order to investigate the tolerance limit for UT1 - UTC. The IAU resolution is next explained, and finally a proposal is made regarding a possible time system for the future.

1) Navigation and UT.

Celestial navigation is still widely employed, notwithstanding the development of electronic and satellite navigation systems. It is difficult to assign any specific value for the accuracy of position fixing by celestial navigation. Some may require an accuracy of 1 nautical mile or better, although an error of 3-5 n. miles is tolerated in many cases. We may therefore not be far wrong in saying that in practice this accuracy is ± 2 n. miles in most cases. An accuracy of better than 1 n. mile cannot generally be expected in celestial navigation which, moreover, is never employed in coastal areas. It should be noted that the higher accuracy of one n. mile would be required by small fishing vessels when they are seeking their fishing grounds, whereas merchant ships do not generally require high accuracy in ocean navigation by celestial means. Other domains where highly accurate position fixing is required are hydrographic surveying, scientific research, rescue work, and military operations.

Some professional astronomers and radio engineers may not know how navigators actually record the time of their celestial observations. Generally, as an observer takes a sight he calls out or blows a whistle, and the recorder reads the chronometer dial at that instant; or the observer looks at the deck watch in his hand and subtracts a constant (the personal equation), for example 1 sec, from the deck watch reading; or else he walks to the bridge, reads the chronometer dial and subtracts a larger constant, generally a multiple of 1 sec.

Besides the error in the recording of time, there are many other sources of error in position fixing by celestial navigation, such as errors in altitude measurements, rounding off errors in the sight reduction, and errors in plotting. The final accuracy in celestial navigation is naturally affected by the accumulation of these errors. Hence, if we assume that ordinarily the accuracy of celestial navigation is $\pm$ 2 n. miles we must not then tolerate an error of 2 n. miles for each such source of error. In the case of timing, it would for instance be dangerous to tolerate an error of 8 sec (corresponding to 2 n. miles on the equator). A considerably higher accuracy is desirable. Considering all these cases, an accuracy of about 1 sec may finally be appropriate for timing, though the present limit of UT1 - UTC $<$ 0.7 sec was in fact adopted on the basis of the opinion reigning when it was advocated as the accuracy required for celestial navigation. In time signals, any departure of 1 sec or more from UT is inappropriate from the psychological point of view since it may undermine confidence in the time signals. We may therefore conclude that it is desirable that the departure of UTC from UT1 be kept within the limits of *less than 1 sec.* An error of 1 sec in time will shift the position line for a celestial sight by 0.25 cos (lat) n. miles eastward or westward, and thus the fix itself will also be displaced 0.25 cos (lat) n. miles along the parallel of latitude, the maximum error being 0.25 n. miles on the equator. This is a far smaller error than any inaccuracy in celestial navigation.

It is, however, anticipated that in the near future celestial observations of very high accuracy will become possible due to improved gyro-stabilizers.

Air navigation demands less accuracy of UT1 than surface ships because of the faster pace of jet planes. Future air navigation systems will require highly accurate time synchronization (see FEHLNER and MCCARTY, 1973), but such synchronization would be on UTC or TAI rather than on UT1.

2. Surveying and UT.

The determination of latitude and longitude by the observation of celestial bodies is a method not so frequently employed in surveying as in navigation. Today, most surveys are geodetic surveys carried out by electronic methods. Astronomical data are, however, used for the Laplace adjustment of geodetic nets.

For most astronomic surveys the UTC time signals do not provide sufficiently accurate time even when the DUT1 correction is applied. Astronomic observations are frequently used for azimuth determination and an accuracy of 1 sec in time is generally sufficient for this purpose.

It should be noted that usually surveyors do not need to calculate latitude and longitude immediately after taking their observations at the surveying station. In other words, the UT1 value is not required at the actual time of the observation. Surveyors should thus use UTC to record the time of observation since their reductions cannot be made until such time as the definitive values of UT1 — UTC are announced by either the national observatories or the BIH. Polar coordinate data are also needed for this computation.

Astronomic surveys are generally carried out by governmental mapping agencies or geodetic or geophysical institutes, or by private surveying companies. Surveyors employed by these organizations will have obtained the necessary information on both the time system and the time signals. Hence they are never likely to confuse the UTC time signals with those of UT1.

