STANDARD TIME AND FREQUENCY

AT THE INSTITUTE OF RADIO ENGINEERING AND ELECTRONICS

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Abstract

The Institute of Radio Engineering and Electronics of the Czechoslovak Academy of Sciences (IREE), Prague, provides the national primary time a frequency reference for the Czechoslovak metrology. The paper describes main activities of IREE in standard time and frequency generation, dissemination, and measurements.

Key words:

standard time and frequency, time scales, time transfer via satellites, time and frequency service

Introduction

The Institute of Radio Engineering and Electronics of the Czechoslovak Academy of Sciences (IREE), Prague, is responsible for the National Frequency Standard and for the National Time Scale called UTC(TP). IREE closely cooperates with the Time Section of the Bureau International des Poids et Mesures (BIPM), Sévres, France , with several national laboratories abroad and in Czechoslovakia with the Astronomical Institute of the Czechoslovak Academy of Sciences (AI). For many years IREE has also been doing research in various fields of standard time and frequency.

The objective of this paper is to describe IREE's latest activities in standard time and frequency generation and dissemination.

Generation of UTC(TP)

The equipment configuration of the IREE Time Laboratory is sketched in Fig.1.

As can be seen from Fig 1., time and frequency generation at IREE is based on two Cesium Beam Frequency Standards, HP5061 (Hewlett-Packard) and OQ3000 (Oscilloquartz). The standards are placed in a special cell under the ground with stable environmental

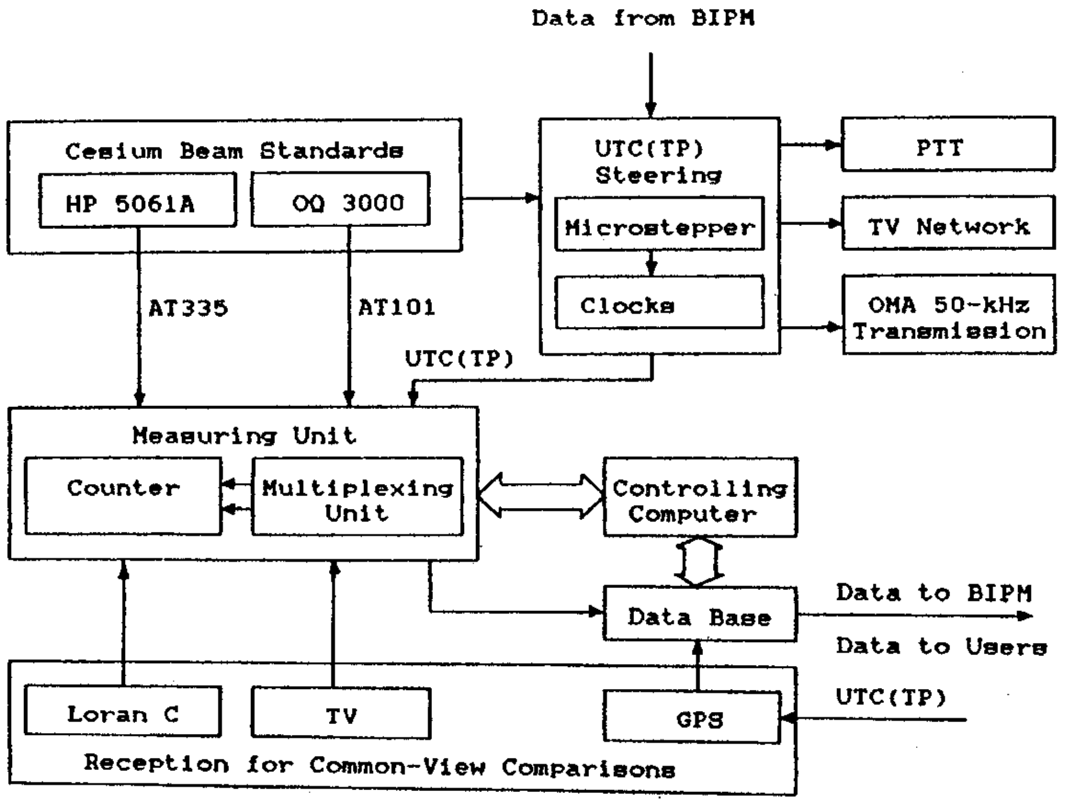

Fig. 1
Configuration of the IREE Time Laboratory.

conditions (temperature changes less than ±0.5 °C, no humidity control so far). Each of the standards is generating its own atomic time scale designated as AT335

