Determination of phase center corrections for Galileo signals

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Introduction

For high accuracy GNSS applications phase center corrections (PCC), which include corrections for the phase center offset (PCO) and the phase center variations (PCV), are mandatory. These corrections are provided by different institutions & methods. At the moment only L1- & L2 frequencies for GPS are GLONASS are published by the IGS. However, partly chamber calibrations for the newer signals (Galileo and GPS L5) are available in the EPN. In this contribution, the PCC estimation approach of the Institut für Erdmessung (IfE) is presented. The estimated pattern are presented and validated with a common-clock set up at the Physikalisch-Technische Bundesanstalt (PTB). Moreover, the impact of the receiver on the estimation process is shown.

Methodology

As an IGS accepted calibration facility, IfE calibrates antennas using the method of absolute field calibration with a robot. The PCC are estimated post processed in the so called *Hannover approach*.

Data acquisition

- Set-up: short baseline (≈ 8 m) and common clock.
- Defined sequence of movements for the robot.
- Tilting and rotating of antenna under test (AUT) around fixed point in space.
- Logging of raw GNSS data for each station and movements of robot with timestamps (orientation parameters).

Figure 1: IfE robot for absolute antenna calibration. In the background the reference station (MSD8) can be seen.

Data analysis

- Finding corresponding observations on both stations where robot was not moving.
- Building of time-differenced single differences (ΔSD):
  - Most errors are cancelled out due to short baseline and short time period.
  - Phase-wind up and robot pose is modelled.

$$\Delta SD = \Delta PCC_A^k(t_i, t_{i+1}) + \epsilon(t_i, t_{i+1}) \quad (1)$$

PCC estimation

- Parametrisation of PCC by spherical harmonics (SH) with degree m = 8 and order n = 8

$$PCC(\alpha^k, z^k) = \sum_{m=1}^{m_{max}} \sum_{n=0}^{m} \tilde{P}_{mn}\left(\cos(z^k)\right)\left(a_{mn}\cos(n\alpha^k) + b_{mn}\sin(n\alpha^k)\right) \quad (2)$$

- SH analysis to estimate unknowns coefficients a_{mn} and b_{mn}.
- Coefficients with an odd index sum are restricted to zero.
- SH synthesis with estimated coefficients to calculate PCC grid.
- Least-squares adjustment to calculate PCO and PCV from PCC grid.

Repeatability of estimated pattern

- Several calibrations with different antennas/antenna types typical for IGS stations in February and August 2019 (Tab. 1).
- Analysing of repeatability by calculating RMS of difference pattern.
- Results show an overall good repeatability (RMS ≤ 1 mm) except for GL5X (less transmitting satellites). Biggest differences occur at low elevations (Fig. 2).
- Frequency dependency of PCC can be clearly seen, especially for LEIAR20 (Fig. 4).
- PCC are similar for LEIAR25 and LEIAR20 and range up to 15 cm.

Table 1: Antenna and antenna types which were calibrated with the *Hannover approach*.

Antenna	Serialnumber	DOY (2019)	RMS [mm] GL1C	GL5X	EL1X	EL5X
LEIAR25.R3 LEIT	08360013	056, 057	0.23	1.36	0.61	0.79
LEIAR20 NONE	22100043	220, 221	0.40	0.93	0.25	0.27
LEIAR20 LEIM	22100043	224, 225	0.62	0.98	0.54	0.71
LEIAR20 LEIM	22100016	227, 228	0.38	1.63	1.01	0.94

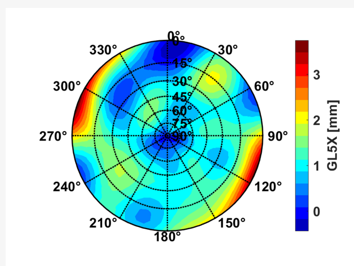

Figure 2: Differential GL5X PCC pattern for LEIAR20 NONE (S/N: 22100043).

