GNSS CALIBRATION REPORT

PT13 VIA 1001-2018

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TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

REFERENCES

REFERENCES	
RD01	**BIPM report 2018 Group 1 GPS calibration trip 1001-2018_GPSP3C1_Group1-trip_V2**
RD02	**Defraigne, P., Aerts, W., Cerretto, G., Cantoni, E., and Sleewaegen, J.-M., "Calibration of Galileo signals for time metrology," IEEE Trans. Ultrason. Ferroelect. Freq. Contr., vol. 61, no. 12, 2014, pp. 1967-1975.**
RD03	**BIPM guidelines for GNSS calibration, V3.0, 02/04/2015**
RD03	**BIPM TM.212 (G. Petit), Nov. 2012**
RD04	**J. Kouba, P. Heroux, 2002, *"Precise Point Positioning Using IGS Orbit and Clock Products,"* GPS Solutions, Vol 5, No. 2, 12-28**
RD05	**W. Lewandowski, C. Thomas, 1991, *"GPS Time transfers,"* Proc. IEEE, Vol. 79, No. 7, 991-1000**
RD06	**P. Defraigne and G. Petit, "CGGTTS-Version 2E: an extended standard for GNSS time transfer, Metrologia 52 (2015) G1**
RD07	**BIPM / GP Continuity of GNSS "INTDLY" values of Group 1 geodetic receivers in successive Group 1 trips, TM 266 V2.5 19 June 2020.**

ACRONYMS

ACRONYMS	
BIPM	**Bureau International de Poids et Mesures, Sèvres, France**
BKG	**Bundesamt für Kartografie und Geodäsie, Frankfurt, Germany**
CGGTTS	**CCTF Generic GNSS Time Transfer Standard**
EURAMET	**The European Association of National Metrology Institutes**
IGS	**International GNSS Service**
GNSS	**Global Navigation Satellite System**
GOW	**Geodätisches Observatorium Wettzell, Germany**
PPP	**Precise Point Positioning**
PTB	**Physikalisch-Technische Bundesanstalt, Braunschweig, Germany**
RINEX	**Receiver Independent Exchange Format**
R2CGGTTS	**RINEX-to CGGTTS conversion software, provided by ORB / BIPM**
TDEV	**Time deviation**
TIC	**Time interval counter**

SUMMARY

Since April 2019 a new GNSS receiver is operated at PTB premises, owned by BKG and managed by staff from GOW. It is designated as IGS station PTBB and its BIPM designation is PT13. The GPS and Galileo delays were determined relatively to those of receiver PT09. The PT09 GPS delay calibration was available from Cal_Id=1001-2018 [RD01]. The PT09 Galileo delays were obtained by the methode published by Defraigne et al. [RD02]. The exercise of transfer of the calibration to PT13 followed as much as possible the BIPM Guide [RD03]. Results provided are the visited receiver's internal delays for GPS P-code signals on the two frequencies L1 and L2 (INT DLY (P1), and INT DLY(P2)) and Galileo E1 and E5a delays. The delays for the C/A-code signals on L1 were also determined during this campaign using PT09 as the reference.

PT13 CGGTTS files became available only step by step, thus the individual calibrations are based on different days of data taking.

With publication of V2 of [RD01] and V2.5 of [RD07] in June 2020, Galileo delay values for the G1 laboratories were published. In case of PTB, values for PT09 were provided. Subsequently, the Galileo delay values of PT13 were aligned using the same method as in 2019. Results are illustrated in Section 2.3.

The final results are included in Section 3. As a reminder: All uncertainty values reported in this document are 1-σ values. In the Annex the BIPM information table is added.

1. RECEIVER INSTALLATION AT PTB

The installation of the receivers in PTB is depicted in Figure 1-1 for 1 PPS signals and in Figure 1-2 for 5 MHz signals. The PT03 receiver is supplied with 20 MHz from a times 4 multiplier. PTB's mobile receiver PTBT is mentioned in the pictures but was not involved in the current exercise. The Calibration Information Sheet in the Annex gives all details, dates given are for the GPS L3P delay determination.

