GNSS Interference

White paper

Septentrio
satellite navigation

Versatile OEM Receivers for Demanding Applications

Abstract

Because GPS and other satellite navigation signals are very weak signals, they are relatively vulnerable to interference – a phenomenon where other (unwanted) signals disrupt the satellite navigation signals, causing reduced accuracy, or even the complete inability of the receiver to calculate a position.

This white paper will describe the basics and different types of interference of GPS/GNSS signals, the effect on the operation of a GPS receiver, and the unique solutions Septentrio has developed to monitor and eliminate the effects of harmful interference.

Executive Summary

GNSS signals are vulnerable to radio-frequency interference. To address this threat, Septentrio has implemented unique interference mitigation techniques. These countermeasures include adaptive notch filtering, pulse blanking and GLONASS L2 band remapping. Working in concert, these and other analog and digital countermeasures form Septentrio's AIM+ (Advanced Interference Mitigation) technology. The effectiveness of AIM+ has been demonstrated in real field applications. AIM+, as part of a larger range of Septentrio innovations, helps to safeguard positioning accuracy and availability in all possible circumstances.

Introduction

GNSS signals as received by the user are extremely weak signals by design: they are about 100 times weaker than the background noise. In other words, without special techniques, using general purpose antennas and radio-frequency receivers, you would not even "hear" the signals above the background static. Think of GNSS signals as if you were watching a 100W light bulb flying at a height of 20 000 km.

Moreover, the radio-frequency spectrum is crowded, and getting more crowded every day. Even though the frequency bands in which GPS is transmitting are legally protected – transmitting signals directly on most GPS frequencies is not allowed - there are many radio-frequency signals which are emitted "just next to" GPS, and some of those signals spill over into the GPS bands and can have harmful effects.

Often these spill-over signals are also very weak, and GPS receivers can extract the GPS information from the background, even if that background noise is increased slightly by these extraneous signals.

However, in many cases, the effect of interfering signals is noticeable. For instance, some radio-navigation aids for assisting airplanes to navigate and land, share their radio spectrum with one of the GNSS signal bands. Notably the L5 band which has a center frequency of 1176.45 MHz is shared by Distance Measuring Equipment (DME) and Tactical Air Navigation (TACAN). These radio beacons are deployed in the neighborhood of many airfields, and emit high-power radio pulses which disturb GNSS receivers trying to use the (new) GPS and Galileo signals in this band. Similarly, part of the GLONASS L2 band overlaps radio amateur bands in certain countries, causing local loss of signal reception by GNSS receivers – typically high-precision receivers – using this part of the spectrum.

And of course, people also disturb GPS signals unintentionally, or on purpose. For example, there have been reports of some active maritime television antennas that have inadvertently turned into GPS jammers due to a flaw in their design. With the proliferation of vehicle tracking systems based on GNSS, and the future expansion of road toll collection systems based on GNSS, it is likely that use of illegal GPS jammers will also become an increased nuisance in the future.

Effect on Positioning Accuracy and Availability

GNSS positioning accuracy ultimately depends on the availability and the accuracy of satellite measurements. When one individual measurement is adversely affected or becomes unavailable due to interference, the advanced positioning engine implemented in high-end receivers is able to limit the effect (if any) on final positioning accuracy. This is facilitated by the large redundancy of measurements, particularly in multi-frequency receivers. However, a source of interference is likely to affect multiple signals in the same GNSS band and may entirely block reception of a whole GNSS band. In such cases, the effect at the positioning level can be more severe. If GLONASS L2 reception were completely lost, for example, a receiver in GPS+GLONASS dual-frequency RTK mode would have to switch to GPS-only dual-frequency RTK mode, with potentially reduced accuracy as a result. Should L2 reception be completely lost, the same receiver would have to fall back to another position mode such as L1-only RTK, to DGNSS operation or even stand-alone mode. For applications requiring an RTK solution, falling back to a non-RTK mode is equivalent to positioning unavailability.

Although it depends on the user's application and the particular GNSS receiver (single or multi-frequency, GPS-only or multi-constellation, etc.), it is clear that interference is a threat to positioning accuracy and availability. As a result, interference countermeasures form a crucial part of professional GNSS receivers.

Types of Interfering Signals

Depending on bandwidth of an interfering signal, it may be categorized as being of the continuous wave (CW) type, narrowband or wideband, when its bandwidth is greater than 1 MHz. Looking at its characteristics in the time domain, an interfering signal may be either non-pulsed (continuous) or pulsed.

