Commission 31. TIME: (heure)

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INTRODUCTION

The work of TAU 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 J. Luck, respectively, maintained their activities and will report at the GA Business Sections.

During the period 1991-1993 the following Meetings and Workshops of interest of Commission 31 took place:

6th European Frequency and Time Forum (17-19 march, 1992), Noordwijk, The Netherlands

Journees Systems de Reference Spatio-Temporels Geodinamique Globale et System de Reference (1-2 june, 1992), Paris, France

4th European Congress of Chronometry (29-30 october, 1992), Lausanne, Suisse
Meeting of the Time Laboratories Representatives (22-23 march, 1993), Paris France

7th European Frequency and Time Forum (16-18 march, 1993), Neuchatel, Suisse

Moreover it is right to mention the tutorial Workshops on Precise Time and Time Interval (PTTI) planned by the NASA Goddard Space Flight Center : 23th (1991), 24th (1992) and 25th (1993).

BUREAU INTERNATIONAL DES POIDS ET MESURES (BIPM) - Time Section

This report summarizes the activities of the Time Section of the Bureau International des Poids et Mesures. These activities include: current work on the production of TAI and UTC; some studies concerning time comparisons and time scale algorithms, necessary to maintain the high quality of international time scales; and more general studies, in particular on millisecond pulsars and general relativity.

1. Establishment of International Atomic Time (TAI) and Coordinated Universal Time (UTC)

The time scales TAI and UTC have been maintained and made available by the monthly Circular T, now distributed also through the BITNET and INTERNET

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electronic networks. The Annual Report of the BIPM Time Section has been published each year since 1989.

On average, 190 clocks from 60 laboratories maintained by 45 national timing centres contribute to TAI. Presently, nearly all 45 centres are equipped with GPS time receivers and send regulary their GPS observations to the BIPM. This ensures the accuracy of nearly all time linhs involved in TAI computation. One main new feature in the generation of TAI is the use of data from hydrogen masers, ie. naturally drifting clocks. They presently account for 12% of the total weight.

As in the previous years, the conformity of the TAI scale interval with he SI second still rests almost entirely on the data of a single laboratory, the PTB. A tendency of the TAI frequency to decrease with respect to the PTB standards has been compensated by frequency "steering" corrections of 5 x 10-15 on ten occasions and 7,5 x 10-15 on two occasions since the beginning of 1989. New primary frequency standards are now developed at CRL, NIST, OP and PTB. Their evaluation is under way and, for some of them, first data are being reported to the BIPM.

2. Algorithms for time scales

Since 1989 no change has been made to the BIPM algorithm ALGOS which is considered to be properly optimized for long-term stability. Numerous studies have been carried out, all of which confirm this conclusion. These studies include a comparison of time scale algorithms[19], a report on the correlations among the frequency changes of the clocks[20], a study of the correlation between an individual clock and the ensemble and a study of the entries and exits of clocks. The use of the Kalman filter in time scale algorithms has been investigated.

3. Time links

GPS is the main technique of time comparison for TAI. Using strict common view measurements, it appears that the precision of one single measurement [UTC(k1) - UTC(k2)] is about 2ns for short distances and about 8ns for long distances [12]. The major error sources affecting the accuracy of GPS time links are the errors in antenna coordinates, in receiver internal delays, in determining ionospheric delays and in using broadcast satellite ephemerides. An important part of the research activity of the Time Section deals with these topics. The coordinates of all GPS receivers that provide data to the BIPM have been expressed in the IERS terrestrial frame. Ionospheric measurements are rou tinely used for the computation of the long time links, and the use of precise ephemerides is under study. It has been tested by the closure condition of 3 time links that these corrections greatly improve the precision and accuracy of GPS time transfer [14]. It has also been shown that Kalman prediction can overcome the voluntary degradation of the acces to GPS time (SA) [21].

