**Report of the 23rd Meeting of the CCTF Working Group on TWSTFT**

Reporter: Erik Dierikx (VSL)

Edited by Zhiheng Jiang (BIPM)

The 23rd 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 7 and 8 September 2015 at the Bureau International des Poids et Mesures (BIPM). The WG meeting was chaired by the chairman of the working group, Dr. Dirk Piester from PTB.

The 24th TW WG meeting will be held at NIST in Boulder (CO), USA in 2016 and BIPM will communicate with NIST and select a date.

The 25th meeting in 2017 will be held at NTSC in Xi'an, China.

All contributions to the meeting are available on the BIPM TWSTFT restricted access website: <http://www.bipm.org/wg/CCTF/WGTWSTFT/Restricted/welcome.jsp>.

This WG meeting was held during the 20th CCTF meetings. The chair report to the CCTF given by Dr. Dirk Piester and the CCTF recommendation on TWSTFT can be found also on the site.

User name / password are as usual, if you forgot the log in details, please contact to [zjiang@bipm.org](mailto:zjiang@bipm.org).

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# The Agenda

Session I. 14h-18h, 7 Sept

**Welcome speech** by Dr. E F Arias, Director of Time Department, BIPM

* Designation of rapporteur
* Approval of the agenda

**1.1 Laboratory reports** (about 10 minutes)

1. AOS (Jerzy Nawrocki)
2. CH (Christian Schlunegger)
3. IT (Ilaria SESIA)
4. NICT (Miho Fujieda)
5. NIST (Victor ZHANG)
6. NPL (Peter Whibberley)
7. NTSC (Huanxin LI, Hong ZHANG)
8. OP (Joseph ACHKAR)
9. PTB (Dirk PIESTER, Franziska Riedel)
10. ROA (Javier GALINDO)
11. SP (Kenneth Jaldehag, Carsten Rieck)
12. TL (Calvin Lin)
13. USNO (Jonathan Hirschauer)
14. VSL (Erik Dierikx)

**1.2 Network status** (about 10 minutes)

1. Status of Europe – USA links (Victor ZHANG/Jonathan Hirschauer/Dirk Piester)
2. Status of the Eu-Asia link via KPGO-USNO (Miho Fujieda/Jonathan Hirschauer/Calvin Lin)

Coffee break 16h00-16h20

Diner at 19h at the Novatel Hotel Restaurent

Session II. 9h30-13h00, 8 Sept

**Approval of the TWSTFT calibration Guidelines**

* TWSTFT Calibration Guidelines -- final version V3.0 (Task group BIPM et al.)
* Annex I Report of TWSTFT calibration using TWSTFT mobile station (Javier Galindo et al.)
* Annex II Report of TWSTFT time link calibration using GPS (Zhiheng Jiang et al.)

Coffee break 11h00-11h20

Lunch 13h00-14h00

Session III. 14h00-16h30, 8 Sept

**3.1 Developments** (about 10 minutes)**:**

1. Study on carrier-phase TWSTFT by SATRE modems (Miho Fujieda, NICT)
2. OP-PTB TWCP experiment in collaboration with NICT(Joseph Achkar, OP)
3. The TL-KPGO-USNO-PTB TWSTFT Links (Calvin Lin et al., TL)
4. A new approach for software-defined receivers and the recent results (Yi-Jiun Huang, Calvin Lin, TL)
5. Preliminary results of the ITOC clock comparison campaign in June (Franziska Riedel, Erik Benkler, Julia Leute, Dirk Piester, Ilaria Sesia, Giancarlo Cerretto, Peter Whibberley, Joseph Achkar)
6. Timetech's Status of Digital Modem development, Mobile Calibration Station and Some Conclusions from ACES MWL Tests (Wolfgang Schaefer, TimeTech)
7. Vondrak smoothing, how it works (Demetrios Matsakis, USNO)
8. New development in the TWOTT in Poland (J Nawrocki, AOS)

**3.2 Discussion**

Next TW WG meeting etc.

