Improving the Calibration of the BEV GPS Receiver Calibrated by Using TWSTFT

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Notations:

TWSTFT	Two Way Satellite Time and Frequency Transfer (TW for short)
AV	GPS All in View time transfer
JRG	Joanneum Research GmbH in Graz
BEV	Bundesamt für Eich-und Vermessungswesen in Vienna
PTB	Physikalisch-Technische Bundesanstalt in Braunschweig
TUG	University of Technology Graz in Graz

Resume: Until recently, the only GPS time receiver calibration technique for the UTC time transfer was the traditional GPS-GPS one [8,9], which has been organised by BIPM for most of the GPS equipment in contributing laboratories. The BEV GPS equipment calibration is the first experiment using the TW-GPS technique and the result has been used for BIPM UTC time transfer. This report studies, in the view of the standard UTC computation, the data processing so as to improve the calibration quality and uncertainty estimation.

1. The JRG calibration result

In cooperation with TUG and with the support of PTB and BEV, using a portable TW ground station, the JRG carried out a TW time transfer between PTB and BEV from 9 to 31 October 2007. The main purpose was to calibrate the BEV GPS time transfer receiver (Rx) through the side by side TW and GPS simultaneous time measurement comparisons [1,10] (cf. Figure 1.1). The reference [10] depicts the equipment setting up for the calibration.

The calibration computation and result were reported in the sections 4.5 and 6 of [1] and [2]. The uncertainty estimation was reported to BIPM by BEV in [3]. The calibration result for the official primary GPS Rx for the UTC time transfer at BEV is:

GPS receiver TTS-2 No. 24: INT DLY = - 27.3±1.9 ns

(based on the TW-GPS time link difference: **-12.3±1.9ns**)

The above result has been used for the Circular T computation at BIPM.

The calibration value was calculated based on the difference of the TW link of BEV-PTB and the related GPS AV link derived using the Circular T with the following steps:

1. Measuring the TW time transfer link between MJD 54383 15h 34m and 54384 13h 55m, totally 121 measured points (Table 24 [1]). Figure 1.2 (left) displays the time deviation of the TW measurements;

2. Making a linear regression over the above data set (Figure 1.1 or Diagram 5 in Sect. 4.5 [1]);
3. Interpolating the TW time transfer value on MJD 54384 0h using the linear regression obtained. The result is -50.586 ns;
4. Deriving, from the Circular T 238 (UTC0710), the GPS AV time transfer value between BEV and PTB, i.e., [UTC-UTC(PTB)]-[UTC-UTC(BEV)]= -38.3 ns;
5. Comparing TW-GPS link by differing the steps 3. and 4.: -50.586- (-38.3) = -12.3 ns;
6. Calculating the internal delay: INT DLY = - 27.3 ns (computation detail was not given in [1,2,3]);
7. Finally estimating the calibration uncertainty [3] $u_B = \sqrt{[u_A(BEV)^2 + u_A(PTB)^2 + u_B(PTB)^2 + u_{TW}(BEV\text{-}PTB)^2]} = \sqrt{[1.5^2+0.2^2+0.9^2+0.782^2]}=1.9$ ns

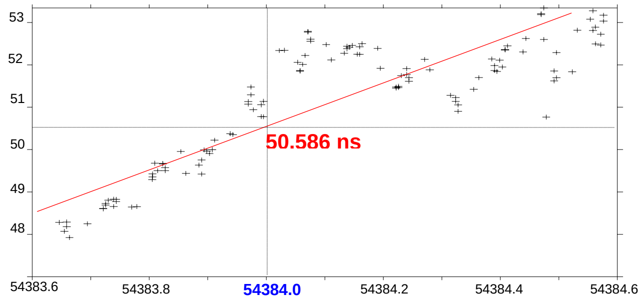

Figure 1.1 TW time transfer between BEV and PTB (from Tab. 24 of [1]) and the linear regression. See Figure 1.2 left for its TDev. Note: the sign of the BIPM UTC time link is inversed w.r.t. the JRG report.

