31. TIME (L'HEURE)

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I. INTRODUCTION

During the last 50 years, about the life time of this Union, the precision of time measurement has increased almost by a factor of 10^8. The best clocks can now be extrapolated to 10^{-9} s over hours. VLBI observations, lunar and satellite laser ranging have achieved resolutions even better than 1 ns. It is clear that the measurement and use of precise time is no longer the sole domain of the astronomer and that revolutionary changes have taken place. The cause of this development has been, of course, a greatly increased influx of ideas, techniques and people into our more traditionally minded specialty.

One can safely expect, however, that progress will slow down now, at least for a while (until the physicists develop a 'Mössbauer' clock with hour and minute indicators) and that we will be able to move from an era of consternation into a time of consolidation.

With an excellent definition of the unit of time on hand, with general agreement on an international atomic clock time reference (TAI) and with a relatively painless transition to the new UTC system for time signals and clocks accomplished, we must now turn our attention to the finer details. The scope of our activities as a commission may then be delineated as follows:

Mode: Exchange of views and information about scientific work in progress.

Subject: (1) Definition of time scales for scientific use (UT, ET, AT);
(2) Astronomical time observations, instruments, methods;
(3) Chronometry;
(4) Time distribution;
(5) Uses of time.

Results: Preparation of recommendations to official bodies, i.e., CIPM, CCIR, etc., and to scientific users of time.

II. FUNDAMENTAL CONCEPTS

It has often been stated that science does not need to define time, that it is only necessary to define procedures to measure it. It begins to appear now that we will have to define what we want to measure before we can agree on refined procedures and terms.

There is little doubt that the concept 'TIME' has its origin in the perception of change around us. The various sciences describe the processes of their concern with one parameter 't' which is ideally identical in all applications because that is what science wishes to accomplish; to relate one process to other processes which we observe. Accepting this view, one will agree that if we find process 'A' to require a different parameter 't' as compared with other processes 'B', 'C', etc., that in such a case our theory about process 'A' requires some modification. From this point of view it is a wrong policy to make ad hoc postulates about f.i. a dynamical time as compared to atomic time or statistical time, etc. We recommend the same concept with which the Earth 'clock' was found to vary – in comparison with several 'clocks', with the Moon and planetary orbits. In order to assure general (cosmic) utility we will have to start with definitions of this one parameter 't' in a small spatial area from which we must extend our observations outwards, following the concepts of relativity. Within each space element, dx, dy, dz, however, the definition and description of

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observed physical processes must be identically the same. Furthermore, for practical as well as for theoretical reasons, we will not base our measurement procedures on a single clock. The concept of a 'master clock' which is right by definition is impractical. It also cannot do justice to the program for a universally useful parameter 't' as suggested above.

We can modify Einstein's definition and propose that "Time is what is indicated by the consensus of standard clocks" ('clocks' again understood in the general sense).

The concept of 'uniformity' of a realized time scale is also easier to establish if one abandons the idea of defining the scale in reference to a single clock.

We generate uniform (equal) time intervals if we can establish that identical processes take place during these intervals. The most practical way to test this is to intercompare many clocks.

Clearly, uniformity is not a yes-no property of a time scale; rather it is a measure of quality since 'noise' is always present and there can be no absolute perfection.

The same quality is known as stability of the 'standard' frequency.

The consequences of the program for a single parameter 't' should not be misunderstood. Newton's distinction between 'tempus verum, mathematicum' and 'tempus vulgare' still applies. We have been concerned with our ideal parameter 't_m' (tempus mathematicum), conceived now relativistically; to be distinguished from its various realizations t_{ET}, t_{AT}, etc. ('Hora, Dies, Mensis, Annus...'), each of which has merits and justifications of its own.

III. UNIVERSAL TIME (UT)

It appears that conventional time determination will continue to be the operational 'workhorse' of many time services. VLBI techniques promise to play a very important role. Many institutes have successfully experimented with UT determination using VLBI techniques. The most significant contribution will come from long time intercomparisons since the problem of proper motions continues to be a main difficulty of optical methods.

The new system of coordinated universal time has been almost generally accepted, albeit grudgingly. Minor problems exist. The BIH needs guidance about the relative importance of announcing the leap seconds at the end of December and end of June versus an occasional slight overrun of DUT1 beyond the 0·7 s tolerance.

In view of the high degree of synchronization of the major time signals, G. Becker suggested that monitoring could now be curtailed and time service bulletins be referred to UTC instead of UT2. The last URSI General Assembly (Warsaw, 1972) has recommended the general use of the UTC system for time signal emissions, a step which will aid in the consolidation of the new system.

IV. EPHEMERIS TIME (ET)

Since TAI is such an excellent clock time realization of ET, the question has been raised why the ephemerides could not refer directly to the International Atomic Clock Time (TAI). Even if it is redefined as proposed (van Flandern), ET and TAI will not indefinitely remain in agreement (if initially adjusted to agree). However, this divergence will happen not because ET and AT are intrinsically different phenomena but for the reason that we may not sufficiently understand gravitation and/or that we do not have a sufficient number of (ET) clocks available to derive a sufficiently uniform time scale in the presence of observational (and perturbation) 'noise'. However, a direct use of TAI as a parameter in tables does not mean that one should drop the *concept* of ET. Therefore the present concept requires clarification regarding relativity. The subject is being studied extensively in commissions 4 and 7.

V. ATOMIC TIME (AT-TAI)

Several questions are being debated. Can TAI be used to provide the SI unit of time? Or is it to be used as a coordinated coordinate time? In the latter case, the second could be derived from TAI

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only after certain corrections have been applied. In principle it seems better to use the definition of the second verbatim, i.e., refer to cesium atoms in the local frame of reference (laboratory).

