Navigating with more than just GPS

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The resurgence of the automotive industry has come with strong buyer interest in technology to improve safety, convenience and awareness in the automobile. GPS is one such technology that has strong consumer demand. While a GPS receiver is at the heart of any navigation system, applications for GPS extend to a wide range of automotive systems. Virtually anything with a sensor can take advantage of GPS data such as date, time, precise frequency, altitude, heading, velocity partly because it is very accurate and independent of any other system. But GPS is not the only satellite in the sky anymore. More and more Global Navigation Satellite Systems (GNSS) are being developed and deployed. Receivers are available to make use of multiple systems that, when used together, improves accuracy and reliability.

This article will help readers understand the trend to multi-GNSS using the example of the Russian GLONASS system as a complement to GPS. Dual mode GNSS receivers are practical and growing in popularity and availability. One of the biggest advantages is coverage in urban areas, but coverage improvements occur in other situations too. It improves overall robustness and signal availability. And if you are selling your product into Eastern Europe or other parts of the world that are not too keen on using the GPS system because it is controlled by the US military, using a dual mode receiver may be a requirement, not an option.

Introducing GLONASS

Now that the GLONASS satellite navigation system has been updated with new satellites and is fully operational, there is an alternative to GPS. Should you consider a dual mode navigation receiver for your application? Chances are, yes, but read on to understand the advantages and implications.

First, a bit of background. Though GPS has entered the vernacular to mean satellite positioning, when we are talking about any satellite navigation system, the accepted term is GNSS – Global Navigation Satellite System. A growing number of new GNSS systems are being launched today. The main systems are GLONASS from Russia, Galileo from the European Union, and Compass/Beidou from China. Japan and India also have plans to launch systems for their countries too, but it will be some years before we see those. The primary motivation for these launches was originally so these countries could have independence from the US military-controlled GPS systems, but now there are additional reasons to use them, even within the USA.

We focus on the Russian GLONASS system because it became fully operational just last year, where the other systems are still in their early phases of deployment. A relic of the cold war, the original GLONASS system was contemporary with the original GPS system, but fell into disrepair after the collapse of the Soviet Union. In the 2000s decade, the entire system was revitalized with new satellites and is operating well. Since it transmits in the same bands as GPS (L1 and L2), though at a slightly higher range, dual mode receivers that operate with both systems are practical and growing in popularity and availability. Ask your current GPS supplier.

A common myth about GLONASS is that it only offers coverage for Russia. Not true. It is a worldwide system with 24 satellites orbiting the globe in Medium Earth Orbit (MEO) with about 12 hour periods, similar to GPS. Coverage is slightly optimized for the higher latitudes, but more than a sufficient number of satellites are visible for a quality position fix at any point on earth with a full view of the sky. The overall system accuracy is slightly less than GPS, but if you use both GPS and GLONASS together as many dual mode receivers do, your resulting accuracy is improved, especially in noisy environments.

Wanted: More Satellites

Both GPS and GLONASS receivers calculate their position on earth by measuring their range from the satellites, which transmit their signals from precisely known orbits. Range is measured by the time delay of the signal from each satellite to the receiver on the surface of the earth. To achieve a 3-D fix, you need a minimum of four satellite measurements – one each for the x, y, and z directions, and the fourth for time. However, not just any satellites will do. Ideally, the satellites should be spread apart across the horizon and toward the zenith so all the measurements are at right angles with each other. When the angles are not orthogonal (near 90 degrees) we say there is Geometric Dilution of Precision (GDOP). Figure 1 illustrates two examples.

