Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin

Fachbereich 4.4
Bundesallee 100, 38116 Braunschweig, Germany

PTB documentation PTB-MIKES calibration campaign 2015

Common Clock measurements before the start of the campaign

The receiver MI04 was functionally tested before shipment from MIKES to PTB but no common-view measurement with respect to an established fixed receiver at MIKES was performed or evaluated. The antenna cable was directly delivered from the supplier to PTB.

Installation of MIKES equipment in PTB

Diagram of the experiment set-up:

The electrical connection is depicted in Figure 1 and Figure 2. The travelling receiver is designated as “T”. CSDA stands for clock signal distribution amplifier, which distributes 1 PPS, 5 MHz and 10 MHz signals of a clock.

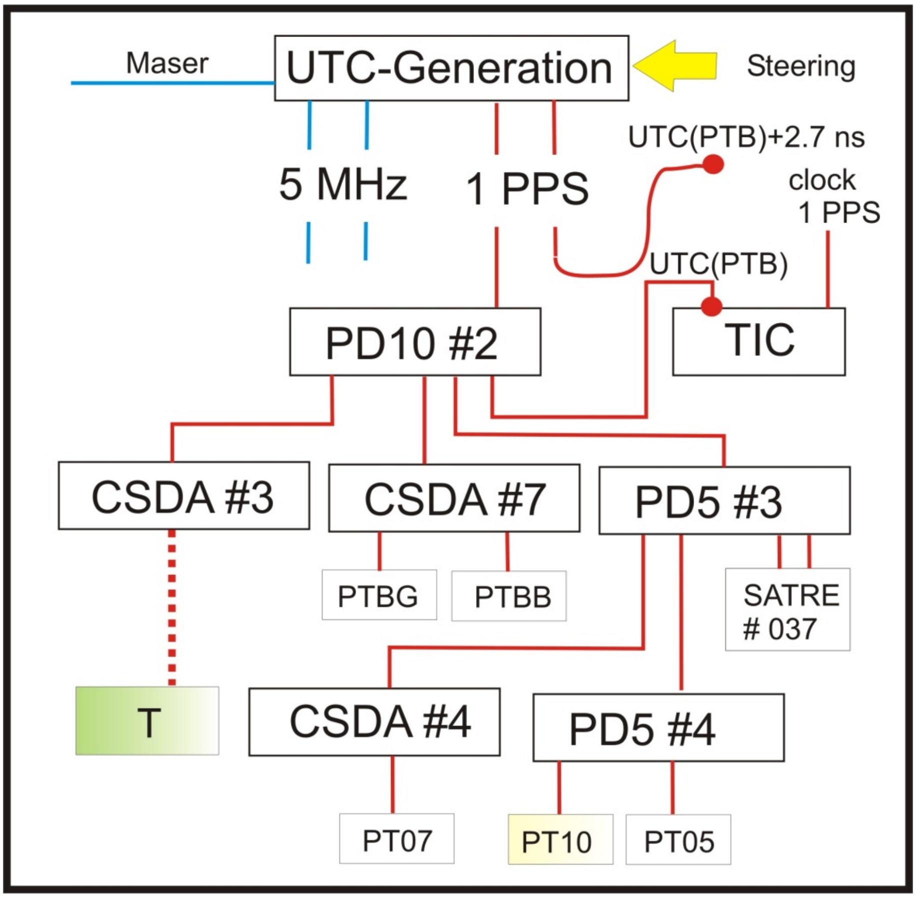


Figure 1: Signal distribution (1 PPS) to PTBB, PTBG and receivers involved

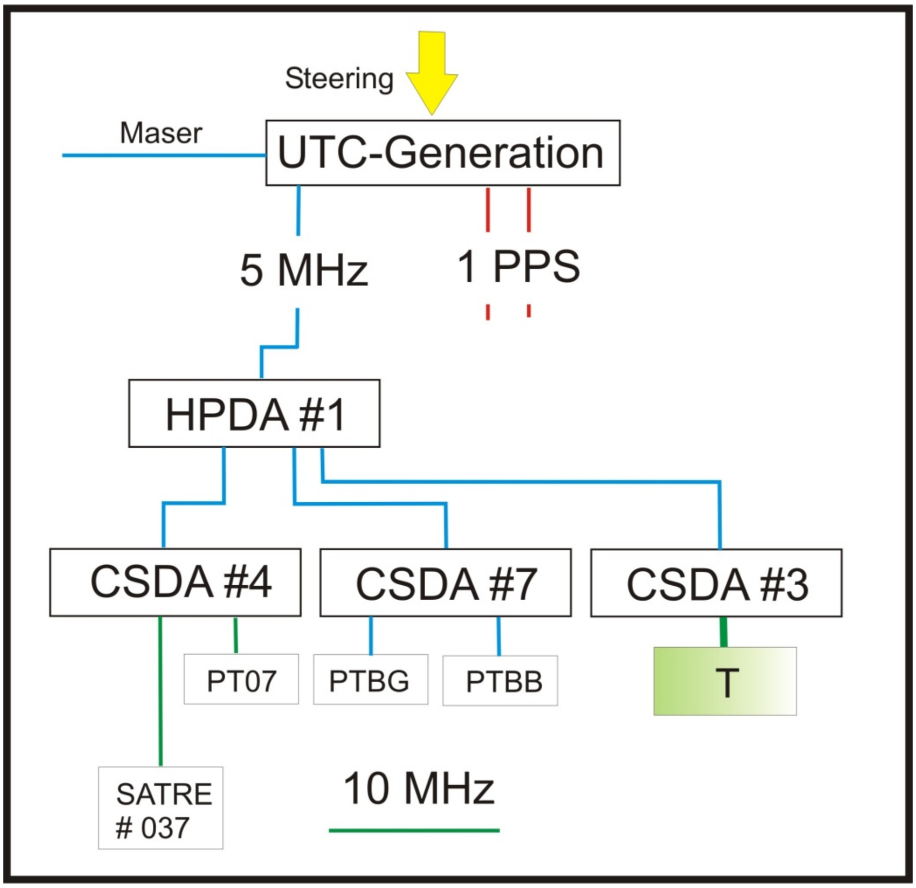


Figure 2: Signal distribution (5 MHz, 10 MHz, 20 MHz) to PTBB, PTBG and receivers involved

Laboratory:	PTB	
Date and hour of the beginning of measurements:	2015-11-03 (0:00 UTC)	
Date and hour of the end of measurements:	2015-11-15 (24:00 UTC)	
Information on the system		
	Local: PTBB	**Travelling:** MI04
• Receiver maker:	ASHTECH	DICOM
Receiver type:	Z-XII3T	GTR51 P/N 2065.10011
Receiver serial number:	RT820013901	1403001 / Inv. MIKES 009375
