TC-TF Annual Report to the 9th EURAMET General Assembly Meeting

26 May 2015

1. General Aspects

Currently 30 countries are represented in the EURAMET Technical Committee for Time and Frequency and the list of contact persons is published on the EURAMET web site. These institutes contributed for the generation of the UTC time scale using more than 130 commercial Cs and H masers. The different CNSS receivers used during time scale generation and the results related to national time scales and uncertainties are published on BIPM web site. Several institutes used primary frequency standards which are used also for time scale generation. Traceable time and frequency information is disseminated using different methods. A list of time dissemination services is available on the BIPM web site. The main aims of research and development projects and comparisons are the development of new standards for time scale generation and industrial applications, dissemination of time and frequency information with low uncertainty, and the comparison of reference equipment for improvement of type B uncertainty in time scale generation. Information about ongoing projects and EMRP projects is given below.

2. Projects

List of current EURAMET project on TCTF is given below:

Project 1303, On-site visits by external technical experts in the fields of electricity and magnetism, thermometry, time and frequency and length (Coordinator: FTMC)
Project 1288, Time interval comparison Pilot Study, (Coordinator: MIRS)
Project 1156, GPS link calibrations in support of CCTF-K001.UTC, (Coordinator: ROA)
Project 1152, GNSS receiver performance monitoring,(Coordinator: GUM)
Project 1146, Time Transfer using optical fiber links, (Coordinator: UFE/IPE)
Project 1130, Preparation of a EURAMET guideline for the assessment of calibration laboratories using GPS signals for frequency and time traceability, (Coordinator: NPL)
Project 1118, Cooperation of European NMIs t&f laboratories in EMRP/A169 project calls, (Coordinator: MIRS/SIQ)

The work for the following projects is ongoing:

Project 1303, proposed by FTMC. This project is a consultancy project and will be realized by the external technical experts in the fields of electricity and magnetism, thermometry, time and frequency and length. NMIs and DIs participating CIPM MRA have to operate a QMS in conformity with ISO/IEC 17025 to support their measurement and calibration activities. This project of QMS peer visits and reviews is intended to support evaluation of QMSs in VMT/FTMC, VMT/VMC and GUM, the development and improvement processes and provides a tool for a better international recognition and fulfillment of the requirements of CIPM MRA. The goal of the project is to review the measurement capabilities of the laboratories in VMT/FTMC, VMT/VMC and GUM, including the declared measurement uncertainty in some specific fields of metrology; detect, analyze and resolve possible metrological problems of the laboratories and also learning from each other and sharing the best practice for QMS implementation.

Project 1288, coordinated by MIRS is second stage of the EURAMET project 828 showed that the transmission delay of any signal through a cable depends on several parameters and does not well define a measurement quantity “time interval” and should be more aware of the fact that the value of a “cable delay”, even for the same cable, is not a fundamental constant. The project results did not immediately support the (then) defined T&F Key Comparison and it was not considered as a Supplementary Comparison. It is believed that a successful ILC on time interval is nevertheless possible, with the goal to support current CMCs for time interval and to gain better understanding of the time interval measurement through cable delay or other measurement techniques. For that, we need first to implement a successful Pilot Study.
In the proposed Pilot Study project 1288, different travelling standards for time interval comparison will be studied and prepared and cable box as provided from BEV will be investigated again. Necessary measurements on these travelling standards will be performed by Pilot Study participants. The Inter-Laboratory Comparison (ILC) Protocol (and especially measurement parameters and methods) will be

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correctly defined so as to enable to launch a EURAMET TF.TI-K2 to serve as a EURAMET Supplementary comparison.
The proposed activities are:
- Study and build of new transfer standards
- Study on using existing cable box
- Performing verification measurements
- Preparation of detailed and harmonised ILC Protocol.

