Update on TWSTFT activities at INRiM Time and Frequency Laboratory

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Abstract

One of the most used time and frequency transfer techniques for the comparison of atomic clocks and time scales over long distances is the so-called Two-Way Satellite Time and Frequency Transfer (TWSTFT). Equipped with two ground stations, INRiM Time and Frequency Laboratory maintains TWSTFT links to compare its local realization of UTC and its atomic frequency standards with other timing laboratories, contributing to the calculation of Coordinated Universal Time (UTC) and to timing aspects of the European Global Navigation Satellite System (GNSS) Galileo. This paper presents the latest TWSTFT activities at INRiM over the last two years.

1. Introduction

For many years, INRiM Time and Frequency laboratory has been utilizing the Two-Way Satellite Time and Frequency Transfer technique as a high-precision long-distance method of comparing its atomic clocks and the Italian national time scale UTC(IT) with other laboratories in Europe and in the USA, following a recommendation from ITU Radiocommunication Sector [1]. TWSTFT measurements between INRiM and other timing laboratories contribute to the calculation of the International Atomic Time (TAI) and the international reference time scale UTC at Bureau International des Poids et Mesures (BIPM).

TWSTFT equipment at INRiM consists of a modem that encodes the local realization of UTC with a pseudorandom-noise code (PRN), which is then sent to other modems of the same principle at other laboratories via microwave link with a geostationary satellite. Following a predefined schedule, each station in the network performs measurements of the remote signal, which are then exchanged via Internet to achieve time and frequency comparison.

Recent developments in TWSTFT have been tested at INRiM, facilitated by our improved laboratory infrastructure. We continue to review the stability of the nominal TWSTFT station through internal monitoring and external calibration as well as upgrade old equipment in the backup station, to ensure the reliability of the technique for the future generation of UTC(IT) and related timing activities.

2. Recent TWSTFT activities at INRiM

2.1 Calibration of the nominal TWSTFT station

As presented in [2], INRiM operates two TWSTFT stations where one acts as the nominal station for UTC(k) comparison. Following the reallocation of allotted frequency bands on the Telesat T-11N satellite in the summer of 2021, the network went through a massive calibration bridging based on GNSS measurements. Unfortunately, the station which was designated nominal, called “IT02”, showed signs of failure soon after the conclusion of the calibration period. It was determined that the Anacom ANASAT transceiver used for the conversion of the modem IF 70 MHz to Ku-band was operating at suboptimal performance, most probably due to its age of more than 10 years of faithful service. INRiM decided to transfer the calibration of IT02 to the backup station “IT01” in early 2022 [3], in order to not interrupt the UTC(k) time scale and clock comparison which is necessary for the computation of UTC at BIPM. IT01 as the nominal station went into full effect at the end of February 2022.

In 2023 the UTC(k) laboratory network that operates TWSTFT stations in Europe, including the 5 UTC(k) laboratories that participate in the Galileo Time Service Provider project, decided to commission a comprehensive calibration campaign with the traveling station. The campaign lasted more than 3 months, due to the large number of laboratories visited. At the moment of writing, the calibration values are being computed and will soon be published on the BIPM database. It is worth noting that this calibration campaign is significant due to the many changes in the calibration values for the nominal station of INRiM.

One of the focus of this campaign is that the calibration values will also be computed for alternatives receivers collocated on the calibrated TWSTFT stations. Currently the UTC(k) laboratories involved employ SATRE modems which contain one transmitter module and most have two receivers. Traditionally only one receiver module is used as the main one, and the calibration is computed for this TX/RX combination. However as the number of stations in the network grow, as well as for resiliency and robustness requirements, the second receiver module of each modem is being considered as the solution. INRiM, as a member of the CCTF Working Group on TWSTFT and as the coordinator of UTC(k) laboratories involved in Galileo, is involved in the discussion of the calculations for the "back-up" receiver, starting from its own experience in [4] and based on a long term measurement of the difference between its two receiver modules. Figure 1 shows said difference, one mean value per day over each link. It was predicted that this difference is constant for all links, which is related to the physical delays between the two modules. However there is a slight difference between each link from 10 to 100 ps, which also seems to be varying in time. This is not necessarily a big problem, however, as link delays might slightly change over time due to multiple reasons, some of which are out of our direct control. As we plan to employ the second receiver module in the future, it would be important to allocate parts of the schedule to monitor the differences between the receivers.