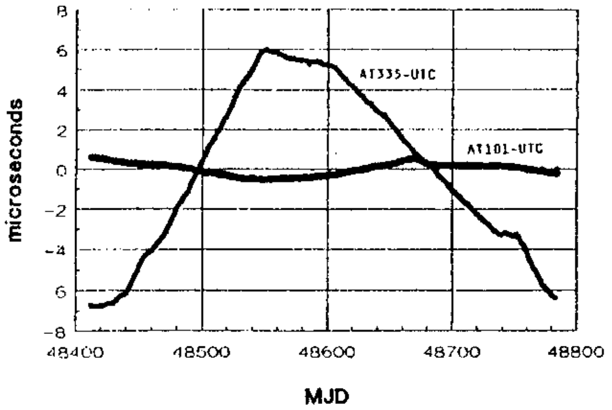

Fig. 2
UTC-AT335 and UTC-AT101 relative differences.

(for the HP5061) and AT101 (for the OQ3000), respectively. In order to illustrate the behavior of the two standards, a record of UTC-AT335 (a systematic rate of 88 ns/day was removed) and UTC-AT101 for the latest one-year period is shown in Fig.2. Time is expressed in terms of Mean Julian Date (MJD 48400 = 24 May, 1991). For a 10-day averaging interval, Allan variance calculated from these records yields frequency stability $\sigma_y(\tau) = 6.9 \cdot 10^{-14}$ for AT335 and $\sigma_y(\tau) = 2.9 \cdot 10^{-13}$ for AT101, respectively. The HP5061 is evidently much more stable than the OQ3000 and therefore it is currently used as the IREE's primary frequency source.

The UTC(TP) time scale (TP stands for Tempus Pragense) is being derived by steering AT335 in order to maintain its approximate agreement with UTC [2],[3]. The steering is performed by means of a microstepper which makes it possible to offset the input frequency in steps of 10^{-14}. The latest record of UTC-UTC(TP) is shown in Fig.3. It has a mean of $-0.6\,\mu s$ with maximum departures of about $0.7\,\mu s$ with respect to this mean. The fractional standard deviation of the UTC(TP) frequency with respect to UTC does not exceed $1.5 \cdot 10^{-13}$. Necessary changes in steering are made according to the UTC-UTC(TP) differences published by BIPM. As to physical represantation, the UTC(TP) time scale is referred to a positive-going edge of a 1pps at 1V level at the input of the TTR-6 GPS receiver.

Daily measurements of all of the important time differences are carried out by means of an automated system which consists of a 2ns counter, a computer controlled multiplexing unit, and a real-time controlling computer. All data measured by the system are stored in a computer data base. On a weekly basis requested data are sent to the BIPM and to other cooperating laboratories through an electronic mail, mainly through BITNET/EARN. In addition, some of the data are provided for Czechoslovak research centers and for users from industry.

The UTC(TP) time and/or frequency is physically sent from IREE to:

- OMA-50kHz Standard Time and Frequency Station, Liblice
- Czechoslovak Television Center, Prague
- Czechoslovak Post, Telephone and Telegraph (PTT), Prague,
- Astronomical Institute, Prague.

Time Comparisons

For a laboratory like IREE with only two commercial standards, good time transfer with other laboratories is a necessity. For many years IREE has been making use of friendly contacts with the Physikalisch Technische Bundesanstalt (PTB), Braunschweig, which has been sending some of its daily comparison data to IREE on a weekly basis. The comparison link with PTB has always been vital for IREE to cover the 2-month gap between the BIPM circulars, particularly at periods when only one standard was in operation.

Nowadays there are three ways of time comparisons used at IREE:

Television Method

Until the mid 1980', the TV method invented by Tolman of IREE in 1967 [1] was the only one used to compare UTC(TP) internationally, i.e. with the access to BIPM. It was performed by employing the East German TV network which enables IREE to carry out time comparisons with PTB. The comparisons are based on the fact that a common TV program from the same source can be received simultaneously at PTB and at IREE, i.e. the program from Brocken (Ch6) at PTB and the program from Dresden (Ch10) at IREE.

Common-view differences are thus given by

$$\left[\mathrm{UTC}\left(\mathrm{TP}\right) - \mathrm{UTC}\left(\mathrm{PTB}\right)\right]_{\mathrm{TV}} = \left[\mathrm{UTC}\left(\mathrm{TP}\right) - \mathrm{Ch10}\right] - \left[\mathrm{UTC}\left(\mathrm{PTB}\right) - \mathrm{Ch6}\right] + \tau \qquad (1)$$

where τ is a differential delay.

They are, however, strongly dependent on the receiving conditions at IREE where, at periods, Ch10 exhibits a very poor SNR. Under normal conditions the jitter of UTC(TP)-Ch10 has a standard deviation of about 150ns. Because of this poor resolution, if compared to other means now available at IREE (see below), the TV comparisons with PTB are no more sent to BIPM.

