# REPORT TO THE 15TH SESSION OF CCTF

## ISTITUTO ELETTROTECNICO NAZIONALE "G. FERRARIS"

# ITALY

## 1. Atomic frequency standards

### Cs Atomic Fountain

The cesium fountain structure, optics and automatic operation system were completed. In the early 2000 we installed two microwave cavities for Zeeman state selection and Ramsey interaction, the drift tube, the quantization field (C-field) coil, and magnetic shields.
We assembled the optical bench for differential optical detection and the data acquisition software for the PC. We also built a frequency synthesis chain for microwave signal using a direct multiplication scheme from a 5 MHz ultra stable quartz oscillator to 9.2 GHz. A new AOM frequency synthesis system for the launch and post cooling of the atoms was installed, using 3 independent PLL circuits working at 80 MHz. This system allowed atom launching up to 1.35 m above the capture region and a post-cooling effective down to 3 μK.
We routinely detect a Ramsey fringe line width of 0.8 Hz of FWHM ($Q_a \approx 1.1 \times 10^{10}$).

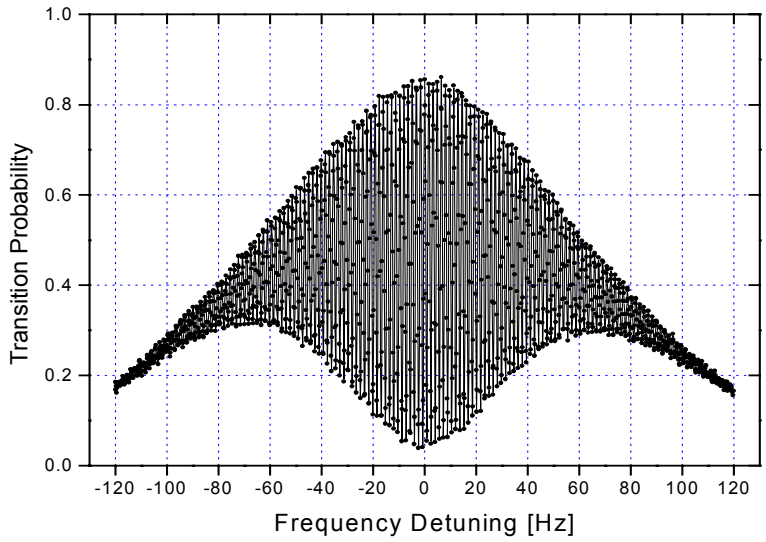


Fig 1 – Ramsey fringes pattern of IEN CSF1

We also started the fountain evaluation as a primary frequency standard, giving a preliminary characterization of the main biases.
Latest results are given in the table below:

| Physical Effect | Magnitude | Uncertainty |
|---|---|---|
| Second Order Zeeman | $42 \times 10^{-15}$ | $.3 \times 10^{-15}$ |
| Black Body radiation | $28 \times 10^{-15}$ | $.2 \times 10^{-15}$ |
| Gravitational Red Shift | $32 \times 10^{-15}$ | $.1 \times 10^{-15}$ |
| Cavity Pulling | $<.1 \times 10^{-15}$ | $<.1 \times 10^{-15}$ |
| Atomic Density | Under evaluation | $<10 \times 10^{-15}$ |

Table 1 – Main biases of IEN CSF1

Using the Ramsey signal on magnetic sensitive transitions we carried on an accurate time integrated C-field measurement: magnetic field inhomogeneities were evaluated using low frequency magnetic transitions ($\Delta F=0$, $\Delta m_F=-1$), maximum non-homogeneity was evaluated to be less than 300 pT ($3\cdot10^{-3}$ of the total field applied).
At the moment we are evaluating the effect of atomic density shift, that however is measured to be below the $10^{-14}$ level.
The fountain stability was measured against the free running BVA oscillator to be $\sigma_y$ (3 s) = $2\cdot10^{-13}$, limited by Dick effect.
The long term stability measurements are limited by UTC(IEN), currently realized by means of commercial cesium beams.

