

Achieving Sub 20 cm Autonomous Positioning Accuracy Using Nexteq PAD Dual-frequency Receivers

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BIOGRAPHY

Dr. Yufeng Zhang is the VP engineering of Nexteq Navigation. He received his PhD degree from Beijing Institute of Technology in 2001 and has been working on GPS and Inertial navigation since his PhD study. Dr. Zhang has worked 3 years in Huawei Technology as a system engineer and 3 years in the University of Calgary for his post doctoral fellow research before he joined Nexteq Navigation Corporation in 2007.

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 more than a decade of 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 Dual-frequency (PAD) GPS receiver products. Nexteq's PAD products are extensions of its previous Precise Autonomous Single-frequency (PAS) products and is a simplified and cost-effective alternative to current real-time PPP products on the market, with benefits including no initialization time and no need of subscription for precise orbit and clock corrections. The development is focused on innovations for shortening the initialization time and reducing the dependence on the precise orbit and clock corrections, which are the inherent weakness of traditional PPP. Nexteq's PAD products have achieved instant sub 20cm stand alone GPS positioning accuracy with freely available SBAS corrections, which makes them outstanding candidates for all kinds of applications requiring precise position solutions and at unprecedented system simplicity and cost-effectiveness.

Nexteq PAD products currently include rigid enclosures like the PAD110 and PAD116 products, and the OEM board PAD115 for system integration, and are available for ordering. Testing results showed that Nexteq's PAD

receivers powered by Nexteq's Freedom technology can readily achieve sub 20 cm positioning accuracy once SBAS corrections are available. Nexteq's PAD receivers also have outstanding repeatability in harsh environments, including under dense canopy or near tall buildings. This exceptional performance is appealing to applications working in challenging environments.

INTRODUCTION

After more than 20 years of development, the performance of GPS system has been improved from tens of meters to centimeter and millimeter level of accuracy as most of the error sources residing in GPS measurements have been treated properly through different techniques. One popular method for error treatment is to cancel the measurement errors by double differencing simultaneous measurements from two GPS receivers in close proximity; this is the method used in differential GPS (DGPS) systems. Another method is to estimate the error sources separately, and then broadcast them to users for error mitigation, which results in different augmentation systems including Satellite Based Augmentation systems (SBAS), Ground Based Augmentation systems (GBAS), and Precise Point Positioning (PPP) system.

DGPS systems include code based differential system with sub-meter accuracy, commonly referred to as DGPS in the market, and phase based differential system with accuracy as high as centimeter or even millimeter level, commonly referred to as Real Time Kinematic (RTK). DGPS systems do improve performance, but since this more resource-intensive method requires at least two nearby GPS receivers to improve positioning accuracy, it has inherent problems including complicated logistics, increased cost, limited working range and only a relative position is available, which limit its application to a minority of users. Another approach named Network RTK combines the measurements from a network of base receiver stations to extend the working range of DGPS to several tens of kilometers (Rizos, 2002). Permanent base receiver networks are intend to be deployed to provide GPS error correction services based on Network RTK

technologies, so improved positioning accuracy can be obtained using a single receiver within a specific area. Even though such an approach simplifies the working logistics while also enlarging the usable working area, it still has several major drawbacks from the user's point of view including the subscription of the correction service, and the requirement of using a compatible GPS receiver designated by the service provider.

Several augmentation systems are currently in operation. Similar to the DGPS systems, augmentation system also include code based and phase based augmentation systems. A typical code based augmentation system such as SBAS enables only sub-meter positioning accuracy, which is not enough for precise applications. Classic phase based augmentation systems are real time PPP systems (Kouba and Héroux, 2001; Gao, 2006), with decimeter level positioning accuracy, but requires very accurate orbit and clock corrections currently available only via subscription services. This data subscription service fees plus additional hardware requirement are 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.

