**REPORT OF THE 22nd MEETING OF THE**

**CCTF WORKING GROUP ON TWSTFT**

15-16 September 2014, Mendeleev, Russia

Reporter E. Dierikx

Edited by Z Jiang

The 22nd meeting of the Consultative Committee for Time and Frequency (CCTF) Working Group (WG) on Two-Way Satellite Time and Frequency Transfer (TWSTFT) was held on 15 and 16 September 2014 in Mendeleev, Russia. The WG meeting was co-organized by VNIIFTRI and the BIPM and was chaired by the chairman of the working group, Dirk Piester from PTB.

All contributions to the meeting are available on the BIPM TWSTFT restricted access website: <http://www.bipm.org/wg/CCTF/WGTWSTFT/Restricted/welcome.jsp>. User name / password are as usual, if you forgot the log in details, please contact to zjiang@bipm.org.

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# Agenda

1) Welcome speech (Director of FSUE VNIIFTRI ‐ Sergey Donchenko)

2) Laboratory reports:

 AOS (Jerzy Nawrocki), METAS (Christian Schlunegger), NIM (Aimin ZHANG, given by Zhiheng JIANG), NIST (Judah Levine), NTSC (Wenjun WU), PTB (Dirk Piester), SP (Kenneth Jaldehag), TL (Calvin Lin), VNIIFTRI (Andrey Naumov), VSL (Erik Dierikx)

3) Network status:

3.1) Status of Europe – USA links (Judah Levine)

3.2) Status of Asian Network (Calvin Lin)

3.3) Status of the Eu‐Asia link (Dirk Piester)

4) TWSTFT calibrations:

4.1) 2014 USNO – PTB calibration (Dirk Piester)

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5) Developments

5.1) GNSS carrier‐phase time transfer on short baselines in real time mode (Ivan Skakun)

5.2) Time domain measurement standards (David Allan)

5.3) Proposals on modifications of TWSTFT data file names and data file’s header (S. Bolginova, N. Koshelyaevsky)

5.4) Some considerations on the TWOTFT (Erik Dierikx)

5.5) Status report on European broadband TWSTFT experiment (Dirk Piester)

5.6) A software defined TW receiver (Calvin Lin)

6) TAI calibrations:

6.1) Global Triangle Network Calibration (Zhiheng JIANG)

6.2) A standard procedure for the TWSTFT link calibration for UTC:

 a) Some considerations in the past and future calibrations (Zhiheng JIANG and Felicitas ARIAS);

 b) Requirements for the labs and the status of the labs participating in the calibration campaigns

7) Discussions

8) VNIIFTRI Laboratory visit

# Summary of the meeting

## 1) Opening of the meeting

***15 Sept. 2014***

Welcome speech from the deputy director of FSUE VNIIFTRI.
(The director ‐ Sergey Donchenko - is excused because of other obligations.)

The chairman expresses thanks on behalf of the WG to VNIIFTRI for organizing this meeting and for providing the accommodation. Special thanks are expressed to Andrey Naumov for all the preparations.

E. Dierikx is named as the reporter and will prepare the minutes of the meeting.

There are no comments on the agenda and time schedule that have been circulated in advance.

All participants in the meeting shortly introduce themselves.

**Technical Program:**

## 2) Laboratory status reports

### • AOS (Jerzy Nawrocki)

- The AOS TW station was visited by the mobile station from TimeTech for a calibration trip in May 2013. In the same trip measurements with the mobile station were performed at TIM, VSL and ESTEC.

UTC calculations are based on the time links of UTC(k) with respect to UTC(PTB). Since PTB was not included in this trip there is no calibration results for the link AOS-PTB.

AOS suggests that this situation should be restored by including AOS in the next calibration trip of the mobile station in which also PTB is included.

The discussion on this issue is continued under point 4.5 of the agenda.

- The AOS TW station has a problem with the KST transceiver. It failed during a day with high outside temperature. The KST transceiver has failed already 2 times before.

- Optical time links in Poland

TA(PL) is composed of clocks from GUM and 7 other institutes. Three of these other institutes are connected to GUM by an optical fibre time transfer links. These time links are operated in a dedicated network of dark fibres. For the realization of these optical time links, a collaboration of several organizations was started under the name OPTIME.

Suggestions are proposed for further improvement of the time link stability.

### • METAS (Christian Schlunegger)

- TW operation during the last year was interrupted a few times as a result of technical problems: water in a waveguide, broken connector and a problem with the down converter.

In the summer of 2014 the results of UTC(CH) are more noisy than before. As a result of a problem with the H maser, the CH timescale was temporarily based on a Cs clock.

- Experiments have been performed to characterize the delays of the equipment in the TW station. With this information delay changes in the station can be verified after replacement or repair of equipment. To determine the delays, several "ranging" loops were created to measure parts of the system. These delay measurements are not automated, loops are created manually.

- The access to the METAS FTP server will be protected by username and password. Also the transfer protocol will become SFTP. It is not exactly known when this change will happen. Participants who use this data will be informed.