Another point of argument is the question of weighting of contributing clocks or better, the algorithm to be used to derive a most uniform scale. The BIH is presently testing practical schemes and that is the best approach to a solution. In addition, more Time Services and Standard Laboratories should contribute to the BIH effort.

VI. CHRONOMETRY

In addition to 'more and better' of the conventional devices, Cesium beam, Rubidium vapor cell, Hydrogen Maser and improved quartz oscillators, precision frequency control has been extended into the optical range. This opens up the important possibility of replacing the present definition of the meter (standard of length) with a defined velocity of light and the second. This 'standard of distance' is in practical use in Radar Astronomy and Lunar Laser Ranging. It may even be wise to recommend official adoption of the *present* IAU value for c since this would still leave us within the 'error limit' of the present meter realization.

VII. SYNCHRONIZATION

LORAN C has emerged as a major means of synchronization. Clock trips, televison signals and satellites are being used. VLBI and PULSAR signals are feasible to accomplish precision synchronization, albeit at a high level of effort and sophistication. The use of VLF signals to maintain coherence is decreasing but new applications (small aircraft navigation) may reverse the trend. G. Becker suggested that only monitoring which can guarantee coherence should be continued.

VIII. APPLICATIONS OF TIME - PRIORITIES

There is still a very large number of users who need UT1 and who depend on the time signals entirely. There is also a considerable group of users who need UT1 with greatest precision (Satellite Geodesy, deep space tracking). There is a growing number of observatories who need to point their telescope to within 1 or 2″ (for optical retro reflector satellite tracking, Pulsar studies, etc.). They are very concerned about DUT1.

The need for precise clock time has increased even more dramatically. Pulsar time of arrival observations can be done with microsecond precision. Lunar optical ranging measures travel times with 10^{-10} s resolution. Indeed there is no doubt that in a large number of scientific observations the superior accuracy of time measurements, compared to any other quantity, will become useful.

In view of these ever growing applications, not only in pure science, the following priorities in our work can be recommended:

(1) Details of the 1 second steps in UTC and of the DUT1 dissemination should be resolved. In general, the BIH needs more support.

(2) The questions regarding Ephemeris Time should be clarified.

(3) The derivation of TAI should include more contributors as links with other time scales become available.

IX. LITERATURE

Following is a list of contributions of importance to commission 31 which have not been published in the strictly astronomical literature. They document subjects V to VIII in greater detail. Also the observatory reports below represent a fair, but by no means exhaustive cross section of activities. Some reports which are not listed here are available in sufficient detail in the *Reports 1970* (Vol. XIVA) as for example the observatories in the U.S.S.R., Switzerland, the PTB (Germany) and others.

[1] *Special Issue on Time and Frequency*, Proc. IEEE, May 1972.

[2] *Transactions on Instrumentation and Measurement*, IEEE, Vol. IM-21, #4, November 1972, (Papers presented at the CPEM 1972).

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[3] *Transactions on Instrumentation and Measurement*, IEEE, Vol. IM-19, #4, November 1970, (CPEM 1970).

[4] *Characterization of Frequency Stability*, J. A. Barnes *et al.*, pp. 105–120, Transactions I&M, IEEE, Vol. IM-20, May 1971.

X. REPORTS OF OBSERVATORIES AND LABORATORIES

Australia, Mount Stromlo & Siding Spring Observatory

The observations with the Mount Stromlo PZT have continued as before, but the administration of this instrument has been transferred from the Australian National University to the Division of National Mapping in the Department of National Development. Second and third cesium frequency standards have been ordered, one of which will be portable. Clock comparisons, and the operation of the roof of the PZT house, are to be made automatic. Mean clocks are also computed from a number of other atomic standards in Eastern Australia. These are compared via TV transmissions.

Belgium, Uccle

L'objectif du plan de recherches du Départment I de l'Observatoire Royal de Belgique vise à constituer un point fondamental commun aux différents réseaux de stations de contrôle de la rotation de la Terre:

(1) BIH
(2) IPMS
(3) NWL

Dans ce but on a enrichi l'équipement instrumental qui, actuellement, se compose principalement de:

astrolabe Danjon No. 7
astrolabe Danjon No. 40
cercle méridien Askania de 190 mm
système de tracking de satellites Transit par méthode Doppler
confié par l'U.S. Navy (juin 1972)
2 étalons atomiques au Césium
1 étalon atomique secondaire au Rubidium
1 récepteur LORAN-C (Novembre 1972)
1 récepteur de signaux de télévision (Septembre 1972)

Observations	aux astrolabes	Réceptions Doppler	
1970	124 séances	Juin 1972	49 passages
1971	213 séances		
1972	184 séances au 1 Novembre 1972	au 1 Octobre 1972	1543 satellites Transit

Au cercle méridien on a repris l'observation des étoiles de l'IMPS et de certains PZT afin de contribuer à la révision des anciennes donées de latitude. On développe sur ce thème des programmes d'analyse particuliers.

Brasil, Observatorio Nacional, Rio de Janeiro

Universal Time determination continued with the two transit instruments, Bamberg and Askania. The feasibility for an equatorial astrolabe, Belem 2° S, is being studied.

A new transmitter for signals in the standard frequencies is being installed. VLF, LF (Loran-C), HF and VHF (ATS3 US Satellite) signals are received.

Since 1970, the time scale is based on Hewlett-Packard cesium and rubidium standards, checked against portable clocks of U.S. Naval Observatory (once) and National Bureau of Standards (twice).

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Synchronization of various Brasilian laboratories' time scales was begun by transportation of a rubidium standard in December 1972.

A speaking clock disseminates time through commercial telephone lines and five radio stations.