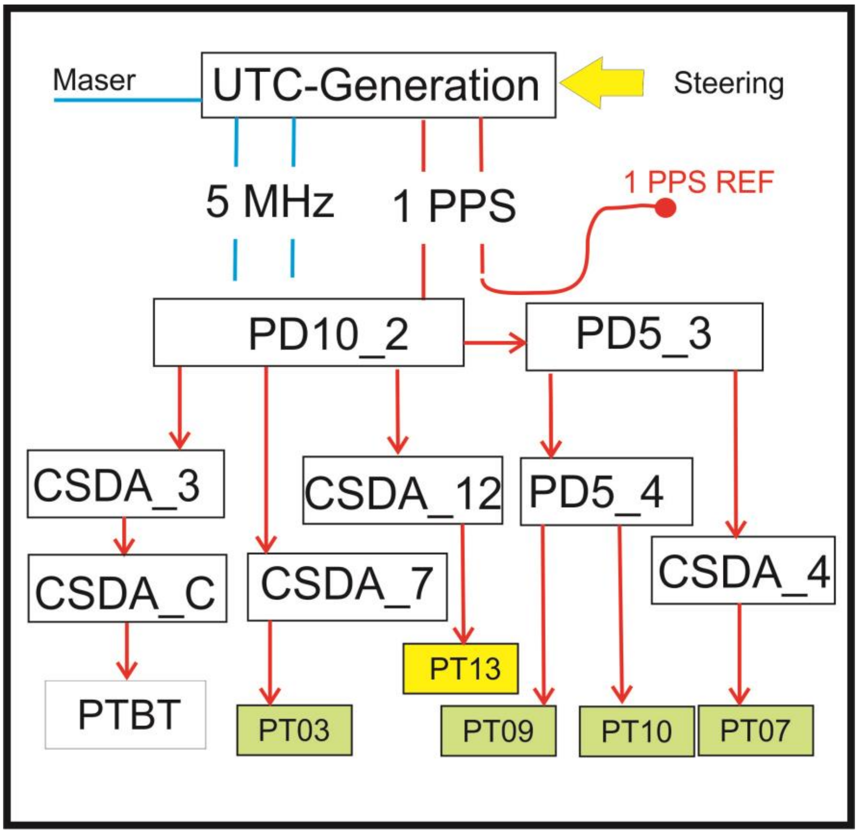

Figure 1-1: UTC(PTB) reference point and 1 PPS signal distribution to PTB GNSS receivers; PD5 and PD10 stand for pulse distributor, CSDA stands for clock signal distribution amplifier

Figure 1-3 illustrates the installation of GNSS antennas on the roof of the PTB time laboratory (clock hall). The PT13 antenna is marked with a yellow arrow, the PT09 antenna is the geodetic antenna next to the right.

