Proceedings of the 21st International Conference on Global Research and Education (Inter-Academia 2024)

Remote Fiber Optic Connected Station for Two-Way Satellite Time and Frequency Transfer Method

M. Marszalec[a,*], M. Lusawa[a], T. Kossek[a], W. Lewandowski[a] and A. Czubla[b]

[a] *National Institute of Telecommunications (NIT), Szachowa 1, 04-894 Warsaw, Poland*
[b] *Central Office of Measures (GUM), Elektoralna 2, 00-139 Warsaw, Poland*

Doi: 10.12693/APhysPolA.146.635 *e-mail: m.marszalec@il-pib.pl

The National Institute of Telecommunications (NIT), in cooperation with the Central Office of Measures (GUM), has established a station for two-way satellite time and frequency transfer in 2018. Firstly, comparisons were carried out within the European–Asian group on various satellites (ABS-2A, E80) and from early 2023 in the European–American group on the Telstar T-11N satellite. The main part (reference atomic clock) of the system is located in GUM, and the satellite station is located in NIT. These two locations are connected with a ≈ 34 km single-mode fiber and a dedicated transmission system. Such a solution is uncommon for this type of comparison. The station took part in the calibration campaign organized by the National Metrology Institutes (NMI) all over Europe in order to verify the parameters of the whole transfer system and its accuracy time and frequency transfer. In this paper, we describe the station's technical solutions and analysis of measurement and calibration results, thus confirming the correctness of the station's operation and enabling the use of the presented solutions for international transfer of UTC(PL) — the main Polish local realization of Universal Coordinated Time determined in GUM and being the source for legal time in Poland.

topics: two-way satellite time and frequency transfer (TWSTFT), Coordinated Universal Time (UTC), time synchronization, atomic clocks

1. Introduction

The importance of precise and accurate time in everyday life, as well as in technology, is obvious. It means not only that access to the precise clocks is needed, but also a reliable distribution of time and an awareness of the relation between them. This can be achieved in various ways, which have become even better thanks to the technical development, especially in telecommunications. First of all, the data of comparisons of very precise and accurate clocks, which are maintained mostly by National Metrology Institutes (NMI), are used by the Bureau International des Poids et Mesures (BIPM) as for the realization of *International Atomic Time* (TAI) and of *Coordinated Universal Time* (UTC).

The *Global Positioning System* (GPS) *common view* (CV), *GPS carrier-phase/precise point positioning* (GPS PPP) and *two-way satellite time and frequency transfer* (TWSTFT) using geostationary satellites are used for time transfer. The TWSTFT is used for over 25 years as the main method of time transfer by NMIs or other institutions responsible for realization of national time scales [1–6].

Central Office of Measures (GUM) generates UTC(PL) and also has GPS time transfer systems.

Both laboratories cooperates closely in the time transfer domain. Their atomic clocks are successfully and permanently compared using *electronically stabilized* (ELSTAB) fiber-optic connection system [7, 8]. The ELSTAB system offers link stability of almost 10^{-17} (for 24-hour averaging) and is two orders of magnitude lower than the noise of TWSTFT time transfer.

This experience was the base for the unique idea of the TWSTFT station divided into two parts: (i) the atomic clocks laboratory at the GUM facility and (ii) the satellite transmission system at NIT (National Institute of Telecommunications), which are located ≈ 15 km apart in a straight line and ≈ 34 km in fiber connection (Fig. 1). The reason for proposing this solution was the location of the GUM time laboratory in the center of Warsaw, where satellite visibility is poor, while at the NIT facility, it is much better.

The new TWSTFT station among almost 25 European stations was established in 2017 by GUM in cooperation with the National Institute of Telecommunications (NIT) in Warsaw, Poland [9].

Fig. 1. Location of GUM and NIT laboratories.

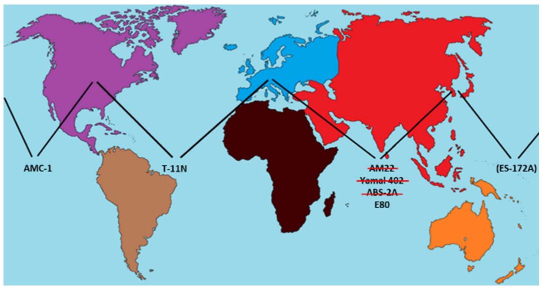

Fig. 2. Satellites used for two-way satellite time and frequency transfer.

