31. **TIME** : (Heure)

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Introduction

The work of IAU Commission 31 is contained in the following sections contributed by the Members.

The two Working Groups installed during the period 1984-1987 :

"The Use of Millisecond Pulsars and Timing of Pulsars"
and
"Time Transfer with Modern Techniques",

chaired by D. ALLAN and H. FLIEGEL respectively, maintained their activities and will report at the General Assembly. Time transfer with GPS has been and is still of concern with the introduction of the Selective Availability (SA), but the adaptation of the common view method seems to overcome part of this difficulty (Fliegel et al., 1990).

BUREAU INTERNATIONAL DES POIDS ET MESURES (BIPM) - TIME SECTION

Since the 1st of January 1988, the BIPM is officially in charge of the establishment and dissemination of TAI and UTC. This transfer of responsibility from the ex-BIH (a FAGS service) to BIPM (an intergovernmental body) did not imply any modification of the scientific work, other than improvements required by the technical progress.

Establishment of TAI

(a) STABILITY ALGORITHM ALGOS.
This algorithm, since its development in 1972, is producing a time scale EAL, with optimum frequency stability in the range of sample times of 2 months - 1 year. Without changing the basic principles which have been carefully reexamined and found satisfactory, it has been necessary to adapt the weighting procedures in 1988 for a better use of improved clocks and time comparisons (Guinot and Thomas, 1989). The number of participating clocks in EAL is fairly stable (170 to 180),

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although new laboratories, especially in the Southern hemisphere have joined the TAI community. These clocks are mostly industrial cesium clocks, but a few hydrogen masers (about 5) and laboratory cesium clocks (4 to 6) bring an important contribution, on account of their high stability. An idea of the long-term frequency stability of EAL can be obtained by comparison with the primary frequency standard PTB-CS1, which is nearly independent from EAL (its contribution being about 2%):

the square root of the pair variance of the normalized frequency difference y(PTB-CS1) - y(EAL) is 8×10^{-15} on a one-year sample time.

(b) ACCURACY STEERING.

The frequency of EAL is evaluated by comparison with the primary frequency standards, then TAI is derived from EAL by a long-term steering. We observe, by comparison with PTB-CS1 and PTB-CS2 that the frequency of EAL tends to decrease at a rate of about 7×10^{-15} per year. After more than 5 years, when no steering was found necessary, the steering resumed in June 1989. It is now accomplished by frequency steps of 5×10^{-15} at intervals not shorter than 2 months, the general rule being that the frequency adjustments be of the same order of magnitude as the frequency changes due to the instability of EAL. With respect to the primary standards and also to some hydrogen masers, the frequency of EAL exhibits an annual frequency variation with a peak to peak amplitude of about 4×10^{-15}. This is probably due to humidity effects on industrial cesium clocks (Tavella and Thomas, 1990).

(c)DISSEMINATION OF TAI AND UTC.

The TAI and UTC are disseminated by circulating the values of TAI-TA(k) and UTC-UTC(k) for 43 laboratories : monthly circular T (data also made available by electronic mail) and Annual Report.

Studies

(a) ALGORITHMS

The establishment of time scale algorithms is still a problem having no general solution. Prediction of clock rates, weighting, detection of abnormal behaviour are the key factors, but they intervene differently, depending on the acceptable delay for the availability of the time scale, the domain of optimum stability, etc. There is no optimum algorithm in a broad sense. But it is important to understand the mechanisms of the various algorithms, sometimes hidden under the mathematics, in order to obtain the best algorithm for a specific purpose.

A comparison of the NIST algorithm for estimation of the time scale AT1 and the BIPM algorithm ALGOS has shown that the two algorithms rest on the same basic ideas but have differences in the mode of frequency prediction and weighting required for their different purposes (Tavella and Thomas, 1990a).

Further investigations on the use of a Kalman filter have shown that it is not possible to design a time scale algorithm optimized for accuracy, based on this filter. The mathematical reason is that the errors in time corrections, which provide access to the time scale, are divergent.

