European Partnership on Metrology
Call 2023 –Fundamental Metrology, Industry, Normative and Research Potential

Selected Research Topic number: **SRT-f06**
Version: 1.0

Title: Advanced TWSTFT for measuring the future SI-second

Abstract

The redefinition of the SI-second requires development of reliably operating optical primary frequency standards, and correspondingly capable intercontinental comparison methods. Two Way Satellite Time and Frequency Transfer (TWSTFT) is one of the two existing microwave domain transcontinental comparison techniques and is completely independent from GNSS technology. However, neither GNSS based methods nor TWSTFT can currently meet the requirements for the SI-second redefinition. In order to improve TWSTFT to support the redefinition of the SI-second and improve its use in the realisation of the UTC timescale, the link stability of TWSTFT needs to approach 10^{-17}at 5 day intervals (@5d) Allan deviation (ADEV). In addition, a system level approach is needed to enable the design of an advanced digital TWSTFT modem that will support the future implementation of digital TWSTFT systems.

Keywords

TWSTFT, time and frequency, SI-second redefinition, digital modem, UTC, carrier-phase, broad-band

Background to the Metrological Challenges

TWSTFT is currently used in Europe, the US and parts of Asia. One of its strengths is the possibility to operate at large and intercontinental distances and it is currently the preferred time and frequency comparison technique for the realisation of the timescale UTC: several international TWSTFT-networks are currently operating and contribute to UTC. TWSTFT systems are calibrated to one nanosecond and are regarded as the most accurate intercontinental time-transfer methods available. However, the typical frequency instability of the TWSTFT link is below 10^{-14}@1d ADEV and is considered better than the best GNSS method currently available the Integer Ambiguity PPP Technique Precise Point Positioning (iPPP).

Further to this, a performance improvement is needed for TWSTFT to be able to interface with optical frequency standards and hence improve the accuracy of UTC. At a standard 5 day intervals (used by BIPM to compute UTC) the best TWSTFT link (using a software defined radio receiver chain (SDR) demonstrates a stability close to 10^{-16}. But further improvements in the carrier phase TWSTFT have the potential of reducing the link instabilities close or below 10^{-17} ADEV at 5 day intervals.

Most modems currently used by NMIs contributing to UTC with TWSTFT measurements are based on a single brand of modem which is expected to end production by 2025. So far no commercially available modem exists that may be used as a replacement and as a successor. Therefore, a new alternative modem is needed. In 2017-2022 the BIPM's Consultative Committee for Time and Frequency (CCTF) working group on TWSTFT supported a study on the use of SDR for signal reception in order to mitigate diurnal errors in TWSTFT measurements at low chip rates. Another study used hardware based transmit functions in combination with SDR based receivers to reproduce the performance of the currently used modems. Despite these successes, the outputs from both studies are closed source and commercially unavailable. Furthermore, the latter study did not address future metrological needs such as the redefinition of the SI-second.

In different research the development of new TWSTFT techniques has concentrated on the use of multi- carrier pseudo random noises to improve bandwidth, and on the use of the carrier phase to reduce measurement noise. The availability of powerful computing devices has also allowed the use of SDR methods which offer flexible signal processing and the implementation of a large part of conventional modem into software. However, several error sources remain in TWSTFT (e.g. delays in the dispersive atmosphere), and require further research.

Objectives

Proposers should address the objectives stated below, which are based on the PRT submissions. Proposers may identify amendments to the objectives or choose to address a subset of them in order to maximise the overall impact, or address budgetary or scientific / technical constraints, but the reasons for this should be clearly stated in the protocol.

The JRP shall focus on the traceable measurement and development of advanced digital TWSTFT systems

The specific objectives are

1. To develop an advanced open-design digital TWSTFT modem based on SDR components, with advanced modulations, coding, detection algorithms and security/authentication of data transfer. In addition, to study the limits posed by ground stations and in orbit transponder and identify adequate technical solutions so as not to limit the performance of the advanced TWSTFT.
2. Using the advanced TWSTFT from Objective 1, to increase TWSTFT frequency transfer performance, to meet the transfer capability requirements for the SI-second redefinition. This includes (i) improving short term transfer stability, (ii) mitigating diurnal error sources, and (iii) reducing the link stability to approach 10^{-17}@5d ADEV.
3. Using the advanced TWSTFT from Objective 1, to develop improved time transfer calibration capabilities below 1 ns that meet the requirements for future UTC(k). In addition, (i) to produce calibration procedures suitable for legacy and advanced TWSTFT systems, (ii) to determine long term equipment instability and (iii) to identify error sources impacting TWSTFT calibrations.
4. Using the advanced digital TWSTFT from Objective 1, to demonstrate long baseline frequency transfer between optical frequency standards using TWSTFT combined with accurate optical fibre frequency transfer inside the timing laboratories.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain, research organisations (NMIs, EMN Quantum), standards developing organisations (BIPM CCTF, EURAMET TC-TF) and end users in the optical and time and frequency sectors.

These objectives will require large-scale approaches that are beyond the capabilities of single National Metrology Institutes and Designated Institutes. Proposers shall give priority to work that aims at excellent science exploring new techniques or methods for metrology and novel primary measurement standards, and brings together the best scientists in Europe and beyond, including other European Partnerships, whilst exploiting the unique capabilities of the National Metrology Institutes and Designated Institutes.

Proposers should establish the current state of the art and explain how their proposed project goes beyond this. In particular, proposers should outline the achievements of the EMRP project SIB55 ITOC and how their proposal will build on those.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 2.0 M€ and has defined an upper limit of 2.5 M€ for this project.

EURAMET also expects the EU Contribution to the external funded beneficiaries to not exceed 40 % of the total EU Contribution across all selected projects in this TP.

Any industrial beneficiaries that will receive significant benefit from the results of the proposed project are expected to be beneficiaries without receiving funding or associated partners.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the ’end user’ community, describing how the project partners will engage with relevant communities during the project to facilitate knowledge transfer and accelerate the uptake of project outputs. Evidence of support from the “end user” community (e.g. letters of support) is also encouraged.

You should detail how your JRP results are going to:

- Address the SRT objectives and deliver solutions to the documented needs,
- Feed into the development of urgent documentary standards through appropriate standards bodies,
- Facilitate improved industrial capability or improved quality of life for European citizens in terms of personal health, protection of the environment and the climate, or energy security,
- Transfer knowledge to the optical and time and frequency sectors.

You should detail other impacts of your proposed JRP as specified in the document “Guide 4: Writing Joint Research Projects (JRPs)”

You should also detail how your approach to realising the objectives will further the aim of the Partnership to develop a coherent approach at the European level in the field of metrology and include the best available contributions from across the metrology community. Specifically, the opportunities for:

- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards
- the metrology capacity of EURAMET Member States whose metrology programmes are at an early stage of development to be increased
- organisations other than NMIs and DIs to be involved in the work.

Time-scale

The project should be of up to 3 years duration.