1 PPS trigger level /V:	1 V	1 V
• Antenna cable maker:	Nokia	Andrews
Antenna cable type :	RG214	FSJ-50A / Cab ID: #1050.433.01
Phase stabilised cable (Y/N):		Y
Length outside the building /m:	approx. 25 m	approx. 25 m
• Antenna maker:	Ashtech	NOVATEL
Antenna type:	ASH700936 SNOW	GPS-703-GGG
Antenna serial number:	CR15930	P/N 01018146 / Inv. MIKES 009375
Temperature (if stabilised) /°C		

Measured delays /ns		
	Local:	**Travelling:**
• Delay from local UTC to receiver 1 PPS-in (X_P)	20.1 ns ± 0.1 ns(*)	34.08 ns ± 0.1 ns
Delay from 1 PPS-in to internal Reference (if different): (X_O)	38.0 ns ± 0.1 ns	N/A
• Antenna cable delay: (X_C)	301.7 ns	193.9 ns *
Splitter delay (if any):		
Additional cable delay (if any):		22.4 ns**

Notes:

* CAB DLY as measured by supplier and labelled on the cable

** lightning arrester plus short connection to receiver

Data used for the generation of CGGTTS files				
	Local:		**Travelling**	
• INT DLY (or X_R+X_S) (GPS) /ns:	303.9 ns (P1), 319.3 ns (P2) (*)		0	
• INT DLY (or X_R+X_S) (GLONASS) /ns:			0	
• CAB DLY (or X_C) /ns:	301.7 ns		216.3 ns	
• REF DLY (or X_P+X_O) /ns:	74.0 ns (*)		34.08 ns	
• Coordinates reference frame:	ITRF (*)		ITRF	
Latitude or X /m:	+3844059.89 m (*)	Mast P10	+3844064.99 m (+)	Mast P2
Longitude or Y /m:	+709661.48 m (*)		+709659.03 m (+)	
Height or Z /m:	+5023129.73 m (*)		+5023126.04 m (+)	