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A study of the correlations among the clocks contributing to TAI was called for by the 11th session of the CCDS. Such correlations may have trivial origins such as the noise of the time comparisons or the noise of TAI itself, but the main cause of real correlations is change in the environment of the clocks, especially the variation of relative humidity (Tavella and Thomas, 1990b).

(b) TIME LINKS

In the domain of time links, BIPM research activity has been dominated by the improvement of GPS time comparisons. In addition, we participated in the coordination of two-way time transfers and started some work on GLONASS.

The potential accuracy of GPS time comparisons should be well below 1 ns (Guinot et al.), even with the "Selective Availability" (SA) applied to satellites of Block II, but to achieve such an accuracy will require many improvements and a standardization of receiver softwares. To solve these problems, we have proposed to create a group of experts in charge of establishing "GPS standards for time comparisons". This group is under formation in the framework of the CCDS working group on TAI.

At present, there is still a sufficient number of satellites of Block I, without SA, to allow the traditional GPS time comparisons, but manoeuvres to optimize their constellation generate practical difficulties in establishing observation schedules.

A method of improvement of antenna coordinates, using the GPS time comparisons themselves has been developed (Guinot and Lewandowski, 1989). Using this method and other sources of information, coordinate corrections have been issued which express the coordinates in the reference frame IERF88 of the IERS, for 12 laboratories in Europe, 4 in North America, 1 in the Middle East and 6 in Far East. Following our proposal, these corrected coordinates have been adopted by most of the laboratories and came into operation on 12 June 1990. They should significantly improve the accuracy and consistency of time comparisons.

Precise ephemerides from the Defense Mapping Agency (USA) are now regularly received at the BIPM. Their use has been tested (Lewandowski and Weiss, 1989) and sometimes found useful, even without SA. However they cannot be employed in current work because they reach us too late and because the broadcast ephemerides are not recorded. The software of the BIPM time receiver is being modified to overcome this latter difficulty.

Measured ionospheric delays have been applied to GPS data covering a one month period, January 1990, for three long-distance links between the Paris Observatory, the NIST and the CRL, these laboratories being equipped with codeless dual-frequency receivers of CRL and NIST types. Apparently the daily time comparisons are not always improved, but their closure error around the world is much reduced, which shows that the accuracy of time transfer is indeed better (Weiss et al. 1990). Since November 1989, measured ionospheric delays have been used operationally for the link OP-TAO.

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A comparative study of the ionospheric measurements obtained from the dual frequency receivers of CRL type, at the BIPM, and of NIST type, at the OP, has been performed (Weiss and Thomas, 1990). Good agreement was observed, but with a constant bias of a few nanoseconds (with a standard deviation of ·2 ns). This may be due to multipath interferences which are clearly seen. It has also been shown that an averaging time of about 15 minutes, as usually scheduled for international time comparisons, corresponds to the best stability of the two receivers.

An unexpected sensitivity of some GPS receivers to the external temperature has been found in a cooperative experiment with the OP. This effect is also a function of the length and type of the antenna cable. A report has been sent to the maker.

The BIPM publications give UTC-GPS time and also the deviations of individual satellites from GPS time, measured at the Paris Observatory, but corrected for the measurements of inonospheric delay.

In the USSR, GLONASS is the equivalent of GPS. With the approval of VNIIFTRI, BIPM Circular T began to publish in June 1990 values of UTC-GLONASS time provided by Prof. P. Daly of the University of Leeds. Further information is needed to link GLONASS time to UTC(SU). Discussions with Prof. Daly and authorities in the USSR are in progress. Software has also been developed to produce tracking schedules of GLONASS satellites.

(c) OTHER STUDIES AND ACTIVITIES

Pulsars. Annual versions of improved atomic time scales for pulsar studies were issued (Guinot, 1988). Simulations of pulsar time scale and atomic time scales were performed in order to study their respective role in the long term (Guinot and Petit, 1990).

A one-day seminar, given by Prof. A. De Marchi (University of Ancona, Italy) on the subject "Techniques for improving the long-term stability of commercial cesium clocks" was organized at the BIPM on 6 February 1990, and was attended by 45 participants from European laboratories.

