Investigating the Impact of High Voltage Power Lines on GPS Signal

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Abstract
Some surveyors claimed that problems were experienced when one collects GPS observations beneath high voltage power lines. They had reported quite large anomalies. Still others had reported no problems beneath high voltage power lines. Several tests were performed by RTK beneath or close to high voltage power lines (Gibing et. al., 2001), radar towers, generators and cell phone towers. A complete loss of ambiguities initialization was occurred. This is mainly due to wireless interruption, failed in transmitting the base data to the rover unit.
To see the effect of the high voltage power medium on the pure GPS signal, we need to separate the interruption of the transmitting medium of base station data from the GPS signal. Thus, the current paper studies the effect of high voltage power lines (HVP) only on differential static GPS and post processing kinematic observations and the related results. The study is based upon investigating the effect of the HVP on GPS stations located directly beneath or close to the power lines with other stations more away from the HVP. The results show that the obtained coordinates are not affected in static mode while the epoch-wise coordinates are insignificantly affected by the HVP.

Zusammenfassung
Einige Vermesser berichteten von Problemen bei der Durchführung von GPS Messungen unter bzw. in der Nähe von Hochspannungsleitungen. Sie entdeckten hier große Abweichungen in den Beobachtungen. Andere Vermesser dagegen berichteten von keinerlei Problemen im Umfeld von Hochspannungsleitungen. Verschiedene Tests wurden mittels RTK bei Hochspannungsleitungen (Gibing et al., 2001), Radaranlagen, Stromgeneratoren und Mobilfunkmasten durchgeführt. Aufgrund von Unterbrechungen bei der Datenübertragung von der Referenzstation zum Rover konnten die Mehrdeutigkeiten oftmals nicht gelöst werden.
Um den Einfluss von Hochspannungsleitungen auf das reine GPS-Signal zu untersuchen, muss dieser Effekt von den Störungen auf die Datenübertragung getrennt werden. Folglich wird im nachfolgenden Beitrag der Einfluss von Hochspannungsleitungen (im Folgenden HVP = high voltage powerlines) nur auf differenzielles statisches GPS und im Postprocessing prozessierte kinematische GPS-Beobachtungen untersucht. Die GPS-Punkte befinden sich hierbei direkt unter bzw. in der Nähe von HVP's aber auch weiter entfernt, um Referenzdaten für einen Vergleich zu erhalten. Die Untersuchungsergebnisse zeigen, dass die prozessierten Koordinaten im statischen Fall nicht durch die HVP beeinflusst werden, während die epochenweisen Lösungen einen schwachen Einfluss aufweisen.

Keywords: high voltage power lines, differential static GPS observations, RTK, magnetic field

1 Introduction

Electric and magnetic fields (EMF) are always created in varying levels with the generation and use of electricity and at the frequency of the electrical power system. Electric fields are produced by the presence of electric charges. Magnetic fields are produced by the current flowing (movement of electric charge) on a conductor. The current of a system may vary depending on the number of devices (load) supplied by the system. The effect of the magnetic fields is inversely proportional to the distance from the source (conductor).

Electric fields created in the vicinity of overhead power lines depend on the voltage on the line, the tower configuration and the conductor height above ground. Magnetic fields created in the vicinity of overhead power lines depend on the current flowing on the line, the tower configuration and the conductor height above ground. The following chapter explains in details the physical characteristics of both fields.

Power lines primarily affect the Radio Frequency (RF) section of each GPS receiver. Since each manufacturer has different methods of shielding to detect and minimize external interference, each receiver will react differently in that environment. Depending on its amplitude this reaction will affect the GPS solution. The issue of potential interference with GPS receivers under or close to electric power lines has been raised since some documentations from GPS receivers manufactures include vague warnings about such use. However, researchers have indicated that electromagnetic interference is only a problem when the following three conditions are satisfied (Matthes et al. 2003):

1. The transmission line voltage is above 230 kV.
2. The frequency of interest is less than 30 MHz.
3. The distance between the transmission line and the receiver is small (i.e. less than 100 m).