Canada, Ottawa

The Ottawa and Calgary PZT have been operating in their present locations with no interruptions. Calgary, on the same latitude of Herstmonceux, is providing very satisfactory collaboration. A further revision of the Ottawa PZT catalogue became effective 1972·0. Woolsey, E. G., Publication of Earth Physics Branch, *E.M.R.*, Vol. 42, #6 (Ottawa PZT Observations 1956 to 1970, Comparison with BIH Values by Graphical, Spectral and Fourier Analysis). During 1972 both E. G. Woolsey and R. W. Tanner retired.

The Time and Frequency Section of NRC has been developing a new long beam laboratory cesium standard, Cs V and the preliminary tests are encouraging. Cs III, with a precision of about a part in 10^{12}, continues to serve as the NRC atomic standard for time and frequency. Six-hour frequency calibrations are made twice a week of 1 HP type 5060, and 2 HP type 5061. Support equipment includes 2 laboratory hydrogen masers, and a rubidium standard. Time comparisons are made by Loran-C and by USNO flying clocks. CHU is maintained in frequency and in time by an HP frequency standard and monitored by TV link. M. M. Thomson retired at the end of 1972, and was replaced by C. C. Costain.

Czechoslovakia, Prague

The clock system includes a commercial cesium beam frequency standard (since April 1970) and a group of quartz oscillators. The time scale UTC(TP) was related to UTC(BIH) by clock transport in June 1971 (courtesy of the Paris Observatory and Hewlett-Packard, Geneva) and is regularly compared by TV with several European Institutions. A PZT has been installed at the Ondřejov observatory in October 1971 and experimental observations started early in 1972. The OMA time signals on two standard frequencies are synchronized with the atomic standard mentioned.

France, Bureau International de l'Heure (BIH)

The BIH work on the rotation of the Earth is presented to commission 19 and will not be reported here. Methods of computation and results are given in full in the *BIH Annual Reports* as well as details concerning the special steps made by the various time keeping authorities at the beginning of 1972.

The International Atomic Time (TAI)

The atomic time established on an experimental basis by the BIH since 1955 was endorsed as the International Atomic Time (TAI) by the XIVth General Conference on Weights and Measures in October 1971. The rules applied by the BIH to compute it since 1969 were also accepted by the CCDS meeting in June 1970.

Since October 1969 TAI is the mean of the time scales AT(i) of 7 laboratories in North America and Europe, linked by LORAN-C pulses. It is not yet possible to include some other well-equipped laboratories, because of the lack of a sufficient means of time comparisons.

Studies of the long term behaviour (over 2 months) of TAI and of the local time scales AT(i) showed that they are affected by frequency flicker noise modulation. The probable change in frequency of TAI was of the order of 1×10^{-13}, in relative value, for one year.

The duration of the scale unit of TAI, estimated by three laboratories (NBS, NBC, PTB) by comparison with laboratory cesium standards, was $(1\text{–}7 \times 10^{-13})$s (at sea level). As the standard error of this estimation is about 5×10^{-13} s, it was agreed that no intentional change in the TAI scale unit should be made.

At the higher degree of precision, TAI is made available through the published values of TAI-AT(i) and UTC-UTC(i), i.e., through corrections to the clocks of a number of laboratories. The accuracy is the one of the LORAN-C time transmissions: accidental errors of 10-day means are usually 0.1 to 0.2 μs; constant systematic errors, due to the choice of the origins amount to a few 0.1 μs and might be corrected by an adjustment of the origins if necessary. It seems that systematic variations reaching almost 1 μs occurred in only one case. On the other hand, it appears that some fluctuations, with a semi amplitude smaller than 0.2 μs are introduced by the LORAN-C link across the Atlantic; this problem is under study.

Studies on the improvements of TAI

For future improvements of TAI, it is of the utmost importance to know for what purposes TAI is used. TAI cannot compete with the AT(i) in stability for periods of less than 1 to 2 months (presently), since TAI is affected by the noise of the distant time comparison methods. In our opinion, the role of TAI is: (a) to provide a basis for effective synchronization of clocks, (b) to provide a measure of time for long term dynamical studies (astronomy, space research), (c) to provide the SI unit of time.

For synchronization purposes, TAI needs to be uniform or stable in the very long term, so that the extrapolation of the rates of the TAI-AT(i) will be possible. For (b) and (c), the accuracy of the TAI scale unit is needed. In particular, this accuracy ensures the infinite term stability which is required in dynamics.

At present, the absolute determinations of the second are very few and our goal is to ensure the best long term stability with reference to the frequency laboratory standards. However, as soon as the new laboratory standards with accuracies of $\pm 1 \times 10^{-13}$ become operational, it will be necessary to steer the frequency of TAI with a sufficient lag in order to maintain both long term stability and accuracy (as was proposed by the scientists of NBS).

Several attempts to weight the AT(i) from their past properties were disappointing. For the long term studies, the past data cover too short an interval of time. In addition, during this interval, the equipment and procedures greatly changed in most of the laboratories. For these reasons the statistics cannot be reliable. A difficulty experienced by several laboratories is that, in their set of clocks, sometimes only 1 or 2 were operational. No internal control of the stability was then available and some frequency changes of AT(i) or losses of independence thus occurred.

In order to overcome these difficulties, we tested on an ensemble of 9 clocks a method using directly the weighted data of individual clocks; in spite of the time errors introduced by the LORAN-C or television time comparisons, the faulty clocks are well detected and the results were satisfactory. The CCDS (at its meeting of July 1972, in Paris) agreed that these tests should be extended at the international level, before the possible introduction of the new method. One must remark that the proposed method gives more freedom for computing the AT(i) and makes possible the use of some small ensemble of clocks or even isolated clocks. We expect that results of these tests will be available before the 15th General Assembly of the IAU.