- In November 2012, the TW station of METAS was visited by the TimeTech mobile station in a calibration trip. So far, the results of this calibration have not yet been implemented in the calculation of UTC. There is a question to Z. Jiang from BIPM what procedure should be followed. (This discussion was continued under point 6.2 of the agenda.)

### • NIM (Aimin ZHANG, given by Zhiheng JIANG)

- In June 2014, NIM was visited by the BIPM travelling standard for calibration of the TW and GNSS links between NIM and PTB by means of MEasurement of TOtal DElay (METODE). NIM implemented the new CALR value for TW.

- Results are shown from the links PTB-NIM, NICT-NIM, TL-NIM.

- Next year NIM will work on a temperature control for the converter unit and SSPA.

### • NIST (Judah Levine on behalf of Tom Parker and Victor Zhang)

- Studies have been performed on diurnals. Diurnals are observed in the links PTB-NIST and OP-NIST, but not in PTB-OP via NIST.

From these and previous observations, it is expected that the diurnals are not caused by changes in the environment of the stations. They could be caused by satellite motion, temperature effects in the satellite transponder or variations in ionosphere or troposphere.

Despite the diurnals in the link PTB-NIST, the results of the link USNO-NIST via PTB seem pretty well.

- Calibration of station delays

After changing from the primary timescale to the backup time scale, an unexpected difference was observed. Therefore, investigations have been made of internal delays. The problem has been found. (No problems were discovered in the SATRE modem.)

### • NTSC (Wenjun WU, Li Huanxin and Zhang Hong)

National Time Service Center (NTSC) of the Chinese Academy of Sciences is an institute which is mainly engaged in research and service on time & frequency and GNSS.

Timekeeping is realized by 34 cesium clocks and 6 active H-masers.

NTSC has 3 TW stations:

NTSC01 is not operational

NTSC02 is used for the Asia-Europe links on satellite AM2. From June 2012 this station is operated with a SATRE modem at 2.5 Mcps.

NTSC03 is used in the C-band for domestic links via a Chinese satellite. This station also uses a SATRE modem.

NTSC expresses the intention to pay two months of the transponder lease of AM2

Z. Jiang remarks that the NTSC02 station does not report data for the links with SU and NPLI.

### • PTB (Dirk Piester)

In the framework of EMRP projects, two Ph.D. students have joined the Time Dissemination Group: J. Leute works on GNSS measurement, and F. Riedel on broadband TW.

E. Benkler and A. Hoppmann have also (part time) joined the group.

The activities of this group are:

- Realisation of UTC(PTB),

- Dissemination by LF transmitter (DCF77), NTP servers and telephone time service

- Remote Comparisons by GNSS and TWSTFT

UTC(PTB) is realized from an active H-maser and is steered by a phase micro stepper, based on daily comparison with CsF-1 and CsF-2 or with CS1, CS2 and 5071s for backup.

PTB has 4 TW stations:

PTB01 is used for the link to EU and US laboratories via T-11N

PTB03 is used for the link to Asia and Russia via AM2

PTB04 is a spare Ku-band station, use previously for TWSTFT carrier phase experiment.

PTB05 will in the future replace PTB01. It is nearly complete. First it will be used for a broadband (20 Mcps) TWSTFT experiment in the EMRP ITOC project.

The realization of a new location for an antennae ensemble is almost complete.

### • SP (Kenneth Jaldehag, Carsten Rieck)

At SP, TWSTFT is considered as a production facility and therefore there is not much research here.

- The SATSIM is currently not used; a new SATSIM antenna is needed.

- Temperature, humidity and pressure data have been included in the ITU-files (again).

- In August 2013, PTF1 and PTF2 were included in the schedule.

- In July 2014, SP was included in the calibration campaign with the mobile station within the ESA Galileo TGVF project.

Studies have been performed on diurnals and closures

A Kalman filter implementation is used to study either post-process data from ftp-servers or real-time data as provided by ROA, PTB, NIST and SP through UDB.

Estimates are made of: diurnals, time scale differences and triangle closures.

New studies also include 2-minute data downloaded from the BIPM FTP-server.

Several examples of analyses and statistics are shown in graphs.

The intention is to make the results of this analysis externally available on a webpage with a user-friendly interface; may-be on monthly basis.

*SP is asking permission from BIPM to download available data from the FTP-server and from participating stations to use their data for this analysis.*

Z. Jiang says that BIPM has no restrictions (expect that only BIPM can publish UTC).

From the participants present in the meeting, there are no objections on the use of their data.

To ask permission from laboratories that are not present, SP will send an e-mail.

### • TL (Calvin Lin)

TA(TL) is based on an ensemble of 12 high performance Cs clocks (5071A).

Furthermore, TL has 4 active H-masers: 2x Kvarz CH1-75, 1x iMaser-3000 and 1x Microsemi MHM-2010. UTC(TL) is based on the iMaser-3000 and is steered by an AOG-110.

TL has 4 TW stations:

- TL01: Asia-Pacific links via EutelSat 172A, in Ku band, with NICT modem has stopped operation.

- TL02: Asia-Europe links via AM2, in Ku band with SATRE modem. This link has been calibrated by the BIPM METODE travelling standard and implemented in April 2014.

