European Metrology Programme for Innovation and Research

Delivering Impact

Extending European access to high precision time and frequency information

Most time and frequency reference signals are currently transmitted from orbiting satellites equipped with atomic clocks. Although sufficient for many applications it is problematic for long distance metrological comparisons or investigations into cutting edge science. Transmitting signals over existing optical networks from ground-based clocks is an attractive alternative – but requires new technology and solutions.

Europe's National Measurement Institutes working together

The European Metrology Programme for Innovation and Research (EMPIR) has been developed as part of Horizon 2020, the EU Framework Programme for Research and Innovation. EMPIR funding is drawn from 28 participating EURAMET member states to support collaborative research between Measurement Institutes, academia and industry both within and outside Europe to address key metrology challenges and ensure that measurement science meets the future.

Challenge

Time and frequency (T&F) reference signals underpin electricity grids, global navigation and the internet. Most applications use signals from orbiting satellites, but their precision is insufficient for advanced research into such things as fundamental physics and quantum technologies.

One alternative is to deliver clock signals via established fibre optic telecommunication networks but there are problems limiting this approach. Optical signals can fade over long distances due to losses or reflections from fibre joins and are affected by "propagation noise" caused by temperature fluctuations or mechanical vibrations in the fibre. These signals also require isolation from network traffic to prevent interference.

Many problems were addressed in EURAMET projects NEAT-FT (2012-2015), OFTEN (2016-2019) and the French REFIMEVE+ project (2012-2024) performed by the ***Laboratoire de Physique des Lasers*** (USPN, CNRS), ***LNE-SYRTE*** (Observatoire de Paris, CNRS, SU) and ***RENATER,*** the French Network for Research and Education (NREN). Ultra-stable T&F dissemination from LNE-SYRTE's atomic clock was demonstrated over a 540 km telecommunication fibre. Together with PTB, the problem of signal degradation, when T&F is extracted from a link to one or more user, was also addressed. However, the solution was not compatible with automated signal distribution and regeneration.

Solution

REFIMEVE+ established a ring topology network between several universities in Paris using both dedicated fibres and RENATER telecommunication fibres. The loop, of around 2 x 20 km, connected LNE-SYRTE to ***Sorbonne Université***, to ***Université Paris Cité*** and back to LNE-SYRTE. A multibranch station fed by an ultra-stable laser at LNE-SYRTE sent the T&F signal to the loop and simultaneously to other loops or links for global dissemination over France. The signal was mixed with telecommunication traffic using a dedicated wavelength channel (1542.14 nm).

During the TiFOON project extraction signals, from hub branches, were improved by partner Muquans allowing signal regeneration with an enhanced compensation for noise. A major development was the upgrade on an interferometer, to compare the signal from the input and output ends of the main link, allowing detection and compensation for noise on the output signal of each extraction station. This was designed to prevent main link perturbations and to be insensitive to signal variations. Results indicated that SI traceable T&F data could be sent to multiple users automatically, with a frequency instability below 10^{-15} (1s).

Impact

Muquans, who helped develop the extraction stations, are now part of Exail - a leading high-tech industrial group specialising in cutting-edge robotics, maritime, navigation, aerospace and photonics technologies. The company acknowledge that working with TiFOON allowed them to test their components and technology on a daily basis over several years in a "real world" setting – knowledge they can now pass onto their customers.

T&F signals from LNE-SYRTE are now provided to over 30 laboratories in France and the resulting network has been labelled as national research infrastructure REFIMEVE. One of its fundings is a new ANR project T-REFIMEVE (2021-2028) to provide SI traceable T&F signals over extended scientific communities. It will allow cutting edge research into such things as tests for special relativity, the search for dark matter, and timing in geodesy or astrophysics networks.

The system now extends thousands of km across France with links to Italy, Germany, the UK and Switzerland with a measurement uncertainty typically below 10^{-19}.

This precision allowed an international comparison of 11 optical clocks from 7 different countries during EURAMET project ROCIT, greatly augmenting the high-accuracy clock comparison data available worldwide - essential information for the planned future redefinition of the SI second.

Using telecommunication networks to deliver precise time and frequency (T&F)

TiFOON developed technologies for disseminating and comparing ultra-stable optical T&F over telecommunication fibre links.

- Dense Wavelength Division Multiplexing approaches developed allowed T&F transfer using only a single optical channel and a good practise guide produced.
- T&F services with parallel data traffic were demonstrated in the networks of RENATER (France), PSNC (Poland) and CESNET (Czech Republic).
- In Italy, a 1739-km-long fibre link was established, disseminating frequency references from INRiM to radio telescopes, Medicina and Matera, both part of the International VLBI Service.
- In Sweden, the UTC(SP) site at Borås was connected to Onsala Space Observatory, part of the International GNSS Service (IGS), enabling an increase in robustness and reliability.
- A connection between IGS stations at Torino and Paris, was exploited for comparing primary and secondary frequency standards over months.

The work has enabled a better delivery of high-accuracy T&F in Europe which, in turn, will contribute to a planned future redefinition of the SI second.

EMPIR EURAMET

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