The Universal Coordinated Time (UTC)

The necessary documents for the introduction and the implementation of the new UTC were regularly distributed; circulars E for the 1s-steps, circulars F for the values of DUT1. Two items deserve special consideration.

On the 1st of January 1972, the second order term of the previous UTC offset was diversely treated: it produced a discrepancy of 0.3 μs in the data of various sources. In order to bring back consistency, it was found that the easiest way was to modify from 0.1077577 s to 0.1077580 s the step adjustment of UTC on the 1st of January 1972, 0h UTC; this was done.

On the other hand it was found hazardous to choose between the 1st of January 1973 or the 1st of July 1973 for the step of TAI-UTC from 11s to 12s. As the Earth's rotation is still slowing down, guidance should be issued for choosing intermediate dates.

Except for the above remarks, the use of the new UTC was found most convenient for the BIH

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work. No complaints on the new UTC were received. We had to answer many questions from press agencies, radio and televison stations and from the public; we found that the new UTC system was generally understood and well accepted.

On the 1st of January 1972, most of the laboratories and observatories adjusted their UTC(i) so that it is in agreement with UTC to a few microseconds. We can conclude that the unification of time on the Earth is now almost achieved in the microsecond region.

Time signals

A special effort was made to publish, in the *BIH Annual Reports*, the current characteristics of the time signals, as well as the addresses of the responsible authorities. The times of emission, which are very close to UTC, are published monthly.

Publications

No change in the published series of the BIH was made, except for the addition of Circulars E and F (see above). All the publications were regularly issued.

The request for the current results (Circular D, *Annual Report*) is increasing. Many requests are coming from geodetic services of developing countries, space research centers and individual scientists working on the Earth rotation. More than 650 copies were distributed in 1972.

Staff

In October 1972, the members of our staff were:
M. B. Guinot, Director;
Miss M. Feissel (assistant), Mr. A. M. Desprats (assistant);
Mr. E. Eisop (calculator), working on the current determinations of UT, x and y;
Mrs. N. Capitaine (assistant) working on the satellite determination of the Earth rotation;
Mr. M. Granveaud (engineer), Mr. D. Bourquard (calculator) working on TAI and TUC;
Mrs. C. Mulhauser (secretary) and Mr. R. Thomas (bookkeeper).

In addition, researches are carried out in collaboration with some groups of the Paris Observatory (lunar laser ranging).

France. Commission Nationale de l'Heure

Les recherches sur les étalons, en France, ont porté essentiellement sur le maser à hydrogène: le Laboratoire de l'Horloge Atomique a construit deux masers qui sont en fonction. Un autre maser à hydrogène est en cours de construction, avec la collaboration du Centre National d'Études des Télécommunications (CNET), à fin purement métrologique.

Plusiers laboratoires intéressés par le maintien d'une échelle de temps, sont équipés d'horloges à césium commerciales, maintenues dans une ambiance contrôlée afin d'assurer la meilleure stabilité: Observatoire de Paris, 3: CNET, 3; Centre National d'Études Spatiales, 1; Observatoire de Besançon, 1; Centre d'Études et de Recherches Géodynamiques et Astronomiques, 1.

Tous les étalons ci-dessus sont régulièrement comparés en utilisant des impulsions de la télévision publique comme signaux horaires. Ils contribuent à la formation d'une échelle nationale TA(F) qui n'a subi aucun changement de fréquence intentionnel et qui est indépendante des autres temps atomiques locaux et de TAI. Depuis avril 1972 TA(F) est calculé en pondérant les indications des horloges, d'après la fluctuation de leur fréquence moyenne mensuelle.

Les moyens de comparaison en temps ont été developpés. Des récepteurs adaptés aux impulsions de la télévison et automatisés ont été construits. Les expériences de synchronisation par simple survol d'horloges embarquées ont été réalisées entre l'Europe et l'Amérique du Nord par l'Office National d'Études et de Recherches Aérospatiales avec une précision de quelques dizaines de ns. Des transmissions horaires par laser sont entreprises par ce même office et des transmissions de fréquence utilisant la fréquence porteuse de la télévision sont à l'étude au CNET.

Le lien des laboratoires français avec l'extérieur est assuré par la réception des signaux de

LORAN-C de Sylt (Norwegian Sea chain) et d'Estartit (Mediterranean Sea chain), reçus à l'Observatoire de Paris.

L'Observatoire de Paris a une échelle TUC(OP) qui est maintenue à moins de 5 μs de TUC. TUC(OP) est la base des signaux horaires français, ainsi que de la distribution de l'heure pour les usages courants (horloges parlantes, stations de radiodiffusion).

Germany. Deutsches Hydrographisches Institut, Hamburg (DHI)

The determination of Universal Time was continued with the PZT. Time service bulletins giving the results of the PZT observations and time signal reception times were published quarterly. The DHI has participated in the BIH Rapid Service for the determination of UT1 and the pole path.

UTC (DHI) is being kept by a Hewlett-Packard 5061 A caesium beam clock. Coordinated radio time signals were transmitted via DAM, DAN, and DAO on high frequencies.

Measurements of LORAN-C from Sylt were carried out regularly with a special receiver constructed in the time service workshop. The television method has been applied to compare DHI time with that of IRE, Prague; ZIPE, Potsdam; and PTB, Braunschweig. In addition, coordination with the PTB has also been maintained by means of phase measurements of the DCF77 LF emission. The television method, with $\sigma(2, 1\mathrm{d}) = 35$ ns, proved to be the most accurate means of comparison.

The propagation delays for the LORAN-C measurements and the time comparisons with the PTB have been checked about twice a year by means of travelling clocks of the U.S. Naval Observatory.