General information	
Rise time of the local UTC pulse:	< 3 ns
• Is the laboratory air conditioned:	Yes
Set temperature value and uncertainty:	23 °C ± 0.5 °C
Set humidity value and uncertainty:	

Notes:

(*) values provided by BIPM as part of coordinate alignment 2014 and G1 calibration Ca_Id=1001-2014

(+) Coordinates determined as described below.

Determination of MI04 antenna position

The PPP software package from NRC Can plus IGS rapid products were used to determine the Antenna Reference Point (ARP) of mast P2 as

X: 3 844 064.949 m

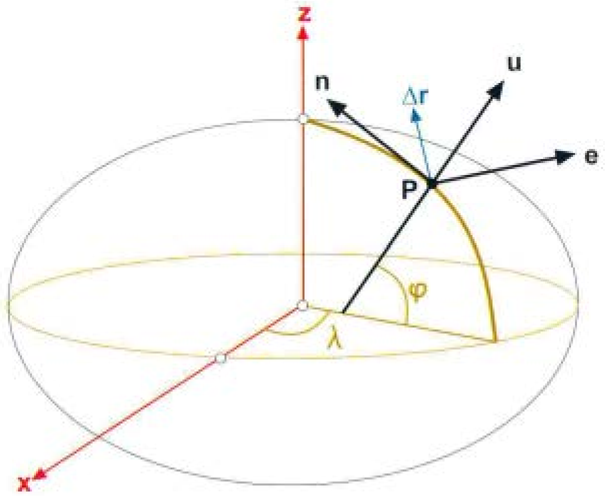
Y: 709 659.027 m

Z: 5 023 125.991 m

The Antex file for the antenna type states the phase centre offset from the ARP, ΔN, ΔE, and ΔU in mm as

L1: 1 0 61 L2: 0 2 59

Using the transformation B.7 and B.8, copied from "GNSS data processing, ESA TM-23/1 March 2013", the Antenna Phase Centre to be used for CGGTTS L3P file generation – as stated in the table above - was obtained (φ = 52.3° λ= 10.5°).



Thus

$$\begin{bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{bmatrix} = \mathbf{R}_3[-(\pi/2+\lambda)]\,\mathbf{R}_1[-(\pi/2-\varphi)] \begin{bmatrix} \Delta \mathrm{e} \\ \Delta \mathrm{n} \\ \Delta \mathrm{u} \end{bmatrix} \qquad \text{(B.7)}$$

which, according to expressions (3.6) of the rotation matrices given in section 3.6, yields

$$\mathbf{R}_3[-(\pi/2+\lambda)]\,\mathbf{R}_1[-(\pi/2-\varphi)] = \begin{bmatrix} -\sin\lambda & -\cos\lambda\sin\varphi & \cos\lambda\cos\varphi \\ \cos\lambda & -\sin\lambda\sin\varphi & \sin\lambda\cos\varphi \\ 0 & \cos\varphi & \sin\varphi \end{bmatrix} \qquad \text{(B.8)}$$

Calibration Procedure

The calculation of INT DLY values for the receiver to be calibrated follows the description given in BIPM TM.212 (G. Petit) [1] and is coded in cv.py written by Julia Leute of PTB. The following text piece that describes its function is generated via copy-paste from the TM with small changes of the designation of quantities.

In principal we distinguish receivers V, T, and G: V for visited, T for travelling, and G for golden_reference when dealing with G1G2 calibrations. G1 labs committed to ship their T to the other sites. In the variant when the receiver to be calibrated is shipped ***to*** G1 the roles of T, G and V are reversed: Then V = G, and T is the device under test.

We assume that the delay (specified below) D for receiver G is known. Then the relative calibration provides

$D_{Ti} = D_{Gi} + \Delta_{T\text{-}G}$ for receiver T, and for the two frequencies, i = 1, 2.