Amateur astronomers use UTC time when signals observing the various astronomical phenomena for which the almanac predictions are given in UT. Professional astronomers have a responsibility towards their amateur counterparts in the matter of instructing them about the UTC system.

3) Amendment of the UTC system.

As already related, amendment of the UTC specification was recommended at the 15th General Assembly of the IAU. The limit for the departure of UTC from UT1 was altered from the current value of 0.7 sec. to 0.950 sec. If the limit had been set at 1.00 sec the DUT1 value would be + (or —) 10 ($= 1^s/0.1^s$) if UT1 — UTC were between 0.95 and 1.00 sec. We should thus always reserve two digits for the DUT1 coding. The limit 0.950 sec was thus recommended in order to avoid an increase in the number of digits for DUT1. From a technical point of view the new limit for UT1 — UTC is preferable to $<$ 1.0 sec.

In the current system a leap second may be introduced at the end of any month, preference being given to the months of June and/or December. The new IAU recommendation adds March and September as a second possibility. The frequency with which a leap second has to be introduced is closely connected with the limit of UT1 — UTC, both being bound to the speed of Earth's rotation. This relation was pointed out by Iijima (1973) and Morrison (1973 b). Morrison gives the following formula :

$$A \leqslant N\,(2L - 1)$$

where A (sec/year) is the rate of increase of TAI — UT1, N the number of leap second insertions per year, and L (sec) is the tolerance limit for UT1 — UTC. Some examples are shown in the following table.

	Current system	Recommended system 1st preference	Recommended system 2nd preference
L (sec)	0.7	0.950	0.950
N (per year)	2	2	4
A (sec/year)	0.8	1.8	3.6

As seen in figure 1, the rate of TAI — UT1 for the period is increasing — in other words the earth's rotation is becoming slower (for example, by about 1.21 sec in 1972. This is why at the beginning of 1973 UT1 — UTC exceeded | 0.8 sec. For the period before the introduction of AT we can only infer the rate of TAI — UT1 from the trend of ET — UT since originally the AT second was determined as being equal to the ET second. Figure 3 (IIJIMA, 1973 — figure 3) shows the yearly changes in ET — UT. The curve in this figure is a sort of time derivative of the curve ET — UT in figure 1. The actual difference in rate between AT and ET has not been definitely confirmed. If it exists its magnitude would be of an order of less than 10^{-9}, or 0.03 sec per year (MORRISON 1973 a).

Although the trend of TAI — UT1 is not predictable, as can be inferred from figure 3, it seems that the rate for TAI — UT1 is likely to remain within 1.8 sec per year in the near future. We should, however provide for cases of an abrupt change in the rate within a few weeks (MORRISON 1973 b). The IAU recommendation thus specifies dates for the introduction of leap seconds.