Other business

**3.3 Lab tour** (Mass, Watt balance, Chemistry etc.), 16h30, 8 Sept. 2015

# Summary of the meeting

## 2.1 Opening of the meeting

Dr F E Arias, the director of the BIPM Time Department, gave the welcome speech.

The chairman, Dirk Piester (PTB), expressed our thanks to BIPM for hosting this meeting. This is his last meeting as the chairman. The working group on strategic planning of the CCTF has proposed Victor Zhang (NIST) as the next chairman. If agreed by the meeting, it would be good to make a recommendation to the CCTF to support this proposal.

E. Dierikx was named and accepted as the reporter and would prepare the minutes of the meeting.

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

All participants in the meeting shortly introduce themselves.

Session I. 14h-18h, 7 Sept

## 2.2 Laboratory status reports

### AOS (Jerzy Nawrocki)

Jerzy Nawrocki was not present.

### CH (Christian Schlunegger)

A short overview is given on the activities of the TF and Photonics division.

At METAS there have been no significant changes to the TW station in the past year.

METAS has re-investigated the results of the 2012 calibration campaign and compared the results of OP and PTB with the results of the 2014 campaign. In the link OP-PTB there is a difference of about 3 ns between the 2012 and the 2014 result. The 2014 result is closer to the 2008 result. Anyway, all results (2008, 2012 and 2014) of the OP-PTB link calibration agree with each other within the combined expanded uncertainties. For this reason, it is safe to assume that the results of the links to METAS of the 2012 calibration are also correct within the reported uncertainty.

The report of the 2012 campaign has been signed by all participants.

METAS will send this report to BIPM. BIPM is requested to provide CI codes for the calibrated links.

Although TimeTech (TIM) is not a UTC-lab and the TW results of TIM are not used for UTC computation, for statistical reasons it would be good to also monitor the link calibrations of UTC(k)-labs to TIM. Therefore, BIPM is requested to also provide CI's for the calibrated links to TIM.

### IT (Ilaria SESIA)

An overview is given of the TW status and operation. IT02 is the main operation station.

IT01 is used for research (e.g. EMRP ITOC (International Time Scales with Optical Clocks) project). IT01 will be cross-calibrated with respect to IT02, probably early 2016.

### NICT (Miho Fujieda)

At NICT, regular links are operated on EUTELSAT 172A. These links are for domestic purposes, to the Asian TW labs KRISS, NIM and TL, and to KPGO in Hawaii.

TW operations on satellite AM2 were stopped in November 2014. Alternative satellites are being investigated as will be discussed under agenda item 1.2.

R&D work at NICT has been focussed on a frequency measurement system for optical clocks without a flywheel oscillator. Experiments have been done with a Sr-Yt optical clock versus UTC(NICT).

### NIST (Victor ZHANG)

An overview is given of the TW team and the station. Currently, NIST has one TW station. A second station is under construction

Studies have been performed on diurnals in some TW links. The direct TW link OP-PTB shows significant diurnals. However, in an indirect link OP-NIST-NIST-PTB, the diurnals are much lower.

Studies on the indirect link NIST-USNO via PTB show that the noise pattern in the link USNO-PTB is different from the noise patterns in the link NIST-PTB. The find an explanation, the orbits of satellite T11-N were investigated and also the Rx frequencies at the stations were reviewed. It is interesting to see that the Rx frequency from NIST observed by PTB and OP shows a yearly pattern. The Rx frequencies from PTB and OP observed by NIST show a pattern that is much different (without a clear yearly cycle).

Finally also effects form doppler have been investigated.

NIST invites the working group to have its next meeting at NIST in Boulder (CO), USA.

### NPL (Peter WHIBBERLEY)

There have been no regular TW operations at NPL for about 18 months. First, there have been problems with the SATRE modem and then there problems with the location of the station.

It is expected that the regular operations can be restarted within a few weeks from now.

In the meantime, a second station has been set up for operations in the EMRP ITOC project.

### NTSC (Huanxin LI, Hong ZHANG)

An overview is presented of the time keeping laboratory.

NTSC has 4 TW stations:

NTSC01: Until November last year, used for domestic links on AM2.

NTSC02: Being prepared for the link to Europe via EUTELSAT 172A.