Conventionally, the receiver delay D is considered as the sum of different terms that are defined subsequently:

INT DLY
The sum $X_R + X_S$ represents the "INT DLY" field in the CGGTTS header:
X_R represents the receiver hardware delay, between a reference point whose definition depends on the receiver and the internal time reference of the measurements. X_S represents the antenna delay, between the phase center and the antenna cable connector at the antenna body. We distinguish the two quantities for the two frequencies, 1 and 2.

INT DLY(P1), and INT DLY(P2) of receiver T are the basic quantities that are determined during the relative calibration.

The following terms are considered frequency independent, i. e. no distinction is made for P1 and P2 and other signal frequencies.

CAB DLY
The sum $X_C + X_D$ represents the "CAB DLY" field in the CGGTTS header.
X_C corresponds to the delay of the long cable from the antenna to the input socket at either the antenna splitter or the receiver body directly. If a splitter is installed, X_D corresponds to the delay of the splitter and small cable up to the receiver body. For a simple set-up with just an antenna cable, $X_D = 0$.

REF DLY
The sum $X_P + X_O$ represents the "REF DLY" field in the CGGTTS header.
X_P corresponds to the delay of the cable between the laboratory reference point for local UTC and the 1 PPS-in socket of the receiver.
X_O corresponds to the delay between the 1PPS-in socket and the receiver internal reference, the latter depending on the receiver type:

- For Ashtech Z12-T: The first positive zero crossing of the inverted 20 MHz-in following the 1PPS-in, delayed by 15.8 ns,
- For Septentrio PolaRx2: The 1PPS-out, delayed by 8.7 ns,
- For Septentrio PolaRx4: The 1 PPS-out, no further correction
- For DICOM GTR50 and GTR51: The 1PPS-in, i.e. $X_O = 0$,
- For Javad/Topcon: The first positive zero crossing of the 5/10 MHz-in following the 1PPS-in.

Details of the measurement procedures for the Ashtech Z12-T are given in the BIPM calibration guideline [2], but the parameters of PT02 were not determined on occasion of the current campaign.

Valid CGGTTS files (including correct, accurate antenna coordinates) were available from receivers G. After the determination of the correct antenna coordinates for mast P2 (used by T) had been made, RINEX files from T were re-processed with r2cggtts V5.1 including the delay parameters as stated above to obtain valid CGGTTS files. Then the software cv.py in calibration mode was used to calculate:

$REFGPS_{P1}(K) = REFGPS(K) + MDIO$
$REFGPS_{P2}(K) = REFGPS(K) + MDIO + ((f_1/f_2)^2 – 1) \times MSIO$, where $(f_1/f_2)^2 = 1.647$ for GPS

for each satellite observation.

If the common-view condition is fulfilled, the differences

$\Delta Pi: = REFGPS_{Pi}(T) – REFGPS_{Pi}(G)$

are calculated.

cv.py at the end of the computation edits the median value of all individual observations ΔPi for P1 and P2, and the number of data points used. In addition cv.py generates a file deltap_stats that contains observation epoch (MJD.frakt) and the average ΔP1, ΔP2 of all satellite observations at that epoch. These values are plotted below in Figure 3.

The final step is the calculation of the INT DLY values:

$\{X_R + X_S\}(T)i = \Delta Pi + [(X_R + X_S)i + X_C + X_D - X_O - X_P](G) – [X_C + X_D - X_O - X_P](T)$,

where the values in [..](K) are taken from a file named calib.cfg that is read by the software.

In the file calib.cfg parameters for the reference system: rec1 (G) and the travelling receiver rec2 (T) are given.

cab_del1 = 0.0	$X_C + X_D$ (T)
ref_del1 = 0.0	$X_O - X_P$ (T)
p1_ref = 0.0	$X_R + X_S$ (T) for P1
p2_ref = 0.0	$X_R + X_S$ (T) for P2

system under study: rec2

cab_del2 = 0.0	$X_C + X_D$ (V)
ref_del2 = 0.0	$X_O - X_P$ (V)

INT DLY is nominally zero before the calibration, so this is not reported for rec2.

In the example above, all entries in calib.cfg are zero, as all the delays are being taken into account when CGGTTS files were generated while T was in PTB. The PTB receiver G is – as said before – the PT02 (Ashtech Z12-T). PT02 CGGTTS files are complete.

