Publishable JRP Summary Report for JRP SIB 02 (NEAT-FT) Accurate time/frequency comparison and dissemination through optical telecommunication networks

Europe has the largest number of modern ultra-precise clocks and plays the pivot in time and frequency dissemination throughout the world, putting Europe in the leading position in time and frequency metrology.

The vision behind this project is to lay the foundations for a novel approach to disseminate high-precision timing and ultrastable frequency signals in a wide range of science and technology applications by using existing fiber infrastructure.

Background:

Nowadays optical clocks reach a fractional frequency uncertainty of the order of 10^{-17} and outperformed the best caesium-based atomic clocks in both accuracy and stability. This outstanding performance makes them the most promising candidates for the redefinition of the SI unit of time, the Second, and an ideal tool for various tests of fundamental physics. Scientific programs or European space missions like the development of the GNSS Galileo, the Cosmic Vision program of ESA, or the ACES mission rely on the availability of highly accurate and ultrastable frequencies or timing signals. However, today's conventional satellite based techniques lack the required performance for clock comparisons with relative frequency instability below 10^{-17} at one day measurement time.

The need for improved time and frequency comparisons has been stressed by the Consultative Committee for Time and Frequency (CCTF) and is regarded as of extremely high priority for a future redefinition of the SI Second and of supreme importance for the sustained development of a European time and frequency infrastructure.

It is generally agreed that optical fiber links are the sole alternative to satellites based distant clock comparison, (besides using transportable optical clocks). The demonstrated instability of an optical frequency transmitted over a fiber link is several orders of magnitude more stable than the signal used in satellite transmission systems. Up to now experiments used dedicated and specially selected fiber routes within national testbeds. To tap into the full potential of optical clocks and optical time and frequency dissemination, however, user-friendly and reliable pan-European fiber links, as well as new time and frequency transfer protocols need to be developed.

Innovation:

The joint research project (JRP) aims to investigate new techniques for phase-coherent comparison of remotely located optical clocks, separated by distances of up to 1500 km. This includes a study of the fundamental limitations of optical fiber links to the attainable instability and accuracy of optical reference frequencies and timing signals. The JRP aims to reduce the contribution of the link to the relative uncertainty of a frequency comparison to a level significantly below that of the clocks involved (typical relative uncertainty about 10^{-17}).

The JRP will experimentally investigate alternative transmission schemes for distances of up to 1500 km. , like the use of *dark fibers* [1] or fibers carrying data traffic on parallel channels, so called *dark channels* [2]. Within the scope of the JRP the equipment necessary for reliable operation of fiber links will be developed and all technological steps towards a full optical link infrastructure demonstrated.

[1] A "dark fiber" is optical fiber infrastructure that is currently in place but is not being used for data communication. Light transmitted over a dark fiber is provided by the customer rather than the local exchange carriers.

[2] A "dark channel" is a dedicated wavelength channel of a telecommunication network that is not being used for data communication. However, neighbouring channels carry data traffic. Light transmitted over a dark channel is provided by the customer rather than the local exchange carriers, but is subject to certain restrictions.

EMRP European Metrology Research Programme Programme of EURAMET

The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union

Beside frequency dissemination, new techniques for time transfer over optical fiber networks will be investigated in order to provide better timing signals than currently available with GPS receivers. For typical spans up to 100 km the JRP aims to improve the accuracy down to about 100 ps. This will enable better synchronisation of next generation of accelerator facilities or across typical antenna arrays for radio astronomy and to improve the robustness and cost-efficiency of accurate time comparisons for the International Atomic Time (TAI). Moreover the full availability of jamming robust synchronisation signal with unprecedented event marking capability will unveil novel applications for a broad community of new users. Thus, dissemination of UTC through optical fiber can also provide a secure backup for GPS timing in vital systems, such as power grids and mobile telecommunication networks. Fiber based techniques for time broadcasting, two-way time transfer over future high capacity links, and dark fiber solutions will be investigated, as well as the necessary analysis of fundamental limits.

- The consortium will develop techniques, tools and equipment necessary to enable reliable operation of long-haul fiber links and frequency comparisons at the level of about 10^{-18} at one day. This will allow us to investigate the fundamental limits of very long-haul (2000 km), ultra-stable frequency comparison & distribution techniques by gradually expanding the total link length towards the continental scale.
- Novel techniques for accurate time transfer over fiber using fs- frequency combs as pulsed systems or multiple coherent optical carriers will be developed. This complements the tasks that will develop novel methods and protocols for distant time comparisons using two-way as well as one-way time dissemination techniques based on amplitude modulation.
- Techniques that utilize the increasing deployment of fibre optic networks for continuous time transfer will be investigated and improved in order to increase the robustness and cost-efficiency of accurate time comparisons for TAI, as well as to provide UTC(k) to wide spectra of users.
- We will investigate future applications and the required performance of remote fiber links in particular outside the Time Frequency NMIs community and identify necessary steps towards establishing fiber links between selected points of presence (PoP) within Europe.
- Eventually, this will establish a platform for NMIs, stakeholders from science, industry and network services and politicians of the EU, to evaluate future applications, benefits that may be expected to come from remote fiber links, and possibilities for funding a pan European network. Two stakeholder workshops are planned to disseminate the JRP output to the target user community, and a series of presentations at international conferences will enable this JRP to reach beyond the metrological community.

The results of the JRP 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 included in the list of collaborating institutes.

For more details see homepage of the JRP: http://www.ptb.de/emrp/neatft_home.html

The JRP recognizes optical fiber links currently being developed in the US, Japan and Australia.

JRP start date and duration:	June 2012, 36 month
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