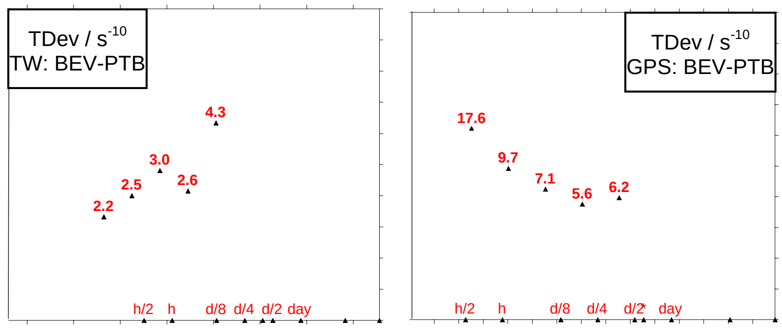

Figure 1.2 Comparison of the Time Deviations of the links of BEV-PTB: Left TW, Right GPS. The short term time stability of the TW is much better than that of GPS. Here h is hour, d is day and unit is in s^{-10}.

2. Improving the JRG calibration and uncertainty result

We first analyse the JRG result and discuss where and how we can improve it. Then we do the calibration computation and uncertainty estimation. In order to be traceable, we list all the details of the data and the computation procedure. Because the calibration was completely based on the TW and GPS AV time link comparison of the side by side simultaneous measurements, the key is to make an accurate comparison.

2.1 Analysing the JRG calibration

On one side, the linear regression in the step 2 may be affected by the non linear variations and noises in the master clocks' differences (cf. Figure 1.1) and on the other side, in the step 5, only one point of the Circular T 238 was used. As displayed in the Figure 1.2 (right) and Figure 2.1, the GPS time transfer used for the Circular T 238 was disturbed *round about on the MJD on question*: 54384. In addition to the bump before 54384, there is unfortunately a gap of about 10 hours in the PTB GPS data file between MJD 54383 18h 36m 30s to MJD 54384 05h 28m 30s, noting that the normal interval is 780 seconds. The value on MJD 54384 of Circular T 238 used for the JRG calibration was without any doubt affected by the disturbance and the gap in the GPS data.

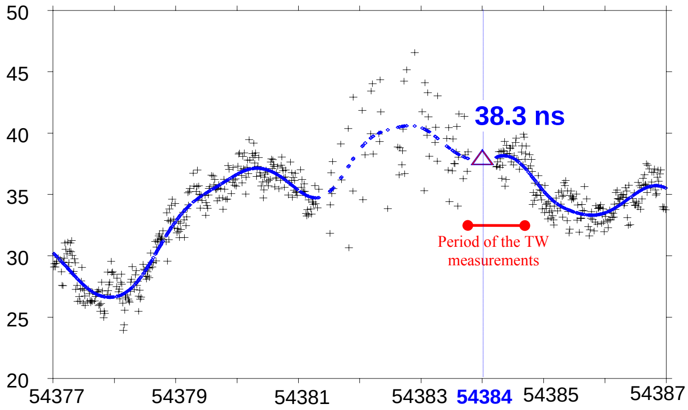

Figure 2.1 GPS AV time transfer link between BEV and PTB used for the Circular T 238. From MJD 54381.1 to 54383.8, the GPS link was disturbed, and just before and after 54384.0, there is a gap of 10 hours. The Circular T 238 was affected by the disturbance. The blue curve is the Vondrak smoothing and the sigma of the residuals of the smoothing is 1.386 ns. The short red line is the 1-day duration of the TW measurements (see Figure 1.1), of which the first half is corresponding to the gap in GPS link data.