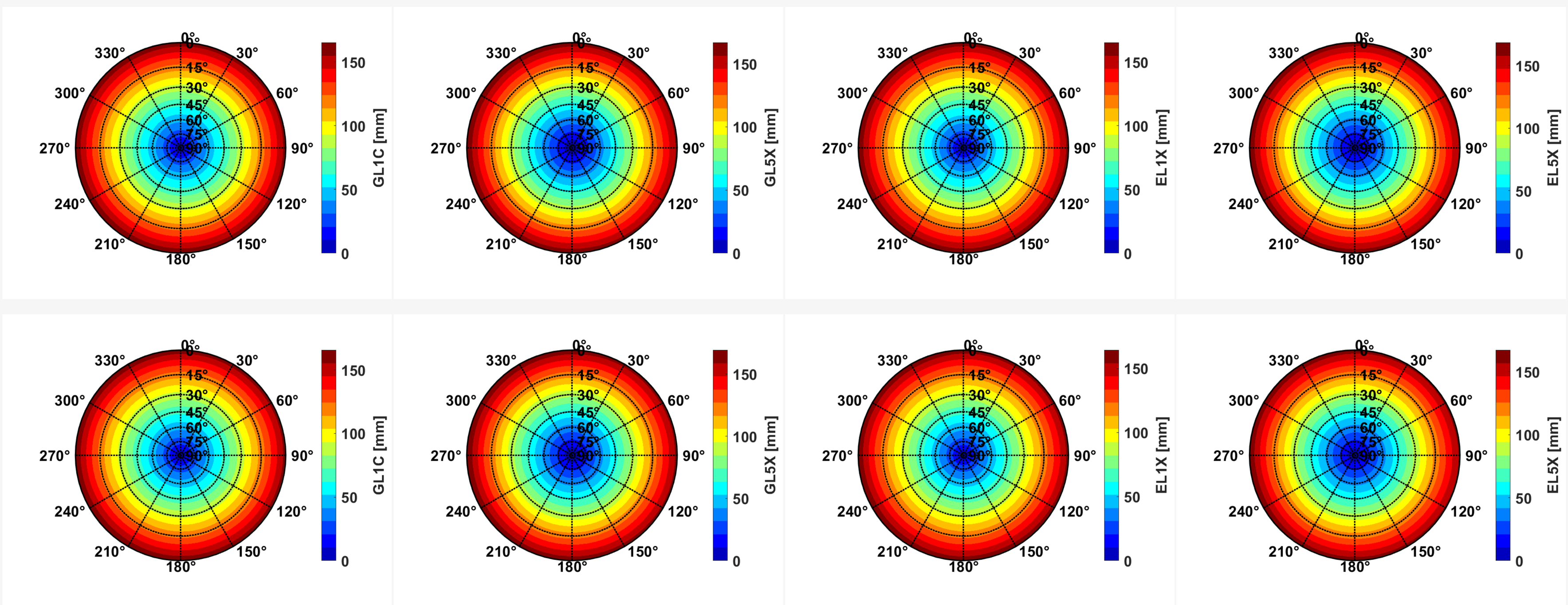

Figure 3: Estimated PCC pattern by using *Hannover approach* for LEIAR25.R3 LEIT (S/N: 8630013). The top row shows PCC pattern for following signals on DOY 56 (from left to right): GL1C, GL5X, EL1X, EL5X. The bottom row shows the PCC for the same signals on DOY 57.