A signal may be either in band, partially in band or out of band with respect to the radio-frequency spectrum occupied by GNSS signals. It is important to note that radio-frequency filters in GNSS receivers cannot practically be made to be infinitely selective, so strong “out of band” signals adjacent to a GNSS band may still cause concern. A case in point is the recent controversy surrounding the LightSquared communications provider in the U.S., which proposed to deploy terrestrial base stations transmitting just below the GPS L1 band. Even though the LightSquared plans were ultimately barred by regulatory authorities, this example goes to show that spectrum is an increasingly rare commodity.

AIM+ : Septentrio Interference Countermeasures

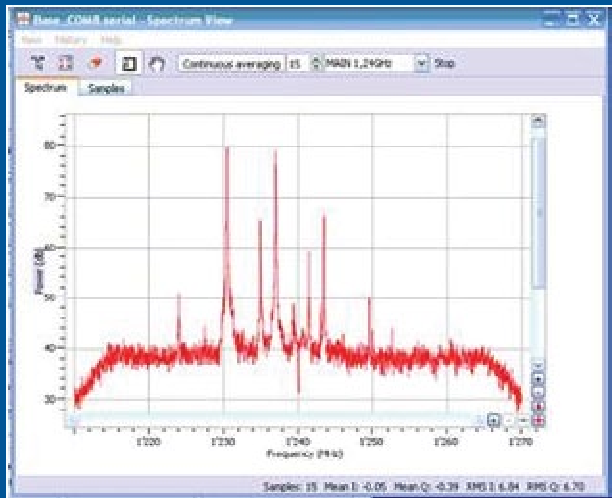
Sources of potential interference are an important consideration throughout the whole design of Septentrio equipment. In the analog domain, interference robustness is taken into account in the antenna and receiver radio-frequency design. This includes aspects such as the out-of-band rejection performance of filters and amplifier saturation avoidance. Careful design at the analog level is also accompanied by countermeasures at the digital level. Working in concert, these analog and digital countermeasures form what is known as Septentrio's AIM+ (Advanced Interference Mitigation) technology.

Adaptive Notch Filter

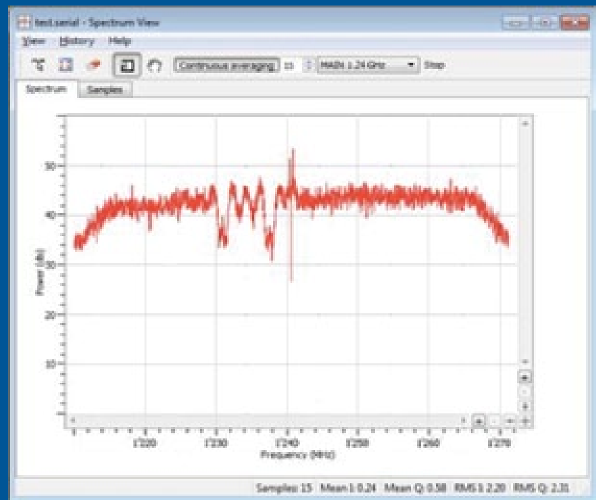
The Septentrio AIM+ adaptive notch filter minimizes the impact of CW and narrowband interference on receiver performance. In the identification stage, the adaptive notch filter continuously "scans" the incoming signals for the presence of an interferer. Whenever an interferer is detected, the signal is digitally processed such that the interferer is suppressed. Installation of the notch filter is fully automated, including the fine-tuning of its bandwidth and center frequency. If required, manual adjustment is also possible. In summary, the AIM+ adaptive notch filter is an effective technique for minimizing the impact of CW and narrowband interference on receiver performance.

USER CASE
> Adaptive Notch Filtering in Action: Precision Agriculture in Russia

Near Tuymen in Russia, a local farming community was upgrading their farm equipment to add high-precision (RTK) GPS systems for autosteer and precision-farming applications. To that end, they had also set up a local basestation to provide the required correction signals. However, when they were trying to bring up the service, rovers receiving data from this basestation were unable to obtain an RTK positionbecause of high levels of local interference. Equipping the basestations with Septentrio AIM+ technology, and activating the adaptive notch filtering feature, largely suppressed the interference and cm-accurate positioning became possible.