2.2 Improving the JRG calibration

A procedure was proposed in [4] to transfer the TW calibration to GPS PPP Rxs. The same procedure can be used to improve the calibration of the BEV GPS MC Rx. As illustrated in Figure 2.1, the second half (MJD 54384.23 - 54384.56) of the 1-day TW measurements covers a period of the non-disturbed GPS measurement, totally 26 GPS points (Tab. 2.2.1) and 41 TW points (Tab. 2.2.2).

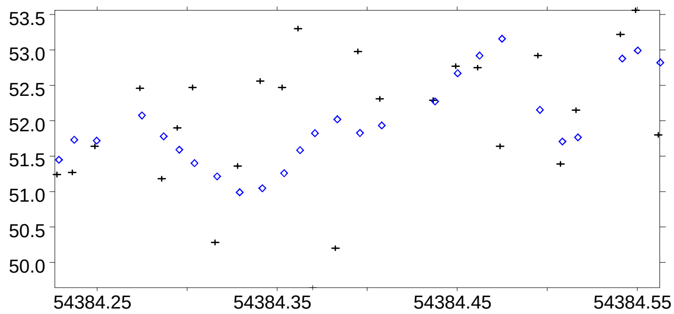

Figure 2.2 Comparison of the BEV-PTB time links corresponding to Table 2.2.3. The black crosses are the GPS and the blue squares are the TW. The GPS is much noisy than the TW. The number of the compared points is 26. The mean value between the GPS and TW is -13.983±0.189 ns which is removed in the plot (cf. Tab. 2.2.3).

The principal idea to improve the calibration is to use this common part where both TW and GPS were available and not disturbed to compute the difference between TW and GPS. Table 2.2.3 lists the 26 differences of the two links with the TW measurements interpolated onto the GPS epochs. The GPS data interval is 16 minutes and the TW interval is about 10.5 minutes which is small enough for an accurate interpolation. It is important to note here that, by making the differences between the two links, the clocks are cancelled. The differences are nothing but the total calibration constant plus the measurement errors. The later, as shown in Figures 1.2 and 2.2, mainly come from the GPS measurement instability. The mean value of the difference is -13.982 ns. The standard deviation of the 26 differences is ±0.964 ns. So the standard deviation of the mean value is $\pm 0.964/\sqrt{26} = \pm 0.198$ ns (see table 2.2.3).

Tab. 2.2.1 BEV-PTB GPS link /ns

MJD	GPS/ns
54384.22813	37.270
54384.23924	37.300
54384.25035	37.670
54384.27257	38.490
54384.28368	37.210
54384.29479	37.930
54384.30590	38.500
54384.31701	36.310
54384.32813	37.390
54384.33924	38.590
54384.35035	38.500
54384.36146	39.330
54384.37257	35.670
54384.38368	36.230
54384.39479	39.010
54384.40590	38.340
54384.43924	38.320
54384.45035	38.800
54384.46146	38.780
54384.47257	37.670
54384.49479	38.950
54384.50590	37.420
54384.51701	38.180
54384.53924	39.250
54384.55035	39.590
54384.56146	37.830

BEVPTB.MMMA_.dat

Tab. 2.2.2 BEV-PTB TW link /ns

MJD	TW/ns
54384.23194	51.747
54384.24028	51.773
54384.24236	51.912
54384.24444	51.615
54384.24653	51.697
54384.27361	52.129
54384.27986	51.882
54384.31528	51.281
54384.32361	51.139
54384.32569	51.229
54384.32778	51.053
54384.32986	50.903
54384.35694	51.424
54384.36319	51.699
54384.38819	52.140
54384.39028	51.868
54384.39236	51.983
54384.39444	51.844
54384.39861	52.111
54384.40694	51.952
54384.40903	52.363
54384.41111	52.351
54384.41319	52.447
54384.44028	52.307
54384.44653	52.623
54384.47153	53.185
54384.47361	53.207
54384.47569	53.345
54384.47778	52.600
54384.48194	50.768
54384.49028	51.859
54384.49236	51.621
54384.49444	52.291
54384.49653	51.697
54384.52361	51.837
54384.52986	52.819
54384.55486	53.078
54384.55694	53.277
54384.55903	52.811
54384.56111	52.894