- TL03: Test/Backup station, in Ku band, currently used for software defined receiver.

- TL04: Hawaii-US link via EutelSat 172A, in Ku band with SATRE modem. (Data from USNO on this link has not been available from July 2014)

Results of the links PTB-TL and NICT-TL have been analysed by comparison with respect to GPSPPP results. In the links PTB-TL and NICT-TL, starting from MJD 56780, discrepancies up to 2 ns are observed between the TW links and the GPSPPP links. An explanation has not been found so far.

Research and future work will be done on: the Software defined receiver, UTC link calibration by BIPM METODE and a new lab for optical fibre time transfer.

### • VNIIFTRI (Andrey Naumov)

UTC(SU) is realized from a set of 8 active H-masers CH1-75A. Steering is done with respect to a Cs fountain. CsFO1 is operational, CsFO2 is under development.

VNIIFTRI has one fixed TW station SU01 and a mobile station SU02.

SU01 is used for Europe and Asia links via AM2 in Ku-band with a SATRE modem

In April 2014, the KST2000a transceiver failed; it was replaced in July. The station is equipped with a SATSIM, but currently there is a problem in loop 7.

In September 2013, 3 temperature sensors have been installed with automated alarm function.

(Dallas semiconductor sensor DS18B20; accuracy ±0.125 °C; range -55 to 125 °C)

Results of the link SU- PTB have been analysed. After replacement of the KST, there are more variations in the Rx power. Effects from diurnals seem to be larger in summer than in winter.

The mobile station SU02 is also pointed at AM2 in Ku-band and uses a SATRE modem.

In SU02, temperature sensors have been installed as well.

In July and August 2014, SU02 was used for a timescale comparison UTC(SU)-UTC(GEO-ZUP) for GNSS.

Zero baseline measurements between SU01 and SU02 have been analysed. Diurnal effects of 2ns are observed. Last year it was less. Rx Power levels also vary diurnally. This is probably related to the inclined orbit of satellite AM2.

### • VSL (Erik Dierikx)

UTC(VSL) is still based on 4 high performance Cs clocks (5071A).

VSL has one TW station for Europe and US links on T-11N.

Early this year, the LNA had to be replaced after water leakage.

Developments on the new version of the SATSIM have been on a low level. Experiments with a new SATSIM antenna (on loan from TimeTech) have been successful.

A new SATRE modem has been purchased and will be installed after the measurement software has been updated to support the 2 Rx channels. Meanwhile this new modem is used for experiments in a set-up for GNSS antenna cable delay calibration and in the development of a home-built up-converter.

## 3) Network status

### 3.1) Status of Europe – USA links (Judah Levine)

The contract with RiteNet Corp. for lease of transponder bandwidth on T-11N is continued. We are now in option period 3 (July 27, 2014 to July 26, 2015) and after this period we have the option to renew the contract for one more year. The transponders and bandwidth will stay the same.

After July 26, 2016, a new contract will be required. Since it is rather complicated at NIST to renew contracts, it is recommended to start contract negotiations early: about one year in advance.

### 3.2) Status of Asian Network (Calvin Lin, Miho Fujieda)

- Link Asia-Hawaii-USNO: Satellite Eutelsat 172A, bandwidth 2.5 MHz, SATRE modem, to connect NICT and TL to USNO. (No data from USNO is available from July 2014.)

- Link Asia-EU: Satellite AM2 (operational between 10h~22h UTC), bandwidth 2.5 MHz, SATRE modem, provides TAI links between NICT, NIM, NPLI, NTSC, PTB, TL and VNIIFTRI.

From MJD 56780, the links NICT-TL through satellite AM2 and ES172A give different results up to 2 ns. Also UTC(USNO)-UTC(TL) via AM2 and ES172A give different results.

### 3.3) Status of the Eu‐Asia link (Dirk Piester, Miho Fujieda)

Satellite AM2 is at the end of its life and is in an inclined orbit and will be kept in position till Q4 2015.

The 2nd launch of AM4R failed in may 2014. (V. Palchikov: Next launch will be with the next 3 years.)

The link quality on AM2 is good so far, but effects of the satellite movement are clearly visible in the measurement results: for example Rx power level variations.

M. Fujieda has studied alternative satellites:

- AM4R: A single transponder covers all participants. Waiting for the launch of this satellite may cause a gap.

- Eutelsat70B: 2 transponders will be required. India is in the same beam as EU, so they will not be able to connect with EU. Russia will (probably) not be covered. (VNIIFTRI has to test if they can receive the beacon signal.) Lease of 2 transponders will be expensive. Changing to 1 Mcps could reduce the costs. May-be band pass filters are required. (In EU we don't use band pass filters)

- IS20: Only Germany and Russia are covered.

- ABS2: Only C-band is available. Most stations are not equipped for this frequency range.

The current proposal is: We continue to use AM2 as long as possible and wait for AM4R.

In case a gap occurs before the launch of AM4R, it is suggested to use EutelSat70B as a temporary solution.

*The WG TWSTFT recommends continuing TW operations on EU-ASIA links without significant interruption.*

Arrangements should be prepared on how the costs will be financed by the contributing participants.