The cv.py thus outputs INT DLY (P1/P2) (T)new - INT DLY (P1/P2) (T)old. As said before, the median value is given and the resolution is limited by construction to 0.1 ns for P1.

Illustration of results

MI04 was compared to receiver PTBB / PT02. Here PTBB is the designation in the IGS network and is used when RINEX files of the receiver are used. PT02 is the acronym used by BIPM when the receiver is used in all P3 AV or CV comparisons between timing labs world-wide and PTB. The internal delay values for P1 and P2 and the antenna coordinates were provided by BIPM in 2014 / 2015. Cal_Id=1001-2014 refers to the calibration campaign undertaken by BIPM. The antenna coordinates for MI04 were determined as explained before.

In addition to the P1 and P2 INT DLY values, relevant for generation of L3P data, the L1C calibration value was determined by comparing MI04 with PTB receiver PT07, a DICOM GTR50. Its L1 delay is linked to the P1 delay value with a constant C1-P1 value provided by the manufacturer. The P1 value had been adjusted so that PT07 and PT02 L3P data agree. PTB can only guess about the uncertainty of the C1-P1 value, which is reflected as contribution $u_{b,31}$ in Table 2. The difference of L1C CV between MI04 and PT07 is zero when choosing the proper INT DLY (L1C) for MI04, as shown below. For the moment this seems an adequate procedure. The MI04 L1C data files were generated using the "old" accepted antenna coordinates of mast P02 while MI04 was operated at PTB. We checked that the error introduced by this negligence does not exceed 0.3 ns. An incomplete CABDLY was considered initially, and after the fact the data were corrected, noting the procedure of building CGGTTS files. It is

$REFSYS_{CGGTTS} = REFSYS_{RAW} - CABDLY_{CGGTTS} - INTDLY_{CGGTTS} + REFDLY_{CGGTTS}$. Here values Q_{CGGTTS} are reported in the CGGTTS file header, and Q_{raw} refers to the uncorrected value.

The ΔPi values used for the MI04 calibration (P1, P2) are depicted in Figure 3. The statistical analysis is provided in Figure 4 and Figure 5.

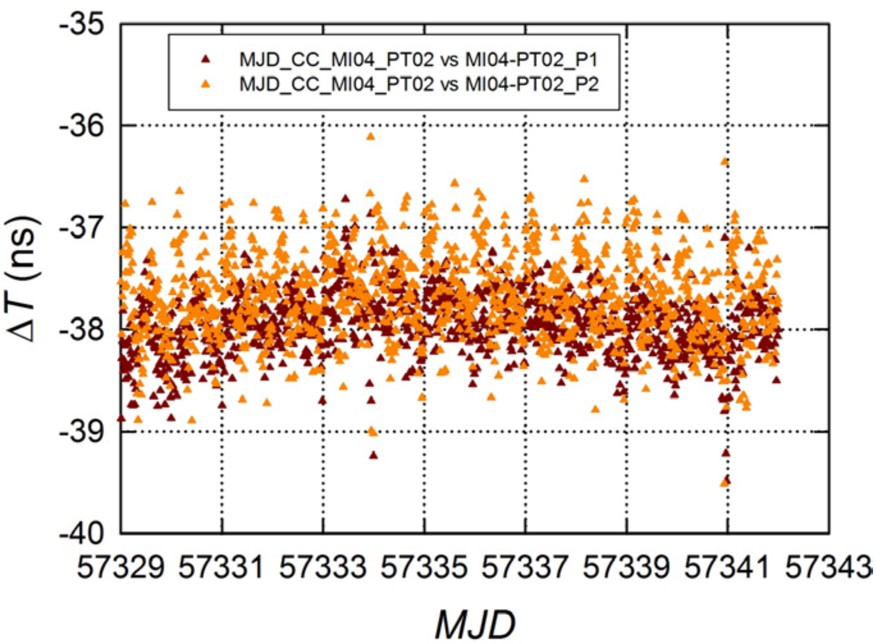


Figure 3. Common Clock comparison MI04 - PT02, P1 / P2, PT02: new antenna coordinates, new PT02 INT DLY P1/P2, (reference: calibration Ca_Id=1001-2014), DI 03. - SO 15. November 2015 (inclusive)