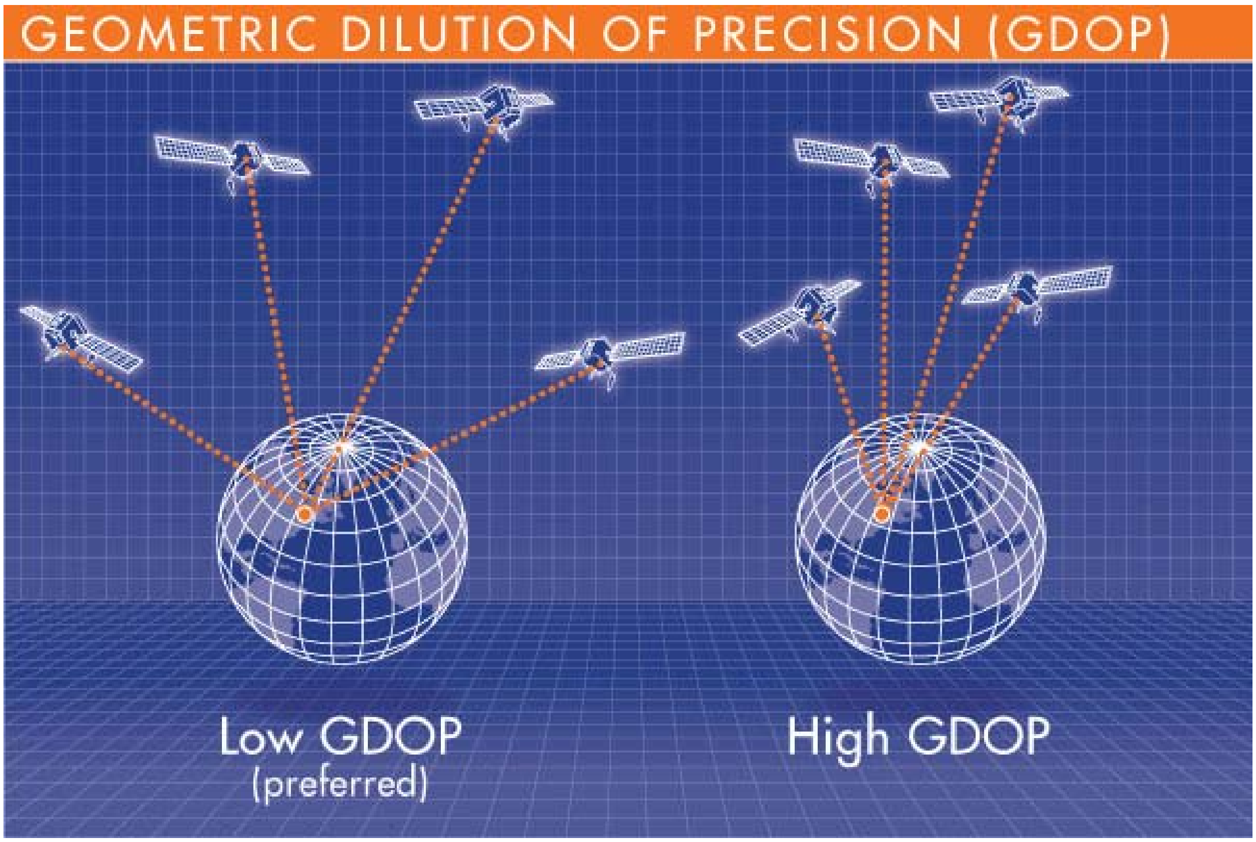

Figure 1: A narrow spread of satellites results in a geometric dilution of precision

On the left, the satellites in view are arranged so the GDOP is low, but on the right, the measurement ranges do not align very well with the x, y, z axes, so the precision is diluted by a larger factor. With more satellites visible when using both GPS and GLONASS, you have more opportunity to select the better satellites to reduce your GDOP and improve your accuracy.

One of the biggest advantages of a dual mode receiver is coverage in urban areas, but coverage improvements occur in other situations too. Consider the “urban canyon” problem depicted in Fig 2. The height of the buildings in a city masks the satellites at the horizon.