At IREE the TV method is now used only for time transfers to users within the Czechoslovak TV network.

In search of further applications of the TV method, IREE has taken part in recent international experiments with the objective to apply it on geostationary satellites. The fact that the satellites cover a large area with TV signals is promising for TV time comparisons. Though geostationary, the satellite is actually slowly moving with repect to observers. Thus in order to achieve an accurate time and/or frequency transfer, it is necessary to determine also its position with an adequate accuracy. And this seems to be a problem. A study has been made for a case of two observers and a pseudoranging [4],[5] but due to strong correlations the accuracies achieved are so far much worse than expected.

Loran-C

Time comparisons via the Loran-C navigation system are performed by means of the 7970-W station (Norwegian Chain). The station is transmitting from Sylt, Germany, about 670km from IREE. The signal from Sylt is received by three identical Loran-C timing receivers which are based on a high-quality quartz oscillator phase-locked to a zero-crossing of the carrier with a loop constant of about 50s.

Common-view differences for this case can be written as

$$\left[UTC(TP) - UTC(PTB)\right]_{SYLT} = \left[UTC(TP) - Sylt\right] - \left[UTC(PTB) - Sylt\right] \qquad (2)$$

As the signal from Sylt has a poorer SNR at distant IREE than at nearer PTB, a good approximation to a true value of UTC(TP)-Sylt is that of a linear fit made over one day. This yields a standard deviation typically less than 20ns (based on 24 samples ϑ measured in one-hour intervals).

In turn, the daily values of (2) fluctuate with a standard deviation of about 40ns. This has been estimated from differences

$$\left[UTC(TP) - UTC(PTB)\right]_{SYLT} - \left[UTC(TP) - UTC(PTB)\right]_{GPS}$$

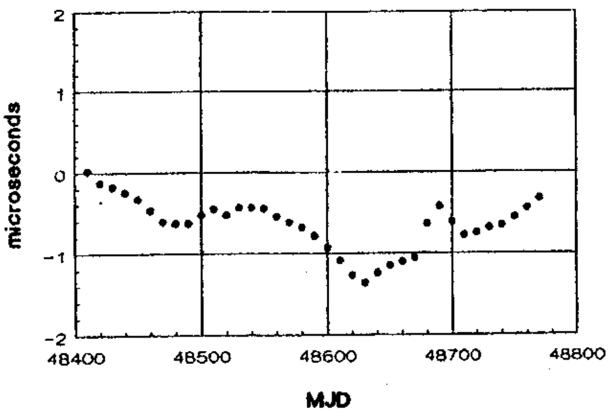

Fig. 3
UTC-UTC(TP) long-term relation.

assuming that the fluctuations of $\left[UTC(TP) - UTC(PTB)\right]_{GPS}$ are negligible (see next).

Global Positioning System (GPS)

The IREE laboratory is equipped with a TTR-6 Allen Osborne GPS receiver which was installed in April, 1991.

The antenna of TTR-6 is placed on the roof of IREE where it is attached to a vertical metal pipe. The height of the antenna above the roof is very low (only 50cm) since a significant improvement of the track rms has been observed when placing the antenna to a lower position above the roof. This effect is not well understood.

The antenna coordinates within the WGS-84 reference have been determined by employing the navigational capabilities of the TTR-6 itself. The resulting coordinates

Latitude 50°07'51.2" N,
Longitude 14°27'11.0" E,
Height 367.0 m,

are averages over 19 days of navigational tracks for three different satellite constellations chosen to be close to optimum for navigation. These coordinates are promised to be improved by BIPM [6] with an expected uncertainty of 20cm.

A good GPS timing receiver has opened the door for IREE to take part in various experiments based on GPS common-view observations given by

$$\left[UTC(TP) - UTC(i)\right]_{GPS} = \left[UTC(TP) - GPS\right] - \left[UTC(i) - GPS\right] \qquad (3)$$

IREE is now following the complete BIPM schedule for common-view GPS measurements. The protocol as provided by TTR-6 is regularly sent to BIPM through the BITNET/EARN mail. On a weekly basis the GPS data are also exchanged with PTB and with the Istituto Elettrotecnico Nazionale (IEN), Turin. The data exchange with IEN is due to a planned recognition of the measurement of time unit between Czechoslovakia and Italy.

For IREE the most important GPS common-view observations are those with PTB. As was expected the transfer (3) with PTB (i.e. for i = PTB) is not affected by the Selective Availability introduced to the Block II satellites for satellite time. The resolution is limited by noise (white phase) which gives about 3.5ns for the middle of the track in terms of standard deviation of a linear fit of (3) for all common-view tracks made in one day.

