European Partnership on Metrology
Call 2022 – Digital Transformation, Health, Integrated European Metrology, Normative and Research Potential

Selected Research Topic number: **SRT-s03**
Version: 1.0

Title: Transportable optical clocks for key comparisons

Abstract

Considerable progress in the development of optical clocks has resulted in them surpassing established primary frequency standards in accuracy and stability. Achievement of an uncertainty of 5×10^{-18} in comparisons of optical clocks in different laboratories has been cited as an important step towards the redefinition of the second. Fibre links between a few national metrology laboratories in Europe enable frequency comparisons with low 10^{-18} uncertainty but are limited by relativistic effects. Moreover, fibre links are not available to many European NMIs and over intercontinental distances. To overcome these limitations, transportable optical clocks capable of performance exceeding the current state-of-the-art need to be developed, evaluated, and employed.

Keywords

Optical clocks, trapped and cooled atoms and ions, frequency standards, frequency comparisons, SI second

Background to the Metrological Challenges

An optical redefinition of the second was identified as one of the “Grand challenges on fundamental metrology” within the EMRP Outline in 2008 and was restated as a key target in the 2016 EURAMET roadmaps for time and frequency. An important milestone defined in the CIPM CCTF roadmap towards a redefinition of the SI second is the demonstration of at least three independent comparisons of optical clocks in different laboratories with fractional uncertainty below 5×10^{-18} using transportable clocks or other means.

The most advanced optical clock systems reach fractional systematic uncertainties of 10^{-18} and below whilst international key comparisons in time and frequency performed with established satellite-based techniques are limited to about 10^{-16}. Dedicated optical fibre links have been installed between several NMIs in Europe that enable clock comparisons in the 10^{-18} uncertainty range. However, the uncertainty of the correction of relativistic gravitational frequency shifts between the remote clocks has proved to be a limitation since it is not possible to determine clock elevation with adequate resolution. Furthermore, optical fibre links are unavailable to many European NMIs and research institutes and for intercontinental comparisons. Transportable optical clocks provide the solution to these issues. They are also required to provide accurate and stable frequency references outside NMIs and DIs, for example at specialized research facilities, for geodetic base stations or in future telecommunications and navigation systems.

Initial proof-of-concept comparison experiments carried out with transportable optical clocks have demonstrated higher uncertainties than those obtained with optical fibre links. Research is needed to develop and evaluate clock components meeting the particular requirements for transportability in terms of power consumption, size, weight and durability. Transportable optical clocks then developed with these components should be assessed by comparison against laboratory standards to verify their accuracy, frequency stability, and reproducibility. Measurements should be taken before and after real and simulated transportation of the clocks to detect any resultant errors. Finally, the feasibility of using transportable clocks in comparisons to achieve the targeted uncertainty needs to be demonstrated.

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 development of an integrated European metrology infrastructure for the development and deployment of highly stable and accurate transportable optical clock systems.

The specific objectives are

1. To develop and to demonstrate the performance of commercially unavailable components of transportable optical clock systems (e.g., ultra-16 stable laser, optical bench for atom/ion cooling, trapping and interrogation, UHV physic package for atom/ion clock) capable of operation within 5 days after transportation.
2. To develop transportable optical clocks that demonstrate short-term frequency instabilities below $5 \times 10^{-15}\sqrt{\tau(s)}$ and a systematic uncertainty equal or below 5×10^{-18}.
3. To evaluate the transportable optical clocks by comparison with fully evaluated stationary laboratory systems to assess their performance in terms of frequency stability and accuracy and to estimate their reproducibility. This includes measurements before and after a real or simulated transportation of the transportable optical clock for investigation of possible errors.
4. To demonstrate the feasibility of future key comparisons using transportable optical clocks as an alternative to established time and frequency key comparisons performed via satellite-based techniques.
5. To demonstrate the establishment of an integrated European metrology infrastructure and to facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (NMIs, DIs), international metrology committees (CIPM CCTF) and end users (research facilities in geodesy, space and physics, telecommunications and aerospace enterprises, scientific and precision instrumentation manufacturers).

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 both within and outside Europe, plus engagement with existing European research infrastructures and European Partnerships 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 and end users.

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 EMPIR projects 15SIB03 OC18 and 18SIB05 ROCIT and how their proposal will build on those.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 1.9 M€ and has defined an upper limit of 2.6 M€ for this project.

EURAMET also expects the EU Contribution to the external funded beneficiaries to not exceed 25 % 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,
- Develop an integrated self-sustaining European metrology infrastructure,
- Feed into the development of urgent documentary standards through appropriate standards bodies,
- Transfer knowledge to the metrology, physics, geodesy, telecommunications, aerospace, scientific and precision instrumentation 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.