METODE Experiments 2013-IV

-- MEasurement of TOtal DElay for UTC Time Link Calibration

Phase IV: Measurements at and between AOS, PL and PTB

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Résumé

During 12 July and 12 Aug., MJD 56485-56517, the BIPM GNSS calibrator (StdB) visited PL in Warsaw and AOS in Borowiec, Poland. This visit has two missions: 1) calibrations of the UTC time links of PL-PTB and AOS-PTB; 2) using the optical fiber link [1,2] between PL-AOS to study the attainable uncertainty and the characters of the StdB equipped with the GNSS receivers (Z12T, TTS3/4, PolarX3 and GTR50) using the METODE scheme to calibrate the UTC time links. Declared self-calibration capability with an accuracy of 112 ps, the optical fiber link is therefore the best uncertainty indicator at present. This TM presents the first mission and the TM 221 [3] presents the second.

Experiment setups were as similar as at the earlier ones [4,5,6]. Measurements were made at and between BIPM [4], PTB [6], PL (56485-56502) and AOS (56502-56516).

The goal of the METODE is to unify the UTC time link calibrations with different technique and reaches the type B uncertainty ≤ 2 ns, cf. [7,8] for the principles. However, this TM is not a research report but a record of the technical details of the experiments. The results given here are only preliminary and only for reference but publication in any case.

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Notation

METODE: MEasurement of TOtal DElay, a scheme with related methods and equipments proposed by BIPM for UTC time link calibration

u_A,u_B: type A and type B uncertainties

Link: a time link is a clock comparison result using a particular technique, e.g., a link of GPS C/A, P3, PPP or GLN or TWSTFT. A UTC link is a time link between a UTC Lab(*k*) and PTB

Baseline: a baseline between two clocks or laboratories may be measured by several links using different techniques. A baseline may be short in a same laboratory or long between two continents

CC: common clock(s); **SCC/DCC:** single/double CC; **CCD**: CC difference; **CCB/CCL**: CC baseline/link;

$\mathbf{Dly_{R/i}}$: the total delay of a *receiver* system at Lab(*i*), *i* = BIPM, PTB, Lab(*k*), …

$\mathbf{Dly_{L/ij}}$: the total delay of a time *link* system which is defined as the difference of Dly_{Ri} and Dly_{Rj}

$\mathbf{Ref_i}$: the reference or mast receiver at Lab(*i*)

$\mathbf{Std_B}$: the BIPM standard traveling calibration station (calibrator) consisting of N ≥2 GNSS receivers+antennas+pps/freq.distributors+cables. It is a black box calibrator with unknown but a constant delay during a calibration tour. The output is Z12T0

RCV0: mean value of two receiver measurements: Rcv0=½[Rcv1+Rcv2]. Z12T0 is that of the two Z12Ts receivers used as the BIPM stationary reference and GRT0 is that of the two GTR50 traveling receivers in the Std_B.

$\mathbf{UTCP_i}$: the UTC point at Lab(*i*)

$\mathbf{CLBP_i}$: the calibration point at Lab(*i*). The $Dly_{R/i}$ is the total delay between this point and the phase center of the antenna at laboratory *i*

$\mathbf{\Delta_i}$=$CLBP_i$–$UTCP_i$ is the delay between the UTCP and CLBP. Δ is considered as known in the following discussion.

I. Summary

The last BIPM calibration for AOS was carried in 2010 [9]. It was made with TTS3 of AOS which was then after used to calibrate the master receiver TTS2 at PL. When TTS4s became their master GNSS receivers, they were relatively calibrated with the TTS3 and TTS2 correspondingly.

During 12 July and 13 Aug. 2013, MJD 56485-55517, the BIPM METODE calibrator was installed at PL/GUM in Warsaw and at AOS in Borowiec in Poland. Before that, the calibrator had visited separately the OP and PTB [4-6]. Together with the starting and closure measurements at the BIPM, we can compute the calibration corrections for the UTC time link PL-PTB and AOS-PTB with the METODE scheme. We use the PPP solutions for all the calibration computations. The setup requirement can be found in [10].

The calibration result is the time link corrections. From the Table 3.1, we obtain the Table 1.1a. The total delay corrections should be *subtracted*[1] from the CAB DLY of the GNSS receiver to be calibrated, e.g. from the total delay of the master GNSS receiver TTS4 sn112 (cf. Table 1.1a). However the TW calibration correction should be *added* to the present CLAR value of the TWSTFT link AOS-PTB. For example, the CALR in the raw data file: TWAOS56.437 is -164.141 ns for AOS01 AOS01 PTB01 14 56467. The correction in Table 1.1a for TW AOS-PTB is +1.861 ns. The calibrated CALR is equal to -164.141+(+1.861)=-162.280 ns. Accordingly, the CALR for PTB-AOS is +162.280 ns. Table 1.1b is derived from the Table 1.1a.

Table 1.1a The total delay correction for the UTC GPS and TW time links

Labo	Time link	Total delay correction /ns
PL	GPSPPP:/P3 TTS4 sn108-PTBB	**0.680**
AOS	GPSPPP/P3: TTS4 sn112-PTBB	**-0.276**
AOS	TW: AOS-PTB	**1.9/-162.3**

Table 1.1b The total delay correction for the non UTC GNSS and TW time links

Labo	Time link	Total delay correction /ns
PL	GPS L1C: TTS2-PTBB	
PL	GPS L1C: TTS4-PTBB	
PL	GLONASS L1C: TTS4-PTBB	
AOS	GPS L1C: TTS3-PTBB	
AOS	GPS L1C: TTS4-PTBB	
AOS	GLONASS L1C: TTS3-PTB	

Based on this and earlier experiments [3-6,11], the *total uncertainty* of the *total delay* in the METODE link calibration is composed of (values on average are given here):

- Measurement uncertainty (u_A): about 0.1 ns~0.3 ns (u_A of PPP link);
- Calibration uncertainty of the calibrator Std_B: 0.3~1.0 ns;
- Instability of the reference and travel receivers: 0.5~0.8 ns;
- Uncertainty relating to the measurements of UTCp-CLBp: 0.2~0.5 ns;
- Others 0.3~0.6 ns (unexpected)

The total uncertainty of METODE U_M is hence 0.8~1.5 ns (1σ), compared with 0.8~1.8 ns given in [11]. This uncertainty does not include that of the cable/devices measurements in lab(k) nor long-term variations.

As shown in Figures in the sections 3.1 and 3.2, the GTR50 [20] receivers were disturbances due to the measurement noise and instabilities in the internal receiver reference or the antenna-cable system. This is expected to be partially averaged out and the residual impact is included in the instability or unexpected error sources in the total uncertainty estimation above. The advance of the GTR50 is that after changing setups, the internal delay keeps no change with an instability of about 0.5 ns on average [4,5,20]. However, this experiment also suggests that the GTR50 is less stable than TTS4 in short terms with, from time to time, the presents of daily biases.

Given the relations between the master (UTC) time link and other time links, we can compute the required calibration corrections. As discussed and computed in [8,12], the total delay can be converted to the classical differential receiver calibration results.

[1] keep the sign in GNSS_CLB.Lst file

Similar discussions about the link calibrations by different authors using different schemes can be found in [12-18]. It is no need to repeat all here.

II. Experiment setups

2.1 The BIPM METODE calibrator StdB

The BIPM METODE UTC time link calibration system is composed mainly two "black boxes", one fixed and the other mobile, cf. Figure 2.1.1. "Black" here means the internal delays are unknown and not needed to be known[2]. The basic require in the METODE scheme [8] is the short term stability of the whole system during the calibration tour of typically three months. We observed the instability in the relative variations of about 1 ns over 10 days for two side by side receivers under laboratory condition [11,17]. This is the basic consideration that we need N≥2 receivers in the mobile calibrator.

The right plot in Figurers 2.1.1 illustrates the BIPM calibrator in its shipping and working condition with a pps distributor and a 10 MHz frequency distributor, two GTR50 GPS receivers and a Polarx3 GPS-GLONASS receiver as well as the related antennas, cables etc. Each receiver has its proper antenna and connecting cables hence is an independent system. The enforced shipping container severs as both the shipment box and the operational setup, Figure 2.1.2. The devices are pre-cabled in the container. The internal delays are fixed (except for the Polarx of which the receiver reference delay depends on the input frequency forms. Ideally, to reduce the systematic error by the TIC [19], a BIPM SR620 TIC[3] is shipped together with the Polarx to measure the PPS in-out delay).

The dimension of the container is 106 cm in height (with the wheels), 92 cm in length and 70 cm in width. It weights about 110 kg with the three GNSS receiver systems (Figure 2.1.2). The calibrator requires an input of the reference frequency and an input of the reference pps. The antenna support can hold three antennas and needs one male to be fixed on, as shown in Figure 2.1.2. The inter-impacts between the three antennas have been carefully studied and are within 30 ps which is practically negligible in the METODE calibration, see [10] for details.