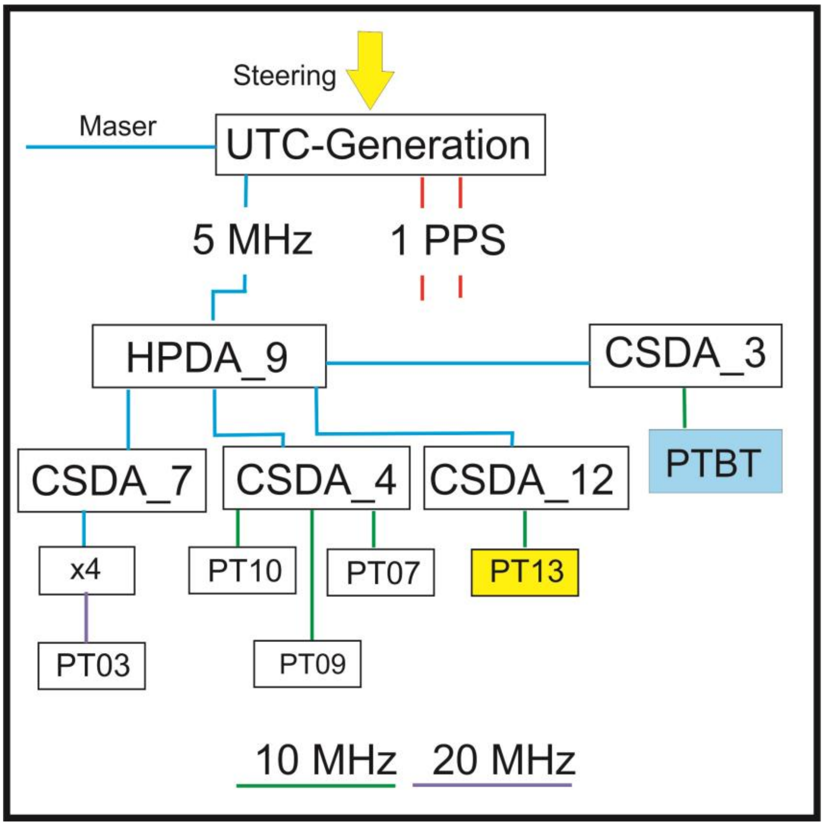

Figure 1-2: UTC(PTB) signal distribution (5 MHz, 10 MHz, 20 MHz) to PTB GNSS receivers; HPDA stands for High-precision distribution amplifier (for rf frequencies)

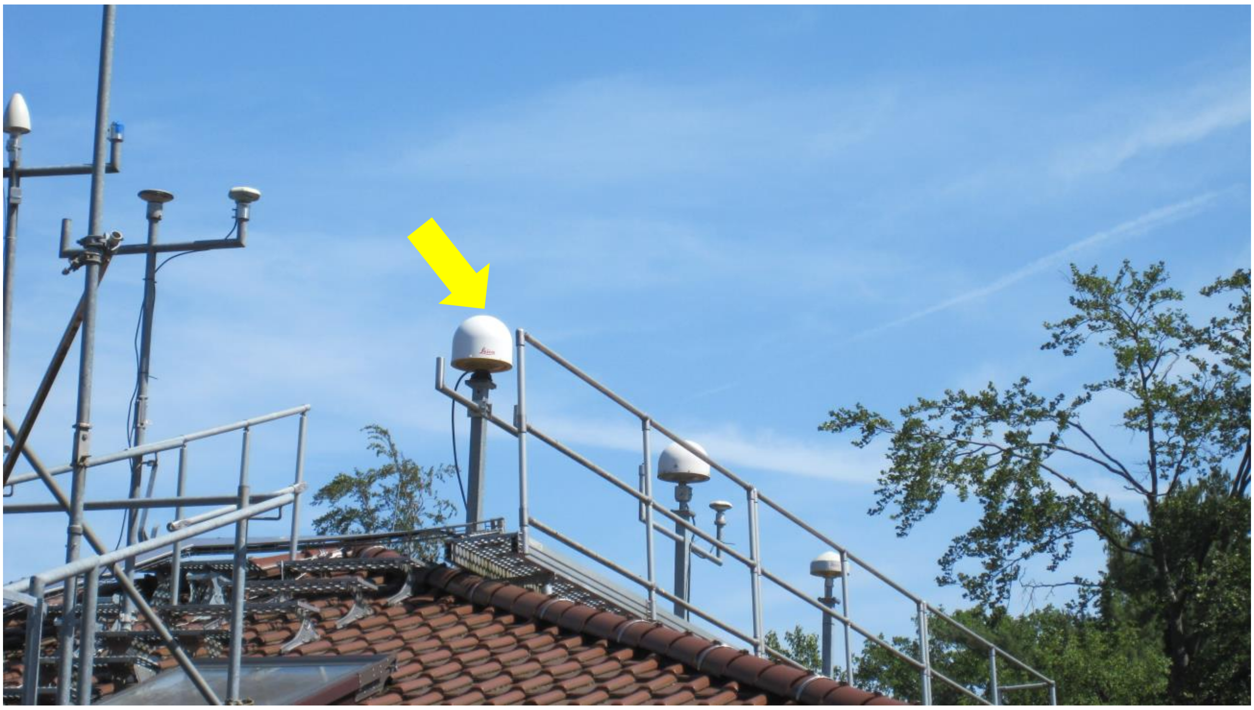

Figure 1-3: Installation of GNSS antennas at PTB, the PTBB/PT13 antenna marked

2. RESULTS OF COMMON-CLOCK DATA TAKING

2.1. DETERMINATION OF DUAL FREQUENCY DELAYS

The period 58576 to 58580 (5 days) was chosen to determine the PT13 INT DLY values. The result of comparison with PT09 as the reference are shown in Figure 2-1 illustrating in total 433 ΔPi values obtained as mean over all common view observations at a given epoch. The numerical results are given in Section 3.