Based on this current situation in precise GPS positioning, Nexteq Navigation released its PAS receivers (Precise Autonomous Single-frequency) in 2008 (Y. Zhang etc., 2008) that combine the benefits of autonomous positioning (simplicity, flexibility and cost) with unprecedented single-frequency positioning accuracy of 30 cm, suitable for many precise applications. Building upon this achievement, Nexteq Navigation has now released its PAD receivers (Precise Autonomous Dual-frequency) that offer sub 20 cm autonomous positioning with the added stability and integrity inherent in dual-frequency receivers, especially from high ionosphere activities. Like its single-frequency receivers, the Nexteq PAD receivers offer best in-class positioning accuracy with virtually no convergence time. It is a truly next-generation product and redefines the limits of autonomous GPS.

Extensive field tests including testing under challenging environments have been conducted to assess the performance of the Nexteq PAD receivers. In open sky conditions, Nexteq PAD receivers can achieve 10-20 cm positioning accuracy over multiple day testing runs. Nexteq PAD receivers work equally well in dynamic applications; testing in vehicles with high velocity and dynamics show horizontal positions that differ less than 20 cm as compared with post-processed dual-frequency RTK solutions.

This paper will introduce Nexteq's PAD GPS receiver products. Taking a different approach from existing

precise GPS solutions, Nexteq's PAD 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 GPS receiver; c) virtually no initialization time. These make Nexteq's PAD receiver products the first instant high precision autonomous GPS solution available commercially.

PRODUCT DEVELOPMENT

Several significant technology innovations are behind the remarkable performance of the Nexteq PAD products. Breakthrough Nexteq technology that optimally combines the use of all available GPS measurement information and freely available corrections enable precise positions with virtually no convergence time, unlike existing products based on PPP techniques whose long convergence times are a major negative aspect and greatly hamper their use in real-time applications. The PAD receivers are also equipped with advanced quality control technology which ensures high reliability of the position solutions. The collection of these innovations is named as Nexteq Freedom technology, and is the key component of Nexteq PAD GPS receivers.

PAD110 Receiver Series Products

The PAD110 series consists of the PAD110, the PAD115 enclosures and the PAD116 OEM board. They are the first commercially available high precision autonomous dual-frequency GPS receiver products with the capability of sub 20 cm autonomous positioning accuracy with virtually no initialization time. As shown in Figure 1 (a), the PAD110 is a compact and lightweight enclosure with two COM ports for communication, one power port and one antenna connection. The PAD116 is a rugged, waterproof, shockproof and vibration resistant enclosure. Its durable metal enclosure ensures it will work well in harsh environments and EMI conditions. It has 3 COM ports and one USB port, making it the most flexible PAD receiver. The PAD115 is a compact, low-power, dual-frequency GPS card with integrated L-band and GLONASS capability; it is ideal for applications requiring accurate positioning performance in a small package.

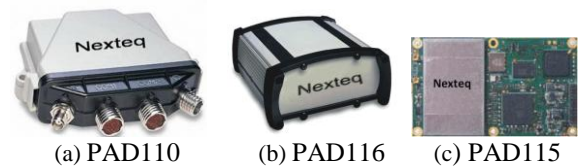


Figure 1: PAD110 Series Products

FIELD TEST DESCRIPTION

Extensive field tests have been conducted on the PAD110 series and selected test results are described in the following sections, including testing results under challenging environments to assess the performance of PAD receiver products in a worst-case scenario. Since the PAD110 series receivers employ the same GPS engine, only the PAD116 enclosure results are presented for the PAD110 series performance evaluation.

Static Tests

The first type of test is an open sky static test to evaluate the performance in the best possible conditions. The location of the tests was on the roof top of a building with an open sky environment and a NovAtel GPS-702GG dual-frequency antenna was employed. Three PAD110 open sky tests were conducted on August 7th, 2008, July 31st, 2009 and August 22, 2009 respectively. All tests were conducted for longer than 24 hours.

The second kind of 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 tests for the PAD110 were conducted on August 6th, 2009, August 11th, 2009 and August 25th, 2009. All these tests lasted several hours. The test site environment is shown in Figure 2 (a).

Environments with nearby buildings obstructing the sky are another troublesome environment (see Figure 2 (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 tests for the PAD110 under such conditions were conducted on August 8th, 2009, August 12th, 2009 and August 26th, 2009 respectively and lasted several hours. The test site environment is shown in Figure 2 (b).