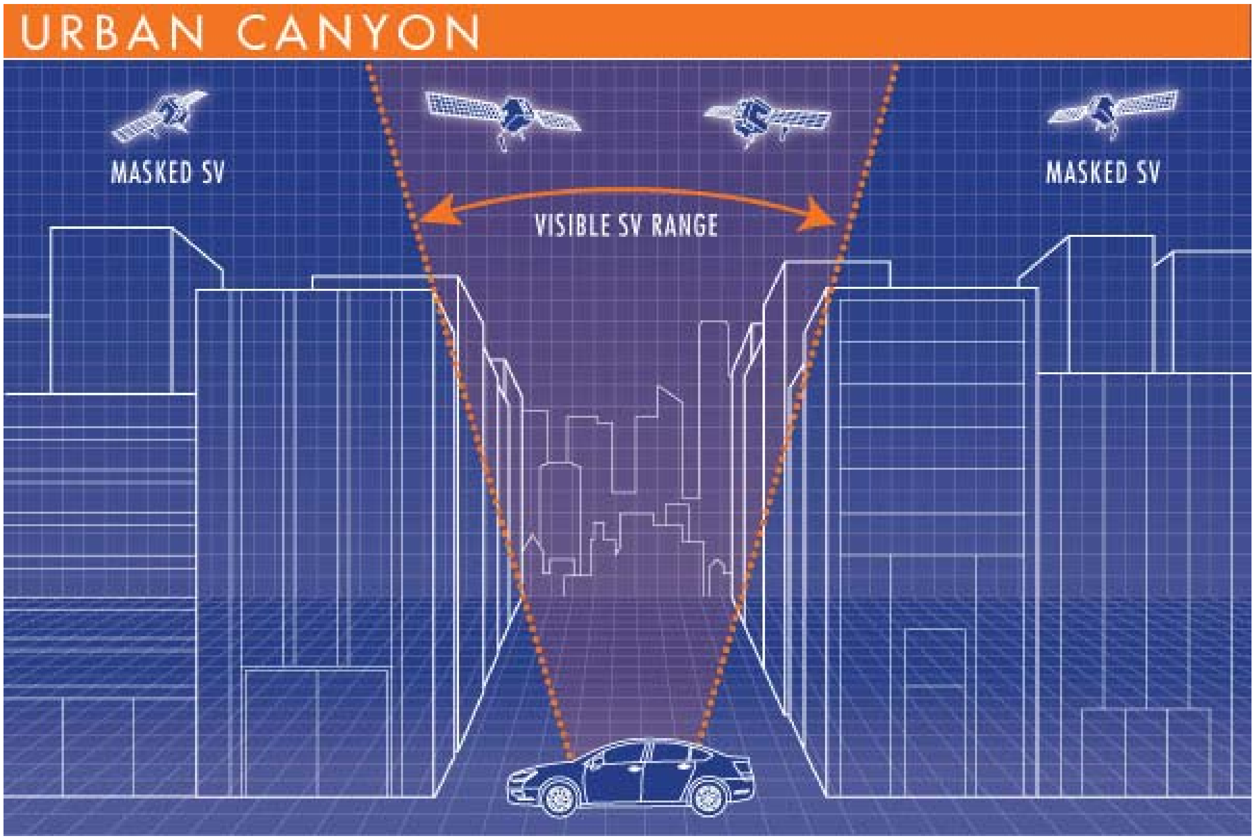

Figure 2: The urban canyon problem prevents a full view of the sky

With a dual mode GPS+GLONASS receiver, there are twice as many satellites available, making it less likely you will track less than four satellites and lose position fix when masked. The graph in Figure 3 shows this quantitatively. The elevation mask angle is measured up from the horizon, so a zero value is a full view of the sky.