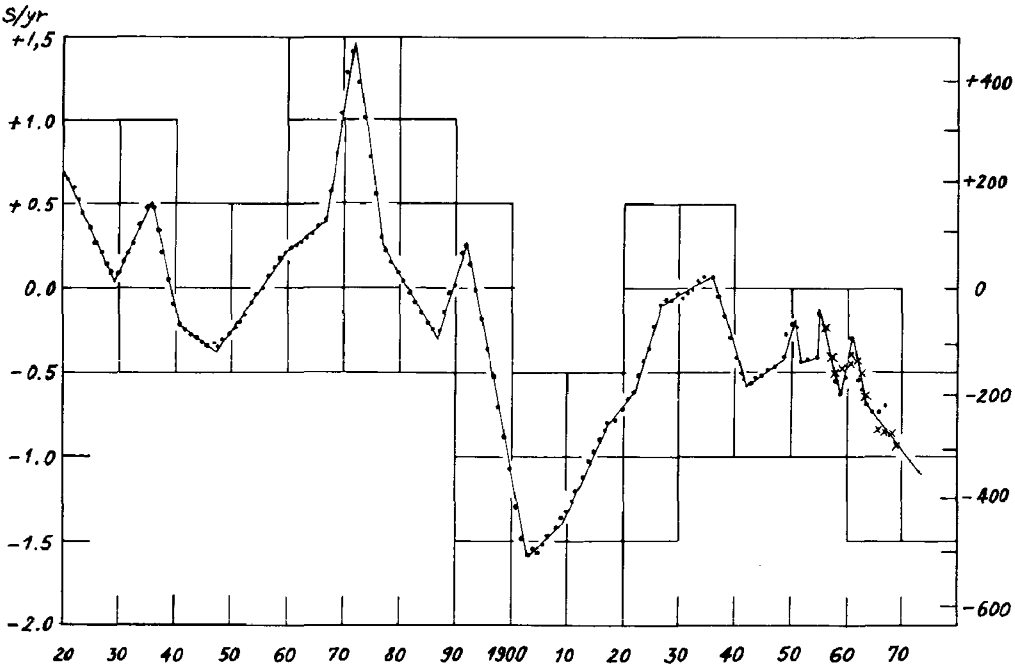

Fig. 3. — Rate of divergence of UT from ET. (IIJIMA, 1973).

4) A time system for the future.

It now seems worthwhile to reconsider the UTC system to see whether it is really appropriate as the basis for standard time, and to investigate the possibility of the introduction of TAI as the basis for standard time in place of UTC.

We should therefore re-examine the text of the CCIR Recommendation 460. It considered the "continuing need of many users for Universal Time". This "many users" obviously does not mean all human beings for many never make use of the irregularity of the earth's speed of rotation. The term here certainly signifies direct users of the phenomena of the earth's rotation. These users are navigators and surveyors, but not astronomers since there are relatively few of them. However is the number of navigators and surveyors really to be considered an important part of the earth's population ? Obviously no. They may be of an order of 10^{-4}, or less, of the total population. Moreover, as we have already noted, most surveyors do not need UT1 data at the actual time of the observations. Accordingly they do not require to have the UT1 data on time signals.

Is there, furthermore, any good reason for wishing to retain UT ? We have already abandoned apparent solar time (sundial time) and adopted mean solar time, since the basis of the latter was considered to be "equal intervals". The difference between UT and AT is fortunately far smaller than the magnitude of the equation of time. It would be far better to put all human activity on a time system that has a strictly "equal interval" basis and has no discontinuity such as the leap second. The IAU recommendation provides for the introduction, if necessary, of a leap second at the end of any month. The insertion or omission of a leap second at the end of unspecified months will surely be the cause of future difficulties in the matter of investigating changes in natural phenomena over a long interval of time. There is obviously no reason that everyone be compelled to follow a complicated time system merely in the interests of a limited number of UT users.

At present most navigators do not need to know that the time signals give a time which differs from UT, this last being the time argument GMT shown in Nautical Almanacs. If time signals were to be emitted in TAI instead of UTC, navigators would have constant difficulties as the time signals would have to be corrected, and any errors could be the cause of danger at sea. Such difficulties could be avoided by indicating a simple correction formula so that the navigator would merely have to apply this correction without necessity to use his judgement. His work must be reduced to the minimum, but the danger is not in the number of procedures but of scope for a possible error of judgement. A clear indication of the correction method would go far to reduce the disadvantages arising from the increase in procedures. In this connection we may cite another IAU resolution adopted at the 15th General Assembly which recommended that in order to bring ET and TAI into accordance a change in TAI should be introduced in order to make the new TAI equal to the old TAI + 32 sec. This recommendation is being put before the Comité Consultatif pour la Définition de la Seconde (CCDS) for decision. If this change is not made for several years TAI — UT1 will have taken on fairly large values — probably about 50 sec, since TAI — UT1 amounted to about 12 sec at the beginning of 1974 and will be increasing by about 1 to 1.5 sec per year. Such a large value would be so conspicuous that navigators would have no difficulty in recognizing the difference TAI — UT1. Coarse values of TAI — UT1 would become common knowledge to UT users, and the possibility of dangers arising from correction errors would be very small since the yearly change in TAI — UT1 is itself fairly small.

It would not be difficult to supply information on TAI — UT1 to UT users. Voice announcements and also emphasized seconds markers during the time signal emissions could be used for this purpose. For example, TAI — UT1 could be disseminated each minute by the artifice of allocating integral multiples of 0.1 sec to the seconds markers between 1 and 9 sec, integral multiples of 1 sec to the seconds markers between 11 and 19 sec, and integral multiples of 10 sec to the seconds markers between 21 and 29 sec of each minute.