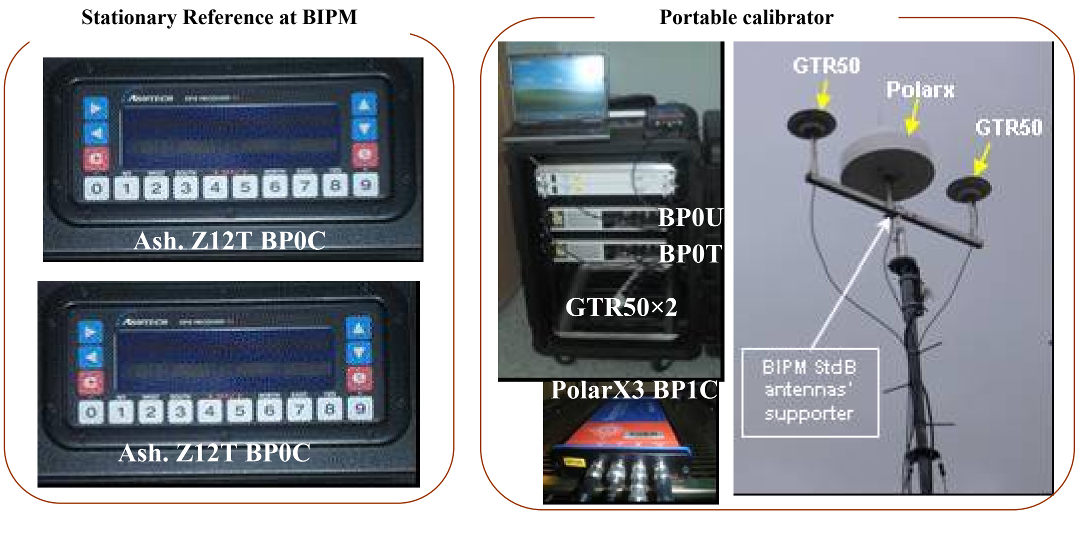


Figure 2.1.1 The BIPM calibration system

Two Pre-cabled black boxes with unknown delays only require table during calibration period (~3 months): 1) The stationary reference system fixed at BIPM.: 2) The portable calibrator with N≥2 receivers: usually 2 GTR50 GNSS and enforced with a Sept. PolarX. The BIPM antenna support can hold three antennas.

It was arranged with AOS and PL that the BIPM calibrator should visit AOS and PL and make a side by side comparison between the masters GPS receivers: TTS4 sn112 and 108 including other time transfer equipment.

[2] Except the Sept. Polarx, it needs the 'latching measurement' for each setup and this is the only measure to make

[3] The SR620 TIC shipped with Polarx3 is to reduce possible systematical error in different SR620 TICs in the PPS in-out measurements. This may be up to 0.5 ns according to the manufacture's notice. In case the BIPM SR620 TIC is not shipped, we ask the laboratory to measure the delays of at least two cables of the BIPM calibrator to validate the possible systematic biases of the TICs, e.g. the cables C151 and C157. Their delays are 10.1 ns by the BIPM SR620 TIC

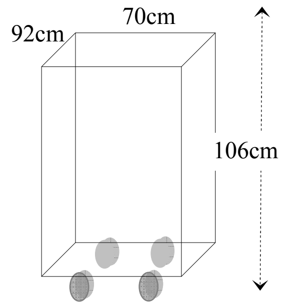


Figure 2.1.2 The shipping/working container of the BIPM calibrator
with two GTR50 GPS receivers and a Polarx3 GPS-GLONASS receiver as well as the related antennas, cables etc. in an operational setup in the enforced shipping container, 106 cm in height (with the wheels), 92 cm in length and 70 cm in width

The fully operational calibrator is comprised of three GNSS receivers: two GTR50: BP0U and BP0T and a third receiver either a TTS4 or a Septontrio PolarX. Table 2.1.1 gives the total delay values for BIPM reference and traveling receivers aligned to the reference receiver Ash. Z12T BP0M [2]. The later was differentially calibrated with respect to BP0C which was absolutely calibrated in 2001 [21-24]. Since then the two receivers have gradually a difference which becomes 1.629 ns [3]. An earlier study shows, the BP0M is now more stable than BP0C.

Table 2.1.1 Total delays of the BIPM reference and traveling receivers vs. the Ash. Z12T BP0M and PTB [4,5,6]

Receiver	Tsoft acronym	Total delay /ns	Correction 1 /ns	Correction 2 /ns	Correction 3 /ns	Correction 4 /ns [6]
BP0M	BZM3	-338.418				
BP0C	BZC3	-425.717	1.629[4]			
BP0U	BGU3	20.781				
BP0T	BGT3	17.670				
BP1C	BPC3	-64.284	44.0[5]	-213.6[6]	215.84[7]	215.84[8]

The BP0T has not visited the PTB. We differentially calibrate it vs. the BP0U, i.e. to be aligned to the BP0U to the BP0U. Figures 213a, b and c show the differences and the averages between BP0T and BP0U during three periods before and after the BP0U visited PTB: -0.066 ns, -0.961 ns and 0.153 ns. Taking the simple mean values 0.3 ns (to be added to BP0T data) as the alignment correction, the BP0T data can be used for the calibration computation. Note here that, its weight is reduced. The weight ration of BP1C:BP0U:BP0T is 2:2:1 for the measurements at PL: 56487-56490-56496, see the section III. However, as given by the 'dif.' in Table 2.1.2, with the BP1C and BP0T as references, the BP0U seems a jump down about 1 ns. The weight of BP0U is reduced with the weight ration 2:1:1 at AOS between the MJD 56511-56516.

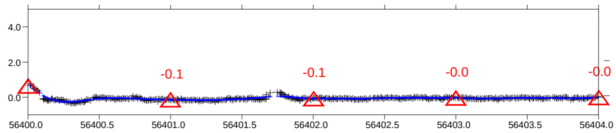


Figure 2.1.3a Differences of BP0T-BP0U between MJD 56400-56404 with average -0.066 ns

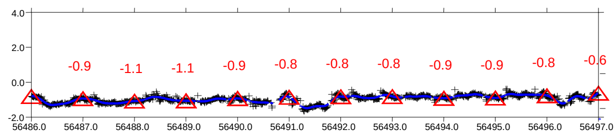


Figure 2.1.3b Differences of BP0T-BP0U between MJD 56486-56497 with average -0.961 ns

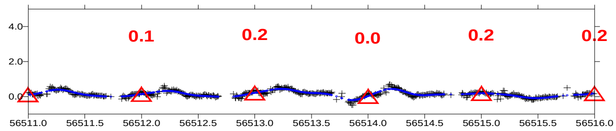


Figure 2.1.3c Differences of BP0T-BP0U between MJD 56511-56516 with average 0.153 ns

[4] Correction to BP0C vs. BP0M
[5] Setup change, cf. Table 2.2.1b of TM216 [6]
[6] Latching measurement at BIPM before going to PTB, cf. Figure 2.2.1 of [10]
[7] Latching measurement at BIPM after back from PTB, cf. Figure 2.2.1
[8] Latching measurement at BIPM after back from PTB, cf. Figure 2.2.1

Table 2.1.2 CCD of BP0U and BP0T vs. BP1C at AOS between 56511-56516

MJD	56487-490 /ns	56491-496 /ns	56511-516 /ns
BP0U-BP1C	1.066	-0.311	-1.767
BP0T-BP1C	0.353	-1.180	-1.597
Dif.	+0.713	+0.869	-0.170

Below is the description of the fully operational setup of the BIPM calibrator in the container with the three GNSS receivers.

2.2 The BIPM METODE scheme for PL and AOS

The BIPM traveling calibrator (StdB) has visited PTB. The Figures 3.2.2b and 3.2.3 of TM216 [6] demonstrated the agreements with the BIPM master reference receiver BP0C within 0.3 ns. This proves the stability of the PTBB. The differences between the PTB master receive PTBB is 1.309 ns for BP0U (GTR50) and -0.295 ns for BP1C (PolarX3), cf. Figures 3.2.2a and 3.2.3 in TM216 [6]. These values should be used to the calibration computation. The BP0T has not visited the PTB but to be aligned to the BP0U as mentioned above. Its results will be considered as a reference to check the stability of the BP0U and BP1C during the calibration tour in Poland.

By the definition of the METODE UTC time link calibration correction [6,8], we have the following steps:

- We set the PTBB to be fixed master GNSS receiver to be zero;
- We align the StdB to PTBB, i.e. the BP0U and BP1C are to be corrected 1.309 ns and -0.295 ns;
- The StdB goes to the Lab(k), k=PL, AOS …, and make side by side measurement with the master receiver of Lab(k)
- We compute the double clock difference:

DCD=[StdB-UTC(PTB)]-[UTC(k)-UTC(PTB)], k = PL, AOS (2.2.1)

Equation (2.2.1) is the basic equation for the METODE time link calibration. Note here that, the StdB keeping the calibration of PTBB is now at Lab(k) and driven by the master clock of Lab(k).The first term is therefore the true clock difference without the calibration impact. The second term can be a GPS PPP or P3 or C/A or TWSTFT link which should be equal to the first term theoretically;

- The no-zero DCD is the calibration correction to the master GNSS receiver of Lab(k).

Remark: *This DCD correction should be subtracted from the total delay of the GNSS master receiver and added to the CALR of the TW link Lab(k)-PTB*.

Tables 2.2.1 and 2.2.2 give the calibration values for the master GPS receivers and the TW links of PTB, PL and AOS.

Table 2.2.1 Total delays of the PTBB, TTS4(PL) and TTS4(AOS)
The delay values are from the CGGTTS header files of July 2013 (1307)

Rcv/Sys	P1	P2	P1-P2	P3(XR+XS)	XC	XD	XO	XO'	XP	Total Dly	Note
	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	
PTBB/PZB3	304,5	318,9	-14,4	282,252	301,7	0,0			75,3	508,652	TM172
GUM/GTa3	-22,3				138,48				96,65	19,510	
AOS/AO_3	4,3				165,65				81,9	88,040	

Table 2.2.2 The calibration value CALR in the ITU TWSTFT data file on MJD 56500

TW link	ITU file	CALR /ns	ESDVAR /ns	ID
AOS-PTB	TWAOS56.500	-164.141	0.000	
PTB-AOS	TWPTB56.500	164.141	1035.000	

The calibrator contains the BP0U, BP0T and the Sept. PolarX3 BP1C. Unlike the GTR50, the PolarX requires measuring the 1 pps pin point with respect to the local frequency forms and this is done with a TIC SR620. To evade the impact of the systematical offset in the TIC, it is better to use the same TIC for each setup.