A commercial cesium clock, on loan from the USNO, was installed at the BIPM in April 1990. The BIPM receiver for GPS time comparisons will be moved from the OP to the BIPM. We intend to make experiments aiming at the improvement of the accuracy of time comparisons by GPS and other techniques.

Very long baseline interferometry is one of the most demanding applications of atomic clocks. It also has the potential to provide ultra-accurate time comparisons, in the region 10 to 100 ps. Expertise within the BIPM was maintained by individual participation in pulsar positioning using VLBI.

Through one of the BIPM physicists, the BIPM participates to the Working Group on Reference Systems (Sub-Group on Time).

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THE INTERNATIONAL EARTH ROTATION SERVICE AND UTC

The International Earth Rotation Service (IERS) was established in 1987 by IAU and IUGG and it started operation on 1988 January 1st. It replaces the International Polar Motion Service (IPMS) and the earth- rotation section of the Bureau International de l'Heure (BIH); the activities of BIH on time are continued at Bureau International des Poids et Mesures (BIPM). IERS is a member of the Federation of Astronomical and Geophysical Data Analysis Services (FAGS). According to the terms of references of IERS, its Central Bureau decides and disseminates the announcements of leap seconds in UTC and values of DUT1 to be transmitted with time signals.

The present system of UTC, Universal Coordinated Time, was introduced in 1972 by the Bureau International de l'Heure (BIH). It is defined by the CCIR Recommendation 460-4 (1986). UTC differs from TAI by an integer number of seconds, in such a way that UT1-UTC stays smaller than 0.9s in absolute value. According to the CCIR Recommendation, first preference is given to the opportunities at the end of December and June, and second preference to those at the end of March and September. Since the system was introduced only dates in June and December have been used.

Between 1972 and 1988, the BIH introduced 14 leap seconds, the last one being at the end of December 1987. The Central Bureau of IERS has continued this task by introducing leap seconds in UTC at the ends of December of 1989 and 1990. The announcements are made in IERS Special Bulletin C, distributed to 250 address and reproduced in numerous national publications. The relationship of UTC with TAI since 1962 is published in the Annual report of IERS, in continuation with the BIH Annual Reports.

DUT1 is the difference UT1-UTC, expressed with a precision of 0.1 second, which is broadcasted with the time signals. The changes in DUT1 are announced in the IERS Special Bulletin D, continuing the BIH Circular F.

OBSERVATOIRE DE PARIS
Laboratoire Primaire du Temps et des Frequences

Work is in progress at the Laboratoire Primaire du Temps et des Fréquences/Paris Observatory (LPTF) in three directions.

First of all, a laboratory cesium standard is being built based on optical pumping techniques. Preliminary work has been carried out on various points : laser diodes, cesium atoms velocity distribution, magnetic effects; simulation studies have been made. This standard, planned to be operational in a few years, will being an alternative to the current "magnetic" standards. The LPTF effort is supported by an EEC contract.

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Secondly, work has been carried out to improve time comparisons both on international and national basis. GPS possibilities are commonly used between various french T/F laboratories. Thanks to the lending of an american (USNO and NIST) MITREX station, experimental time comparisons are made between Grasse and Graz; precision is below one nanosecond. The LPTF studies the possibility of MITREX as an operational time transfer method.

Finally, the LPTF has been associated to the Paris Observatory effort on ms Pulsars.

TIME AND FREQUENCY LABORATORY OF THE PTB, FRG

The PTB primary cesium atomic clocks, CS1 and CS2, have been operated continuously. Frequency comparisons reveal a systematic frequency difference between the two clocks of 25.10^{-15}. As a result the time scales of the two clocks differ in reading by 3.2 microseconds after 1500 days of operation. The combined frequency instability seems to reach a flicker-level of several parts in 10^{15} (Bauch et al., 1990).

One of the new primary clocks has been operated for a few months in 1988. The final operational state of the CS3 and CS4 is however, not yet reached (Bauch and Heindorff, 1988).

The experimental cesium beam frequency standard CSX has been used to measure the spatial phase variation of the microwave field in a ring microwave cavity (H. de Boer et al., 1990), which had been proposed by A. de Marchi et al. (1986). The future use of these new kind of cavities will considerably facilitate the determination of the end-to-end phase difference of the Ramsey cavity used in the primary clocks. Lower figures of the total uncertainty will become accessible.