As shown in Figure 2 the nominal INRiM TWSTFT station IT01 hosts the SDR receiver whose data has been contributed continuously since 2017 to the BIPM, first as part of the pilot study [5] then as possible backup to the SATRE data. According to the pilot study most SDR links show significant improvement over SATRE links, hence the idea of developing a whole software-defined platform for advanced TWSTFT towards the fulfillment of the requirements for the redefinition of the SI second [6]. The 2023 calibration campaign also considers SDR receivers hosted at some UTC(k) labs. This is the first time INRiM SDR receiver is calibrated together with the SATRE modem. INRiM proposed to treat the SDR receiver in the same way as the second SATRE receiver, allowing a homogenous approach to the calibration method and reducing the proliferation of calibration identifiers. Figure 3 shows a preliminary assessment of the difference between INRiM SATRE and SDR, during the period when the traveling station was visiting our site.

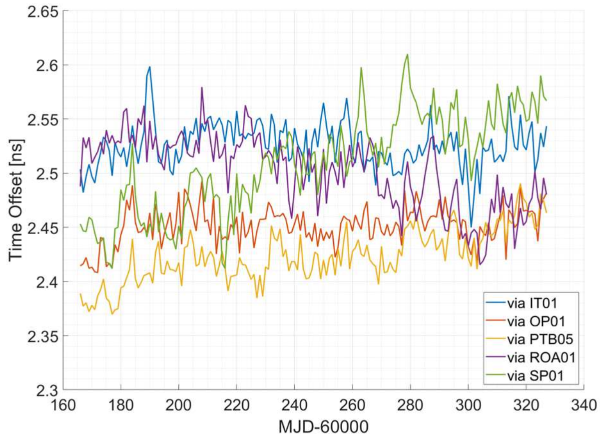

Figure 1. Daily difference between the two receivers of IT01 SATRE modem, calculated via different links, over the most recent 5 months (at the time of writing).

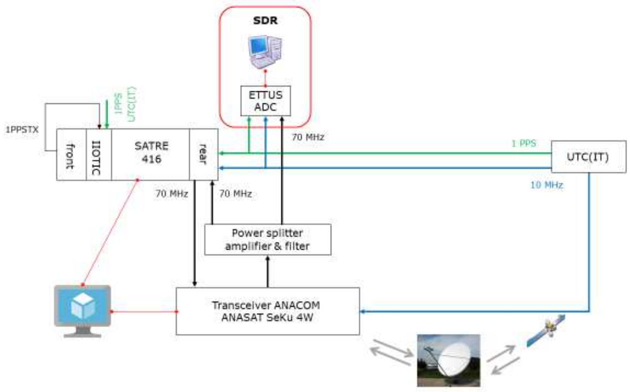

Figure 2. Architecture of the nominal station IT01. UTC(IT) reference signal is connected to the SATRE modem, the SDR receiver and the outdoor Ku-band transceiver. The SATRE modem is controlled by a virtual machine as part of the architecture of the laboratory, while the SDR consists of a dedicated desktop computer with a powerful GPU for advanced parallel processing of TWSTFT signals.