BEVPTB.TTTT_.dat [1]

Tab. 2.2.3 Differences TW-GPS /ns

Mjd	GPS	TW	GPS-TW
54384.2281	37.270	51.747	-14.477
54384.2392	37.300	51.770	-14.470
54384.2504	37.670	51.758	-14.088
54384.2726	38.490	52.112	-13.622
54384.2837	37.210	51.817	-14.607
54384.2948	37.930	51.629	-13.699
54384.3059	38.500	51.440	-12.940
54384.3170	36.310	51.252	-14.942
54384.3281	37.390	51.028	-13.638
54384.3392	38.590	51.083	-12.493
54384.3504	38.500	51.297	-12.797
54384.3615	39.330	51.623	-12.293
54384.3726	35.670	51.864	-16.194
54384.3837	36.230	52.060	-15.830
54384.3948	39.010	51.866	-12.856
54384.4059	38.340	51.972	-13.632
54384.4392	38.320	52.312	-13.992
54384.4503	38.800	52.709	-13.909
54384.4615	38.780	52.959	-14.179
54384.4726	37.670	53.196	-15.526
54384.4948	38.950	52.192	-13.242
54384.5059	37.420	51.745	-14.325
54384.5170	38.180	51.803	-13.623
54384.5392	39.250	52.916	-13.666
54384.5503	39.590	53.031	-13.441
54384.5615	37.830	52.894	-15.064

N=26,Mean=-13.983,SD=0.964,SD/√N=0.198ns
BEVPTB.GTAT4

2.3 Uncertainty and expanded uncertainty of the improved calibration

The aim of the calibration is to calculate the UTC(BEV)-UTC(PTB). Because the TW link is calibrated, we have UTC(BEV)-UTC(PTB)=TW(BEV-PTB)= GPS(BEV-PTB)-*Total Delay*. That is, the *total delay* of the GPS Rx is simply the difference of the TW and GPS links:

Total Delay = GPS(BEV-PTB) - TW(BEV-PTB) = -13.983 ±0.198 ns

Here the ±0.198 ns is the standard deviation of the mean value. The total uncertainty of the TW calibration is 0.9 ns (Table 25 of Section 4.5.3 [1,3,7]). Therefore the total calibration uncertainty of the BEV TTS-2 No. 24 GPS Rx is $u_{B_1}=\sqrt{(0.9^2+0.198^2)}=0.92$ ns.

The GPS AV data are corrected by using the IGS precise GPS satellite orbits and ionosphere delay information [5]. Because the distance between BEV and PTB is only several hundred kilometres, the biases due to the residual influences can be well cancelled. Even so, because the simultaneous measurements were maintained only 8 hours, the comparison calibration may be subject to unexpected error sources which are not averaged out within 8 hours, such as the multi-paths or diurnal temperature variations or the residual influence of the atmosphere delays etc. On the other side, the long-term instability of the GPS receiver and the related laboratory equipment should be also taken into account in the total uncertainty budget. We hence apply a coverage factor to ensure the uncertainty estimation. If we use the coverage factors 1, 2 and 3, we obtain the uncertainty and the expanded uncertainty estimations:

$u_{B_1}= 0.92 \approx 1.0$ ns (coverage factor = 1)
$u_{B_2}= 1.84 \approx 2.0$ ns (coverage factor =2)
$u_{B_3}= 2.76 \approx 3.0$ ns (coverage factor = 3)

3. Summary

The quality of the calibration is based on the uncertainties of TW link and the comparison of the TW and GPS links. The first is 0.9 ns and the second depends on the methods used. We used the direct comparison of the 26 measurement points and considerably reduced the comparison uncertainty. Doing so, the quality of the calibration is improved.

