

**CALIBRATION REPORT OF TTS-4 sn. 108 AT GUM**  
**PERFORMED BY ALIGNMENT AFTER REPLACING THE GNSS ANTENNA**  
**ON MJD 59473 (16 September, 2021)**

### 1. Description of equipment and operations

On MJD 59473 (Thursday, 16 September 2021) at 11:00 UTC, the antenna of TTS-4 receiver sn. 108 (GUM4 – RINEX data, PL\_3 – CGGTTS data -referred further as PL\_3) has been replaced with a new antenna of 3G+C reference of NavXperience, sn. RE 0674. The old antenna was a Javad Grant G3T with J-Shield, sn 00456. J-Shield technology introduced additional internal delay of about 790 ns, what caused visible diurnals due to external temperature influence. After replacing the antenna, the internal delays of PL\_3 have been changed. The rest configuration parameters were fixed (antenna cable, antenna mounting position, reference 1 pps and 10 MHz cables and sources).

Determination of new internal delays of PL\_3 receiver for GPS signals was performed as a transfer of calibration from “PL\_3 before change” to “PL\_3 after change” with the usage of DCD (Double Clocks Difference) between  $[UTC(AOS) - UTC(PL)]_{GPS_{CV}}$ , obtained from AO\_4 (TTS-4 sn. 112 at AOS) and PL\_3 receivers, and  $[UTC(AOS) - UTC(PL)]_{ELSTAB}$ , obtained from the calibrated optical link GUM-AOS.

The AOS receiver (AO\_4) and GUM receiver (PL\_3) were both previously calibrated within *CAL\_ID 1014-2018 [1]*. Since the calibration of AO\_4 in 2018, there was not introduced any change to the receiver delays and configuration of AO\_4.

Fiber ELSTAB link GUM-AOS has a fixed delay [as reported in Śliwczyński Ł. at all: Dissemination of time and RF frequency via stabilized fiber optic link over the distance of 420 km, Metrologia, vol. 50 (2013), 133-145], with possible seasonal variations estimated at the level up to 35 ps. It can be assumed that during total analysed period (before and during calibration: MJD 59460--59497) these variations should be smaller and can be omitted.

Introduction of new internal delays into PL\_3 receiver was performed in three steps:

- first step – **rough alignment**: all internal delays were decreased by **781.5 ns** (-781.5 ns = a predicted step of internal delays) – since 11:30 UTC on MJD 59473
- second step – **precise alignment**: all values lowered additionally by **9.5 ns** (-781.5 ns - 9.5 ns = -791.0 ns of total time step of internal delays based on short period of observations for L1C) – since 10:10 UTC on MJD 59474
- third step – **final precise alignment**: every values of internal delay corrected individually according to the last row in the Table 2. (based on longer period of observation for L1C, L1P, L2C, L2P, L3C, L3P) – since 11:44 UTC on MJD 59516.

Table 1. Summary information on the calibration

Institute	Status of equipment	Dates of measurements	Receiver type	BIPM code	RINEX name
GUM	<u>Calibrated 1014-2018</u>  <u>Before the change (Old antenna)</u>	59460-59473  <u>(Used as a reference)</u>	TTS-4 sn. 108	PL_3	GUM4
AOS	Calibrated 1014-2018	59460-59497	TTS-4 sn. 112	AO_4	AO_4
GUM/AOS	Optical link – calibrated on line	<u>Used as a bridge to calculate DCD</u>	ELSTAB system	Data of UTC(AOS)-UTC(PL) collected at BIPM ftp server: data/UTC/AOS/links/fibre/	
GUM	<u>After the change (New antenna)</u>	59473-59497	TTS-4 sn. 108	PL_3	GUM4

## 2. Data used

There was used CGGTTS data processed every 16 min directly by AO\_4 and PL\_3 stored in files GMAO\_459.xxx and GMPL\_359.xxx and optical fiber data of the GUM-AOS ELSTAB link collected every 5 s.

