TIME KEEPING AND TIME AND FREQUENCY DISSEMINATION AT THE ISTITUTO ELETTROTECNICO NAZIONALE (IEN)

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ABSTRACT

The Istituto Elettrotecnico Nazionale time scale UTC(IEN), based on the definition of the SI second, is realized by means of six commercial cesium beam standards and is synchronized with UTC within 5 μs.
The IEN time scale is compared with UTC by means of the Loran-C and GPS signals reception and the measurement results are made available to the time and frequency community on the General Electric Mark III network.
The time differences over 10 days between UTC(IEN) and the cesium clocks are also sent to BIH to contribute to the generation of the international atomic time scale TAI.
In recent years (1982-1985), the IEN took also part in some international time synchronization experiments via geostationary and GPS satellites in order to check their capabilities.
The dissemination of standard time and frequency signals is carried out by means of HF transmissions, coded time signals emissions and "time of the day" telephone service.
The time and frequency laboratory acts also as reference laboratory for time and frequency quantities for the Italian Calibration Service (SIT) and is therefore charged of the technical tasks necessary to the approval of calibration centers.
Frequency and time traceability to UTC(IEN) of standard clocks kept in other Italian scientific organizations and factories is also provided by means of daily television measurements and portable clock comparisons.
Research activities have been carried on in recent years in the fields of the cesium frequency standards and of the Mg beam standard. In the former case, the influence of the Rabi pulling effect, has been theoretically evaluated and experimentally observed; in the latter case the $^{24}Mg\ ^3P_1 - {}^3P_0\ \ \Delta mj = 0$ transition has been observed both with a Rabi and Ramsey interaction technique.

1. Introduction

Time and frequency metrological activity at the Istituto Elettrotecnico Nazionale, began in 1937 when the first frequency standard, a General Radio quartz oscillator, was put into operation at the Department of Radiotechnics [1].

In the following years, other quartz oscillators, throughly studied and built at the IEN, were used as reference oscillators and in 1945 was started the dissemination of standard time signals by means of the Italian Broadcasting Company (RAI).

Since December 1969, the IEN time scale is derived from commercial cesium beam standards and a selected number of these clocks has been used since 1972 by BIH in the International Atomic Time scale [2].

The IEN attends regularly the International Radio Consultative Committee (CCIR) meetings and is member of the Consultative Committee for the Definition of the Second (CCDS).

For its work in the metrological field, including the research activity on submillimeter signals generation and measurement [3] and on new frequency standards [4], the IEN time and frequency department has acquired the status of national reference laboratory for Italy.

2. The IEN time scale generation

The time scale UTC(IEN), based on the definition of the SI second, is obtained from six commercial cesium beam standards that are kept in temperature controlled environments. The cesium clocks that contribute also to the TAI time scale are kept in a room located 12 meters underground at a temperature of 24 ± 0.5°C.

All the time and frequency signals supplied by these standards are carried by means of coaxial cables to the metrological laboratory where they are used to generate UTC(IEN) and for the standard time and frequency dissemination services.

The laboratory master clock is chosen among those at disposal according to the uniformity of its rate as inferred from the time comparisons between the cesium clocks and from the BIH bi-monthly rates and weights. In Fig. 1 and Fig. 2 are reported the BIH data for the period 1981 to 1986 relative to the IEN clocks used in the TAI computations. The periods of normal operation of these clocks for the same years are represented in Fig. 3.

The master clock frequency is supplied to a phase microstepper the rate of which is periodically adjusted in order to maintain a long term agreement of some units of 10^{-13} between UTC(IEN) and UTC.

It is planned for the next year to begin the computation of an independent national atomic time scale using also the cesium clocks kept in other Italian institutions having already a synchronization link with IEN.

Table 1 lists the mean daily rates selected on the phase microstepper in the years from 1981 to 1986 together with the information relative to the master clock used.

On 13 May 1986, UTC(IEN) was delayed of 19 microseconds in order to be in closer agreement with UTC; since that date, UTC(IEN) is being maintained synchronized to UTC within 5 μs. In Fig. 4 is showed the long term behaviour of UTC(IEN) versus UTC in the period 1981-1986 according to BIH Circulars D.

In Figg. 5 and 6 are reported the environmental parameters, temperature and relative humidity, of the cesium clocks room during the same years.

Table 1

Date	IEN Master Clock (MC)	UTC(IEN)-IEN MC
26 Dec 80	Cs 5061A-004 s.n. 893	+15 ns/d
8 Feb 81	Cs 5061A s.n. 609	-100 ns/d
31 Aug 83	Cs 5061A-004 s.n. 893	+50 ns/d
30 Nov 83	Cs 5061A s.n. 609	+62 ns/d
1 Mar 84	Cs 5061A-004 s.n. 893	+60 ns/d
13 Apr 84	"	+40 ns/d
28 May 85	"	+34 ns/d
12 Feb 86	"	+10 ns/d
20 Oct 86	"	+32 ns/d

The IEN time scale is compared with UTC by means of the reception of the signals transmitted from the Loran-C station of Estartit (7990-Z) of the Mediterranean Sea Chain and from the GPS satellites. Fig. 7 reports UTC(IEN)-UTC(USNO) obtained by means of the two synchronization methods from March to October 1986.

An NBS/GPS receiver was lent in May 1985 to IEN in the framework of a scientific cooperation between IEN and NBS (*) and since the end of 1985 the measurement results are made available to the time and frequency laboratories on the General Electric Mark III Information System. The IEN-GPS file is updated every Tuesday. The GPS measurements schedule follows the NBS/BIPM common view measurement program [5]. In Fig. 8 are reported UTC(IEN)-UTC(NBS) and UTC(IEN)-UTC(PTB) as obtained from NBS monthly dissemination reports and IEN computations.

The time differences between UTC(IEN) and the cesium clocks are measured twice per day at 00h00min UTC and 12h00min UTC with a 1 ns resolution. The mean over ten days of the readings taken at 00hUTC, together with the daily Loran-C readings are sent to BIH to contribute to the generation of the international atomic time scale.

The data acquisition system is based at present on a personal computer which controls all the routine measurements inside the laboratory.

A functional diagram of the equipment used for the realization of UTC(IEN) is reported in Fig. 9.

All the instruments used for the UTC(IEN) generation and dissemination are operated by a fail-safe power system. This system is made of three groups of static inverters, batteries and rectifiers and of an emergency power plant. The fail safe power system supplies the laboratory with three independent 220 V - 50 Hz power lines.

(*) A recognition of equivalence of the SI unit of time maintained at IEN and NBS was signed on October 1985 as a result of a joint seminar between USA and Italy on calibration services [1].