The setups of the GTR50 BP0U and the PolarX3 BP1C at BIPM are illustrated in the Figure 2.1.1. If only for the METODE link calibration, we do not need to know the configuration and the internal delays of the calibrator with respect to the BIPM reference receiver system. However, to be able to compare the link calibration result and that of the classic method, we carefully measured the delays using two methods: the TIC and the BIPM fixed reference receivers vs. the portable calibrator. The fixed reference can be used also for the closure measurements after the calibrator coming back from PTB to verify its stability. The concerned delays are given below in the corresponding figures and tables.

Remarks:

Theoretically, the METODE does not need any known delay as reference. However, all the UTC time links should have been calibrated. Therefore we compute the calibration correction to the existing calibration. P3 and PPP have the same calibration. The relation of the P1, P2 and P3 is given by the equation:

Dly(P3)=2.545*Dly(P1)-1.545*Dly(P2) = Dly(P1)+1.545*Dly(P1-P2)

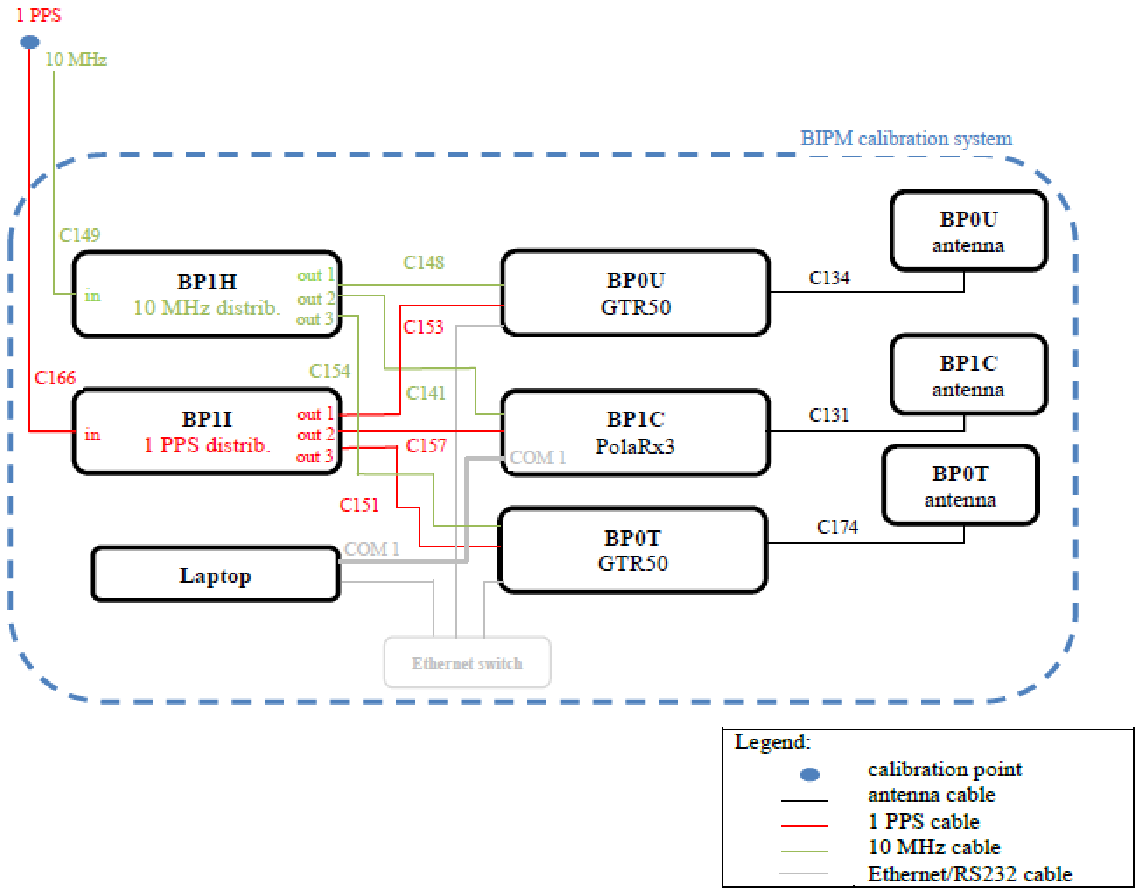
The classic calibration results are the delays of the receiver and the antenna (XR+XS). The total delay can be presented in the form of the total delay of P1 and P2 code. For example, for the BP0C.

BP0C GPS P1: -XP-XO+XR1+XC+XD+XS1 = 515.6 ns
BP0C GPS P2: -XP-XO+XR2+XC+XD+XS2 = 531.9 ns

Table 2.1.1 gives the calibration information at PTB in which the total delays and related corrections of receivers BP1C and BP0U. BP0T is aligned to the BP0U.

2.3 The calibrator setups

The setup of the BIPM time link calibrator StdB is kept always the same, that is, the internal delays are kept no change as its visit to PTB.



<**Figure 2.3.1** The calibrator setups at the BIPM, PL and AOS [10]

III. The calibration measurements

The calibration measurements were made between 56487-56489 and 56491-56495 at PL. The first setup was in the main laboratory on the ground floor. Due the failure of the air-conditioner, the StdB was move to the basement laboratory and that was the setup2. On 56496, the StdB was moved to AOS and the UTC time link calibration measurements were carried out during 56511-56516. Between from 56496 to 56510, the StdB was used for the optical fiber link calibration experiment setups at PL and AOS, cf. TM221 [3].

We use the equation (2.2.1) for the time link calibration.

The Tables 3.1.1-3.2.1 are the summaries of the calibrations of demonstrated in the Figures in the section 3.1 and 3.2. Here the PL stands for master GNSS receiver TTS4 sn 108 and AOS for the TTS4 sn 112. CCD is the common clock differences of the Lab(k) master receiver and one of the StdB receivers. Link is the time link between the StdB, Lab(k) and PTB.

As concluded in the TM216 [3], the BP0U and BP1C have been aligned to the PTBB buy not the BP0T which is aligned to the BP0U. The weighted meaning value is used with the ratio of the weights for the BP1C:BB0U:BP0T = 2:2:1, except AOS 56511-56516 when the BP0U was biased (Sec. 2.1) hence the ratio is 2:1:1. The link calibration result is used as the final result. Based on the Tables 3.1.1-3.2.1, Table 3.1 lists the final results for PL and AOS.

Table 3.1 summary of the Tables 3.1.1, 3.1.2 and 3.2.1

Lab(k)	Setup)	Calibration type	MJD	Result	weight	Weight-mean /ns	Remark of weight
PL	1	Receiver	56487-56490	1.175±0.052	0		
	1	Link	”	1.136±0.052	0		1 day data
	2	Receiver	56491-56495	0.773±0.053	0		
	2	Link	”	0.680±0.053	**1**	**0.680**±0.053	5 day data
AOS	2	Receiver	56511-56516	-0.280±0.053	0		
	2	Link	”	-0.276±0.053	**1**	**-0.276±0.053**	5 day data

Table 3.1.1a Setup1 at PL: Receiver calibration between 56487-56490 (Figures 3115-3117)

CCD	Average±σ /ns	weight
BP1C-PL	0.947±0.033	1
BP0U-PL	1.557±0.066	1
BP0T-PL	0.869±0.065	0.5
Weight mean	**1.175±0.052**	2.5

Table 3.1.1b Setup1 at PL: Link calibration between 56487-56490 (Eq. 2.2.1, Figures 3111-3114)

Link	Average /ns	DCD /ns	weight
PL-PTBB	-6.238		
BP1C-PTBB	-5.351	0.887	1
BP0U-PTBB	-4.692	1.546	1
BP0T-PTBB	-5.426	0.812	0.5
Weight mean		**1.136±0.052**	2.5

Table 3.1.2a Setup2 at PL: Receiver calibration between 56491-56495 (Figures 3125-3127)

CCD	Average±σ /ns	weight
BP1C-PL	1.035±0.034	1
BP0U-PL	0.721±0.069	1
BP0T-PL	0.155±0.075	0.5
Weight mean	**0.733±0.055**	2.5

Table 3.1.2b Setup2 at PL: Link calibration between 56491-56495 (Eq. 2.2.1, Figures 3121-3124)

Link	Average /ns	DCD /ns	weight
PL-PTBB	-11.700		
BP1C-PTBB	-10.651	1.049	1
BP0U-PTBB	-11.111	0.589	1
BP0T-PTBB	-11.578	0.122	0.5
Weight mean		**0.680±0.055**	2.5

Table 3.2.1a Setup1 at AOS: Receiver calibration between 56511-56516 (Figures 321-323)

CCD	Average±σ /ns	weight
BP1C-AOS	0.490±0.019	1
BP0U-AOS	-1.280±0.077	0.5
BP0T-AOS	-0.818±0.073	0.5
Weight mean	**-0.280±0.053**	2.0

Table 3.2.1b Setup1 at AOS: Link calibration between 56511-56516 (Eq. 2.2.1, Figures 324-327)

Link	Average /ns	DCD /ns	weight
AOS-PTBB	4.408		
BP1C-PTBB	4.898	0.490	1
BP0U-PTBB	3.130	-1.278	0.5
BP0T-PTBB	3.600	-0.808	0.5
Weight mean		**-0.276±0.053**	2.0