The time scales UTC (PTB) and TA(PTB) have been generated by using the output of one of the laboratory's commercial cesium clocks whose output frequency is steered to follow closely to that of the primary clocks. International time scale comparisons have been performed by means of TV-signals, LORAN-C and GPS. The latter has become the most important system and is used following a measurement schedule which is coordinated by the BIPM. The PTB measurement data, among others, have been used to correct the receiver coordinates of the participating timing centres within the GPS reference coordinate system. Thereby the potentials of the GPS for time scale comparisons were improved.

Signals according to the legal time of the FRG have been transmitted by the long wave transmitter DCF77. In addition to the amplitude modulation by second markers, the carrier of DCF77 is now phase modulated using pseudo-random phase shift keying. At the receiver side the arrival time of the pseudo-random cycles can be determined by cross correlation. This technique makes better use of the frequency spectrum available and results in a LF time distribution as precise as a few microseconds during undisturbed transmission conditions, (Hetzel, 1988).

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U.S. NAVAL OBSERVATORY (USA)

Optical observations for time were made only with the Photographic Zenith Tube (PZT7, 65 cm) in Washington, D.C.; observations with PZT6 (20 cm) in Richmond, FL were discontinued on May 15, 1989.

The first 24-hour duration joint Goddard/Navy Universal Time (GNUT) experiment was performed on September 10-11, 1988. In January 1989, the first NAVNET VLBI observations were begun using antennas in Green Bank, Richmond, Hawaii and Alaska. In March 1989, the first daily "intensive" experiments with the Navy VLBI Network were begun.

Approximately 40 cesium beam frequency standards and 9 hydrogen masers frequency standards were available for participation in the formation of the USNO mean time scale. An improved algorithm for computing the time scale UTC (USNO) is currently being tested. The new algorithm utilizes both hydrogen masers and cesium clocks with a weighting scheme in which recent maser data get higher weight than recent cesium data and older cesium data get higher weight than older maser data in order to combine the short term performance of the masers with the long term performance of the cesium.

A new redundant master clock system, based on four hydrogen masers being steered by adjustments to their frequency synthesizers, is being developed. This will greatly increase redundancy and reliability of operations.

A hydrogen maser was delivered to Richmond, FL in April, 1990 for participation in clock operations.

Data on the Navy Clock Ensemble located at Falcon Air Force Base, the Master Control Station for the NAVSTAR Global Positioning System (GPS), is being collected and processed on a regular basis.

JET PROPULSION LABORATORY (JPL)

JPL has been actively involved in many areas that are key to several IAU Commissions; briefly, they can be outlined as follows :

* the development of constants, models and ephemerides for use by the community and by the IERS analysis centres;
* reference frame studies : 1) establishment of the JPL Radio Frame; 2) the establishment of the Dynamical Reference Frame of the Lunar/Planetary Ephemerides; 3) determination of ties between the various reference systems; and 4) development of the concept of the dynamical equinox as a reference point for the modern ephemerides and the unification of coordinate systems;
* acquisition, reduction and analysis of VLBI data for Earth rotation, (UT1, PM) precession, and nutation studies;
* reduction and analysis of lunar laser ranging (LLR) data for Earth rotation, (UT1, PM) precession and nutation studies;

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* investigation into the utilization of GPS in Earth rotation and reference frame studies;
* the use of GPS for time transfer ; JPL's Deep Space Network now uses the GPS technique for time transfer and clock sync between its remote antenna around the world;
* intercomparisons of Earth rotation results from the various techniques;
* combination of Earth rotation measurements with a Kalman filter;
* analysis of the scientific implications of these measurements.

The new scientific findings that have resulted from these studies are many and varied and details can be found in the report to IAU Commission 19.

NATIONAL ASTRONOMICAL OBSERVATORY, JAPAN

National Astronomical Observatory of Japan (NAO), established on July 1, 1988, combined Tokyo Astronomical Observatory and International Latitude Observatory of Mizusawa. Two branches of the NAO are for a moment keeping the activities which concern the Commission 31.

