INRIM TIME AND FREQUENCY LABORATORY: STATUS AND ONGOING ENHANCEMENT ACTIVITIES

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Abstract

INRIM Time and Frequency Laboratory (hereafter indicated as TFL), realizes and makes available to the users the UTC(IT) time scale, the legal time scale for Italy. Generated by means of an active hydrogen maser (AHM) and supported by an ensemble of cesium beam frequency standards, hydrogen masers and cesium atomic fountains, it is synchronized via satellite (GPS and TWSTFT, Two Way Satellite Time and Frequency Transfer) with those generated by other international NMIs (National Metrological Institutes) and it is kept in agreement with the international time scale UTC (Universal Time Coordinated) computed by BIPM. Also, TFL regularly contributes to the realization of the TAI time scale, sending to BIPM the measurement results carried out following protocols defined at the international level. In this paper the status of the TFL is presented, highlighting the wide range of ongoing activities that are carried out in order to enhance its robustness and performances, with the aim to better solve the task of national NMI as well as preparing for providing accurate and reliable services to the European navigation system Galileo. In particular, the automatic measuring and controlling system functions basically to collect essential timing measurements and synchronization data, together with information about the status of all the equipment involved in the measurement processes. In order to improve the current system and to cope with ISO/IEC 17025 standard requirements, a new system called DMS (Data Management System) has been designed, allowing for an efficient integration of data coming from different sources. This system will work associated with a informatics system called FMS (File Management System) that will allow for flexible and robust management of the measurement files to be exchanged within the TFL and with external entities. Beside this and being the core of the laboratory, a new system for the UTC(IT) time scale generation is under design, foreseen to be totally automatic and relying on at least two parallel chains (based on AHM), a switching matrix allowing for commutation among the chains in case of failures/anomalies, and new steering and clock anomaly detection algorithms. Enhancements in the TLF dissemination services will be addressed, as well as the new power supply and informatics systems, together with a system able to send e-mail and SMS (Short Message Service) in case of failures/anomalies affecting the different TFL elements.

1. INTRODUCTION

The INRIM Time Frequency Laboratory (TFL) is continuously in evolution in order to improve the robustness, the reliability, and the main activities' results linked to other metrological laboratories or to the external users. This paper describes the main ongoing activities and projects in the TFL. After the TFL presentation, the following points will be described: the new power supply system, the new Data Management System (DMS) and the File Management System (FMS), the project for a new UTC(IT) time scale generation system, the Time and Frequency signals distribution system, the monitoring and alert diffusion system, and in conclusion, some general indications about the support to the Galileo projects.

2. INRIM TIME FREQUENCY LABORATORY PRESENTATION

The INRIM TFL is in charge of generating the UTC(IT) time scale **[1]** and supporting all the related activities. The TFL is housed in three rooms: the TFR (Time and Frequency Room), the CCR (Cesium Clock Room), and the HMR (Hydrogen Maser Room). The CCR hosts six cesium clocks (Symmetricom high performance HP5071A), while the HMR hosts three active hydrogen masers (namely 2 Symmetricom MHM-2010 and 1 Kvarz CH1-75A). These last two rooms have two air conditioning systems (main and back-up) maintained at a temperature of (23 ± 1) °C. The TFR, (23 ± 2) °C, hosts all the devices used for the TFL activities, like the UTC(IT) generation equipment, the equipment for synchronization and dissemination systems, the monitoring and all the required auxiliary devices.

The TFL power supply system is one of the most critical devices as the TFL activities are continuously running, and hence, it is necessary to guarantee this condition. To improve on the performance of the previous equipment, a new system has been implemented that will be described later on.

The main TFL activities and the actual structure are shown in Figure 1.

