Achieving 30 cm Autonomous Positioning Accuracy with Nexteq Single-Frequency GPS Receivers

Y. Zhang, S. Lee, C. Chen, *Nexteq Navigation Corporation, Canada*

BIOGRAPHY

Dr. Yufeng Zhang has been working in the GPS and INS navigation field for 10 years and is currently the R&D manager at Nexteq Navigation.

Suen Lee has a Masters degree in Geomatics Engineering and has consulted for several companies regarding GPS and wireless tracking. Currently he is a Geomatics engineer at Nexteq Navigation.

Chang Chen has 8 years software development and testing experience and is currently an application engineer at Nexteq Navigation.

ABSTRACT

This paper will introduce Nexteq Navigation's recently released Precise Autonomous Single-frequency (PAS) GPS receiver products. Nexteq's PAS product development is focused on providing new products able to provide precise positioning solutions using only a typical GPS engine. Nexteq's technology innovations (collectively known as Freedom technology) have resulted in unprecedented performance for its PAS products; 30cm autonomous GPS positioning accuracy. Nexteq's PAS products also do not need base stations or depend on precise orbit and clock correction data from subscription service, making them outstanding candidates for all kinds of applications requiring precise position solutions and at unprecedented system simplicity and cost-effectiveness.

Nexteq PAS products currently include the PAS110 and PAS120 series of receivers and are available for order. Testing results show that Nexteq's PAS receivers powered by Nexteq's Freedom technology can readily achieve 30 cm positioning accuracy. Nexteq's PAS receivers also have outstanding repeatability in harsh environments, including under dense canopy or near buildings. This exceptional performance is appealing to applications conducted in challenging environments.

INTRODUCTION

Autonomous GPS is the original and simplest method of positioning for the GPS system, deriving position solutions using only a single GPS receiver. Since the signals from GPS satellites are subject to numerous errors like satellite orbit and clock, atmosphere delay and environmental affections, autonomous GPS could typically provide positioning accuracy of only several meters.

Differential GPS has been developed to satisfy applications requiring positioning accuracy as high as the centimeter level. As this more resource-intensive method employs two GPS receivers (one serves as base receiver at a known location and another acts as the rover receiver) to achieve higher positioning accuracy, some inherent problems are unavoidable including complicated logistics, increased cost, limited working range (typically about 10 kilometers) and only a relative position is available. Network RTK is a more recent approach which uses a network of base receiver stations to extend the working range of differential GPS to several tens of kilometers (Rizos, 2002).

In recent years, the performance of autonomous GPS has been improved by the introduction of Satellite Based Augmentation System (SBAS). Meter level positioning accuracy has been widely demonstrated. SBAS enabled GPS receiver has now become a standard for almost all GPS receiver products.

To further improve GPS positioning with a single receiver, the concept of Precise Point Positioning (PPP) has gained wide attention in the past several years (Kouba and Héroux, 2001; Gao, 2006). PPP with a dual-frequency GPS receiver is able to provide decimeter accurate positioning solution but it requires very accurate orbit and clock corrections currently available only via subscription services. As a result, the data subscription service fees plus additional hardware requirement become a concern for many applications. Further, a long initialization period, which can be greater than one hour, still remains the most significant technical challenge in PPP receiver product development. For PPP to gain wider acceptance, the development of fast ambiguity convergence methodology including integer ambiguity resolution is needed (Wang and Gao, 2006).

The existing product development effort has largely focused on the deployment of permanent base receiver networks to provide GPS error correction services so improved positioning accuracy can be obtained using a single receiver. Such an approach has several major drawbacks from the user's point of view. First of all, the users within the network have to subscribe to the correction service, which could be a concern to many applications. Second, the users must have a wireless connection to a cellular network or a communication satellite (this means additional hardware is required). A loss of connection will reduce the actual availability of such a system, resulting in unexpected downtime for the field work. Finally the users are often required to use a compatible GPS receiver designated by the service provider.