3.1 The calibration measurements at PL

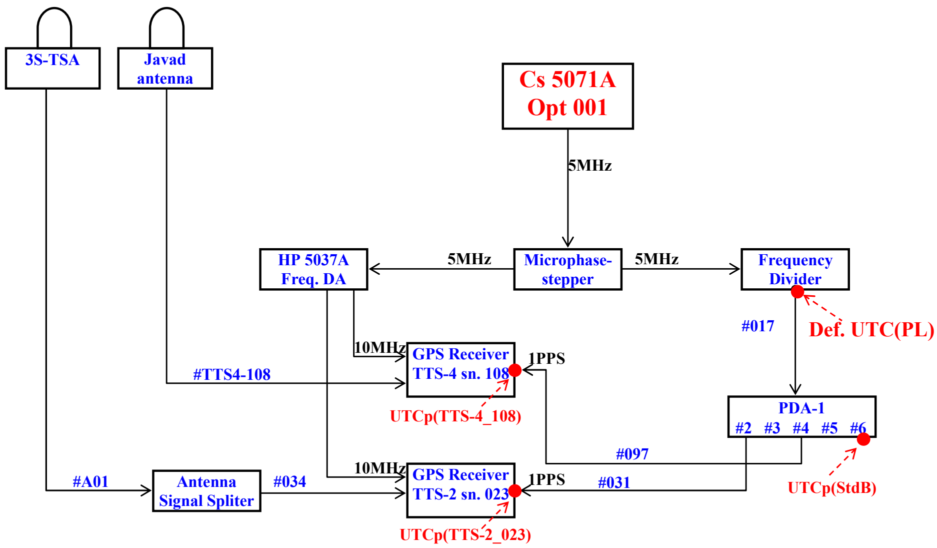


Figure 3.1a Setup 1 on the ground floor: Std_B and the PL devices (Room 20C, 56487-56489)

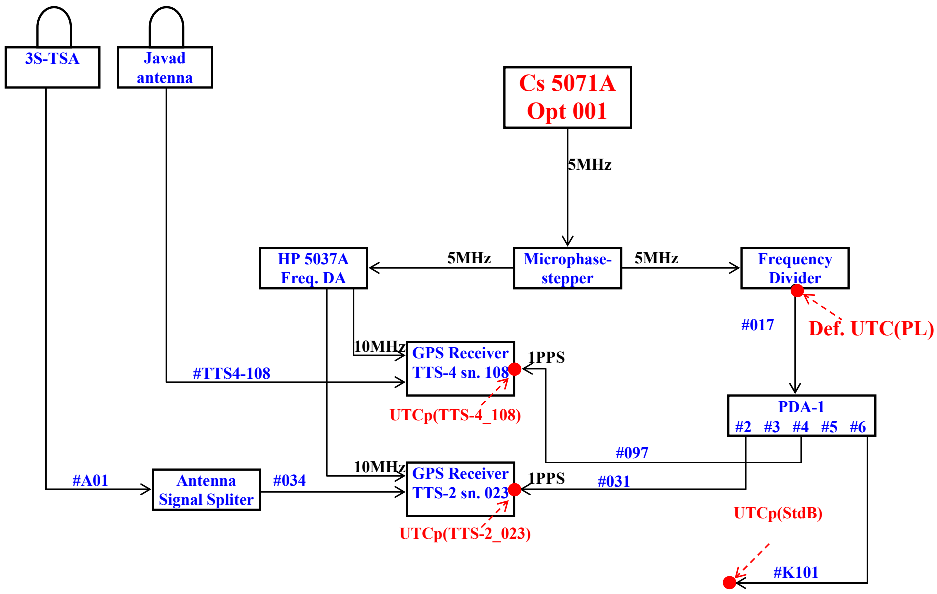


Figure 3.1b Setup 2 in the basement: Std_B and the PL devices (Room 061a, 56491-56495)

Table 3.1 Delays of the cables and devices at PL

Cable/device	Delay	Expanded uncertainty Type A	**Delay of StdB** (BNC ~ 0.1 ns)
#017	64.50 ns	± 0.20 ns	
PDA-1 #2	7.20 ns	± 0.20 ns	
PDA-1 #4	6.80 ns	± 0.20 ns	
PDA-1 #6	6.8 ns	± 0.20 ns	64.5+6.8+0.1=71.4±0.34ns
#097	25.25 ns	± 0.20 ns	
#031	35.30 ns	± 0.20 ns	
#K101	50.39 ns	± 0.20 ns	71.3+50.39+0.1=121.8±0.34 ns
#TTS4-108	138.48 ns	± 0.20 ns	
#A01	251.27 ns	± 0.20 ns	
#034	8.76 ns	± 0.20 ns	
Antenna Signal Splitter	4.7 ns		the same for all channels (1-4)

3.1.1 The first setup 56487-56489 at PL

```
--- Calibration to Lab RefGps:
   1: BPC3 71.4 -3.592 -225.184 201.13,      Total=    43.754 ns
   2: BGU3 71.4 20.781 -5.221,               Total=    86.960 ns
   3: BGT3 71.4 17.670 0 -5.221 0.3,         Total=    84.149 ns
   4: ATs3 0,                                Total=     0.000 ns
   5: AO_3 -88.040,                          Total=   -88.040 ns
   6: GTa3 -19.51,                           Total=   -19.510 ns
   7: PZB3 -508.652,                         Total=  -508.652 ns
```

The air-conditioner was out of service during the first setup measurements which were suffered a strong temperature affect for the two GTR50 receivers and only the data of the last one-day was collected. The PolarX receiver seemed not so influenced by the high temperature. The results were computed for reference but taken into account into the calibration, see Table 3.1.

