# 31. TIME (L'HEURE)

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We pay tribute to the memory of A. Gougenheim, a leading personality in the hydrographic world and late President of the Bureau des Longitudes in 1963/64 and 1970/71, and of J. Verbaandert, late Head of the Time Service of the Observatoire Royal de Belgique and constructor, with P. Melchior, of the well-known Verbaandert–Melchior quartz horizontal pendulum.

## 1. GENERAL

The preceding years have seen a noteworthy degree of international and interdisciplinary co-operation in our field. The development of international clock time to be applied for scientific, technical and civil purposes can be considered as completed. In fact, an Intergovernmental Organisation, the Fifteenth General Conference of Weights and Measures (May 1975) passed a resolution in which it is declared that the use of Co-ordinated Universal Time (UTC) as the basis of civil time is recommendable. Resolutions furthering that development were adopted at the IAU General Assemblies in 1970 and 1973.

Wm. Markowitz and H. M. Smith have represented the IAU on the Consultative Committee for the Definition of the Second (CCDS) and the Study Group No. 7 (Standard Frequencies and Time Signals) of the International Radio Consultative Committee (CCIR), respectively.

The activity of our Commission has been stimulated by the many letters of the members in response to the circular letters of the President. The exchange of views concentrated upon the actions to be taken by the IAU in order to achieve a single international terminology on time-scales, taking into consideration recent pronouncements by the CCDS and CCIR. Fundamentally, regret has been expressed that 'time-scale' has been also utilized to designate *integrated* time-scales as produced by atomic clocks, and not reserved – as from ancient times – for *observed* time-scales.

Commission 31 co-sponsored the Second Cagliari International Meeting on Time Determination, Dissemination and Synchronization. The meeting was initiated by the Astronomical Institute of the University of Cagliari and the International Latitude Station of Carloforte-Cagliari (Italy) and held 3–5 June 1974. It was attended by 35 persons, mainly astronomers and physicists. The 19 papers read represented a fair survey of present problems and activities in our field. The Italian authorities who made the meeting possible, and our Italian colleagues who made the excellent arrangements have earned the thanks and appreciation of all participants. The proceedings of the meeting were published, in 1975, by Edizioni Anastatiche, Cagliari.

## 2. EPHEMERIS TIME (ET)

About 2 decades after the first successful operation, in 1955, of a caesium beam standard there is considerable evidence that gravitational time and atomic clock time do not proceed at a constant relative rate. Van Flandern (*Monthly Notices Roy. Astron. Soc.* **170**, 333, 1975) analysed photoelectric observations of lunar occultations from 1955 to 1974 utilizing an atomic time-scale as reference time-scale, and obtained a value for the empirical part of the



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secular acceleration of the Moon's mean longitude of $-65'' \text{cy}^{-2}$. This differs by $-27'' \text{cy}^{-2}$ from other determinations which utilized an ephemeris time-scale derived from observations of the Sun. The resultant deceleration of the ephemeris time-scale with respect to the atomic time-scale amounts to $(50\text{s} \pm 35\text{s}) \text{cy}^{-2}$. The author suggests that the most probable cause of this phenomenon is a decrease in the Gravitational Constant at the rate of $8 \times 10^{-11} \text{yr}^{-1}$. Other causes cannot be excluded, as yet; changes may also occur at the atomic level. In any case, we must assert *pragmatically* that atomic phenomena produce a 'uniform' measure of time.

The 'Joint Report of the Working Groups of IAU Commission 4 on Precession, Planetary Ephemerides, Units and Time-Scales' to be submitted for approval at the IAU General Assembly in 1976 contains recommendations concerning the revision of the definition of ephemeris time. It is proposed that the general concept of ephemeris time as the independent time-argument of dynamical astronomy should be retained. However, ephemeris time is no longer to be defined in terms of the mean longitude of the Sun, but in terms of the readily available second of the International System of Units. A distinction is to be made between 'terrestrial (apparent) ephemeris time' and 'barycentric (co-ordinate) ephemeris time', as is necessary in a relativistic theory. Theoretically, each apparent ephemeris of a solar system body determines its own ephemeris time-scale; in practice, according to the proposed definition, very few of these are expected to differ significantly from each other or from International Atomic Time.

## 3. UNIVERSAL TIME (UT)

The BIH has continued to provide as a *Permanent Service* UT1 and polar co-ordinates based upon the determinations of UT0 and latitude by means of classical instruments, and the polar co-ordinates from Doppler satellite data processed by the Defense Mapping Agency, U.S.A. The use of other new techniques, such as local radio interferometers, satellite laser ranging, and – most promising as regards precision and accuracy – VLBI and lunar laser ranging, is still in the experimental state. The requirements for precise clock time, synchronization and/or frequency, which are involved within all these methods, can be met without major difficulties; moreover, the application of the whole of the potentialities available can be advantageous.

## 4. CO-ORDINATED UNIVERSAL TIME (UTC)

The CCIR Interim Working Party 7/1, under the chairmanship of H. M. Smith, has continued its work which may result in slight modifications to the provisions of CCIR Recommendation 460-1 (concerning the UTC system).

In order to complete the implementation of the UTC system, there remains the task for those familiar with time-scales to continue efforts of providing information of its particuliarities to users. It appears that some of the observing astronomers and surveyors are not yet aware that clock time UTC *approximates* only to rotation time UT1, and is conceptually quite different. Lack of knowledge may have led and – in future – may lead to confusion and errors.

## 5. INTERNATIONAL ATOMIC TIME (TAI)

According to measurements with primary standards, the TAI second departs from its defined value (SI second at sea level) by about $-1 \times 10^{-12}$ s. The question arises as to whether or not the BIH should remove that departure and, if so, how. Strict conformance with the 'Mise en Pratique' of TAI would call for the early adjustment in one step, and subsequent steering with appropriate use of calibrations by primary standards. However, such discontinuity in the TAI unit would inconvenience numerous users of TAI und UTC (which has, by definition, the same scale measure), for whom stability is more important than accuracy.

The IAU should consider carefully and give a pronouncement of its attitude to this matter.

