TWSTFT Calibration Guidelines for UTC Time Links

(V3.0)

Acronyms

BIPM: Bureau International des Poids et Mesures
CCD: Common Clock Difference
DCD: Double Clock Difference, i.e., difference between two time links
CCTF: Consultative Committee for Time and Frequency
CI: Calibration Identification
GPS: Global Positioning System
GPSPPP: GPS Precise Point Positioning
ITU: International Telecommunication Union
TCC: Triangle Closure Calibration
TWSTFT: Two-Way Satellite Time and Frequency Transfer
UTC: Coordinated Universal Time
UTC(*k*): Acronyms for laboratory *k*[1]

[1] Refer to "Acronyms and locations of the timing centres which maintain a local approximation of UTC, UTC(k) and/or an independent local time scale TA(k)" at ftp://ftp2.bipm.org/pub/tai/publication/acronyms/acronyms.pdf.

I. General

Two-Way Satellite Time and Frequency Transfer (TWSTFT) has been a primary technique contributing to the comparison of clocks and primary frequency standards in UTC generation for over one and a half decades. TWSTFT has proved to be the most accurate technique for time transfer measurements based on the exchange of radio frequency signals via satellites [1,14]. It is independent from and complementary to GPS time transfer and the long-term stability of its calibration has been demonstrated in many cases. In addition, quasi-real time data exchange and computations are currently operational.

The importance of TWSTFT has grown over the past few years, with the introduction into UTC computations of time-links based on a combination of TWSTFT and GPS Precise Point Positioning (GPSPPP). This strategy combines the accuracy of the TWSTFT calibrations with the precision of the GPS carrier phase solutions while also minimizing the effect of diurnal variations seen in time transfer results in some TWSTFT links. It also brings greater importance to the need for systematic calibration and recalibration of TWSTFT links. Wider application is nevertheless recommended whenever possible.

The members of the CCTF Working Group on TWSTFT and the BIPM are authors of the Guidelines and are responsible for keeping it up to date. Proposals for updating the Guidelines will be discussed at the annual TWSTFT meetings and will be based on calibration experiences.

Calibration of a TWSTFT link via GPS is also possible and in some cases, such as the Asia-Europe network and the Europe-USA network, it is the only practical means available. The Type B uncertainty (u_B) of the GPS link calibration has been reduced to 1.5 ns as reported by PTB, ROA, NIM, INRIM, TL and BIPM [2-7], and the BIPM's GPS-based calibration system (METODE) [7,8] has been applied successfully to the UTC TWSTFT links NICT-PTB, NIM-PTB and TL-PTB. It is suggested, that GPS calibrations be undertaken as a complementary part of TWSTFT calibrations. Simultaneous calibrations, if agreed by participants, would serve as a check against large errors and also help to improve both techniques.

II. Performance of a TWSTFT link calibration

A TWSTFT link calibration campaign is carried out using a TWSTFT mobile station and/or a GPS travelling system that is circulated among several time laboratories contributing to UTC, referred to as the "participants" in this document. The provider of the travelling calibration device can also be considered as a participant.

2.1 Using a TWSTFT mobile station

This is the primary technique used for a UTC TWSTFT time link calibration.

The technical specifications for the participating and the mobile stations are not mandated by this document. As a demonstration and for reference, Annex I provides a TWSTFT calibration experience containing the uncertainty budgets for the Type A and Type B uncertainties [11,12].

For each calibration campaign, and as agreed by all the participants, one coordinator is appointed. The coordinator's laboratory must operate a TWSTFT station, and be a member of the CCTF.

The coordinator will interact with the participants to reach agreement on the planning, the provider, the costs and the procedure/schedule of a calibration campaign, more specifically:

1. Establishing the list of the participants;
2. Deciding on the TWSTFT station which will be used for the closure measurements of the campaign;
3. If the "pivot" station of the TWSTFT network (at present PTB) is not a participant in the campaign, selecting the station that will serve as intermediate station to calculate the calibration result (CALR values) via triangulation (TCC);
4. Establishing, with the support of the provider, the measurement schedule of the campaign;
5. Reporting to the BIPM on the campaign under preparation, informing on items 1) and 2) above, and 1) below;
6. Collecting the technical specifications and the raw data of each visited station;
7. Processing the data and computing the calibration results using the CCD measurement data processed and submitted

by each participant;
8. Preparing the draft report and submitting it to participants for approval;
9. Preparing the final report in agreement with participants and submitting it to the BIPM.

In agreement between the coordinator and the participants, one provider is appointed. The provider will interact with the coordinator and the participants to reach an agreement on the following points:

1. Discussing with the participants the contractual conditions and dates for the calibration campaign;
2. Establishing with support of the coordinator the measurement schedule;
3. Agreeing with the participants on the technical protocol;
4. Planning with support of the coordinator, the visits to different sites according to the schedule;
5. Operating the mobile station at each site according to the protocol.