Germany, Potsdam. Zentralinstitut für Physik der Erde (ZIPE)

For determinations of UT2 (ZIPE) time observations have been continued with a Danjon astrolabe and a transit instrument. A PZT was installed; test observations have shown good results. At Lohrmann-Observatorium of the Technische Universität Dresden construction and test of a photoelectric device for transit instruments were finished. The device automatically eliminates the seeing effect.

Investigations on variations in the rotation of the Earth have been made.

For ET determination visual observations of star occulations have continued.

The time system UTC (ZIPE) is formed by a group of crystal clocks. A cesium Atomic Clock will be installed.

To control the UTC (ZIPE), comparisons are made with UTC-systems of other time services. For this purpose phase readings of VLF signals and navigation stations are used. Time comparisons by the TV-method were made in collaboration with the time services in Prague and Hamburg every day. The connection with UTC (BIH) is possible due to the very accurate comparison between UTC (ZIPE) and UTC (DHI).

The time service is responsible for the time signal emission DIZ (4525 kHz).

Investigations of the TV method of time comparison have been continued. Measurements with the Institute of Radio Engineering and Electronics (IRE) Prague showed precision of 10 ns for the time comparison. For precise measurements TV receiver delay must also be taken into consideration. The delay time can depend upon the receiver tuning, contrast, or upon the field intensity of the received transmitter. Different delay times of up to 1 μs and variations depending on field intensity up to 0·3 μs were measured with different receivers.

Italy, Cagliari Astronomical Observatory (CAO), University of Cagliari

(1) Astronomical time determination is carried out in CAO by means of a Large Transit Instrument ($D = 120$ mm, $f = 1{\cdot}290$ mm). A PZT, supported by the Italian Geodetic Commission, is being considered.

(2) Two quartz clocks (Tracor/Sulzer 2, 5C/5P and Ebauches B 1300a-5MHz Frequency Stan-

dards) are utilized for time keeping. Reception of VLF signals has been started with VLF/LF Tracor receivers 599K. Reception of standard time signals in HF will begin in 1973. Loran-C signals emitted from the master station in Simeri-Crichi and the Estartit Station of the Mediterranean chain have been received with an Austron receiver and compared with the master clock with an accuracy of $\pm 0{\cdot}1$ μs.

(3) Statistical properties of frequency fluctuations of a quartz clock compared with GBR have been examined. Random walk and flicker noise modulation were established (F. Chlistovsky and E. Proverbio, Mathematical Features of Integrated Time Scale and Statistics of Frequency Fluctuations, *Mem. SAIt.*, **XVI**, 1971, 335).

Italy. The Rome Astronomical Observatory and the ISPT

Star transits observations for the determination of UTO have been carried out since 1967·7. The results are sent to the BIH and the IPMS with only a short delay, as permitted by an automatic data acquisition system and electronic processing developed at the Observatory. A stellar program composed of FK4 star pairs symmetrical with respect to the zenith has also been observed since 1970·5. Research on smoothing techniques, instrumental techniques and analysis of the Earth rotation is continuing.

The UTC reference scale is maintained at the ISPT and is distributed daily by the HF transmitter IAM. It is obtained from a system of rubidium and quartz clocks controlled daily by HF, VLF and Loran-C, and compared weekly with the cesium standard of the IEN by means of TV signals. Continuous phase comparison with the IEN is obtained through coaxial cable at 300 kHz. Flying clock synchronization took place in December 1967 by HP and in April 1972 by IEN. A cesium standard is expected during the summer of 1973.

Japan. Tokyo Astronomical Observatory (TAO)

The astronomical observations for time and latitude are continued with the PZT, using the star system, $\alpha 59/\delta 66$.

In addition to two cesium beam oscillators, #1 (h/p 5060 A) and #2 (h/p 5061 A), another cesium beam oscillator, #3 (h/p 5061 A), was installed in 1971. UTC (TAO) was kept by the #1 as the master clock during 1970 and 1971. At the beginning of 1972, however, #1 was replaced by the #3.

The sidereal clock in the Observatory has been driven by the master oscillator through a frequency offsetter (home-made) adjustable by steps of 50×10^{-10} and a mean-to-sidereal convertor (RMS Inc.) on 100 kHz with the conversion ratio of $2313/1661 \times 355/493$, since the beginning of 1972.

Reception of standard frequency time signals has continued regularly on JJY(2·5 MHz), WWV (15 MHz), and WWVH(15 MHz). The signal VNG(12 MHz) had been also received regularly, but was replaced by the signal RID(15·004 MHz) in the middle of 1971.

The VLF signal, GBR(16 kHz), has been received using a chart recorder for relative phase comparison with the master oscillator, but was replaced by signals, NLK(18·6 kHz) and NWC(22·4 kHz), in the middle of 1972.

The Loran-C signal emitted from the Iwo Jima master station (North-West Pacific Chain) has been received with a home-made receiver and compared with the master clock with the accuracy of $\pm 0{\cdot}1$ μs.

Delay time of signals in the Loran-C receiver including the antenna system was investigated in detail by use of artificial signals. Continuous phase recording of Loran-C was commenced in 1971 with a commercial receiver (Austron Inc.).

International clock comparisons were made with flying clocks among UTC's of the TAO, the RRL, and the USNO by courtesy of the USNO, 4 times in 1970, 3 times in 1971, and 3 times in 1972 (until August) with the accuracy of $\pm 0{\cdot}2$ μs.