3. International comparisons

Since 1982, the IEN has been involved in some international synchronization experiments via satellites using different techniques:

- a one-way time synchronization experiment performed during 1982-1983 with other European timekeeping laboratories (DVFLR, PTB, NPL, TUG, VSL) using the television signals broadcasted by the OTS-2 satellite [6,7];

- a synchronization experiment with USNO, lasting one week in October 1983, using a Naval Research Laboratory receiver for GPS satellites [8];

- a two-way synchronization experiment, which lasted two weeks, in June 1984 with the Shaanxi Astronomical Observatory (China) and other Chinese Observatories by means of Sirio 1 satellite [9];

- a two-way synchronization experiment still via Sirio 1 satellite using MITREX modems, lasting one week in March 1985, with the Shaanxi and Shanghai Astronomical Observatories (China) and the Technische Universität of Graz (Austria), the last one operating in a one-way mode [10,11].

For the measurements performed by means of Sirio 1 was used the Telespazio-Lario ground station, whereas for the OTS-2 experiment the IEN used its own receiving station in the band 11-12 GHz equipped with a 3 m antenna mounted on the roof of the Time and Frequency laboratory.

Following BIPM Recommendation S3(1985) proposed by CCDS [12], the IEN is planning to take part in 1988 to a synchronization experiment in cooperation with the Istituto Superiore Poste e Telecomunicazioni in Roma using a direct television broadcasting satellite and MITREX modems.

4. Standard Time and Frequency services

The standard time dissemination activity began in 1945 by supplying the Italian Broadcasting company (RAI) with time signals derived from the IEN standard clocks.

In 1951 the IEN started to transmit standard time and frequency signals by means of its own transmitting station IBF located upon the hills near Torino. The IBF transmitting schedule is reported in Fig. 10. The standard frequency carrier at 5 MHz is presently derived from a VHF standard frequency transmission on 160 MHz made by IEN for the area of Torino. The radiated time signals and the carrier frequency follow the UTC system.

The time signals generated by IEN and broadcasted by RAI were modified in 1979 by adding a coded signal with the date information [13]. In Fig. 11 is depicted an example of coded date information carried by these signals.

These time signals are becaming widely used to synchronize automatically electronic clocks with a precision that can be better than 1 ms and to correct the frequency of crystal oscillators limiting their frequency offset and drift. An investigation on the time synchronization precision was carried out over a one month period in 1986 for the three RAI networks and the results are depicted by the histograms of Fig. 12; it was found out that the mean number of emissions per day was of 16 (RAI 1), 17 (RAI 2) and 11 (RAI 3). The standard deviation of the synchronization measurement was, at worst, of 0.2 ms. Further investigation on the capabilities of these signals to provide a traceability to UTC (IEN) are in progress [14]. In Fig. 13 has been reported the daily distribution of the coded time signals emissions related to the time of transmission.

The IEN performs other time and frequency dissemination services covering limited areas that are described in Table 2 where are also given detailed information on the abovementioned services.

The laboratory performs by request frequency and time interval calibrations and frequency stability measurements both in the frequency and time domains. Table 3 shows the IEN time and frequency measurement capabilities.

5. Clocks synchronization by passive television method

Television synchronization measurements using the passive method [15] have been performed by IEN since 1970 in order to provide the standard clocks located in other Italian laboratories with the traceability to UTC(IEN). Presently the following organization have a synchronization link with IEN:

- Istituto Superiore delle Poste e Telecomunicazioni (ISPT) in Roma;
- Osservatorio Astronomico di Cagliari (CAO);
- Piano Spaziale Nazionale - Laser ranging station of Matera;
- Consiglio Nazionale delle Ricerche - VLBI station of Medicina (Bologna).

A series of time interval measurements, lasting one minute, is performed daily in all these laboratories and the results are sent to IEN by telex. The IEN supplies the users with a calibration report every three months. A standard deviation of a series of measurements is of the order of 10 to 30 nanoseconds, depending on the link.

Atomic clock transportation are also carried out by IEN periodically to check the differential propagation delay of the television signals.

6. Activity for the Italian Calibration Service (SIT)

The time and frequency laboratory acts also as reference laboratory for time and frequency quantities for SIT [16]. As a consequence, it is charged of all the technical tasks, as the survey of the measurement procedures, the reference standards calibration and long term control, necessary to approve the laboratories requesting to operate as SIT calibration centers.

The frequency offset of the calibration centers reference standard, mainly rubidium oscillators, is checked daily by means of television synchronization measurements according to the measurement schedule quoted in the previous point.

At IEN the measurement data supplied by the calibration centers are processed, and calibration certificates giving the normalized frequency departure and frequency drift (see Fig. 14) versus UTC(IEN) are supplied every three months. Up to 1986 IEN has approved for frequency measurements six calibration centers, but we expect to double this number during 1987.

Fig. 15 shows the distribution in Italy of metrological laboratories and SIT calibration centers having a frequency and/or time traceability to IEN by means of the television synchronizing pulses.

7. Research on primary frequency standards

The research activities in the field of primary frequency standards have been mainly devoted to the development of a Mg beam operating in the submillimetric region (601 GHz) and to the cooperation with NBS concerned with the analysis of errors in Cs beam standards and with the design of a new Cs beam laboratory standard with optical pumping [17,18,19,20].

The $^3P_1 - {}^3P_0$ $\Delta m_J = 0$ transition of the metastable triplet of ^{24}Mg has been observed and its frequency has been measured with an uncertainty of $\pm 3x10^{-10}$ [4] by use of an atomic beam interacting with the electromagnetic field in an open resonator, driven by a frequency stabilized backward-wave-oscillator. The atomic transition linewidth was 77 kHz ($Q = 8x10^6$) limited by the transit-time of the atoms through the cavity field.

The Ramsey interference fringes have also been observed in a spatially-modulated atomic beam via a doubly folded open resonator; with a distance between the two interaction zones of 30 cm a linewidth of 1.1 kHz has been obtained ($Q \approx 5x10^8$)[17].

Experimental and theoretical work are in progress in order to measure the short--term frequency stability and the transition frequency with respect to the Cs standard, and to perform a metrological characterization of the Mg standard on the basis of the recent experiments.

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Beginning of service	Kind of service and uncertainty	Network or transmitter	Signal format and schedule	Coverage
1945 (1979)	Coded time signals on AM, FM, TV emissions time: <1 ms	Transmitters operated by national broadcasting company (RAI)	7 pulses beginning at second 52 and ending at 60, the pulse at second 59 being omitted. The first pulse lasts 960 ms; the other pulses last 100 ms. The first pulse code gives the following information: hours, minutes, month, day of the month, day of the week, solar time or daylight saving time. Broadcasted from 20 to 30 times a day.	Nationwide
1951	HF emissions time: 1 ms	IBF transmitter on 5 MHz standard frequency	Second pulses of 5 cycles of 1 kHz modulation. These pulses are repeated 7 times at the minute. Voice announcements in Italian, French and English at the beginning and end of each transmission. Time announcement (C.E.T.) by Morse Code every ten minutes beginning at 0^h0^m DUT1 code according to CCIR. Radiated during 15 m preceding 7^h, 9^h, 10^h, 11^h, 12^h, 13^h, 14^h, 15^h, 16^h, 17^h, 18^h (UTC). Advanced by 1 hour in summer.	European
1960	Time and frequency signals on telephone lines	Telephone network of Turin operated by Italian Telephone System (SIP)	Second pulses of 5 cycles of a 1 kHz tone. At the minute the signal length is increased to 100 ms and is followed by a voice announcement giving the time in C.E.T.. Two standard tones of 1000 Hz and 440 Hz are given at alternate minutes. Available continuously	Torino telephone network
1969	VHF emissions frequency: same as UTC(IEN)	IEN transmitters	Coded time signals as in point 1) amplitude modulating a 155 MHz standard frequency. 160 MHz standard frequency. Continuous.	Torino area
1976	MF standard frequency emission frequency: 5×10^{-11}	RAI transmitter of Milano 1	900 kHz carrier is stabilized by means of a rubidium standard. Its frequency is maintained within $\pm5\times10^{-11}$ with UTC(IEN) Continuous.	Northern Italy