In the TC-TF 2015 meeting, MIRS give a short report on recent developments. The Slovenian company InLambda has produced a prototype of the fibre-based time interval standard, with 25 ns delay, and proposes making separate standards for each delay (20 ns, 50 ns, 200 ns). The device outputs a cleaned-up version of the input pulse so that input and output pulses are available with the same waveform. When using a Tektronix oscilloscope, measurements below 4 ps RMS and less than 30 ps peak to peak were obtained. No strong temperature dependence has been seen, although there is some variation with pulse shape and with restarts of the equipment. The optimal operating frequency was found to be 1 kHz. Time interval generator was developed under AGH and GUM cooperation, which operates with 1PPS signals. A broad range of tests have been carried out, including study of the signal dependence on temperature and external time base as well as long-term stability. The cables and connectors were found to be a strong influence on both systems, and more consideration is needed of measurement parameters such as the averaging time.
The next stage of the project is to determine which labs are interested in participating in a new comparison and how best to set up a campaign.

Project 1156, led by ROA (ES) on performing regional campaigns of GPS (in the future GNSS) receiver characterization, in reaction to Recommendation 2 of CCTF 2009. To the calibration of receivers ROA, PTB, INRIM, OP and NPL were involved. Project, which started in May 2010 and now has 17 participating partners. Three campaigns have been carried out so far. The weakest aspect has been coordination with the BIPM to validate and coordinate the calibration results so that they can be used for UTC time links. Many participating labs have uncertainties based on calibrations carried out more than 5 years ago and the more recent campaign values have not been adopted, despite much discussion about RMOs leading GNSS calibrations. On the last TC-TF, ROA summarized the BIPM proposals, including type B uncertainties for UTC links set by the BIPM and increasing with the age of the calibration. Comparisons of GPS PPP and TW links between ROA and PTB during 2014 showed good agreement, below 1 ns. Project 1156 has achieved its aims, a final report will be prepared soon for successful closing of the project.

Project 1152, led by GUM (PL) on studies of GPS receiver performance in dependence on environmental parameters. Results from GPS receiver comparisons studied in the project (currently receivers in BEV, UFE, GUM, SP, PTB) have been presented. GUM reported on progress during year 4 of the project, and showed a range of anomalies that have been observed in the long-term GPS receiver comparisons, including jumps of various sizes. Annual variations in the TTS2 – GTR50 difference were found to correlate strongly with the outside temperature, and point towards the GTR50 antenna being the source of the problem. Other results from PTB indicate a jump of around 3 ns in the GTR50 data. GPS receiver drifts of 2 ns or more over a few years are not unusual. Next steps in the project will include preparing a short preliminary report, and if possible extending the monitoring to use PPP results.

Project 1146, led by IPE (CZ) on time transfer using optical fibers.
This project was initially launched as a bilateral project. The work done in this project is one part of the activities continued now in the frame of NEAT-FT. In the TC-TF 2014 meeting, BIPM present a activity plans for incorporating fibre time transfer links in the generation of UTC. She highlighted the existing permanent and temporary links, and the wide range of methods in use. Data from the AOS-GUM link has been reported to the BIPM since May 2013 and others (eg. BEV-TP) are expected to be operational soon. Free data formats will be accepted until the CCTF decides on a standard format, with the Working Group (WG) on ATFT appearing to be the most appropriate place to propose recommendations on formats, methods and coordination.

Project 1130, led by NPL (UK) on GPS disciplined oscillators. The objective is to produce a EURAMET Calibration Guide on the use of GPS disciplined oscillators as reference standards for frequency or time in calibration laboratories. Document preparation started as a EURAMET project in 2009. Unfortunately, at a very late stage of the production of the "final" version in late 2012 TC-TF faced opposition against the content and mandatory or recommended initial calibration was discussed by delegates on 2013 TC-TF.
The project has been continuing for a number of years, but the guide is now complete, but one point still needs to be resolved. NPL will circulate the latest version to all delegates for comment, then complete any remaining revisions and submit guide to the EURAMET secretariat for publication.

3. Comparisons

EURAMET Project 1288, led by MIRS on time interval comparison and cable delay measurement. This project is a second stage of the EURAMET TF.TI-K1 project 828 related to the comparison of time interval (cable delay) measurement. In the TC-TF 2015 meeting, MIRS give a short report on recent developments. Prototype of the fibre-based time interval standard, with 20 ns, 50 ns, 200 ns delay was developed. The next stage of the project is to determine which labs are interested in participating in a new comparison and how best to set up a campaign.