## 4) TWSTFT calibrations

*16 Sept. 2014*

### 4.1) 2014 USNO – PTB calibration (Dirk Piester)

In June 2014, the link UTC(USNO)-UTC(PTB) has been calibrated with the USNO mobile X-band station. In this calibration, 4 different hardware (link) configurations were established.

The difference (X-band) - (Ku-band) and (X-band) - (Circular T) have been determined with there corresponding uncertainties. The total calibration uncertainty is 0.64 ns.

New CALR values have been proposed and will be implemented after approval from BIPM.

Z. Jiang remarks that USNO currently uses GPS PPP as official link contributing to the UTC computation.

*Will USNO use TWSTFT as official link after the CALR value have been implemented?*

4.2) 2014 European calibration campaign 2014 in scope of GALILEO TGVF-FOC
(Javier Galindo)

A TWSTFT calibration campaign was carried out in June and July 2014 in the framework of GALILEO. Besides the PTFs in Italy and Germany, INRIM, OP, PTB, ROA and SP were involved.

A total of 26 links have been calibrated: 10 by "link" method, 10 by "site" method and 6 by triangle closure method.

All links to the PTFs were calibrated by the "link" method, because the normal operation of the PTFs can not be disturbed. The mobile station providing the extra link is operated in common clock with the PTF.

Links between UTC(k) labs were base on the standard "site" method.

Links to USNO were calculated by triangle closure, using the result of the USNO-PTB calibration with the portable X-band station.

The stability of mobile station was determined from reference measurements at the fixed station of TimeTech at the start and at the end of the campaign. The difference was 0.37 ns.

The theoretical approach of the "link" method as applied at the PTFs was explained in detail and an example is shown of the new least square fitting approach. The results of the difference between the PTF and the mobile station, linked via the UTC(k) labs agree within about ± 0.5 ns.

For all involved laboratories, new CALR values and corresponding uncertainties were calculated. (The combined uncertainty is 0.8 ns.) Comparing the new CALR values with respect to the old ones, it shows significant discrepancies for the links to INRIM. For the other links, the agreement is within the combined uncertainties.

Finally, for the links between USNO to PTFs and other UTC(k), the calibrations were done by triangle closure analysis, using the result of the calibration of the link USNO-PTB by means of the USNO portable X-band station. Data from MJD 56816 to 56825 was used. The combined uncertainty was calculated and found to be 1.2 ns

The draft report of this calibration campaign has been prepared by ROA and is currently being reviewed by the other participants.

### 4.3) UTC TWSTFT links in and between Europe and Asia (Wenjun Wu)

**The latest METODE (MEasurement of TOtal DEelay) link calibration results**

The concept of the METODE link calibration is explained. With this method, the total delay of a link between two laboratories is calibrated. The sub-delay of equipment is not determined separately. The link delay is determined by co-locating the BIPM traveling GNSS calibrator with each of the stations in the link. The traveling calibrator is connected in a common clock set-up with the TWSTFT station (or the GNSS receiver) of the labs in the link. In the case of calibration of a TW-link between lab k and PTB, the CALR value is determined as follows:

 CALR(k,PTB) = [UTC(k)GNSS\_calibrator - UTC(PTB)GPS] - [UTC(k)-UTC(PTB)]TW

In this calibration, the traveling GNSS calibrator is considered as a black box with 10 MHz and 1PPS input signals as a reference.

From April 2013 until now, the following laboratories have been visited: BIPM, OP, PTB, AOS, TL, NICT, NIM, PTB and ROA.

Next on the list are: NIST and USNO

The stability of the BIPM GNSS traveling calibrator is evaluated by closure computations of the measurements before and after the visited lab. Closure values vary between 0.01 and 0.6 ns.

The total uncertainty of the METODE calibration has been estimated and is between 0.8 and 1.5 ns (1).

The agreement between the METODE calibration as other types of calibration was found to be within 0.7 ns (well within the combined uncertainty).

CALR values of the links PTB - TL and PTB - NICT as determined with the METODE calibration have been implemented in UTC calculation.

### 4.4) Report of mobile station (Wolfgang Schäfer)

The mobile station is connected in common clock configuration at a fixed station through and optical link interface. This optical link reproduces the PPS and 10 MHz reference signals from the fixed station to the mobile station. The performance of the optical link is monitored by a parallel coaxial cable. The 1PPS reproducibility from the optical link is better than 0.2 ns.

The stability of the mobile station has been evaluated by common clock difference CCD(TW) measurements performed at the beginning and at the end of each trip. The results of these closure computations are within 0.5 ns.

Repeated calibrations of the link TIM-PTB show that the CALR value found in 2012, 2013 and 2014 are within ~1 ns.

At the TIM fixed station a time scale is generated from a Cs-clock (5071A) and a clean-up oscillator with frequency steering. The TW-station has a temperature stabilized rooftop chamber. The stability is monitored by SATSIM measurements.

Z. Jiang remarks that the measurements at the TIM fixed station at the beginning and at the end of a trip of the mobile station contribute to the total uncertainty of the calibration. Is their a better way to guarantee the stability of the station?

