EMRP Call 2012 – Open Excellence, Industry and SI Broader Scope

Selected Research Topic number: **SRT-s20**
Version: 1.0

Title: International timescales with optical clocks

Abstract

Integration of optical atomic clocks into the international timescales TAI and UTC is a key prerequisite for a future redefinition of the SI second. This SRT calls for a coordinated programme of intercomparisons between European optical atomic clocks at a level limited only by the systematic uncertainties of the clocks themselves. Such a programme will allow the full potential of these clocks to be realised and enable European NMIs to play an influential role in international debates concerning a redefinition of the second. In the shorter term, optical atomic clocks will enhance the stability of international timescales, benefiting applications in navigation and communications as well as fundamental science. This SRT also calls for research to develop a quantitative understanding of gravitational effects on clocks as well as time and frequency comparisons by satellite links, optical fibres, or transportable clocks

Conformity with the Work Programme

This Call for JRPs conforms to the EMRP Outline 2008, section on “Grand Challenges” related to Industry & Fundamental Metrology on pages 9, 10 and 26.

Keywords

Optical clocks, relativistic geodesy, optical fibre links, General Relativity, gravitational red shift

Background to the Metrological Challenges

Time and frequency are the physical quantities that can be measured with the highest accuracy. The realisation of the unit of time therefore plays a central role within the SI, being used in the practical realisation of other units including the metre, the volt and the ampere. International timekeeping is based upon atomic clocks, and has widespread applications in navigation and communications systems.

Optical atomic clocks have now reached a level of performance that clearly surpasses the stability and accuracy achievable with microwave atomic clocks, and an optical redefinition of the second is being actively considered. As a first step towards such a redefinition, in 2006 the CIPM introduced the concept of secondary representations of the second and recommended four different optical transition frequencies that could be used in this way. However, although the principle of secondary representations has been established, none of the optical clocks are yet contributing to international timescales in practice.

A co-ordinated programme of clock comparisons is therefore required to establish a framework and robust procedures whereby the optical clocks can be integrated into international timescales. This programme should involve direct intercomparisons of the highest accuracy optical clocks, where unprecedented levels of stability and accuracy are being investigated. Reliable evaluations and further improvements to these clocks can only be made by comparisons between different realisations of the same optical standard or between optical clocks based on different atomic species. Such comparisons must be carried out both locally (within a particular NMI) and remotely (between clocks in different NMIs) in order to check for self-consistency. Improved determination of the gravitational corrections applicable to the clocks within each NMI are also required if the maximum benefits are to be derived from incorporating optical atomic clocks into international timescales in the longer term.

BIPM has identified, in connection with the establishment of TAI, the need for “increased accuracy in the application of Einstein's theory of General Relativity.” The development of optical clocks has increased precision and stability of clocks to a point that general relativistic effects (gravitational red shift, accelerated

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reference frames, higher order Doppler effects) need to be considered in detail. Thus, interdisciplinary research between time and frequency metrology, General Relativity, and geodesy is required to push the limits to below 10^{-18} by developing a reference frame for time and frequency comparisons in curved space-time. This would follow the CGPM's (General Conference on Weight and Measures) recent adoption (2011) of the common reference ITRS (International Terrestrial Reference System) as defined by the IUGG (International Union of Geodesy and Geophysics).

Scientific and Technological 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 JRP-Protocol.

The JRP shall focus on improved local and remote clock comparison and on further methods to exploit the stability of optical atomic clocks at the 10^{-18} level of accuracy, with the vision of integrating optical atomic clocks into the international timescale.

The specific objectives are

1. To investigate comparison of clocks both under laboratory conditions at the 10^{-17} - 10^{-18} level of accuracy and for comparisons of remote clocks at the 10^{-16} - 10^{-17} level of accuracy. The techniques to be considered shall include femtosecond combs for absolute frequency measurements and frequency ratios, and satellite and fibre links.
2. To investigate the prospect and possibility of continuously operating transportable optical clocks for the comparison of remote clocks including the effects of the trajectory of the clock during travel.
3. To make a complete evaluation of all relativistic effects influencing time and frequency comparisons at the 10^{-18} level of accuracy. These include effects like the gravitational red shift and the Sagnac or Lense-Thirring effect. The connection to geodetic models needs to be established to describe the variation of the frequency of clocks due to changes in the gravity potential, e.g., related to tidal effects. Proof-of-principle experiments utilising optical clocks to measure gravity potential differences should be performed.
4. To perform an analysis of the frequency ratio measurement matrix derived from the above measurements to check the consistency of the measurements
5. To develop hardware and software algorithms for remote clock comparison / deriving steering corrections to UTC based on a matrix of frequency ratio measurements

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. Reference may be made to the following projects: iMERA-Plus JRP T1 J2.1 'Optical clocks for a new definition of the second'; EMRP SIB02 'High Accurate Time/Frequency Comparison and Dissemination Through Optical Communication Networks' and EMRP SIB04 'High Accuracy Optical Clocks with Trapped Ions'.

The total eligible cost of any proposal received for this SRT is expected to be significantly above the 2.7 M€ guideline for proposals in this call. The available budget for integral Research Excellence Grants is 42 months of effort.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the "end user" community. This may be through the inclusion of unfunded JRP partners or collaborators, or by including links to industrial/policy advisory committees, standards committees or other bodies. Evidence of support from the "end user" community (e.g. letters of support) is encouraged.

You should detail how your JRP results are going to:

- feed into the development of urgent documentary standards through appropriate standards bodies
- transfer knowledge to the fundamental physics, communications and navigation sectors.

You should detail other impacts of your proposed JRP as detailed in the document “Guide 4: Writing a Joint Research Project”

You should also detail how your approach to realising the objectives will further the aim of the EMRP to develop a coherent approach at the European level in the field of metrology and includes 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 Member States and countries associated with the Seventh Framework Programme whose metrology programmes are at an early stage of development to be increased
- outside researchers & research organisations other than NMIs and DIs to be involved in the work

Time-scale

The project should be of up to 3 years duration.