NTSC03: C-band station with motor driven antenna. Test have been performed for receiving the beacon signal of EUTELSAT 172A

NTSC04: New Ku-band station being prepared for the link to Europe via AM22.

NTSC invites the working group to have its next meeting at NTSC in Xi'an, China.

### OP (Joseph ACHKAR)

OP is now offering a service for calibration of the delay of GPS receivers. The lowest expanded uncertainty is 3.2 ns for receiver calibrations and 2.1 ns for GPS links.

Comparisons have been made between T2L2 and GPS links.

OP has 2 TW stations:

OP01 is used for routine operations and for supporting Galileo activities.

OP02 is used for R&D purposes: the 20 Mcps experiment in the ITOC project; TW carrier phase experiments with PTB and NICT.

Common clock difference (CCD) measurements are regularly performed between OP01 and OP02. The average CCD over one year, is stable within 200 ps. Typical fluctuations are within ±1 ns.

A study has been made on the difference between TW and GPSP3 on the link OP-PTB. Within the period from MJD 54750 to MJD 57305 the difference is typically within ±5 ns. This means that the techniques agree within the combined expanded uncertainties as declared in CCTF-K001.UTC.

Another French laboratory, LNE -LTFB in Besançon, is preparing to join the TWSTFT network as well. It is expected that routine TW operations will start in January 2016.

For the coming World Radio Conference (WRC) in November 2015, the position of LNE-SYRTE and SYRTE on the future of UTC is to abolish insertion of leapseconds and to retain the name UTC.

### PTB (Dirk PIESTER, Franziska RIEDEL)

An overview is presented of the PTB's time dissemination group and activities. PTB has 4 TW stations:

PTB01 is used for routine measurements to the EU and US labs on T-11N

PTB03 was used until November 2014 for links to Asia and Russia on AM2

PTB04 is a spare Ku-band station, used in the TW carrier-phase experiment with PTB, OP and NICT.

PTB05 is a Ku-band station that will become a replacement of PTB01. Recently, it has been used for the TW-broadband measurements in the ITOC project.

In July2015, the link UTC(USNO)-UTC(PTB) has been calibrated again with the portable X-band station of USNO. The evaluation of the uncertainty of the closure measurements was discussed. The results from this calibration are in good agreement with the results obtained in 2014.

### ROA (Javier GALINDO)

ROA has two operational Ku-band TW stations.

ROA01 uses a modem with 2 Rx channels. One channel is used for routine operations of the links to EU and US laboratories for UTC. The second channel is used for monitoring the Tx signal.

ROA also contributes to Galileo with regular TW links to PTF1 and PTF2.

In June 2015, the link calibration results from the calibration campaign in 2014 have been implemented.

For improvement of the stability of the measurements, the Ku-band transceiver has been placed in a climate chamber. Some of the links seem to have been improved.

A study has been performed on the locking frequency of the received signals.

A new laboratory is under construction. It is expect to become operational in July 2016. This opportunity will also be used to update the hardware and software of the TW station.

### SP (Kenneth Jaldehag, Carsten RIECK)

In March 2015, the calibration results from the campaign in 2014 have been implemented.

Studies have been performed on diurnals and closures. For this purpose, Kalman filtering has been applied.

Results of TW links have been made available on an external website. If a laboratory doesn't appreciate that its results are published this should be reported to Kenneth Jaldehag.

Results can be found on:

http://igsrt.sp.se/twstft

http://igsrt.sp.se/ftp/links

The real-time TW processing is still going on. PTB, ROA and SP are directly casting their SATRE data. USNO is providing data in hourly batches. NIST is willing to provide data and solving problems with the firewall. Other laboratories are still welcome to join.

RT udp-cast 193.11.166.4

2001:6b0:42:1::4

### TL (Calvin Lin)

TL has 4 TW stations and currently 2 of them are active.

After operations on AM2 were stopped, TL is only operating TW links on EUTELSAT-172A.

Connections are made to Asian laboratories. Also there is a connection to USNO via satellite AMC-1 and the KPGO relay station in Hawaii.

An overview is presented of the differences UTC(TL) - UTC(NICT) via TWSTFT and GPS-PPP.