Spectrum plot before applying notch filter



Spectrum plot after applying notch filter

Figure 1.
Radio tower in Hilversum, The Netherlands

USER CASE
> Adaptive Notch Filtering in Action: Hilversum Radio Tower

Following reports that GNSS receivers in the region of Hilversum (The Netherlands) had trouble maintaining an RTK fix, Septentrio visited the location to investigate the issue. The problem was traced to a radio tower which houses, among others, an amateur radio digipeater with a center frequency of 1240.4 MHz, which had become a narrowband interferer in the GLONASS L2 band. Figure 2 shows the L2 radio-frequency spectrum, as observed with the “Spectrum Analyzer” tool included in standard Septentrio support software - the digipeater’s signal is clearly visible. With AIM+ intentionally disabled, Figure 3 shows that the C/N0 of the L2 signal is severely degraded. Figure 4 shows the spectral plot after enabling the AIM+ adaptive notch filter. It is clear that the adaptive notch filter is able to identify and actively suppress the extraneous signal. More importantly, Figure 5 shows that the C/N0 of the L2 signal is much less affected. The residual power drops in the observed signal are due to the very close proximity to the radio tower during the test (less than 100m) which sporadically caused some saturation of the analog signal chain.

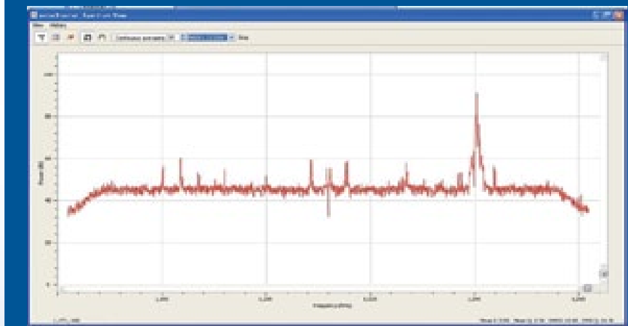


Figure 2.
Observed L2 spectrum before enabling AIM+ with an extraneous signal clearly visible around 1204 MHz

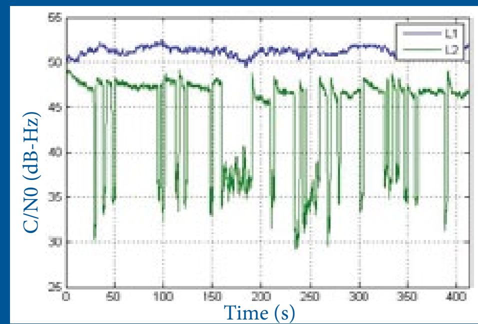


Figure 3.
Observed L1 and L2 signal power before enabling AIM+ showing significant impairment of L2 C/N0

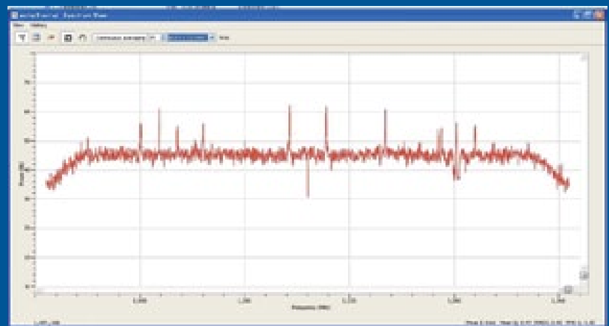


Figure 4.
Observed L2 spectrum after enabling AIM+ showing strongly attenuation of the extraneous signal

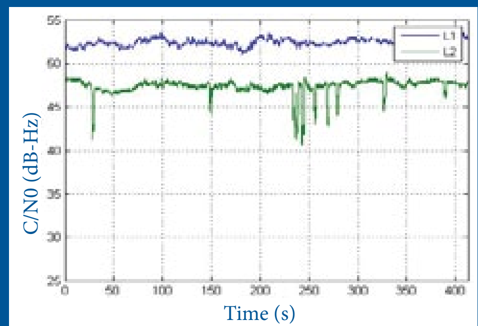


Figure 5.
Observed L1 and L2 signal power after enabling AIM+

Pulse Blanking Unit

The AIM+ pulse blanking unit minimizes the impact of pulsed interference on receiver performance. In essence, the pulse blanking unit immediately triggers whenever a pulse arrives at the receiver's input and prevents the pulse from passing into the tracking/measurement engine of the receiver. The pulse blanking unit is highly responsive by design and tuned such that the input signal is only "blanked out" for the duration of the pulse. Taking a pulse duty cycle of 5% as an example, the effect of the pulse blanking unit is that the signal C/N0 is only reduced by about 0.2 dB-Hz and the impact on the measurements is equally negligible. In summary, the AIM+ pulse blanker mitigates pulsed interference in an effective and robust way.