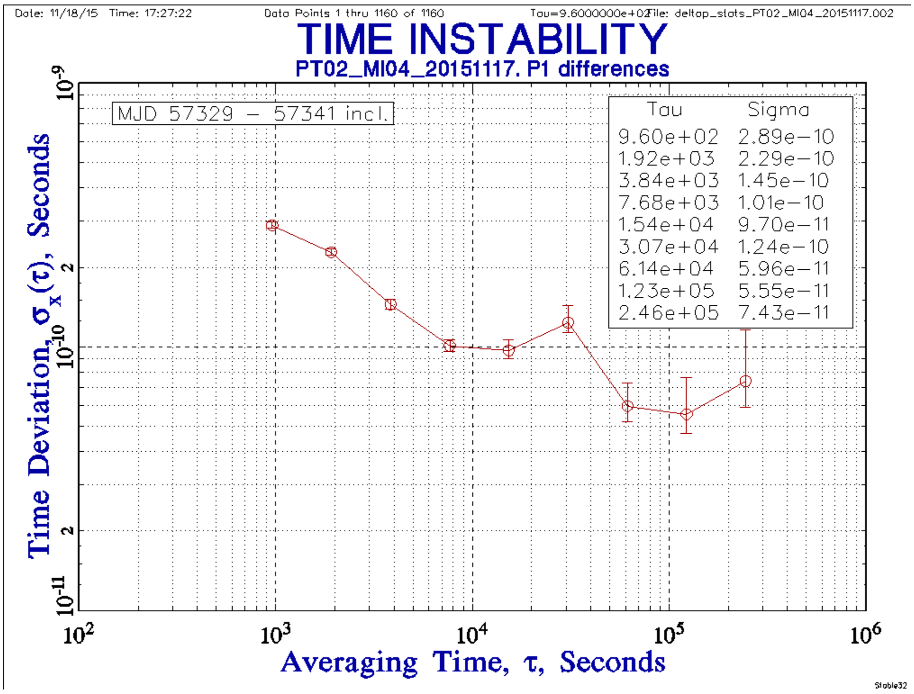


Figure 4. Time instability in seconds of ΔP1: = $REFGPS_{P1}(T) - REFGPS_{P1}(G)$

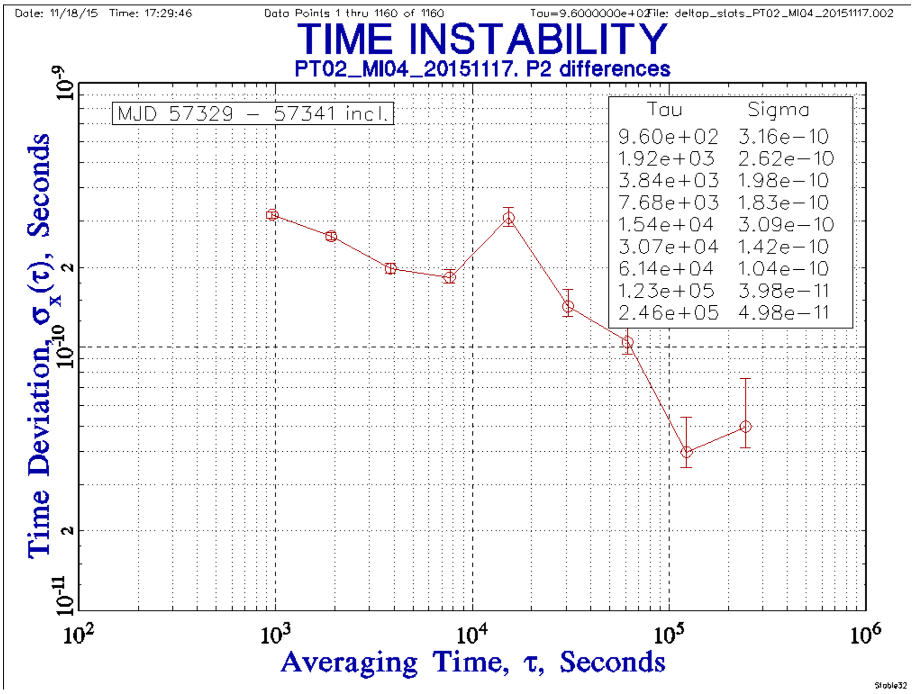


Figure 5. Time instability in seconds of ΔP2: = REFGPSP2(T) – REFGPSP2(G)

The L1C INT DLY is based on the common-clock data shown in Figure 6. Here the outliers are caused by non-identical treatment of the ionospheric delay in the two receivers. The calculation of the L1C delay has thus been restricted to the black points, in total 1120 epochs of 13 minutes. A statistical analysis is provided in Figure 7.