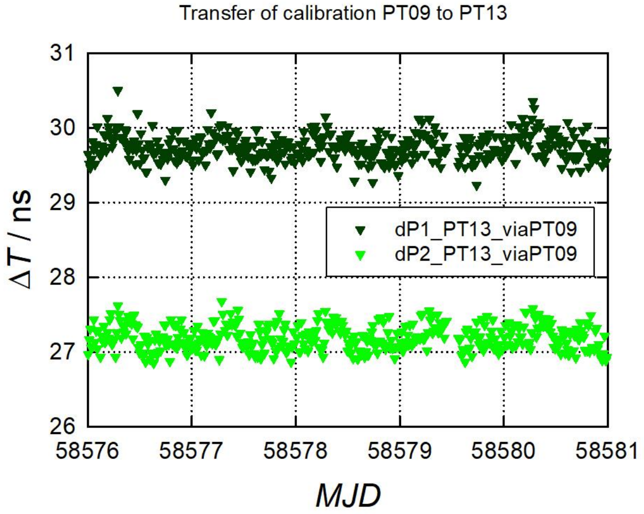

Figure 2-1: ΔP1 (dark green) and ΔP2 (light green) values obtained during the common-clock set-up in PTB.

In a similar way, also the Galileo delays were determined wrt to PT09, results are shown in Figure 2-2.

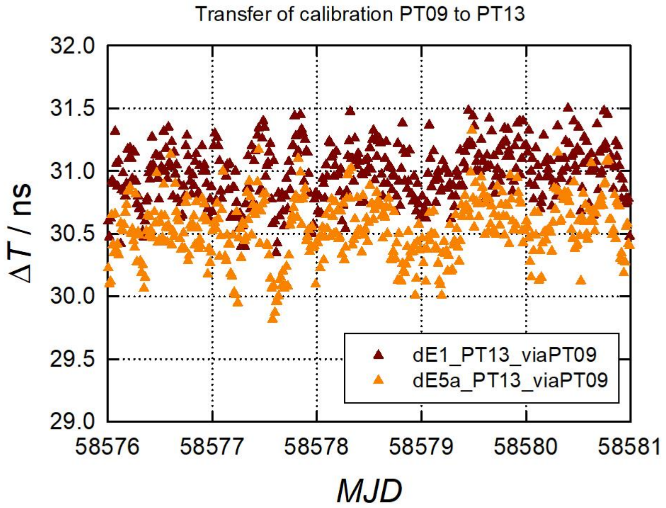

Figure 2-2 ΔE1 (brown) and ΔE5a (orange) values obtained during the common-clock set-up in PTB

2.2. DETERMINATION OF SINGLE FREQUENCY DELAYS

The receiver delays for L1C signals were determined with respect to the same PTB receiver, PT09. We determined the cv difference between PT13 and PT09 during MJD 58603 and 58607 and the results are shown in Figure 2-3.

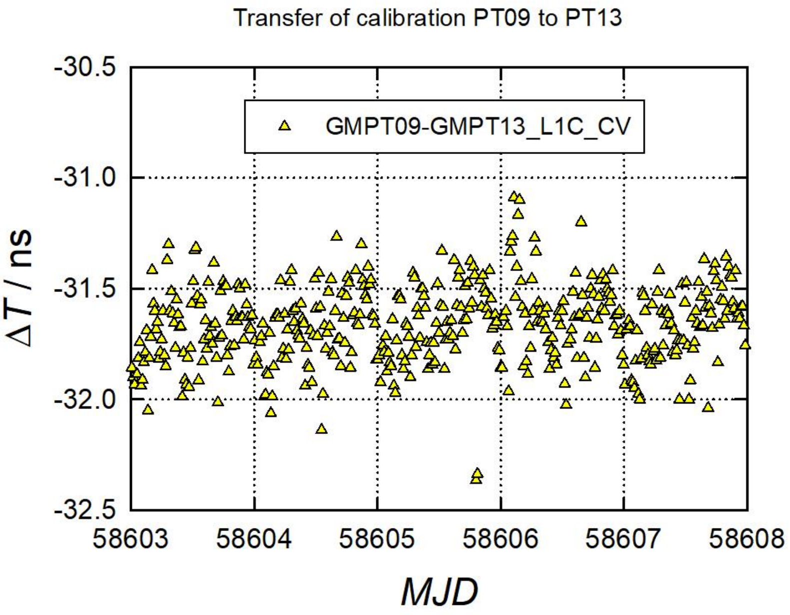

Figure 2-3 CV between receivers PTBT and PT09 using L1C data

For Galileo E1 we assume the same delay as determined before.