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## 6. CHRONOMETRY

Primary caesium standards, recently developed or improved upon at the NBS (U.S.A.), NRC (Canada), and PTB (Federal Republic of Germany), are estimated to provide a relative uncertainty of $1 \times 10^{-13}$ to $2 \times 10^{-13}$, and a reproducibility of some $10^{-14}$.

With hydrogen masers, a short-term instability of less than $1 \times 10^{-14}$ has been attained; the long-term stability still remains rather a problem. For the construction of time-scales, so far hydrogen masers have not been used, other than as a means for high precision interpolation, but there is growing application e.g. in *VLBI*. Navigational requirements for outer planet missions of space probes will necessitate the use of hydrogen masers.

Research on the use of transitions in the optical range for frequency control is in progress. It seems too early, as yet, to be able to estimate whether or not such work may lead to a standard equivalent to the caesium standard.

In this context, it may be noted that the Fifteenth General Conference of Weights and Measures recommended a value to be used for the speed of electromagnetic radiation. The IAU had concurred in this proposal at the General Assembly in 1973. For reasons of consistency of the international system of units and constants it would seem to be desirable that the metre be redefined by the value of the velocity of light adopted as a basic constant, and the second.

## 7. TIME-SIGNALS

Almost all scientific time-signal transmissions conform to UTC within 0.2 ms. Most of them contain information about the value of DUT1; the U.S.S.R. time-signals and the station DIZ in the German Democratic Republic provide, in addition, dUT1 specifying UT1-UTC down to multiples of 0.02 s.

The stations BPV and XSG in the People's Republic of China continue to transmit time-signals which conform to UT1; signals which correspond in rate with UTC but differ from it bv about 20 ms, are transmitted via BPV on 5, 10, and 15 MHz and alternate with those giving UT1.

Time-signals are still an indispensable means of time determination for innumerable users, but their value for time intercomparisons between time services has gradually decreased with the introduction of much preciser methods of time synchronization.

## 8. SYNCHRONIZATION

LORAN-C has continued to be the most important means for time intercomparisons in the submicrosecond range, of time services in North America and Europe, mutually and with the BIH. The caesium standards located in the southern hemisphere and in the Far East cannot contribute, so far, to the formation of TAI. Synchronization once established by a travelling clock may be maintained over one year or more to within some $\mu s$ by a clock ensemble relying on its own stability, VLF phase tracking or/and – in the Far East – measuring 'approximate-synchronized' LORAN-C.

Time links via satellites are a potential possiblity for providing a world-wide service of precise synchronization. From experiments upon intercontinental measurements, an uncertainty of comparisons of some 0.1 $\mu s$ has been demonstrated. The General Assembly of the International Scientific Radio Union (URSI) held in Lima (1974) has recommended that such application of satellite techniques be studied and furthered.

Intercontinental time synchronization using *VLBI* appears promising. *Regular* application may become of significance when the Earth's rotation will be monitored by *VLBI* on a routine basis.

TV pulses are used in many countries for regular national and, in some cases, international time comparisons.

Intercomparisons in the nanosecond range using laser technology, between clocks carried by aircraft and ground station clocks have been planned.

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Clock transportation remains a necessity, as it is the only method which does not suffer from propagation and system delay uncertainties. This is an opportunity to place on record the appreciation to the U.S. Naval Observatory of all those concerned with international co-ordination in timekeeping, for USNO's outstanding efforts dedicated to the performance of numerous clock trips to all continents.

## 9. LITERATURE

Some fields of importance to Commission 31 cover subjects which are normally not documented in the astronomical literature. Recent information on such subjects is provided by the publications listed below. Sections 10 and 11, reports of the BIH, observatories and laboratories, give details of scientific as well as routine work, both of which are indispensable in our speciality.

1. Proceedings of the 4th (5th, 6th) Annual Precise Time and Time Interval (PTTI) Planning Meeting 1972 (1973, 1974).
2. IEE Conference Publication No. 113, IEEE CAT No. 74 (Papers presented at the CPEM 1974).
3. CIC 1974, Vol. A (Papers presented at the IXth International Congress of Chronometry 1974).

## 10. REPORT OF THE DIRECTOR OF THE BUREAU INTERNATIONAL DE L'HEURE (BIH)

The activities of the BIH on the Rotation of the Earth are presented to Commission 19 and will not be mentioned in this report.

### A. *International Atomic Time, TAI*

It is reminded that the International Atomic Time is established by the BIH in accordance with the Recommendation of the 14th General Conference on Weights and Measures.

Until 1969, TAI was obtained by frequency integration. In 1969, it became possible to compute it as a mean of readings of clocks intercompared by use of LORAN-C pulses with a submicrosecond accuracy.

During the period 1969–1973, the averaging of the clock readings was made in two steps. First, the laboratories established their local independent time scales AT(i), and then TAI became a mean of the AT(i)'s. 7 AT(i)'s participated.

In July 1973, the BIH began to compute TAI direct from the data of atomic clocks. This new procedure has been preferred because it uses a common criterion for weighting the data of clocks of similar design, and it makes possible the use of good clocks which do not participate in the formation of an AT(i).

Up until May 1975, the data includes only the readings of commercial caesium clocks. In 1974, for instance, the data of 87 clocks belonging to 15 laboratories of North America and Europe were entered in the TAI evaluation. It is expected that in 1975 it will be possible to add the data of Japanese and Australian clocks, following the improvement of the time link, via satellites and LORAN-C, with these countries. In May 1975, the BIH began to receive the data of the continuously operating primary standard of the National Research Council of Canada.

From May to December 1974, the LORAN-C time link across the Atlantic gave rise to irregularities up to 1 $\mu$s and the publication of the TAI-AT(i) and UTC-UTC(i) had to be delayed. However, thanks to the clock trips organized by the U.S. Naval Observatory, it was possible to restore the continuity of the published values and, after amendments by a few 0.1 $\mu$s, their usual accuracy.

Over an averaging time of about 3 months or above, the random noise of TAI follows a frequency flicker noise modulation model with $\sigma = 0.5 \times 10^{-13}$.

