National Research Institute of Astronomy and Geophysics

NRIAG Journal of Astronomy and Geophysics

www.elsevier.com/locate/nrjag

Influence of GPS antenna phase center variation on precise positioning

Ahmed I. EL-Hattab *

Port Said University, Faculty of Engineering, Egypt

Abstract   The GPS antenna is the connecting element between the GPS satellites and the GPS receiver. It receives the incoming satellite signal and then converts its energy into an electric current, which can be managed by the GPS receiver. The accurate antenna phase center offsets' values and phase center variation factors are critical issues in GPS precise positioning. Some GPS users simply apply the manufacturer's recommended offset values which may not match the precise values determined by calibration process. Other users may ignore the phase center correction factors during GPS data processing. In both cases, the resulted coordinates will have errors especially the height component.

In this study, some static and kinematic field experiments have been carried out to evaluate the effect of using the manufacturer's recommended antenna phase offset and ignoring its variation on precise positioning. The GPS data have been post-processed by two commercial software. The results showed that, a significant error may occur in case of disregarding the calibrated values and applying the manufacturer's recommended ones. Investigation is also made on the effects of mixing different types of antennas. Significant variations are observed on the height components than the associated horizontal component due to phase center variation. The maximum variations are reached about 8 and 4 cm in height and northing components respectively.

© 2013 Production and hosting by Elsevier B.V. on behalf of National Research Institute of Astronomy and Geophysics.

1. Introduction

The GPS antenna is the connecting module between the GPS satellite and the GPS receiver. It is used to filter, amplify, and convert the incoming signal from satellites into an electrical signal that can be processed by the receiver. The point at which the GPS signal is received is called antenna phase center (APC). APC does not coincide with the antenna physical (geometrical) center and varies with elevation, azimuth, intensity of the satellite, and frequency of the incoming signal. Therefore, a mean position of the electrical antenna phase center is determined for the purpose of the offset calibration.

* Tel.: +20 1060147785.
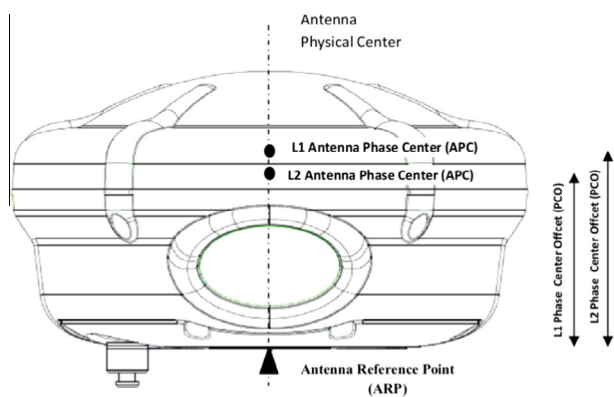 E-mail address: dr.ahmed.elhattab@gmail.com

Fig. 1 Main points of a model GPS antenna.

A relative GPS carrier phase solution effectively measures the vector between the phase centers of two antennas situated at either end of a baseline. To relate this vector to physical points on the ground, the exact location of the phase center of each antenna relative to those points must be known. Standard GPS processing procedures reduce all GPS observations APC to the station reference point by way of the measured vertical antenna height. This height is usually measured by the user to some point on the antenna specified by the receiver manufacturer called antenna reference point (ARP). The constant vector between APC and ARP is called phase center offset (PCO). It should be provided by the manufacturer; if not, the determination of these coordinates is carried out by a calibration procedure (Görres et al., 2006). The main phase center offset component is vertical but there are also small horizontal offsets. There are two-phase centers, one for the L1 frequency and the other for L2, but each phase center has a different offset as introduced in Fig. 1.

Antenna phase center variation (PCV) is a deviation of the antenna phase center beyond the antenna offset. The GPS antenna phase center shifts in position with varying observed elevation angle and azimuth to the satellite. This shift is expressed by mean phase center offsets and by phase and amplitude patterns for L1 and L2. Based on the frequency of received signal the shift is measured in the order of several centimeters (Schupler et al., 1994). PCV problem is significant for applications requiring the highest attainable precision from GPS. Therefore, it is necessary to know the exact position of the phase center of the transmitting as well as of the receiving GPS antenna in order to achieve high-precision GPS results. Antenna calibration is applied to determine the best general phase corrections for a given antenna model. The azimuth- and elevation-dependent PCV define the phase pattern for each carrier frequency. The total antenna phase center correction for an individual phase measurement is composed of the influence by the PCO plus the azimuth- and elevation-dependent PCV (Hofmann-Wellenhof et al., 2008).

