



## Recent TWSTFT experiments at INRiM Time and Frequency Laboratory

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### Abstract

Two-Way Satellite Time and Frequency Transfer (TWSTFT) is a technique selected by many timing laboratories around the world for the comparison of atomic clocks and time scales over distance. INRiM Time and Frequency laboratory operates two TWSTFT ground stations, whose data contributes to the calculation of the Coordinated Universal Time (UTC) and to the generation and performance monitoring of the Galileo System Time. This paper presents INRiM TWSTFT recent and future development and experiments.

### 1. Introduction

The Two-Way Satellite Time and Frequency Transfer technique relies on the code-phase measurement of a time signal modulated by a pseudorandom-noise (PRN) code, exchanged via microwave links with a geostationary satellite.

INRiM operates its two ground stations according to the Recommendation ITU-R TF.1153-4 as part of the European and EU-USA TWSTFT network. Per recommendation from the CCTF Working Group on TWSTFT, INRiM contributes to the generation of the international reference time UTC at Bureau International des Poids et Mesures (BIPM) with its two-way comparison data.

For many years INRiM has been involved with the design and development of the timing aspects of the European Global Navigation Satellite System (GNSS) Galileo. With TWSTFT and GNSS-based time and frequency transfer, INRiM contributes also to the generation of the Galileo System Time (GST) and to the Galileo time performances assessment.

To ensure continuous TWSTFT operations in particular and other timing services in general, INRiM Time and Frequency laboratory is going under a series of improvement on both hardware and software infrastructure [1]. This has increased the TWSTFT stations' robustness, and at the same time facilitated our recent experiments in alternative hardware solutions for the station set-up, including the use of Software-Defined Radio (SDR) receivers [2], the local development of a transmitter prototype called ITX [3], validation of a new BIPM calibration system based on GNSS for TWSTFT links [4] and testing of a digital modem called Software Ranging

System (SRS) from the National Institute of Information and Communications Technology (NICT, Japan) [5, 6].

## 2. Recent TWSTFT experiments at INRiM

### 2.1 INRiM ground stations overview

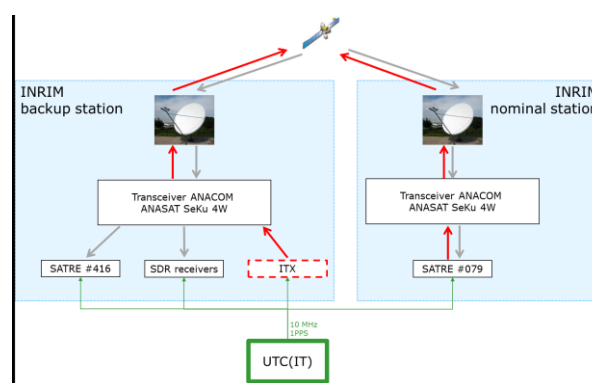
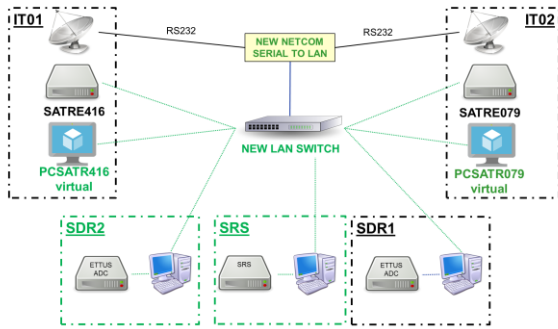


Figure 1. INRiM TWSTFT ground station equipment

INRiM currently has two operational ground stations for TWSTFT (Figure 1), which are both equipped with SATRE modems and connected to the T-11N geostationary satellite through the use of ANACOM ANASAT Ku band transceiver for comparing the local UTC realization called UTC(IT). One of the two is the nominal station, while the other one is used as hot back-up since it is also calibrated, and as our system test bed with various equipment such as the SDR receivers, the ITX transmitter prototype and the SRS modem (during the modem lease period). Figure 2 instead highlights in green the upgrades related to the control segment: the laboratory's new networking infrastructure connected all TWSTFT equipment under the new Local Area Network, which is protected behind a new firewall and new access control policies. Furthermore, the old computers that were in charge of data acquisition and station monitoring were dismissed and virtualised at the laboratory's central hypervisor. This harmonised the laboratory configuration as a whole, and brought new capacity for new monitoring activities which were limited by the old hardware.