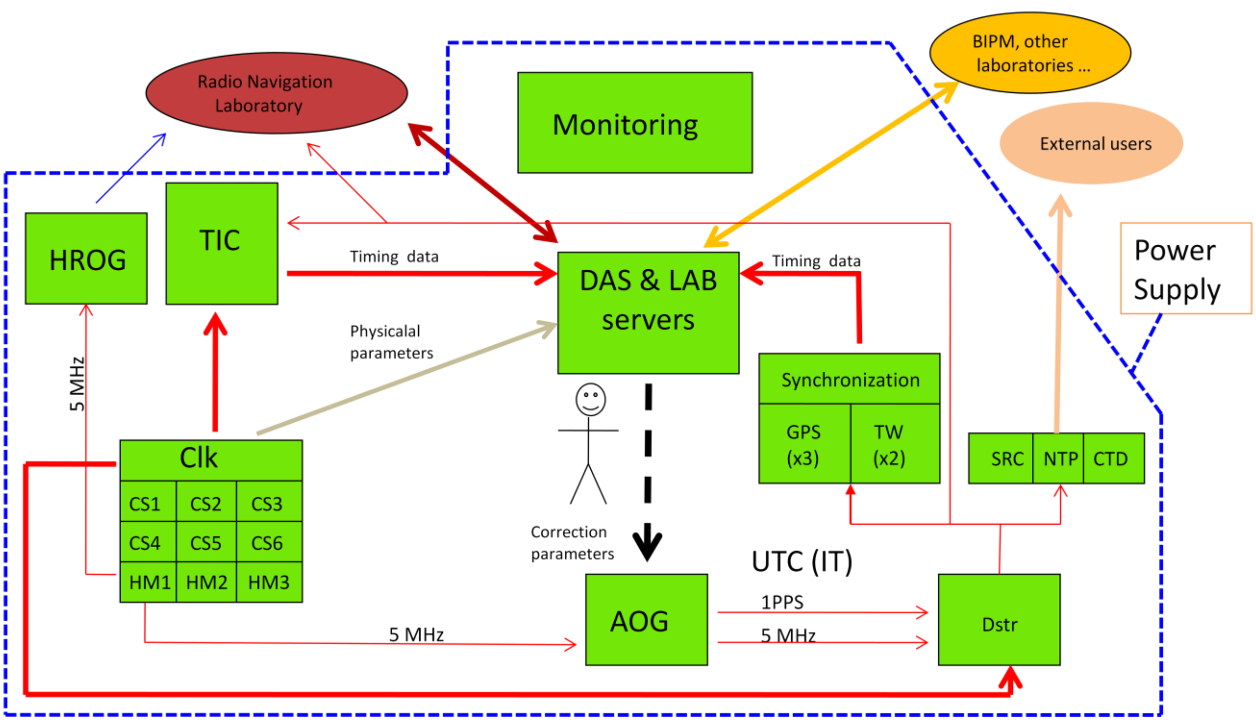

Figure 1. TFL structure diagram.

UTC(IT) is generated starting from the hydrogen maser 1 (HM1), while its frequency offset and drift are compensated using an Auxiliary Output Generator (AOG). A project for new UTC(IT) time scale generation is under development to improve its reliability and to obtain a totally autonomous system.

From the same HM1 maser also another time scale is generated, the Experimental Galileo System Time (EGST) used as reference for a Galileo Experimental Sensor Station (GESS) hosted at the INRIM Radio

Navigation Laboratory (RNL). This time scale is realized with a High Resolution Output Generator (HROG). The RNL is directly associated to the TFL activities and hosts four geodetic receivers.

The time and frequency signal distribution system (Dstr) allows distribution of the reference signals and UTC(IT) to the different internal users. As the current system is quite complex and articulated, an ongoing project will allow it to be centralized in order to access all the critical signals in an easier way.

The dissemination service is based on three systems: the coded time signal SRC (Segnale RAI Codificato) broadcasted by the national radio company RAI (Radiotelevisione Italiana), the telephone time code CTD (Codice Telefonico di Data) available on the telephone network, and the primary NTP (Network Time Protocol) on the Internet.

Concerning the synchronization techniques, three GPS receivers are involved (2 Dicom GTR 50 and 1 AOS TTS3), and two TWSTFT stations are used (Timetech - Satre modem). Both the GPS and the SRC are used to supply the traceability to UTC(IT) for the remote calibration of reference frequency sources.

The Data Acquisition System (DAS) compares the reference signals of the laboratory clocks versus UTC(IT), storing the results in the laboratory servers. The DAS and the laboratory servers are the TFL informatics core as they collect and store all the essential data (time interval measurements, environmental data, and clock status) coming from both the TFL and the RNL, and allow communication with other metrological laboratories or with external users like the Bureau International des Poids et Mesures (BIPM). The DAS and the laboratory servers will be replaced by the Data Management System (DMS) **[2]** and the File Management System (FMS) to increase the flexibility and improve the reliability.