Tokyo Astronomical Observatory (TAO)

Astronomical observations for time and latitude with PZT were terminated at the end of May, 1988.

UTC (TAO) has been kept with a master clock, selected out of eight HP Cesium clocks, controlled with a phase-microstepper.

Eight clocks have been in operation in four clock rooms, each of which has been intended to keep the appropriate environmental conditions. Domestic time comparison of UTC clocks has been continued by using a Cesium portable clock of TAO almost once a year with those of NRLM, CRL, GSI (Geodetic Survey Institute) and KGO (Kanozan Geodetic Observatory).

For international time comparisons, the receptions of Loran-C signals from the Iwo Jima Master station (9970-M) and Okinawa station (9970-Y) have been continued. GPS time comparisons between time keeping laboratories have been continued with an accuracy of the order of then nanoseconds.

National Astronomical Observatory, Mizusawa (NAOM)

The NAOM derived, from Doppler observation of the Transit satellites, an estimation of the total electron content (TEC) (Hara and Sato, 1989); by using GPS dual frequency receiver the ionospheric excess path delay error of the VLBI has been reduced below one tenth of that which would be obtained by a single frequency observation (Sato, 1989).

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NAOM studied also the tropospheric excess path delay of microwave on the basis of the Japan Spectral Model developed by the Japan Meteorological Agency (JMA), (Hanada et al., 1989; Goto et al., 1989; Ichikawa et al., 1989).

The time service of the NAOM is based on 4 cesium atomic standards. UTC (NAOM) was compared with GPS satellites clocks by using a GPS receiver of Trimble Navigation model 4000SX since February 22, 1989 (Horiai et al., 1989). The other GPS receiver, model 5000A, has been operated since February 1990 and both GPS receivers were compared. The international time comparison with 4 cesium clocks were made at the NAOM from January 1988 to June 1990.

Loran-C signals of Iwo-Jima (9970-M) and Hokkaido (9970-X) of the Northwest Pacific chain were received at 21 locations in Northern Japan to estimate the accuracy of time comparison by the Loran-C method. Compared with a theoretical model for the secondary phase estimation, the observed phase shows the additional delay of about 0.35 μsec/100 km for the land path propagation. Deviations of the observed phase show about $\pm$ 0.5 μsec.; Sometimes they show as much as $\pm$ 1.5 μsec., which seem to be due to the terrain effect (Hara et al., 1989).

HYDROGRAPHIC DEPARTMENT OF JAPAN

For the purpose of monitoring the relation between TAI and the dynamical time reduced from the orbital longitude of the Moon (TDT'), the observation of occultations of stars by the Moon have been continued at the head office of Hydrographic Department of Japan (JHD) in Tokyo and three branch observatories, namely, Sirahama, Simosato and Bisei. About 700 timing data including 500 photoelectric data were obtained every year.

TDT'-TAI obtained from the occultation observation for the epochs 1987.5, 1988.5 and 1989.5 (preliminary for this epoch) were : 33.8s, 32.88s and 32.95s, respectively, with the mean error of +0.05s. Details are published in Data Report of Hydrographic Observations, Series of Astronomy and Geodesy as well as in the Japanese Ephemeris.

The services of the International Lunar Occultation Centre have been continued since 1981. The number of the data reported to the Centre in the years 1987 to 1989 amounts to 38.644.

ASTRONOMICAL OBSERVATORY, CAGLIARI, ITALY

The Time Service of the Cagliari Observatory is based on two commercial cesium standards (Oscilloquartz 3200 & hp 5061 B). A new master clock (cesium or hydrogen maser) is planned for 1991.

The local reference scale is compared continuously by Loran-C and TV techniques (comparisons with IEN - Turin and ISPT - Rome). Since 1989, GPS satellite reception has been used to relate UTC (CAO) to the international time scales. A new TV station using Eutelsat satellites became operative in the spring of 1990.

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For 1991, the Time Service of the Cagliari Observatory is planning to realize a national atomic time scale in collaboration with IEN (Turin), ISPT (Rome) and other private laboratories.

