Title: Advanced time/frequency comparison and dissemination through optical telecommunication networks

Abstract

The unprecedented accuracy of modern optical clocks has spurred the development of matching frequency comparison techniques. Advancing fibre-based frequency transfer capabilities in Europe towards a sustainable, universal tool for time and frequency metrology requires further work. Previous activity focused on frequency transfer and now time transfer needs to be included. Also, opportunities are arising to create an affordable fibre backbone based on shared use, and activities to prepare the ground on a technical and organisational level need to be followed.

Keywords

Time and frequency dissemination, optical fibres, frequency comparison, time scales, optical clocks, frequency standards, redefinition of the SI second

Background to the Metrological Challenges

EURAMET TC-TF forecasts in its roadmap that long haul optical fibre links will be established in Europe, paving the way towards routine operation capability of pan-European links at the <100 ps level and fractional frequency transfer uncertainty below 10^{-18} by 2025 [1]. More immediately, there is a need to perform frequency comparisons of remote optical clocks at the highest level of accuracy as an essential part of the preparation for the redefinition of the SI second [2]. There is also growing interest from the Earth science and geodesy scientific communities for improving time and frequency capabilities, and a growing need in industry, as expressed in Recommendation 6 of the 20th meeting of the CCTF in 2015 [3] and confirmed in 2017 [4].

Today's best optical clocks can reach an estimated systematic fractional frequency uncertainty at the level of a few 10^{-18}. Local two-clock comparisons reach down to 2×10^{-18} for optical lattice clocks with identical species and 5×10^{-17} for synchronously interrogated clocks based on different atomic species.

Optical frequency transfer over fibre is currently the only technique capable of comparing such clocks across long distances without degrading the stability and accuracy of the comparison. Satellite-based frequency comparison techniques offer world-wide coverage, but lack the performance required for optical clock comparisons. A transportable clock has become available only recently but with an accuracy of 7×10^{-17} it is still far from the full performance of its stationary counterparts.

In the precursor EMRP and EMPIR projects SIB02 NEAT-FT and 15SIB05 OFTEN, technologies for disseminating and comparing ultra-stable optical and radio-frequencies over fibre links have been demonstrated. Efforts in these projects culminated in the first international comparison of the primary Cs fountains and optical clocks at a level that is not being limited by the link between the clocks. Although optical fibre frequency transfer is capable of reaching stability and accuracy in the 10^{-19} to 10^{-20} range, this level of performance is not achieved routinely without human intervention and under all conditions. Individual fibre links also suffer from the impact of fibre imperfections, which are often beyond the users' control. These issues are starting to be addressed in OFTEN.

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 characterisation of optical time and frequency transfer technology.

The specific objectives are

1. To sustainably expand existing capabilities for optical fibre frequency transfer towards time transfer by integrating optical carrier, radio frequency (rf) and time dissemination and comparison techniques with the aim of limiting spectrum usage to a single channel of the International Telecommunication Union (ITU) grid. The target accuracy for the combined service is 1 part in 10^{18} for frequency and 100 ps for time, simultaneously. Additionally, to investigate extension of the compatibility of specialised amplification techniques with rf and time transfer and explore novel concepts of time transfer over fibre with the potential of reaching sub-ps accuracy.
2. To enhance and develop optical fibre frequency transfer technology, with the aim of human intervention-free operation over several weeks, and to identify and address performance-limiting factors, with the aim of achieving 1 part in 10^{18} uncertainty within less than one hour for long-distance fibre links, matching the expected performance of improved optical clocks.
3. To investigate the compatibility of optical time and frequency transfer with simultaneous data traffic in a laboratory test environment or deployed fibre infrastructure, in order to determine conditions under which they operate mutually disruption-free. Compatibility tests should concentrate on commercial telecommunications equipment deployed in national research and education networks (NRENs) and the pan-European network GÉANT.
4. To disseminate ultra-stable frequency and timing signals beyond the NMIs, with attention paid to identifying the benefits of disseminating time, as opposed to pure frequency. To include demonstrating and facilitating novel applications in geodesy and earth observation, including investigation of essential functionalities for the proper transfer of time between widely spaced geodetic markers.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (NMIs), standards developing organisations (e.g. ITU-T) and end users (NRENs, fibre network operators, Earth science and geodesy communities, and calibration laboratories).

These objectives will require large-scale approaches that are beyond the capabilities of single National Metrology Institutes and Designated Institutes. To enhance the impact of the research work, the involvement of the larger community of metrology R&D resources outside Europe is recommended. A strong industry involvement is expected in order to align the project with their needs and guarantee an efficient knowledge transfer into industry.

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 and EMPIR projects SIB02 NEAT-FT and 15SIB05 OFTEN and the H2020 project CLONETS and how their proposal will build on those.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 1.8 M€, and has defined an upper limit of 2.1 M€ for this project.

EURAMET also expects the EU Contribution to the external funded partners to not exceed 20 % of the total EU Contribution across all selected projects in this TP.

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,
- Transfer knowledge to the fibre optics, Earth science and geodesy 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 EMPIR 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.

Additional information

The references were provided by PRT submitters; proposers should therefore establish the relevance of any references.

[1] Science and Technology Roadmaps for Metrology, Foresight Reference document of EURAMET e.V. (2012), available at https://www.euramet.org/publications-media-centre/documents/

[2] "Towards a new definition of the second in the SI", Annex 1 to the CCTF strategy document (2016), https://www.bipm.org/utils/en/pdf/CCTF-strategy-document.pdf

[3] CCTF recommendation 6, p. 55 of the report of the 20th meeting of the Consultative Committee for Time and Frequency (2015), available at https://www.bipm.org/utils/common/pdf/CC/CCTF/CCTF20.pdf

[4] CCTF recommendation 1, p. 48 of the report of the 21st meeting of the Consultative Committee for Time and Frequency (2017), available at https://www.bipm.org/utils/common/pdf/CC/CCTF/CCTF21.pdf