Title: New generation of frequency standards for industry

Abstract

Time and frequency standards play a key role in industrial sectors including aerospace, optical telecommunications and the pharmaceutical and medical industries. Many applications demand standards with higher stability and accuracy than commercially available devices, but such frequency standards are generally large, complex laboratory-based systems and require highly trained operators. For industrial applications, compact turn-key systems are needed that operate in demanding environments for long periods. Examples include compact atomic clocks for aerospace and satellite platforms, low phase noise oscillators for radar, and 1.5 µm optical frequency standards for optical communications.

Conformity with the Work Programme

This Call for JRPs conforms to the EMRP 2008, section on "*Grand Challenges"* related to *Industry & Environment* on pages 32 and 33.

Keywords

Atomic clocks, frequency standards, satellite navigation, optical communications.

Background to the Metrological Challenges

The operation of satellite navigation systems depends critically on atomic clock technology. Here the main industrial needs are for faster acquisition of high-accuracy navigation signals for accurate positioning and delivery of secure assets (eg missiles) and for longer periods of self-autonomy (particularly significant for self-sufficiency in the event of reduced access to base clock and satellite location signals). These requirements point to the need for atomic clocks with higher frequency stability (both at short and long timescales), but in a payload with acceptable mass, volume and power consumption.

For wireless communications, time synchronisation between network clocks, whether fixed within base stations or within mobile systems, is essential for error-free data transfer. Again there is a need for improved clock performance leading to improved system autonomy to cope with loss of access to master clock synchronisation signals (e.g. from GPS) due to operation within high-rise urban environments or within buildings, or from intentional jamming.

Low phase-noise microwave oscillators play an important role in the aerospace and defence industries, being vital to applications where coherent signal generation and reception is used, for example radar. In these industries, there are two main requirements that are always present. The first is to achieve similar performance to current systems but at lower cost or in a smaller package. The second is to achieve significantly better performance leading to increased system robustness or improved operational success.

Given the ever-increasing and rapid expansion of information transfer by optical fibre, more efficient use of bandwidth is required, and a reduction of the channel spacing within the 1.5 µm International Telecommunications Union (ITU) grid is expected (from 100 GHz to 25 GHz). With such rapid evolution, direct access to fibre communications system calibration methods becomes essential to both telecommunications source and diagnostic manufacturers and system providers, as well as to industrial users seeking to rapidly acquire particular channel data for specific applications. The requisite accuracy of these calibration methods increases as the channel spacing decreases.

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 aim of this SRT should be to develop new compact turn-key frequency standards with considerably improved performances with respect to today's commercially available products. The new standards are needed for industrial applications including aerospace, telecommunications etc, in demanding conditions. The JRP must therefore address not only the different aspects of frequency performance: phase noise, frequency stability and accuracy, but also characteristics such as robustness, power consumption and size.

The objectives include:

1. Detailed analysis of the optical properties of Hollow Core Fibres (HCF) is respect to the realisation of wavelength standards.
2. Investigation of Cs-filled sealed hollow-core-fibre microwave clocks using coherent population trapping to provide a stabilised oscillator output with fractional accuracy levels of 10^{-11}.
3. Development of sealed micro-cell or hollow-core-fibre acetylene-stabilised 1.5 micrometre optical frequency standards with better than 10^{-10} fractional accuracy; extension to solid-state/diode laser systems at other industrially relevant infra-red/visible wavelengths
4. Vibration-insensitive and transportable optical local oscillators based on lasers stabilised to high finesse ULE (ultra low expansion) or optical fibre cavities
5. Low noise microwave synthesis using compact femtosecond combs stabilized to optical local oscillators providing $5x10^{-15}$ fractional frequency stability at 1 second
6. Exploration of the capabilities of cavity-synchronised femtosecond combs for novel frequency standards for industry.
7. Development of optical frequency standard prototypes incorporating cavity-stabilised optical oscillators steered to atomic references, and consistent with space clock performance requirements. This objective requires active participation of the aerospace industry.
8. Development of compact atomic or molecular frequency references using confinement of the atoms/molecules in electric, magnetic or optical traps, to be implemented in frequency standards with fractional accuracy in the 10^{-13} range.

Proposers shall give priority to work that meets documented industrial needs and that which supports transfer into industry e.g. by cooperation and/or by standardisation.

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

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.

Where a European Directive is referenced in the proposal, the relevant paragraphs of the Directive identifying the need for the project should be quoted and referenced. It is not sufficient to quote the entire Directive per se as the rationale for the metrology need. Proposals must also clearly link the identified need in the Directive with the expected outputs from the project.

You should also detail other Impacts of your proposed JRP as detailed in the document "Guidance for writing a JRP"

You should detail how your JRP results are going to:

- feed into the development of urgent standards through appropriate standards bodies
- transfer knowledge to the producers of industrial frequency standards.

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 3 years duration.