D. Allan comments that using PPS to define time is not really suitable for achieving uncertainties < 1 ns. It would be better to think of zero crossings of RF signal.

W.Schäfer: This has been considered in the design of the modem. The output of the modem is directly linked to the phase of frequency reference at 5 or 10 MHz. 100 MHz or more would be even better.

### 4.5) 2013 Calibration of VSL, AOS (Jerzy Nawrocki/Erik Dierikx)

In the TW meeting at the EFTF 2014, a discussion was raised about the TW calibration trip performed in May and June 2013, in which VSL and AOS were included, but not PTB.

Considering the single pivot scheme that BIPM uses to compute UTC, calibration of time links to PTB are most important. Preferably, PTB should participate in each trip of the mobile TW station, but for practical reason this is not always possible.

The results of the calibration at VSL and AOS are not useless. They can still be used to compute the calibration of the links VSL - PTB and AOS - PTB. This can be done by combining the results from the trip of November-December 2012 (in which PTB was included) with the results of the trip of May-June 2013. The results of the stability measurements performed at the TIM fixed station show that the delay of the mobile station has not changed (within its uncertainty) between the first and the second trip. Using the average delay of the mobile station from both trips with its combined uncertainty, the calibration of the links VSL - PTB and AOS - PTB can be computed. The uncertainty in these values is about the same as if PTB had been included in the same trip.

To finalize this calibration trip, a document should be prepared describing the linking of the two calibration trips, the computation of the CALR values and the associated uncertainty evaluation. E. Dierikx will prepare a draft for this linking document.

The calibration report with this linking document has to been signed by the involved UTC(k) laboratories and then submitted to BIPM for approval.

W. Schäfer suggests that as an additional check on the stability of the mobile station, also the data from the 2014 trip could be used.

## 5) Developments

5.1) GNSS carrier‐phase time transfer on short baselines in real time mode
(Ivan Skakun: IAC PNT, TSNIIMASH)

To avoid limitations of day boundary jumps in regular GNSS PPP analysis, an alternative analysis for time transfer is proposed. It uses only phase measurements with integer ambiguity resolution and is based on common view comparison. For short baseline comparisons, real-time analyses can be made (because the orbit is not important). For long baseline comparisons, real-time is not possible because orbit products are required.

The analysis has been tested on experimental results from three experiments:

- 0 km baseline measurements performed at VNIIFTRI;

- 40 km baseline measurements between VNIIFTRI and GEO-ZUP;

- 1700 km baseline measurements between VNIIFTRI and PTB.

The GNSS measurements were performed with GTR51 receivers.

At 40 km and 1700 km the GNSS results were compared against TWSTFT results.

Conclusion: the method provides high resolution and solves the ambiguities.

### 5.2) Time domain measurement standards (David Allan)

NIST has recently published a world record for stability of its ytterbium optical lattice clock. There remains a challenge for comparison of this type of clocks over long distances. TWSTFT still has the advantage that the links can be accurately calibrated for time. To improve the stability of frequency transfer TWSTFT should be combined by other techniques such as advanced common view and/or PPP. If GPS can be improved to 1 ns at 1 s sample time frequency comparison at the level of 10-18 can be achieved in 10 days.

5.3) Proposals on modifications of TWSTFT data file names and data file’s header
(S. Bolginova, N. Koshelyaevsky)

- The filenames for the TW quadrature fit data as proposed by ITU-R TF.1153-2 assumes that a laboratory has only one system: TWLLLLdd.ddd where LLLL is an identifier of the laboratory of maximum 4 characters.

VNIIFTRI had a problem to save data from two different stations. Therefore they proposes to add two additional characters to the filename: TWLLLLMOdd.ddd, where M and O are numerical characters or "\_" to identify the station.

VNIIFTRI proposes that a recommendation should be made for this for the CCTF in 2015.

Z. Jiang remarks that this filename convention is under the responsibility of ITU.

A laboratory can report data from two stations in a single file. In each data line, the station ID of the local station is indicated separately. In case it is too difficult to merge the data from two stations into one file, the laboratory can create additional folders on the BIPM FTP server in which the data from the second, third, etc. station can be uploaded.

Alternatively, the laboratory's identifier could be changed to include the station within the 4 characters that are currently allowed.

- The TWSTFT data file header (of the quadrature fit data files) currently doesn't contain information on which signal is used as reference: local UTC(k), local master clock (MC(k)) or even local clock (CL(k)). VNIIFTRI proposes to include information in the data header to which signal the data are referred.

A proposal is presented to replace the third line of the header:

"\* LAB (ABCD)" by "\* REF UTC(ABCD)" or "\* REF MC(ABCD)".

J. Levin comments that for the computation of UTC by BIPM all data in the quadrature fit data file should be referenced to UTC(k).

C. Schlunegger remarks that METAS used to have a paper clock as UTC(CH). The difference between UTC(CH) and its physical realisation is given in the TW 1s-data files. Therefore, the calculation of the TW files was always processed one day later, when the calculate UTC(CH) was available.