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The calibrations of TAI by the primary standards of the National Bureau of Standards, the National Research Council and the Physikalisch-Technische Bundesanstalt showed that, in 1974, the frequency of TAI was too high by $1 \times 10^{-12}$. In addition, there are some indications that the TAI frequency decreased by about $1 \times 10^{-13}$ per year. This might be due to common effect in the ageing of the participating clocks.

We developed an optimum filter to be applied to frequency calibrations, derived from the work of Yoshimura (*NBS Technical Note* 626, 1972). This filter takes into account the accuracy and reproducibility errors. It was shown that the 'steering' of TAI with a sufficient time lag can improve its very long term stability, simultaneously with its accuracy, without deterioration of the short term stability (Guinot, *Proc. Second Cagliari Intern. Meeting*, 1974). The frequency steering of TAI was recommended by the Comité Consultatif pour la Définition de la Seconde in 1974, but was postponed until the data of the caesium standards under developement in Japan and the United Kingdom are known. In addition, an initial step adjustment of the TAI frequency is to be made before the steering.

### B. *Universal Time Co-ordinated, UTC*

The UTC system is implemented by the BIH. The announcements of the leap seconds and of the values DUT1 were issued regularly.

The values of UTC-UTC(i), UTC(i) being the approximation to UTC kept by the laboratories, are published monthly for 18 laboratories with an approximation of a few 0.1 $\mu$s. In addition, for 4 laboratories of Asia, they are given to ± 5 $\mu$s in the Annual Reports.

With the financial assistance of the host laboratories and of the Paris Observatory, clock synchronization trips were organized in the German Democratic Republic, Holland, the Federal Republic of Germany, Czechoslovakia and Brazil.

### C. *Management of the BIH*

As a consequence of the agreement with the Comité International des Poids et Mesures, an assistant of the Bureau International des Poids et Mesures works on the TAI at the BIH.

The Annual Report of the BIH is published with a delay of 6 months beyond the end of the year it covers. In addition to the data on the TAI, UTC and on the rotation of the Earth, the Report gives a list of time-signals up-dated every year by direct contact with the laboratories. In order to save time and money, most of the tables of the Reports are now direct reproductions of machine listings.

A check of the mailing lists is made approximately every two years. The number of circulated copies of circulars and Reports is given as follows:

| | | | |
|---|---|---|---|
| Circular A (annual) | Conventional value of UT2-UT1 | Copies: | 130 |
| Circular B/C (monthly) | Interpolated and extrapolated values of UT1-UT0 | Copies: | 60 |
| Circular D (monthly) | Current results of the BIH | Copies: | 650 |
| Circular E (irregular) | Announcement of leap seconds | Copies: | 250 |
| Circular F (irregular) | Announcement of DUT1 | Copies: | 50 |
| Annual Report | | Copies: | 650 |

## 11. REPORTS OF OBSERVATORIES AND LABORATORIES

### A. *Argentina, Instituto Geografico Militar, Villa Maipu, Buenos Aires*

Routine observations of UT0 have been made, with a transit instrument and a Danjon astrolabe.

For timekeeping, an Oscillation B-5000 caesium clock and 3 quartz-crystal clocks have been used. A second high performance atomic clock is to be installed in 1976. The caesium clock has been compared with USNO's Master Clock by means of a flying clock. Regular comparisons with the Observatorio Naval's Master Clock have been made using TV. 3 VLF receivers have been in operation.

Radio time-signals have been transmitted on high frequencies four times daily via LQC20 and LQB9. The results obtained are forwarded regularly to the BIH.

### B. *Australia. Division of National Mapping, Canberra*

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

The Australian co-ordinated time-scale UTC (AUS) was established on 1 January 1973. It is based on a small, variable ensemble of caesium standards compared regularly by the TV method, and is a free-running time domain scale with a prediction capability of the order of 1 μs over a 600 day interval.

Due to its distance from Europe and America, UTC (AUS) cannot make use of LORAN-C or VLF methods for reliable comparison with other time-scales, especially those of the BIH and the USNO. Hence, so far, it relies for its relation to these time-scales on infrequent flying clock visits from USNO, its own stability and Timation satellite experiments.

### C. *Belgium. Observatoire Royal de Belgique, Uccle/Brussels*

Astronomical observations for the determination of Universal Time have been performed with Danjon astrolabes. The Doppler tracking station integrated into the Dahlgren Polar Monitoring Service has continued operation.

The Brussels Time Service has, in the main: (a) Two HP 5061 caesium standards, one of which has been modified by installation of a high performance beam tube; (b) A visual LORAN-C receiver, in use since 1972, the results of which are sent to the BIH on a monthly basis.

During September 1975, a TV receiver (model Parcelier) was tested and, since October 1975, it has been used for daily time intercomparisons with the BIH.

### D. *Brazil, Observatorio Nacional, Rio de Janeiro*

The local time-scale is based upon 2 HP caesium standards (a 5061A standard tube and a 5061A high performance tube) which are compared regularly, by clock transport and the line-10 TV method, with 4 caesium standards of other laboratories. Additional equipment includes 2 rubidium standards.

Comparison with UTC is made by means of USNO and U.S. Coast Guard flying clocks. An indirect comparison in co-operation with the Mackensie Radio Astronomy and Astrophysical Center at Atibaia, state of Sao Paolo, using results of VLBI observations is expected soon. Receptions of HF and VLF are continued and Omega is to be commenced.

This Time Service is responsible for time-signal transmissions in HF and VHF, and a new station is being installed at Brasilia to transmit standard frequencies and time-signals. In co–operation with the National Institute of Metrology, Normalization and Industrial Quality, the synchronization of the time-scales of various Brazilian laboratories is continued.

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E. *Czechoslovakia. Prague*

The time UT0 is regularly determined at 3 stations by small transit instruments and at 2 stations by circumzenithals. The work of PZT on an experimental basis is being continued.

The local time-scale UTC(TP) based on a caesium standard is regularly compared with time scales kept at the Braunschweig, Hamburg, and Potsdam stations using the TV method calibrated by the clock transportations in 1973 and 1974. The transmission of the permanent time-signals OMA 50, OMA 2500 and OLB5 continues.