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From the data of meridian observation of the moon obtained at Tokyo, values of ΔTO were recalculated back to 1952; corrected for the effect of irradiation on a consistent basis and for the limb irregularities with Watts' atlas:

Epoch	ΔTO	p.e.	N	Epoch	ΔTO	p.e.	N
1952·5	29·29	±0·17	73	1960·5	32·46	±0.14	93
1953·5	30·14	0·14	64	1961·5	32·33	0·13	104
1954·5	30·68	0·14	87	1962·5	32·54	0·12	90
1955·5	31·14	0·13	113	1963·5	32·71	0·19	74
1956·5	31·70	0·27	64	1964·5	33·88	0·20	60
1957·5	31·01	0·19	91	1965·5	35·18	0·22	79
1958·5	30·86	0·13	99	1966·5	35·78	0·19	75
1959·5	31·18	0·18	89	1967·5	36·68	0·15	105

Japan. Hydrographic Department of Japan (JHD)

To evaluate the value of ΔT for ephemeris and almanac compilations, observations of the lunar occultation have continued as routine, and about 400 data were obtained per year. Values of $\Delta T1$ given below, were determined from the observations made with photoelectric registration of stars of Robertson's catalog.

Epoch	$\Delta T1$	p.e.	N
1968·5	37·13	±0·12	62
1969·5	37·78	0·14	96
1970·5	39·20	0·10	54
1971·5	40·28	0·11	80

The limb corrections were already applied with the Watts' atlas. (A. Yamazaki *et al.*: *Data Report of Hydrogr. Obs., Ser. of Astron. and Geod.*, No. 5, 1970; T. Mori *et al.*: *ibid.*, No. 6, 1971; T. Mori: *ibid.*, No. 7, 1972). From the data at $\Delta T1$ since 1956, the following relation can be obtained:

$$\mathrm{ET} - \mathrm{AT} = 30^{\mathrm{s}}.69 - 0^{\mathrm{s}}.002(t - 1958{\cdot}0)$$
$$\pm 0{\cdot}08 \quad \pm 0{\cdot}009.$$

Japan. Radio Research Laboratories (RRL)

Three cesium beam oscillators, #2 (h/p 5060 A), #3 (h/p 5061 A), and #4 (h/p 5061 A), have been in operation. The UTC(RRL) was kept by #2 as the master clock during 1970. At the beginning of 1971, however, #2 was replaced by #3. A couple of hydrogen masers were investigated and compared with the cesium oscillators.

Since July 1970, transmission of the JJY signals has been controlled by a rubidium gas-cell oscillator. Since November 1970, transmission of the signal JG2AS has been controlled by a cesium beam oscillator (#1, h/p 5060 A), and since then the commencement of time pulses has been made synchronized to the UTC seconds.

Receptions of the VLF signal, NLK (18·6 kHz), and the Loran-C signal from the Iwo Jima master station have continued using chart recorders for relative phase comparison against the master oscillator.

Investigation of hydrogen masers was made principally with respect to the wall shift. Frequency comparisons were conducted between hydrogen masers of the RRL and the NRC, Canada, by transportation of a specific bulb. The measured values of the hydrogen frequencies at the two laboratories agreed very closely with an uncertainty of about 2×10^{-13}.

Since October 1971, clock comparisons have been made by means of TV signals between the RRL and the ILOM every fifth day with an accuracy of almost $\pm 0{\cdot}1$ μs.

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Japan. International Latitude Observatory of Mizusawa (ILOM)

The astronomical observations for time and latitude continued with the PZT and the astrolabe.

A cesium beam oscillator (h/p 5061 A) and a rubidium gas-cell oscillator (Varian Inc.) have been in operation. Another cesium beam oscillator (h/p 5061 A) will be installed in 1972.

The UTC(ILOM) has been kept by the cesium beam oscillator.

Reception of standard frequency time signal, JJY, was continued until April 1971. Travel time of the JJY signal, as received around 0^h UT on 5 MHz at the ILOM, was investigated, and the amplitude of the seasonal change was found to be 30 μs. (T. Hara *et al.*: *Proc. Int. Lat. Obs. Mizusawa*, No. 12, 1972.)

The VLF signal, NLK (18·6 kHz), and the Loran-C signal from the Iwo Jima master station have been received.

A comparison between the master clocks of both the ILOM and the RRL was made by clock transportation on 23 October 1970. The difference was:

$$\mathrm{UTC(RRL)} - \mathrm{UTC(ILOM)} = +647{\cdot}5 \pm 0{\cdot}1\ \mu\mathrm{s}$$

Japan. National Research Laboratory of Metrology (NRLM)

A cesium beam resonator with the interaction region of 2·4 m in length and with the beam optics in ribbon type was constructed in 1971. Slideable carriages containing a pair of ovens and detectors equipped at the both ends of the beam chamber make it possible to reverse the beam direction easily without breaking the vacuum, and this permits the determination of frequency shift due to the cavity phase error. The full resonance width at the half intensity was confirmed as 65 Hz. The short-term stability is estimated as better than $1{\cdot}4 \times 10^{-11}.\ \tau^{-1/2}$ for the averaging time, τ shorter than 10s (Allan variance).

A cesium beam oscillator (h/p 5061 A) was installed in 1970, and has been used for the mutual frequency comparison with the laboratory cesium beam resonator.

Rumania, Bucarest

À l'Observatoire de Bucarest nous continuons la collaboration avec BIH et IPMS concernant les déterminations horaires avec l'instrument de passage Zeiss ainsi que les réceptions des signaux horaires pour le Bulletin TUC(UTC) de notre Observatoire.

De même, nous effectuons les comparaisons des systèmes de temps Bucarest-Prague en utilisant la methode des microondes.