It is suggested that a study group should be created to investigate the subject.

*N. Koshelyaevsky is asking for input from the working group how to deal with this issue.*

### 5.4) Some considerations on the TWOTFT (Erik Dierikx)

VSL is working on fibre optic time and frequency transfer in the framework of the EMRP NEAT-FT project. VSL decided to use the White Rabbit (WR) technology developed at CERN and GSI. The first experiments were performed with fibre patches and spools in the laboratory to get familiar with the equipment.

Then, a 135 km link (dark fibre) was defined between VSL (Delft) and NIKHEF (Amsterdam). In fact a double link is created with a loop-back in Amsterdam. A special quasi bi-directional amplifier was installed in the link. This amplifier creates a bi-directional path in the OSC band, just outside the C-band which is uni-directional.

Experiments have start from mid August 2014. The first results show a frequency stability of 2 x 10-15 at 1 day and time stability of 0.1 ns at day averaging.

The WR equipment still needs to be calibrated to determine the total time uncertainty.

Z. Jiang mentions that the work on TF transfer through optical fibres is discussed in a subgroup of the CCTF WG AFTF, chaired by Dr. Feng-Lei Hong.

### 5.5) Status report on European broadband TWSTFT experiment (Dirk Piester)

In the framework of the EMRP ITOC project, a comparison is being set up for optical clocks at INRIM, LNE-SYRTE, MIKES, NPL and PTB. An experiment is being prepared to compare the clock by broadband (20 Mcps) TWSTFT. For this purpose, each laboratory has a dedicated modem and a dedicate ground station. The link will be set up via satellite Astra 3B with a 35 MHz Ku-band transponder. One week in October 2014 is scheduled for testing and then in June 2015, 3 weeks are scheduled for operation.

The measurement schedule will be set up to gather as much data as possible.

Performance tests have been done on the SATRE modem to find the best configurations and combinations of codes to give low jitter.

Still some problems need to be solved at the NPL and INRIM stations, and furthermore some dedicated software need to be developed to run the stations and to post process the data.

### 5.6) A software defined TW receiver (Calvin Lin and Yi-Jiun Huang)

In the quest of find the cause of diurnal variations in TWSTFT links, TL has investigated an alternative receiver. Instead of the SATRE (hardware) modem, TL uses an open loop software defined receiver (SDR). A paper on the SDR has been published at CPEM 2014.

Two versions of SDRs are available at TL: one is based on VSSP 32, made by NICT and another is based on USRP N210, made by National Instruments.

A common clock test has been performed using two stations (TL03 and TL04) via Eutelsat172A. Each station was equipped with a SATRE modem (at 2.5 Mcps with SAW filter in the Tx path) and an SDR in parallel in the Rx path. The results from the SATRE show diurnals of about 0.4 ns. In the results from the SDR, no diurnals are observed.

Then a 3 m baseline with dual clock experiment was set up. The clocks were compared by: a TIC, SATRE modems and SDRs.

Again, clear diurnal were visible in the results from the SATRE modem, and no diurnals were visible in the results from the SDR.

The SDR shows a higher noise level at the short term.

The hardware for the SDR is available. The software for the SDR is open and can be obtain from TL.

## 6) TAI calibrations

### 6.1) A Global TWSTFT Network / Triangle Closure Calibration (Zhiheng Jiang)

In the Europe + US network triangle closure calibrations (TCC) have been used before:

in 2008, in 2009 a bridge + TCC was used for the switch of satellite from IS-3R to T-11N and in 2011 a bridge + TCC was used for the frequency change on T-11N.

The concept is simple: the sum of three links should be zero. If, in a triangle of three laboratories two links are calibrated, the third link can be calculated from the other two.

In 2011 in the EU+US network, there were 11 UTC TW links. 6 of them had been calibrated by a TW mobile station and 5 by GPS calibration. By means of TCC a total of 108 links were calibrated.

In the Asia+EU network, 3 links have calibrated by METODE at present. The TW links to NPLI and NTSC have been aligned to GPS, but these laboratories have not been visited by a mobile station or traveling GNSS receiver.

In the years 2012 to 2014 several TW links have been calibrated by a mobile TW station:

2012/2013: AOS, CH, OP, PTB, VSL

2014: PTB, USNO and IT, OP, PTB, ROA, SP.

So far, none of these link calibrations have been included in the UTC computation. The reports of these calibrations have not been submitted to BIPM for approval.

The TW links from OP, AOS and ROA to PTB have been calibrated by METODE, but also the results are not yet implemented in the UTC computation.

All new calibration values (CALR) in the TW network should be implemented. In some case it may be better to use TCC because this gives a lower systematic uncertainty (uB).

With the implementation of the new CALR values, the ESDVAR value should be reset to 9999/0000 and ESIG is also reset to 0. When, afterwards, the station delay changes, the ESDVAR should indicate the estimated change of delay and ESIG should be the corresponding uncertainty. ESIG will contribute to the uB in the UTC-UTC(k) computation.

Schedule:

- Calibration of NIST and USNO by METODE programmed in October 2014.

- Complete all the TimeTch/Lab(k) calibration reports and submit them to BIPM for approval in October 2014.

