TC-TF Annual Report to the 2014 GA

24 May 2014

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 917, Calibration of time-stamp appliances, (Coordinator: UFE/IPE)
Project 1017, Workshop for EURAMET T&F laboratories, (Coordinator: METAS)
Project 1018, Cooperation of European NMIs t&f laboratories in EMRP/A169 project calls, (Coordinator: MIRS/SIQ)
Project 1130, Preparation of a EURAMET guideline for the assessment of calibration laboratories using GPS signals for frequency and time traceability, (Coordinator: NPL)
Project 1146, Time Transfer using optical fiber links, (Coordinator: UFE/IPE)
Project 1152, GNSS receiver performance monitoring,(Coordinator: GUM)
Project 1156, GPS link calibrations in support of CCTF-K001.UTC, (Coordinator: ROA)
Project 1288, Time interval comparison Pilot Study, (Coordinator: MIRS)

Project 917, 1017, 1018 are started many years before and after discussion on TCTF 2014 meeting this projects are closed and final report will be send to EURAMET secretariat.

The work for the following projects is ongoing:

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 and submits to the EURAMET secretariat for publication.

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.

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 after year 3 of the 4-year project. One anomaly in the comparison between 2 receivers has been traced to differences in their handling of ionospheric delays. Other anomalies observed in the GPS receiver data were described. Steps of 12.5 ns seen in some TTS-4 data are likely to be due to cycle slips of the internal 80 MHz frequency. The aims now

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are to extend the analysis by using the PPP method, and to prepare a preliminary report on the results obtained so far.

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 summarised the BIPM proposals, including type B uncertainties for UTC links set by the BIPM and increasing with the age of the calibration.

3. Comparisons

New EURAMET Project 1288, led by MIRS on time interval comparison and cable delay measurement. This project started this year and will be very important for uncertainty analyses in time interval and cable delay measurements. This project will be the second stage of the EURAMET TF.TI-K1 project 828 related to the comparison of time interval (cable delay) measurement.

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 will be start 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.

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 commented on some issues that arose from a review of revised CMCs from NIM, China. In addition, the review of SIM.TF.8.2013 CMC was done by Andreas Bauch and Ramiz Hamid. Within the TC, there are 4 delegates who carry out CMC reviews (Andreas, Peter Whibberley, Anton Niessner, Kenneth Jaldehag), and this year there has been only one review, of CMCs submitted by Peru, which was carried out by Andreas.

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:

2010 call:

IND14, New generation of frequency standards for industry

2011 call:

SIB02, Accurate time/frequency comparison and dissemination through optical telecommunication networks
SIB04, High-accuracy optical clocks with trapped ions

2012 call:

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

Some of the projects were presented at the last TC-TF meeting and also information about this project is given in the last TC-TF chair report for 2012/13. Project results will also be presented at the 2014 TC-TF meeting.

Short new information about EMRP projects are given below:

2010 call:
IND14, Frequency - New generation of frequency standards for industry

- JRP Coordinator: Patrick Gill, NPL
- Duration 3 years, started August 2011
- Aim: Transform NMI-based standards into compact, robust and turn-key standards for industrial applications
- Sectors: Telecoms, aerospace, navigation, defence and security
- Output: Optical and microwave frequency standards
- WP1: New compact hollow-fibre-based optical wavelength standards,
- WP2: Compact, vibration-insensitive and transportable optical local oscillators
- WP3: Low noise microwave synthesis from compact optically-referenced fs combs
- WP4: Atom-referenced microwave standards

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 will finish in August this year and good progress has been made on each of the 4 work packages (WPs). WP1, led by METAS, covers the development of hollow-core fibre (HCF) wavelength standards. The Spanish company CSIC is investigating two types of acetylene-filled fibre while DFM (Denmark) has developed an HCF-based acetylene fibre laser and is evaluating its performance, and METAS has constructed a high pressure acetylene filling system. In WP2, NPL has developed a highly stable cubic-spacer optical reference cavity, which is mounted in a compact frame designed at PTB. Under WP3, methods for low-noise microwave synthesis from compact femtosecond combs have been developed at NPL and at OP. The remaining WP covers atom-referenced microwave standards, and has included studies at OP/SYRTE of laser-cooled Rb atoms trapped on a chip, as well as work at NPL on a Cs-filled HCF using coherent population trapping.

2011 call:
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 fibre links.