Initially, tests of the system from Timetech with the SATRE modem, which complies the Recommendation ITU-R TF.1153-4, started for the Europe–Asia TWSTFT comparison group on the AM22 satellite (June 2017) and on the Yamal 402 satellite (July 2017). First tests on the ABS-2A satellite started in November–December 2017, and the final operation on the ABS-2A satellite was in 2018.

The scheme of the global TWSTFT time transfer system is shown in Fig. 2. The figure also shows the change in satellites used by the Europe–Asia group in recent years.

In the Europe–Asia of TWSTFT group took part the following stations from: Germany — Physikalisch-Technische Bundesanstalt (PTB), Poland (PL-NIT/GUM), Russia — All-Russian Scientific Research Institute for Physical-Engineering and Radiotechnical Metrology (SU) and (KM), India — National Measurement Institute of India (NPLI), China — Chinese Academy of Sciences/National Time Service Center (NTSC) and The National Institute of Metrology of China (NIM), Taiwan — National Standard Time and Frequency Laboratory (TL), Korea — Korea Research Institute of Standards and Science (KRISS), Japan — National Institute of Information and Communications Technology (NICT).

In September 2020, a *software defined radio* (SDR) receiver module was added to the station system to reduce fluctuations in the daily period, the so-called "diurnals". In March 2021, there was a switch of operation satellite to the Express-80 satellite.

The participation of our TWSTFT station in the Europe–Asia comparison group was important for us and proved its proper operation, but due to frequent changes of satellites it was rather impossible to use the obtained comparison results for UTC(PL) international transfer.

At the beginning of 2023, the decision was made to switch the NIT/GUM station to the Telstar 11N satellite and join the European–European TWSTFT comparison group.

Fig. 3. Direction of satellite dish for TWSTFT in NIT's location for the T11N satellite (see [10]).

In Fig. 3, the location of satellite dish of NIT/GUMTWSTFT system is shown, as well as its new direction for the T11N satellite [10].

The NIT/GUM station has an optimal antenna location from which the satellites used for comparisons of the eastern and western network are simultaneously visible and close to the other instruments comprising the station. We hope to join the Europe–Asia group in the future again.

2. Participation of NIT/GUM in TWSTFT calibration campaign 2023

Since its launch, the NIT/GUM station has been awaiting an international calibration campaign. In the case of the Europe–Europe TWSTFT group, it took place last in 2019. The campaign is organized sporadically due to its complexity and relatively high costs.

The 2023 calibration campaign was organized together by PTB and the Dutch National Metrology Institute (VSL) in strict cooperation with

Fig. 4. TWSTFT mobile transfer station (fot. J. Charakopidis).

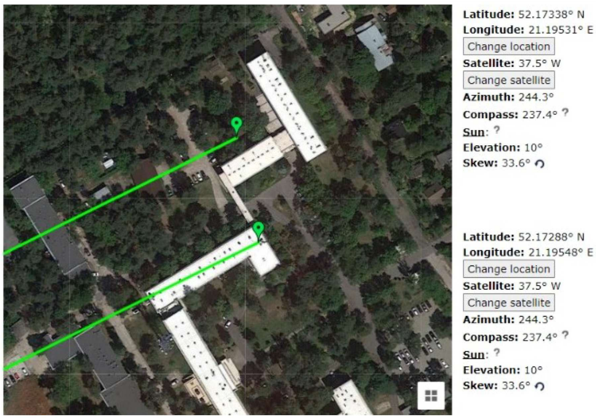

Fig. 5. The mobile calibration station location (upper green point) and NIT/GUM station location (lower green point), see [10].

TimeTech GmbH company, which delivered a mobile TWSTFT station. The main motivation was the replacement of the satellite transponder, which caused changes in the TWSTFT link delays.

