EMRP Call 2011 - Health, SI Broader Scope & New Technologies

Selected Research Topic number: **SRT-s11**
Version: 1.0

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

Abstract

This project will support intercomparison of the European, and ultimately, global ensemble of optical atomic clocks at a level only limited by the systematic uncertainties and stabilities of the clocks themselves, enabling optical clocks to enhance the international timescale and support redefinition of the SI second. The project will build up the technological capability to compare clocks within Europe, at the better than 10^{-17} level of stability, providing the capability to exploit existing optical fibre networks. Europe is unique in having a dozen or more institutes engaged in optical clock development, separated by distances up to 1500 km, so the project can take a world-leading position in this rapidly-developing area and support the development, operation and use of space and land based time and frequency calibration and dissemination systems.

Conformity with the Work Programme

This Call for JRPs conforms to the EMRP Outline 2008, section on “Grand Challenges” related to Health, New Technologies & Fundamental Metrology on pages 10 and 11.

Keywords

Optical clocks, redefinition of the second, frequency and time dissemination, time and frequency comparison, optical fibre links

Background to the Metrological Challenges

Frequency metrology has developed considerably over the past 15 years. The best clocks today reach a fractional accuracy of the order of 10^{-17}. High performance frequency metrology is also at the heart of a number of industrial and technological applications, such as defence and aerospace engineering, navigation, telecommunication systems. The present challenge consists of accurately comparing the non-portable ultra-stable clocks in distant laboratories, with the longer-term goal of dissemination of such standards to the large community of potential user beneficiaries. Accurate time and frequency transfer is essential for geodesy, very high resolution radio-astronomy (VLBI), space exploration, and for underpinning the accuracy of almost every type of precision measurement as well as the UTC system.

The conventional means for remote frequency transfer is based on satellite links such as the Global Positioning System (GPS) or the future European Galileo GNSS, and is limited at a level around 10^{-15} over one day of measurement. Today’s best existing methods for long-distance frequency comparisons use satellite links and allow frequency comparisons at the global scale at a fractional instability (uncertainty) of 10^{-15} for one day of measurement. This falls short of matching the instability of the present generation of primary caesium microwave clocks and the current state-of-the-art of optical clocks. Progress on satellite-based links may lower the noise floor to the 10^{-16} range and advanced space missions are being designed to make comparisons in the high 10^{-17}. However, even if achieved, such performance would be insufficient for the next generation of optical clocks. Optical clocks using a trapped single ion or cold atoms confined in lattice are expected to reach a frequency instability below 10^{-17} and will consequently require even more stable frequency transfer systems to allow their outputs to be fully exploited.

State-of-the-art Two Way Time Transfer (TWTT) using DWDM wavelength channels (Dense Wavelength Division Multiplexing) and unidirectional optical fibre pairs has demonstrated the potential of achieving nanosecond timing accuracy, using fibre pairs of 740 km total length with known path delay asymmetry. Similar accuracy is achieved using fibre-based TWTT over active SDH/SONET networks using a “piggy-

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back” technique, where the start sequence of each data frame is detected in both ends. A prototype setup has been in operation between Borås and Stockholm, a distance of 560 km, since 2008 and it has been verified that the uncertainty introduced by the time transfer is comparable to the presently used GNSS techniques (~1 ns). One-way time transfer through optical fibres at the level of 10-100 ns has been shown to be possible by making use of a ‘dual-wavelength’ technique.

Comparing optical clocks at the level of $<10^{-16}$ is essentially solved for local experiments which involve clocks in a given institute and separated by intermediate distances of up to a few 10 km. At NIST a stability of $<3 \cdot 10^{-15}\ \tau^{-1/2}$. has been demonstrated for Al^+/Al^+ comparison.

Several NMIs have already demonstrated frequency transfer over dark fibre networks up to a few hundreds of km, achieving transfer stabilities in the few times 10^{-17} to 10^{-18} range; several of these have made absolute frequency measurements of optical frequency standards at remote institutions. PTB has set up a 900 km dark fibre link to the Max-Planck Institute for Quantum Optics, near Munich, whilst LNE-SYRTE, in collaboration with Université Paris-Nord, have demonstrated frequency transfer over live networks, alongside internet/data traffic over 300 km. NPL has focused on microwave frequency transfer by transmission of an optical frequency comb over an installed network and is also working on optical frequency transfer, using a test bed installed dark fibre network.

For the current development of European optical clocks separated by typical distances of 1000-1500 km, optical fibres provide the only alternative to comparisons via satellite. However, the issue of cost must also be considered as well as performance, so work is also necessary to find limits of performance for different investment cost alternatives.

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.

A mandatory pre-requisite for any proposal is to demonstrate that secure funding for access to the necessary fibre links can be obtained. These costs will not be supported by the JRP. The JRP shall provide a go/no-go decision for the realisation of a European metrology network or specific point-to-point connections.

The JRP shall focus on developing methods for comparison of optical frequency standards and dissemination of highly accurate time/frequency signals by using long-distance optical fibre connections. Different approaches shall be considered, based on dark fibre or fibres with parallel Internet data traffic for distances of about 1000 km.

The specific objectives are

1. to develop the techniques to enable comparisons of the best optical clocks on a relative uncertainty level of about 10^{-18} at one day integration time. This will include addressing the use of bi-directional optical add-and-drop multiplexers, signal processing, channel separation and channel cross talk.
2. to develop methods and protocols for accurate time dissemination through optical fibre. With the aim of establishing a set of time-transfer tools with as wide an application range as possible, different complementary methods and levels of accuracy will be considered: very high accuracy two-way time-transfer method targeted at timing accuracies substantially below 1 ns, moderately high accuracy (10 ns – 100 ns) methods for one-way time-dissemination. For this specific point, stakeholders should be clearly known.
3. to identify applications which require or significantly benefit from remote fibre links such as calibration of ground and space clock hardware, and demonstrate the fibre link capability for these applications. Interaction with the stakeholders is required for this objective.

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.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this.

The total eligible cost of any proposal received for this SRT is expected to be around the 2.7 M€ guideline for proposals in this call.

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 (eg letters of support) is encouraged.

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

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 time and frequency instrumentation sector;
- transfer knowledge to potential end users such as space, aerospace and telecommunications.

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. 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.