In addition, a considerable amount of activity is directed towards better standardization of GPS time receivers, a necessary step to reach the subnanosecond level of accuracy. This work is done through the CCDS Group on GPS Time Transfer Standards (CGGTTS), the secretariat of which is in the hands of the Time section.

The russian system GLONASS is also routinely observed and its data reported in the BIPM publications. In 1991, the BIPM initiated an experiment whick allowed, for the first time, a direct comparison of GPS and GLONASS common-view time transfers, which demonstrates the capacity of GLONASS [14].

Finally the Time section participates in studies of two-way time transfer via geostationnary satellites and of the LASSO technique, in particular to compare them with the GPS technique.

4. Other activities

The time section participates in the work of the IAU Working Group on Astronomical Standards to update and improve the system of astronomical models and constants. It has also an active participation in the CCDS Working Group on the Applications of General Relativity to Metrology, created in 1993.

Work has been carried out to understand how millisecond pulsar data could be used to realize a pulsar time scale and what implications it would have for atomic time [17]. Collaboration has been established with the radioastronomy groups observing pulsars.

U.S. NAVAL OBSERVATORY, USA

1. Master Clock

Three reference systems are used to realize the coordinated cloch timescale of the Observatory. All time interval measurements are made against these reference systems which are designated MC1, MC2 and MC3. Each system is driven by a hydrogen maser directy. The frequency synthesizers of these masers are set once per day, if necessary, to keep the reference systems close to the computed mean timescale UTC(USNO), which in turn is close to the predicted UTC(BIPM). The unsteered internal reference is designated as A.1, while the reference of the actual Master Clock(s) is UTC(USNO). UTC(USNO) is kept within 100 ns of UTC(BIPM). An estimate of the slowly changing difference UTC(BIPM) - UTC(USNO,MC) is computed daily and published on the Automatic Data Service (ADS).

2. Timescale

The USNO timescale is generated as described by L. A. Breakiron, 1991, Proceedings of the 23rd Annual Time and Time Interval (PTTI) Applications and Planning Meeting, pp. 297-305, except for revisions in the weighting and steering. The ensemble consists of about 9 masers and 30+ cesium clocks. The clocks are included in the actual ensemble or rejected on the basis of both long-term and short-term performance. Most of the cesium clocks are of the new HP5071 type.

The clocks are distributed in 11 vaults, all of which are temperature-controlled. Some are also humidity-controlled. The weights change with time so that the masers are completely deweighted 90 days in the past in order to prevent any residual drift from affecting the timescale. The reference clocks are steered to the timescale by no more than 400 ps/day and with a time constant that varies from 10 to 60 days.

Reference system #2 is designated as lead reference, or MC2, to which all measurements can be corrected if necessary. However, most of the time the differences between these systems are about 1ns or less. Measurements between all clocks are made every hour; a second, independent high precision system measures the high performance clocks every 100s. The various clock vaults are located in several buildings that are separated by as much as 300m. The connecting cables are either low loss coaxial cables or fiber optic links. All are installed underground.

3. Time Dissemination

Various timed systems have been kept within narrow tolerances of the USNO Master Clock. The LORAN chains covering North America have been within about 100ns (rms), whereas the overseas chains had larger tolerances, the largest in the case of the Mediterranean chain (1micros). The GPS, with the correction given in the navigation message (constants A0 and A1), has been within 15ns rms during the period April through July 5, 1993. This refers to observations with the selective availability removed. Including selective availability, observed with a single frequency receiver, the rms error has been 69ns, with a maximum error of 291ns. These measurements include all available satellites with a 13-minute observation per pass.

By obtaining the small residual difference between UTC(USNO,MC) and UTC (BIPM) from the Automatic Data Service (ADS) of the USNO, a near real time access to UTC is, therefore, possible via the GPS at the level of accuracy given above. By averaging over all available satellite passes per day, a fixed station with a cesium frequency standard can increase this precision to below 10ns with appropriate filtering. The obtainable accuracy will usually be limited by the stability and calibration of the local antenna-receiver delays.

