Introduction

Currently, 5 calibration institutions including the Institut für Endmessung (IfE) contribute to the IGS ANTEX. Different approaches like field calibrations and anechoic chamber measurements are in use, thus an adequate comparison concept is necessary.

In this contribution we name PCC the phase center correction which is traditionally given by the 3 x 1 phase center offset (PCO) vector and the gridded phase center variations (PCV) expressed in an antenna body frame.

\[ \text{PCV}(\phi, \theta) = -s' \cdot \text{PCO} + \text{PCV}(\phi, \theta) + r, \]  

(1)

with \( \phi \), \( \theta \) the horizontal and vertical angle in the antenna body frame, \( s \) the line-of-sight unit vector, \( r \) a constant offset that cannot be determined. The PCV are generally estimated by spherical harmonics (SH) of polynomials and then gridded.

Issues of PCC determination

1) The determination of PCC has one degree of freedom. The problem is rank deficient of one, \( \text{cf. parameter } r \text{ in Eq. (1)}. \) Neither can nor should normalization in the field can determine absolute PCC. In fact, in the network analyzer the overall delay is not known at the antenna. Since GNSS are one-way ranging systems, by definition only pseudo-ranges and not absolute ranges can be determined in the field. Constant parts are thus absorbed by receiver clock offset and float ambiguities or eliminated by forming single or time differences.

Consequently, during the PCC determination, this one degree of freedom must be fixed by minimum constraints. Typical examples are \( \text{PCV}(\phi, 90°) = 0 \), or \( \text{PCV}(0, \theta) = 0 \). As a result, only the shape of the pattern can be determined but arbitrary and constant values can be added to all PCV, \( \text{cf. Fig. 1 (2)} \).

- Applying more than minimum constraints will deform the pattern.
- Degrees-of-freedoms in the multi-frequency or multi-GNSS cases to be checked carefully.

2) PCC parameterization and 3) PCO separation is numerically difficult. In general, a spherical harmonics decomposition of a polynomial fit is used for the determination of the PCC. However, only data in a hemisphere or slightly more is given which leads to strong correlations between the PCC coefficients and a weak determination.

[Kenten and Schön, 2010]. Consequently various stabilization strategies are used: additional constraints, normal equation regularization, process noise for UKF approaches or multi-step strategy. Only few information are publicly available how the calibration institutions solve this issue. However, these processing options influence the obtained patterns.

4) Consistent set of PCO and PCV is essential. Traditionally, PCO and PCV are separated somehow arbitrarily and a PCO and PCV, published in the ANTEX format. As reported by [Rothacher et al., 1995, [Menge, 2003)]) PCO and PCV can be transferred in a consistent way:

\[ \text{PCO}(\phi, \theta) = s' \cdot \text{PCO} + \text{PCV}(\phi, \theta) + r_1 \]

(2)

\[ \text{PCV}(\phi, \theta) = s' \cdot \text{PCO} + \text{PCV}(\phi, \theta) + s'' \cdot (\text{PCO} - \text{PCO}_0) + r_2 \]

(3)

\[ s'' \cdot \text{PCO} + \text{PCV}(\phi, \theta) + r_2 \]

(4)

if the same datum is required \( r_1 = r_2 - \Delta h \).

Allowed PCV transformations illustrated for the elevation dependent pattern:

1. Original pattern.
2. Variation of the offset \( r \), \text{cf. Eq. (3)}.
3. Change of the offset \( r \), \text{Eq. (3-4)}.
4. Transforming (3) to original datum \( \text{PCV}((\phi, 90°) = 0) \).

On adequate Comparisons of Antenna Phase Center Variations

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Proposal for a comparison strategy

1. The PCV and PCO should be considered together in a consistent way, \text{cf. Eq. (1)}.
2. The PCC of each antenna to be compared should be transformed on an arbitrarily chosen, but common PCO using Eq. (3).
3. The rank defect of the PCC should be removed in a identical way, e.g. by applying \( \text{PCV}((\phi, 90°) = 0 \). However this is only allowed if the original patterns have minimum constraint datum.

4. The resulting PCV can be compared e.g. by forming difference patterns (\( \Delta \text{PCV} \)).

5. Since the comparison in the observation domain may be misleading (see below) also the impact on all estimated parameters should be analyzed, i.e. on coordinates, clock errors, tropospheric parameters and ambiguities.

Discussion observation domain

- Since PCV are rank deficient (issue 1), also differences of PCV (\( \Delta \text{PCV} \)) are rank deficient.
- Thus, only the form of PCV and \( \Delta \text{PCV} \) pattern can be determined and discussed. Consequently, it is not possible to associate in a unique way a PCV pattern to a specific elevation, \( \text{cf. Fig. 1} \).
- Thresholds for maximum allowed differences between PCV from different calibration institutions or repeated calibrations should be reviewed, taking the datum dependency into account.
- Numerical values should be based on datum independent measures. We propose:
  - the spread \( \text{PCV_{min} - PCV_{max}} \)
  - the RMS of the pattern in zero mean datum which equal the standard deviation of the pattern.

The impact of PCV variations on the estimated parameters is difficult to assess in general. Thresholds for maximum allowed differences between PCV from different calibration institutions or repeated calibrations should be reviewed, taking the datum dependency into account.

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References


Conclusion and Outlook

- The main issues of PCC determination are highlighted.
- Subsequently, a comparison strategy is proposed, taking the one degree of freedom in the PCC into account.
- Generic PCV patterns are proposed to assess the impact on the parameters.
- Due to the high mathematical correlation in the GNSS adjustment, the impact on all parameters must be considered.

Further work will focus on

- Extension of the generic PCV patterns to higher order \( \sin(2\phi), \ldots, \cos(2\phi), \ldots \)
- Consideration of multi-frequency, multi-GNSS cases
- Impact of different analysis concepts and parameterization (PPP or relative positioning, static or kinematic)

Example of generic PCV patterns

The impact on the parameter domain depends on the GNSS analysis strategy proposed. Here, first results from 24h PPP are shown. For further studies \text{cf. e.g. [Dißner, 2007]}.

Typical PCV and \( \Delta \text{PCV} \) patterns

Discussion parameter domain - impact of generic PCV patterns

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