2.3. DETERMINATION OF PT13 GALILEO DELAY IN JUNE 2020

The period 59024 to 59028 (5 days) was chosen to determine the new PT13 Galileo INT DLY values. The result of comparison with PT09 as the reference are shown in Figure 2-4 illustrating in total 445 ΔEi values obtained as mean over all common view observations at a given epoch. The numerical results are given in Section 3.

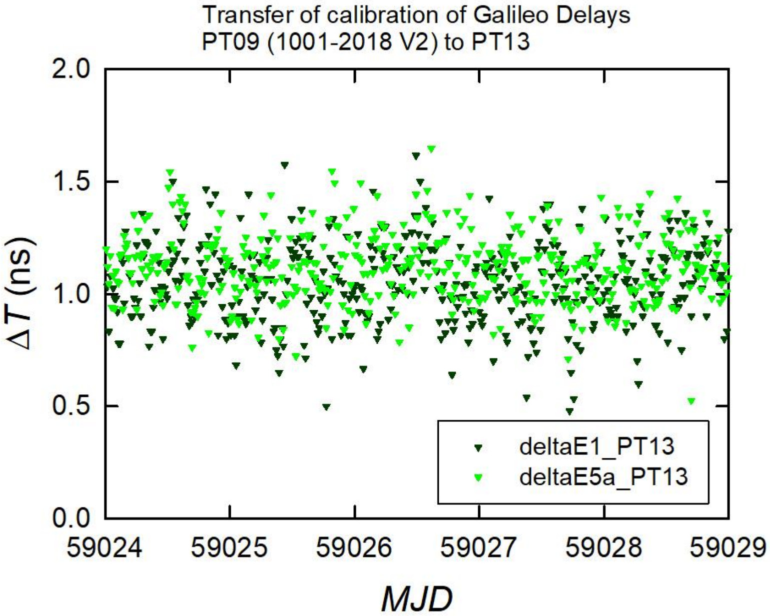

Figure 2-4 ΔE1 (dark) and ΔE5a (light green) values obtained during the common-clock set-up in PTB

3. RESULTS

As the PT13 internal delay were set zero initially, the values given in the upper rows of Table 3-1 represent the delay values to be used furtheron. The lower rows contain the corrections to be applied to the Galileo delays as consequence of the current campaign and the values to be used. These new PT13 delay Galileo delay values have been used in processing per 30 June 2020 (Rev Date in CGGTTS File).

Table 3-1: Result of common clock measurements at PTB

Quantity	Median (ns)	Sigma (ns)	TDEV (ns)
P1 (PT13)	29.74	0.20	0.1
P2 (PT13)	27.20	0.26	0.1
E1 (PT13)	30.98	0.22	0.1
E5a (PT13)	30.54	0.24	0.1
C1	31.66	0.17	0.1
Determination of new Galileo Delays June 2020			
ΔE1 (PT13)	1.05	0.18	0.1
E1 (PT13) new	32.0		
ΔE5a (PT13)	1.12	0.15	0.1
E5a (PT13) new	31.7		

4. INT DLY UNCERTAINTY EVALUATION

The overall uncertainty of the INT DLY values obtained as a result of the calibration is given by

$$u_{CAL} = \sqrt{u_a^2 + u_b^2}\,, \qquad (6)$$

with the statistical uncertainty u_a and the systematic uncertainty u_b. The statistical uncertainty is related to the instability of the common clock data collected at PTB. The systematic uncertainty is given by

$$u_b = \sqrt{\sum_n u_{b,n}}\,. \qquad (7)$$

The contributions to the sum (7) are listed and explained subsequently. Values in column P3 are calculated according to $u(P3) = \sqrt{u(P1)^2 + (1.54 \times u(P1\text{-}P2))^2}$. Note that the uncertainty of the INT DLY values of PTB's fixed receiver PT09 which served as the reference is not included.