A comparison has been made between measurements on the SATRE modem and on a Software Defined Receiver (SDR). On the long term, there is an agreement between the receivers, and on the short term the SDR gives more stable results.

TL is preparing to operate a new link to Europe via AM22.

### USNO (Jonathan Hirschauer)

USNO has worked on standardizing the equipment in their Ku band systems. As a result of this, remote IIOTIC data can be collected from all the SATRE modems.

At the Alternate Master Clock (AMC), fibre optic transceivers have been replaced.

An update has been made of the laboratory's air conditioning

Power levels have been adjusted in the national stations to, more or less, equalize Rx powers levels.

The new GATR antenna (X-band) has been used for the first time in the calibration of the link to PTB.

R&D: USNO has started research on Software defined modems, in collaboration with TL.

Future: Attempts will be made to realize a Ku-band link between NIST and USNO.

USNO will work on a better documentation of its operational TW systems.

### VNIIFTRI (Nikolai KOSHELYAEVSKY, Andrey NAUMOV)

No TW measurements have been performed at VNIIFTRI after the links via satellite AM2 were stopped.

Experiments have been performed with 2 SATRE modems for two-way optical fibre time and frequency transfer (TWOTFT). The experiment was performed with two fibre spools with a total length of 95 km. The stability of the result (uncertainty from type A evaluation) was estimated to be 10 ps for averaging times larger than 1000 s. Uncertainties from type B evaluations were estimated to be 260 ps.

### VSL (Erik Dierikx)

Research at VSL has been mainly concentrated on time and frequency transfer through optical fibres using White Rabbit technology. Therefore, activities on the satellite simulator have been at a low level.

With respect to diurnals, some results are shown of combined DRMS levels of TW links to VSL. Combined DRMS values are an estimator for the stability of a link. In all of the European links to VSL, a daily varying pattern is clearly visible. In the links CH-VSL the average DRMS level and variations in the DRMS are significantly higher than in other links.

TimeTech mentions that this probably related to the relative short codes used by the SATRE modem at 1 Mcps. Changing to another code may give some improvement.

## Network status

## Status of Europe – USA links (Victor ZHANG / Jonathan HIRSCHAUER / Dirk PIESTER)

The contract with RiteNet for the use of satellite T-11N is now in its last extension period. A new contract will be requird before July 27th, 2016. (For the current contract, the US laboratories pay one half of the total amount and the European laboratories pay the other half. The payments from the European laboratories are coordinated by PTB.)

In October 2015, NIST will start working on a new contract.

Satellite T-11N is still a good candidate, but alternative satellites will also be investigated.

Some important notes for the contract negotiations:

- If we stay on T-11N, we might be lucky and be able to maintain the current frequencies.

- If we change to another satellite and/or to other frequencies, new calibration values will have to be determined.

- We should be aware that in some countries, some frequencies within the satellite transponder band are allowed for secondary services (transmission from ground). This can cause interference problems as was observed in the ITOC experiments at OP.

In each country a list should be available of frequencies that are allowed for secondary services.

### Status of the Eu-Asia link via KPGO-USNO (Miho FUJIEDA / Jonathan HIRSCHAUER / Calvin LIN / Nikolai KOSHELYAEVSKY)

TW operations on satellite AM2 were stopped in November 2014, because the TW measurements were clearly affected by the inclined orbit of the satellite. Therefore, currently there is no direct TW link from Asian laboratories to Europe.

The connection of Asia to North-America via EUTELSAT-172A to KPGO and AMC-1 to USNO is still operational.

Alternative satellites for the link between Asia and Europe are being investigated:

- AM4 is not yet available;

- EUTELSAT-70B seems too expensive;

- ABS-2; (I think there was a limitation on the foot print; check the NICT presentation)

- ABS-2B;

- AM22 has been moved from 53E to 80E, replacing AM2. This satellite is already past its guaranteed life time. However, it is expected to operate for 3 more years. The costs of this satellite are relatively low; 65000 RUB/month/MHz (corresponds to € 800).

VNIIFTRI, TL and NICT already managed to receive the beacon signal from AM22. However, as a result of the foot print of the transponder, the signal received at NICT is about 20 dB lower.