Table 2 - The IEN standard time and frequency dissemination services

Measured quantity	Range	Range of associated parameters	Uncertainty ($\pm$)	Remarks
Time interval	10×10^{-9} s to 10 s		1 ns + E_{Tt}	E_{Tt}, E_{Tf}: trigger error
	10 s to 20000 s		2 ns + E_{Tt}	
Frequency	50×10^{-6} Hz - 20×10^{9} Hz		$1\times10^{-12} + E_{Tf}$	direct reading on frequency counter
	20×10^{9} - 110×10^{9} Hz		1×10^{-9}	
	20×10^{9} - 2.5×10^{12} Hz (*)		1×10^{-11}	this uncertainty can be obtained by means of measurement techniques which imply frequency synthesis and down conversion
	1×10^{6}, 5×10^{6}, 10×10^{6} Hz		1×10^{-12}	
Frequency stability	0.1 Hz - 100 kHz for the frequency domain	5 MHz $\leq \nu_{\sigma} \leq$ 500 MHz	$\mathcal{L}_{\phi}(f) = \frac{10^{-13}}{f} + 10^{-16}$	reported at 5 MHz
	10 ms - 10000 s for the time domain	10^{-2} s $\leq \tau \leq$ 10 s	$\sigma_y = \frac{5\times10^{-12}\ \mathrm{s}}{\tau}$	
		$\tau > 10$ s	$\sigma_y = 5\times10^{-13}$	

(*) This range is not continuously covered

Table 3 - IEN time and frequency measurement capabilities

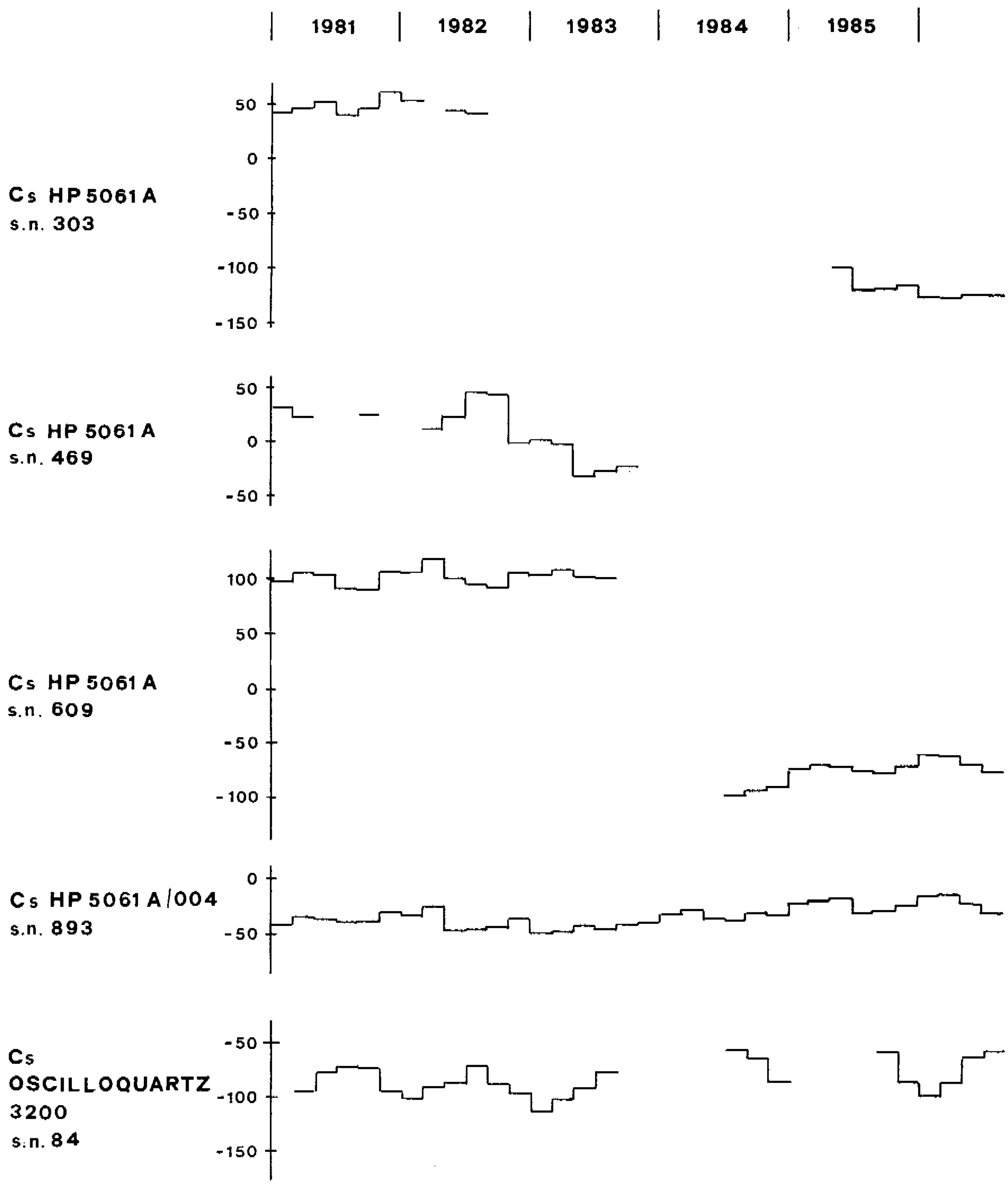


Fig. 1 - Bi-monthly mean frequency departures of IEN clocks versus TAI .