F. *France. Commission Nationale de l'Heure*

I. *Générateurs de fréquence*

Pour les travaux courants, ainsi que pour la formation du temps atomique français TA(F), la référence est une batterie de 10 étalons commerciaux à jet de césium, situés dans plusieurs établissements et comparés entre eux en permanence au moyen des impulsions de la télévision à moins de 0.1 $\mu$s près. La référence pratique, notamment pour les comparaisons internationales de temps est UTC(OP), approximation de UTC à $\pm$ 5 $\mu$s près, issu d'une des horloges à césium de l'Observatoire de Paris.

Bien qu'on n'ait pas construit d'étalon à jet de césium en France, le Laboratoire de l'Horloge Atomique a essayé, au NRC, une méthode nouvelle pour évaluer l'effet Doppler du second ordre. A l'Institut d'Electronique Fondamentale, on a étudié le pompage optique hyperfin des jets de césium ainsi que les oscillateurs micro-ondes à cavité supra conductrices.

Plusieurs masers à hydrogène ont été construits par le Laboratoire de l'Horloge Atomique dont un, construit en collaboration avec le Centre National d'Etudes des Télécommunications (CNET), est réservé aux problèmes métrologiques et doit entrer prochainement dans le calcul de TA(F) et de TAI. Il est muni d'un accord automatique de la cavité résonnante de sorte que ses défauts de stabilité à très long terme doivent être inférieurs à $1 \times 10^{-13}$ (Petit *et al.*, *CIC 74,* A 1.5).

Le développement des étalons de fréquence dans le domaine optique (890 GHz à 474 THz) a fait l'objet d'un programme coordonné par le Bureau National de Métrologie (B.N.M.). Les différents lasers sont déjà réalisés (Clairon, Henry, *Compt. Rend. Acad. Sci. Paris* 279, 14 Oct 1974, Sér. B; Brillet *et al.*, *IEEE J. Quantum Electr.*, *QEIO*, no 6, 1974). La chaîne de raccordement qui permet la mesure absolue des fréquences de ces lasers par rapport à l'étalon primaire de fréquence (césium) sera assemblée en 1976 au Laboratoire Primaire de Métrologie des Fréquences, créé par le BNM et installé à l'Observatoire de Paris.

II. *Comparaisons de temps – Diffusion du temps*

La méthode utilisant les impulsions de la télévision permet maintenant d'atteindre une précision de quelques ns, en vue d'un émetteur commun. Il apparait qu'on peut encore faire mieux et l'on y travaille à l'Observatoire de Paris.

L'emploi d'impulsions de lasers, dans une phase initiale, a permis à l'Office National d'Etudes et de Recherches Aérospatiales de transporter le temps à moins de 1 ns près sur quelques km (Besson, Parcelier, *CIC 74,* A 2.6). Cette méthode sera employée lors d'une expérience de synchronisation entre l'Espagne, l'Italie et la France, par horloge aéroportée, prévue pour la fin de 1975. Elle pourrait être employée en prenant pour cible un satellite.

Des transports d'horloges à césium ont été organisés par l'Observatoire de Paris en Hollande, R.D.A., R.F.A., Tchécoslovaquie. Un transport en U.R.S.S. a été fait en Octobre 1975.

Le CNET a expérimenté avec succès une diffusion codée de l'heure par modulation de phase de la porteuse d'un émetteur de radiodiffusion à modulation d'amplitude.

III. *Travaux sur la caractérisation des oscillateurs et la formation des échelles de temps*

L'incertitude sur la caractérisation dans le domaine temps de la stabilité de fréquence d'oscillateurs très stables, due au nombre fini de mesures a été établie théoriquement. Les

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résultats ont été confirmés par l'expérience pour le bruit blanc de phase et le bruit flicker de fréquence.

Une analyse théorique a permis d'introduire de nouveaux concepts pour la caractérisation dans le domaine temps de la stabilité de fréquence à court terme. Il en est résulté, sur le plan expérimental, la mise en oeuvre d'une nouvelle technique de mesure de la variance d'Allan.

Des appareils permettant la caractérisation des oscillateurs, dans les domaines temps et fréquence, ont été réalisés. L'un deux permet le tracé automatique de la courbe de stabilité (Laboratoire de Physique et de Métrologie des Oscillateurs).

TA(F) est calculé par un algorithme proche de celui qu'utilise le BIH, mais les échantillons de fréquence sont pris sur un mois au lieu de deux.

### G. *France. Stoyko, Paris*

M. et Mme. Stoyko ont continué l'étude du temps des Éphémérides par rapport à l'éphéméride améliorée de la Lune et au temps atomique. Le tableau des valeurs améliorées de ΔT est publié dans *l'Annuaire Astronomique de l'U.R.S.S.*, 1976, p. 643 et 1977, p. 643.

### H. *Federal Republic of Germany. Deutsches Hydrographisches Institut, Hamburg (DHI)*

The determination of UT0 has been continued with the PZT. UTC(DHI) has been compared regularly with the UTC's of other time services using LORAN-C, LF, and the TV method. Time-signal transmissions DAM, DAN, and DAO have remained unchanged. A second HP 5061A caesium standard was purchased in 1975. A phase-lock device has been applied to the LORAN-C receiver by which synchronization between the output frequency of a quartz clock and the LORAN-C signal is maintained.

### I. *Federal Republic of Germany. Physikalisch-Technische Bundesanstalt, Braunschweig (PTB)*

#### I. *Primary Time and Frequency Standard CS1*

After realignment and reduction of the average beam velocity to about 105 m $s^{-1}$, the estimated uncertainty of the PTB standard CS1 is now $1 \times 10^{-13}$. The square root of the sum of squares of the uncertainty contributions is $3 \times 10^{-14}$ (Becker, *CIC 74*, A1.1). TAI frequency measurements between 1969 and 1973, with respect to CS1, revealed a TAI frequency systematic decrease of more than $1 \times 10^{-13}$/year. The frequency was too high: about $1.5 \times 10^{-12}$ in 1969, and $1.1 \times 10^{-12}$ in 1973. In 1975, a deviation of nearly $1 \times 10^{-12}$ is still in existence. Results of measurements of the frequency of AT(PTB) have been communicated to the BIH direct, ever since 1973.