2.2 Using GPS travelling calibration equipment

Calibration via GPS can be used as a supplement or an alternative when the TWSTFT mobile calibration is not applicable.

Unlike differential GPS receiver calibration using the CCD of the two GPS receivers (the travelling and the local receivers), the DCD is used in this case. It is obtained by the differences between the TWSTFT and GPS time links. The local GPS receiver of Lab(*k*) is not involved. Based on [2-7], a combined calibration uncertainty of 1.5 ns is attainable.

The coordinator of a GPS calibration campaign is usually the GPS calibration equipment provider, which may be either a UTC(*k*) laboratory or the BIPM. The technical specifications for the participant's and the travelling calibration equipment are not mandated by this document. As a demonstration and for reference, Annex II describes a TWSTFT calibration campaign with GPS calibration equipment.

GPS calibrations for UTC are in general free of charge. Each participant in a calibration campaign covers the total cost of the door-to-door shipping of the travelling equipment to the next laboratory, including the related custom fees and insurance when necessary.

III. The calibration report

The coordinator is charged with the preparation of the report, based on the input of the participants. For this purpose, the participants will provide the raw data and any other technical information relevant to the measurement. Sections 3.1 and 3.2 specify what the report must contain, and examples are provided in the annexes.

3.1 Calibration using a TWSTFT mobile station

1. The description of the calibration campaign;
2. The technical protocol;
3. A technical description of the common clock difference or link difference measurements performed at each visited station;
4. Report of the results and their corresponding uncertainties;
5. The measurement data processing for the computation of the CALibration Result (CALR), Earth station delay variation (ESDVAR) and their related uncertainties;
6. The complete evaluation of the uncertainty budget;
7. In cases where the pivot of the TWSTFT network does not participate in the campaign, the report must include uncertainty of the link between the selected intermediate station for the calibration and the pivot;
8. In the case of calibration by the TCC technique, a description of the method for evaluating the uncertainties is required.

The calibration report must be approved by all participating laboratories, and will be published on the BIPM website after approval.

Annex I is an example of the TWSTFT calibration campaign and the calibration report. The exact style is not mandated by these guidelines, but the annex is provided as a reference to carry out the calibration and prepare the report.

3.2 Calibration using GPS calibration equipment

Using GPS to calibrate a TWSTFT link is a simple alternative. Nevertheless, reporting the results is essential and all key points listed in subsection 3.1 should be addressed in an adequate way. Annex II is an example of the GPS time link calibration campaign and the calibration report. It is not mandated by the guidelines but is a reference to carry out a calibration and to prepare the report.

Notes:

1. Any of the following stations can be used as the starting-closing station for a calibration campaign:
   a. The pivot laboratory in the UTC time links network (PTB at present);
   b. A UTC(*k*), i.e. any UTC TWSTFT station that is part of the calibration trip;
   c. Other stations as decided by the TWSTFT working group.
2. As a reference, Annex I gives an example of the uncertainty of the closure measurement at the pivot or intermediate stations.
3. The stability of the intermediate station needs to be guaranteed over the period of the calibration campaign. This could be achieved by performing repeated common clock measurements, by the use of a satellite simulator, and/or by comparison with the corresponding GPS measurements.
4. TCC can be used, cf. [13] for the method and related uncertainty;
5. If applicable, the TWSTFT link calibration result is suggested to be compared to the latest GPS calibration results. Considering the independence of the two techniques, the difference should be in agreement with the combined uncertainty: $U \leq \sqrt{[u^2(\mathrm{TW})+u^2(\mathrm{GPS})]}$. If not, a discussion over the causes is recommended;
6. The implementation of the calibration results will be decided between the participants and the BIPM.

IV. The role of the BIPM

The role of the BIPM is:

1. To verify that the report respects the Guidelines for UTC time links, and to approve it.
2. To assign a Calibration Identification (CI) number to each accepted Result (CALR).
3. To review the calibration report, and publish it on the BIPM website.
4. To propose the date of implementation of the calibration results in the ITU data files in agreement with the participants. The implementation of calibration results should be made, by preference, within the two months following the assignment of the CI numbers. To facilitate the calculation of *Circular T*, the date of implementation of calibration results should be fixed between two periods of calculation of *Circular T*, on a MJD date not ending in 4 or 9.
5. To monitor the stability of UTC time link calibrations through the monthly comparisons between the TWSTFT and GPS time transfer links. The comparison results are regularly published at ftp://tai.bipm.org/TimeLink/LkC/. As a supplement to the laboratories' monitoring their systems and links, the BIPM will contact the relevant laboratories if anomalous behaviour is apparent. When necessary, the BIPM will perform the global network calibration through the TCC technique.
6. To report to the CCTF Working Group on TWSTFT on the status of the time link calibrations.

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Annexes

Annex I Report of TWSTFT calibration using TWSTFT mobile station

Annex II Report of TWSTFT time link calibration using GPS

Version History

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