2. Determination of antenna phase center variations

Combining GPS with other space-geodetic techniques becomes difficult in case of unmodeled systematic errors due to improper GPS antenna calibration models. As a consequence scale differences have been seen in GPS reference frames. Nowadays, relative PCV calibration models are commonly used as the standard GPS processing method, but there is no guarantee that they are applicable for different circumstances. Three methods are currently used to determine GPS receiver antenna phase center variations: relative field calibrations, anechoic chamber measurements, and absolute field calibrations.

The relative phase center variation models are based on the assumption that the Alan Osborne antenna type AOAD/M_T has been approved of being the "zero" antenna. This antenna type forms a standard with elevation dependent variations set to zero referring to a mean fixed offset (Rothacher, 2001). PCVs for a calibrating antenna can be determined using short baseline field measurements. A database of relative calibrated antenna types has been generated with free access to everyone.
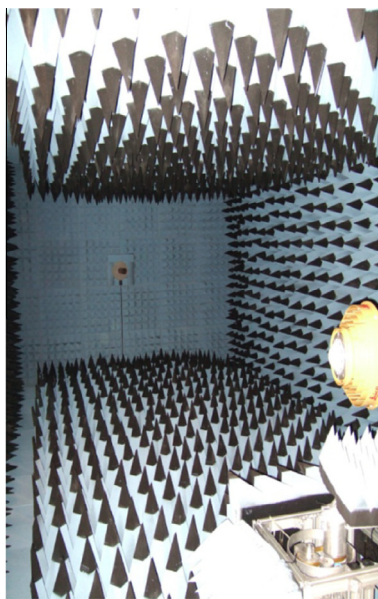
(a) Uni. of Bonn robot in anechoic chamber

(b) Geo++ robot in field

Fig. 2 Absolute antenna calibration methods (Bilich et al., 2012).

Fig. 3 First experiment arrangements.

Fig. 4 Bottom of R8-model3 antenna.

The drawback is that the corrections are dependent on the zero/reference antenna and that PCVs at low elevations are not reliable due to the increase of noise and multipath in measurements below 10° (Mader, 2002). National geodetic survey (NGS) is one of the organizations that provides complete summary of all calibration results free of charge.

The main idea of the laboratory antenna calibration procedure is to simulate the different signal directions by rotations of the antenna. Therefore, the calibration setup consists of a fixed transmitter on the one end and a remote-controlled positioner carrying the test antenna on the other end of the test range. At every selected antenna position (equal to a satellite direction) a network analyzer generates a signal which is transmitted in the direction of the GNSS antenna. The antenna is also connected equipment that the network analyzer can measure the phase shift between the outgoing and incoming signals. This phase delay depends on the signal direction. Since the outgoing signal is constant, a grid of phase corrections is directly obtained as a result of the calibration (Zeimetz and Kuhlmann, 2011). In case of calibration the multipath effects can be reduced to a low level by using special anechoic chambers as in Fig. 2a. The advantage of the laboratory procedure

is achieving constant environments for all calibrated antennas and its very high efficiency. The main disadvantage is that the test signal differs from the real GNSS signal.

Absolute field calibrations are performed using a high precision robot and two antennas. The robot rotates and tilts the antenna while the reference antenna is kept fixed. The advantages of the absolute field calibration are that the real GNSS signals are tracked with a real receiver and the antenna is in the natural field environment. In contrast to the relative antenna calibrations, the robot measurements allow the determination of patterns to 0° elevation and allow elimination of multipath effects to a large extent as shown in Fig. 2b. This is because the time difference between consecutive epochs amounts to just a few seconds. Therefore the environmental multipath error in consecutive epochs is highly correlated and can be well described as a stochastic process within a Kalman filter (Wübbena et al., 2006).