(a) Tree environment



(b) Near building environment

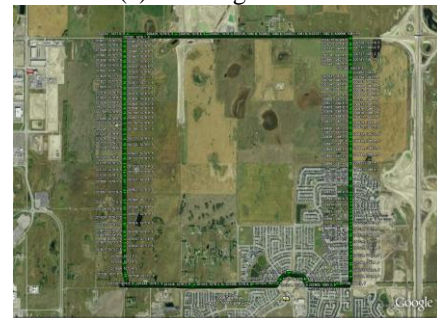
Figure 2: Challenging Observation Environment Tests

Kinematic Tests

Beside static tests, extensive kinematic tests were also conducted to evaluate the dynamic performance of the PAD110 series. The first types of kinematic tests were open sky kinematic tests conducted on the road among farm land with the same hardware as used in the static test. The antenna was set on the roof of testing car as shown in Figure 3 (a). Two road tests were conducted on July 15th, 2009 and August 8th, 2009. The references of the trajectory were generated by the post processed RTK function of GrafNav, with a baseline about 17 kilometers, whose accuracy is at centimeter level.



(a) Testing environment



(b) Road Test Route

Figure 3: Open Sky Kinematic Tests

Kinematic testing in harsh conditions was also carried out for the PAD110. During these tests, heavy canopy was

widely present. This test is to evaluate the suitability of the PAD110 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 two stop points in the Brentwood community and one stop point in the parking lot. The tests were conducted on August 10, 2009 and August 13, 2009.



(a) Heavy Canopy Condition



(b) Canopy Road Test Route

Figure 4: Heavy Canopy Road Test

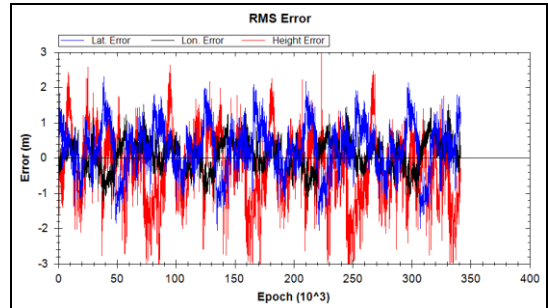
TEST RESULTS AND PERFORMANCE ANALYSIS

Static Tests

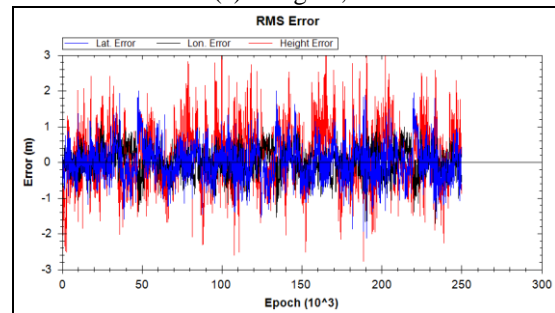
a) Open Sky Static Test

In the open sky static test, the traditional dual-frequency SBAS results without Nexteq Freedom technologies (Figure 5) are noisy, especially for height, and have a range of several meters. The statistics of the SBAS result are given in Table 1. The noise in the pseudorange

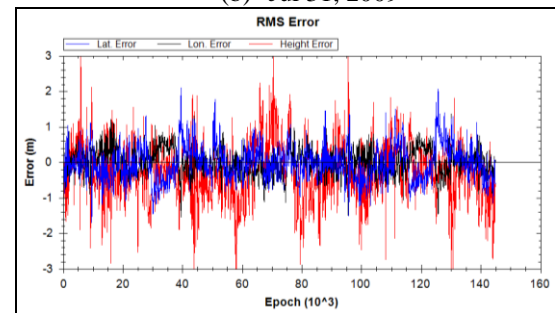
measurements and satellite orbit and clock residuals are the primary cause of the positioning errors and bias. By comparison, the PAD receiver with Nexteq Freedom technology (Figures 6) performs much better. Its statistics can be seen in Table 1 and 2. The PAD receiver has excellent positioning performance with horizontal accuracy of better than 0.20 m.