This paper will introduce Nexteq's recently released Precise Autonomous Single-frequency (PAS) GPS receiver products. Taking a different approach, Nexteq's PAS product development is to offer new precise autonomous GPS receiver products that have the following characteristics: a) precise position solution without subscription to a correction service; b) no additional hardware requirement other than a typical single-frequency GPS receiver. Testing results show that Nexteq's PAS receiver products can achieve 30 cm positioning accuracy. It also has outstanding repeatability performance in harsh environments, making them attractive to applications conducted in challenging environments. These results make Nexteq's PAS receiver products the first truly high precision autonomous single-frequency GPS receiver available commercially.

PRODUCT DEVELOPMENT

Nexteq has developed a technology known as Freedom to support its PAS series product development. Nexteq Freedom technology is a collection of innovations that re-examines the way how errors are handled in GPS and maximizes the use of available GPS information. Nexteq Freedom technology is now available on two GPS receiver series: the PAS110 series and the PAS120 series. Both series have 30 cm positioning accuracy despite being based on different GPS engines.

PAS110 Series Receiver Products

The PAS110 series consists of the PAS110 GPS enclosure, the PAS112 GPS compact antenna and the PAS115 GPS OEM board (see Fig. 1). They are the first commercially available high precision autonomous single-frequency GPS receiver products with the capability of 30 cm autonomous positioning accuracy. As shown in Figure 1 (a), PAS110 has a compact and lightweight enclosure with two COM ports for communication, one power port and one antenna connection. PAS112 is a rugged, self-contained GNSS receiver and antenna, which requires minimum installation effort. As shown in Figure 1 (b), it only has one compact port for both power and communication, which helps make it resistant to environmental contaminants including salt spray, sand, and dust. PAS115 is a compact, low-power, single frequency L1 GPS card with integrated L-band and is ideal for applications requiring accurate positioning performance in a small package.

(a) Enclosure (b) Compact Antenna (c) OEM Board

Figure 1: PAS110 Series Products

PAS120 Series Receiver Products

PAS120 series is the latest high precision autonomous single-frequency GPS receivers offered by Nexteq Navigation. The PAS120 series currently consists of only the PAS120 GPS enclosure (see Figure 2). The PAS120 features convenient features such as colored LEDs and LCD screen enabling users to view the status of the receiver at a glance. For more details, please refer to www.nexteqnav.com.

Figure 2: PAS120 Enclosure

FIELD TEST DESCRIPTION

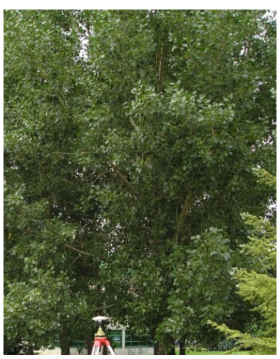
Extensive field tests have been conducted and some test results are described in the following, including testing results under challenging environments to assess the performance of different PAS receiver products. Since the PAS110 series receivers employ the same GPS engine, only the PAS110 enclosure results are presented for the PAS110 series performance evaluation. The PAS120 enclosure results are included to evaluate the PAS120 series performance.

Static Tests

The first test is an open sky static test to compare the performance of the different receivers in the best possible conditions. The location of the test was on the roof top of a building with an open sky environment. The PAS110 test was conducted on March 20, 2008 and lasted 4 days; the PAS120 test was conducted on August 12, 2008 and lasted 30 hours.

The second test is a static test conducted under a group of tall trees. It can be expected that the performance of all classes of GPS equipment will be poorer when near or under trees, as compared to open sky conditions. The same hardware as that from the static open sky test was used for this test. The test for the PAS110 was conducted on August 11, 2008 and lasted 4 hours; the test for the PAS120 was conducted on August 6, 2008 and lasted 6 hours. The test site environment is shown in Figure 3 (a).

Environments with nearby buildings obstructing the sky are another troublesome environment (see Figure 3 (b)) for GPS applications due to strong multipath from signals reflecting off buildings and bad geometry. These problems can lead to incorrect ambiguity fixes even for RTK GPS applications. The test for the PAS110 was conducted on August 11, 2008 and lasted 2.5 hours; the test for PAS120 was conducted on August 7, 2008 and lasted 6 hours. The test site environment is shown in Figure 3 (b).