Until AM4 becomes available, AM22 seems to be the best candidate to continue TW operations between Asia and Europe.

Session II. 9h30-13h00, 8 Sept

## 2.4 Changes to ITU-R TF1153.4 from August 2015 (Joseph ACHKAR)

Over the past year, a revision has been prepared for ITU-R TF.1153 on TW operation. This new version, number 4, has been agreed in August 2015.

The ITU-R TF1153.4 is available on the ITU website (www.itu.int/rec/r-rec-tf.1153/en) and it is also available on the BIPM website as "rapport BIPM-2011/01"

(http://www.bipm.org/utils/common/pdf/rapportBIPM/RapportBIPM-2011-01.pdf)

The changes in this version are in the details of the Sagnac correction. The geocentric x and y coordinates were not determined correctly.

For conversion from geocentric to geodetic coordinates also a new equation is applied. The changes are summarized in the section "Scope" of the document.

The effect of this correction on the given example link USNO - VSL is 340 ps.

## 2.5 Approval of the TWSTFT calibration Guidelines (Zhiheng JIANG)

TWSTFT Calibration Guidelines -- final version V3.0 (Task group BIPM et al.)

In the 22nd meeting of the WG on TWSTFT, it was proposed to prepare a guideline for TW calibrations. A task group was formed consisting of: Erik Dierikx, Calvin Lin, Andrey Naumov, Dirk Piester, Victor Zhang and Zhiheng Jiang. After several iterations, the task group proposed a draft to an independent panel of reviewers consisting of: Javier Galindo, Joseph Achkar and Felicitas Arias. A few more iterations followed between the task group and the reviewers. Then a final review on style and correct English was performed by the BIPM editor ? What is his name?. The final version v3 is been distributed to all members of the working group and is ready for approval.

A summary a characteristics of this guide:

- The guide is clear and simple; consisting of only 3 effective pages.

- A TW calibration is collaboration between the participants, the provider of the mobile station and BIPM.

- TW laboratories are considered to be professional enough to perform the calibration without technical details in the guide.

- The primary calibration technique is by means of a mobile TW station. The estimated uncertainty of this technique is approximately 1.0 ns (*k* = 1).

- The secondary calibration technique is a link calibration using a GNSS mobile receiver. The estimated uncertainty for this technique is about 1.5 ns (*k* = 1).

- As a third technique, calibration by triangular closure (TCC) is also accepted under the conditions that the involved laboratories have to agree on the computation of the results and on the evaluation of uncertainties.

- Consistency between TWSTFT, TWOTT and GPS link has been checked and there is a good agreement.

There are two comments/suggestions on the current version of the guide.

- Joseph Achkar proposes that uncertainties mentioned in the guide should be expressed as expanded uncertainties (with 95% coverage interval). This is more in line with uncertainties presented in Appendix of C of the BIPM key comparison database (KCDB).

- Erik Dierikx remarks that the guide has now different requirements on the coordinator for a calibration with a mobile TW station or with a mobile GNSS receiver. It is proposed to harmonize this in one set of requirements.

**Annex I** Report of TWSTFT calibration using TWSTFT mobile station (Javier GALINDO et al.)

This annex will be available at:

ftp://tai.bipm.org/temp/ZJ/TWSTFT\_Guidelines/Annex/AnnexI

An explanation is given on the contents of Annex I.

**Annex II** Report of TWSTFT time link calibration using GPS (Zhiheng JIANG et al.)

This annex will be available at:

ftp://tai.bipm.org/temp/ZJ/TWSTFT\_Guidelines/Annex/AnnexII

An explanation is given on the difference between a GPS receiver delay calibration and a TW link calibration by means of a GPS mobile station. In a TW link calibration the GPS receiver of the participant is not included. Only the GPS receiver of the UTC pivot (PTB) is involved as a reference for calibrating the travelling GPS receiver. The stability of the travelling GPS receiver is only relevant for the duration of the calibration trip.