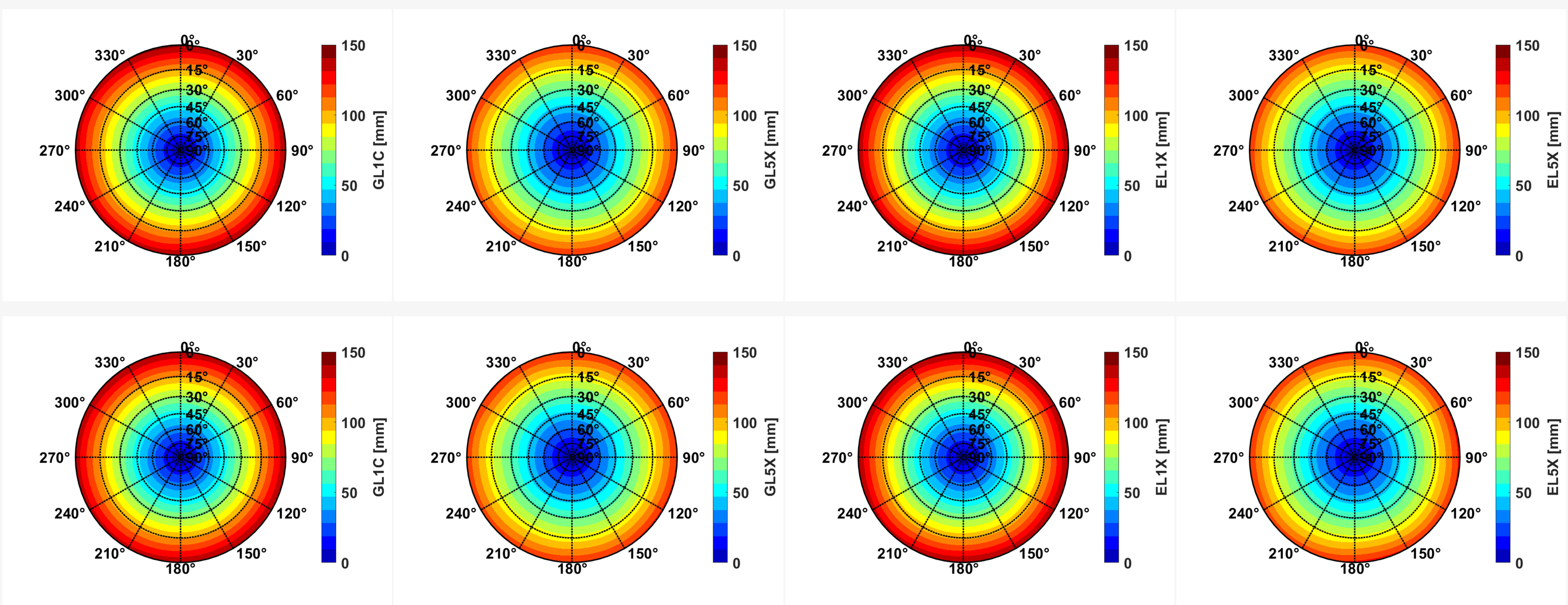

Figure 4: Estimated PCC pattern by using *Hannover approach* for LEIAR20 LEIM (S/N: 22100043). The top row shows PCC for following signals on DOY 224 (from left to right): GL1C, GL5X, EL1X, EL5X. The bottom row shows the PCC for the same signals on DOY 225.

Validation of estimated PCC

- Experimental setup at the PTB (Fig. 5): common-clock short baseline (∼ 5 m) configuration is used to calculate receiver-to-receiver-single differences (SD) (Tab. 2).
- GNSS measurements (GPS, Galileo, GLONASS) from February 4^{th} to 7^{th} 2019 (DOY35 - DOY38).
- Precise coordinates are calculated relative to reference station PT11 with sub-millimeter accuracy.
- Estimated pattern of NOV703GGG.R2 can be found in [1] and [2]. As there are no chamber PCC available for this antenna, the similar PCC of LEIAX120GG are used instead.
- IfE's PCC fit very good into SD and decrease its RMS up to 3.5 mm for EL5X.

Figure 5: Experimental setup at the PTB. The used Antennas are indicated by a red circle.

Table 2: Hardware setup at the PTB.

Station	Antenna	S/N	Receiver	S/N
0081	NOV703GGG.R2 NONE	12420040	JAVAD DELTA TREG3T	081
0082	LEIAR25.R3 LEIT	08360013	JAVAD DELTA TREG3T	082
PT11	LEIAR25.R4 LEIT	725101	SEPT PolaRx4TR Pro	3007572