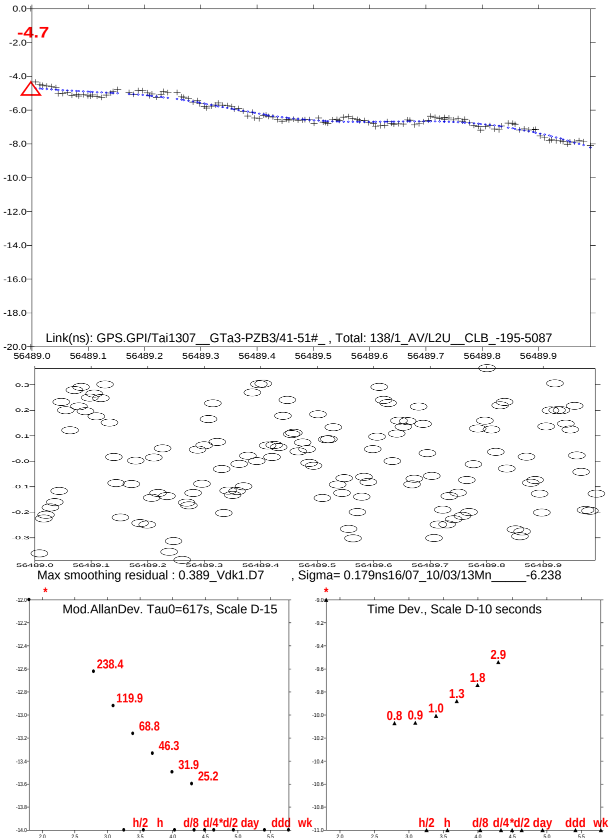


Figure 3.1.1.1 Link PL-PTBB av=-6.238±0.179ns

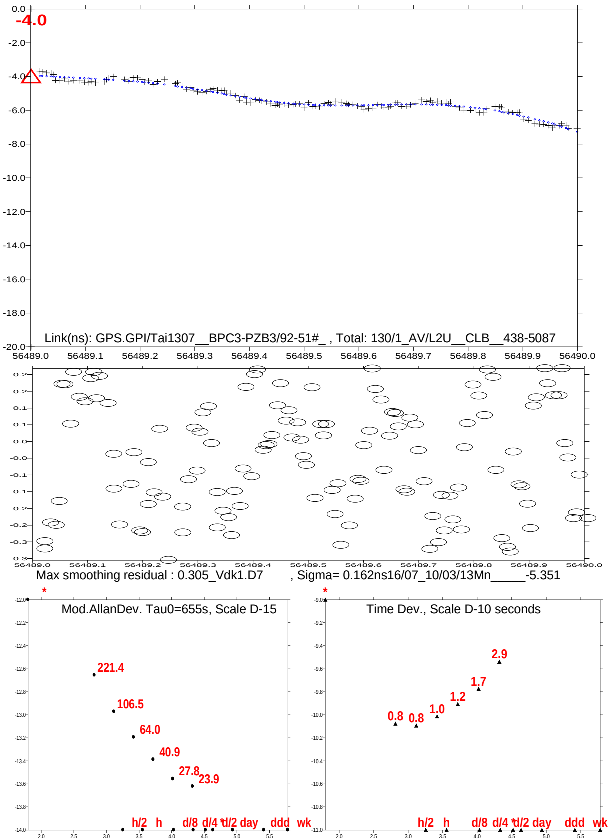


Figure 3.1.1.2 Link BP1C-PTBB av=-5.351±0.162ns

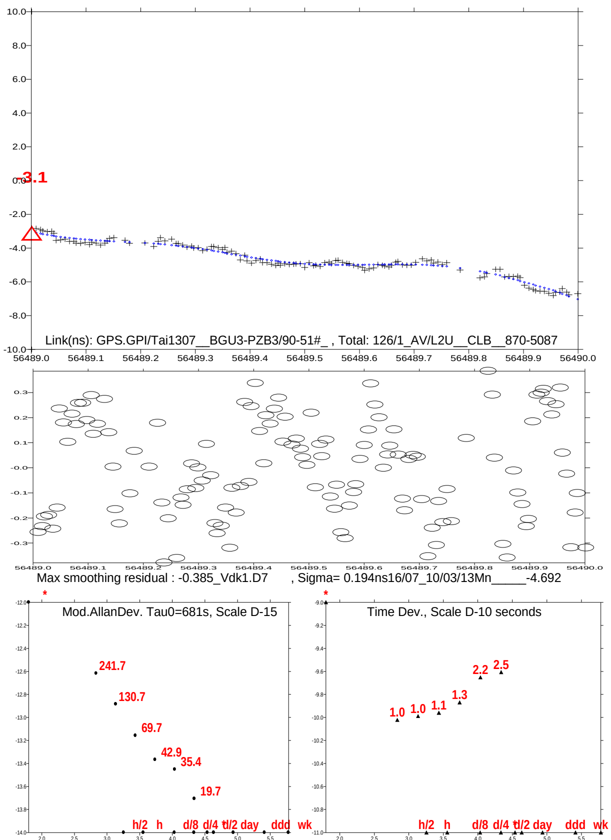


Figure 3.1.1.3 Link BP0U-PTBB av=-4.692±0.204ns

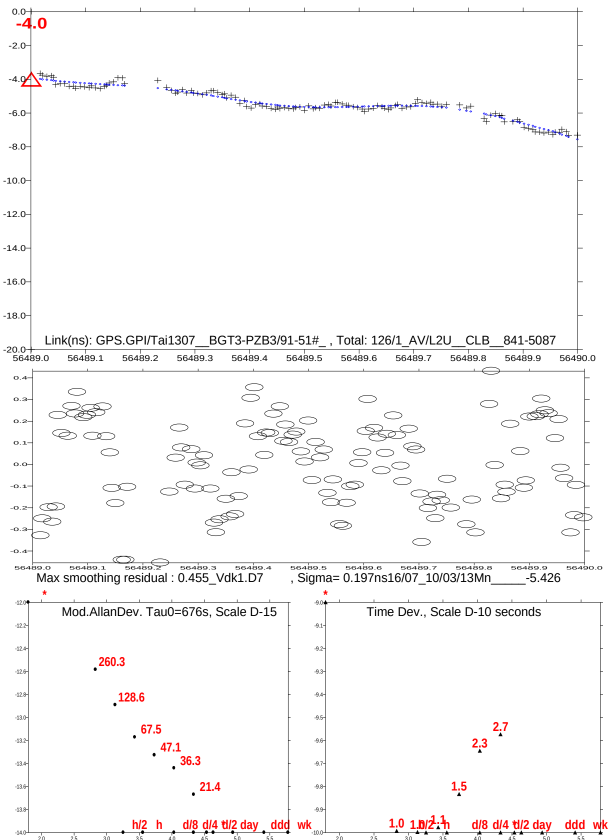


Figure 3.1.1.4 Link BP0T-PTBB av=-5.426±0.197ns

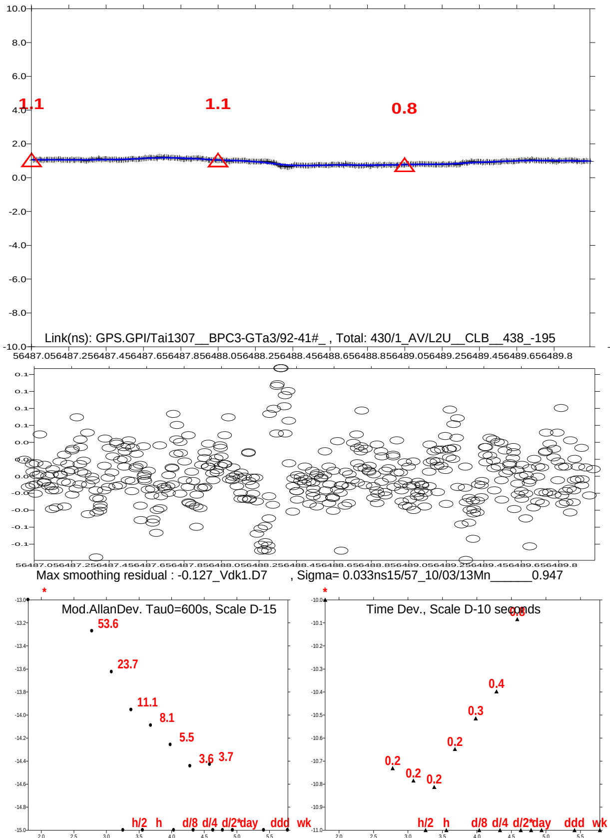


Figure 3.1.1.5 CCD BP1C-PL av=0.947±0.033ns

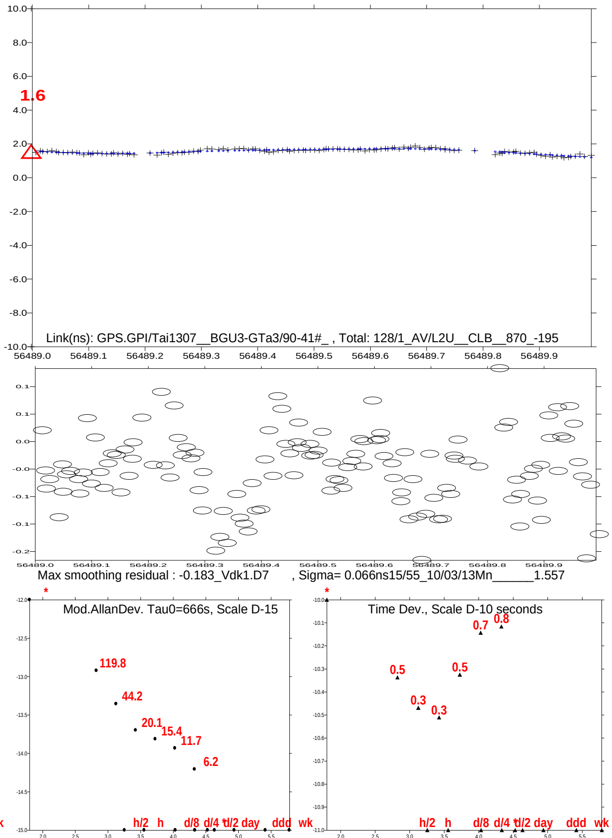


Figure 3.1.1.6 CCD BP0U-PL av=1.557±0.066ns

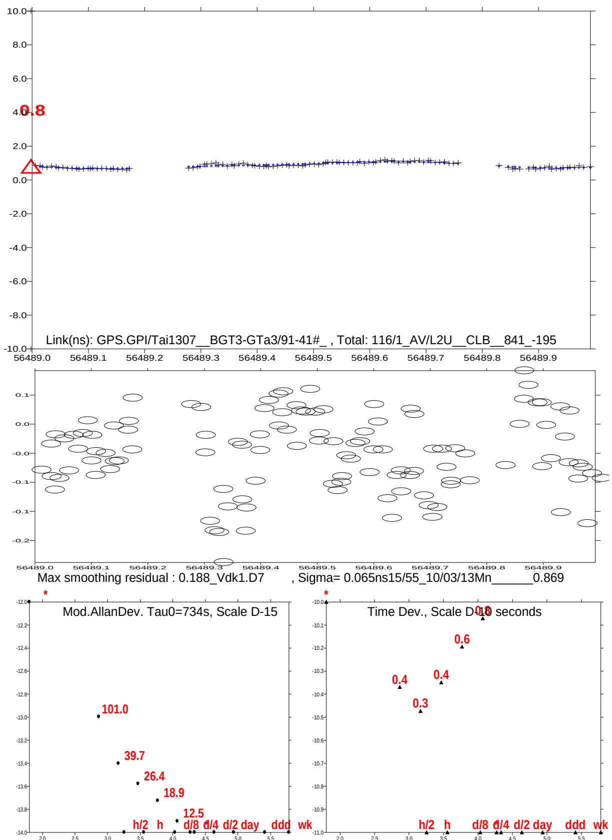


Figure 3.1.1.7 CCD BP0T-PL av=0.869±0.065ns

3.1.2 The second setup 56491-56495 at PL

```
--- Calibration to Lab RefGps:
   1: BPC3 121.8 -3.592 -225.184 203.94,     Total=    96.964 ns
   2: BGU3 121.8  20.781 -5.221,             Total=   137.360 ns
   3: BGT3 121.8  17.670 -5.221 0.3 0,       Total=   134.549 ns
   4: AO_3 -88.040,                          Total=   -88.040 ns
   5: GTa3 -19.51 0,                         Total=   -19.510 ns
   6: PZB3 -508.652,                         Total=  -508.652 ns
```