Since GPS receivers operate at microwave frequencies significantly higher than 30 MHz (typically 1,228 GHz to 1,575 GHz), the second condition is not met and therefore it is not expected that interference to GPS receivers will be caused by nearby transmission lines. Silva and Olsen (2002) studied the potential effects of electromagnetic interference and/or signal scattering from overhead conductors. The effects were analytically evaluated and corroborated by practical measurements under transmission lines. They demonstrated that it is unlikely that power line conductors will interfere with the use of GPS satellite signals. Additionally, in order to verify whether the high voltage power line of 380 kV with a vertical clearance of 20 m above ground would disturb the observed GPS data, Alsalman (2001) carried out two static GPS campaigns. The first campaign was performed while the power was shut off and the second one while the power was turned on. The results of the two campaigns were compared with each other. The results of two days confirmed that there is no statistical evidence of any degradation of GPS positioning accuracy due to the high voltage electric power lines. Several tests were performed by RTK (Gibing et. al., 2001), or RTK-Network (Zainon and Wan Aziz, 2010), beneath or close to HVP. The results demonstrated that the GPS receiver may cease to track satellites when placed close to the transmitting source.

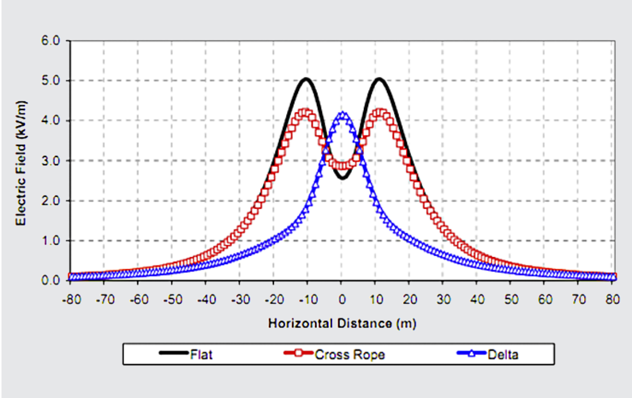
The difference in the results of the aforementioned researches motivated us to investigate the effect of HVP on the GPS signal. The current research deals with studying the effect on the GPS solution with a receiver located in a magnetic field of a HVP and comparing the results with a similar one which is not influenced by the magnetic field. The results confirmed that the magnetic fields have no effect on the GPS signal in static mode, nor do power lines. Even electric transmission towers and their stronger EMF emissions have only a minimal effect.

It is possible to subdivide the entire work of the current research into three major steps. First of all the physical characteristics of the HVP itself and the related magnetic field are investigated. The second step contains the study of the influence of the magnetic field on static differential GPS observation results. In the third step the effect of the magnetic field on kinematic GPS solutions is investigated.

2 Modern power line structures and associated electric and magnetic fields

Discussing electric and magnetic fields from overhead power lines, it is useful to refer to the maximum field level below the line as well as to the field level at the servitude boundary. Maximum field levels are found at the mid-span position (the position midway between two adjacent towers), where the conductors are closest to the ground (ESKOM Holdings Ltd, 2006). Electric fields and related magnetic fields created in the vicinity of overhead power lines depend on the voltage on the line, the tower configuration and the conductor height above ground.

Fig. 1a and 1b demonstrate typical electric and magnetic field profiles associated with a 400 kV line with different design configurations as depicted in Fig. 2 (ESKOM Holdings Ltd, 2006). It is clear that different