For highest accuracy, the USNO has extended the use of its two-way satellite time transfer instrumentation. Regular time transfers have been continued with the NIST in Boulder, Colorado, with the NRC in Ottawa, Canada, and with the USNO station in Richmond, Florida.

During 1992, experiments have also been conducted with the Technical University in Graz, Austria , and with OCA in Grasse, France. An additional high precision time reference station has been established on the island of Oahu, Hawaii, and initial two-way time transfers have been started with that station.

Some problems with the spread-spectrum modems have limited the obtained precision of these measurements to about 3ns. The mobile Earth station has been used to make relative delay calibration between USNO and several other sites. It is currently being planned to resume the time transfers to Europe, but approval from INTELSAT has not yet been received.

The instrumentation at the USNO consists currently of two 4.5m VERTEX antennas, the mobile Earth station, one VSAT, and a new "Fly-Away" small terminal that will be used for the quick calibration of remote stations because this terminal can be easily transported by air and assembled by one person in a few hours.

The ADS has been accessible to users via the INTERNET and via high speed mo dems. Recently, an automatic E-mail delivery system has been added. Users who cannot telnet into the ADS can now request files via E-mail. The requested file is then sent to the requester within 10 minutes. A list of available files, currently about 200, is also available in this way. As an example for such a request, a message with the file name or 'list' as subject, without any message body, would be sent to adsmail@tycho.usno.navy.mil (the numerical address of tycho is 192.5.41.239). A request for a file that does not exist will also produce the list.

4. Research

L. Breakiron analyzed the power spectra of cesium and maser clock data and found-short and long-term periodicities, some of which are related to temperature and humidity variations.

D. Matsakis investigated the use of stored-ion clocks for routine timekeeping purposes. Two phenomena, which may be related, limit the usefulness of the three prototype devices currently available at the USNO as long-term frequency standards. There is an apparent systematic drop in the frequency with time. One cause may be a change in the temperature of the mercury ions (determined by the temperature and pressure of the helium). Superimposed upon this is a set of frequencey jumps.

Matsakis also continued comparing the time-transfer accuracy for the GPS system to that of VLBI for the Green Bank-Richmond baseline. All pre-hurricane data have now been analyzed, and it was found that the double difference had a peak-to-peak of 200ns since the new Mark III recorder was installed at the Green Bank 85' control building. Presumably, this error is entirely within the GPS comparisons, which were not conducted in common view. This accuracy, however, is sufficient for the pulsar investigations at Green Bank.

Matsakis began an investigation into the use of millisecond pulsars for timekeeping.

JET PROPULSION LABORATORY, PASADENA, USA

JPL has been actively involved in many areas that are key to IAU Commission 31; briefly, they can be outlined as follows:

(1) the determination of constants and the development of models and ephemerides for use by the community and IERS analysis centers;

(2) 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; 4) development of the fiducial-free approach using GPS data and the realization of an independent GPS terrestrial reference frame tied to the IERS.

(3) acquisition, reduction and analysis of VLBI data, including the TEMPO program, for Earth rotation, precession and nutation studies;

(4) reduction and analysis of lunar laser ranging (LLR) data for Earth rotation, press[Bion and nutation studies;

(5) acquisition, reduction and analysis of GPS data in Earth rotation and reference frame studies;

(6) intercomparisons of Earth rotation results from the various techniques;

(7) combination of Earth rotation measurements with a Kalman filter;

(8) analysis of the scientific implications of these measurements.

SHANGHAI OBSERVATORY, ACADEMIA SINICA, CHINA

Research work of high precise time synchronization have been carried out at Shanghai Observatory (SO), Shaanxi Observatory (CSAO), Beijing Observatory

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(BAO), Beijing Institute of Radio Metrology and Measurement (BIRM), National Institute of Metrology (NIM), Institute of Geodesy and Geophysics (WTO) and Beijing University. National time service broadcasts standard time and frequency at PuCheng near Shaanxi Observatory. Some significant results were obtained in recent years.