The calibrated total delay equals the difference of the time links of GPS-TW is -14.3. The internal delay can be derived: INT DLY= **- 29.0** ns (instead of -27.3 reported by JRG-BEV [2]). The difference of the calibrations is 1.7 ns. It is suggested to use the expanded calibration uncertainty **u_{B_3} = ±3.0 ns**.

GPS-TW Link difference = **-14.0 ns ± u_B**
INT DLY= **- 29.0 ns ± u_B**
Expanded uncertainty: u_B= ±3.0 ns

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(vs. -12.3 and -27.3 ±1.9 ns in the JRG-BEV report [2])

Similar calibration can be made for the GPS TTS-2 No 55 if the GPS data are available.

Further improvement of the calibration is possible by increasing the duration of the TW-GPS comparison up to 1-3 days to average out or at least reduce the GPS bias.

Reference

[1] Becker J., Blanzano B., Koudelka O., Merdonig A., Piester D., Ressler H.: Two-Way-Satellite-Time-Transfer between BEV (Vienna) – PTB (Braunscheig), Joanneum Research Report, BEV report, 2007
[2] Niessner A.: BEV Report to BIPM on the result of the calibration of the GPS receivers, 14 Jan. 2008
[3] Niessner A.: email communication to Z. Jiang of BIPM on 28 July and 12 Aug. 2008, see ANNEX
[4] Jiang Z.: Transfer the UTC Calibration from TWSTFT to GPS PPP, BIPM TM 152
[5] Jiang Z. Petit G.: Time transfer with GPS All in View, IN Proc. ATF 2004 pp 236-243
[7] Piester D., Hlavać R., Achkar J., de Jong G., Blanzano B., Ressler H., Becker J., Merck P., Koudelka O.: Calibration of four European TWSTFT earth stations with a portable station through Intelesat 903, IN Proc. EFTF 2005 pp 360-365
[8] De Latour A., Cibiel G., Dantepal J., Dutrey J.-F., Brunet M., Ries L., Issler J.-L.: Dual frequency absolute calibration of GPS receiver for time transfer, IN Proc. EFTF 2005 pp 366-371
[9] Petit G., Jiang Z., Ulrich P., and Taris: Differential calibration of Ashtech Z-12T receiver for accurate time comparisons, IN Proc. EFTF 2000, pp. 40-44, 2000
[10] Piester D, Bauch A, Breakiron L, Matsakis D, Blanzano B, and Koudelka O: Time transfer with nanosecond accuracy for the realization of International Atomic Time, Metrologia, vol. 45, 185 – 198, 2008

ANNEX Emails of the Reference [3]:

(1).

De: Niessner Anton [mailto:Anton.Niessner@bev.gv.at]
Envoyé: **lundi 28 juillet 2008 11:19**
À: Zhiheng Jiang
Cc: Elisa Felicitas Arias
Objet: AW: GPS Calibration Report

Dear Dr. Jiang,
I can inform you that we estimated the uncertainty uB for our reference receiver by rather simple calculation:
uB(BEV) = ((uA(BEV))^2 + (uA(PTB))^2 + (uB(PTB))^2 + (uTWSTFT)^2)^0.5 =
= (1.5^2 + 0.2^2 + 0.9^2 + 0.782^2)^0.5 = **1.92653 ns**
The specific values are from CircularT and the TWSTFT Calibration Report.
Best regards
Anton Niessner

(2).

De : Niessner Anton [mailto:Anton.Niessner@bev.gv.at]
Envoyé : **mardi 12 août 2008 13:16**
À : Zhiheng Jiang
Cc : Elisa Felicitas Arias ; Hawai Konate; Mache Werner
Objet : AW: GPS Calibration Report

Dear Dr. Jiang,
> A question, if I understood well your report, the **uncertainty of the TW**
> **BEV-PTB is 0.9ns** ? (Summary in Page 69)
yes, this is the result of the measurement campaign.

> There is a TW working group meeting at SP on 2-3 Oct. Are you going to ?
no, I am not a member of this group.
Regards
Anton Niessner