## 3. Results of raw data processing

Firstly, for each frequency/code separately, UTC(AOS)-UTC(PL) differences were obtained from CGGTTS data for every common-view observations with applying filter of 3-RMSE (Root Mean Squared Error) criterium of linear fitting daily data and averaging values for each observations every 16 min independently. Next, UTC(AOS)-UTC(PL) differences obtained from optical fiber data were averaged every 16 min according to the schedule of GNSS observations. Finally, DCD were calculated as a difference between data obtained from CGGTTS for each frequency/code separately and data obtained from ELSTAB link. The obtained results are shown in the Table 2.

Table 2. Summary raw results of alignment calibration

Measurement period	Frequency/code (Pi)	<u>DCD + differential residuals (Pi) between AO 4 and PL 3 – fiber link residuum</u>				Number of 16-min epochs
		Mean (ns)	Median (ns)	Std.Dev. (ns)	TDEV (ns)	
59460-59473 (period before the change of antenna)	L1C	0.03	0.02	0.51	0.25	1000
	<b>L1P</b>	<b>0.02</b>	<b>0.02</b>	0.54	0.28	
	L2C	-18.66	-18.65	0.60	0.33	
	<b>L2P</b>	<b>-2.48</b>	<b>-2.48</b>	0.55	0.33	
	L3C	28.75	28.74	1.07	0.81	
	L3P	3.92	3.86	1.01	0.71	
59473-59474 (after rough alignment)	L1C	9.11	9.10	0.42	0.29	81
59486-59497 (after precise alignment)	L1C	0.32	0.36	0.46	0.23	1000
	<b>L1P</b>	<b>0.37</b>	<b>0.40</b>	0.48	0.29	

	L2C	-38.56	-38.55	0.70	0.43	
	<b>L2P</b>	<b>-23.11</b>	<b>-23.09</b>	0.66	0.40	
	L3C	60.53	60.49	0.80	0.68	
	L3P	36.67	36.68	0.69	0.72	
Correction required for the final precise alignment (to be added to internal delays of TTS-4 sn. 108)	L1C	-0.3	X			
	<b>L1P</b>	<b>-0.4</b>				
	L2C	19.9				
	<b>L2P</b>	<b>20.6</b>				

Finally, the resulted correction of final precise alignment for L3P, obtained according to formula:

$$\Delta\text{INT DLY}(P3) = 2.54 \times \Delta\text{INT DLY}(P1) - 1.54 \times \Delta\text{INT DLY}(P2) \text{ amounts to } \mathbf{-32.7 \text{ ns.}}$$

#### 4. Uncertainty estimation

GUM-AOS ELSTAB link, used as a bridge, has observed type A uncertainty less than 0.05 ns (0.035 ns for every 16 min period) and possible influence of uncompensated differential non-linearities of TIC (type B uncertainty): approx. 0.1 ns. The type A uncertainty of the GUM-AOS GPS link is represented by the Std.Dev. of the raw calibration results and is less than 0.7 ns for L1C, L1P, L2C and L2P (5-th column in the Table 2) before and after the change of the antenna.

The standard uncertainty of the corrections of internal delays for L1C, L1P, L2C and L2P, which were set as a final precise alignment into the TTS-4 sn. 108 software, is equal to:

$$u_{\text{CAL}} = \sqrt{2 \cdot (0.7^2 + 0.1^2 + 0.035^2)} \text{ ns} = 1.0 \text{ ns}.$$

Remarks:

During total analysed period, a possible systematic difference between GPS link and ELSTAB fiber link is cancelled by DCD and therefore it does not influence the results of calibrations.

#### 5. Final results

Total corrections added to the internal delay values into the TTS-4 sn. 108 software after the antenna change on MJD 59473 are given in the Table 3.

Table 3. Final results of alignment calibration

Frequency/code (Pi)	INT DLY (Pi)		$\Delta\text{INT DLY (Pi)}$ correction	
	Before the antenna change (ns)	After the antenna change (ns)	Total correction (ns)	$u_{\text{CAL}}$ (ns)
L1C	763.1	-28.2	-791.3	1.0
<b>L1P</b>	<b>761.7</b>	<b>-29.7</b>	-791.4	
L2C	738.6	-32.5	-771.1	
<b>L2P</b>	<b>738.6</b>	<b>-31.8</b>	-770.4	

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