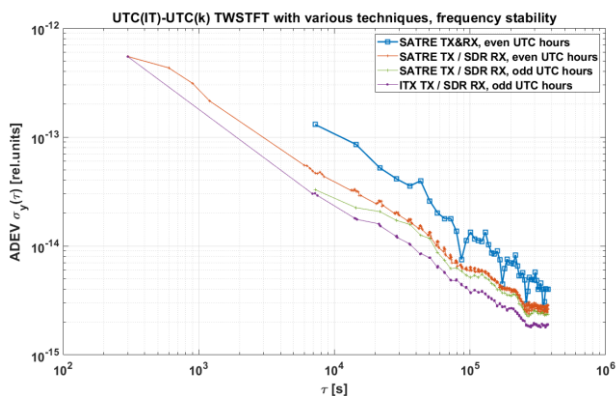


**Figure 2.** New network infrastructure for TWSTFT control segment

INRiM participated in the pilot study organized by the CTF Working Group on TWSTFT and BIPM regarding the use of SDR receivers. These receivers are based on a digital sampler whose data is then processed by novel signal processing algorithms. The algorithms are implemented in a workstation-grade computer running commercial off-the-shelf graphical processing units, which not only allows rapid development and testing but also lowered the equipment costs. SDR receivers allow significant gain on short-term noise and daily variations seen on traditional links between SATRE modems. The pilot study's successful conclusion encouraged the use of SDR receivers in UTC calculation since 2018 [2] and INRiM has been regularly submitting SDR receivers data to BIPM for this purpose.

## 2.2 ITX transmitter prototype

Motivated by the performance of the SDR receiver, in 2020 we developed a digital transmitter called ITX compatible with both the SDR receiver and SATRE modem. In collaboration with SKK Electronics (Italy) and Rovera Freelance Consulting (France) a ITX prototype was manufactured, verified and tested online. Figure 3 shows the improvement over a baseline with another European UTC(k) time scale using all available equipment: using both the ITX and SDR receiver at INRiM side improved up to 2 times at 1-day averaging time with respect to the nominal TWSTFT operation.



**Figure 3.** ITX performance during time scale comparison, presented at IEEE IFCS-ISAF 2020 [3]

## 2.3 Validation of the new BIPM TWSTFT calibration system based on GNSS

TWSTFT stations contributing to the calculation of UTC are regularly calibrated to ensure time and frequency transfer accuracy. Recently the stations in Europe are calibrated using a validated TWSTFT travelling station, which shows high performance and reliability but is complex to operate and maintain not only due to its large physical size but also the complex equipment.

In light of recent development on GNSS calibration, BIPM has developed a travelling station based on multi-GNSS receivers, dubbed BIPM Time Transfer Transportable System (B4TS). The equipment included are small in size and put together neatly in a relatively small box, which allows for installation at locations that has restricted space or access and facilitates autonomous operations. INRiM participated in the validation of the system as part of a calibration campaign involving also the Paris Observatory (LNE-SYRTE/OP, France) and the Côte d'Azur Observatory (OCA). The calibration values calculated with this travelling system is in excellent agreement with the official TWSTFT calibration within a combined uncertainty of around 1 ns, as presented at EFTF-IFCS 2021 [4].

## 2.4 Carrier-phase TWSTFT experiment with SRS modem

A new digital modem for TWSTFT called SRS has been recently developed at NICT in Japan. The modem was extensively tested between NICT and regional laboratories [5] which showed a strong performance and is clearly an alternative to the current equipment.

In collaboration with NICT, OP and the Physikalisch-Technische Bundesanstalt (PTB, Germany), INRiM hosted a SRS modem and performed tests within the European TWSTFT network. SRS modem's code-phase operation shows compatible results with the current set-up, and might even be better than using SDR receivers for certain links. Carrier-phase analysis was also carried out and showed promising stability [6], with ADEV as low as  $3e-13$  at 1-second averaging time, despite being limited by the bi-hourly test time slots in the network operation schedule.

## 3. Conclusion and future works

Despite being greatly impacted by the COVID-19 pandemic situation, various works has been carried out at INRiM laboratory regarding the TWSTFT operation. For the upcoming years we have planned more upgrade on the station equipment to increase its robustness and continuity, which has proven to be crucial for the understanding of UTC(IT) time scale performance and for the services that depend on it, for example the monitoring of Galileo System Time and Galileo time performances (carried out in the frame of the different ESA and EUSPA contracts). The ITX experiment will be continued with the development of another prototype with improvement as discovered during testing the first one, and will be deployed at another

laboratory to test in conjunction with SDR receivers, allowing a better understanding of their performance as an alternative to traditional TWSTFT equipment. Studies are being carried out to take better advantage of the already available SRS carrier-phase test data in Europe, but does not exclude the possibility of another extensive test campaign late 2022 – early 2023.

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