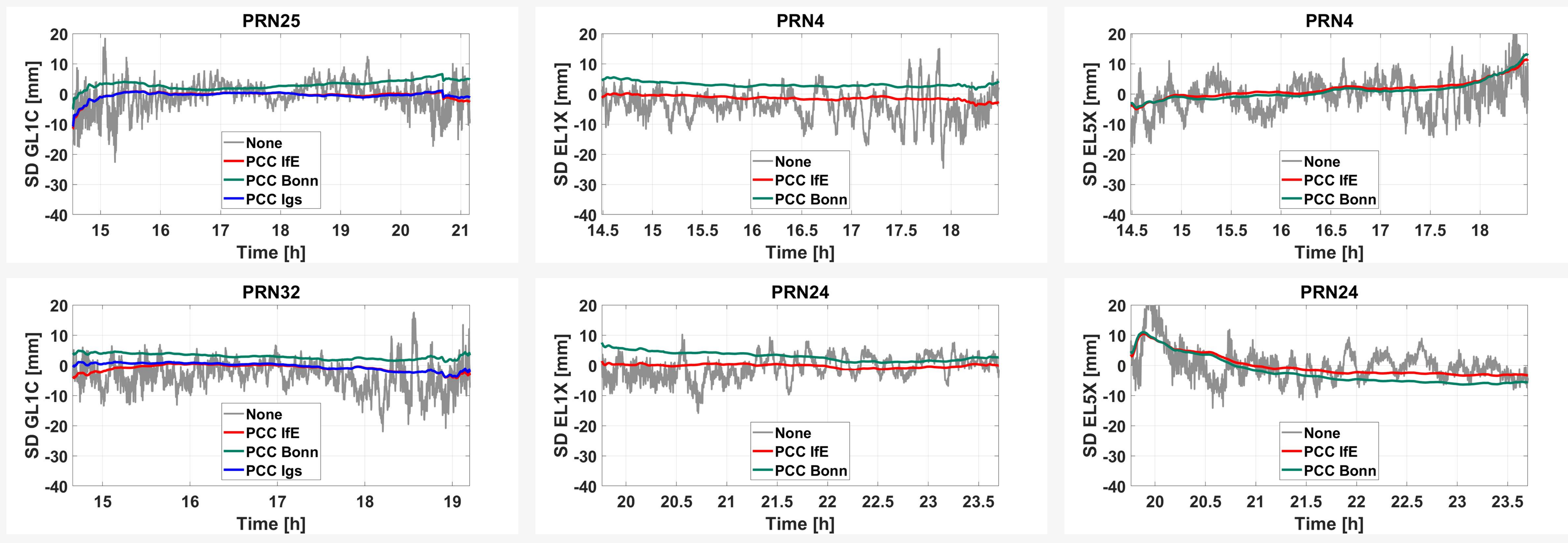

Figure 6: SD (light grey) of DOY 35 with respect to antenna reference point (ARP) without taking PCC into account. The top row shows the result for GL1C (PRN25), EL1X and EL5X (PRN4). The bottom row shows the result for GL1C (PRN32), EL1X and EL5X (PRN24). Coloured SD contain PCC and are smoothed for a better visibility. The PCC offset (e.g. PRN4) can be explained by the different datum definitions between chamber and absolute calibration. Oscillations of the SD occur due to multipath effects in the challenging surrounding.

Impact of different receiver on estimated PCC

To analyse the impact of different receivers on the estimated PCC (as the combination of antenna and receiver affect the PVT result) a zero baseline is set up.

- Two receivers are connected to the antennas on both stations (Tab. 3).
- AUT is LEIAR25.R3 LEIT (S/N: 08430002), estimation process equal to the one described in section *Methodology*.
- Tracking loop parameters, calibration time & robot pose are identical for all four receivers.

Table 3: Hardware setup for zero baseline configuration at IfE.

Station	Antenna	S/N	Receiver	S/N	Frqz. G	Frqz. E
ROBO	LEIAR25.R3 LEIT	08430002	JAVAD DELTA TREG3T	082	L1C, L5X	L1X L5X
			SEPT PolaRx5TR	3051345	L1C, L5Q	L1C, L5Q
MSD8	LEIAR25.R3 LEIT	09330001	JAVAD DELTA TREG3T	081	L1C, L5X	L1X, L5X
			SEPT PolaRx5TR	3051372	L1C, L5Q	L1C, L5Q