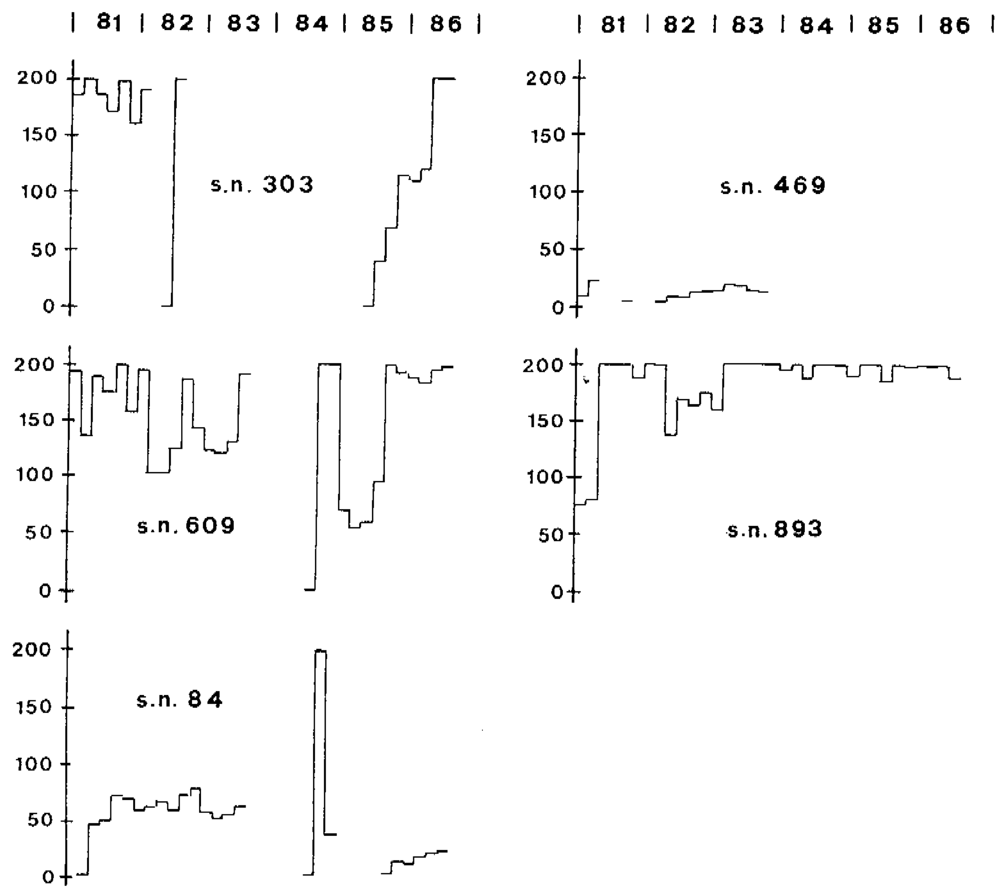


Fig. 2 - Weights of IEN clocks used for TAI.

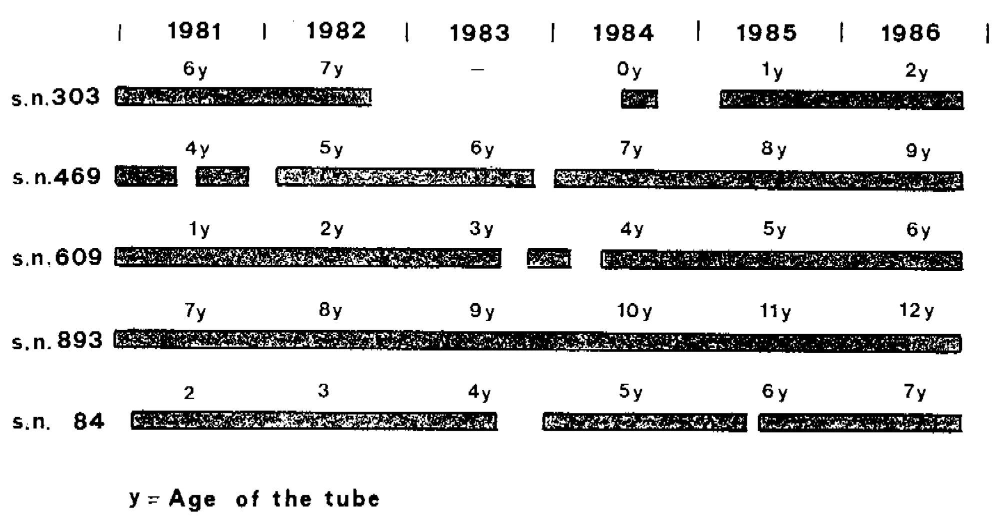


Fig. 3 - IEN Cesium clocks operating time periods and ages.

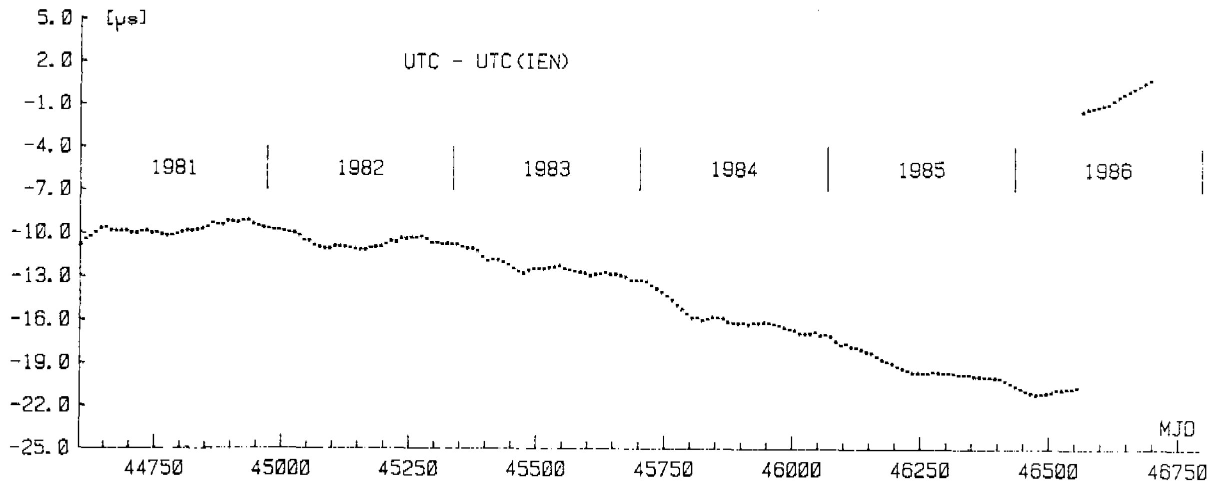


Fig. 4 - UTC(IEN) time scale versus UTC from BIH Circulars D.