The last element concerning the TFL structure is the monitoring system, a complex and very articulated system allowing the critical points to be checked. The monitoring tools available, together with the new alert broadcasting system, will allow the operators to be informed in case of problems or anomalies.

In the following sections, the ongoing enhancements and future projects that will allow improvement of the activities supported by the INRIM Time Frequency Laboratory will be detailed.

3. NEW POWER SUPPLY SYSTEM

The current power supply system used by the TFL consists of an AC power line supplied by an external provider and, in case of a power cut-off, a diesel generator will provide the AC power to all INRIM metrological laboratories. However since this generator needs approximately 20 s to start and to avoid interruptions, the TFL devices are powered with three different UPSs (Uninterruptible Power Supply). As the redundancy and the reliability offered by this system has not always been adequate, a new power continuity system has been implemented using three new UPSs placed in an independent room that allows for an easy access to these equipment and avoids perturbing the TFL activites during the maintenance operations. The UPS flexibility allows performance of all the maintenace operations without stopping the system.

Thanks to a new electrical distribution box and to new wiring, three power lines from the UPSs and one from the diesel generator are distributed in the laboratory. As the most critical instruments have two input power supplies, it is possible to connect these devices to two different sources to improve their reliability. The alert broadcasting system, connected to the electrical box, allows monitoring the behavior of the whole system.

The new power system, already installed and under test, has been confirmed to be reliable. The next step will be to switch all the devices in the TFL from the old power supply system to the new one, without stopping or perturbing the main laboratory activities.

4. NEW DATA MANAGEMENT SYSTEM (DMS) AND NEW FILE MANAGEMENT SYSTEM (FMS)

The DMS and FMS will be the new informatics system core and will replace the actual DAS and the laboratory servers. The most important difference between the DAS and the DMS is that the DMS is based on a data base in order to offer more flexibility and reliability.

The DMS is used with all the devices that do not need to work with files and contains all the data instrumental to the TFL activities. However the DMS is not only a storage system, but also a measurement system allowing different daily tasks to be realized. The main DMS activities are:

- to perform automatic and manual time interval, frequency and phase measurements versus UTC(IT) of the reference clocks and of other devices (dissemination services, equipment under calibration);
- to perform the acquisition and processing of the internal parameters of INRIM clocks. These parameters show the clocks' health status and inform about possible failures;
- to perform the acquisition and processing of the "internal" and "external" time transfer measurements as obtained using the GPS and TWSTFT synchronization systems. Even if these devices work with files and consequently with the FMS, the main data will be stored in the DMS;
- to perform the acquisition and processing of the temperature and humidity parameters of the TFL rooms and of the external environment;
- to automatically generate a bulletin to be sent to the BIPM, with flexible characteristics in terms of scheduling and measurement rate;
- to automatically generate a daily internal report, containing the main DMS measurement results.

To ensure the DMS activity reliability, the DMS is based on robust hardware and software. A Stanford Research Systems SR 620 universal time counter is used for the measurements versus UTC(IT). A RACAL 1256 Switching System allows switching among all the timing signals to be measured. An industrial PC under Windows XP OS allows the DMS to run, while measurement results are stored in a NAS (Network Attached Storage). The DMS software is designed to provide significant scalability and modularity, aiming to easily add new functions in the future. A commercial tool based on Object Pascal programming language is used for coding the Windows-based, object-oriented, COM-like software of DMS. The DMS is based on a relational database, namely mySQL, to store automatically all measurements carried out by the local measurement systems. The Database tables, Windows Registry keys, and other up-to-date means (such as XML) are used to achieve an effective run-time configuration and programming of DMS.

A DMS based on a database was chosen because it offers several advantages. The DMS is a provider of products for generic external applications; the archive is self-consistent and exhaustive, avoiding fragmentations and allowing for a wider use. The status of all the DMS components is controlled, potential anomalies are shown, and it offers a wide range of capabilities in term of configuration and maximum grade of flexibility.