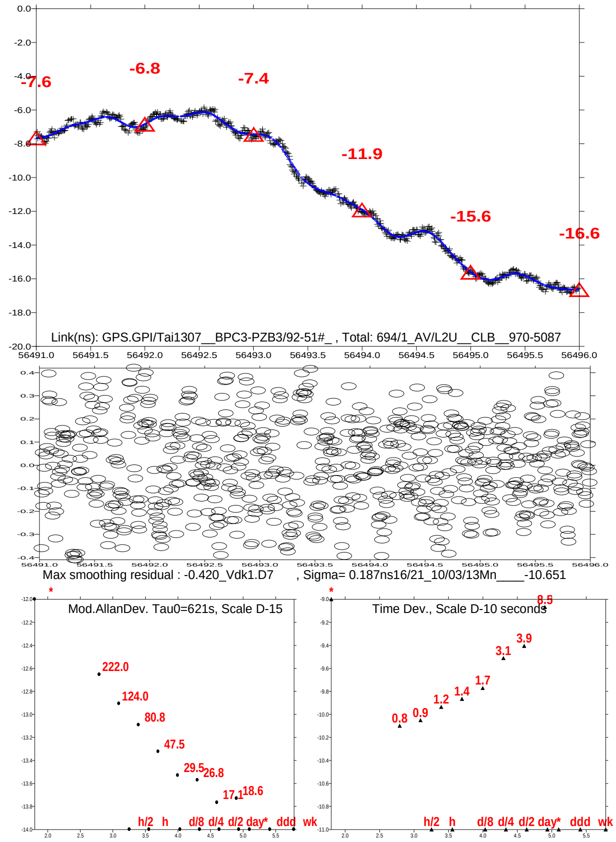


Figure 3.1.2.1 Link BP1C-PTBB av=-10.651±0.187ns

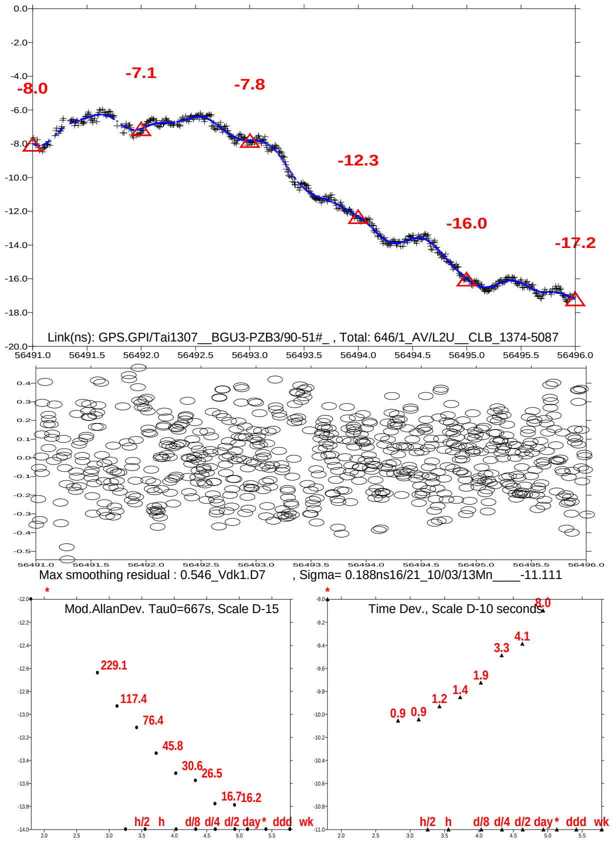


Figure 3.1.2.2 Link BP0U-PTBB av=-11.111±0.188ns

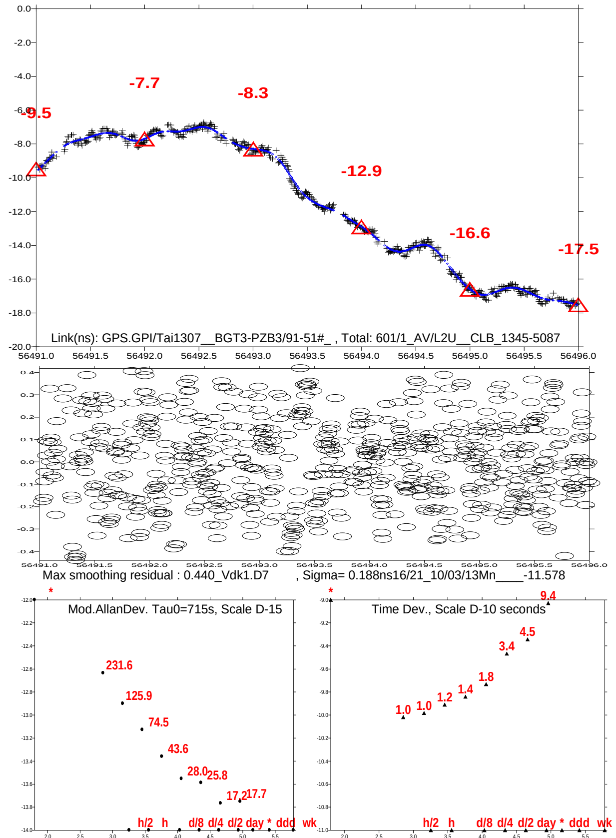


Figure 3.1.2.3 Link BP0T-PTBB av=-11.578±0.189ns

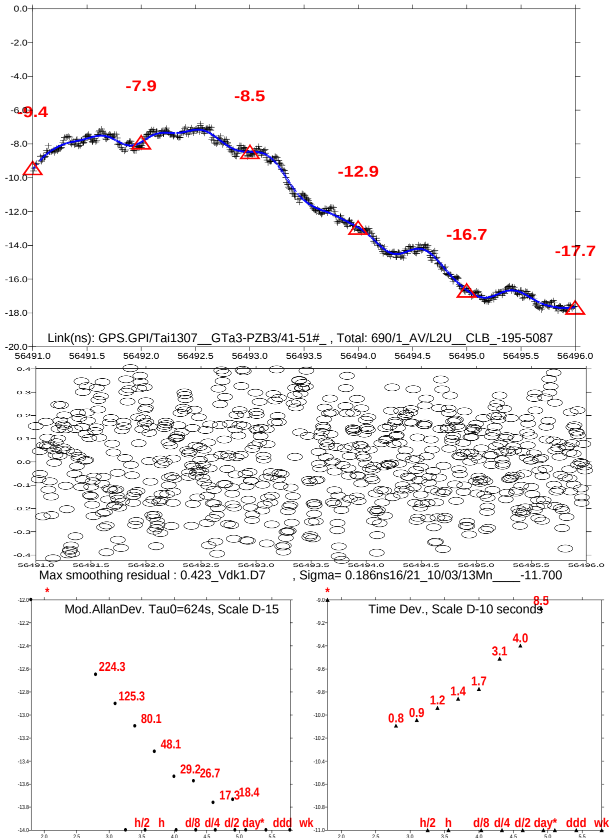


Figure 3.1.2.4 Link PL-PTBB av=- 11.700±0.186ns

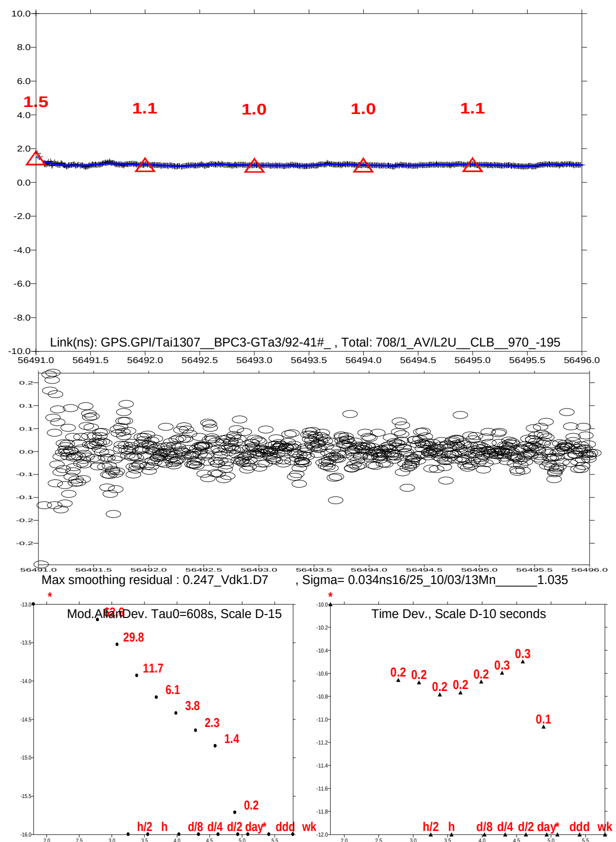


Figure 3.1.2.5 CCD BP1C-PL av=1.035±0.034ns

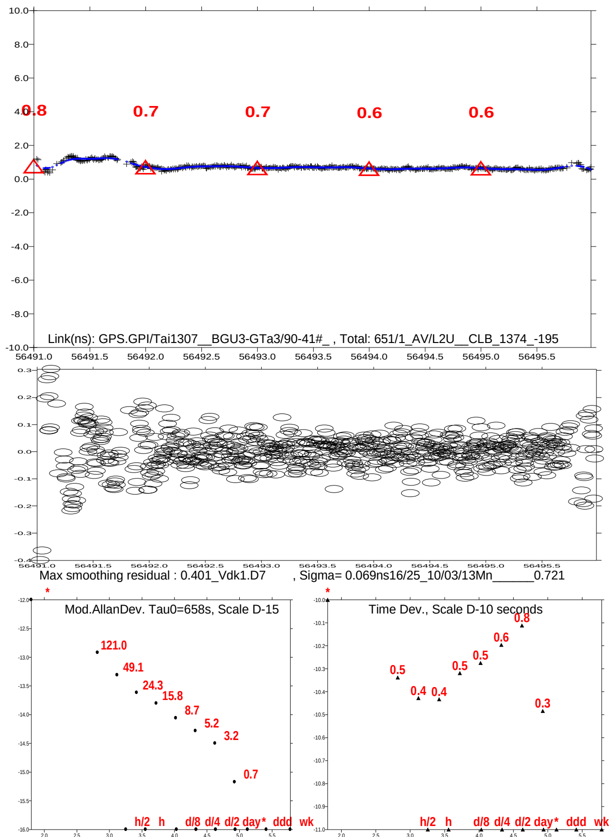


Figure 3.1.2.6 CCD BP0U-PTBB av=0.721±0.069ns

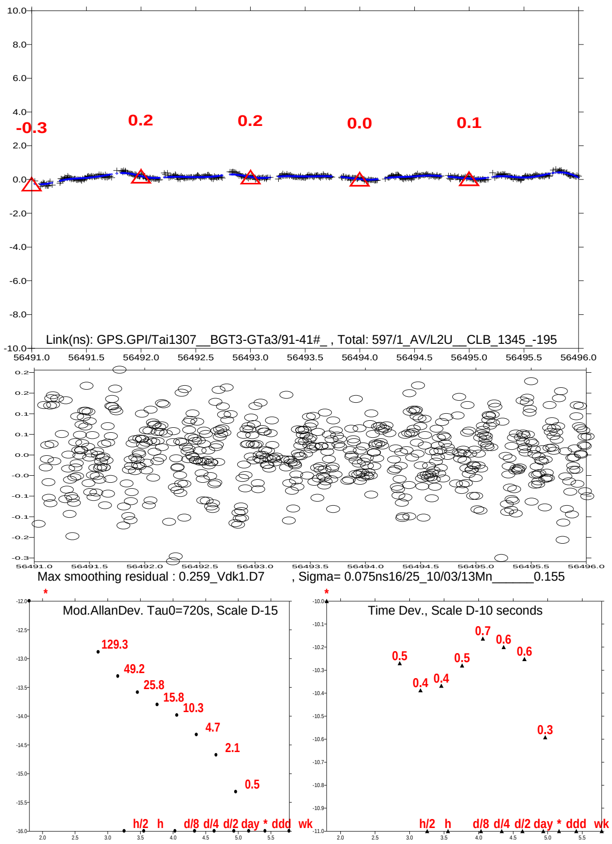


Figure 3.1.2.7 CCD BP0T-PL av=0.155±0.075ns

3.2 The calibration measurements at AOS between 56511-56516

Jerzy, please supply this plot

Figure 3.2 Setup 2 StdB and the AOS devices

```
--- Calibration to Lab RefGps:
   1: BPC3 -3.592 -225.184 213.469 -24.965,  Total=   -40.272 ns
   2: BGU3 20.781 -5.221,                    Total=    15.560 ns
   3: BGT3 17.670 -5.221 0.3,                Total=    12.749 ns
   4: AO_3 -88.040,                          Total=   -88.040 ns
   5: GTa3 -19.51,                           Total=   -19.510 ns
   6: PZB3 -508.652,                         Total=  -508.652 ns
```