#### II. *Theory of Time-Scales*

Becker (*Proc. Second Cagliari Intern. Meeting* 1974) amongst others, proposed to distinguish clearly between time in the sense of a time concept based on theoretical assumptions on one hand, and time in the sense of time-scales (with existing time markers) on the other hand. Distinction should not be made between 'observed' (astronomical) and 'integrated' (atomic) time as astronomical and atomic periods do not differ in principle. That paper deals with the relativistic effects on time scales, and recommends that TAI be used direct for astronomical measurements. Relativistic corrections should not be applied to TAI, but should be applied to the measurements.

#### III. *Realization of Time-Scales*

Hübner and Becker (*CIC 74*, A.1.4.) proposed a new weighting method for the production of time-scales.

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According to the Algos results of the BIH, the PTB commercial clocks, on average, achieve the highest weight. For the production of AT(PTB), the 0/1 weighting method is still used with great success. There are now commercial caesium clocks at the PTB, 2 of high performance. The long-term stability of one of the latter is unsatisfactory.

AT(PTB) is not controlled by CS1 direct. UTC(PTB), as calculated, is realized twice by the use of two rate-corrected clocks. The actual UTC(PTB) time-scale normally differs less than 30 ns from the UTC(PTB) paper clock.

IV. *Time Comparisons*

3 LORAN-C receivers are used in parallel for the reception from the Sylt transmitter. VLF phase trackings are made for transmitters GBR and NAA. TV time comparisons are made with DHI, ZIPE, and Prague.

V. *Transmission of Time and Frequency*

The transmitter-power of DCF77 has been increased to 50 kW. In 1973, a time code was added which – between second markers 20 and 58 – transmits at minute intervals the values of minute, hour, day, day of the week, month, and year, in the Official Time of PTB(CET). Commercial decoding devices are now available. The DCF77 carrier phase time is remotely controlled to be stable to within a few tenths of 1 μs in respect of UTC(PTB).

### J. *German Democratic Republic. Zentralinstitut für Physik der Erde, Potsdam (ZIPE)*

Universal time has been determined with an astrolabe and, from 1 January 1975 onwards, also with PZT.

UTC(ZIPE) was formed from a group of quartz clocks until replaced, at the beginning of 1975, by an HP caesium standard. This time-scale has been compared with that of other time services using VLF, LORAN-C, and the TV method. In November 1973 a direct intercomparison between UTC(ZIPE) and UTC(OP) took place by means of a travelling clock.

Since 1 February 1974, time-signal transmissions via DIZ have been the responsibility of the Amt für Standardisierung, Messwesen und Warenprüfung (ASMW), and no longer of ZIPE. The time-scales UTC(ZIPE) and UTC(ASMW) are co-ordinated.

### K. *Italy. Instituto Elettrotecnico Nazionale, Turin (IEN)*

The Time and Frequency Section of the Institute carries out researches into optically pumped caesium and magnesium beam frequency standards.

The IEN time-scale is generated by 4 HP 5061A caesium beam frequency standards (one with a high performance tube). An HP 5082A caesium standard and 2 rubidium standards are also available.

Time comparisons are performed by 3 LORAN-C receivers and 4 LF and VLF receivers. Time and frequency disseminations are carried out over: (a) The national radio and TV networks of Radiotelevisione Italiana (RAI); (b) The IBF transmitter (5 MHz); (c) Two VHF transmitters (155–160 MHz); (d) Telephone lines.

### L. *Japan. Tokyo Astronomical Observatory (TAO)*

Time and latitude observations have been made with the PZT. The instrument has been driven completely by sidereal frequency since May 1975.

Of 3 HP caesium clocks, clock No. 3 (5061 A) was in use as the master clock until February 1975. After that, the clock was replaced by clock No. 2 (5061 A). Clock No. 4 equipped with supertube, was installed in April, and the old beam tube of clock No. 3 was replaced by a super-tube in July 1975.

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Two phase micro-steppers (Austron) were installed, the one in 1973 and the other in 1975. These micro-steppers will be used as master clocks in 1976 to keep mean clock made of 4 HP caesium oscillators.

Sidereal time has been maintained by driving a mean solar clock by the master oscillator through a frequency offsetter ($-350 \times 10^{-10}$) and a sidereal converter (2313/1661 x 355/493).

An experiment to prove the potential red-shift was conducted by the use of caesium clocks Nos. 3 and 4 during 4 weeks in August 1975. Clock No. 3 was carried up to the Norikura Coronagraph Station of the TAO (2876 m altitude), and clock comparison against clock No. 4 placed at Mitaka (58 m altitude) was obtained by receiving LORAN-C signals from the Iwojima master station of the North-West Pacific Chain. Fractional frequency difference by about $+2 \times 10^{-13}$ from Mitaka to Norikura was obtained preliminarily without applying corrections for different environmental conditions in atmospheric pressure and temperature etc. between the two sites.

Receptions of radio time-signals have been made regularly on JJY (2.5 MHz), WWV (15 MHz), WWVH (15 MHz), and RID (15 MHz). VLF and LF signals – NLK (18.6 kHz), NWC (22.3 kHz), and JG2AS (40 kHz) – have been received. LORAN-C signals from the Iwojima master station have been received by an exclusive receiver (Austron 2000C) since 1973.

Since 1973, clock comparisons by TV signals have been made once a day between the Kanozan Geodetic Observatory (KGO); and, once a week, against those of RRL, NRLM, and ILOM, with the precision of 0.1 $\mu$s except for that of ILOM which is situated about 500 km from Tokyo.

### M. *Japan. International Latitude Observatory of Mizusawa (ILOM)*

Time and latitude observations have been made with the PZT and the astrolabe. Another PZT was installed in 1973, and routine observation with this new PZT has been in effect since March 1974. Whereas, the routine observation with the old PZT was suspended in May 1975.