3. GPS observation model

For short base lines the double-difference observation model between stations a, b and satellites i, j can be written for L1 or L2 frequency as:

$$\lambda\phi_{a,b}^{i,j} = \rho_{a,b}^{i,j} + \lambda N_{a,b}^{i,j} - \Delta_{a,b}^{i,j}\text{Ion} + \Delta_{a,b}^{i,j}\text{Trop} + \Delta_{a,b}^{i,j}\text{MP} + \Delta_{a,b}^{i,j}\text{PCO} + \Delta_{a,b}^{i,j}\text{PCV} + \varepsilon$$

where $\phi_{a,b}^{i,j}$, phase measurements in cycles; $\rho_{a,b}^{i,j}$, range between the receivers at station; $N_{a,b}^{i,j}$, unknown integer ambiguity; $\Delta_{a,b}^{i,j}\text{Ion}$, ionospheric delay in range unites; $\Delta_{a,b}^{i,j}\text{Trop}$, tropospheric delay in range unites; $\Delta_{a,b}^{i,j}\text{MP}$, multipath effect; $\Delta_{a,b}^{i,j}\text{PCO}$, antenna phase center offset residuals; $\Delta_{a,b}^{i,j}\text{PCV}$, antenna phase center variation; λ, signal wave length; ε, noise of the phase measurements and unmodelled errors.

When the antennas at opposite ends of relatively short baselines are identical, PCV will be canceled out and no effect

Table 1 Results of G1-T baseline.

Point	Easting (m)	Northing (m)	Height (m)	Remarks
G1	469306.503	3505726.892	845.000	Reference
T	469306.894	3505727.282	845.021	Manufacturer's PCO
T	469306.895	3505727.281	845.002	NGS calibration factors
T	469306.895	3505727.281	844.998	Without PCV factors

is remained. However, different antenna types exhibit different PCV and baselines with different antenna types will show increasing sensitivity to such things as elevation cutoff angle and the distribution of observations within a solution (Mader, 2002). Antenna PCO residuals should also be canceled out if the same antenna type is used. Using mixed types, some effects may remain which have influence on the calculated coordinates. In case of long baselines, PCV at the opposite ends will not be canceled out since the satellite zenith angles will be different and accordingly the PCV.

4. Field experiment procedures and results

To evaluate the effect of antenna phase center offset and its variation on the baseline solution, three field experiments have been performed. In the first experiment three GPS antennas have been used; two Leica GS15, and one Trimble R8-Model 3. Trimble and one of the Leica antennas have been fixed over a leveled flat table as shown in Fig. 3. The two stations were named T and G1 respectively and hence the ARP of the two antennas has the same height value. The other Leica antenna named G2 was fixed over tripod 70 m away from the table. Two hours of GPS data were collected with 10 s sampling interval and 15° cut-off angle.

Fig. 4 shows the bottom of trimble antenna where the manufacturer's recommended L1 PCO is printed with a value of 6.49 cm. To evaluate the recommended PCO, the baseline

G1-T was processed using Leica Geo Office (LGO) Ver.7. The station G1 was considered as a reference and T as a rover. The processing was performed to solve the baseline using the manufacturer's recommended PCO value, using calibrated PCO and PCV factors, and without applying PCV factors. The resulted coordinates of the rover station T are listed in Table 1.

One can notice that the rover's height component has 0.02 m difference in case of using the manufacturer's recommended PCO for Trimble antenna. Only 0.002 m height difference in case of NGS calibrated PCO and PCV. In case of ignoring PCV the height difference becomes −0.002 m. Since ARP of both antennas has the same level, it is expected that the resulted height components will have the same value for the reference and rover stations. It is obvious that, NGS calibration is more accurate than the manufacturer's recommended value while ignoring PCV has no significant effect since the baseline is too short. The same results are obtained in case of using Trimble business center (TBC) software ver. 2.7.

To evaluate the effect of combining different types of antennas in one session, the baselines G2-G1 and G2-T were processed. Station G2 was considered as reference and the other stations as rovers. Table 2 shows the results of the processed baselines using LGO and TBC software.

Almost no variations in the horizontal components are observed in all cases. Using LGO software, the height component

Table 2 Results of G2-G1 and G1-T baselines.

Point	Easting (m)	Northing (m)	Height	Remarks
G2	469254.802	3505680.527	844.292	Reference point
G1	469306.503	3505726.892	845.000	LGO software
T	469306.895	3505727.279	845.003	PCV corrections are applied
G1	469306.503	3505726.892	845.000	LGO software
T	469306.895	3505727.279	845.003	PCV corrections are not applied
G1	469306.503	3505726.893	844.996	TBC software
T	469306.896	3505727.279	845.020	PCV corrections are applied
G1	469306.503	3505726.893	844.996	TBC software
T	469306.896	3505727.279	845.027	PCV corrections are not applied

Table 3 Results from processing baseline GMN-TMP.