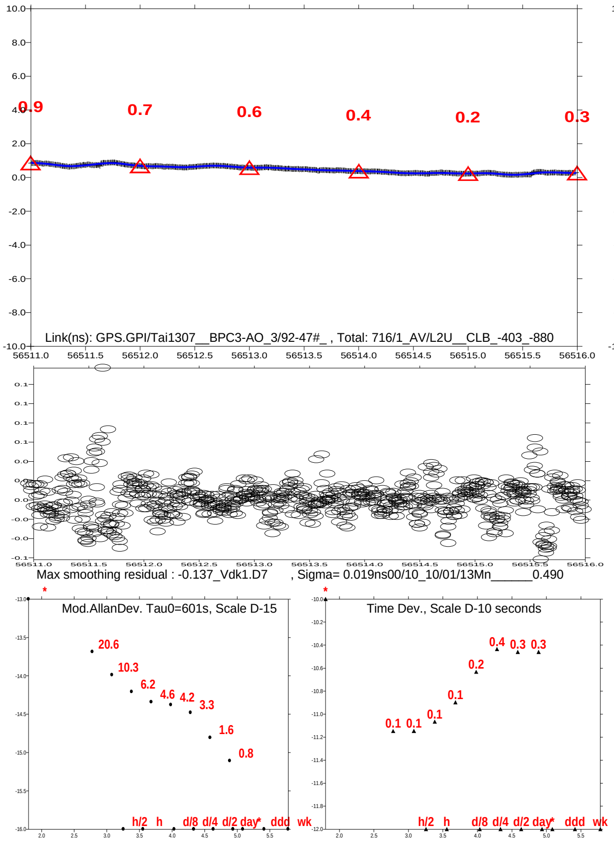


Figure 3.2.1 CCD BP1C-AOS av=0.490±0.019ns

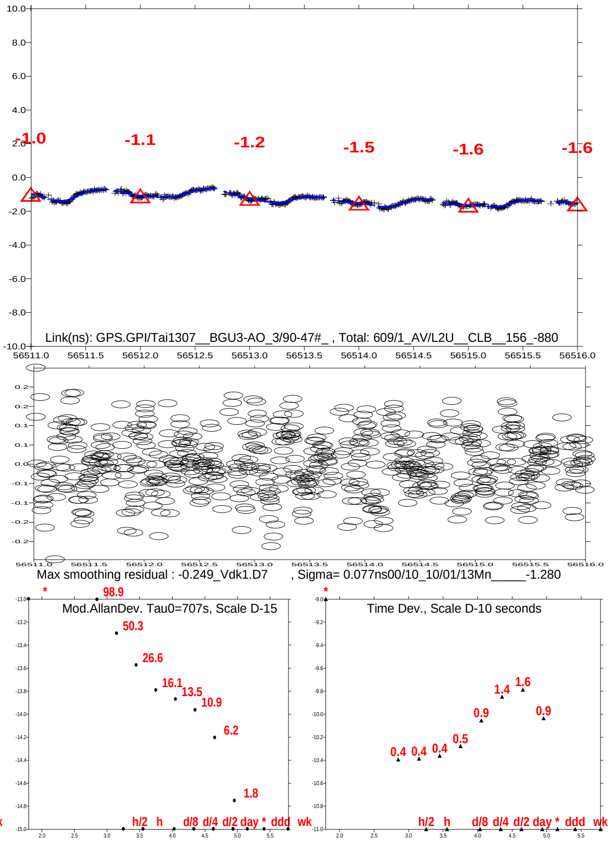


Figure 3.2.2 CCD BP0U-AOS av=-1.280±0.077ns

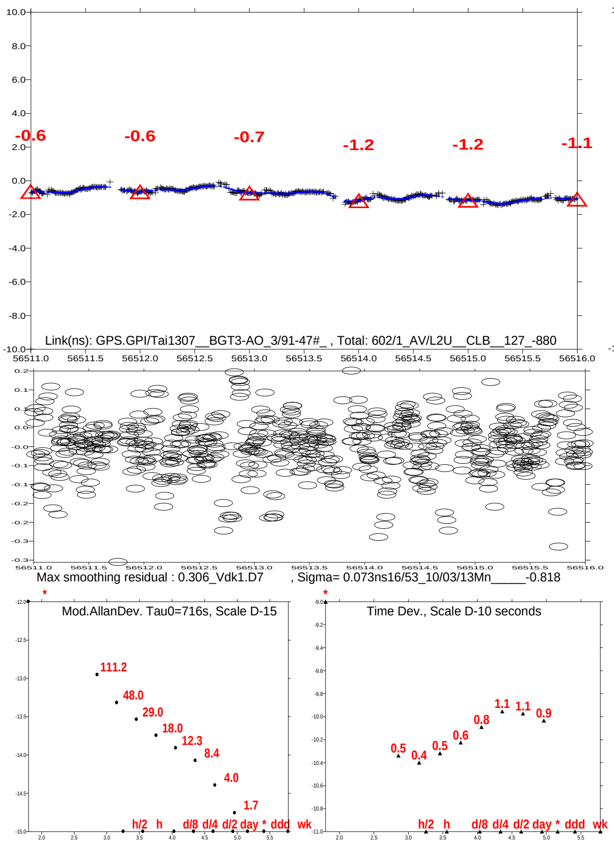


Figure 3.2.3 CCD BP0T-AOS av=-0.818±0.073ns

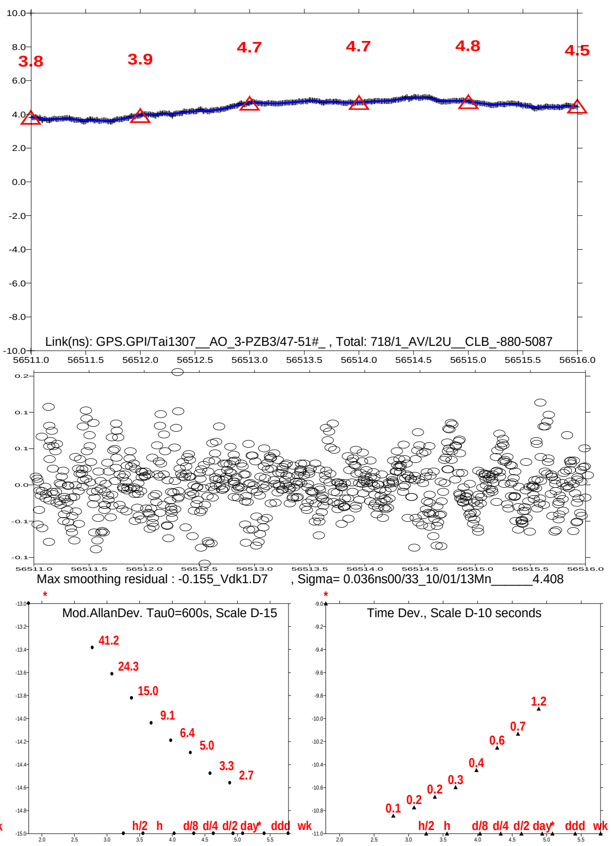


Figure 3.2.4 Link AOS-PTBB av=4.408±0.036ns

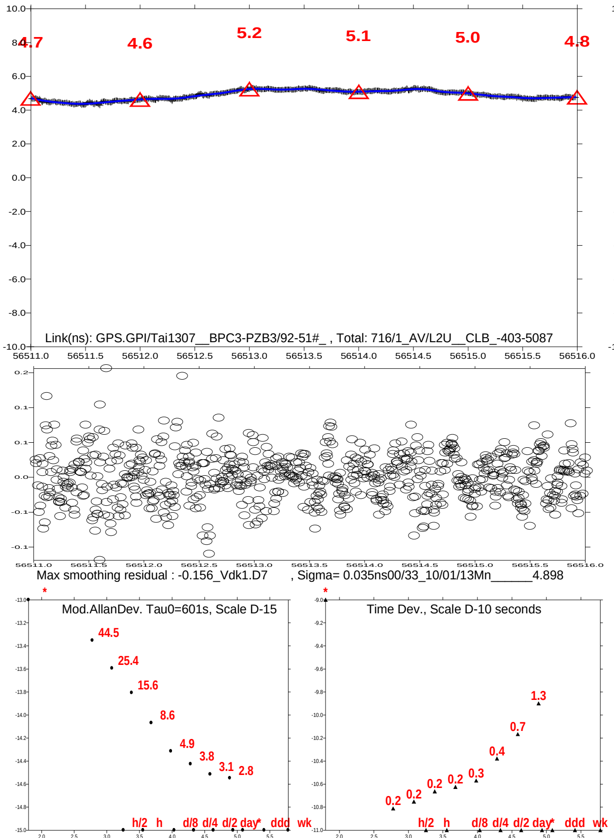


Figure 3.2.5 Link BP1C-PTBB av=4.898±0.035ns

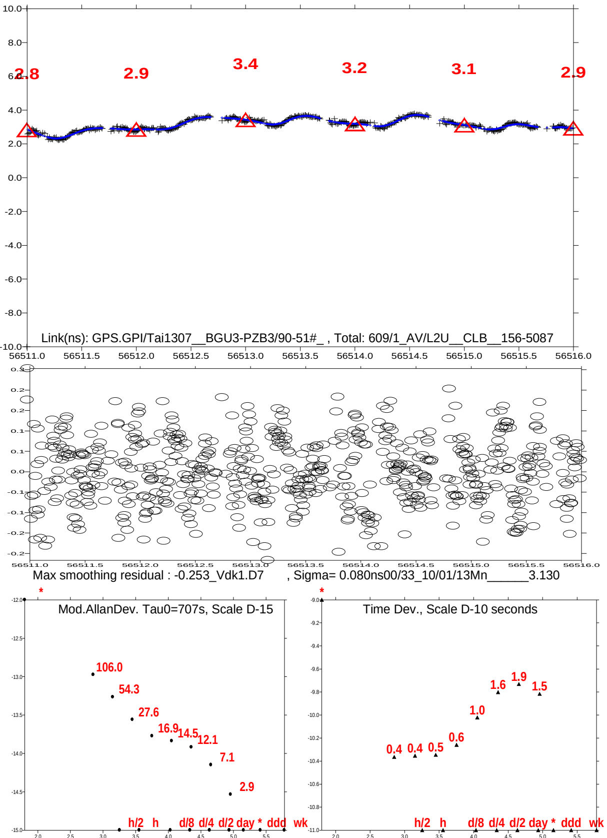


Figure 3.2.6 Link BP0U-PTBB av=3.130±0.080ns

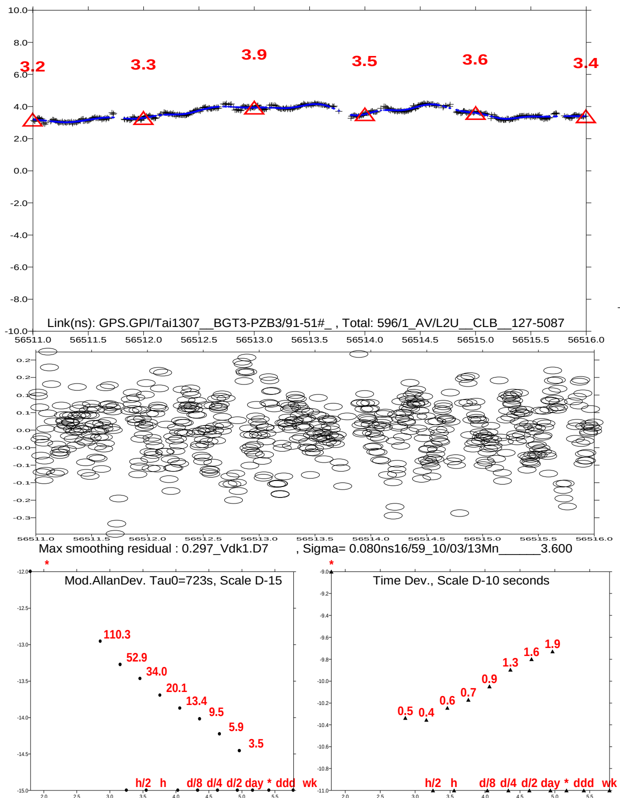


Figure 3.2.7 Link BP0T-PTBB av=3.600±0.080ns

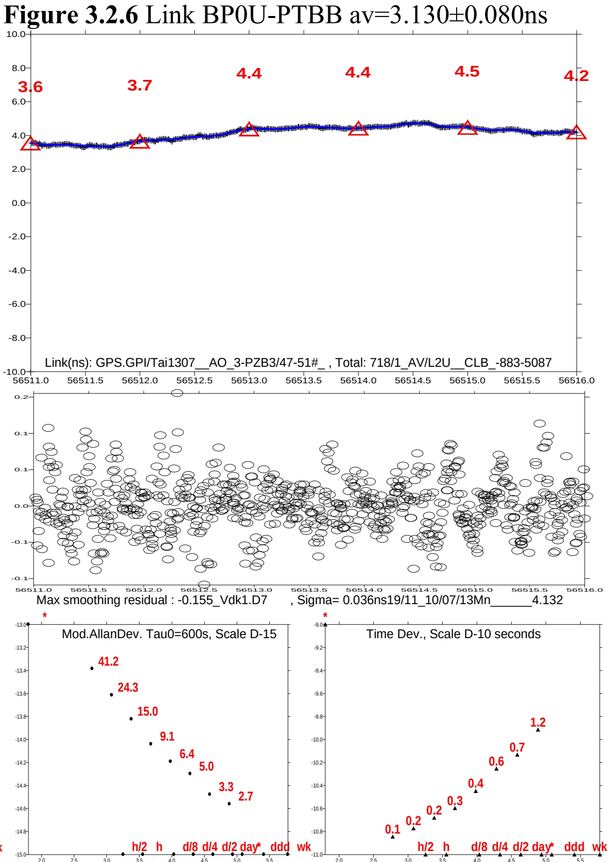


Figure 3.2.8 Link AOS-PTBB aft METODE Cor. av=4.132±0.036ns