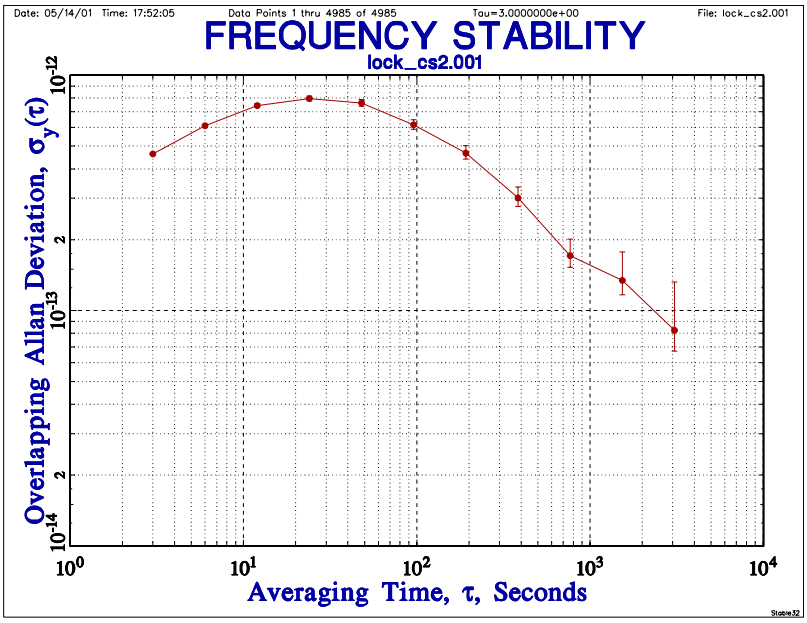


Fig 2 – Stability measurement of CSF1 against UTC(IEN)

**CPT Maser**

We are developing theoretical and experimental studies on some phenomena observed in an optically thick atomic ensemble of $^{87}$Rb with buffer gas prepared in a CPT state.
In particular, we observed inverted dark lines and line narrowing in the transmission signal as a consequence of electromagnetic induced transparency (EIT) phenomenon; in the CPT maser we observed a linewidth below the collision limit, as it was predicted theoretically.
These atomic systems are also interesting because they can slow coherent light pulses (dark state polaritons). In particular it is possible to measure a time delay of the information carried by light; this information may be represented, for example, by an amplitude modulation. We measured the time delay between the output laser amplitude modulation signal and the CPT maser signal as a function of the frequency modulation.
We also designed a CPT maser prototype for space application: two color radiation that is needed to induce CPT, is produced by a compact setup with a single laser source and a microwave optical phase modulator.

## 2. Generation of the national time scale UTC(IEN)

Four commercial cesium clocks ( HP 5071A high performance type) contributed in the average to the generation of the IEN time scales and to TAI.

The average time difference of the national time scale UTC(IEN) versus the international time scale UTC has been of –92 ns in 1999 (peak fluctuations –159 ns to +13 ns) and of –14 ns in 2000 (peak fluctuations –74 ns to +60 ns). The corresponding maximum frequency deviation over 5 day measurements was $\pm3\times10^{-14}$ limited by the comparison technique used (GPS common view). In the year 2000 the maximum time deviation of UTC(IEN) versus UTC has been well under 100 ns.

In the frame of a research project aiming to improve the accuracy of the realization in real time of the national time scale, two active hydrogen masers by DATUM have been purchased in December 2000 and will be included in the clock ensemble.

UTC(IEN) was compared with the international time scales by means of the GPS and GLONASS satellites, according to the BIPM measurement schedules, supplying to BIPM the synchronization results obtained from the two satellite systems in the common-view and multichannel techniques.

To investigate the capabilities for frequency and time comparisons of the carrier-phase measurement technique using the GPS signals, an Ashtec Z12-T Metronome geodetic receiver has been purchased and is expected to be available in mid 2001.

The Ku band station to be used for the synchronization of clocks with the two-way technique was eventually approved by INTELSAT in May 2000 with the code designation IEN01-N; a failure occurred during summer in the transceiver, prevented to join the international synchronization network using INTELSAT 706 satellite.

Since the beginning of April 2001, IEN is regularly performing the TWSTFT measurements taking part in both the European and transatlantic sessions and the data files in the ITU format are made available trough anonymous ftp (address *ftp.ien.it)*.

As a sample, in the figure below is reported the comparison between the time scales of IEN and NIST for the period April to May obtained with this technique.