ESKOM Holdings Ltd, 2006

Fig. 1a: Typical electric field profiles for a 400 kV line

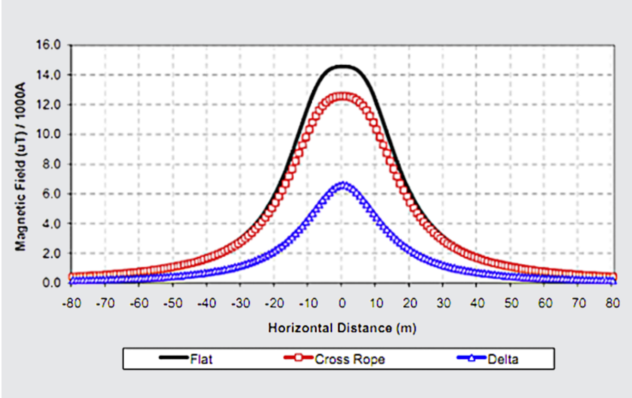


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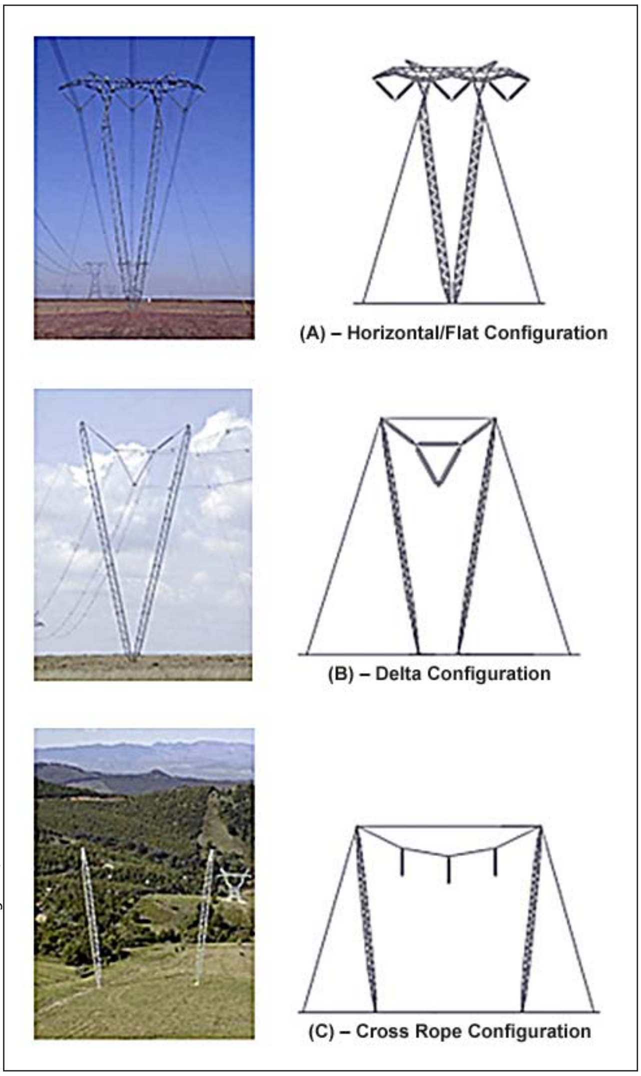
Fig. 1b: Typical magnetic field profiles for a 400 kV line

tower configurations create different field profiles. Power line design engineers use this fact to optimize power line configurations to the lowest (and therefore desired) field levels in the vicinity of the power line. It should be noted that electric and magnetic field levels are not the main parameters in the design of an overhead power line, but that other parameters related to the geometry (e.g. conductor type, placement of shield wires and phase spacing) play a significant part in the design of the line in order to optimize its electrical performance and to minimize costs.

Fig. 1b shows the strength of the magnetic field produced from a 400 kV transmission line in relation to the ground distance (rectangular to the lines, away from an origin beneath the centre of the transmission lines). It indicates that approximately 80 m from the centre line most of the magnetic field influences are minimal (ESKOM Holdings Ltd, 2006). Both graphs are based on a nominal wire height above the ground of 13 m. In Fig. 1b it is also shown that the maximum magnetic field level for the 400 kV flat design is higher than the maximum magnetic field level for the 400 kV cross rope and delta designs. The simple reason for this is that the flat design has the lowest conductor height. As already mentioned specific tower designs could be selected to reduce the maximum field levels. But in practice the field reduction is not the main goal in the selection of a specific tower type.



