EMPIR Call 2015 – Health, SI, Normative and Research Potential

Selected Research Topic number: **SRT-s15**
Version: 1.0

Title: Optical frequency transfer - a European network

Abstract

It is essential for the redefinition of the SI second to perform optical clock comparisons between NMIs at a level not limited by the transfer medium and on a regular basis. Frequency transfer over optical fibre is the most promising technology to achieve this goal. Europe has an exceptionally high concentration of optical atomic clocks using a number of different atomic references, and point-to-point links are being set up between several European NMIs. However the number, performance and reliability of the links need to be improved significantly. A European network for high availability, high stability frequency comparison will also benefit current microwave-based standards and the ACES mission due to be launched in 2017.

Keywords

Optical clock, frequency transfer, optical fibre, SI second, International Atomic Time, optical frequency comparison

Background to the Metrological Challenges

There are now optical clock standards available with accuracies better than caesium standards, with the best optical clocks claiming a systematic fractional uncertainty of parts in 10^{18}. In terms of an optical standard, the CIPM has already introduced secondary representations of the second. In preparation for a redefinition of the SI second, there is a need for extensive remote clock comparisons. Large scale remote comparisons across two or more NMIs will improve the validation of optical clock uncertainty budgets and help select candidate species for the redefinition.

Frequency transfer over optical fibre has been recognised as the most promising technique, with links operational in Japan, France, Germany, Italy, the UK, and the US, for remote clock comparisons. The links have demonstrated fractional instability and uncertainty at the level of about 5×10^{-19} over a distance of >1000 km and with an averaging time of less than an hour, sufficient to compare the best existing optical clocks. In contrast, conventional methods as routinely used in the comparison of Cs fountain standards are insufficient for optical clocks; they would require on the order of a year to achieve adequate stability for a comparison at the parts in 10^{17} level. The improved stability of optical fibre compared to satellite links would also allow fountain comparisons at a level of parts in 10^{15} to be performed in hours rather than days. Even with current standards this would enable much faster detection of any malfunctions and deviations. There is a need to establish protocols for fountain comparison over fibre, which will also be immediately transferrable to optical clocks if and when the second is redefined.

Current challenges for fundamental geodesy require positioning accuracy of the reference geodesy centres at the 1 mm level**.** This requires clock instabilities at the parts in 10^{16} level over a few hours of measurement, which cannot be provided by currently-used GPS-disciplined hydrogen masers. In contrast, optical fibre links address these demands, enabling the dissemination of primary frequency standards and optical clocks to reference geodesy centres. Red-shift measurements of clocks connected by fibre links will also improve our knowledge of the geoid, which is beneficial both to geodesy and timescale generation. In addition, optical fibre offers a completely ground-based and well-understood channel with a higher stability than the space-based microwave links such as used in ACES.

Comparing the same pair of clocks through ACES ground-space-ground links and optical fibre will enable direct comparative evaluation of both techniques. Comparisons of the order of parts in 10^{17} should be achievable at averaging times of a few days for international baselines between European NMIs equipped with an ACES ground terminal. Comparisons between the performances of ACES links at different NMIs would only be possible using ground optical fibre links between two MWLs and MWL/ELT stations.

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 frequency standards over an optical fibre link network.

The specific objectives are

1. To connect two or more clocks belonging to NMIs in Europe with optical fibre links and enable multiple optical clock comparisons at a fractional instability level from 10^{-17} to 10^{-18}.
2. To assess and improve the accuracy and stability of remote optical frequency transfer by optical fibre, aiming for a fractional instability and uncertainty < 10^{-19} (over one day). To develop techniques that improve the reliability and scalability of frequency transfer over optical fibre, striving for continuous measurements (more than one day duration) and simultaneous operation of branched long-distance links.
3. To operate long-distance optical fibre links (fractional measurement uncertainty < 10^{-17} at one day) and to perform fast and accurate frequency comparisons (0.5 - 1 day duration, combined statistical fountain fractional clock uncertainty 2 - 3×10^{-16}) between European Cs fountain clocks.
4. To develop applications of fibre-based frequency comparison techniques for long-baseline (> 300 km) geodesy experiments and for ground-space-ground frequency comparisons, especially to assess the performance of the MicroWave Link (MWL) and/or the European Laser Timing Link (ELT) technology in ACES, by simultaneously comparing clocks over both fibre and space links.
5. To facilitate the take up of the technology and measurement infrastructure developed by the project by the measurement supply chain (accredited laboratories, instrumentation manufacturers) and end users (space, geodesy, telecommunications, etc.)

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 project SIB02 and EMRP project SIB55 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 21 % of the total EU Contribution to the project. Any deviation from this must be justified.

Any industrial partners that will receive significant benefit from the results of the proposed project are expected to be unfunded 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,
- Transfer knowledge to the metrology, physics, and geodesy communities.

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.