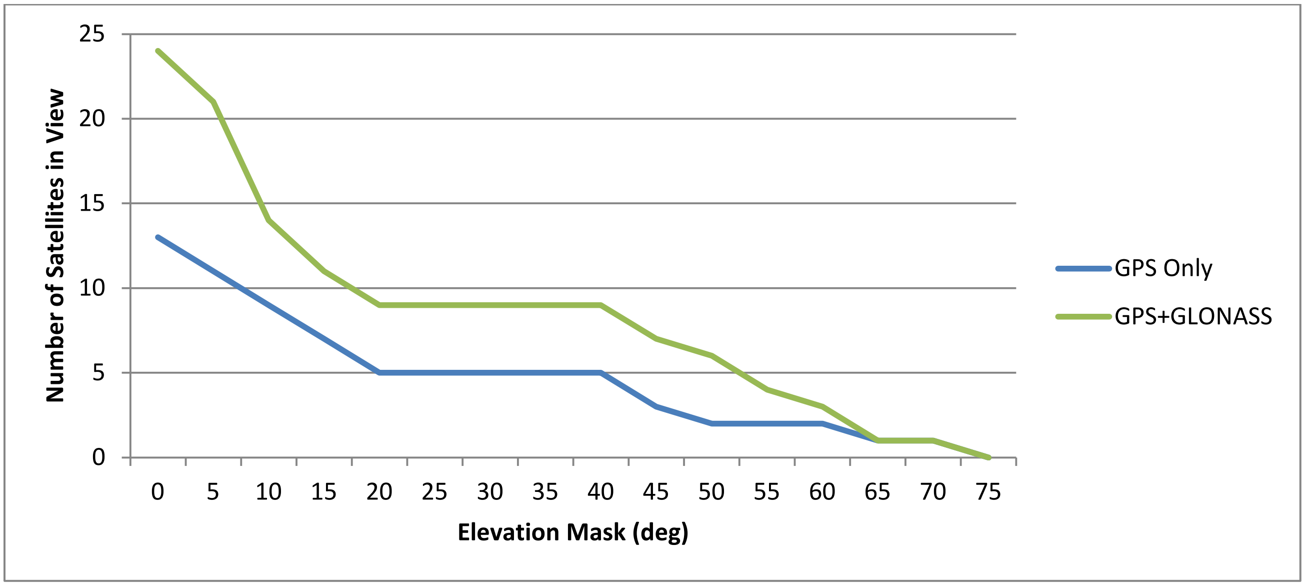

Figure 3: When combining systems, a larger elevation mask can be tolerated

With only GPS, the number of satellites in view falls below four above 40 degrees, but with both systems available, this doesn't occur until above 55 degrees. Of course, your GDOP will be poor, but tracking with a less accurate solution is better than not tracking at all. Moreover, in the 20 to 40 degree range, the availability of nine satellites instead of five reduces the GDOP in those situations, as the receiver can choose the best four of the nine.

Coverage and accuracy improvements occur even when masking is not an issue. With an open view of the sky, having more satellites (20 or more with no masking) prevents momentary drop outs in moving vehicles because the over-defined navigation solution can maintain track better in the presence of noise or interference. In these situations the error due to GDOP goes to zero (GDOP factor = 1.0). In the over-determined case, satellites that are experiencing multipath will be marginalized or eliminated from the navigation solution because their range error will make them an outlier. Those satellites with no multipath errors converge to a single point quickly, so with 20 or more satellites in view, the solution can afford to throw away the outliers.

Better, more accurate tracking means the time to acquire weaker signals is shorter, raising the effective sensitivity of the receiver. Understand that the signal from the satellite is very weak, below the noise floor. Spread spectrum techniques are used to integrate the signal from the noise. To do this, the receiver's signal processor must search for the signal in both time and frequency. Initially, the time and frequency of the incoming signal is only known approximately. Since the satellites are moving relative to the earth, as well as the receiver moving across the surface of the earth, there is a Doppler shift in frequency. To find these weak signals, the receiver must search a number of frequency ranges or "bins", both above and below the nominal carrier frequency as the Doppler shift can be positive or negative. The better the receiver knows its own position and movement, the better it can predict the Doppler shift from each satellite, and therefore the less frequency range error over which it must search. With less search range, it will find the weak signals faster, and track them that much longer.