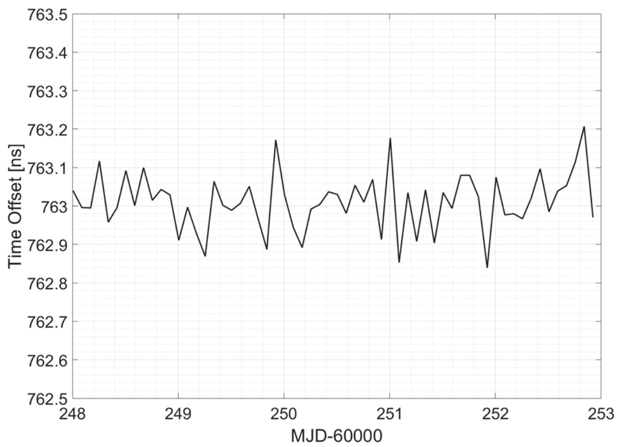

Figure 3. Difference between SATRE modem and SDR receiver during the stay of the traveling station.

2.2 Upgrade of the backup TWSTFT station

As discussed in the previous section, currently the backup TWSTFT station at INRiM is IT02 which has undergone some major modifications. After an extensive market study, it is concluded that a direct 70 MHz – Ku-band transceiver similar to the old Anacom ANASAT transceiver is no longer in favor by the telecommunication community. Some low noise 70 MHz – Ku-band low noise up and down converters are available, which might be a good choice. Another choice is to do a 2-stage frequency conversion with L-band signal as intermediate, as 70 MHz is being phased out by most modern modems. Given the physical limitations of our infrastructure, we identified that the first choice is currently not possible as the 70 MHz – Ku-band converters must be under the temperature-controlled environment of the laboratory and so the Ku-band signal would be too attenuated before it could reach the antenna.

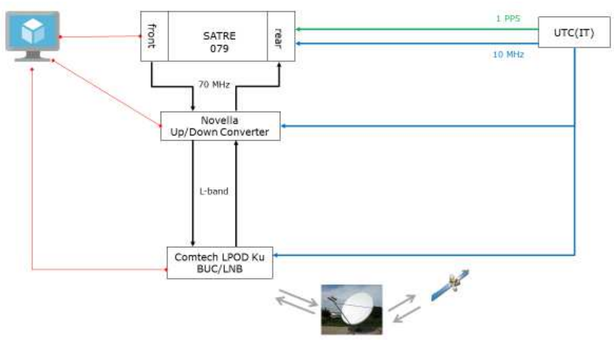

Figure 4. Architecture of the backup station IT01. New frequency converters are installed to replace the old transceiver.

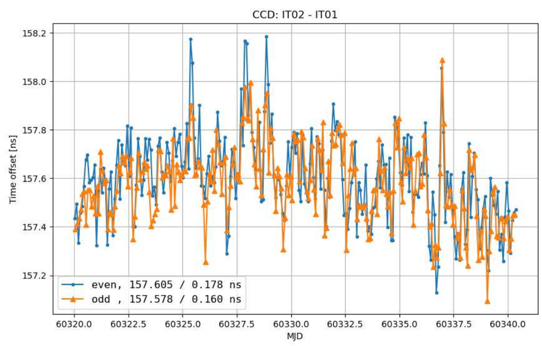

Figure 5. Common clock difference statistics between the backup station IT02 and nominal station IT01, taken directly from INRiM Time and Frequency Laboratory monitoring software.

Therefore, IT02 is now composed of a pair of 70 MHz – L-band frequency converters collocated with the SATRE modem inside the Time and Frequency laboratory, connected by 30-meter cables that lead to a BUC/SSPA and LNB mounted on the outdoor 1.8-m dish antenna (Figure 4) All equipment is locked onto the 10 MHz reference signal of UTC(IT), which allows virtually error-free frequency conversion. This was deemed to be a prerequisite for the success of the use of carrier-phase measurements [7].

Despite our best efforts to put together the new equipment for IT02, the finishing touches were carried out after the visit of the traveling station for the calibration campaign. Therefore, we resort to in-house characterization and calibration of IT02, either by transferring the IT01 calibration when it is available or by GNSS measurements. Figure 5 shows the common clock difference between IT01 and IT02, which serves as the basis for the calibration transfer. It could be interesting to involve other links in this analysis to involve the confidence in the calibration uncertainty. GNSS measurements such as GPS or Galileo common-view can also be used to calibrate links with IT02, considering that the GNSS links were also recently calibrated [8].