Almost all European institutions that operates TWSTFT stations took part in the campaign: TimeTech — TimeTech GmbH GUM; Central Office of Measures — PTB; OP — Observatoire de Paris; LNE-LTFB — OSU Theta, Université de Franche-Comté; UBFC — Université de Bourgogne, SUPMICROTECH — École Nationale Supérieure de Mécanique et des Microtechniques, ROA — Real Instituto y Observatorio de la Armada; CNRS — Centre national de la recherche scientifique; NPL — National Physical Laboratory; RISE — Research Institutes of Sweden Measurement Technology; INRIM — Istituto Nazionale di Ricerca Metrologica; METAS — Federal Institute of Metrology.

It was quite a challenge for us to be appointed as the participant starting the calibration campaign on schedule, with a very short time to prepare our station for calibration.

Fig. 6. View from the calibration station location in the satellite direction before tree crown trimming.

Fig. 7. View from the calibration station location in the satellite direction after tree crown trimming.

A number of preparatory activities were carried out before, including logistics and the identification of potential sites for the TWSTFT mobile calibration station and its antenna (Fig. 4), from which the T11N satellite is visible (Fig. 5).

The mobile calibration was carried out between August 21 and 27, 2023. The mobile station was placed on the NIT site. As expected, in order for the satellite to be visible from the ground, additional trimming of the tree crowns proved necessary (Figs. 6 and 7).

Delays of all signal cables used for UTC(PL) comparisons were determined. It was also necessary to develop and implement dedicated software to adapt the measurement results obtained, as well as the 2 h schedule support, the bi-hourly scheduler starting a new/set sequence every 2 h and in configuration files.

The necessary software was prepared and implemented by NIT.

The complete cable delays from the UTC(PL) definition point in GUM to the 1PPS IN input of the SATRE modem (UTC(PL)-SATRE(1PPS_IN)) and to the PPS IN input of the SDR module (UTC(PL)-SDR(1PPS_IN)) at NIT were determined using high accuracy measurement setup.

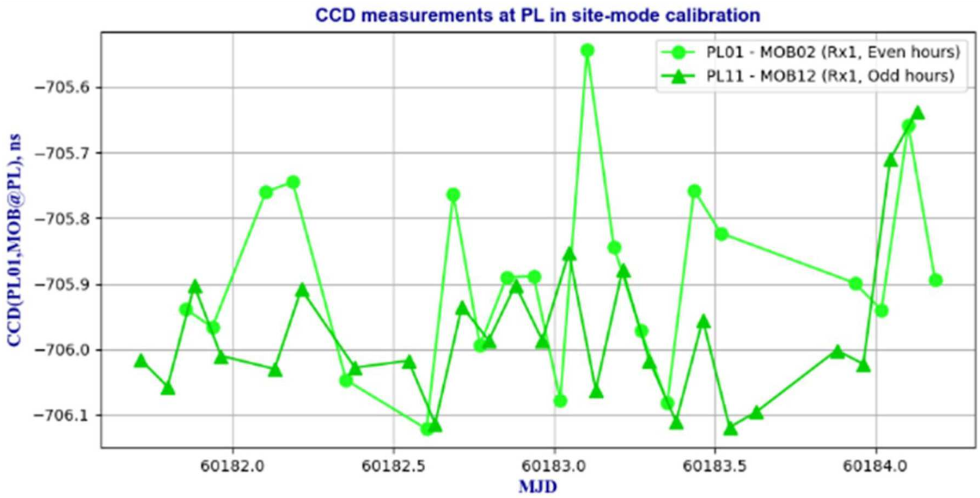

Fig. 8. Common clock differences (CCD) between PL and MOB TWSTFT stations, where MJD is Modified Julian Date for the SATRE modem (calculated by VSL).