(a) Aug 07, 2008

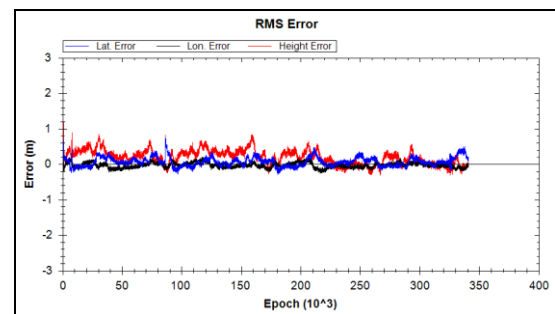


(b) Jul 31, 2009

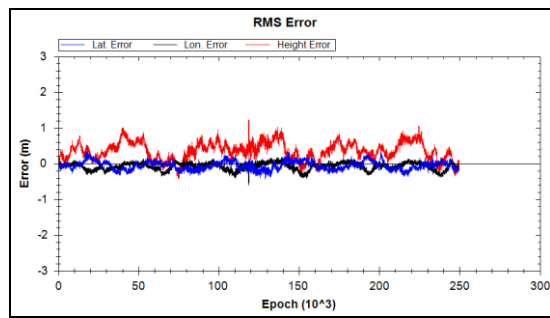


(c) Aug 22, 2009

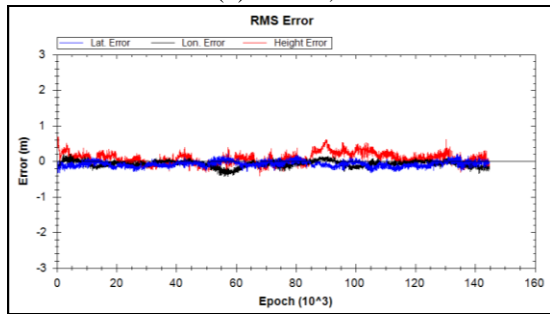
Figure 5: SBAS Errors



(a) Aug 07, 2008



(b) Jul 31, 2009



(c) Aug 22, 2009

Figure 6: PAD110 SBAS Errors

Table 1: Traditional SBAS Statistics

Test date	Horizontal RMS (m)	Height RMS (m)
Aug 07,2008	0.879	1.013
Jul 31, 2009	0.615	0.800
Aug 22,2009	0.587	0.825

Table 2: PAD110 Statistics

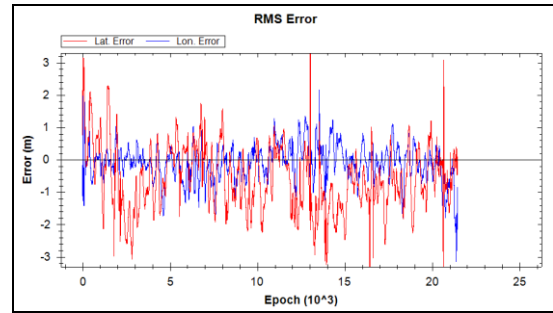
Test date	Horizontal RMS (m)	Height RMS (m)
Aug 07,2008	0.169	0.288
Jul 31, 2009	0.182	0.434
Aug 22,2009	0.159	0.186

b) Under Tree Static Test

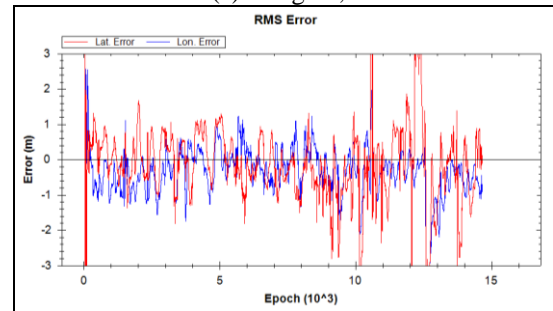
For the control points used in the Under Tree test and the Near Building test, only their horizontal positions have been precisely determined beforehand. Therefore, only the horizontal accuracy of the traditional dual-frequency SBAS and Nexteq PAD receiver will be discussed. For height, only the noise level will be discussed.