For the time transfer with the Observatoire de Paris (OP), the resolution is even less than 3ns [7].

At the beginning of July, 1992, the TTR-6 receiver was calibrated during a BIPM mission to IREE. Calibration was performed with a standard deviation of approx. 2ns. As a result of the round trip, from OP to IREE and back to OP, a preliminary difference of 12ns has been found between TTR-6 and the GPS receiver at OP. The final results will be published by BIPM.

Dissemination of UTC(TP)

As mentioned previously, UTC(TP) time and/or frequency is disseminated to different users in this country.

OMA-50kHz Transmission

The OMA signal is transmitted with about 5kW of radiated power from Liblice located some 30km east of Prague (50°04'24" N, 14°52'24" E) . During maintainance periods at this transmitter, the OMA transmission is taken over by an auxiliary transmitter, located at Poděbrady (50°08'30" N, 15°08'10" E), with approx. 50W of radiated power.

The OMA time and frequency information is conveyed by

- carrier phase which is continuously related to UTC(TP)
- second and minute markers formed by carrier breaks of 100ms and 500ms, respectively, with the on-time point corresponding to the leading edge
- day marker made up of 20-Hz carrier breaks generated from 2h59m01s to 2h59m05s of the Czechoslovak Civil Time
- OMA time code generated by inverting the carrier; the code provides U[illegible] hour and minute, day of week, day of month, month, year,leap second announcement, announcement of a civil time change in Czechoslovakia, information on whether the summer time is currently in use, information on which transmitter is in operation (main/auxiliary).

Long-term frequency stability and accuracy of the OMA carrier are the same as those of UTC(TP). Short term stability is limited by phase steps of about 100ns introduced to control the carrier phase with respect to UTC(TP). Another factor limiting short-term stability is an additive noise, both atmospheric and man-made , and at long distances also phase variations due to diurnal ionosphere shifts. Thus the short-term stability available for a user depends on the receiving conditions and on the way of signal processing.

The OMA-carrier frequency stability as measured at IREE is

$$\sigma_y(\tau) = 4 \cdot 10^{-8} \quad \text{for } \tau = 1\,\text{s}$$

$$\sigma_y(\tau) = 3 \cdot 10^{-12} \quad \text{for } \tau = 1\,\text{day}$$

(Allan variance at the output of a receiver with $B \approx 500$ Hz).

Under the same conditions a second-mark jitter of $20\,\mu s$ was found.

While it has been designed to meet Czechoslovak requirements, the OMA signal is accessible all over Europe. Experiments have been made with a clock driven by the OMA code at long distances (Egypt, North of Russia) with accuracies of several milliseconds against UTC.

TV Network

Using a microwave link, a 5-MHz UTC(TP) frequency is sent to the Czechoslovak TV Center, Prague, where it is used to synchronize the line and frame pulses during so called industrial transmissions, i.e. when a test chart is being transmitted.

To illustrate the case, frequency stability of frame pulses as obtained at IREE for a TV signal transmitted from the Prague TV Tower is $5 \cdot 10^{-11}$ for $\tau = 300$ s (Allan variance).

Link to PTT

The UTC(TP) frequency is also sent to PTT, Prague, located about 5km from IREE. A sine wave signal at 100kHz is fed to a telephone line to PTT where it is filtered and amplified. Using the TV method it has been proved that in spite of assumingly unstable telephone line, the signal at PTT still meets the requirements of the CCITT G.811 recommendation for digital communication networks.

This link, however, is considered provisional and an optical cable is to be laid very soon between IREE and PTT (in the second half of 1992). This link will be advantageous for both sides: PTT will obtain an excellent stand-by frequency and will benefit from IREE's metrological facilities and IREE , in turn, will have an access to two HP5071A cesium beam frequency standards which are going to be installed at PTT.

Link to AI

A 6.25-kHz UTC(TP) frequency along with 1-kHz second and minute ticks is sent via a telephone line to AI in order to control local secondary time and frequency standards.

From AI time ticks are sent, also by telephone, to the near Czechoslovak Radio Center, Prague, to be broadcasted by radio.

Conclusion

During the last three years basic improvements have been accomplished in time and frequency metrology at IREE. It concerns particularly time transfer, automation of measurements, data processing, and data exchange.

Present common-view comparisons based on GPS permit to define the UTC(TP) time scale with an estimated uncertainty of 10ns with respect to the time scales of principal time laboratories contributing to the definition of UTC. The resolution of IREE's international frequency comparisons is better than 10^{-13} in one day.

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