HP caesium oscillators, No. 1 (5060 A) and No. 2 (5061 A), and a rubidium gas-cell oscillator have been used for keeping time. Another HP caesium oscillator equipped with super-tube, No. 3S (5061 A), has been in operation since August 1974. Clock No. 1 had been used as the master clock until July 1973, and after that was replaced by clock No. 2.

VLF signals, NLK (18.6 kHz), and LORAN-C signals from the Iwojima master station have been received. Clock comparisons by TV signals through microwave relay link have been made on a routine basis against TAO, RRL, and NRLM with the precision of 0.6 $\mu$s in every 5-day mean.

### N. *Japan. Hydrographic Department (JHD)*

In order to determine ET, occultation observations have been made on a routine basis at the Head Office in Tokyo and at three branch observatories in the countryside. Number of data acquired per annum exceeded 800, including 300 data of photo-electric observation. Data and results of observations have been published annually in the *Data Report of the Hydrographic Observations, Series of Astronomy and Geodesy*. Results from 1969 to 1974 are summarized as follows:

| | ET2-TAI | m.e. |
|---|---|---|
| 1969.5 | 30.61 | ± 0.14 |
| 1970.5 | 30.38 | 0.20 |
| 1971.5 | 30.54 | 0.14 |
| 1972.5 | 30.72 | 0.15 |
| 1973.5 | 30.78 | 0.06 |
| 1974.5 | 30.67 | 0.05 |

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### O. *Japan. Radio Research Laboratories (RRL)*

A system of working frequency standards which had been in preparation since 1973 has been completed and put into effective use, in the new building of the RRL, from the beginning of 1975. The system consists of 7 HP caesium oscillators, 2 of which are equipped with super-tubes and automated measuring equipment. UTC(RRL) is kept by this system.

2 new hydrogen masers are under construction, in addition to 2 old hydrogen masers which have been in use so far for various investigations.

Transmissions of JJY signals have been controlled effectively by a caesium oscillator from April 1975, in the same manner as JG2AS (40 kHz). Station JJY is scheduled to be moved to the new transmitting site in 1977, the preparation for which is in progress.

Clock comparisons by TV signals have been made on a routine basis, since 1974, against clocks of TAO, NRLM, and ILOM. Reception of VLF signals, NLK (18.6 kHz), and LORAN-C signals from the Iwojima master station have been continued. Receptions of Omega signals commenced in 1975 from 3 stations, North Dakota, Hawaii, and Japan.

An experiment for precise clock comparison via earth satellite ATS-1 was conducted in August 1975 between Kashima Station (RRL) and Rosman Station (NASA) with the co-operation of NASA and USNO. An HP caesium oscillator equipped with super-tube was used at each station. Precision better than 10 ns is expected, because – in this experiment – the pseudo noise modulation was used as well as the two-way method. Diurnal variations, effects of ionospheric layer, etc. are scarcely observable in the preliminary result. Reduction of data is under way.

### P. *Japan. National Research Laboratory of Metrology (NRLM)*

A caesium beam primary standard (NRLM-I) constructed in 1971, is now being improved as concerns the homogeneity of the C-field and the evacuating system.

The second primary standard (NRLM-II) was constructed in 1975. The S/N ratio has been shown to be remarkably improved owing to the adoption of a shorter interaction length of 1.2 m which was useful to attain higher homogeneity in the C-field and to make the evacuating system more effective. The short term stability is estimated as $0.8 \times 10^{-11}\ \tau^{-1/2}$ where $\tau$ is in seconds, and the long term one as $0.8 \times 10^{-13}$ for $\tau = 10^4$s. Evaluation of resettability and accuracy is now in progress.

The beam tube of the HP caesium oscillator installed in 1970 (5061A) was replaced by a new one in 1974. Another HP caesium oscillator equipped with super-tube has been recently installed, and in operation since 1974.

Clock comparisons by TV signals were commenced against RRL and ILOM in 1972, and against TAO in 1973.

### Q. *South Africa. National Physical Research Laboratory, Pretoria*

When in January 1972 the Republic Observatory in Johannesburg, which had been responsible for time in South Africa since 1910, was incorporated in the new South African Astronomical Observatory, the Time Department was transferred to the Precise Physical Measurements Division of the National Physical Research Laboratory in Pretoria.

In September 1972 an additional ZUO transmission was started on 2.5 MHz. Operating only between $18^h$ and $4^h$UT, this transmission has proved invaluable to users within a few hundred kilometres of the transmitter – mainly astronomers and surveyors – who had often experienced a complete failure of the 5 MHz signals after dark.

Since the beginning of 1974 regular monthly clock trips using an HP rubidium clock have been made to the French Satellite Tracking Station at Paardefontein, and more recently to the S.A. Bureau of Standards, which at the end of 1974 obtained its own caesium clock.

South Africa therefore now has 2 caesium clocks permanently installed, but for a country which is so far from the world's major time centres this is hardly adequate to guarantee an uninterrupted service. Precise time comparisons with other centres have in recent years been carried out with the aid of portable caesium clocks, generally sent for specific projects by the USNO and other organisations. 1973 saw one such comparison, and 1974 two, but there were none in 1975, and the present position gives rise to some concern. With the closing of the Hartebeeshoek Space Station it is less likely that such visits will take place in future, and a more satisfactory arrangement will have to be found.

No decision has been taken on the proposals for the installation of a PZT or other instrument for astronomical time determination, and it is most unlikely that anything will be done in this direction within the foreseeable future.

R. *Spain. Instituto y Observatorio de Marina San Fernando, Cádiz*

Routine observations of UT0 have been made with the Danjon astrolabe.

Ephemeris Time is observed traditionally by means of occultations of stars by the Moon. Field expeditions for observation of grazing occulations are organized whenever possible. The data of occultations made at Cádiz and San Fernando, preserved in the archives from 1773 onwards, has been collated. The interval 1960-1974 using $j = 2$ ephemeris has been analyzed.

Atomic Time has been studied from 1972 onwards; collaboration with the BIH for TAI began in 1973. Some improvement in equipment has been achieved, in the main: (a) An HP 5061 A caesium oscillator has been added and completed with a digital clock constructed at the Observatory; (b) An HP portable rubidium standard was purchased to serve as travelling clock; (c) A second LORAN-C receiver (Austron 2000C), and a Tracor linear phase time comparator have been received on loan from the USNO.