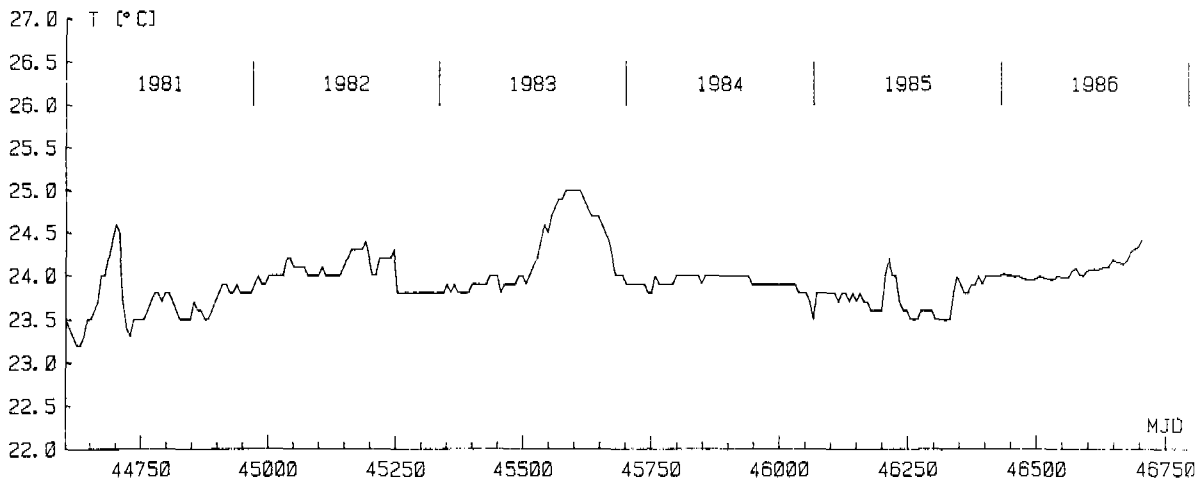


Fig. 5 - Temperature variation in the cesium clocks room.

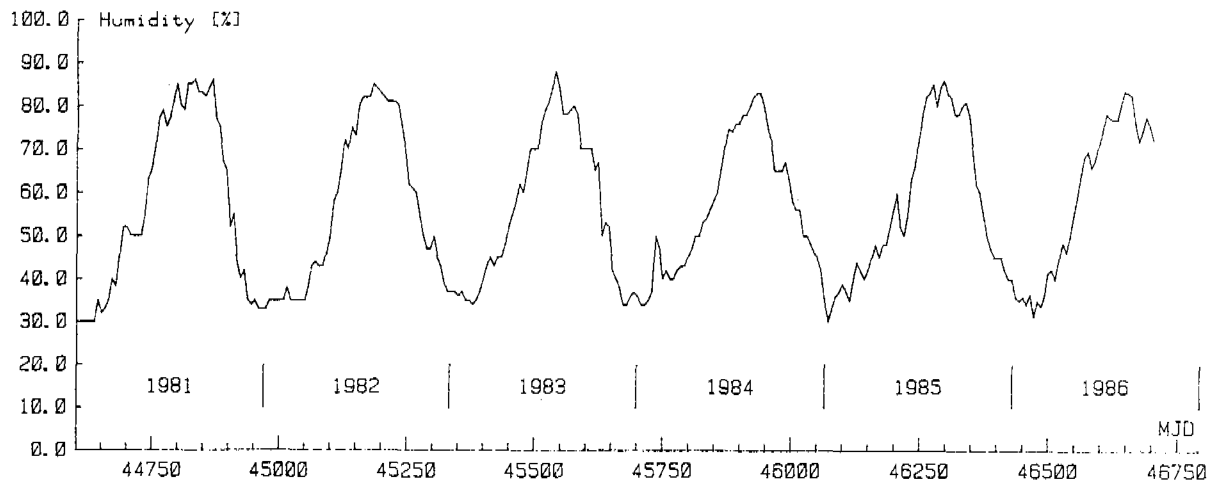


Fig. 6 - Relative humidity variation in the cesium clocks room.

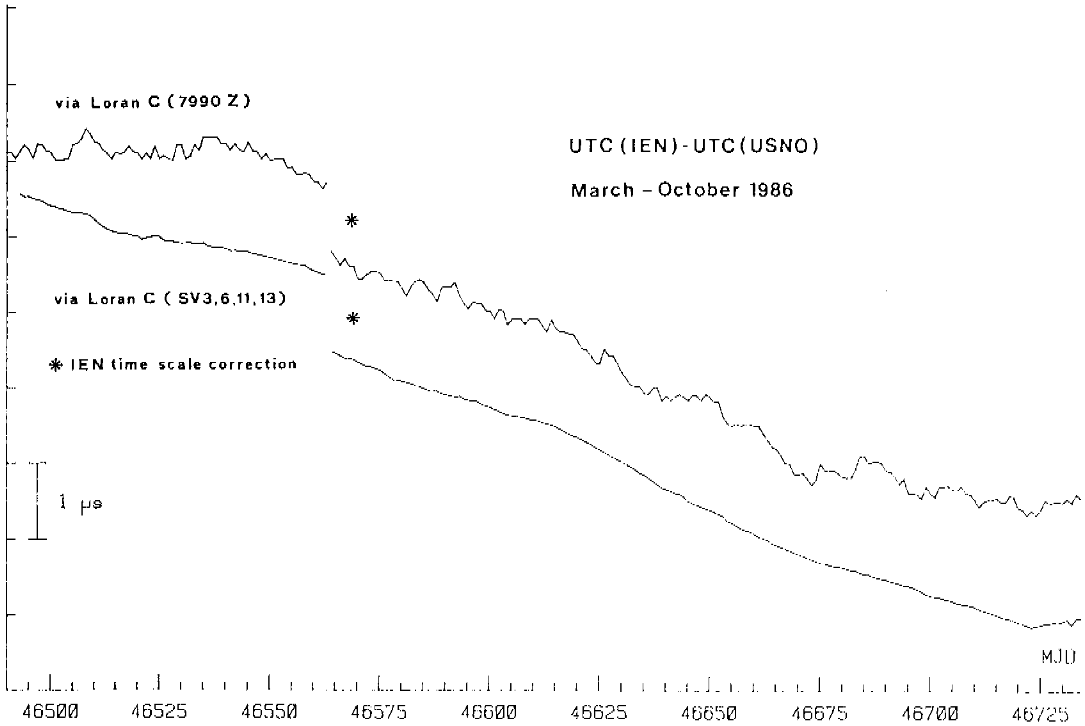


Fig. 7 - UTC(IEN) - UTC(USNO) via Loran-C and GPS.