For many years the BIPM Time Department had organised international calibration campaigns for the GPS and more recently GLONASS receivers used by many laboratories for the inter-comparisons of their atomic clocks, which allow them to participate in the only time and frequency key comparison, CCTF-K001.UTC. Recently the BIPM Time Department prepared "BIPM guidelines for GNSS equipment calibration" master document. This master document is discussed on TC-TF 2014 and new activity related comparison of GNSS receivers started in this year. This work is very important for improvement of type B uncertainty with targeting value 2-3 ns in time scale generation which is given in the Circular T published by the BIPM.

In the TC-TF 2015 meeting responsibility of pilot laboratories at RMO's specified in BIPM Guidelines for GNSS calibrations was discussed. ROA, PTB and LNE will be pilot G1 laboratories (the primary nodes in each RMO) for EURAMET GNSS equipment calibration projects. In contrast, TWSTFT calibrations are coordinated by the CCTF WG on TWSTFT, and guidelines being prepared by the WG and BIPM are expected to be approved this year.

4. CMCs

At the last TC-TF meeting, frequency instability measurements at averaging time >1000 seconds, the range of measurements and expression of uncertainty was discussed. Kenneth Jaldehag reported briefly on his experience reviewing a CMC table from KRISS, Korea. A particular concern was a cable delay measurement capability of 100 ps claimed in the supporting analysis document, which was however not challenged as it was not a significant contribution to the derived CMCs. Peter Whibberley from NPL commented on some issues that arose from a review of revised CMCs from NIM, China. Within the TC, there are 4 delegates who carry out CMC reviews (Andreas Bauch, Peter Whibberley, Anton Niessner, Kenneth Jaldehag), and this year there has been review of CMCs submitted by INTI (SIM.TF.12.2014) of Argentina, TL (APMP.TF.13.2014) of Taiwan, SNM - INDECOPI (SIM.TF.9.2014) of Peru, ICE (SIM.TF.11.2014) of Costa Rica, INM (SIM.TF.10.2014) of Colombia, COOMET.TF.7.2014 of Kazakhstan. In general, the process of the inter-RMO review of CMCs was noted as smooth and cooperative. The support of the JCRB Secretariat at BIPM is greatly appreciated.

5. Activities of the Sub-Committees

TC-TF has no sub-committees.

6. Participation in EMRP

List of EMRP projects in TC-TF is given below:

IND14, New generation of frequency standards for industry
SIB02, Accurate time/frequency comparison and dissemination through optical telecommunication networks
SIB04, High-accuracy optical clocks with trapped ions
IND55, Compact microwave clocks for industrial applications
SIB55, International timescales with optical clocks
SIB60, Metrology for long distance surveying
EXL01, Quantum engineered states for optical clocks and atomic sensors

Project results presented at the 2015 TC-TF meeting.

Short new information about EMRP projects are given below:

IND14, Frequency - New generation of frequency standards for industry, Coordinator Patrick Gill (NPL)

Key Deliverable:

- Robust and compact optical source with a frequency instability of 5×10^{-15} at 1 – 100 s
- Microwave standards with frequency stability and accuracy in the 10^{-10} - 10^{-13} range

The project completed in August 2014 and good progress has been made on each of the 4 work packages (WPs). WP1, led by METAS, covered the development of compact wavelength standards using acetylene-filled hollow-core fibre. Under WP2, a highly stable cubic cavity developed at NPL has been mounted in a temperature-stabilised vacuum chamber designed by PTB. WP3 investigated methods for low-noise microwave synthesis from compact femtosecond combs, and WP4 included studies of laser-cooled Rb atoms trapped on a chip at OP/SYRTE and of CPT in a Cs-filled hollow-core fibre at NPL as potential microwave frequency standards.

SIB02, NEAT-FT - Accurate time/frequency comparison and dissemination through optical telecommunication networks, Coordinator Harald Schnatz (PTB)

The aim of the project 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 fiber links.

VSL reported on progress with this project, which aims to extend capabilities for both frequency and time transfer over fibre links. Under WP1, a range of equipment has been developed for use in very high stability frequency comparisons, including regenerative amplifiers, compact stabilized lasers and multi-user distribution schemes. WP2 covers implementation of long-haul links between PTB, MPQ, OP and NPL, and from INRIM, and these should be operational before the end of the project. A novel time transfer technique has been developed by NPL under WP3, based on transmission of a section of a femtosecond comb, and has produced good results. WP4 addresses long-distance comparisons, including a trial of a 1000 km White Rabbit link by MIKES and the well-established link between Prague and Vienna, as well as development of the AGH system under a REG. VSL has demonstrated WR over a 137 km single fibre, locking a Rb oscillator at the end point, then returning the signal. When the signal was looped back in the same fibre an expanded uncertainty of 7 ns was achieved, limited mainly by correction of the dispersion due to 2 wavelengths being used, and a stability of 30 ps at 1 day.