A 1 KW HF transmitter has been installed and preliminary transmission tests are being carried out.

From January 1973 onwards, a local UTC scale generated by a maximum of 4 atomic clocks (including one rubidium) was established for national time and frequency needs.

From 1973 to 1975, San Fernando has been included in 3 of the USNO travelling clock trips for global synchronization. National co-ordination with other official and private laboratories using atomic clock transportations was initiated during 1975.

Co-operation with ONERA (France) and the Paris Observatory to perform a flyover clock synchronization experiment using laser technology has been initiated. It is hoped to achieve nanosecond range accuracy.

S. *U.K. Royal Greenwich Observatory (RGO)*

Observations of UT0 have been made continuously with the Herstmonceux PZT.

The Greenwich atomic time-scale, GA2, has been determined from selected caesium beam standards at RGO; all are commercial atomic clocks of the type HP 5060 A and HP 5061 A. A sixth clock, with one of the new high performance beam tubes, was purchased at the end of 1974 and brought into operational use early in 1975. Rate corrections have been applied to the clocks in order to maintain the uniformity of GA2 which is an independent atomic time-scale. The frequency of GA2 has been within about 5 parts in $10^{13}$ low on TAI. UTC(RGO) is derived from GA2; since 1974 January it has been adjusted by means of a rate correction to bring UTC(RGO) into close agreement with UTC(BIH).

The atomic clocks have been intercompared with a resolution of 10 ns. Prototype equipment for measuring time comparisons to sub-nanosecond resolution has been designed and tested.

Measurements of LORAN-C signals from Ejde and Sylt in the Norwegian Sea Chain and Estartit in the Mediterranean Sea Chain have been continued. In addition, measurements of Ejde in the North Atlantic Chain commenced in 1975 April in order to monitor directly the difference between the two chains and so increase the accuracy of time transfer across the Atlantic. The results of comparisons of individual atomic clocks with the LORAN-C signals have been communicated to the BIH for use in the formation of TAI.

As part of a joint US-Australian-British satellite experiment the Naval Research Laboratory, Washington, has lent the RGO a NTS timing receiver. The experiment, which commenced in 1975 July, is intended to evaluate time transfer techniques for global clock synchronization using the Navigational Technology Satellite, NTS-1, previously known as TIMATION 3.

The Greenwich Time Reports have been published quarterly and contain the results of the PZT observations, the Greenwich Atomic Time-Scale and corrections to radio time-signals. Monthly Time Service Circulars, series B, have given results of LORAN-C measurements and VLF phase comparisons.

An ephemeris time-scale for the period 1677–1973 has been derived from a recent analysis of the collected timings of the Transits of Mercury (*Monthly Notices Roy. Astron. Soc.* **173**, 1975). This ephemeris time-scale is in closest agreement with that derived from observations of the Moon when a value of $-26'' \text{ cy}^{-2}$ is used for the tidal deceleration of the Moon in its orbit.

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

#### I. *Very Long Baseline Interferometry*

A series of 8 *VLBI* experiments concluding 30 April 1973 has been reduced to obtain source position corrections and estimates of Earth rotation rate, using the Deep Space Network stations at Goldstone, California, and Madrid, Spain. Results have been compared with corresponding data derived from spacecraft tracking and optical astrometry. The mean value of UT1(BIH) during the eight experiments was assumed, and corrections were calculated for each experiment from the mean value. Corrections ranged from 0.13 ms to −1.1 ms over a two month period.

#### II. *Spacecraft Navigation*

High precision navigation of Mariner 9 to Mars and Mariner 10 to Venus and Mercury has shown that existing BIH data is adequate for Viking (Fliegel and Wimberley, *NASA-JPL Techn. Rep.* 32-1587, 1974), but *VLBI* may be needed to support outer planet missions. It is proposed, subject to final NASA approval, that the NASA-JPL Deep Space Network (DSN) determine UT1 and polar motion weekly to the demonstrated *VLBI* accuracy of 50 cm during the Mariner Jupiter-Saturn (MJS) mission, beginning in 1977, using antennas at Goldstone, California, at Canberra, Australia, and at Madrid, Spain.

#### III. *Time and Frequency Synchronization*

It has been established that data routinely available during a planetary space mission can be used to determine frequency offsets between widely separated antennas, after the fact, to a precision of 1 part in $10^{12}$ under fair conditions, and to about 1 part in $10^{13}$ under the best conditions.

Data acquired using a 9-m truck-transportable *VLBI* antenna and an HP rubidium standard, interacting with the hydrogen maser at the 64-m DSS14 antenna at Goldstone (180 km away) shows that clock offset can be solved for after the fact to better than 1 ns. Thus, it is possible to establish time synchronization virtually anywhere using *VLBI*; it is not necessary that both antennas be large, permanently fixed installations. There are three limitations:

(1) JPL is now limited to short baselines (< 300 km), largely because of the ionosphere. However, it will be able to operate intercontinentally when X-band or dual channel operation is available.

(2) Clock and frequency offsets are determined only weeks after the fact, because of the extensive computer processing required.

(3) What is called 'clock offset' refers to a whole antenna system – including cable delays, antenna and circuit delays – and not just the oscillator. The limit on the practical accuracy attainable at the clock will probably be set by the measurement of total system delays.

### U. *U.S.A. The University of Texas at Austin*

Different aspects of the problem of experimental determination of UT0 for the McDonald

Observatory by means of lunar range observations have been examined by J. D. Mulholland, P. Bender of JILA, J. G. Williams at JPL, and Slade at MIT. There is of course no possibility of obtaining UT1 from the McDonald data alone, and as yet there are essentially no other data. The principle conclusions that may be drawn from these various researches are as follows: (a) The median accuracy of UT0 determined from lunar ranging on individual days with at least a spread of three hours between first and last observation is less than 0.5 ms; (b) The results are not inconsistent with the present uncertainties in UT1(BIH); (c) The use of Vondrak-smoothed values for BIH data appears to give better results than the less sophisticated smoothing used in circular D; (d) The data indicate a small annual residual fluctuation relative to the BIH values of UT1; (e) There appears to be very little power in the high frequency spectrum in UT0 from these measures.