Table 4-1: Uncertainty contributions for the GPS calibration of receiver delays

	Uncertainty		Value P1 (ns)	Value P2 (ns)	Value P1-P2 (ns)	Value P3 (ns)	Description
1	u_a (PTB)		0.1	0.1	0.14	0.18	CC measurement uncertainty at PTB, TDEV
	Systematic components due to antenna installation						
2	$u_{b,11}$		0.1	0.1	0.14	0.28	Position error at PTB
3	$u_{b,13}$		0.2	0.2	0.0	0.20	Multipath at PTB
	Installation of receivers to UTC(PTB)						
4	$u_{b,21}$		0.2	0.2	0	0.2	Connection of receivers to UTC(PTB) (REF DLY)
5	$u_{b,24}$		0.1	0.1	0	0.1	TIC nonlinearities at PTB

All uncertainties considered are small compared to the "standard" uncertainty attributed to a link between PTB and any laboratory contributing to TAI. Any error in the CAB DLY measurements is absorbed in the INT DLY values. Although the installation of the two receivers requires signal distribution via different distribution equipment, the final REF DLY measurements have been made (for PT09 in Nov. 2018 during campaign 1001-2018) and for PT13 in March 2019 using the same method so that only a small uncertainty due to possible non-linearities need to be considered.

The uncertainty estimate is considered valid in 2020. The slightly different frequency ratio in case of Galileo compared to GPS results in slightly different values, but after rounding to 0.1 ns the differences are negligible.

ANNEX: BIPM CALIBRATION INFORMATION SHEETS

Common clock measurement at PTB

Laboratory:	**PTB**			
Date and hour of the beginning of	2020-06-24 0:00 UTC (MJD 59024)			
Date and hour of the end of measurements:	2020-06-28 24:00 UTC (MJD 59028)			
Information on the system				
	Reference:		**DUT:**	
4-character BIPM code	**PT09**		**PT13**	
Receiver maker and type: Receiver serial number:	PolaRx4TR (2.9.6), S/N 3001148		Septentrio PolaRx5 470 1292	
1 PPS trigger level /V:	1		1	
Antenna cable maker and type: Phase stabilised cable (Y/N):	ECOFLEX 15plus		ECOFLEX15	
Length outside the building /m:	approx. 25		25	
Antenna maker and type: Antenna serial number:	NOV750.R4		LEICA AR25 726333, Calib Geo++ 18.08.2015	
Temperature (if stabilised) /°C				
Measured delays /ns				
	Reference:		**DUT:**	
Delay from local UTC to receiver 1 PPS-in (X_P) / ns	35.25 ± 0.1 (**)		9.33 (to port 1 PPS REF)	
Delay from 1 PPS-in to internal Reference (if different): (X_O) / ns	147.92 ± 0.1 (**)		45.00	
Antenna cable delay: (X_C) / ns	198.7 ± 0.1		205.7 ± 0.1	
Splitter delay (if any):	N/A			
Data used for the generation of CGGTTS files				
	Reference:		**DUT**	
☐ INT DLY (or X_R+X_S) (Galileo) /ns:	57.6 (E1), 66.3 (E5a) (**)		31.0 (E1) 30.5 (E5a) (***)	
☐ INT DLY (or X_R+X_S) (GLONASS) /ns:				
☐ CAB DLY (or X_C) /ns:	198.7		205.7	
☐ REF DLY (or X_P+X_O) /ns:	183.2 (**)		54.3	
☐ Coordinates reference frame:	ITRF (*)		ITRF	
X /m:	+3844057.34 (*)	Mast P12	+3844059.86	Mast P10 (****)
Y /m:	+709663.82 (*)		+709661.56	
Z /m	+5023131.76 (*)		+5023129.87	

General information	
☐ Rise time of the local UTC pulse:	3 ns
☐ Is the laboratory air conditioned:	Yes
Set temperature value and uncertainty:	23.0 °C, peakt-to-peak variations 0.5° C

Notes:

(*) values provided by BIPM as part of coordinate alignment 2018 reported in TM.281.

(**) Local measurement 2018-11-05, other results based on report Cal-ID1001-2018 V2
(***) values as reported in V1 of this Document

(****) new coordinates introduced 2019 on request of BIPM (REV DATE 2019-08-08)

Names of files to be used in processing:
DUT EZPT13MJ.DDD,
Reference receiver EZPT09MJ.DDD

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