

Publishable JRP Summary Report for JRP SIB02 NEAT-FT

Accurate time/frequency comparison and dissemination through optical telecommunication networks

Background

The aim of the NEAT-FT is to investigate new techniques for phase-coherent comparison of remotely located optical clocks, separated by distances of up to 1500 km using optical fibre links. Within the scope of the project the equipment necessary for reliable operation of fibre links will be developed and all technological steps towards a full optical link infrastructure demonstrated. Beside frequency dissemination, new techniques for time transfer over optical fibre networks will be investigated in order to provide better timing signals than currently available with GPS receivers. For typical spans of up to 100 km the project aims to improve the accuracy down to about 100 ps. Furthermore, the feasibility of a European fibre network connecting optical clocks in Europe will be studied in close collaboration with potential fibre providers.

Leading European National Metrology Institutes (NMIs) and one representative (CESNET) from the National Research and Educational Networks (NREN) have joined to meet the scientific and technical needs for highly stable and accurate reference signals in fundamental physics, GNSS, geodesy, astronomy, and (space-) industry.

Need for the project

The best optical clocks today reach a fractional accuracy of the order of 10^{-17} and this outstanding performance makes them ideal tools for various tests of fundamental physics. Moreover, optical clocks have now surpassed the best caesium-based atomic clocks in both accuracy and stability and are the most promising candidates for the expected redefinition of the SI unit of time, the second.

Nowadays adequate means to compare distant clocks at the highest level of accuracy are missing. Comparison is a vital issue for optical clocks development and to explore their fundamental limitations. However, as conventional satellite-based techniques do not reach the required performance alternatives must be developed.

There is an increasing demand by scientific organisations and universities for accurate links to NMIs for reference to the SI second. In typical research laboratories, high-resolution optical frequency measurement is limited by the accuracy of commonly-used rubidium clocks, which are referenced to UTC via GPS. In the longer term, it is likely that some of the most advanced applications of future atomic clocks will be space based, and their operation will require ground stations with access to ultra-stable frequency references linked to the best available ground clocks. In this respect optical fibre links to such locations will become of central importance. Furthermore, those sites will allow linking the network to other continental networks (USA, Asia, Australia) using relay satellites and optical free space techniques that are being developed today.

Scientific and technical objectives

The project addresses the following scientific and technical objectives:

- Novel techniques for frequency comparisons in the $\sim 10^{-18}$ range at 1 day measurement time using optical fibres and the necessary equipment such as repeater stations, amplification concepts and remote control systems will be developed.
- “The development of methods, protocols and techniques for accurate time dissemination” and “the consideration of different complementary methods and levels of accuracy reaching from a sub-1 ns level to the sub- μ s level” will be carried out.
- “Applications that require or significantly benefit from remote fibre links” will be identified and considered in close collaboration with stakeholders with the aim of fostering the decision of funding a future European fibre network or bi-directional connections of selected points of presence.

Report Status: PU Public

Expected results and potential impact:

- The **prototype Brillouin amplifier module** for low noise signal amplification including the communication unit has become available in December 2013. Modules are currently installed in the German part of the fibre link between Paris and Braunschweig.
- The prototype Remote Laser Station was tested in field and duplicated four times for the Paris-Braunschweig link.
- A **novel time transfer technique** based on the propagation of a pulse train in fibre- - has been developed and tested over a 50 km spooled fibre demonstrating a timing jitter significantly below 1 ps and a timing accuracy of the absolute delay of 160 ps.
- We have focused on **testing of White Rabbit equipment over long distance**. The main result in this reporting period is the first demonstrated long-term operation of a long-distance. In a 120 day comparison between GPS-PPP time transfer and the 1000-km long link White Rabbit time link in a live DWDM network, the performance and reliability of the fibre link were found to be excellent and the results were limited by the statistics of the GPS-PPP link.
- **Two long haul links** between Torino Modane (640 km), and Munich-Braunschweig-Munich (1840 km) have been characterized.
- Work towards the implementation of **three new long haul links** is progressing well. The links are expected to be established before the end of the project: Paris-Strasbourg-Paris (2x750 km), Braunschweig-Strasbourg-Braunschweig (2x700 km), London-Paris-London (2x800 km).
- **The national link LIFT** has been extended from INRIM to the Italian-French cross-border at the tunnel of Frejus. The link will be operational by the end of July. This link will support activities within the project ITOC by providing the basis for a proof of principle experiment on relativistic geodesy.
- **REG AGH** has built a system for long-distance time and frequency transfer that is now ready for the field experiments at the location of the project partner. Potential localizations of further experiments have been discussed with project members.
- **REG UoS** developed a regenerative amplifier for optical frequency transfer based on optical injection locking. Stable optical injection locking over 3 days was achieved by using electronics phase locked loop (PLL). The portable prototype built with 19-inch rack boxes shall be tested at a project partner site. Additionally a wavelength converter based on optical frequency comb generator, OFC was developed. The wavelength converter covers a frequency band of 1.2 THz (9.6 nm) with a net gain of 32 dB.
- **REG CNR** investigated Distributed Raman Amplifier, DRA in co- and counter-propagating configuration. A first laboratory experiment was carried out on a dedicated fibre at the premises of project partner INRIM (Turino, Italy) demonstrating that the DRA does not add extra noise to the optical link, allowing one to bridge very long fibre spans in bidirectional links without the need of intermediate stations.
- **ESRMG IMBiH** received training at NPL on frequency metrology including frequency stability and phase noise concepts as well as on general and specialized laboratory equipment.
- The achievements have been presented at the **European Frequency and Time Forum, EFTF 2014**, in Neuchatel. <http://www.eftf-2014.ch/programme.php>.
- The consortium has been interacting with the **CCTF Working Group on Coordination of the Development of Advanced Time and Frequency Transfer Techniques (WG ATFT)**
- During the lifetime of this project, **27 presentations** have been made at international and national conferences and **7 peer-review papers** have been published with reference to the EMRP.

The results of the project will enable NMIs to perform better clock comparisons within Europe, and to disseminate highly accurate and stable frequency and timing signals to the user community for groundbreaking science and innovation. Some members of the potential user community are already collaborating with the project.

JRP start date and duration:	June 2012, 36 months
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