Spain. Instituto y Observatorio de Marina San Fernando (Cadiz)

Atomic Time

In January 1972, the existing timing system was replaced by a new installation, designed for naval and national needs, comprising:

(a) Two Oscilloquartz Caesium beam Time and Frequency standards 'Oscillatom B-5000'.
(b) A Loran-C automatic receiver 'Lorchron'.
(c) A recorder for the Gain & Phase outputs of the Loran-C receiver.
(d) Two Digital Time Displays B-1330.
(e) One (H.P.) Universal counter with a resolution of 0·1 μs.
(f) One Calibrated Delay Line, B-6100, capable of delays from 1 μs to 1s in steps of 1 μs.
(g) Oscilloscope: together with the Delay Line, allows same resolution as the counter in (e).
(h) One Time Signal Programmer B-6200, and a Code Generator B-6220; together provide time signals including the coded information DUT1.
(i) A 5 MHz Sulzer oscillator from the former equipment completes the installation.

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VLF transmissions may also be monitored using Smithsonian Astrophysical Observatory (SAO) facilities.

In the near future, a 1 kW, HF transmitter will be added to the system for the transmission of time signals.

Propagation delay Estartit-San Fernando for Loran-C signals was computed and confirmed by the visit on April 1972 of a portable Rubidium clock from the Paris Observatory. Accuracy of this synchronization was 1·3 μs. Cesium beam clocks keep AT, while the two Digital Time Displays are adjusted to UTC for Observatory use and, in the future, for the transmission of time signals.

Resolution of the Loran-C phase record is about 0·1 μs and allows the removal of occasional irregularities due to reception conditions.

The whole set is backed by an array of external batteries which guarantees the proper operation of the equipment for more than 24 hours in case of mains failure.

The equipment is located in an air-conditioned room, with temperature regulated to 1°C.

This basic equipment will be expanded in the future with the addition of some other control and measurement instruments and, hopefully, a new Cs beam standard.

Notes

Resolution of the complete system	0·1 μs
Accuracy of measurements	0·1 μs
Accessibility to TAI	
Immediate, to within	2·5 μs
After the fact, to within	1·5 μs

Universal Time

Astrolabe observations for UT0 have continued.

Beginning January 1971, corrections of star groups and a revised longitude of the instrument ($\Delta\lambda = +0^{s}\!.0107$) are used.

Details of this work can be found in the Commission 8 and 19 reports.

Ephemeris Time

More than 260 times of occultations (visual observations) were sent to RGO for analysis in the interval September 1969 to September 1972.

General

In addition to current yearly Time bulletins, updated information on TAI, UTC and UT1 scales is distributed in Circulars, *Éfemérides Astronómicas, Almanaque Nautico* etc., for the fulfillment of national needs.

Spain. Madrid Astronomical Observatory

Two commercially built quartz clocks and one cesium atomic clock are now in use. A Lorchron receiver, acquired in 1972, permits a continuous comparison with Loran-C. The installation of two additional atomic standards is planned.

Time observations of occultations of stars by the moon were sent to RGO for analysis.

U.K. Royal Greenwich Observatory (RGO)

Routine observations of UT0, made with the PZT, have continued.

In April 1971, the observing catalogue was revised; 98 stars were retained and 27 stars were rejected from the old catalogue and 22 new stars were added to the list. The adopted positions of the new stars were based on observations made at Herstmonceux and Calgary in 1969 and 1970. They were computed from the mean error in the provisional positions adopted for those years and the adopted value, for each star, was weighted according to the number of observations of the star made at the two stations. The agreement in the results of the two observatories was very good.

This analysis also revealed substantial errors in the star places adopted in 1968 (with mean epoch of observation in 1963) and these errors were subsequently shown to be due to errors in the proper motions. Proper motion corrections, based on the mean annual error of the star relative to the PZT system, have been computed for those stars that were observed at Herstmonceux from 1958·0 to 1971·2 and the corrected proper motions are now being used to derive corrections to all the stars in the PZT catalogue. The work is being carried out independently at both Herstmonceux and Calgary.

From January 1972 the UT results published in the Greenwich Time Report have been corrected for deflections of the vertical arising from semi-diurnal tidal activity. The corrections applied were derived from an analysis of the PZT observations made between 1958·0 and 1970·0 and are computed from the expression

$-0\overset{s}{.}0015 \sin (2h - 18\overset{\circ}{.}4) \cos {}^2\delta$

where h = the Greenwich Hour Angle of the Moon and δ = declination of the Moon.

These corrections are not applied to the results forwarded to the BIH and the IPMS.

Examination of the observations has also revealed that the results are affected by fortnightly terms with periods of 13·66 and 14·19 days.

The phonic motors and clutches used for driving the plate carriage were removed from the PZT in July 1970 and were replaced by a stepping motor. The new system has greatly improved the mechanical performance of the instrument but it suffers from the disadvantage that the present arrangement only allows the use of a single speed for all the stars.

The linear motor used in the rotary drive is to be replaced by a constant torque motor with a magnetic clutch; this equipment is now being prepared for fitting.

The differences between the atomic time scale, GA2, and UT2, and from January 1, UT1 as well, have been published in the quarterly Greenwich Time Reports.

GA2 continues to be determined from selected cesium beam frequency standards at the RGO. In September 1970 the number of Hewlett Packard cesium beam frequency standards was increased from 3 to 4, and in January 1971 the number was further increased to 5. The clocks have been compared automatically three times daily, to one/tenth of a microsecond, with printed and punched paper tape outputs, and continuous phase records have been maintained giving one hundredth of a microsecond resolution from June 1972. In September 1972, after a continuous run of five and a half years on low beam current, CsB was taken out of use for investigation as the frequency had started to drift. This was found to be due to a fault in the control operational amplifier and the beam tube was still satisfactory. In order to maintain uniformity of the GA2 scale, rate corrections have been applied to the standards used in its formation. Commencing with the issue of the Greenwich Time Report for the period October-December 1970, the five-day values of the individual uncorrected standards referred to GA2 are published. The figures were back-dated to commence from January 1969.