Case No.	Easting (m)	Northing (m)	Height	Remarks
1	496310.100	3507967.535	888.096	Leica + TBC with PCV
	496310.104	3507967.546	888.115	Leica + TBC with PCV
	496310.103	3507967.529	888.071	Trimble + TBC with PCV
2	496310.106	3507967.533	888.092	Leica + LGO with PCV
	496310.110	3507967.548	888.109	Leica + LGO with PCV
	496310.116	3507967.502	888.144	Trimble + LGO with PCV
3	496310.102	3507967.529	888.093	Leica + TBC without PCV
	496310.104	3507967.546	888.115	Leica + TBC without PCV
	496310.116	3507967.502	888.144	Trimble + TBC without PCV
4	496310.107	3507967.533	888.091	Leica + LGO without PCV
	496310.110	3507967.548	888.109	Leica + LGO without PCV
	496310.116	3507967.494	888.168	Trimble + LGO without PCV

of rover station G1 is correct by applying PCO and PCV correction factors. While ignoring PCV produces no significant height difference. Using TBC for baseline processing, station G1 has −0.004 m height difference in case of applying PCO regardless of implements of PCV correction factors.

Using mixed types of antenna as in case of rover station T, the changes in height component increase. It is 0.003 m in case of applying PCO and PCV correction factors and LGO software while it reaches 0.02 m when using TBC software. Ignoring PCV produces 0.006 and 0.027 m height differences in case of using LGO and TBC software respectively.

Practically, the baselines during GPS surveying are longer than those in the previous experiment. Therefore, the GPS data of longer baseline GMN-TMP were used for further investigation. The baseline length is about 27.3 km and the same antennas in the previous experiment have been used. The experiment has been carried out on day numbers 129, 131, and 174 of year 2013 for about 3 h observation time per day. During the first and second day, Leica antennas were used at both baseline ends. On the third day, mixed antennas were applied where Trimble antenna was operated at point TMP. There baseline was processed using LGO and TBC software with/without applying PCV correction factors.

Table 3 shows the resulted coordinates of station TMP where station GMN was considered as a reference station. Fig. 5 illustrates the variation in the resulted coordinates in the different cases. The first row of Table 3 is considered as a benchmark for calculating the variations in Fig. 5.

It is obvious that in case of using Leica receivers on both ends of the baseline; the coordinates are close in all cases. The maximum difference is always in height component then northing and the least is in easting. When using TBC software without applying PCV correction factors, the maximum differences in height and northing components are 0.022 and 0.017 m respectively. In all cases, changes in easting component are small and in the range of 0.002–0.004 m.

Using mixed types of antenna causes increasing of the coordinate differences where the maximum differences in height and northing components are reached at 0.077 and 0.039 m respectively when LGO software is used for processing without applying PCV correction factors.

By comparing the coordinates, regardless using PCV corrections, it is noticed that there is no significant change when the same type of antenna was used. In case of using mixed types of antenna, the difference in height component increased from 0.024 to 0.073 m when using LGO, and TGO respectively.

Real time GPS precise positioning is required in many applications where on-the-fly kinematic techniques are applied to resolve the GPS unknown ambiguities and determine the instantaneous coordinates. To investigate the effect of antenna phase center variation on GPS kinematic positioning, GPS data collected during bathymetric survey are utilized. LEICA GX1230GG GPS antennas have been used for base and rover stations. The coordinates of the rover station have been computed by applying PCV correction factors. The process is
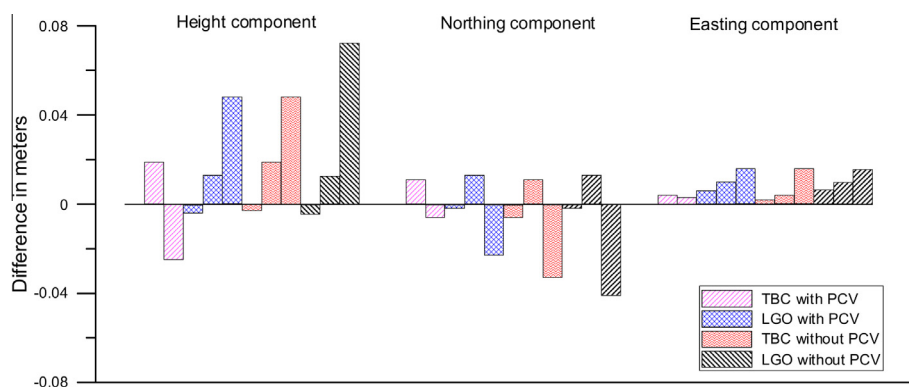