At the present time the DMS is under test and works in parallel with the previous measurement system. The first results are encouraging and the software will be enhanced to add other applications that are of interest for the TFL.

The DMS is associated to the FMS for all the devices working with files. The FMS role is to collect all the files coming from different devices and to provide them to the external users or to the DMS.

The files collected by the FMS come from the GPS receivers of the TFL (2 Dicom GTR50 and 1 AOS TTS3), from the GPS receivers of the RNL (Septentrio PolaRx2, Javad Legacy, Septentrio PolaRx3TR, Ashtech ZXII-T), from the TWSTFT (Two-Way Satellite Time and Frequency Transfer) (two TimeTech Satre stations), from some other devices (like the time interval counter or the spectrum analyser of the RNL used during the measurement campaigns), from the ESA with the GESS data (Galileo Experimental Sensor Stations), or from external entities sharing their GNSS receiver data.

The files collected by the FMS are sent to BIPM, EUREF (European Reference Frame), IGS (International GNSS Service), GMV Innovating Solutions, and other laboratories collaborating with INRIM.

An FMS prototype is already in use by the TFL. The next step will be the DMS and the FMS completion, and then the establishment of the connection between these two systems which actually work independently.

5.A PROJECT FOR A NEW UTC(IT) TIME SCALE GENERATION

The actual UTC(IT) generation starts from a 5 MHz signal provided by an active hydrogen maser sent to an AOG that automatically compensate the signal for its frequency offset and drift versus UTC. The compensation parameters are computed starting from the monthly BIPM evaluation of UTC(IT). The frequency offset correction is manually applied to the AOG, on a monthly base, while the frequency drift correction is automatically applied every the 6 hours via a PC.

The UTC(IT) generation system is not autonomous; in case of a failure of either the maser or the AOG, human intervention is required to replace the main chain with the backup one. Figure 2 shows the new UTC(IT) generation principle to obtain an autonomous system and to improve the reliability.

A PC controls the two AOGs working simultaneously, and automatically calculates the frequency offset and drift corrections to be applied. The two parallel chains will be realized with 2 different hydrogen masers and the corrections applied to the AOGs will be calculated in order to obtain the two AOG outputs as close as possible.

The algorithm used to compute the corrections will take into account the difference between UTC(IT) and UTC as in the past, together with the behavior of the INRIM cesium clocks and the active hydrogen masers. The future time scale will benefit from a clock ensemble algorithm under detailed design, and the monitoring activity will implement an automatic evaluation of the INRIM clocks status by recurrent evaluation of the Dynamic Allan Deviation **[3,4].**

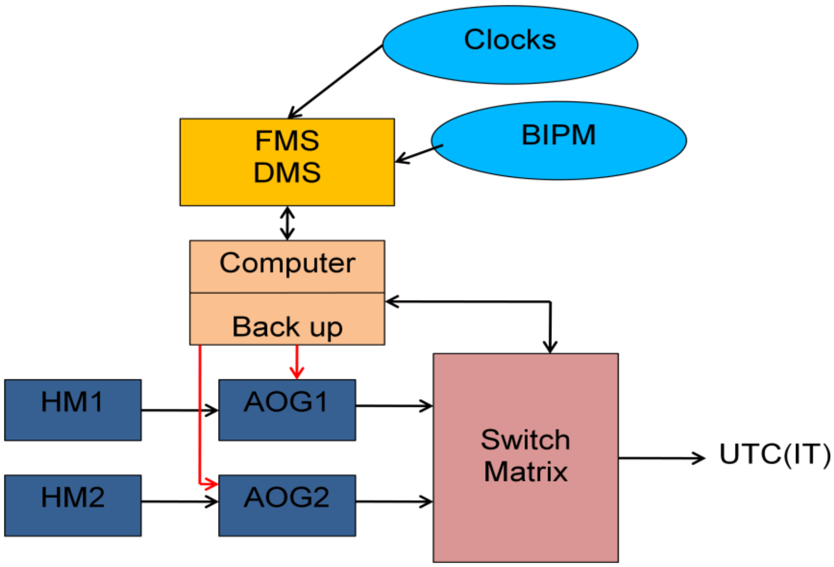

Figure 2. The new UTC(IT) generation diagram.