Source: ESKOM Holdings Ltd, 2006

Fig. 2: Some of the existing and newer 400kV line designs of Eskom

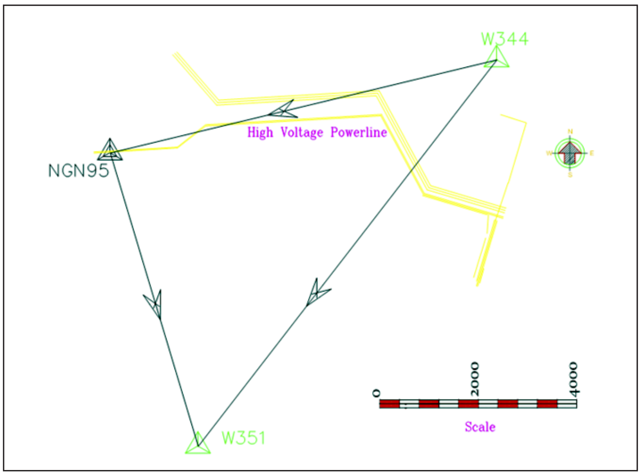


Fig. 3: The HVTP effect is reflected by the closure error.

3 Investigating the effect of HVP on GPS signals

Theoretically the HVP generates an electromagnetic field. The field interacts with the gas molecules in the space surrounding the power lines, which results in a large number of ions, similar to the gas ionization created by solar radiation. In contrast to solar influences the ionization is limited in size and space according to the electromagnetic field profile, see Fig. 1b. Like any electromagnetic signals propagating through an ionized medium GPS signals should be affected by the linear and non linear dispersion characteristics of this medium. So one can expect a GPS signal influence similar to the ionosphere dispersion.

To proof the above theory a GPS base station is set up on point W344 which is far away (8.5 km) from another rover setup point W351 (see Fig. 3). NGN95 is a third point which is installed directly beneath the centre of the transmission lines close to the maximum effect of the HVP. It is located 6 km away from W351. Theoretically point NGN95 is completely affected by the magnetic field created permanently by HVP i.e. its solution resulted from GPS baseline processing should be affected. On the other hand W351 is completely free from any effect of the magnetic field. i.e. its solution should be free from any HVP magnetic field effect.

So, one can compute the W351 position through two different routes:

1. The first route is the direct route by the W344-W351 baseline processing (see Tab. 1). The GPS data processing was realized by LEICA GEO OFFICE (LGO).
2. The second route is realized by conducting two baselines: W344-NGN95 and NGN95-W351 (see Tab. 2).
3. By considering the aforementioned circumstances, one can easily find out that the solution of two different routes should be different, where the solution of the second route is contaminated by the HVP. This will be reflected in the closure error of the triangle at station W351. Keep in mind that the positioning closing error,

Tab. 1: The results of the first route W344-W351 as computed by LGO SW.

Point Id	Sol. type	East. (m)	North. (m)	El. H. (m)	Pos. + Hgt. Qlty. (m)
W351	Phase	822637.404	3175872.092	18.463	0.0001

Tab. 2: The results of the second route W344-NGN95 and NGN95-W351 displayed by LGO SW.

Point Id	Sol. type	East. (m)	North. (m)	El. H. (m)	Pos. + Hgt. Qlty. (m)
NGN95	Phase	820699.689	3181805.723	17.265	0.0002
W351	Phase	822637.395	3175872.082	18.452	0.0001

namely in the following tables the error in position can be computed as:

$$\text{Error in Position} = C.Error_{Hl-Position} = \sqrt{\Delta E^2 + \Delta N^2} \qquad (1)$$

with

$\Delta E = E_{1st-route} - E_{2nd-route}$; $\Delta N = N_{1st-route} - N_{2nd-route}$.