Results from these two methods (TW mobile station and GPS mobile receiver) have been compared and the results agree within the combined uncertainties. Comparisons between TW links and GPS links have been performed for example on the link ROA-PTB. Evaluation of the double clock differences (DCD) show changes at the level of about 1 to 2 ns.

We should remember that results from calibrations and their corresponding uncertainty degrade and therefore repeated calibrations are required.

It is remarked that after calibration, the laboratory cannot claim lower uncertainties for its TW link until the laboratory has published a report on improvements that have been confirmed by a new calibration.

When, in a link calibration different calibration methods have been used, one technique must be leading. The report may include a paragraph on an alternative method. This is not a full validation, but at least confirms the leading method. If there is a disagreement between the methods there is reason for suspicion and this must be investigated.

The participants in the meeting agree on version 3 of this calibration guide. The guide and its annexes will be published on the BIPM website.

In the next revision the requirements on the coordinator will be harmonized and all uncertainties will be expressed as expanded uncertainties with a coverage interval of 95 %.

Session III. 14h00-16h30, 8 Sept

## 2.6 Developments:

### Study on carrier-phase TWSTFT by SATRE modems (Miho FUJIEDA, NICT)

Results are reported from three experiments on TW carrier-phase (CP) frequency transfer with SATRE modems.

1) In a common clock measurement, the mean frequency difference is at the level of 10-16 Hz/Hz. The modified Allan deviation (MDEV) is less than 10-12 at  = 1 s, and 10-15 at 1 h.

2) UTC(NICT) was compared against a hydrogen maser. The TW CP measurements were compared with a dual-mixer time delay (DMTD) measurement. The agree between the two techniques was at the level of a few parts in 10-15 Hz/Hz.

3) UTC(NICT) in Tokyo was compared against an H-maser in Okinawa over a distance of 1500 km. The TW CP measurements were compared with GPS CP. The agreement between the techniques is again at the level of a few parts in 10-15 Hz/Hz. The MDEV is 10-12 at 1 s and ~5×10-15 at 1 h.

### OP-PTB TWCP experiment in collaboration with NICT(Joseph ACHKAR, OP; Miho FUJIEDA, NICT)

TW CP experiments have also been performed in Europe, between OP and PTB. For this purpose, NICT equipment for the CP technique was installed in the OP02 station (using an RF combiner and RF divider). Results are presented of the frequency difference between UTC(OP) and UTC(PTB). The MDEV is ~3×10-13 at 1 s and 4×10-16 at 1 day.

These experiments were performed within the ITOC project, on the Astra 3B (location 23.5E) satellite.

More TW CP measurements between OP and PTB were performed from 1 to 6 September 2015 on satellite T-11N.

In the PTB setup, the Ku band signal is transfer in cables of 20 m length.

At OP, two configurations were used: one with converters inside and 45 m cable to the antenna, and another one with converters outside and a short cable to the antenna.

The configuration with converters inside results in better phase stability for TWCP: 4×10-16 at 104 s is better than in the ITOC campaign.

### The TL-KPGO-USNO-PTB TWSTFT Links (Calvin LIN et al., TL)

During the time when satellite AM2 was still used, TL made an analysis of the closure of TW links around the world. The total chain of links is: TL-KPGO-USNO-PTB-TL. The closure of this chain shows a drift.

For NICT a similar analysis was made. In this case, there is also a drift, but it is smaller than in the case of TL.

The TW links via AM2 to PTB and via EUTELSAT-172A and AMC-1 to USNO have been compared with GPS time transfer links to the corresponding labs. The discrepancies between TW and GPS were up to 3 ns.

The TW laboratories in the Asian region appreciate that USNO regularly uploads the TW data from the KPGO station. If the links to this station could be calibrated, these links could also contribute to the UTC computation. The uncertainty of these links will, however, be increased by the relay station.

### A new approach for software-defined receivers and the recent results (Yi-Jiun HUANG, Calvin LIN, TL)

Advantages of the software-defined receiver (SDR) are that there is no mathematical smoothing on the raw data and it reduces errors related to non-linearity.

A configuration is shown that uses the SATRE RF in monitor port as input to the SDR. In this way, the SATRE modem can be easily extended to a multi-channel receiver.