One of the two generated UTC(IT) will be used as the main time scale and a switch matrix will allow selection between them. The switch must be able to change automatically if an anomaly is detected on the main chain, and it must guarantee the operation without gaps or critical phase jumps. Software will allow the choice of the best performing chain as the main UTC(IT), but the operator has the possibility to manually change the conditioning. The possibility to use a Timetech device (clean-up oscillator) to realize the switch function is under test. This device is based on a local short-term high-performance oscillator locked to some external reference signals.

All the devices used for the new UTC(IT) time scale will have their own UPS system in order to improve reliability. The timing and frequency signals required will be the 1PPS and the 5 MHz signals provided by the two masers. The PC will communicate with the DMS and the FMS to exchange information about the correction applied to the AOGs, the switch matrix conditions, and the anomalies detected, and they will obtain the information about the INRIM clocks and the time deviations between UTC and UTC(IT).

All the steps required for the new UTC(IT) generation are under investigation in order to realize as soon as possible a first implementation of the system.

6. TIME AND FREQUENCY SIGNAL DISTRIBUTION SYSTEM

During the past years the Laboratory developed notably its signals distribution system as several amplifiers have been placed in the TFL according to need. As a consequence, the actual distribution system is randomly distributed through the TFL and it is difficult to easily access all the standard clock signals. The goal is to realize a new concentrated and optimized distribution system.

Different possibilities to have a new distribution system that could supply more reference signals than the current one have been investigated. The new distribution system will provide 5 MHz, 10 MHz, 100 MHz and 1PPS signals generated from the reference clocks and UTC(IT). Some points are still under investigation, notably the type and the number of the UTC(IT) signals needed, and where the new distribution system should be installed to easily integrate it into the TFL. A major problem that one has to face in implementing this project is the switch from the old to the new distribution system without perturbing the Laboratory activities.

7. MONITORING AND ALERT BROADCASTING SYSTEM

This chapter is divided in two parts: the first describes the monitoring system used by the operators to follow the UTC(IT) behavior and the other critical parameters, the second describes the new alert diffusion system implemented at INRIM. These two systems are complementary and allow a total supervision of the TFL critical points.

A. MONITORING

The TFL critical data are monitored from a webpage accessible via the INRIM LAN. This webpage is accessible from INRIM network, or from outside using a VPN connection, where it is possible to follow the UTC(IT) behavior and the other critical parameters concerning the clocks or the TFL activities, but here only the tools to monitor the UTC(IT) behaviour are described.

The first way to monitor UTC(IT) is to plot UTC(IT)-GPS time, thanks to the data files obtained by a GPS receiver, currently a Dicom GTR50 (Figure 3); the plot is updated periodically and has a span of one week.

The second way to monitor UTC(IT) is to plot the NRCan PPP (Precise Point Position) computation results from the geodetic GPS receivers hosted in the RNL. From the INRIM webpage a link shows the RNL webpage (Figure 4). The plots (with or without the frequency rate removed) obtained with this webpage, allow comparison of UTC(IT) and other internal time scales/clocks to IGS time with a latency of three days and two weeks depending on the IGS products used to perform the computation. In Figure 4, the receivers Septentrio PolaRx2 (INR2), Javad Legacy (INR3) and Septentrio PolaRx3TR (INR4) are respectively related to EGST, HM1 and UTC(IT).

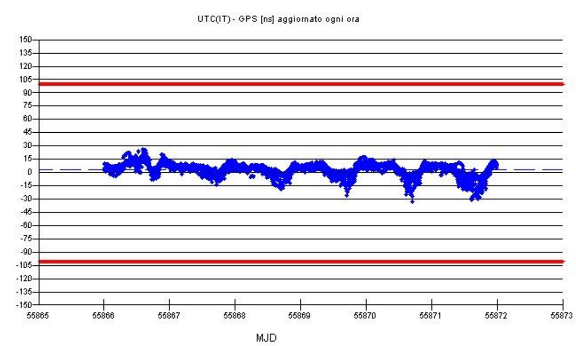

Figure 3. UTC(IT)-GPS time obtained via Dicom GTR50 data files.