(a) Tree environment

(b) Near building environment

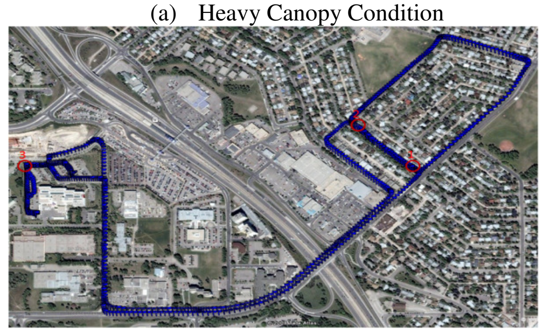
Figure 3: Challenging Observation Environment Tests

Kinematic Tests

Kinematic testing in harsh conditions was also carried out for the PAS110 and PAS120. It was common during these tests to be in the presence of heavy canopy. This test is to evaluate the suitability of the PAS110 and PAS120 for applications in these types of conditions.

Because of the conditions, it was difficult to obtain a true reference because even RTK GPS has problems under a heavy canopy. Instead, the test was performed by driving through a route with heavy canopy for several loops, and making stops at pre-selected points to assess the height repeatability only (it is not possible to stop at the exact same horizontal position but the height for each stop should be similar given a flat section of road). The test started in the parking lot beside Nexteq's office and then went through the Brentwood community of NW Calgary. The test made 3 loops in the community before coming back to the parking lot. The testing road environment can be seen in Figure 4 (a) while the driving route can be seen in 4 (b). There were one stop point in the parking lot and two stop points in the Brentwood community. The tests for both PAS110 and PAS120 were conducted on August 8, 2008 and lasted one hour.

(a) Heavy Canopy Condition

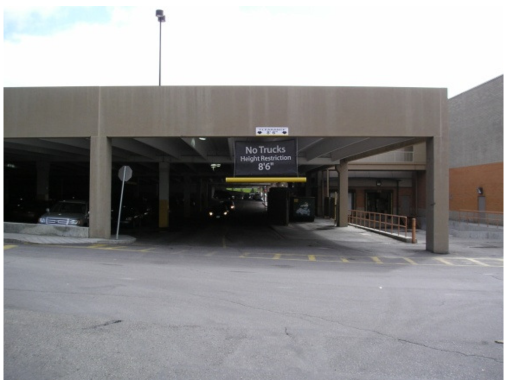


(b) Canopy Road Test Route

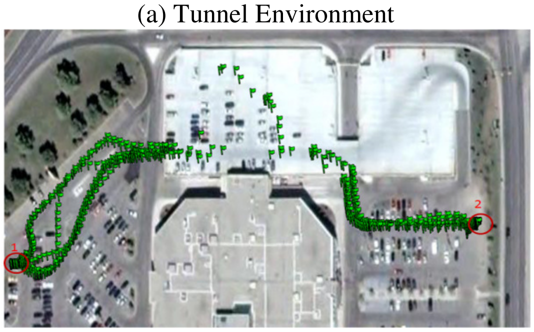
Figure 4: Heavy Canopy Road Test

Going through a tunnel with complete blockage of the GPS satellites is another challenge that occurs in some GPS applications and the ability to quickly recover after such outages is important. The test was conducted in the parking lot of Northland Mall, Calgary, Alberta, where a two story parking structure is available for simulating a tunnel when a car travels through the lower level (see Figure 5 (a)). During this test, the testing vehicle passed through the lower level of the parking structure six times, and stopped three times each at two pre-selected points, one on each side of the parking structure. While inside the parking structure, nearly all the GPS satellites were obstructed. The test driving route is shown in Figure 5 (b).

Here we will also evaluate the performance of the tested receivers by comparing only the height for different stops since a good reference is also difficult to obtain for such conditions. If similar heights are obtained between different stops, this would represent good recovery ability and repeatability. This test was performed on August 12, 2008 and lasted one hour.