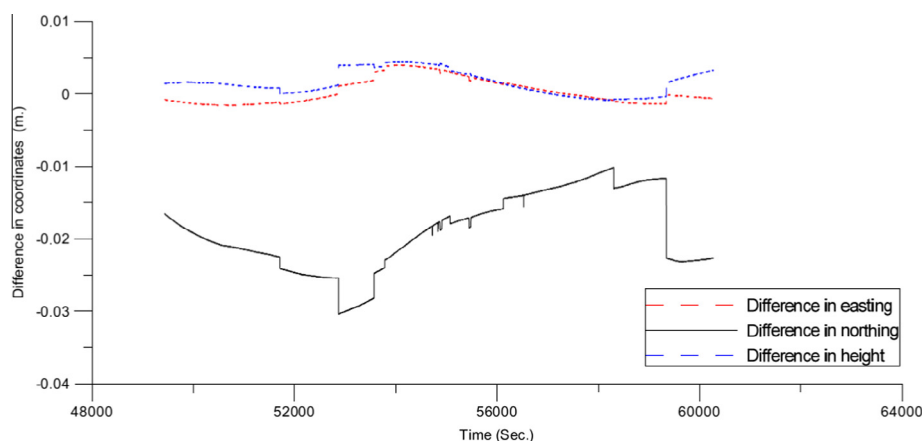**Fig. 5**   Changes of coordinates of station TMP.

Fig. 6   Coordinate difference due to ignoring PCV.

repeated to compute the coordinates ignoring the PV corrections. The difference between the corresponding coordinates has been computed and plotted in Fig. 6

It is obvious from the figure that PCV has greater impact on height component than the horizontal components in static positioning. The differences in height range from 0.01 to 0.03 m while they range from 0.002 to 0.004 m and from 0.001 to 0.005 m in easting and northing respectively.

The continuous variations of difference in the coordinates are due to PCV changes with elevation, azimuth, and number of tracked satellites. The broken lines in figure are due to the changes in the number of the tracked satellites.

5. Conclusion

The influence of antenna phase center offset and its variation have been evaluated using GPS data from some static and kinematic field experiments. The effect of using the manufacturer's recommended antenna phase offset and ignoring the phase center variation has been investigated using two different GPS post-processing commercial software. The following outcomes have been confirmed:

1. Applying the manufacturer's recommended offset values which may differ from the accurate calibrated values will lead to height error equal to the difference between the two values.
2. Using identical antennas at both ends of baselines, the phase center variations may cancel out, particularly over short baselines.
3. Even on short baselines, using mixed antennae ignoring phase center variations can lead to serious errors (about 8 cm as in this study) in height component. In this case, the only way to avoid these errors is by applying the accurate antenna phase center variation factors in processing.

4. Each GPS post-processing software has a different procedure to manage the antenna phase center variations.
5. Antenna phase center variation affects the vertical and horizontal components, but its effect on the vertical is greater than the horizontal components in case of static and kinematic GPS positioning.

References

Bilich, A., Schmitz, M., Görres, B., Zeimetz, P., Mader, G., Wübbena, G., 2012. Three-Method Absolute Antenna Calibration Comparison. IGS Workshop 2012. University of Warmia and Mazury (UWM), Olsztyn, Poland, July 23–27.

Görres, B., Campbell, J., Becker, M., Siemes, M., 2006. Absolute calibration of GPS antennas: laboratory results and comparison with field tests and robot techniques. GPS Solut. 10 (2), 136–145.

Hofmann-Wellenhof, B., Lichtenegger, H., Wasle, E., 2008. GNSS–Global Navigation Satellite Systems. Springer-Verlag Wien, Austria.

Mader, G., 2002. GPS Antenna Calibration at the National Geodetic Survey. National Geodetic Survey, NOS, NOAA, Silver Spring, MD.

Schupler, B.R., Allshouse, R.L., Clark, T.A., 1994. Signal characteristics of GPS user antennas, navigation. J. Inst. Navig. 41 (3), 277–295.

Rothacher, M., 2001. Comparison of absolute and relative antenna phase center variations. GPS Solut. 4 (4), 55–60.

Wübbena, G., Schmitz, M., Boettcher, G., 2006. Separation of Near-Field and Far-Field Multipath: New Strategies for Station Calibration. 10th EUPOS® ICS, Budapest, Hungary, November 23–24.

Zeimetz, P.H., Kuhlmann, H., 2011. Validation of the Laboratory Calibration of Geodetic Antennas based on GPS Measurements. FIG Article of the Month, February, 2011.