The traditional dual-frequency SBAS results (Figure 7) vibrates a lot, up to tens of meters for the horizontal, since the signals for under tree condition are very weak and multipath is very significant under such conditions. The results with the PAD receiver are excellent by comparison, with horizontal errors of less than half a

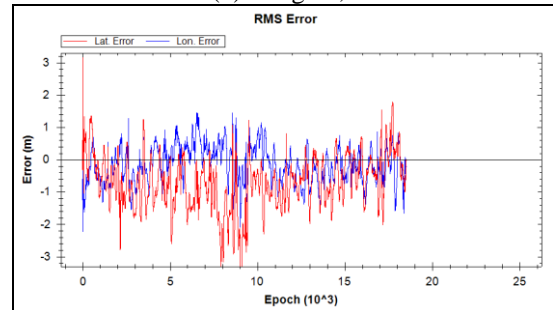
meter (Figure 8). Their statistics are given in Table 3 and 4.



(a) Aug 06, 2009

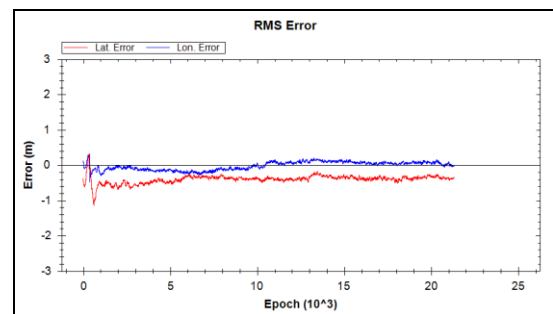


(b) Aug 11, 2009

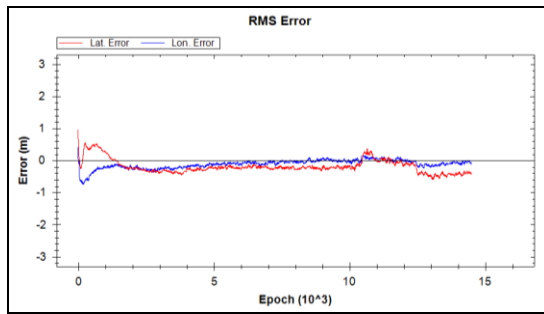


(c) Aug 25, 2009

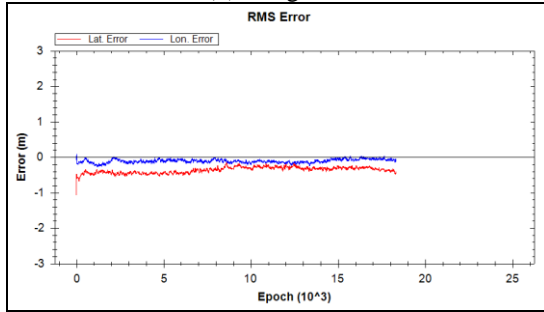
Figure 7: Traditional SBAS Under Tree Result



(a) Aug 06, 2009



(b) Aug 11, 2009



(c) Aug 25, 2009

Figure 8: PAD110 Under Tree Result

Table 3: Traditional SBAS Statistics

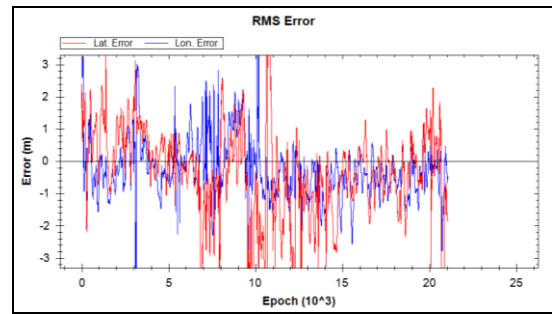
Test date	Horizontal RMS (m)	Height STD (m)
Aug 06, 2009	1.307	1.324
Aug 11, 2009	1.580	1.655
Aug 25, 2009	1.276	1.621