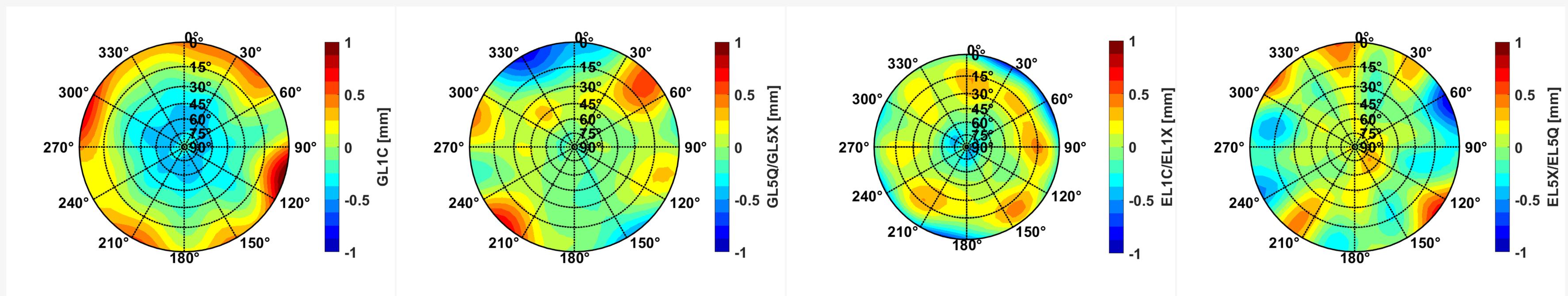

Figure 7: Difference pattern between estimated PCC using Javad or Sepentrio receivers on DOY 239 for following frequencies: GL1C, GL5Q/GL5X, EL1C/EL1X and EL5Q/EL5X.

Fig. 7 shows that the used receiver has an impact on the estimated PCC pattern:

- Small differences on all signals up to 1 mm occur. This can also be explained by the different tracking algorithms (e.g. GL5Q for Sepentrio, GL5X for Javad receivers).
- RMS < 0.3 mm, Spread ($dPCC_{max}$ - $dPCC_{min}$) less or equal 1.6 mm (Tab. 4).

Table 4: RMS and Spread [3] for the difference pattern (estimation with Septentrio or Javad receiver).

Frequency	G01	G05	E01	E05
RMS [mm]	0.29	0.16	0.22	0.17
Spread [mm]	1.57	1.58	1.25	1.60

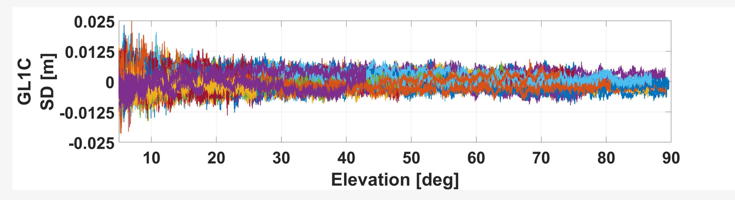

Figure 8: Expected noise of the zero baseline configuration for GL1C.

Conclusion & Outlook

- IfE is ready to estimate PCC for several GNSS signals using the *Hannover approach*.
- A good repeatability (RMS ≤ 1 mm, except for GL5X) is reached. Differences in repeatability can occur due to different robot movements and different calibration times (different satellite geometry).
- Calibration of further signals like GL2L, EL7Q and EL8Q is possible with Septentrio receiver.
- Further analyzing of the antenna-receiver impact on the estimation procedure, especially regarding the repeatability and the validation.

References and Acknowledgement

[1] Breva et al. (2019). Validation of phase center corrections for new GNSS signals obtained with absolute antenna calibration in the field. In: *Geophysical Research Abstracts 21, 7-12 April, 2019, Vienna, Austria.*

[2] Kröger et al. (2019). Phase Center Corrections for new GNSS signals. In: *Geophysical Research Abstracts 21, 7-12 April, 2019, Vienna, Austria.*

[3] Schön, S. and Kersten, T. (2014). Comparing antenna phase center corrections: challenges, concepts and perspectives. In: *IGS Analysis Workshop, 23-27 June, 2014, Pasadena, California.*

Antenna calibration data from IGS (method ROBOT & CHAMBER) are available at ftp://igs.org/pub/station/general/igs14.atx

Antenna pattens from University of Bonn (method CHAMBER) published by Europoean Permanent GNSS Network (EPN), available at ftp://epncb.eu/pub/station/general/indiv_calibrations/

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