(a) Tunnel Environment



(b) Tunnel Test Route

Figure 5: Tunnel Test

TEST RESULTS AND PERFROMANCE ANALYSIS

Static Tests

a) Open Sky Static Test

In the open sky static test, the traditional SBAS result (Figure 6) is noisy, especially for height, and has a range of several meters. The statistics of the SBAS result is given Table 1. The noise in pseudorange measurements, the still significant residual ionospheric delay after correction from WAAS and satellite orbit and clock residuals are the primary cause of the positioning errors and bias. By comparison, the PAS receivers with Nexteq Freedom technology (Figures 7 and 8) perform much better. Their statistics can be seen in Table 2 and 3. Both receivers have excellent positioning performance with horizontal accuracy of about 0.30 m and also have very small biases in the horizontal and height.

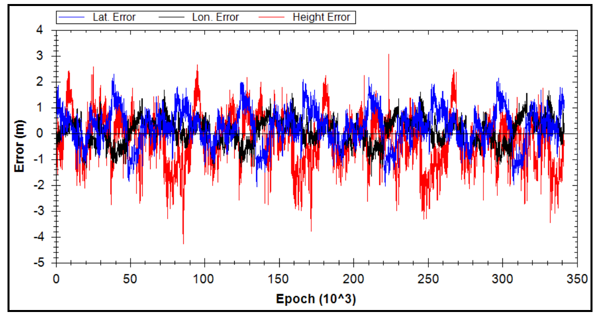


Figure 6: SBAS Errors

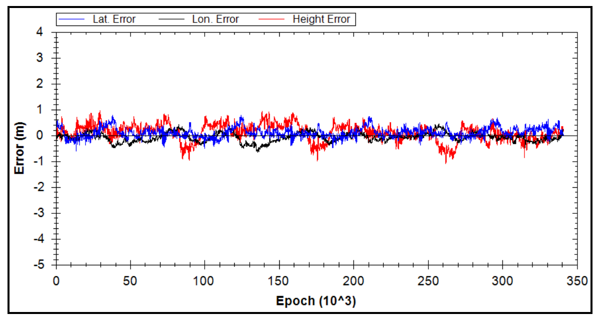


Figure 7: PAS110 Errors

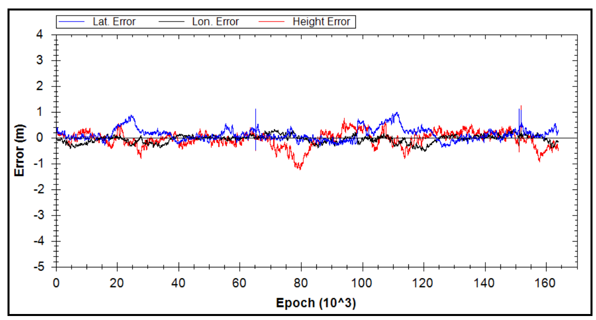


Figure 8: PAS120 Errors

Table 1: SBAS Statistics

Horizontal RMS error	0.901 m
Height RMS error	1.013 m
Horizontal bias	0.263 m
Height bias	-0.310 m
Horizontal STD	0.861 m
Height STD	0.965 m

Table 2: PAS110 Statistics

Horizontal RMS error	0.295 m
Height RMS error	0.340 m
Horizontal bias	0.127 m
Height bias	-0.100 m
Horizontal STD	0.266 m
Height STD	0.325 m

Table 3: PAS120 Statistics

Horizontal RMS error	0.315 m
Height RMS error	0.312 m
Horizontal bias	0.135 m
Height bias	-0.065 m
Horizontal STD	0.285 m
Height STD	0.305 m

b) Under Tree Static Test

For the control points used in the Under Tree test and the Near Building test, only their horizontal positions have been precisely determined beforehand. Therefore, only the horizontal performance of the SBAS and Nexteq PAS receivers will be discussed.

The SBAS results (Figure 9) vibrate a lot, up to 6 meters for the horizontal, since the signals for under tree condition are very weak and big multipath is very common under such conditions. The results with the PAS110 and PAS120 are excellent, with horizontal errors of less than half a meter (Figure 10 and 11). Their statistics are given in Table 4, 5 and 6.