Table 4: PAD110 Statistics

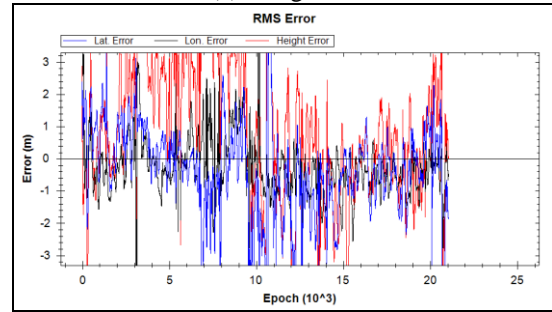
Test date	Horizontal RMS (m)	Height STD (m)
Aug 06, 2009	0.438	0.497
Aug 11, 2009	0.336	0.152
Aug 25, 2009	0.395	0.244

c) Near Building Static Test

As with the Under Tree test, only the horizontal accuracies and height noise are discussed for the Near Building tests. 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 dual-frequency SBAS results shown in Figure 9 and Table 5, where sometime the vibration amplitude is more than 5 meters. The PAD receiver maintains accurate and smooth results in this environment, with the position error remaining in the decimeter range (Figure 10). Table 6 provides the statistics for the Nexteq PAD receiver.

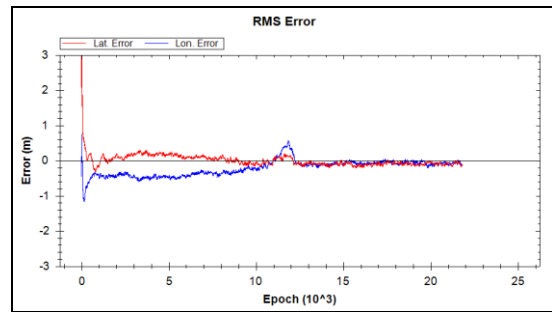


(a) Aug 08, 2009

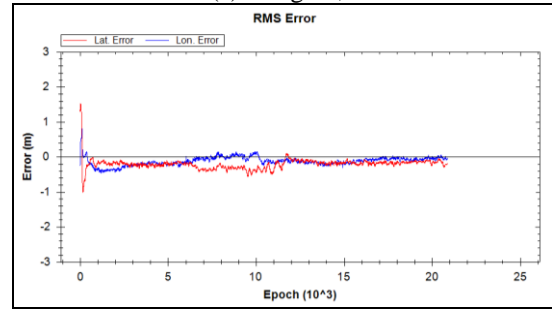


(b) Aug 26, 2009

Figure 9: Traditional SBAS Near Building Results



(a) Aug 08, 2009



(b) Aug 26, 2009

Figure 10: PAD110 Near Building Results

Table 5: Traditional SBAS Statistics

Test date	Horizontal RMS (m)	Height STD (m)
Aug 08, 2009	1.672	2.297
Aug 12, 2009	1.889	2.817
Aug 26, 2009	1.912	2.549

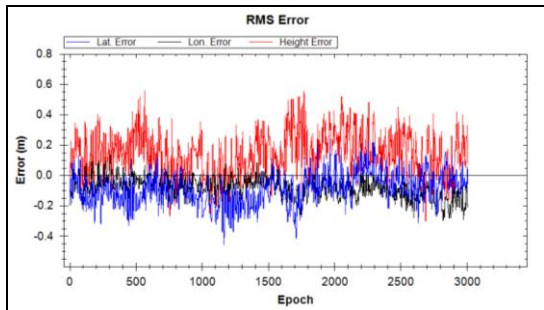
Table 6: PAD110 Statistics

Test date	Horizontal RMS (m)	Height STD (m)
Aug 08, 2009	0.363	0.263
Aug 12, 2009	0.295	0.583
Aug 26, 2009	0.315	0.268