- Computations of the (with the TimeTech mobil station) and the network/TCC CALR values, in November 2014.

- BIPM will report to the TW WG during PTTI 2014

*A task group including PTB, CH, OP, NIST and TL is suggested to support and review the TCC computations and report.*

There remains one issue: the Calibration Identifiers (CI) that we have used so far have only 3 characters. With the large number of TCC calibrations, we will soon get to 999. We could solve this by also allowing non-numerical characters.

### 6.2) A standard procedure for the TWSTFT link calibration for UTC (Zhiheng JIANG)

#### a) Some considerations in the past and future calibrations (BIPM);

A short summary of advantage and disadvantages of TWSTFT is given.

There are still some open point with respect to the calibrations:

- The use of TCC and its corresponding uncertainty

- TWSTFT calibration by GNSS, such as the METODE

- There should be a guideline for organizing calibrations.

- What exactly is the role of BIPM in the TWSTFT calibrations?

Role BIPM:

- In GPS/GLONASS calibration (incl. METODE), BIPM take the lead and full responsibility.

- In TWSTFT calibrations with a mobile TW station, BIPM is not consulted or involved in the data processing.

- BIPM provides TW CI and keeps track of calibrations

- BIPM is fully responsible for application of calibration results in the UTC computation.

BIPM should be closer involved in the TW calibration with a mobile TW station:

- BIPM should be informed by the pilot lab about TW link calibrations.

- The pilot lab should submit the calibration report to BIPM for verification.

- If approved, BIPM provides the CI.

- BIPM reports on the calibration status in the TW WG meetings.

The calibration report should include:

- A description of the data processing method,

- A description of the uncertainty evaluation method,

- The (UTC) link calibration results with their corresponding uncertainties,

There is a need for a standard procedure for organizing calibrations of (UTC) TW links. This procedure should consider the following topics: quality of pilot laboratory, calibration scheme (direct or TCC), pivot/reference laboratory, schedule, method for data processing, method for uncertainty evaluation, contents of the report, (technical details are not required).

*A task group is created to make this procedure. The group consists of: Z. Jiang, A. Naumov, C. Lin, D. Piester, E. Dierikx and someone from US (to be determined).*

*BIPM will prepare a first draft for the task group.*

Can the results of TCC be used in the UTC computation?

The answer is yes, but the evaluation of the uncertainty needs to be further investigated.

#### b) Requirements for the labs and the status of the labs participating in the calibration campaigns

Except for the case of the PTFs, none of the calibration results from the last two year of TW calibration with the mobile station have been implemented. Why not?

The main reason was, as far as I know, the BIPM had not received the official calibration report from the related UTC(k).

Ad 1: The reports were circulated among the participants, but have not been submitted to BIPM for approval and implementation. BIPM will check if the report fulfils the requirements to be described in a guideline as discussed under the previous topic.

Ad 2: The reports of the recent campaigns have been prepared by TimeTech with input from the participants. From a technical point of view, the reports are fine. However, for BIPM, in terms of responsibilities, the author is important. It is not correct that TimeTech should be fully responsible for the contents of the report. It is the participating UTC(k) laboratories that should take full responsibility of the measurements performed at their laboratories, the related data analysis and uncertainty evaluation and the calculated link calibration values with the corresponding uncertainties. This responsibility of UTC(k) laboratories should be made clearly visible by having them sign the report as co-authors.

As a minimum requirement, the report should be co-authored by at least one UTC(k) laboratory. The uncertainty issued on the calibration values in the report should be covered by the CMC for delay measurements of the respective UTC(k) laboratory.

## 7) Discussion

A summary of the actions from the meeting:

- Calibration values should be implemented as soon as possible. The date of implementation is to be determined.

- A guideline for TWSTFT link calibrations will be prepared by a task group. BIPM will make the first draft.

- A recommendation is made to continue the TW-links in Asia and between Asia and Europe. An alternative solution should be selected for the case when AM2 fails and AM4 is not yet operational. The next launch of the AM4 is planned in 3 years with no more details announced. *This solution should be selected before PTTI 2014*.

# Recommendations

## 1) Recommendation on the TWSTFT calibration guideline

Proposed by the draft Guideline task group, 20 Sep; 2014

The CCTF Working Group on TWSTFT, at its 22nd meeting held in Mendeleevo (Russian Federation) on 15-16 September 2014, proposed the following recommendation on the TWSTFT calibration:

Considering

* that one of the advantages of the TWSTFT is its accurate calibration. The state-of-the-art of the time link calibration is 0.6 ns [1] and 0.8 ns [2];
* the important contribution of the TWSTFT technique to UTC time transfer;
* the capability of performing time link calibrations using GNSS and to transfer them to the corresponding TW links, as done by using METODE [3].