Where:

E, N: represent the Easting and Northing of the computed position of the different routes,

$C.Error_{Hl-Position}$: represents the horizontal positioning closing error,

Posn. + Hgt. Qlty.: refers to the root mean square of the standard deviations of position and height elements,

Posn. Qlty.: refers to the root mean square of the standard deviations of the two position elements,

Hgt. Qlty.: refers to the root mean square of the standard deviations of the height element.

In the following a numerical example for the closure error computation at W351 is presented:

Point Id	East. (m)	North. (m)	El. H. (m)
W351 resulted from the 1st route	822637.404	3175872.092	18.463
W351 resulted from the 2nd route	822637.395	3175872.082	18.452
Differences	0.009	0.010	0.011
$C.Error_{Hl-Position} = \sqrt{(0.009)^2 + (0.010)^2}$ = Error in Position = 0.014			

As shown in Tab. 3 a closure error due to the effect of the HVP is not reflected at all either in computed position or related height. The inherent values are just expressing the normal closing errors for ordinary differential GPS biases. Keep in mind that the data was collected in a static mode for the three stations over four hours and the static baseline accuracy of the processing software as given by LEICA brochure is 5 mm + 0.5 ppm (Leica GPS 1200 Series Technical data). This is reflected in the expected accuracy of the baseline NGN95-W351 with a value of ca. 10 mm. Therefore, it is not clear that the closing error at point W351 physically reflects the effect of the HVP. However, several tests need to be applied using the aforementioned concept to see the physical effect of the HVP on GPS signal.

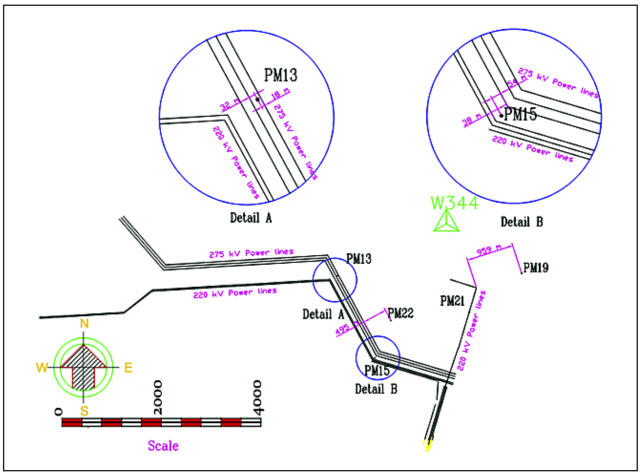


Fig. 4: The distribution of the chosen setup GPS points to perform the tests.

As mentioned before the effect of the HVP on the magnetic field and on the GPS signal is dependent from the following factors:

1. The value of the voltage,
2. The tower design geometry,
3. The distance between conductors,
4. The maximum sag, the clearance to the earth.

The above factors were taken into consideration when performing further practical investigations. In a test scenario PM13 is located between the combined effects of multi-lines at 18 to 32 m from the closest power line, see Fig. 4. PM15 is installed at 38 to 54 m between the closest two lines of several groups of power lines where in the northwest of the GPS point are three adjacent transmission power lines with 275 kV while on the other side there are two adjacent lines with 220 kV. The minimum wire heights range between 12 to 15 m above the ground. The third point PM21 is installed directly beneath the power line. The value of this power line is 220 kV with a height of 10 m above the ground. Two points are set up far away from the above group of power lines. The first point PM22 is set up at a distance of 495 m from the closest line of the three 275 kV adjacent power lines. The second point PM19 is installed at 959 m from the 220 KV line.

In the following the results are analysed. Consider the station PM13 which is located under the combined effect of three 275 kV power lines. As depicted in Fig. 5 the position of PM22 is computed from two different routes. The first route is computed by the baseline W344-PM22 where no effect of HVP on the baseline occurs while the second route is computed by the two baselines W344-PM13 and PM13-PM22. Tab. 4 shows the computation results of the two routes. The closure error for both the computed position and height does not exceed the normal values for the processed baseline as specified by the manufacturer. The solution of PM13 does not reflect any effect of the HVP.