Shanghai Observatory: Eight transportable hydrogen masers were developed in recent years. Some of them have been put into operation in Chinese VLBI network and other fields. The frequency stability is better than 3x10-15 for a several hours sample time. A new hydrogen maser has been used in Shanghai Observatory' s atomic time scale since last year. The comparison results between Hydrogen masers and the satellite clocks of GPS have been sent routinely to BIPM. The long term stability keeps within 30ns for two-months sample time and 60ns for ten-day sample. An extremely small atomic hydrogen maser (40x60x70cm), the third generation of II-maser. has been completed successfully last year at Shanghai Observatory.

The maintance of standard time and frequency at Shanghai Observatory is based on 3 HP commerical Cs clocks. UTC (SO) has been compared with GPS satellites clocks for international time comparison since 1990. The local atomic scale is compared routinely by Loran-C and TV techiques.

Shaanxi Observatory:Besides the astronomical research work, the time and frequency standards with more precise accuracy are kept here as a center of Chinese time service broadcasting time signals by means of short-wave and long-wave radio signals (BPM and BPL). Some research work related to precise time synchronization by means of using BPM. BPL. GPS and Screen satellite have been carried out routinely.

"Screen Satellite" time service system is based on the common view of the 714MHz signal of screen satellite. The precision of time service with BPM is about 1 ns and the precision of time comparisom is about 1 us. CSAO is also responsible for the reduction and publication of the Chinese Joint Atomic Time System which is composed of all commerical Cs clocks of five institutes (SO,CSAO,BAO,BIRM,WTO).

Beijing Observatory: A HP commercal Cs clock is used to control Chinese national radio broadcasting station which has a timing program for civil purpose. It also joined the Joint Atomic Time System.

Beijing Institute of Radio Metrology and Measurement: Commerical Cs clocks were Joined the Chinese Joint Atomic Time system. Some kinds of high performance crystal oscillators were developed and used in the field of scientific research.

National Institute of Metrology: It has established local time scale with HP Cs clocks. The Cs clocks were available to control the standard frequency in TV signals for the national TV broadcasting station. So it can provides time comparison by TV technique all over the China. The first laboratory' s Cs clock was developed at NIM and has the frequency accuracy of 3x10-13.

Institute of Geodesy and Geophysics: A HP Cs clock has been joined the Joint Atomic Time System. Time comparisons with BPM, BPL are carried out on a daily bais. The research work about the propagation characteristics of shortwave signal has obtained good results.

Beijing University: A laser pumping Cs frequency standard has developed over the past years and the stability of 1.2x10-11 t1/2 (t is sample time) by means of Allan Variance was obtained.

In China some research works are being discussed and developed as follos:

1. VLBI is one of applications for the use of atomic clocks. It also has the potential to provide more-accurate time comparison in the range of 10 to 100 ps.
2. Time comparison by means of GPS common view experiments.
3. "Broadcasting Satellite" time service.
4. Joint time keeping. by using Cs clocks and hydrogen masers in China.
5. The determination of more accurate time period by using pulsar Observations.
6. Further research in the field of time definition.

ISTITUTO ELETTROTECNICO NAZIONALE G. FERRARIS, TORINO, ITALY

1- Generation of UTC(IEN) and dissemination

The time scale UTC(IEN), which is the basis of legal time in Italy, has been maintained in agreement within 1.5 us with UTC in the period 1990-1993. At least three cesium clocks, of the five HP 5061 clocks avalaible, contributed to the generation of the international time scale TAI; in February 1993 an HP 5071A cesium clock with improved specification has been added to the IEN clock ensemble.

UTC(IEN) has been compared with the international time scale by means of two GPS receivers programmed for the BIPM common view Schedule.

In July 1992, a two-way time transfer experiment in the Ku band between the IEN and the Istituto Superiore delle Poste e delle Telecomunicazioni in Rome , using Olympus satellite at 19 W, was started. Two mobile Alenia groundstations and Mitrex 2500A modems have been used.