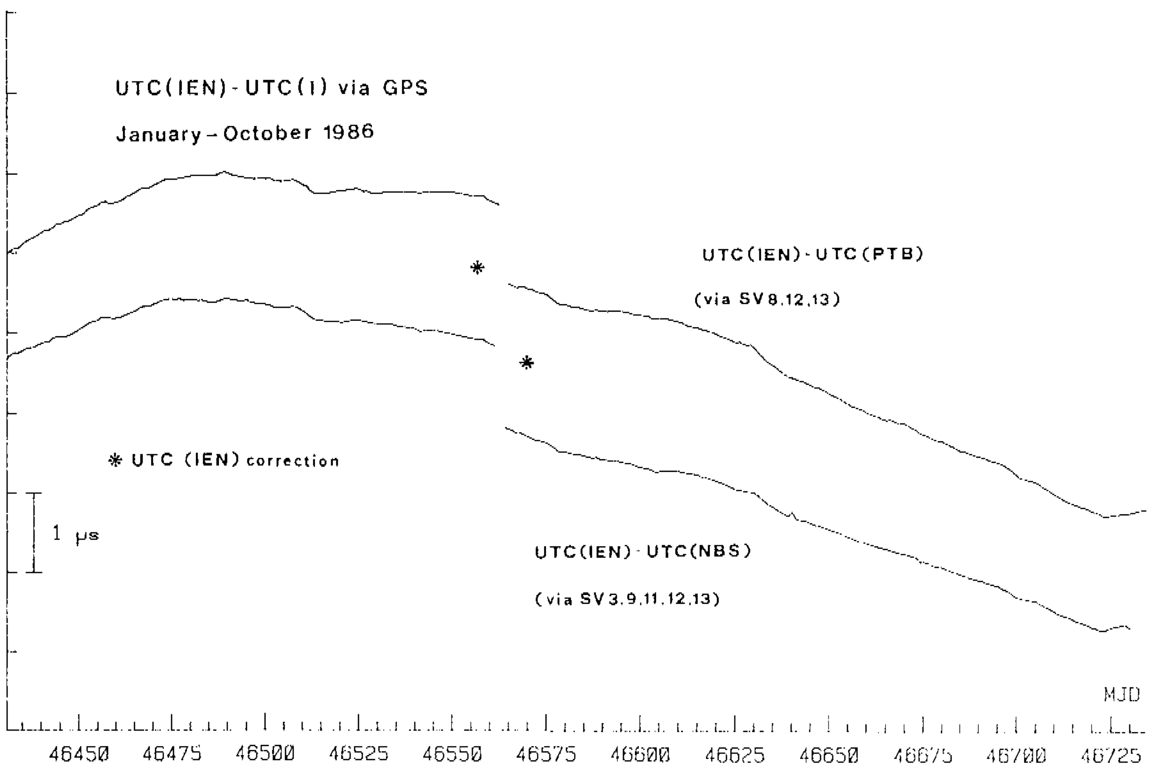


Fig. 8 - UTC(IEN) versus UTC(NBS) and UTC(PTB) via GPS.

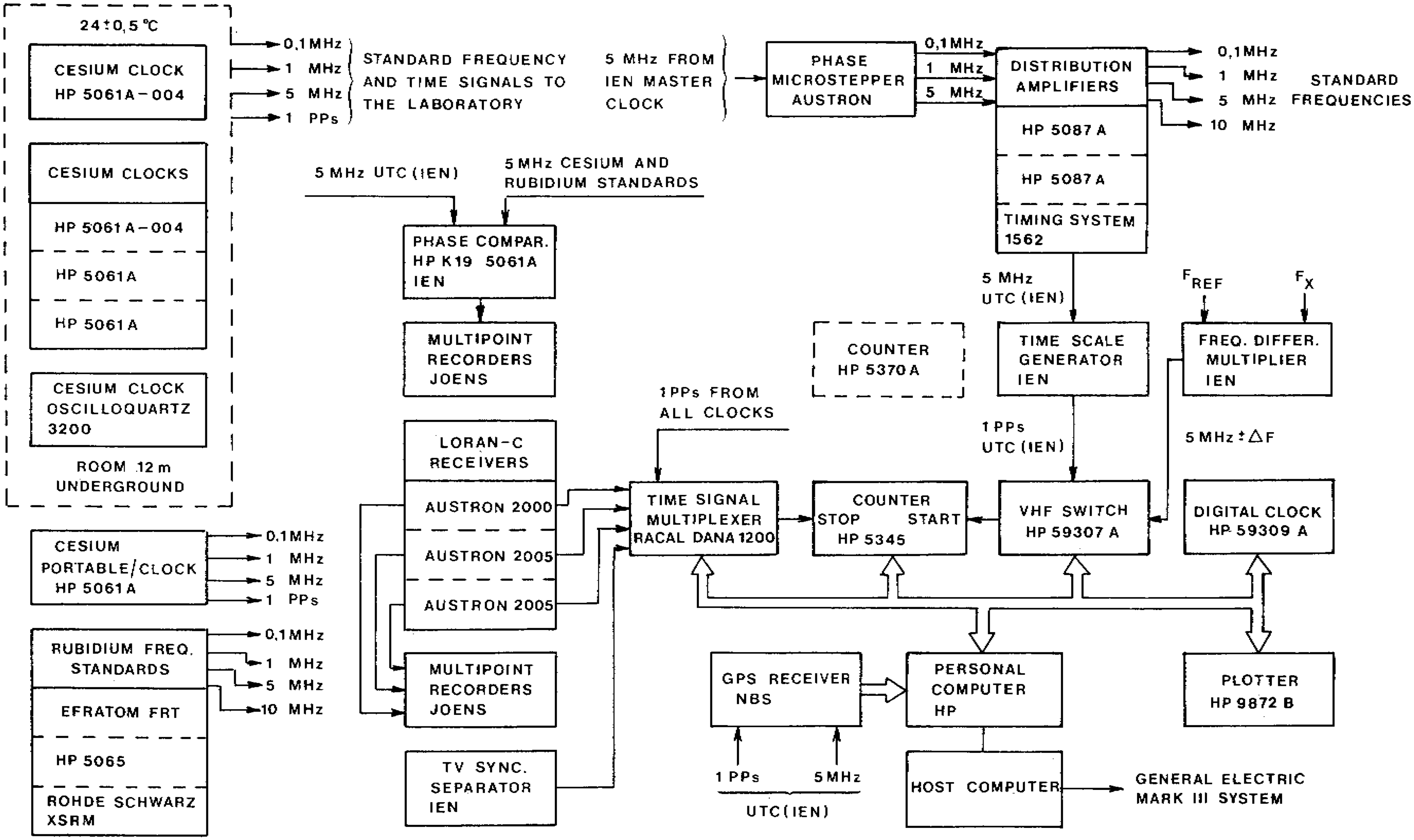


Fig. 9 - Equipment set-up for the realization of UTC(IEN).

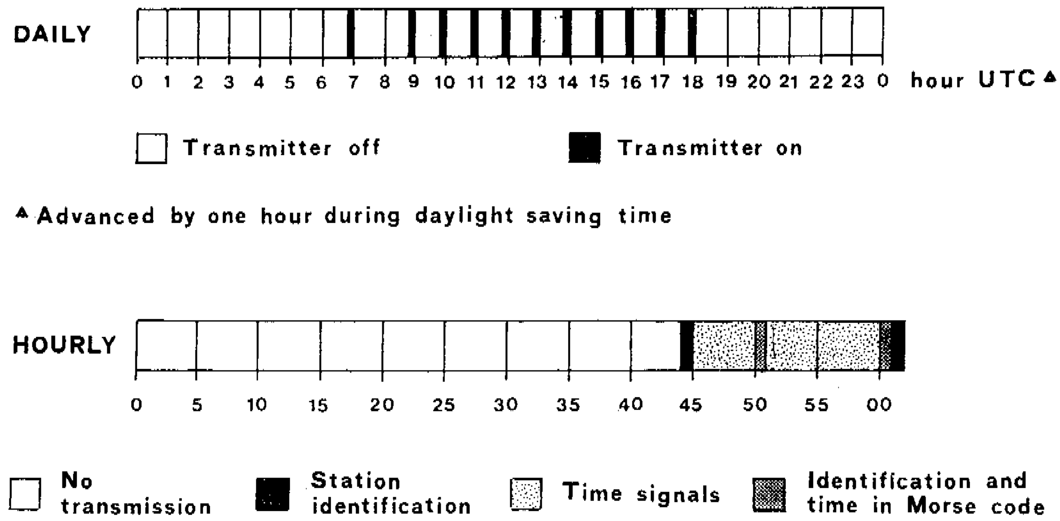


Fig. 10 - IBF transmitting schedule.