### V. *U.S.A. U.S. Naval Observatory (USNO)*

Routine observations of UT0 have been made continuously with PZT No. 3 in Washington and PZT No. 2 in Richmond. Observations with Danjon astrolabes at both stations continued. Planetary observations at both stations were begun in 1973.

UTC(USNO) is based on A.1 (USNO, MEAN). This local independent scale is kept as the mean of nominally 16 caesium beam frequency standards. In addition to HP 5060 A and 5061 A models 12 'super' tube models are used. These are stable to about $1 \times 10^{-14}$ for 10 days. An H-maser is used as a very high precision interpolation oscillator. Observations and monitoring results are published in various series of Time Service Announcements.

Portable clock trips were performed regularly to many observatories and laboratories which contribute to the BIH. Results are published in Time Service Announcements, Series 4.

Time measurements via the Defense Satellite Communications System are given in Time Service Announcements, Series 16.

The real time transfer technique via television introduced at the Third Annual PTTI Planning Meeting, 16–18 November 1971 has been implemented at Channel 5 in Washington, DC.

#### I. *PZT Instrumentation*

The construction of PZT No. 6 is complete. This instrument has an apochromatic lens of 20 cm aperture and will be operated in Richmond, FL, on completion of a new building.

Construction of the 65 cm PZT has been completed. The tube was installed in May 1974 by Boller and Chivens and the lens (designed by Perkin-Elmer) in December 1974. Since then, the instrument has been undergoing extensive testing. There have been several modifications made to the original design of several components. The environmental control system has proven to be the major component which has caused the most trouble.

#### II. *Astrolabe Instrumentation*

In Washington the astrolabe was completely repaired in the Fall of 1974 and observations resumed. The old DC motor is to be replaced by an electronic motor in January 1976.

### W. *U.S.S.R.*

Le temps universel aux moments des émissions des radiosignaux est calculé dans le système TU1 d'après les résultats des observations des 11 services horaires de l'U.R.S.S. et aussi des trois services horairers de la République Socialiste de Tchécoslovaquie, de deux services horaires de la République Populaire de Pologne, des services horaires de la République Démocratique Allemande, de la République Populaire de Bulgarie, de la République Socialiste Fédérative de Yougoslavie, de la République Socialiste de Roumanie (à partir de 1974) et de la République Populaire de Mongolie (à partir de 1975) participant au travail du Service Horaire de l'U.R.S.S. à titre de libre coopération.

Jusqu'à 1975 en calculant le temps universel, les observations astronomiques ont été réduites

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au pôle moyen de l'époque des observations et les résultats ont été publiés dans les bulletins mensuels *L'heure étalon*. A partir de 1975 on utilise une nouvelle méthode de calcul du temps universel basée sur l'application de la théorie des probabilités pour l'élimination des erreurs systématiques et pour le lissage d'observations. Les résultats obtenus donnent l'information plus détaillée sur les changements de la vitesse de la rotation de la Terre avec les périodes dépassant une semaine.

Simultanément avec l'application de la nouvelle méthode à partir de 1975 on utilise les coordonnées du pôle relativement à l'OCI. Le système du temps universel de 1975 coïncide pratiquement avec le BIH System 1968 (la divergence moyenne pour la période de 1975 est égale à 0.8 ms). Les résultats des calculs sont publiés dans les bulletins semainiers (les données urgentes obtenues avec les valeurs préalables des coordonnées du pôle) et dans les bulletins trimestriels (les valeurs définitives calculées avec les coordonnées du pôle d'après les données du BIH).

En U.R.S.S. les déterminations astronomiques du temps universel ont été effectuées à l'aide des 11 instruments photoélectriques de passage et des 3 instruments visuels de passage, des 5 astrolabes à prisme Danjon, d'un PZT. Le traitement des observations sur les instruments de passage s'est effectué dans le système du Catalogue général des ascensions droites des étoiles des services horaires de l'U.R.S.S. (KCB) avec l'utilisation de nouveaux valeurs des mouvements propres des étoiles (*Traveaux Obs. Princ. Astron. Poulkovo,* série 11, *XXVIII,* Léningrad, 1971).

En R.P.B. et R.S.R. les observations astronomiques sont effectuées à l'aide de l'instrument visuel de passage et en R.P.P. sur l'instrument photoélectrique et les 2 instruments visuels de passage.

On a effectué les travaux sur l'automatisation des observations sur l'instrument de passage (à Riga), sur le perfectionnement de la méthode photoélectrique de l'enregistrement des passages des étoiles (à Moscou, Kharkov et à Irkoutsk). On a continué les observations sur les 2 instruments photoélectriques de passage avec l'isolation thermique renforcée et la stabilité mécanique élevée (à Poulkovo). On a étudié l'influence du milieu ambiant sur les résultats des observations (à Poulkovo, Leningrad, Riga, Nicolajev, Irkoutsk). On a étudié le coefficient de réfraction de l'air après les données des études aérologiques (à Irkoutsk). On a étudié la liaison de l'irrégularité de la rotation de la Terre avec certains phénomènes géophysiques (à Novossibirsk, Moscou, Kharkov). La bibliographie des travaux soviétiques concernant le problème de la détermination du temps universel a été publiée dans les numéros de décembre du bulletin 'L'heure étalon'.

Les échelles locales atomiques sont basées: en U.R.S.S. – l'échelle UTC(SU) sur le groupe de générateurs à césium et d'hydrogène; d'autres services horaires de l'U.R.S.S. – sur l'horloge à quartz ou l'horloge quantique; en R.D.A. et R.S.T. – sur l'horloge à césium; en R.P.B., R.P.P. et R.S.R. – sur l'horloge à quartz.

La comparaison des échelles locales du temps entre elles et avec le BIH s'effectué par l'intermédiaire des canaux de télévision, de la réception des signaux LORAN-C, des comparaisons de phase des fréquences des radiostations et aussi à l'aide des horloges transportables.

H. ENSLIN
*President of the Commission*