The SDR is useful is studies on diurnals, multiple access and effects from multipath.

The results of the SDR agree with the results from the SATRE receiver, but on the short the SDR results are more stable. In the results from the SDR, diurnals seem to be suppressed with respect to results from the SATRE receiver.

Because of the processing time, the SDR cannot do real-time comparisons.

TL is open to collaborations on developments on the SDR and is willing to share the source code.

### Preliminary results of the ITOC clock comparison campaign in June (Franziska RIEDEL, Erik BENKLER, Julia LEUTE, Dirk PIESTER, Ilaria SESIA, Giancarlo CERRETTO, Peter WHIBBERLEY, Joseph ACHKAR)

ITOC is an EMRP project investigating practical and theoretical challenges of realizing an International Timescale with Optical Clocks. For comparing optical clocks, an experiment was prepared for TWSTFT measurement at 20 Mcps, "broadband TW".

The first link test on satellite Astra 3B SES was preformed from 24 to 31 October 2014.

This first test consisted mainly of measurements of maser versus maser with broadband TW and GPS-CP. Additionally, in some laboratories, a Cs fountain or optical clock could be used.

The MDEV of the first results was of 3×10-16 on 1 day averaging, and 2×10-11 on 1 s.

Second period of measurements was 3 weeks, from 4 to 29 June 2015. In this campaigne, Cs fountains or optical clock could be used in each of the participate institutes.

After filtering out bad data caused by known problems, the MDEV was less than 10-15 on a 1 day average.

INRiM performed a data analysis, comparing the results of broadband TW with results from GPS PPP processed with Atomium software from ROB.

A method was investigate for calculating the Allan deviation in cases were data is missing. The proposed method is presented in the Time Scale Algorithm Symposium on 10 and 11 September 2015.

More information on the ITOC project can be found on: www.optical-time.eu

### TimeTech's Status of Digital Modem development, Mobile Calibration Station and Some Conclusions from ACES MWL Tests (Wolfgang SCHAEFER, TimeTech)

TimeTech is working on the development of a digital modem. The interface and functions will be similar to the SATRE modem and to some extent this new modem will be compatible with the SATRE.

The digital modem operates at intermediate frequencies of 70 MHz or 140 MHz. The input is a 14-bit 200 Msamples/s ADC. The digital bandwidth is 56 MHz. The modem has 2 Tx channels and 4 Rx channels. The expected stability in terms of TDEV is at picosecond level at 1 s. This new modem is expected to become available near the end of 2016.

There have been no calibration trips with the TW mobile station in 2015. After a small car accident, the trailer was repaired. Some issues with the stability of the optical link have been resolved.

Cross calibrations have been performed between the TimeTech mobile TW station and the PTB travelling GPS receiver on the link PTB -TIM. The average difference between the two techniques was 200 ps.

ACES MicroWave Links (MWL)

A short overview is presented of clock comparisons in the ACES project using TW-CP measurements in the ku-band. Techniques have been investigated for CP measurements with integer carrier cycle identification. Measurements are affected by orbit dynamics such as relative acceleration. The conclusion of the measurements is that frequency transfer at 10-18 at 1 day averaging is feasible.

### Vondrak filtering for timescale, how it works (Demetrios MATSAKIS, USNO)

USNO has investigated the application of Vondrak filtering on the generation of a timescale. The filter consists of two stages:

The first stage checks the fidelity and smoothness of the input data. Outliers are removed.

The second stage is the Vondrak filter in which two sets of data are combined. The Vondrak filter combines the time series of phase data from TWSTFT measurements and time series of frequency data from GPS PPP solutions.

With correct filter settings, this provides a good combination of the long term accuracy of TWSTFT and the short term stability of GPS PPP.

Simulations have been performed to observe the effect of the Vondrak filter on diurnals in TWSTFT results. Diurnal variation of 100 ps in TW data were reduced to 8 ps in the output of the filter. Also simulations have been performed on phase steps, frequency steps and constant frequency offsets between the two input data series.

(With a Kalman filter a similar kind of data processing can be done.)