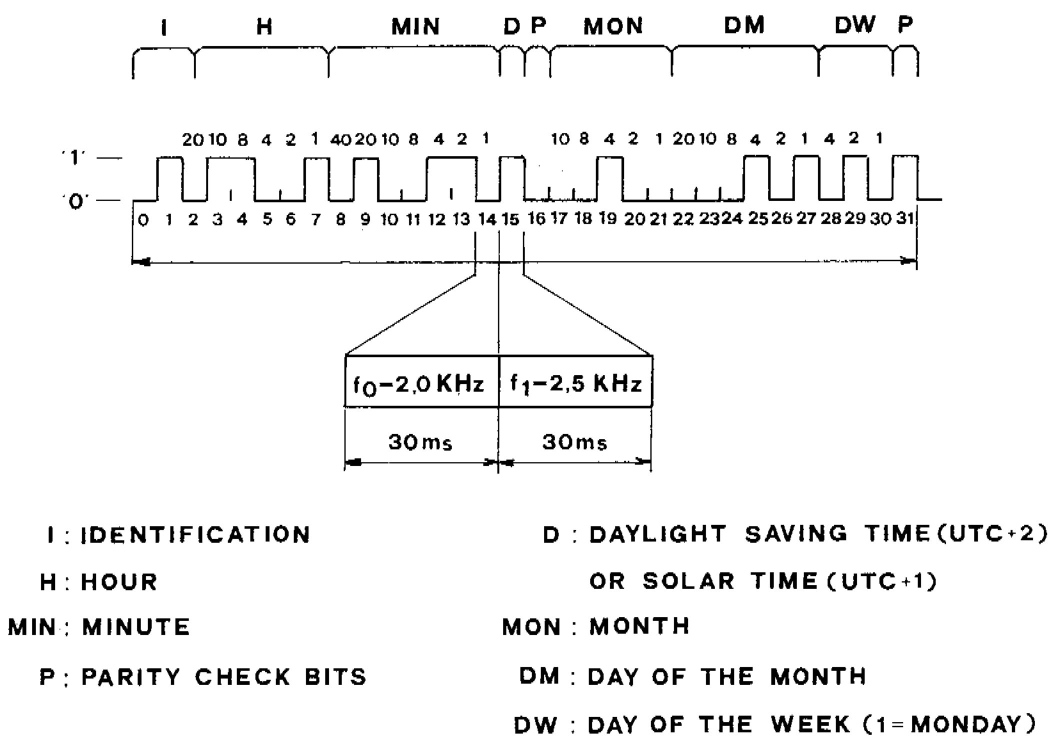


Fig. 11 - Example of coded date information: Tuesday, 5 April, 19^{h} 26^{min}, UTC + 2.

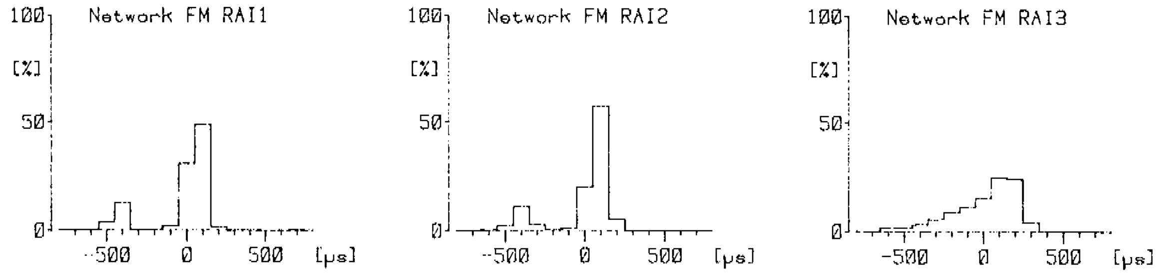


Fig. 12 - Histograms of the time synchronization errors obtained with the IEN coded time signals.