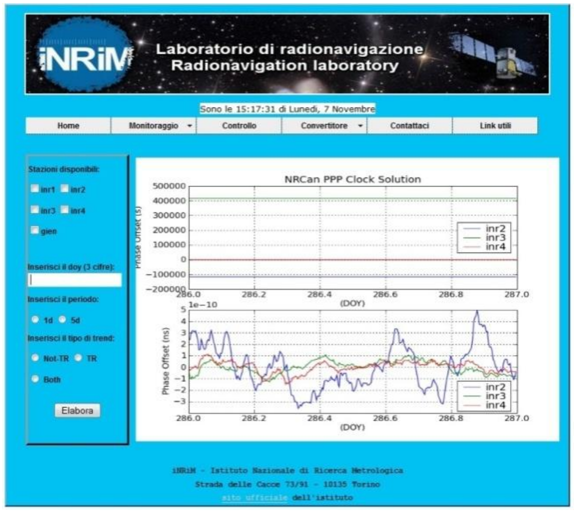

Figure 4. RNL monitoring web page.

"G*mv, Magicgnss*" and "*NRCan real time RTIGS*" are two other ways, based on a network approach, allowing the monitoring of UTC(IT). A receiver ensemble constitutes a network, and using a network algorithm (different for the two tools), international time scales are compared to one of the networks used as a reference.

"*Gmv, Magicgnss*" is a tool created by GMV Innovating Solutions (Madrid, Spain). A webpage, accessible via the Internet, allows the monitoring of several stations versus the selected one. IENG, a geodetic receiver, Ashtech ZXII-T, placed in the RNL, is one of the station's networks. A link on the TFL webpage goes directly to the "*Gmv, Magicgnss*" internet webpage that offers high flexibility in choosing the reference station and the network stations one wishes to compare. In Figure 5, three time scales connected to the stations PTB, ROA, and UNS3 are compared versus IENG (connected to UTC(IT)). The span can be of one or several days, the frequency drift can be removed, and it is possible to plot the Allan deviation and download the data files. The plot is updated every hour, 30 minutes after the last hourly file generation. The biggest advantage is that "*Gmv, Magicgnss*" is accessible by internet or mobile phone and not only through the INRIM network.

With "*NRCan real time RTIGS*" the reference station chosen automatically by the algorithm is the best time scale of the network; "*NRCan real time RT IGS*" is accessible only from the INRIM network. Compared to "*Gmv, Magicgnss*" the latency is reduced: the new data are available every hour, 5 minutes after the last hourly file.

The "*Gmv, Magicgnss*" and "*NRCan real time RT IGS*" tools are provided by two different entities which collaborate with the INRIM TFL. In the both cases it is necessary to send the file locally generated to the computing center.

The last monitoring tool available from TFL web page is a link to the Observatoire de Paris/ LNE-SYRTE webpage, made available by Paris Observatory. This web page (Figure 6), which can be reached with a public address, allows comparison of several UTC(k) with respect to UTC(OP) by using the TWSTFT technique. The plots obtained are updated every 2 hours.

All the tools described enable the knowledge, as well as possible, of the behavior of the UTC(IT) time scale, of the other time scales, and the INRIM clocks, together with the status of the TFL critical parameters. Other tools not accessible from the INRIM TFL web page allow performance of other deeper analyses.

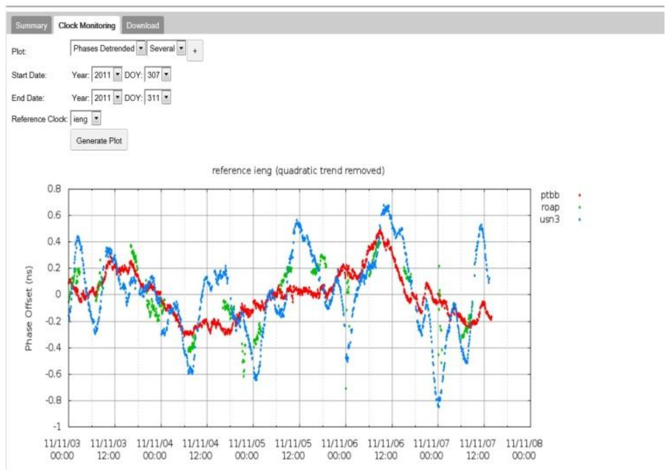

Figure 5. "*Gmv, Magicgnss*" monitoring.