Recommends that

* the procedures for organizing and implementing the TWSTFT calibrations for use in UTC be established in a document “TWSTFT Calibration Guidelines for UTC Time Links”, and that all calibrations affecting UTC links in the future strictly follow these Guidelines;
* a task group composed of representatives of time institutes involved in TWSTFT calibrations and the BIPM prepares a proposal which will be circulated among the members of the CCTF Working Group on TWSTFT and agreed by 15 November 2014;
* the draft version will be submitted to the Working Group meeting held during the PTTI, 1-4 Dec. 2014 for a draft approval. Before the final version to be approved, the new calibrations should be used a reference; Approval of the guideline will be at the next annual meeting of the CCTF Working Group on TWSTFT in September 2015 held at BIPM.

Reference

[1] Piester D, Bumgarner R and McKinley A (2014) The June 2014 calibration of the link UTC(USNO) – UTC(PTB) by means of the USNO portable X-band TWSTFT station, presented to the 22nd CCTF Working Group on TWSTFT, VNIIFTI, 15-16 Sept. 2014, Mendeleev, Russia

[2] Galindo F J and Bauch A (2014) THE EUROPEAN TW CALIBRATION CAMPAIGN 2014 IN THE SCOPE OF GALILEO (TGVF-FOC), An opportunity to update, TW link calibrations in Europe, presented to the 22nd CCTF Working Group on TWSTFT, VNIIFTI, 15-16 Sept. 2014, Mendeleev, Russia

[3] Jiang Z (2014) Accurate time link calibration for UTC time transfer -- Status of the BIPM pilot study on the UTC time link calibration, Proc. EFTF 2014

## 2) Recommendation on the Asia-Europe TWSTFT links

Proposed by D Piester, C Lin and Z Jiang, 16 Sep. 2014

Recommendation of the CCTF WG on TWSTFT

(22nd Meeting of the CCTF WG on TWSTFT, VNIIFTRI, Mendeleevo, Russia, 15-16 September 2014)

To connect Asian and European laboratories by TWSTFT links the Russian geostationary satellite AM-2 is used, presently. As the end-of-life of AM-2 is already reached its position/orbit is no longer controlled and the resulting increased inclination will degrade the quality of time transfer soon. Intersputnik plans to stop service in spring 2015. The launch of the successor AM-4R failed and according to a statement of the Russian agency the next launch will take place within 3 years.

The CCTF WG on TWSTFT recommends to use the AM-2 satellite as long as the quality of time transfer justifies the operation. As soon as AM-4R is available links should be established through this satellite. Because of an expected gap of 2 or 3 years from now it is highly recommended to find a suitable solution to continuously keep the Asia-Europe TWSTFT links.

Since the satellite Eutelsat 70B has been identified as the most suitable candidate for intermediate operation, the interested laboratories should test the visibility (measurement of beacon frequency signal strength) of Eutelsat 70B and report their results to the CCTF WG on TWSTFT.

# Next meeting in 2015

The next meeting of the WG TWSTFT will be held in September 2015 at BIPM in conjunction with the CCTF meeting. The date of the WG meeting is to be determined.

For the meeting in 2016, both NIST and NTSC have offered to organize this meeting. No selection has been made so far.

The chairman thanks VNIIFTRI again for the organization of this meeting!

In the afternoon, 15 Sept., the participants visited the VNIIFRI laboratories.

# List of the participants

|  |  |  |
| --- | --- | --- |
| **Participant Name** | **Organization** | **E-mail** |
| David Allan | Allans Time | <davidwallan7@gmail.com>, <david@allanstime.com> |
| Jerzy Nawrocki | Astrogeodynamical Observatory | <nawrocki@cbk.poznan.pl> |
| Wenjun Wu  | NTSC / BIPM | <wenjun.wu@bipm.org> |
| Zhiheng Jiang | BIPM | <zjiang@bipm.org> |
| Anton Shvain | GEO ZUP | <a.shvain@geozup.ru> |
| Anton Berdnikov | Institute of Applied Astronomy | <polany\_ipa@mail.ru> |
| Evgeny Nosov | Institute of Applied Astronomy | <e84@mail.ru> |
| Christian Schlunegger | METAS | <Christian.Schlunegger@metas.ch> |
| Judah Levine | NIST | <Judah.levine@nist.gov> |
| Dirk Piester | PTB | <Dirk.Piester@ptb.de> |
| Jürgen Becker | PTB | Juergen.Becker@ptb.de |
| Javier Galindo | ROA | <jgalindo@roa.es> |
| Kenneth Jaldehag | SP | <kenneth.jaldehag@sp.se> |
| Wolfgang Schäfer | TimeTech | <Wolfgang.Schaefer@timetech.de> |
| Shinn-Yan Lin | TL | <sylin@cht.com.tw> |
| Ivan Skakun | TSNIIMASH | <ivan.skakun@glonass-iac.ru> |
| Andrey Naumov | VNIIFTRI | <naumov@vniiftri.ru> |
| Fedor Smirnov | VNIIFTRI | <frsmirnov@vniiftri.ru> |
| Igor Blinov | VNIIFTRI | <blinov@vniiftri.ru> |
| Nikolay Koshelyaevsky | VNIIFTRI | <nkoshelyaevsky@vniiftri.ru> |
| Vitaly Palchikov | VNIIFTRI | <vitpal@mail.ru> |
| Erik Dierikx | VSL | <edierikx@vsl.nl> |