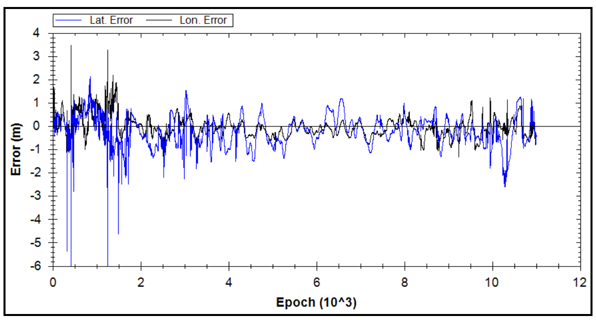


Figure 9: SBAS Under Tree Result

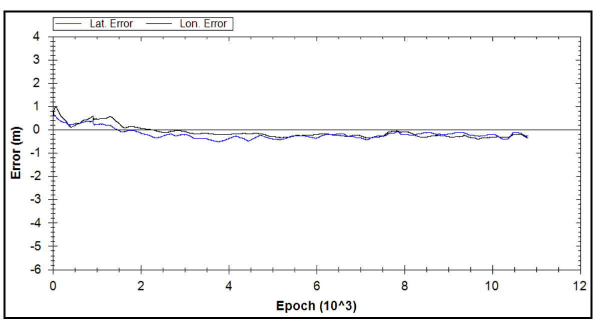


Figure 10: PAS110 Under Tree Result

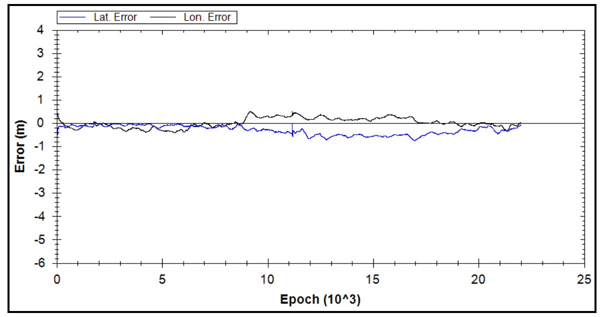


Figure 11: PAS120 Under Tree Result

Table 4: SBAS Statistics

Horizontal RMS error	0.819 m
Horizontal bias	0.225 m
Horizontal STD	0.788 m

Table 5: PAS110 Statistics

Horizontal RMS error	0.406 m
Horizontal bias	0.226 m
Horizontal STD	0.337 m

Table 6: PAS120 Statistics

Horizontal RMS error	0.419 m
Horizontal bias	0.304 m
Horizontal STD	0.288 m

c) Near Building Static Test

As with the Under Tree test, only horizontal results are shown for the Near Building test. Reflections off the building will result in strong multipath effects entering the pseudorange measurements and will lead to the vibration of the position result. This can be seen in the traditional SBAS results shown in Figure 12 and Table 7, where sometime the vibration amplitude is more than 5 meters. The PAS110 and PAS120 receivers maintain accurate and smooth results in this environment, with the position error remaining in the decimeter range (Figure 13 and 14). Table 8 and 8 provide the statistics for the Nexteq PAS receivers.