ROYAL OBSERVATORY OF BELGIUM (ROB)

In 1990, the ROB installed a third Cesium beam tube, of the Oscillaquartz type, while time comparisons with LORAN-C and GPS are conducted on a daily basis.

We started also a permanent control, with a PC, of the three atomic clocks aiming to determine in real time their drift with respect to an external reference (TAI or GPS); the drift parameters are estimated over a period of 100 days.

The mean of the three clocks, corrected for their drift, generates a mathematical clock which is materialized by a Rubidium slaved by the PC to be in agreement with the mathematical clock. For the first few months of the experiment the second of time is realized with an accuracy of about 2.10^{-13}.

REFERENCES

Bauch, A. : 1990, Proc. of the 2nd EFTF, Neuchâtel, 1988, 425 - 436.

Bauch, A., Heindorff, T. : 1989, Proc. of the 4th Symposium on Frequency Standards and Metrology, Ancona 1988, 370-373.

de Boer, H. : 1990, Proc. of the 4th EFTF, Neuchâtel 1990.

De Marchi, A. : 1986, Proc. 40th Ann. Symp. Frequ. Contr., 441-444.

Fliegel H., Beard R.L., Landis G.P., Stebbins S.B.: 1990, An Alternative Common View Method for Time Transfer with GPS. Journal of Navigation, 1990 (in press).

Goto, T., Hanada, H., Sasaki, H., Goto, Y.: 1989, Estimation of excess path delay by using the Japan spectral model of Japan Meteorological Agency, Proc. Japanese Symp. GPS (1989), 174-180.

Guinot B.: 1988, Astron. Astrophys., 192, 370-373.

Guinot B., Lewandowski, W.: 1989, Bull. Géod., 63, 371-386.

Guinot B., Lewandowski, W., Thomas, C.: 1990, Proc. 4th EFTP, Neuchâtel 1990.

Guinot B., Petit, G.: 1990, Berkely Workshop on impact of pulsar timing on Relativity and Cosmology.

Guinot B., Thomas, C. : 1989, Proc. 21st PTTI meeting, 95-106.

https://doi.org/10.1017/S0251107X00010117 Published online by Cambridge University Press

Hanada, H., Goto, Y. and Goto T.: 1989, Excess path delay estimated with the numerical prediction data in Japan spectral model of Japan Meteorological Agency. Proc. Japanese Symp. Earth Rotation, Astrometry, and Geodesy (1988), 298-303. (AAA 49A, 1990, 036.156).

Hara, T., Horiai, K., Sato, K.-H., Fujishita, M., Sakai, S., Iwadate, K. and Asari, K.: 1989, Measurements of the propagation time of Loran-C signals, Proc. 20th Annual PTTI Meeting, 145-150.

Hara, T. and Sato, K.-H.: 1989, Total electron content observation by Doppler method, Proc. Japanese Symp. GPS (1988), 55-59.

Hetzel, P.: 1988, Proc. of the 2nd EFTF, Neuchâtel, 1988, 351-364.

Horiai, K., Tamura, Y., Sato, K.-H. and Hara, T.: 1989, Time Comparison with a Trimble 4000SX GPS Receiver, Proc. Japanese Symp. GPS (1988), 74-79.

Ichikawa, R., Kasahara, M. and Naito, I.: 1989, An estimation of excess path delay based on JMA Global Analysis Data, Proc. Japanese Symp. GPS.

Sato, K.-H.: 1989, Ionospheric excess path delay correction using GPS dual channel receiver, Proc. Japanese Symp. GPS (1988), 60-65.

Tavella, P., Thomas, C.: 1990a, Metrologia (Submitted).

Tavella, P., Thomas, C.: 1990b, Proc. 4th Europ. Freq. and Time Forum.

Weiss, M., Thomas, C.: 1990, Ann. Rep. BIPM Time Section, 2, D-3 to D-22.

Weiss, M., Weissert, T., Thomas, C., Imae, M., Davies, K.: 1990, Proc. 4th EFTP, Neuchâtel 1990.

https://doi.org/10.1017/S0251107X00010117 Published online by Cambridge University Press