USER CASE
> Pulse Blanking in Action: DME Interference near Airports

The GNSS L5 band has a center frequency of 1176.45 MHz and belongs to a wider band allocated to aeronautical radio-navigation services. Aeronautical Distance Measuring Equipment (DME) beacons and Tactical Air Navigation (TACAN) beacons also operate in the same band. These ground-based transponders are installed at nearly all major airports worldwide and transmit high-power pulses when interrogated by airborne equipment. The AIM+ pulse blanking unit ensures undisturbed receiver operation in the vicinity of DME/TACAN beacons. For example, Figure 6 shows DME pulses observed in close vicinity of the "BUB" beacon at Brussels Airport (Belgium), as obtained with the "Time Plot" tool included in standard Septentrio support software. Figure 7 shows that the observed pulses fall directly inside the GNSS L5 band. The DME pulse-pair shown in Figure 6 has a pulse width of 3.5 μs and pulse separation of 12 μs. These pulse-pairs are typically repeated at a rate of 2700 per second. The AIM+ pulse blanking unit, once enabled during the test, reported a blanking percentage of about 3%, as expected. While such a low jamming percentage would not significantly degrade receiver operation, it does show that the pulse blanking unit is operational. Although not observed during the test, a batch of synchronized responses to different airplanes can be transmitted, increasing the jamming percentage. The situation is even worse for airborne receivers which may 'see' a number of beacons at the same time. This shows that the AIM+ pulse blanking unit is indispensible for any receivers operating in the region of a DME station, but particularly for receivers on board aircraft.

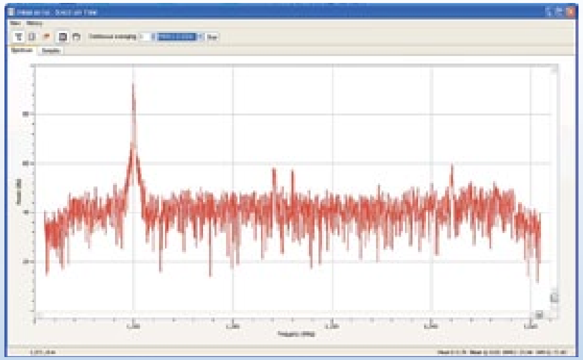


Figure 7. Spectrum measured near DME beacon "BUB" (Brussels Airport) using Septentrio Spectrum Analyzer tool

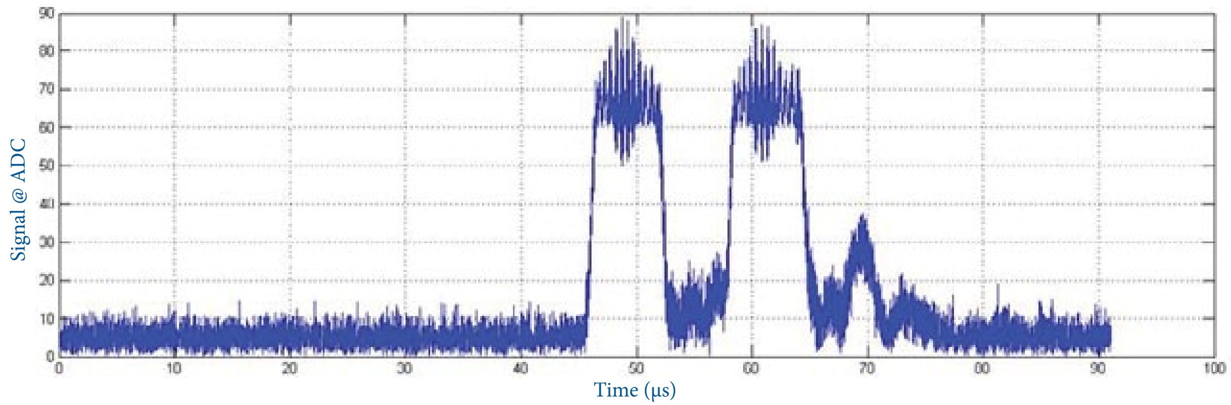


Figure 6. Pulse pair observed near DME beacon "BUB" (Brussels Airport) using Septentrio "Time Plot" tool