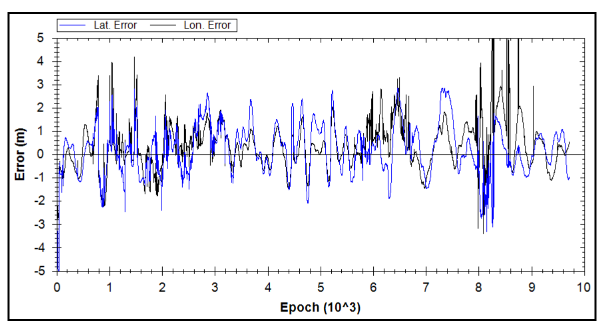


Figure 12: SBAS Near Building Results

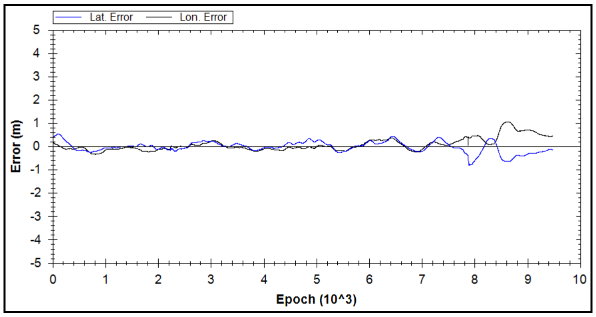


Figure 13: PAS110 Near Building Results

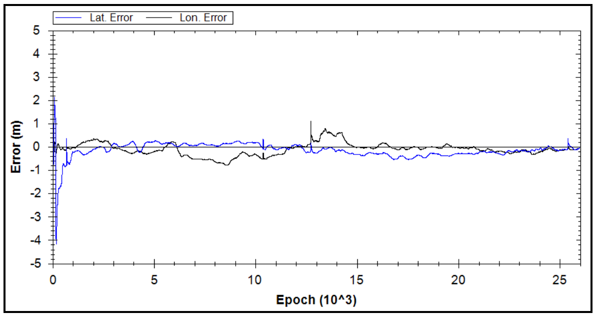


Figure 14: PAS120 Near Building Results

Table 7: SBAS Statistics

Horizontal RMS error	1.622 m
Horizontal bias	0.426 m
Horizontal STD	1.565 m

Table 7: PAS110 Statistics

Horizontal RMS error	0.371 m
Horizontal bias	0.079 m
Horizontal STD	0.278 m

Table 8: PAS120 Statistics

Horizontal RMS error	0.462 m
Horizontal bias	0.183 m
Horizontal STD	0.424 m

Kinematic Tests

a) Canopy Road Test

The heavy surrounding canopy during the test greatly weakened the GPS signals, resulting in periods where only one or two satellite signals can be tracked. The multipath effect is large and losses of signal tracking are frequent making the environment difficult even for RTK GPS. Figure 15 and Figure 16 are results for Point 1 and 2, which are on the road with heavy canopy as shown in Figure 4. Three stops were made at each point, these two figures shows that the height from SBAS varies greatly between stops, upwards of several meters even between one stop and the next. The Nexteq receiver results are smoother for each stop and the difference between stops are small, within one meter.

Figure 17 shows the heights from Point 3, the stop point in the parking lot, which has fewer obstructions and is a much easier environment. The time interval between the two stops was approximately 1 hour. Results for PAS110 and PAS120 are very good, with the difference in height for the two stops at only 20 centimeters.