SIB04, Ion Clock - High-accuracy optical clocks with trapped ions, Coordinator Ekkehard Peik (PTB)

This JRP addresses the development of ultra - precise optical clocks using laser - cooled trapped ions. The combination of laser cooling and ion trapping provides an ideal spectroscopic system that permits the observation of unperturbed atomic frequencies, thus laying the foundation for atomic clocks of the highest accuracy. The realization of the unit of time plays a central role within the SI because of its unequalled precision and because it is also used in the realizations of other units, such as the meter, volt and ampere.

In WP1, PTB and NPL have constructed new micro trap designs and demonstrated their operation. CMI have developed an improved resonator design in WP2, and MIKES is working on an improved vacuum

enclosure for its resonator, currently being vacuum baked before evaluation. MIKES have also developed DFB laser sources for its Sr+ ion trap. Under WP3, CMI have developed a finite element model for ion trap heating that has already been used by PTB, and the dominant shifts have been evaluated. WP4 includes new Cs-referenced measurements of the Yb+ and Sr+ quadrupole and the Yb+ octupole transitions from both PTB and NPL. The uncertainty of the Yb+ octupole transition has been evaluated to be only 3.3×10^{-18} when using the hyper-Ramsey method to greatly reduce the light shifts, and a similar value should be achievable in Sr+. A direct comparison between the Yb+ quadrupole transitions realized at NPL and at PTB was carried out in October 2014, at the same time as the ITOC broadband TWSTFT trial period, so that link results were available from that method as well as GPS PPP. Analysis is continuing, but it appears that the PPP and BBTW methods have similar stabilities.

IND55, MCLOCKS - Compact microwave clocks for industrial applications

- JRP Coordinator: S. Micalizio, INRIM
- Partners: UME (TR), SYRTE (FR), UFC (FR), Université de Neuchatel (UniNe-LTF), Switzerland, CNRS (FR)
- This JRP is supported by the following stakeholders:
- Spectratime, DGA, CNR, Spectracom, Thales Electron Devices SAS,
- Thales R&T, CSEM, METAS, Selex Galileo, Italian Space Agency (ASI)
- Duration 3 years, started 2013
- Aim: Development reliable and hand-held standards for wide industrial applications
- Sectors: Telecommunication networks, satellite navigation, research
- Output: development of compact and high-performing microwave clocks based on the vapour-cell technology

Key Deliverable:

- Robust and compact, optimizing size, reliability and suitability to operate in industry
- To offer better accuracy
- Realization of hand-held clock with frequency stability in range 10^{-10} - 10^{-12} at 1 s

Aim of the Mclocks project to develop novel types of microwave clock with performance comparable to masers, but at a significantly lower cost. Several types are being investigated. Under WP1, a Rb cell clock based on pulsed optical pumping with a microwave Ramsey detection scheme is under development. WP2 covers development of an alternative type of POP Rb cell clock, but using optical detection. Good results have been obtained using an existing cavity magnetron, but a more compact magnetron is under development. Another Rb clock is being developed in WP3, based on cold Rb atoms ("Rubiclock"), and incorporating a tunable cavity and a compact laser system using frequency-doubled telecoms lasers. WP4 covers the development of a Cs vapour cell clock based on coherent population trapping (CPT), which will result in a more compact design than the Rb devices but with lower performance. Current effort is focused on developing a more compact physics package and a smaller, higher performance optical system. In addition, an improved synthesis chain is being designed for use with all of the clock types. Environmental, mechanical and EMC testing of the clock designs will be carried out under WP5, mainly by UME.

SIB55, ITOC - International timescales with optical clocks, Coordinator Helen Margolis (NPL)

- Partners: CMI (CZ), PTB (DE), MIKES (FI), LNE (FR), OBSPARIS (FR), INRiM (IT), LUH(DE), CNRS (FR), UPMC (FR),
- Duration 3 years, started 2013,
- Aim: Tackle key challenges before any future optical redefinition of the second,
- Sectors: International metrology community,
- Output: The possibility of a future redefinition of the second in terms of an optical transition frequency.