In the fied of standard time signal dissemination, a date code, to be distribuited via modem on telephone lines, has been experimented since 1991 and will become operational in June 1993. The code format has been agreed among four European laboratories, IEN, SNT, TUG and VSL and is suitable to synchronize computer clocks. The syncronization precision and accuracy of this system, used both in a one-way and in a two-way mode and especially related to the CCITT V.22 modems behavior, has been investigated; timing accuracies of 100-120 ms (one-way) and 10 ms (two-way) have been found.

2- Algorithms for time reference generation

2.1 Individual instability estimation

The problem of estimating individual clock instability from comparison measurement has been deeply investigated proposing a general and consistent model for data analysis. For the case of 3 clocks a particular algorithm has been devised to individuate the minimum correlation solution; the analysis of the general case of N clocks with a suitable matricial formulation gives several information about clock instabilities and their correlations.

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2.2 Ensemble time scale

In collaboration with the BIMP a study has been undertaken on the possibility of using pulsar data to improve the long-term stability of atomic time scale. The use of an "ensemble pulsar time" with an appropriate algorithm has been tested both on simulated data and with the real observation data at disposal. It turns out that with the real data now available an ensemble pulsar time with 10-14 instability for observation interval from one to almost three years is obtainable. Pulsar time can also be used as a flywheel to transfer atomic time accuracy from one epoch to another.

2.3 Application to telecommunication

In collaboration with the Italian telecommunication research group, a study has been undertaken and is still in progress on the best suited clock characterization tools to be used in case of the Synchronous Digital Hierarchy network.

3- Atomic frequency standard

3.1 Mg atomic beam

The Mg frequency standard prototype, realized at IEN, has been evaluated by comparison with UTC(IEN): the short-term frequency stability turns out to be : sigma y(t) = 1.10-11.t-12 (1<t<3000 s) without optical pumping.

The uncertainty budget is limited at 10-12, mainly due to the residual first order Doppler shift, whose evaluation is under way. All the other sources of uncertainty can be improved to the limit of 10-13 or better.

Frequency comparison between Mg and UTC(IEN) have been performed several time in 1992 showing a repeatability of 3.10-13.

3.2 Semiconductor lasers

In 1991 a research activity has started in the field of frequency stabilized semiconductor lasers, also in collaboration with the Metrological Institute G. Colonnetti (IMGC) and with the Polytechnic of Turin, at the following wavelengths: 780 nm (Rb), 852 nm (Cs) and 657 nm (Ca).

4- Infrared frequency standards

An OSO 4 molecular beam is under developement at IMGC: CO2 laser prestabilized on the P(46) of OsO4 via the Lamb-diptechnique has been set up as well as the vacuum system and the molecular source.

The frequency of the 81.5 um and of the 263.4 um NH3 lines have been measured demostrating also the feasibility of coherent frequency synthesis up to 3.7 THZ.

ROYAL OBSERVATORY OF BELGIUM (ROB).

A computed time scale deduced as a mean of three Cesium Beam Tubes, is operational since 1991; the mathematical clock is physically represented by a Rubidium; the physical and the mathematical clocks agree at the level of 2x10-13. In July 1992 one Hydrogen Maser CH1-75, produced by KVARZ, has been turned in continuous operation.

To get the performance of this unit KVARZ recommends to use,at the same site, two masers to perform an automatic auto-tuning of the cavity. As only one maser is in operation at the Royal Observatory of Belgium, in principle the auto-tuning is not operational. However, in the same laboratory, a BVA quartz oscillator is in operation since several years. Its short term stability is of the order 5 10-13 over time interval of 30 seconds; for this reason, KVARZ suggested to experiment to tune the CH-75 with an external frequency provided by the BVA. Experiments are in process.