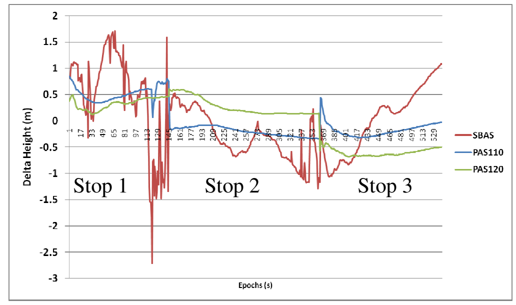


Figure 4: Point 1, Canopy Road Test

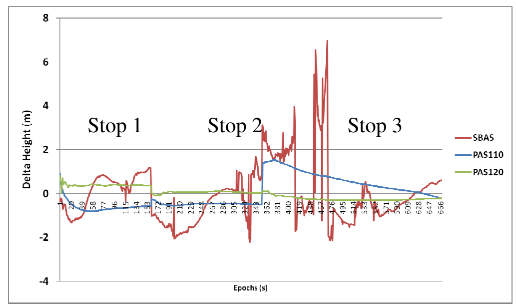


Figure 5: Point 2, Canopy Road Test

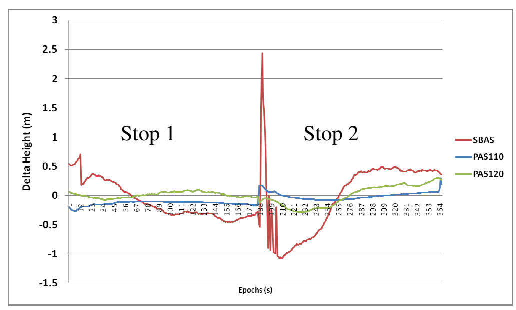


Figure 6: Point 3, Canopy Road Test

b) Passing Tunnel Test

Passing through a tunnel, all the GPS signals will be blocked and the receiver will need to re-track the signals once the receiver comes out from the tunnel. This sudden loss of all signals is challenging for all GPS applications. Typically, this will require a long recovery period. Figure 18 and Figure 19 show the results for passing a tunnel which demonstrate that the PAS110 and PAS120 are able to achieve precise GPS solutions quickly after a GPS blockage, showing no apparent recovery time. Rather PAS receivers are able to quickly offer precise positions even after complete satellite outages.

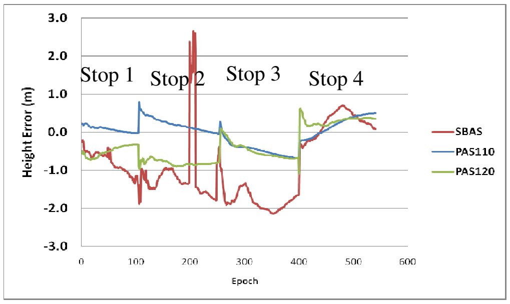


Figure 7: West Stop, Tunnel Test

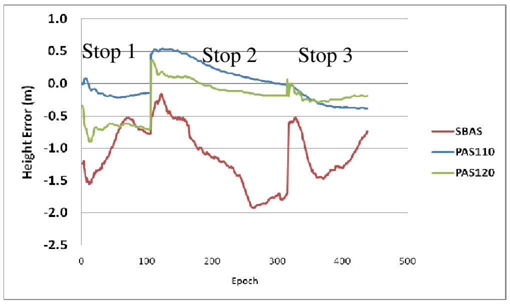


Figure 19: East Stop, Tunnel Test

FUTURE DEVELOPMENT AND APPLICATIONS

Nexteq Freedom technology has enabled the release of the first true single-frequency precise autonomous GPS receivers with positioning accuracies of 30 cm. Despite being based on two separate GPS engines, the performance of the PAS110 series and PAS120 series receivers are comparable. We expect that Nexteq Freedom can be applied to any other GPS engine with comparable tracking and measurement specifications to achieve similar positioning performance.

We believe that Nexteq Freedom also has universal applicability in GPS positioning, not only does it enable precise autonomous positioning with single-frequency receivers, it can offer significant performance benefits to high-end dual-frequency GPS receivers. For instance, the Freedom technology is expected to significantly reduce the position initialization and re-initialization period for precise dual-frequency GPS receiver products, which could significantly expand the range of applications for current products on the market. Beyond high quality GPS products, Nexteq Freedom could also benefit to low cost high volume GPS chipsets to bring their obtainable positioning accuracy to an unprecedented level and allow them to enter new markets.

CONCLUSIONS

With 30 cm positioning accuracy, Nexteq Freedom receivers redefine the limits of autonomous single-frequency GPS positioning without subscription to a correction service. Nexteq Freedom is robust and resilient against tough conditions, providing outstanding repeatability in harsh environments, including under dense canopy or near buildings. This exceptional performance is appealing to applications conducted in challenging environments.

Nexteq Freedom can also be used in higher-end products to improve performance and eliminate initialization time and in lower-cost products to improve their positioning accuracy to an unprecedented level for new markets and applications.

REFERENCES

Gao, Y. (2006). "Precise Point Positioning and Its Challenges", GNSS Solution, *Inside GNSS Magazine*. November/December 2006. pp. 16-18.

Kouba, J. and Héroux, P. (2001). "Precise Point Positioning Using IGS Orbit and Clock Products", *GPS Solutions*, Vol. 5, No.2, pp.12-28

Rizos, C. (2002). "Network RTK Research and Implementation - A Geodetic Perspective". *Journal of Global Positioning Systems*, Vol.1, No. 2, pp. 144-150.

Wang, M. and Y. Gao (2006). "GPS Un-Differenced Ambiguity Resolution and Validation". *Proceedings of ION GNSS'06*, Fort Worth, Texas, September 26-29.