WP1: Local frequency comparisons and absolute frequency measurements,
WP2: Frequency comparisons using transportable optical clocks,

WP3: Relativistic timescales and geodesy experiment,
WP4: Remote clock comparisons via satellite links and analysis for timescale.

Key Deliverable:

- Comparison at 10^{-17} - 10^{-16} level,
- Future optical redefinition of the second.

The JRP covers a range of activities in support of an optical redefinition of the SI second and the use of optical clocks in time scales. Absolute frequency measurements of Sr lattice clocks have been made at PTB and OBSPARIS, and clock transitions observed in new lattice clocks at INRIM and NPL as well as the transportable Sr lattice at PTB. Available results have been fed into the new frequency ratio analysis software, which is performing well. A 7-day trial of 20 Mchip/s TWSTFT was carried out successfully between 4 labs in Oct 2014; the results are still being analysed but have showed stabilities significantly below $1x10^{-15}$ at 1 day. Analysis of relativistic effects in TWSTFT and in time & frequency transfer using both fibre links and portable clocks has been pushed to higher accuracies. Under a REG (Researcher Excellence Grant), the University of Hannover has carried out campaigns of gravity potential measurements at all of the optical clock sites, and planning is continuing for a proof-of-principle demonstration later in 2015 of the use of optical clocks to determine the gravitational potential difference between two locations in Italy.

SIB60 Surveying: Metrology for long distance surveying, Coordinator Florian Pollinger (PTB).

The aim of this project is improvement and comparison of distance measurement by laser and GNSS receivers with mm uncertainty, traceable to definition of meter.

Project is important for improvement and understanding of the uncertainties in GNSS-based distance measurement between two receivers, looking at factors such as antenna phase centre offsets, multipath and local oscillator performance. A model developed by University of Hannover has been modified by PTB for this application. Under a REG, the University of Bonn has carried out a number of antenna calibrations and developed components for use in antenna testing. PTB measured phase plot for a Leica antenna, and demonstrate importance of the antenna phase centre (APC) coordinates in achieving the 3 cm accuracy (equivalent to 0.1 ns) proposed by the CTF WG CGGTTS in its new guidelines. Recent results from PTB have shown discrepancies between 2 antennas that have not yet been explained. Andreas also described the methods installed for frequency and time distribution between buildings at PTB, and noted a 0.8 ns discrepancy between a simple modulated time transfer method and time transfer using Satre modems at both ends.

EXL01, QESOCAS - Quantum engineered states for optical clocks and atomic sensors, Coordinator Sebastian Bize (SYRTE).

The stability of optical atomic clocks is currently limited by two factors which are the frequency noise of the laser used to probe the atomic system and the quantum projection noise that arises when detecting the state of this system. The JRP addresses these key factors that hamper progress towards uncertainties at the 10^{-18} level. Such performance in hand would be beneficial to most major applications of clocks and open the possibility of new applications. To tackle these two noise sources, in the JRP the possibility offered by quantum mechanics to create and exploit entangled states shall be investigated, showing quantum correlations between multiple atoms or ions, and to detect these states in a non-destructive manner. These states are referred to as Quantum Engineered States.

The project aim is to investigate how quantum engineered states (QES) can improve optical clocks and atomic sensors, reducing noise and improving accuracy and sensitivity. Under WP1, led by PTB, a range of methods are being studied to prepare QES by interactions in atoms and ions. OBSPARIS has demonstrated trapping of Sr atoms in WP2, while WP3, led by NPL, includes a range of studies of spectroscopy and clock operation using QES.

7. Meetings

The 2015 TC-TF meeting was at the Bundesamt für Eich- und Vermessungswesen (BEV), Wien, Austria Dutch Metrology Institute (VSL), Delft, Netherland on on 17th and 18th of March 2015. At this meeting, we discussed EURAMET projects, EMRP projects, BIPM guidelines for GNSS equipment calibration master document, CMCs and other new projects. The next annual meeting of the EURAMET Technical Committee for Time and Frequency to be held in MIKES.

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