GLONASS L2 Band Remapping

GNSS receivers supporting GPS+GLONASS L2 usually cover both bands with a single analog L2 reception chain. However, the GLONASS L2 band is more prone to interference than the GPS L2 band. This is particularly the case in the frequency range above 1240 MHz which is shared with, among others, the amateur radio service. In case of severe GLONASS L2 interference, from say multiple high-power wideband signals, the entire L2 reception chain may become unusable. To prevent the loss of GPS L2 in the case of severe GLONASS L2 interference, Septentrio receivers include a special feature which remaps the analog L2 reception chain. When this feature is enabled, the GLONASS L2 band is blocked while GPS L2 remains fully usable (see Figure 8 for a graphical depiction). This feature, while considered an option of last resort, can be very useful because the availability of L2 measurements is of crucial importance to many users. When severe GLONASS L2 interference is present, the "GLONASS L2 band remapping" feature in many cases is able to restore L1+L2 RTK, albeit GPS-only L1+L2 RTK.

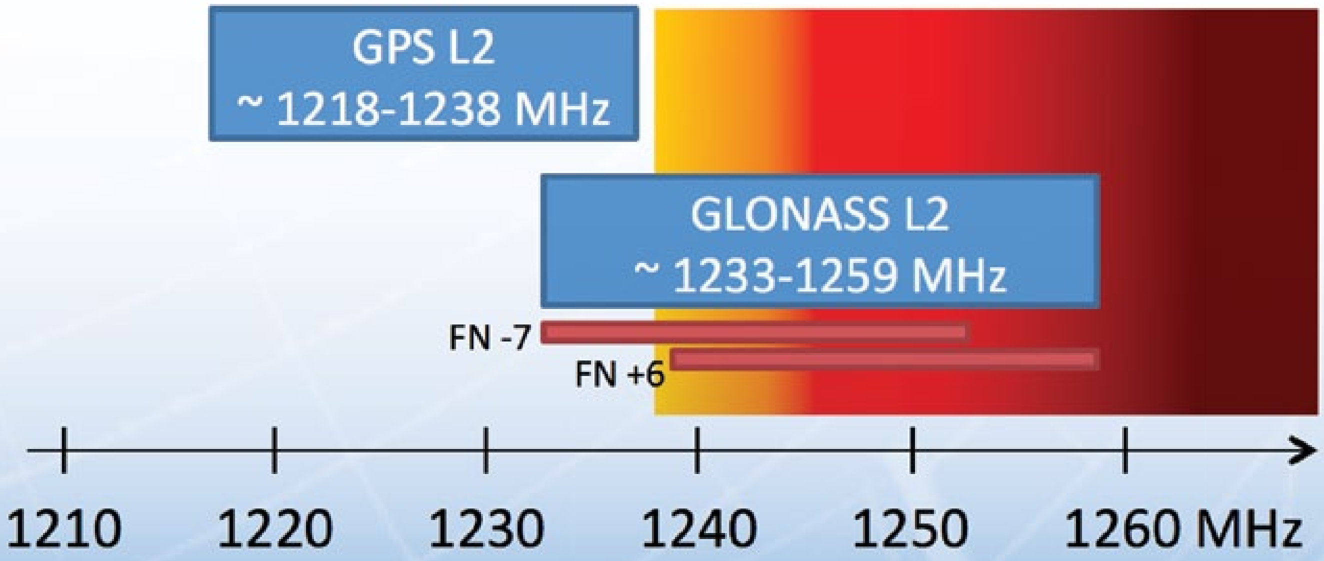
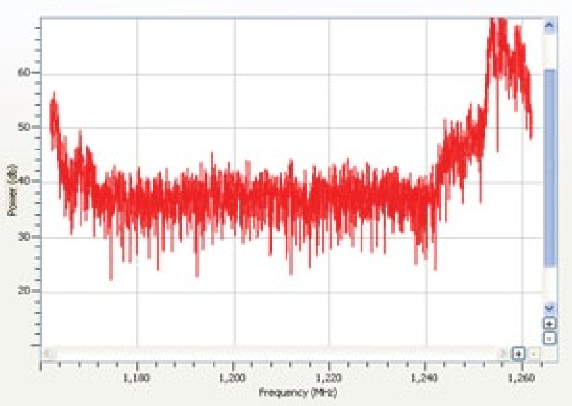
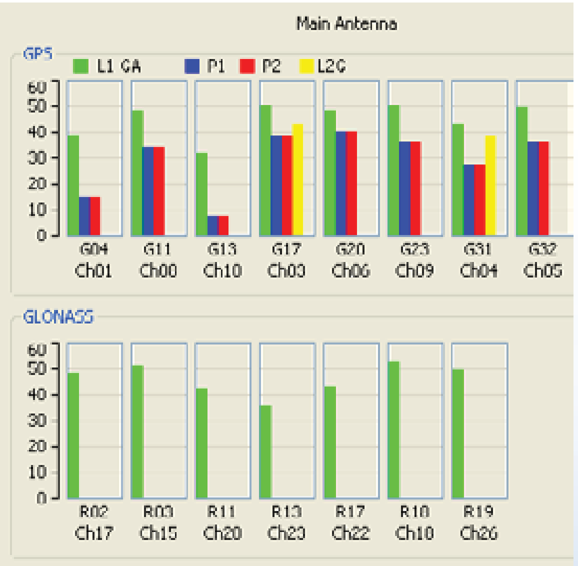