ANNEX

QUESTIONNAIRE CONCERNING UT1 - UTC

A questionnaire was sent out in July 1973 in order to determine how conscious navigators were of the UTC time signals. Among the 400 questionnaires distributed in Japanese ports about 60 answers were received from ocean-going ships within three weeks and 9 returned later. Another 20 answers were obtained as a result of direct interviews on board.

Summaries of the answers are given in table 1.

TABLE 1

Number of answers received :

Cargo ships	58
Tankers	6
Fishing vessels	22
Others	5
Total	91

Classification by nationality :

Cargo ships :

U. S. A.	8
Norway, Panama, U. K.	3 each
Denmark, Liberia, Netherlands	2 each
France, W. Germany, Greece, Philippines, Sweden	1 each
Japan	30

Tankers :

Panama	1
Japan	5
Fishing vessels and others	All Japanese

Question 1 : Are you aware of the leap second ?

YES : 71
NO : 20 (10 were fishing vessels)

Question 2 : Are you aware of the difference of 0.7 sec between the UTC disseminated by time signals and UT (or GMT) which you use for navigation ?

YES : 55
NO : 35
No answer : 1

Question 3 : What limit for UT1 — UTC do you tolerate for your navigation ?

Less than 4 sec	12	75
" " 2 "	10	
" " 1 "	40	
" " 0.7 "	1	
" " 0.5 "	11	
" " 0.2 "	1	
No answer	16	

Question 4 :

(a) Do you make use of DUT1 ?
YES : 6
NO : 21

(b) Are you aware of the emphasized seconds markers ?
YES : 35
NO : 28
No answer : 1

Question 5 : Is accuracy of as much as 0.1 sec provided by DUT1 necessary to you ?

YES : 9
NO : 71
No answer : 11

The above statistics are self-explanatory. As for Question 3 regarding the tolerance limit for UT1 — UTC, we see that less than 20 % of the replies support 0.7 sec or less. Over 50 % support 1 sec, and 30 % tolerate a limit of 2 sec or larger. On the average larger values for the tolerance limit were preferred by the captains, whilst the smaller values are advocated by the younger mates. The questionnaire had asked for the reason for a tolerance limit of 0.7 sec or less, but it was difficult to find any one definite reason among the replies. The main reason for advocating smaller values may be attributed to the traditional method of reading the chronometer dial.

The seconds hand in a classical chronometer advances every 0.5 sec, and thus in most ships comparison with the time signal can be recorded to this degree of precision in the chronometer log. Another reason stated was : "the more accurate the better". 16 replies did not give any opinion on the tolerance limit. It may be conjectured that these users have no need of a small value for UT1 — UTC.

It should be noted that Japan's Captains' Association, the Nautical Society of Japan, and the Tokyo University of Mercantile Marine all support a tolerance limit of up to 1 sec.

BIBLIOGRAPHY

General reading on time systems and time signals.

DUNCOMBE, R.L. & HAUPT, R.F. (1970) : Time and navigation, *Navigation* (Jour. Inst. Nav.), **17**, p. 381.

HALL, R.G. (1968) : Progress in precision, timekeeping and time dissemination, *Navigation*, **15**, p. 154.

SADLER, D.H. (1972) : The new system of Coordinated Universal Time, *Jour. Navigation*, **25**, p. 32.

SMITH, H.M. (1969) : Dissemination of astronomical and atomic time, *Nature*, **221**, p. 221.

Specialized reading :

FEHLNER, L.F., McCARTY, T.A. (1973) : A precision position and time service for the air traffic of the future. *Jour. Nav.*, **26**, p. 37.

IIJIMA, S. (1973) : Communication to the President of IAU Commission 31.

MORRISON, L.V. (1973 a) : Rotation of the earth from AD 1663 - 1972 and the constancy of G. *Nature*, **241**, p. 519.

MORRISON, L.V. (1973 b) : Step adjustment in UTC, paper presented to the 15th IAU General Assembly, Sydney 1973.

SADLER, D.H. (1973) : The leap second of 31 December 1972, *Jour. Nav.*, **26**, p. 238.

STEELE, J. McA. (1972) : The improved UTC system to be introduced on 1 January 1972. *Int. Hyd. Rev.*, XLIX (2), pp. 137-148.

Brief explanations on time systems and time signals can be found in the Admiralty List of Radio Signals. Vol. V (1972), p. 24; and in Nachtrag zum Nautischen Funkdienst (Bd. 1), 1972, 2/72, D-1.