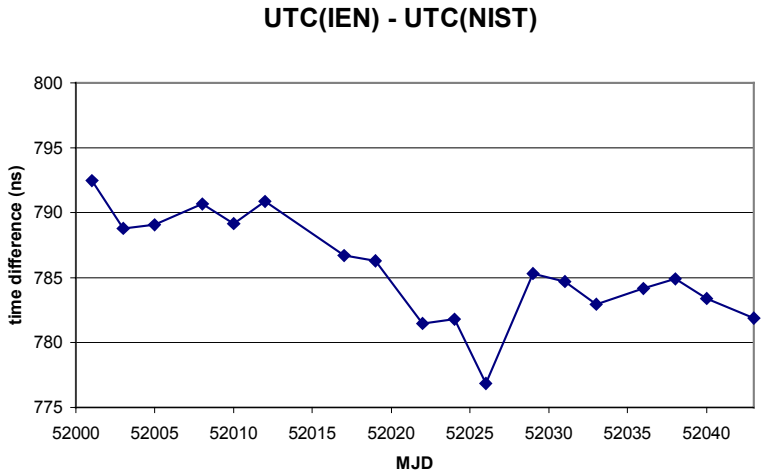


Fig 3- Two way satellite time scale comparison between UTC(IEN) and UTC(NIST), uncalibrated for link delay

To increase the reliability of the IEN two-way measurement system, a second transceiver, namely a SSE Kstar model, and a new modem, the SATRE designed by TimeTech, were purchased at the end of 2000.

The two-way equipment will also be instrumental to compare the IEN cesium fountain standard with the primary frequency standards of other NMIs.

The traceability to UTC(IEN) of the reference standards of about 30 secondary laboratories was provided by daily time comparisons based on different synchronization techniques (coded time signals, TV synchronization pulses, GPS).

The dissemination of the legal time for Italy by the RAI AM and FM transmitters and via modem on telephone lines ( tel. Nr. 166 11 4615 ) has been continued and an experimental NTP primary time server, for the synchronization of computer clocks on Internet, has been set up. This service can be accessed at *time.ien.it*.

The development of models of the measurements performed in the time and frequency field has been started and a list of the IEN calibration capabilities in these fields was sent to the EUROMET Rapporteur.

The accreditation activity in the frame of the Italian Accreditation Service SIT increased the number of the centers accredited for frequency and/or time interval to a total of 22 by the end of 2000. Six interlaboratory comparisons were organized between the IEN and the SIT centers using quartz or rubidium oscillators as travelling standards.

A new approach was followed, and tested with good results, in the case of centers with low uncertainties, that foresees the use of a rubidium frequency standard and a GPS receiver as a travelling standard.

## 3. Algorithms and mathematical methods in metrology

The activities in the last years were strongly related to the participation to four European research projects in collaboration with different space industries and research institutes. In particular, IEN was involved in the definition and design of the new European Global Navigation Satellite System (GNSS) Galileo concerning the timing aspects of the system.

In fact, on the one hand the Galileo system needs the Time and Frequency metrology and the expertise of the European metrological labs to appropriately address its time requirements for the navigation and timing purposes, on the other

hand, Time and Frequency laboratories may become a demanding class of Galileo users, and it is important to clearly express the Galileo expected features.

In the frame of the research contracts funded by the European Commission, IEN was involved in

1) "GALA: Galileo overall architecture definition" with the aim of identifying and counting the possible users of the "time tagging" service of Galileo. This activity was carried out in collaboration with the TimeTech of Stuttgart (Germany) under the responsibility of Racal Tracs Ltd (United Kingdom).
2) "GEMINUS: Galileo service definition" with the aim of revising the GALA documents and identifying the user need in the timing field. The GEMINUS project also organized some "user fora" to which IEN took part. The contract was under the responsibility of Thomson (France).

IEN worked also in the frame of:

3) "GALILEOSAT", funded by the European Space Agency, for the design of the Galileo system time scale, its synchronization to UTC and its dissemination. IEN worked in collaboration with the Neuchatel Observatory (Switzerland) and Detexis (France), under the responsibility of Alcatel Space (France).

4) As a subcontractor of the Gavazzi Space industry, IEN is currently involved in the ESA project "New methods and systems for time and frequency distribution via satellite" on the identification and description of time users and time dissemination systems.

IEN researchers were invited by ESA to form and chair a Working Group on "Galileo Time Interface" sharing expertise on time scale algorithms, clock statistical modeling, UTC synchronization and helping in proposing a European collaboration to interface Galileo System Time to UTC.

In collaboration with the *Politecnico di Milano*, the *Real Observatorio de la Armada* of San Fernando in Spain, the development of a statistical technique apt to estimate the different sources of noises from the clock comparison measures was continued. A Spanish Ph. D. student is working on this topic, and four degree students in Mathematics and Electronics Engineering carried out their thesis activity in this frame.
IEN also chairs the sub Working group of the CCTF on "Algorithms" (http://www.ien.it/tf/cctf/).

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