Figure 8. Frequency range of GPS and GLONASS L2 bands; switchable GLONASS L2 band remapping indicated by gradient



▲ Figure 9. Spectrum plot

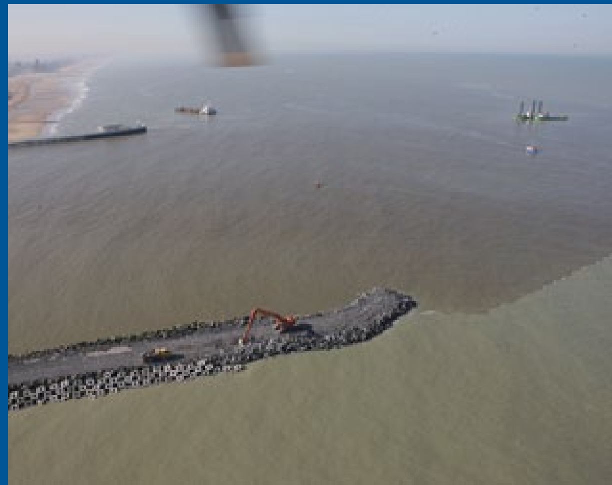
▼ Figure 10. Carrier-to-noise plot



USER CASE
> GLONASS L2 Remapping in Action:
Wideband Interference in Ostend

Several times a week, construction and piling work on the dyke in Ostend had to be interrupted, as all GNSS signals were heavily disturbed. Investigation of the type and source of interference revealed wide band interference in the 1250 MHz region, originating from radio/TV amateur equipment nearby. This interference in the GLONASS L2 band was so significant, that it spilled over into the GPS band as well, and rendered all precision work requiring dual-frequency measurements impossible.

As can be seen from the illustrations, Septentrio's unique L2 band remapping feature effectively tackles this problem. Effectively all harmful signals are filtered out, which also eliminates all GLONASS signals. However, the resulting behavior makes dual-frequency GPS signals available again, and normal operation can resume. The figure illustrates that although the interference is still present (fig.10), dual-frequency GPS signals are available again (blue and red bars), while for GLONASS only L1 signals are available (green bars)



Spectrum Analyzer Functionality

Septentrio AIM+ also provides an easy way for users, or especially for law enforcers, to investigate whether interference is present. Septentrio set of graphical software support tools (called RxControl), when linked to a receiver, can provide real-time spectrum plots that show the frequency spectrum of the signals entering the receiver. The spectrum figures in this paper are actually created using this on-receiver spectrum plot capability.

Conclusion

Maintaining position accuracy and availability constitutes a serious challenge for GNSS receivers operating within the radio-frequency interference environment we can expect to experience now and in the future. Septentrio's "AIM+" technology meets this challenge head-on with a range of countermeasures in the analog and digital domains. This includes dedicated hardware and software to mitigate continuous wave, narrowband, pulsed and other types of interference. In many cases, position accuracy and availability can even be maintained when a whole GNSS band is jammed thanks to the ever-increasing redundancy of GNSS signals. Septentrio's AIM+ technology, combined with Septentrio's commitment to offer all navigation signals in the sky, ensures customers of the highest attainable performance – even in the most challenging conditions.

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Versatile OEM Receivers for Demanding Applications

Septentrio nv

Greenhill Campus,
Interleuvenlaan 15G
B-3001 Leuven, Belgium
tel: +32 (0) 16 300 800
fax: +32 (0) 16 221 640

20725 Western Avenue, Suite #144,
Torrance, CA 90501, USA
tel: +1 (888) 655-9998
fax: +1 (323) 297-4648

www.septentrio.com
info@septentrio.com