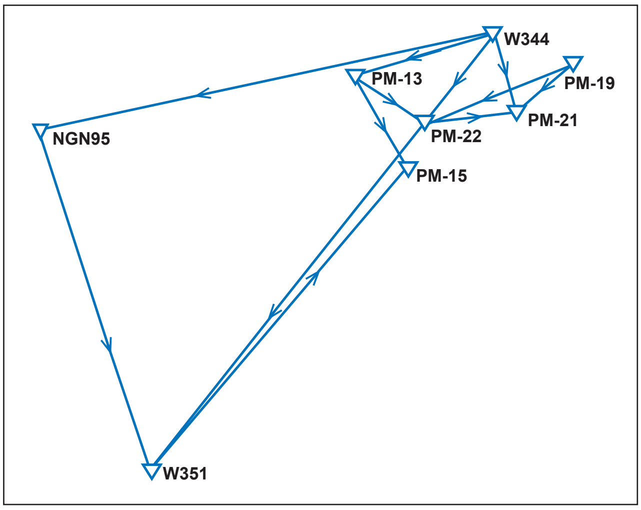


Fig. 5: The possible different routes

The closure error in PM22 is also computed by the direct baseline to PM19 and a non direct route via PM21. PM21 is completely beneath the power line, i. e. in the mid span of the highest magnetic field. As shown in Tab. 5 the computed closure error does not reflect the HVP.

As shown in Tab. 6 the previous results are confirmed by processing W351 with PM13 and PM15 as references. The first route to W351 is affected by the combined effect of the magnetic fields over PM13 and PM15. The second route to W351 is not affected by any magnetic field. The closure errors at W351 show normal values. The results confirm the previous conclusions.

To study the effect of HVP on post processing kinematic GPS solutions the epoch by epoch positioning for the two baselines W344-PM21 and W344-PM13 are determined where PM13 and PM21 are affected by different power lines voltages and different vertical clearance from the earth. The differences between the static position solutions and the resulted epoch by epoch solutions are computed for both baselines. The results are presented in Fig. 6. Compared with the other baseline, W344-PM21 shows worse results. The height component difference of W344-PM21 has a minimum value of −0.055 m and a maximum value of +0.056 m while W344-PM13 has a minimum value of −0.033 m and a maximum value of +0.024 m. The main reason for these results is the height of the power lines. The height in PM21 (220 kV power line) with 10 m from ground is lower than the height of the 275 kV power line in PM13 with 12 to 15 m from ground. It must be also mentioned that both solutions suffer from latency in the ambiguities fixation. Normally, the ambiguities fixation process takes between 3 to 10 epochs for these ranges of baseline

Tab. 3: The closure error computed for W351 by W344 & W344-NGN95 two routes

Route	Reference	Error in Position (m)	Hgt. Difference (m)	Pos.+ Hgt. Quality (m)	The last BL length (m)
W344-W351	W344	0.014	0.011	0.002	8503.08
W344-NGN95, NGN95-W351	NGN95			0.001	6242.04

Tab. 4: The closure error computed in PM22 by W344 & W344-PM13 two routes

Route	Reference	Error in Position (m)	Hgt. Difference (m)	Pos.+ Hgt. Quality (m)	The last BL length (m)
W344-PM22	W344	0.0002	−0.0001	0.0002	2564.57
W344-PM13, PM13-PM22	PM-13			0.0001	1473.75

Tab. 5: The closure error computed in PM22 by PM19 & PM19-PM21 two routes

Route	Reference	Error in Position (m)	Hgt. Difference (m)	Pos.+ Hgt. Quality (m)	The last BL length (m)
PM19-PM22	PM-19	0.006	−0.012	0.001	2798.3
PM19-PM21, PM21-PM22	PM-19 PM-21			0.0001	1595.87