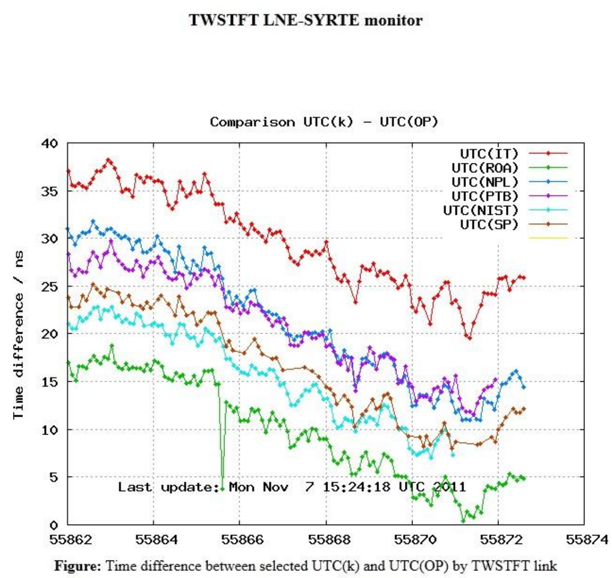

Figure 6. TWSTFT LNE-SYRTE monitoring web page

B. ALERT BROADCASTING

An alert broadcasting system will be implemented at INRIM in order to monitor and advise the staff about a failed device in the INRIM Laboratories. This system should be installed at the beginning of 2012 and will concern all the INRIM laboratories which require continuous supervision. In this paper only the part concerning the TFL is detailed.

A PLC (Programmable Logic Controller), placed in the INRIM informatics office, will receive information about the status and the behaviour of the devices controlling the INRIM power supply. In case of an anomaly, the PLC will send an e-mail or a SMS (Short Message Service) to the users concerned by the problem.

The system will concern, at first, only the INRIM power supply system; then it will be extended to include also the critical devices in the laboratories.

The system is divided in two parts: the first one concerns the alerts and the second one the monitoring. The alerts are based on a binary word informing about the device status (OK or not). The power supply lines distributed by the electrical box of the TFL will be connected to the PLC in order to inform the operator in case of cut-off. The PLC monitoring, which is accessible via internet, will provide only the status of each device connected to the PLC. For a deeper analysis, it is necessary to access the UPS webpage.

The wide monitoring system added to the alert diffusion system will allow the obtaining of a complete system to follow the TFL behavior both from inside and outside the laboratory to face the problem as soon as possible.

8. SUPPORT TO GALILEO DEVELOPMENT ACTIVITIES

The TFL support to the Galileo navigation system development activities concerns two aspects: the GIOVE (Galileo In Orbit Validation Experiment) mission **[5]** and the TVF (Time Validation Facilities) mission.

During the GIOVE mission (2008-2011) INRIM was in charge:

- of the metrological characterization of the clocks on board the first experimental Galileo satellites;
- to evaluate the GPS/Galileo Time Offset (GGTO) **[6]**;
- to evaluate the time offset between UTC and Galileo time as disseminated through the navigation message,
- to evaluate the clock prediction algorithm (strategy for both GIOVE-M and FOC - Final Operation Capability).

Concerning the TVF mission, a Time Geodetic Validation Facility is under development in the time frame of the realization of the Galileo system. It is composed basically by two facilities aimed at evaluating the "timing" and the "geodetic" aspects of the Galileo system. These facilities are called, respectively, TVF (Time Validation Facility) and OVF (Orbit Validation Facility). INRIM is in charge of the TVF for the metrological characterization of the atomic clocks onboard the first definitive Galileo satellites, the Galileo System Time, and for acting as a temporary Time Service Provider (TSP).

9. CONCLUSION

Different activities are carried out at INRIM TFL in order to enhance the UTC(IT) time scale robustness and performance, with the aim to better solve the task of national NMI as well as preparing for providing accurate and reliable services to the European navigation system Galileo. The TFL is continually in evolution, and the changes must not perturb or stop the laboratory activities; therefore, all precautions must be taken and all possibilities investigated before making any modification in the TFL structure.

Some of the solutions envisaged to adapt the laboratory capabilities to the new requirements are presented together with future actions already planned.

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