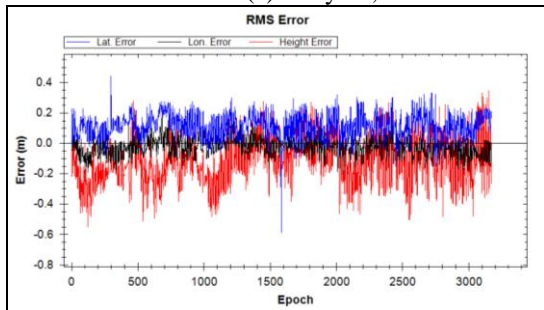
Kinematic Tests

a) Open Sky Road Test

In the open sky dynamic test, the traditional dual-frequency SBAS results without Nexteq Freedom technologies (not shown here) are as noisy as its results from the static tests. The PAD receiver with Nexteq Freedom technology (Figures 11) performs very well, most of the position results are within 20 cm of the reference. Its statistics can be seen in Table 7; the PAD receiver has excellent positioning performance with kinematic horizontal accuracy of better than 0.20 m.



(a) July 15, 2009



(b) Aug 08, 2009

Figure 11: PAD110 open sky kinematic results

Table 7: PAD110 Statistics

Test date	Horizontal RMS (m)	Height RMS (m)
Jul 15, 2009	0.177	0.201
Aug 08, 2009	0.149	0.191

b) 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 12 and Figure 13 are results for two tests, which are on the road with heavy canopy as shown in Figure 4. Three stops were made at each point; these four figures show that the height from traditional dual-frequency SBAS varies greatly between stops, upwards of several meters even between one stop and the next. The PAD receiver results are smoother for each stop and the difference between stops are small, within one meter.

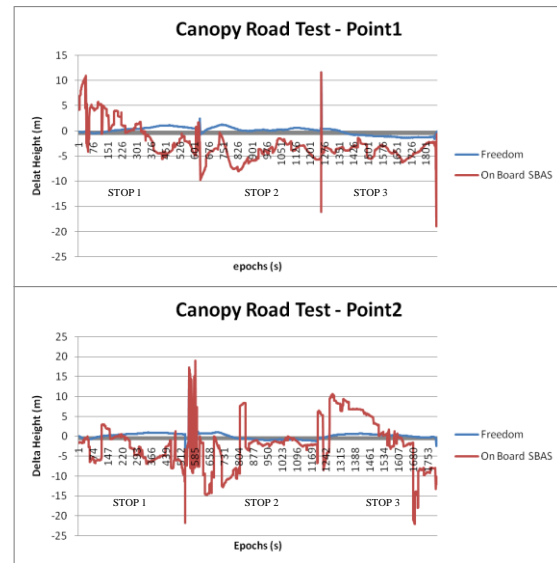


Figure 12: August 10, 2009 results

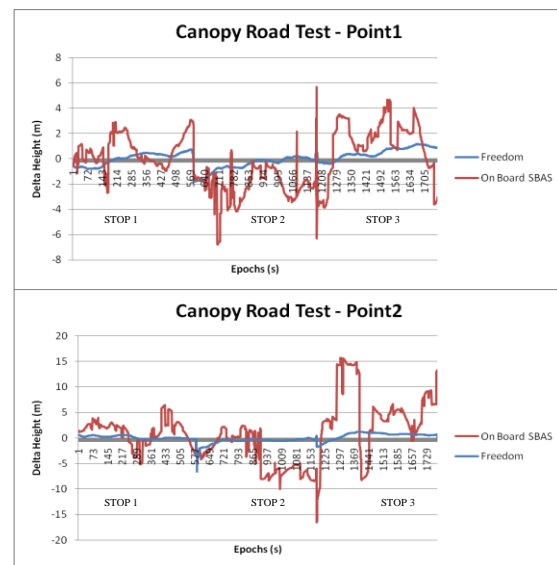


Figure 23: August 13, 2009 results

FUTURE DEVELOPMENT AND APPLICATIONS

Nexteq Freedom technology has enabled the release of the first instant dual-frequency precise autonomous GPS receivers with positioning accuracies of better than 20 cm. 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 high end receivers like Nexteq PAS and PAD products, it can also offer significant performance benefits 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 better than 20 cm positioning accuracy, Nexteq PAD receivers redefine the limits of autonomous GPS positioning without subscription to a correction service. Nexteq Freedom technology 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.

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