Tab. 6: The closure error computed in W351 by W344 & W344-PM13-PM15 two routes

Route	Reference	Error in Position (m)	Hgt. Difference (m)	Pos.+ Hgt. Quality (m)	The last BL length (m)
W344-PM13, PM13-PM15, PM15-W351	W344 PM13 PM15	0.0011	−0.013	0.001	1830.80
W344-W351	W44			0.002	8503.08

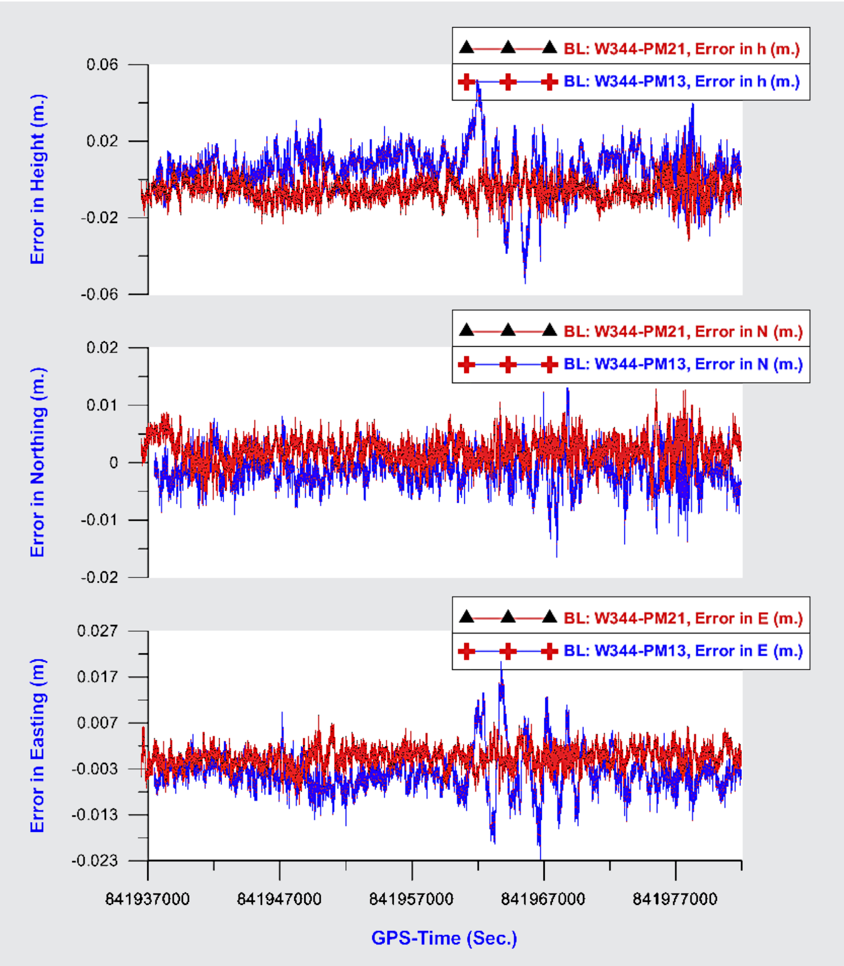


Fig. 6:
The effect of "HVTP" on kinematic GPS baseline solution

lengths. In the current scenario the fixation process takes about 35 epochs for baseline W344-PM13 and 51 epochs for W344-PM21.

4 Conclusions

To investigate whether HVPs with different voltages disturb the observed GPS signal and as consequence the positioning results the concept of the closure error is established which reflects the effect of HVPs on GPS solutions. To fulfil the study requirements a GPS campaign was planned with two types of GPS solutions: static and kinematic solutions. Based upon the results from the above study, we can confirm that the effect of HVP on a LEICA GNSS-1230GG receiver is not proved by the static results. On the other hand the results of the kinematic GPS solutions show that they are affected by the HVP, especially the height component. In this context, the height of the HVP cable above the earth plays sometimes a more influencing role than the voltage.

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