HYDROGRAPHIC DEPARTMENT OF JAPAN, TOKYO

For the purpose of monitoring the relation between TAI and the dynamical time reduced from the orbital longitude of the Moon TDT (observed), 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 1000 timing data including 600 photoelectric data were obtained every year.

TDT(Observed)-TAI obtained from the occultation observation for the epochs 1990.5, 1991.5 and 1992.5 (preliminary for this epoch) were 32.91s, 32.88s and 32.89s, 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 1990 to 1992 amounts to 34,646.

Satellite Laser Ranging (SLR) observation has been carried out at Simosato Hydrographic Observatory since March, 1982. Total return signals obtained from Lageos I and II, Starlette and the Japanese geodetic satellite Ajisai in the years 1990 to 1992 amount to about 969,000.

JHD has also been carrying out SLR system (HTLRS) since 1987. HTLRS obtained in the years 1990 to 1992 about 53,000 returns for the four satellites at some sites within Japan including off-lying islands.

THE NATIONAL PHYSICAL LABORATORY, NEW DELHI.

NPL has been maintaining UTC with the help of three industrial Cesium clocks (all Hewlett-Packrd made) with one acting as the master clock. Time intercomparisons via GPS in common view mode are being regularly made and UTC(NP-I) inputs are being sent to BIPM.

NPL has been transmitting standard time and frequency signals at three carrier frequencies: 5, 10 and 15 MHZ. and disseminating standard time signals via Indian Domestic Satellite INSAT, with an accuracy of 10 micro second to the users. These broadcasts are on a down-link frequency of 2599.675 MHZ.

A development of hydrogen Maser was carried out by NPL in collaboration with NIST, Boulder, Colorado, USA. Work on development of indigenous Rubidium standards is also being carried out. In addition, NPL undertakes the calibration Work from Governament and private sectors for calibration of primary and secondary time and frequency standards.

NEUCHATEL OBSERVATORY, SWITZELLAND

The Observatory of Neuchatel has obtained the nomination of "Center of Excellence" of the European Space Agency (ESA) for the work in the atomic frequency standards. Two majors projects (a Space Rubidium Ultrastable Oscillator and a Space Hydrogen Maser) are presently under way. The pro- jects involve a cooperation between ESA, the Russian Space Agency and the Russian Academy of Sciences

A new basic research field has been introduced: the laser cooling technique applied to the development of the future primary atomic frequency standards.

CAGLIARI OBSERVATORY, ITALY

The Time and Frequency Laboratory of the Cagliari Observatory has been developed during the last years according to some field of interest related to atomic time scales, high precision synchronization and the relations between atomic and astronomical time.

Three commercial atomic standards are operated in good environmental conditions in order to generate a local time scale as uniform as possible. The performances of the local clocks with respect to UTC are continuously monitored by means of a GPS timing receiver, LORAN-C and TV links with other national Laboratories.

The synchronization data are regularly sent to BIPM in order to contribute to the computation of TAI.

In the late 1991 a decoder for geostationary television broadcasting satellites wase set up. It was operated several times during some european campaign, promoted by the Royal Observatory of Belgium to investigate some aspects of the precise orbit determination of geostationary satellites using TV synchronization links.

More recently the Laboratory was connected via computer link to the italian astronomical network ASTRONET, and through it to the main geographic networks such as Bitnet, Span etc. This is the first step for the creation of a national Time Scale, based on the atomic clocks kept in the principal laboratories in Italy (IEN, ISPT, CAO),. A preliminary meeting about this topic was held in Turin in May 1993.

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During 1993 a great effort was devoted by the staff of the Cagliari Observatory to put into operation the Telemetry Laser Station. At the end of June the first echoes were obtained from low-orbiting satellites, and it is foreseable that the complete operational conditions will be reached before the end of the year. This fact is of great importance in the field of time syncronization, because makes it possible for the Cagliari Observatory to participate in synchronization experiments by satellites, such as LASSO, and to start some investigation about relativistic effects on time scales.

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