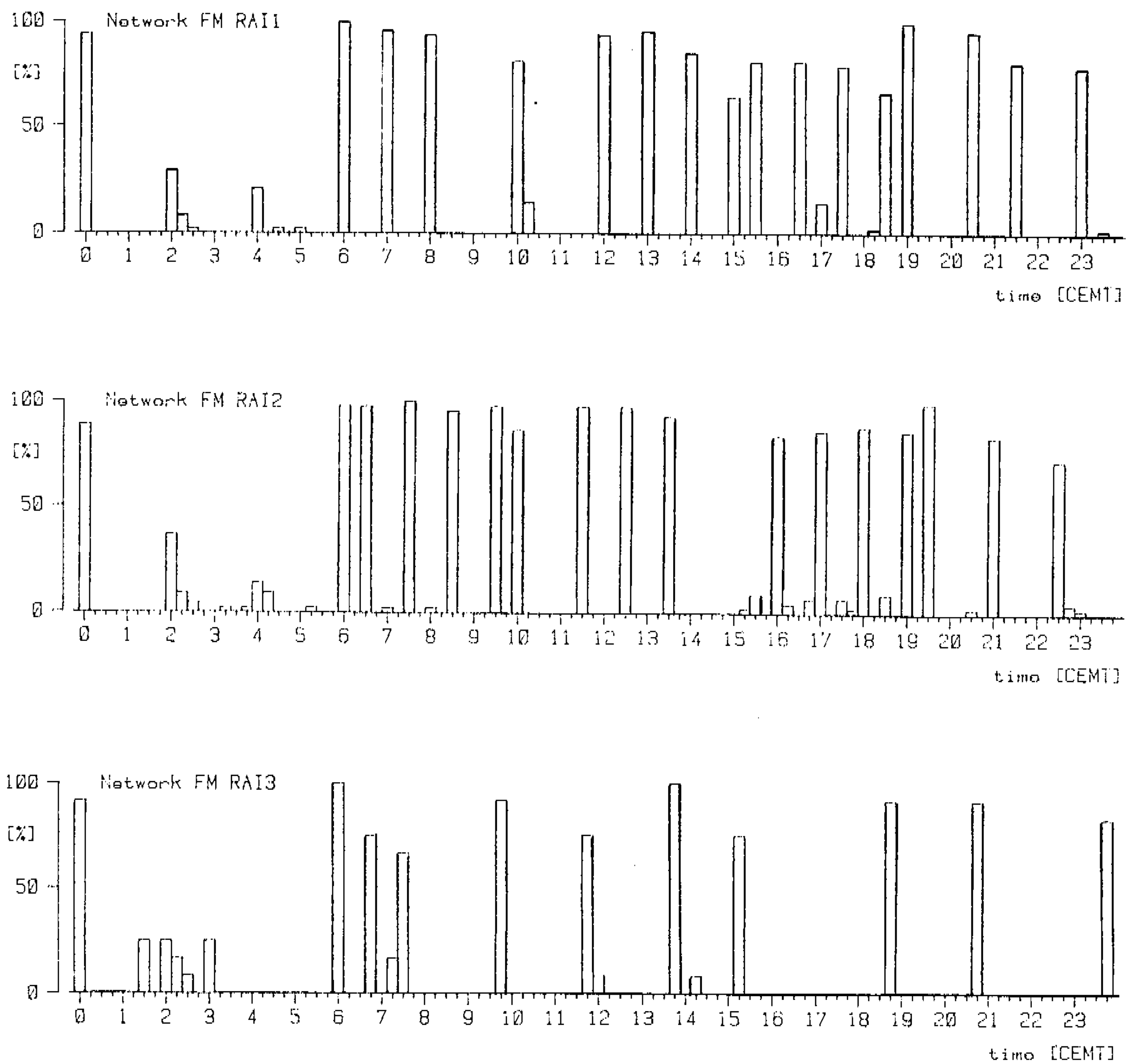
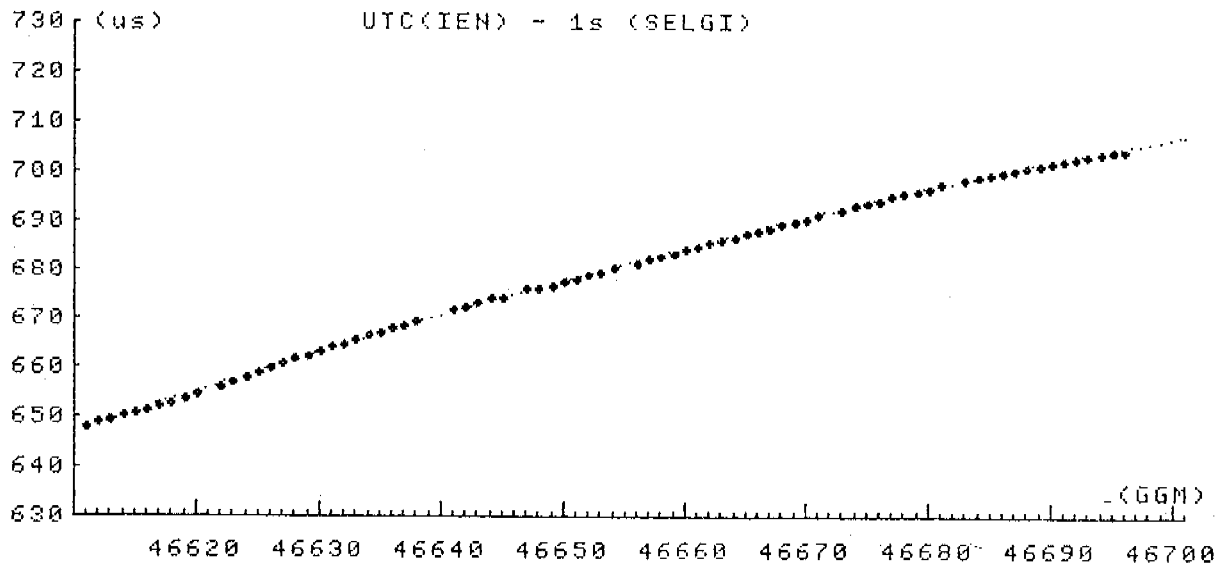


Fig. 13 - Histograms of the daily time of transmission of IEN coded time signals.

Laboratory reference oscillator: rubidium frequency standard
July - September 1986



MJD 46611-46701 Linear fit on 79 data
normalized frequency departure (MJD = 46610) = -1.0×10^{-11}
frequency drift = 2×10^{-12}/month

Fig. 14 - Part of IEN calibration certificate of remote oscillators.

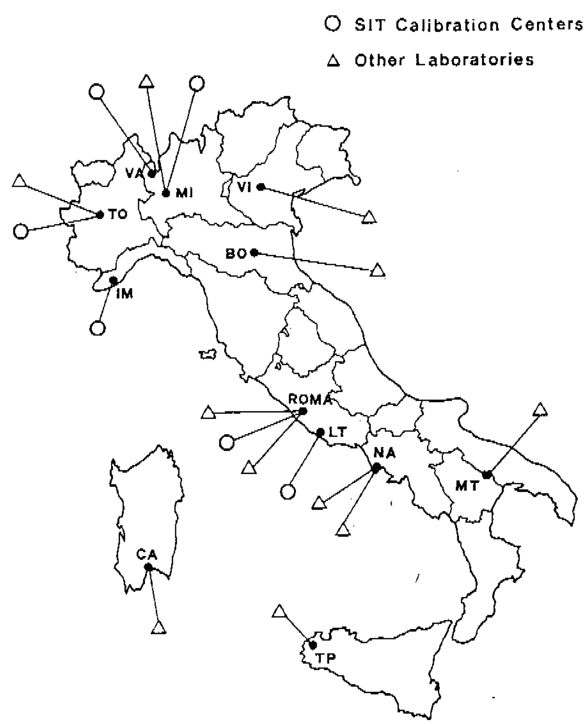


Fig. 15 - Metrological laboratories and SIT calibration centers in Italy in 1986.

QUESTIONS AND ANSWERS

DAVID ALLAN, NATIONAL BUREAU OF STANDARDS: Your paper raises a very interesting point, namely the changing of humidity and its possible effect on clocks. It is my personal opinion that there are two factors which have not been investigated adequately for commercial cesiums. One is humidity and the other is the DC power. I know that the USNO has an experiment on-going to determine the power effects and I really look forward to seeing the result of that work. I see and hear from JPL that they have the ability of looking at humidity. I think that it is very important to look at the some 200 clocks in TAI and the humidity effect. We know that there is a temperature coefficient, we also know that there is a very strong temperature gradient effect on cesiums. If you turn them over and invert the gradient, you get a big frequency shift. One could easily imagine that the humidity could couple through this temperature gradient to cause significant annual variations. It was very interesting to see your data and we hope that JPL would help us determine this sensitivity.

MR. CORDARA: We hope to present a paper at the next European Forum for Frequency and Time about the results of our commercial clocks with reference to the humidity behavior, comparing them also with the clocks of another Italian laboratory, the Post Office in Rome, which controls the humidity.