# III. Discussion

There is a discussion on the presentation of results from time link calibrations. Currently, section 6 of Circular T gives a list of uncertainties of time links used from the computation of UTC. BIPM maintains this information in a database that is mainly for internal use at BIPM. In the future, (read-only) access to this database will be possible through a web interface. Section 6 of Circular T will then point to this database. Within the EURAMET meeting there has been a discussion on the presentation of the uncertainties.

Next meeting of the CCTF WG on TWSTFT

Considering that we have two invitations from laboratories to host the next meeting, it is proposed that the meeting in 2016 will be held at NIST in Boulder (CO), USA and the meeting in 2017 will be held at NTSC in Xi'an, China.

Considering that US visa applications for participants from China take some time to be completed, the date of the meeting shall be announced as early as possible.

BIPM will communicate with NIST and select a date.

Victor ZHANG has been proposed by the WG on strategic planning as the next chairman of the WG on TWSTFT. For the participants in the meeting, there are no objections to this proposal. So normally, Victor ZHANG will be appointed by at the coming meeting of the CCTF.

The chairman proposes to submit a recommendation to the CCTF asking participating laboratories commitment to their continuing support for TWSTFT activities in the future.

# IV. Closing of the meeting

The chairman closes the meeting with a word of thanks:

- to the BIPM for hosting the meeting;

- to Zhiheng Zhang as the local organiser;

- to Erik Dierikx for preparing the minutes of the meeting.

# Annex. The attendee list

**The 23rd Meeting of the CCTF Working Group on TWSTFT**

7- 8 Sept. 2015 at the Bureau International des Poids et Mesures

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|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **No.** | **Inst.** | **Name** | **Email** | **Dinner**  **7 Sept** |
| 1 | NIST | Victor Zhang | victor.zhang@nist.gov | Y |
| 2 | NICT | Miho Fujieda | miho@nict.go.jp | Y |
| 3 | OP | Joseph Achkar | joseph.achkar@obspm.fr | Y |
| 4 | NTSC | Huanxin LI | lhx@ntsc.ac.cn | Y |
| 5 | INRIM | Ilaria Sesia | i.sesia@inrim.it | N |
| 6 | VNIIFTRI | N Koshelyaevsky | nkoshelyaevsky@imvp.ru | N |
| 7 | TL | S-Y/Calvin LIN | sylin@cht.com.tw | Y |
| 8 | TimeTech | Wolfgang Schäfer | wolfgang.schaefer@timetech.de | Y |
| 9 | VSL | Erik DIERIKX | edierikx@vsl.nl | Y |
| 10 | METAS | Christian Schlunegger | christian.schlunegger@metas.ch | Y |
| 11 | USNO | Jonathan Hirschauer | jonathan.hirschauer@usno.navy.mil | Y |
| 12 | USNO | Demetrios Matsakis | demetrios.matsakis@usno.navy.mil | Y |
| 13 | NIM | Zhiqiang YANG | yangzq@nim.ac.cn | N |
| 14 | NTSC | Hong ZHANG | zhong@ntsc.ac.cn | Y |
| 15 | ROA | Javier Galindo | jgalindo@roa.es | N |
| 16 | PTB | Dirk Piester | dirk.piester@ptb.de | Y |
| 17 | PTB | Franziska Riedel | franziska.riedel@ptb.de | Y |
| 18 | SP | Carsten Rieck | carsten.rieck@sp.se | Y |
| 19 | NPL | Peter Whibberley | peter.whibberley@npl.co.uk | Y |
| 20 | NIST | Stefania Römisch | stefania.romisch@nist.gov | Y |
| 21 | NIST | David A Howe | david.howe@nist.gov | Y |
| 22 | AOS | Jerzy Nawrocki | nawrocki@cbk.poznan.pl | Y |
| 23 | BIPM | Zhiheng Jiang | zjiang@Bipm.org | Y |
| 24 | BIPM | Felicitas Arias | farias@bipm.org | N |
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|  |  |  |  |  |
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|  |  | Gianna Panfilo | gpanfilo@bipm.org | N |
|  |  | Aurelie Harmegnies | aurelie.harmegnies@bipm.org | N |
| Total | 17 | 24+3 |  | 19 |