3. Conclusion and future works

A large part of the work carried out for TWSTFT activities at INRiM in the last 2 years have been concentrated on the operational level, due to the failure of the IT02 station. However with the occasion of the calibration campaign, we have started discussion on the use of the secondary receiver on each SATRE modem as well as the SDR receiver. This also reopens the talk around the differences between the two most used time and frequency transfer techniques (TWSTFT and GNSS time and frequency transfer). We plan to contribute to a network wide assessment of such differences, starting with a task group on the long term variation of GNSS hardware delays under the CCTF Working Group on GNSS Time Transfer. The successful upgrade of frequency converters on IT02 station also paves the way for the operation of a permanent SRS modem in parallel with the current set-up, aiding the second SRS carrier -phase measurement campaign in Europe which is now undergoing organization from involved laboratories.

References

[1] "Recommendation ITU-R TF.1153-4", ITU-R, ITU 08/2015

[2] T. T. Thai, "Recent TWSTFT experiments at INRiM Time and Frequency Laboratory," 2022 3rd URSI Atlantic and Asia Pacific Radio Science Meeting (AT-AP-RASC), Gran Canaria, Spain, 2022, pp. 1-3, doi: 10.23919/AT-AP-RASC54737.2022.9814351.

[3] T. T. Thai, I. Sesia, G. D. Rovera, "Calibration of IT01 station – 2022", TWSTFT calibration report with Cal ID 0584-2022, BIPM, https://webtai.bipm.org

[4] T. T. Thai, I. Sesia, G. D. Rovera and J. Achkar, "Characterization of Delays for Spare SATRE Modems in TWSTFT Stations," 2019 Joint

Conference of the IEEE International Frequency Control Symposium and European Frequency and Time Forum (EFTF/IFC), Orlando, FL, USA, 2019, pp. 1-3, doi: 10.1109/FCS.2019.8856143.

[5] Jiang, Zhiheng, Arias, Felicitas, Zhang, Victor, Huang, Yi-Jiun, Achkar, Joseph, Piester, Dirk, Lin, Shinn-Yan, Wu, Wenjun, Naumov, Andrey, Yang, Sung-hoon, Nawrocki, Jerzy, Sesia, Ilaria, Schlunegger, Christian, Liang, Kun, Fujieda, Miho, "Implementation of SDR TWSTFT in UTC Computation," Proceedings of the 49th Annual Precise Time and Time Interval Systems and Applications Meeting, Reston, Virginia, January 2018, pp. 184-208, doi: 10.33012/2018.15617.

[6] N. Dimarcq, M. Gertsvolf, G. Mileti, S.Bize, C.W. Oates, E. Peik, D. Calonico, T. Ido, P. Tavella, F. Meynadier, G. Petit, G. Panfilo, J. Bartholomew, P. Defraigne, E. A. Donley, P. O. Hedekvist, I. Sesia, M. Wouters, P. Dube, F. Fang, F. Levi, J. Lodewyck, H. S. Margolis, D. Newell, S. Slyusarev, S. Weyers, J.-P. Uzan, M. Yasuda, D.-H. Yu, C. Rieck, H. Schnatz, Y. Hanado, M. Fujieda, P.-E. Pottie, J. Hanssen, A. Malimon, N. Ashby, “Roadmap towards the redefinition of the second”, doi: 10.48550/arXiv.2307.14141

[7] M. Fujieda et al., "Advanced Satellite-Based Frequency Transfer at the 10−16 Level," in IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, vol. 65, no. 6, pp. 973-978, June 2018, doi: 10.1109/TUFFC.2018.2821159.

[8] Pierre Uhrich, Michel Abgrall, Baptiste Chupin, “INRIM and RISE GNSS stations relative calibration”, GNSS calibration report with Cal ID 1018-2022, BIPM, https://webtai.bipm.org