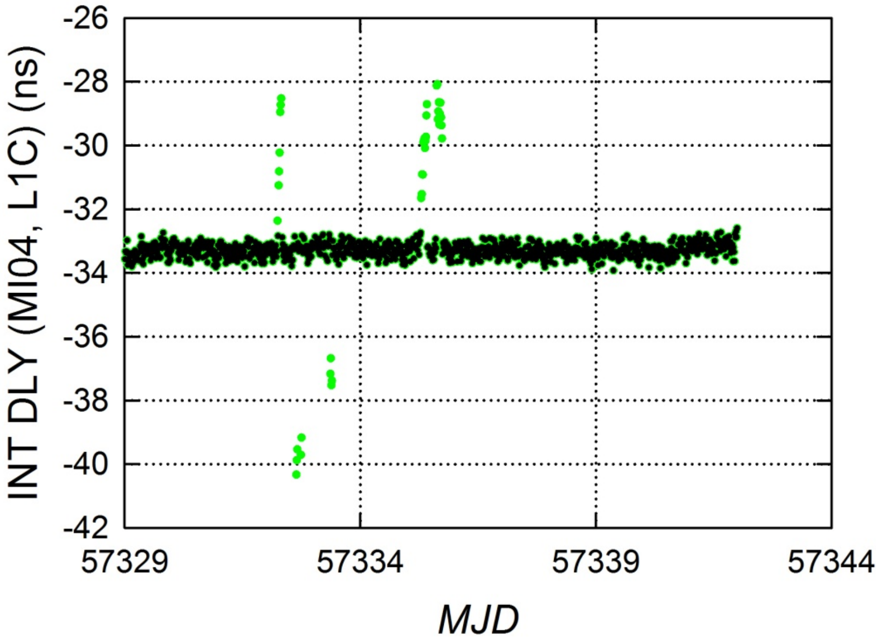


Figure 6. INT DLY (MI04, L1C) based on common clock common view comparisons PT07 - MI04 L1C new antenna coordinates, new PT07 INT DLY L1C, based on reference: calibration Ca_Id=1001-2014, DI 03. - SO 15. November 2015 (inclusive)

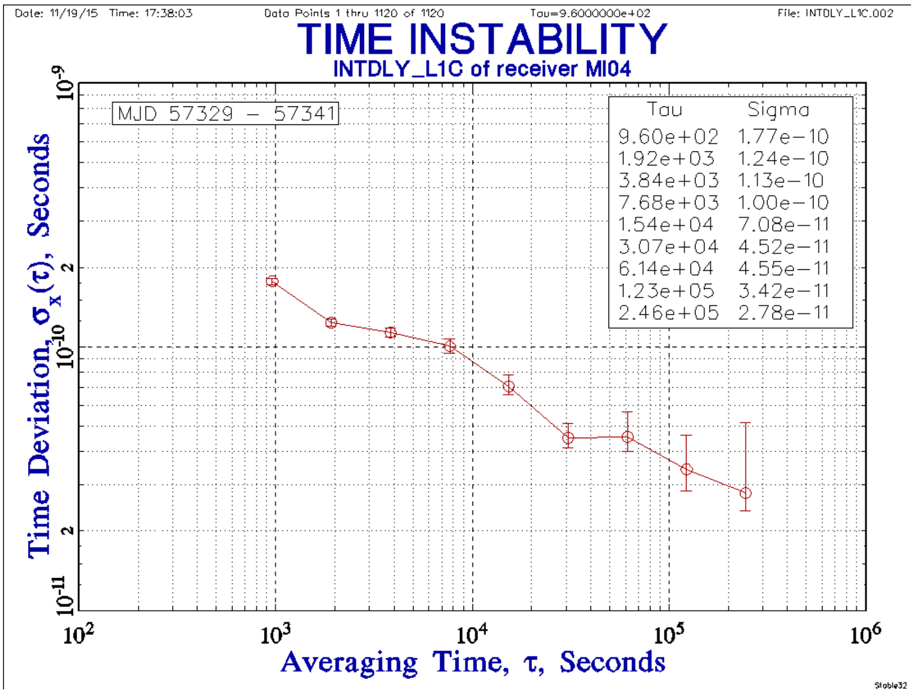


Figure 7. Time Instability in seconds of INTDLY(MI04, L1C) based on 1120 CV observation with PT07