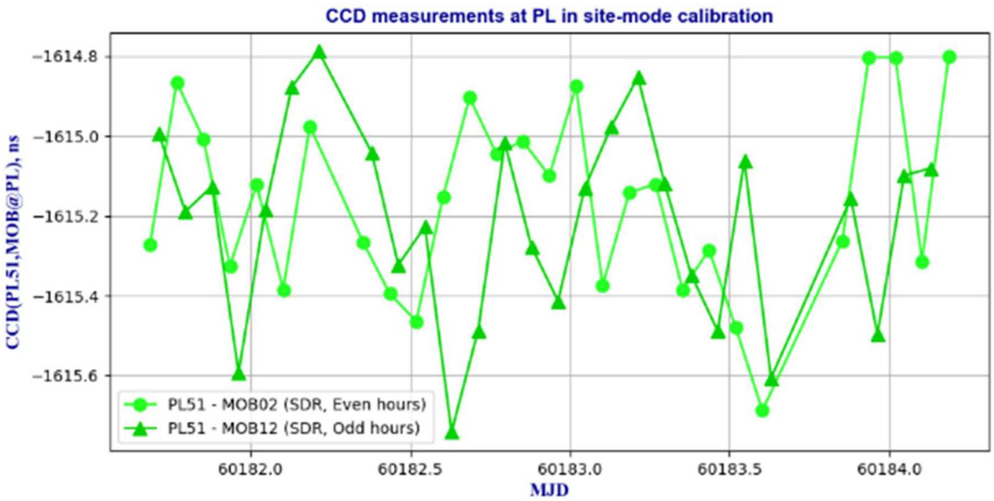

Fig. 9. Common clock differences (CCD) between PL and MOB TWSTFT stations where MJD is Modified Julian Date for SDR modem (calculated by VSL).

TABLE I

Signal delays in cables and electronic components for the SATRE modem.

Ref. delay	Measured value [ns]	Measurement uncertainty [ns]
UTC(PL)-1PPS_IN	20.79	0.20
1PPS_UTC(k)-1PPS_TX	797.78	0.20

TABLE II

Signal delays in cables and electronic components for SDR modem.

Ref. delay	Measured value [ns]	Measurement uncertainty [ns]
UTC(PL)-1PPS_IN	10.66	0.20
1PPS_UTC(k)-1PPS_TX	787.65	0.20

Then the delay of 1PPS_UTC(k)-1PPS_TX relative to the TX output 1PPS OUT of the SATRE modem was determined in accordance with Recommendation ITU-R TF.1153-4.

The delays measurement results are presented in Tables I and II.

The delay introduced by of ELSTAB fiber optic connection system was well known from previous measurements.

The mobile station modem was placed in the same room as the calibration station modem. A UTC(PL) signal was also connected to the mobile station. The comparison schedule was extended to include measurements of the mobile station and additional comparison sessions. The calibrated and mobile station compared the same UTC(PL) signal with individual TWSTFT stations according to a 2-h schedule. The entire calibration process for a single station takes a minimum of about 3 days.

3. Conclusions

The results of the calibration campaign, including the calculated corrections for each participant, will be presented in the forthcoming joint Official "European TWSTFT Calibration Campaign 2023 Calibration Report" (to be published) by Y. Xie et al. The preliminary results of calibration corrections determined by the VSL National Metrology Institute confirm the proper operation of NIT/GUM(PL) TWSTFT station.

The part of the preliminary results obtained during calibration are presented in Figs. 8 and 9.

The *common clock differences* (CCD) measurement results for our (PL) and *mobile calibration* (MOB) TWSTFT stations are in a narrow range of $\approx$ 0.6–0.8 ns for both SATRE and SDR modem types.

Such CCD measurement results can be expected for typical TWSTFT stations. In our case, however, an additional ELSTAB fiber-optic transmission was used. The results of the CCD measurements confirm little or no impact on the performance of the our TWSTFT station, as previously assumed. In addition, accurate calibrated TW delay values have been determined, allowing our TWSTFT station to be formally accepted and recognized by the BIPM.

In addition, by participating in the calibration campaign, it was possible to verify and modify the results on the ongoing basis; the station software created by NIT produced results consistent with those obtained with TimeTech software.

Acknowledgments

Authors are deeply indebted to all co-authors of papers quoted, which testify many fruitful long-lasting cooperation's. The authors specially acknowledges Mr. P. Dudek from Kenbit company and organizers of calibration campaign TimeTech and VSL National Metrology Institute for technical support.

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