3.3 The calibration of the TWSTFT link AOS-PTB

The METODE calibration correction for the GPS link AOS-PTB is -0.477 ns. Use the corrected GPS link, we can calibration the TW link. TW link is usually noisy and we use the combined link of TW and PPP which has the same calibration but much more stable. The difference (PPPlink-TWlink) is +1.861 ns which is the calibration correction for the TW ITU data file of AOS side (last mod 24/4/2014).

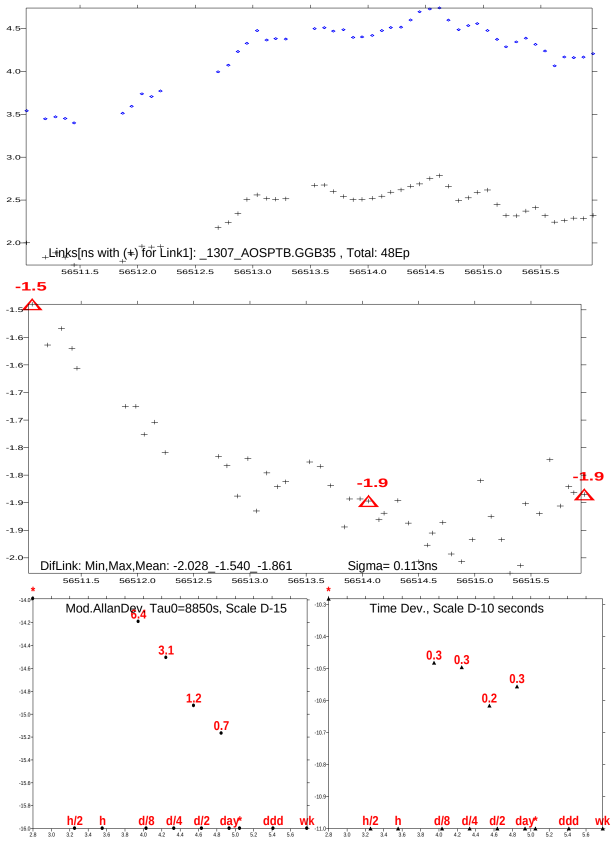


Figure 3.3.1 Comparison of TW-GPSPPP link 1307: the difference is -1.861±0.113 ns (GPS corrected by C_M)

Acknowledgement

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[9] **T**wo-**W**ay **O**ptical **FiB**er **T**ime and **F**requency **T**ransfers