VSL reported on progress with this project, which aims to extend capabilities for both frequency and time transfer over fibre links. WP1 investigates high-stability frequency transfer methods, including development of optical amplifiers. WP2 aims to demonstrate long distance fibre links, with trials over 1800 km between MPQ and PTB. Instability below 1E-18 has already been demonstrated at 100 s. Construction of the PTB-OP link is on schedule. In WP3 a time transfer method is being developed based on a modulated comb within a single 100 GHz ITU channel. WP4 covers demonstration and evaluation of a range of methods for 1-way and 2-way time transfer over fibre networks, with the focus now on the more promising 2-way methods. Erik showed results from White Rabbit over a 950 km all-optical backbone DWDM link in Finland, demonstrating <2 ns error over 60 days by comparison with GPS PPP (but with a 1.8 us offset due to asymmetry between the out and back fibres that was removed by GPS calibration). A link is being constructed between VSL and VUA (Amsterdam) that will use 2 channels (1470 and 1490 nm) over a single fibre. AGH in Poland is also participating in the project through a REG.

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. “Hyper-Ramsey’ method demonstrated at PTB, which promises a substantial reduction in the light shift in Yb+ traps. Direct optical frequency comparisons at PTB have been made with uncertainties below 1E-17.

<u>2012 call:</u>
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

At last TC-TF Coordinator of this project Salvatore Micalizio presented an overview of the Mclocks project, which aims to develop novel types of microwave clock with performance comparable to masers

but at a significantly lower cost. Several types are being investigated. A pulsed Rb cell clock with either microwave or optical detection is under development, with current work including a more compact magnetron cavity design and a compact DFB-based laser system. A second design is based on cold Rb atoms ("Rubiclock"), developed from the SYRTE "Horace" design, but incorporating a tunable cavity and a compact laser system using frequency-doubled telecoms lasers. Another WP is developing a Cs 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. Salvatore will present a tutorial on vapour cell clocks at EFTF in June.

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

The possibility of a future redefinition of the second in terms of an optical transition frequency is being considered by the international metrology community. Nearly all information about the reproducibility of optical clocks comes, however, from independent absolute frequency measurements made in different laboratories, and is therefore limited by the uncertainty of the Cs primary standards. The work carried out within this JRP shall significantly improve upon this current state of the art by carrying out a tightly integrated program of frequency comparisons between European optical clocks at a level limited only by the accuracies of the clocks themselves. In this way a framework and procedures shall be established whereby the optical clocks can be integrated into international timescales. This JRP thus addresses the key steps that must be carried out before a redefinition of the second can occur, and will allow European NMIs to play an influential role in international debates on this matter

- JRP 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 project will investigate how optical clocks can be incorporated into international time scales, making full use of their steadily improving performance. A core activity will be to determine optimal values for optical clock frequencies, based on ratios between optical frequencies as well as absolute frequency measurements against caesium fountains. WP1 involves a series of local frequency measurements, while WP2 covers measurements using two transportable standards: a Sr lattice under development at PTB and an Sr+ ion trap being constructed by MIKES. Under WP5, a campaign of frequency comparisons between the clocks at INRIM, NPL, OP and PTB will be carried out by means of broadband (20 Mchip/s) TWSTFT, to obtain the best achievable stability. A 1-week trial period in late 2014 will be followed by the main measurement period over 21 days in 2015. The results of all these optical frequency ratio and absolute frequency measurements, together with all other available data, will be analysed using a matrix formalism to obtain the optimal values. In addition, other work packages are addressing relativistic effects in time and frequency transfer, and (through collaboration with the University of Hannover) determining the gravity potentials at all of the clock locations. This work will support a proof-of-principle experiment in 2015 to demonstrate that optical clocks can be used to determine the gravitational potential difference between two locations.

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.

At last TC-TF Julia Leute from PTB discussed WP2 of the project, which aims to develop a better understanding of the uncertainties in GNSS-based distance measurement. The aim is to study the uncertainties by removing some influences and evaluating others, for example by using common clock links. A test facility has been set up at PTB using two GNSS antennas calibrated by Univ. Hannover installed 5 m apart, linked to UTC(PTB) by fibre. At present one Leica antenna is feeding 4 Javad receivers, two linked to UTC(PTB) and two to a Rb standard, to investigate the instabilities due to the reference clock.

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. Preparation of QES by interactions in atoms and ions is investigated in WP1 (PTB) and by measurement in WP2 (SYRTE), while WP3 (NPL) will study spectroscopy and clock operation using QES.

7. Meetings

The 2014 TC-TF meeting was at the Dutch Metrology Institute (VSL), Delft, Netherland on 17th and 18th March. At this meeting, we discussed EURAMET projects, EMRP projects, BIPM guidelines for GNSS equipment calibration master document, CMCs and other new projects.

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UME,
May, 2014