European Partnership on Metrology
Call 2025 – Health, Integrated European Metrology, Regulation and Research Potential

Selected Research Topic number: **SRT-s01**
Version: 3.0

Title: Advancing the Roadmap Criteria for the Redefinition of the Second

Abstract

The Consultative Committee for Time and Frequency (CCTF) 'Roadmap towards the redefinition of the SI-second' has established criteria that must be fulfilled before the redefinition of the SI second can take place. The most critical of these include the development and validation of optical frequency standards at the 10^{-18} level, the regular contribution of these standards to International Atomic Time (TAI) and the sustainability of clock comparison techniques. Proposals addressing this topic should advance the roadmap by addressing these criteria. They should promote high-accuracy optical clocks and their validation via fibre links, transportable clocks, or other techniques, and promote the integration of more optical standards into TAI.

Keywords

Optical clocks, SI second, optical frequency standard, clock comparison, redefinition of the second.

Background to the Metrological Challenges

In 2020, the Consultative Committee for Time and Frequency (CCTF) of the CIPM (International Committee for Weight and Measures) established a Task Force on the Roadmap towards the redefinition of the second. This Task Force defined mandatory criteria to be achieved before the redefinition (targeted for 2030) and estimated their current fulfilment level, underlining the areas that still need improvement [1]. The importance of advancing these objectives outlined in the Roadmap has been emphasised by Resolution 5 of the 27th General Conference on Weights and Measures (CGPM, 2022) and the European Metrology Network for Quantum Technologies Orientation Paper 2025. Despite some progress in this area, key challenges remain with some mandatory criteria detailed in the Roadmap lagging behind:

Accuracy of Optical Frequency Standards (Criterion I.1): The current state-of-the-art has seen the development of a number of optical frequency standards based on different reference transitions. To meet the criteria of the Roadmap, at least three independent standards demonstrating uncertainties $\leq 2 \times 10^{-18}$ based on the same reference transition, in different institutes, must be developed. Further evaluations are also needed to consolidate accuracy and ensure consistency.

Validation of Optical Frequency Standards (Criterion I.2): International validation of clock uncertainties via clock comparisons is essential before redefining the second. Only a few unit and non-unit frequency ratios have been measured with uncertainties below 10^{-17}. A non-unit comparison has reached the $< 5 \times 10^{-18}$ level, but no comparisons between different institutes have yet achieved this level as required by the Roadmap. Far more clock comparisons and the publication of their results are needed to build confidence in optical clock accuracy.

Regular Optical Clock Contributions to TAI (Criterion I.4): So far, 8 optical frequency standards from 7 institutes have contributed to International Atomic Time (TAI). However, just two contributions out of a total 148 have reached an uncertainty $\leq 2 \times 10^{-16}$ as required by the Roadmap. Additionally, the number of contributions, even with larger uncertainty, has never reached the required level of 5 per month for a year—the number peaked in 2022 and has since declined. The transfer uncertainty is the limiting contribution as measurement times below 20 days are already exceeding the uncertainty target. Ensuring long-duration, high-duty-cycle calibrations is essential to validate optical clocks as primary standards for timing.

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Sustainable Clock Comparison Techniques (Criterion II.1): Optical fibre links and transportable clocks have demonstrated uncertainties $<5 \times 10^{-18}$, but their availability and long-term sustainability remain uncertain. Comparisons in Europe by optical fibre links involved 6 optical frequency standards in 2022 (with 4 more connected by GNSS, including one in Japan) and 6 optical frequency standards in 2023 (yet to be published). Transportable clocks developed in Germany, Japan, and China have been operated at accuracy levels around 5×10^{-18} but no ongoing global-scale campaigns are in place to routinely assess and improve these techniques. Regular comparisons using fibre links and/or available transportable systems need to be planned to advance this aspect worldwide.

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 proposal shall focus on the development and utilisation of optical frequency standards to advance the criteria of the CCTF Roadmap towards the redefinition of the second.

The specific objectives are

1. To increase the number of optical frequency standards with uncertainties evaluated at $\lesssim 2 \times 10^{-18}$, based on comprehensive, comparable and published accuracy budgets, operated at NMIs with access to means of comparing them remotely.
2. To validate the consistency of optical frequency standards with new clock comparison campaigns using optical fibre links (large scale or bilateral at the European level), by transportable optical clocks (at the European and worldwide level), or other novel techniques and to publish the results. Target uncertainty of the comparisons should be consistent with stated clock accuracy and aim to be $\lesssim 5 \times 10^{-18}$ for both unit and non-unit frequency ratios.
3. To incorporate new optical frequency standards into the computation of International Atomic Time (TAI) and to perform regular TAI calibration with optical frequency standards with total uncertainties $\lesssim 2 \times 10^{-16}$ and high duty cycle contributions longer than 20 days.
4. 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), the international metrology community (e.g., CIPM CCTF) and the broader research community.

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. Where relevant, proposals are encouraged to build on, or seek collaboration with, existing projects and develop synergies with other relevant European, national or regional initiatives and funding programmes. In particular, links are encouraged with (i) the projects funded under earlier relevant topics of the Horizon Europe programme; or (ii) other relevant European Partnerships.

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 15SIB08 OC18 and 18SIB05 ROCIT and the Partnership projects 22IEM01 TOCK, 23FUN02 CoCoRICO and 23FUN03 HIOC and how their proposal will build on those.

Proposers should note that the programme funds the activity of researchers to develop the capability, not the required infrastructure and capital equipment, which must be provided from other sources.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 2.1 M€ and has defined an upper limit of 2.6 M€ for this proposal.

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 proposal's 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 time and frequency sector.

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 Metrology 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.

Timescale

The project should be of up to 3 years duration.

Additional information

The links provided in this section are only correct at the time of publication up until the end of the Call year.

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

[1] Roadmap towards the redefinition of the second
https://iopscience.iop.org/article/10.1088/1681-7575/ad17d2