Discussion of uncertainty

The following table (Table 1) has been copied from the BIPM Calibration Guidelines [2], but was cleaned from all lines that carry an uncertainty contribution < 0.1 ns. It was also adapted to the situation prevailing when MI04 was operated in PTB. The uncertainty of REFDLY and CABDLY (if another antenna cable shall be used) for the MI04 installation at the final site of operation (XX) needs to be taken into account in case that the uncertainty of a link XX-PTB shall be evaluated. Table 2 covers the L1C calibration. Both tables state 1-σ uncertainty values and do not reflect the calibration uncertainty of the two PTB receivers involved.

Uncertainty	Value P1	Value P2	Value P1-P2	Description
u_a (T-G)	0.1	0.2	0.3	P1/P2 values determined as reasonable TDEV on differences ΔP_i, shown as Figure 3.
u_a	0.1	0.2	0.3	
Components related to the link to the local references UTC(k)				
$u_{b,1}$	0.5	0.5	0	$REFDLY_G$ (at ref lab)
$u_{b,3}$	0.5	0.5	0	$REFDLY_T$ (at ref lab)
$u_{b,7}$	0.1	0,1	0	TIC non-linearities
Components related to the antenna cable delays and antenna position				
$u_{b,11}$	0.5	0.5	0	$CABDLY_G$
$u_{b,12}$	0.5	0.5	0	$CABDLY_T$
$u_{b,14}$	0.1	0.1	0	Potential height error at PTB
Components related to ΔPi				
$u_{b,15}$	0.3	0.3	0.4	Multipath at PTB on receiver G
$u_{b,16}$	0.3	0.3	0.4	Multipath at PTB on receiver T
u_b	1.1	1.1	0.6	
U_{CAL}	1.1	1.2	0.7	

Table 1. Uncertainty budget (1-σ) for the INT DLY P1 / P2 calibration of receiver MI04, all values in ns

From this the uncertainty for a P3 link is determined as
$sqr\{U_{CAL}(P1)^2 + (1.54\times U_{CAL}(P1\text{-}P2))^2\} = 1.6$ ns

Uncertainty	Value L1C (ns)	Description
u_a (T-G)	0.1	L1C value determined as reasonable TDEV on INTDLY-values shown as Figure 6.
u_a	0.1	
$u_{b,1}$	0.5	$REFDLY_G$ (at ref lab)
$u_{b,3}$	0.5	$REFDLY_T$ (at ref lab)
$u_{b,7}$	0.1	TIC non-linearities
$u_{b,11}$	0.5	$CABDLY_T$
$u_{b,12}$	0.5	$CABDLY_G$
$u_{b,14}$	0.3	Use of old coordinates in MI04 L1C data generation
$u_{b,23}$	0.3	Multipath at PTB on receiver G
$u_{b,24}$	0.3	Multipath at PTB on receiver T
$U_{b,31}$	1.5	Transfer of L1C calibration from PT02 to PT07
u_b	1.9	
U_{CAL}	1.9	

Table 2. Uncertainty budget (1-σ) for the L1C INT DLY calibration of receiver MI04, all values in ns.

Final Result

The following delay values and their 1-σ uncertainties were obtained for receiver MI04:

INT DLY (P1): -37.9 ns, U = 1.1 ns

INT DLY (P2): -37.7 ns, U = 1.2 ns

INT DLY (C1): -33.3 ns, U = 1.9 ns

References

[1] G. Petit, “Computation and report of the results of GPS P3 differential calibration of geodetic receivers” TM.212, 16 November 2012, Annex 3 in BIPM guidelines for GNSS equipment calibration V1.0 25/11/2013.

[2] BIPM guidelines for GNSS calibration, V3.0 02/04/2015 and its Annexes.