Measurements of Loran-C from Estartit in the Mediterranean Chain were commenced in June 1972 and from Ejdes, the Norwegian Sea Chain Master, in August 1972. These results have been published, along with those from Sylt, in the monthly circulars. Daily readings of the relative phase difference between UTC(RGO), or GA2, as appropriate, and the received carriers of selected LF and VLF radio emissions have continued to be published.

Coordination with the U.S. Naval Observatory (USNO), and the BIH has been maintained by such means as traveling clocks from the USNO, the fly-over experiment organized in 1970 by ONERA and in July-August 1972 a visit of a team from the Naval Research Laboratory, Washington, when clocks were compared using the Timation satellite.

United Kingdom. H.M. Nautical Almanac Office (RGO)

A comparison of the ET2 and IAT time scales over the period 1955.5 to 1972.0 using 30000 lunar occultations reveals that at epoch 1963.0 the second of the ET2 scale is equal to ($1{\cdot}0$–$0{\cdot}8 \times 10^{-9}$) SI second, or 9 192 631 770·8 cycles of the defining cesium transition. An increase of about +1

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cycle per year in the duration of the ET2 second relative to the SI second was found. This results from a correction to the tidal deceleration term in the lunar ephemeris $j = 2$. (Paper to be submitted to *Nature* in November 1972.)

U.S.A. Jet Propulsion Laboratory, Pasadena, California (JPL)

The JPL has used the 'BIH Rapid Service' UT1 (and x y) data for high precision deep space guidance since 1971. Errors due to UT1 variations were reduced by a factor of 3 from what they were before the 'Rapid Service' became available. Very long baseline radio interferometry experiments were performed (Goldstone and Madrid). UT1 so determined agreed within several ms with BIH values with ionospheric corrections as major source of uncertainty.

U.S.A. National Bureau of Standards, Boulder, Colorado (NBS)

The construction of the primary frequency standard of the NBS (NBS-5) has been completed. At present (December 1972), a beam figure of merit of 230 has been observed, which is the highest figure of merit for a cesium beam yet reported (figure of merit of typical commercial tubes is approximately 2). The beam is now well into the evaluation phase with an expected accuracy of about 1 part in 10^{13} to be realized in 1973.

The NBS maintains an atomic time scale based on a group of 8 commercial cesium beam devices as a stable memory of the last frequency calibration by NBS-III.

The NBS has been active in experimental and theoretical research on the stability of clocks and oscillators and on algorithms used in the generation of accurate and stable time scales. Jointly with the U.S. National Committee of URSI, the NBS hosted an International Symposium on Algorithms used in the Generation of Atomic Time Scales, shortly before the CCDS meeting in July 1972.

NBS Radio Stations WWV and WWVH disseminate the internationally coordinated time scale UTC in accord with CCIR recommendations. In addition to Time and Frequency information, these stations provide other special services such as geophysical alerts, reports of the progress of the barium-ion cloud experiment, marine weather information, and more.

U.S.A. U.S. Naval Observatory (USNO)

Routine observations of UT0 have been made continuously with PZT#3 in Washington and PZT#2 in Richmond. New catalogs with improved positions have been introduced both in Washington (1970) and Richmond (1972). Supplementary stars have been introduced into both programs for high precision star positions.

Observations of time and latitude, with Danjon astrolabes at both stations (Washington starting in July 1971), continued.

Observations of the Moon are made with the dual-rate Moon camera at Washington for the determination of ET-UT. No reductions are currently (1972) being made.

UTC (USNO) is based on A.1 (USNO, MEAN). This local independent scale is kept as the mean of nominally 16 cesium beam frequency standards. In addition to HP 5060A and 5061A models two 'super' tube models are used. These are stable to about 1×10^{-14} for 10 days. Two H-masers (USNO and NRL) are used as very high precision interpolation oscillators. During most of 1972 an H-maser NP-4 of NASA was at the USNO for comparisons.

Observations and monitoring results are published in various series of Time Service Announcements.

PZT Instrumentation

Operation of PZT#3, in Washington, D.C., is controlled by an IBM 1800 Data Acquisition System. PZT#2 in Richmond, Florida, is completely automated.

The construction of PZT#6 is nearly complete. This instrument will have an apochromatic lens of 20 cm aperture. Other features will include the use of a stepping motor to drive the plate carriage and one to rotate the head. This instrument will be controlled by a specially designed Datum, Inc. PZT Programmer.

A contract was awarded (1972) the Boller and Chivens Division of the Perkin-Elmer Corporation for construction of a 65 cm PZT. The instrument will incorporate the following features: an $f/20$ apochromatic lens, an environmental control system which will maintain the instrument at the nightly predicted ambient temperature during the day, a field of view of almost 1 square degree, a photo-electric timing system capable of determining the time of events to 0·1 ms, a variable length shutter timing mechanism and the facility for automatic plate changing. Operations will be controlled by the IBM 1800 Data Acquisition System and it will be located in Washington, D.C. Completion is scheduled in 1974.

Astrolabe instrumentation

The Time Service Substation in Richmond, Florida, is in the process of developing a semi-automatic astrolabe. Control of several phases of operation by a mini-computer has been successfully programmed. Currently, the feasibility of using a TV system to make remote observations is being investigated.

IBM 1800 Data Acquisition System

In addition to being programmed to control PZT#3 and to record its observations and those of the astrolabe, the IBM 1800 Data Acquisition System also does the following: records hourly values of the temperature, barometric pressure and relative humidity, records data generated by the Dual-Rate Moon Camera, records hourly values of both phase comparison of various cesium oscillators with the master oscillator and tick comparisons of various cesium clocks with the master clock, and records, at 12 min intervals, phase comparisons between hydrogen, rubidium and cesium oscillators for a program to investigate their relative intermediate term stability.

G. M. R. WINKLER
President of the Commission