There is frequency diversity between GPS and GLONASS that provides another complement. As shown in Figure 4, all the GPS satellites operate on the same frequency at 1574 MHz with a different spreading code for each (CDMA or Code Division Multiple Access, similar to how our mobile phones operate). The GLONASS system operates in an FDMA fashion – Frequency Division Multiple Access, with each satellite transmitting at a slightly different frequency in the range of 1598 – 1606 MHz. Frequency separation offers two distinct advantages: multipath performance and interference rejection. For multipath, the wavelength matters. A bounced signal path reinforces or diminishes the direct path if it is an integral number of wavelengths different. Changing frequency changes the wavelength, so operating on different frequencies will change multipath behavior. One frequency is not necessarily better than the other, but whatever multipath conditions you have at frequency A (good or bad), the conditions on frequency B will be different (bad or good). So diversity can help.

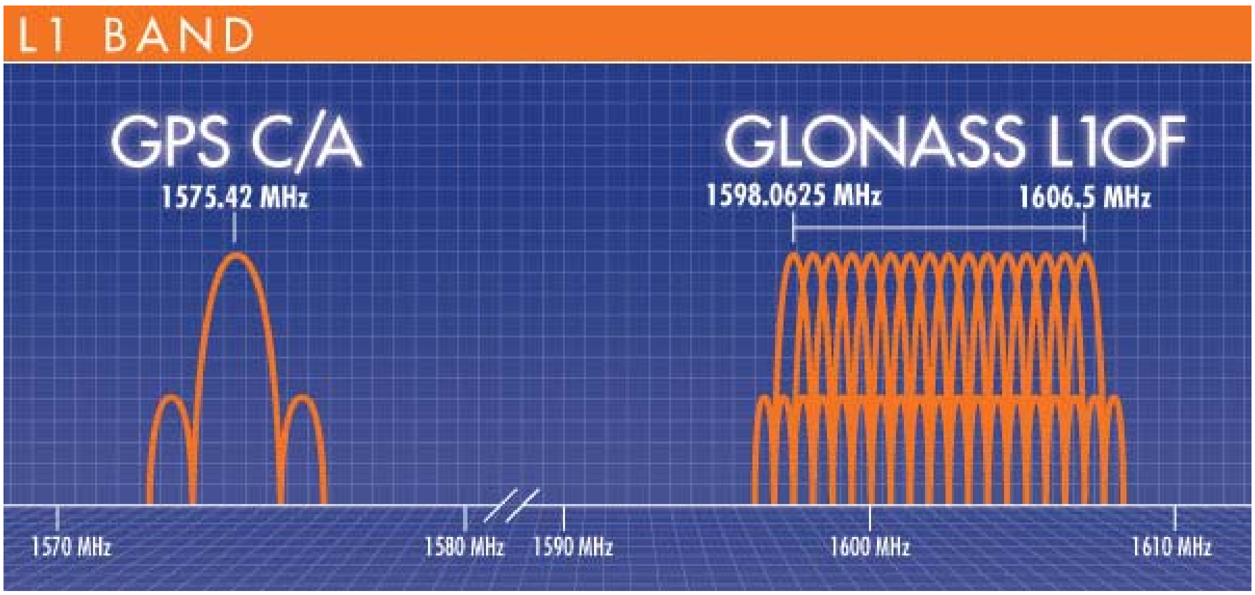

Figure 4: Diversity of signals in the L1 frequency band

The other factor is interference. Granted, there is not a large frequency separation between GPS and GLONASS – only about 25 – 30 MHz (which makes it easy to build a receiver that can receive both) – but that separation can sometimes be enough to offer a small amount of interference rejection from a narrowband source. Often, interference in the GPS band is from a narrowband, unintended source, such as the third harmonic of a high-powered TV transmitter near 525 MHz. A slight change in frequency can do much to avoid these problems.

Having redundant satellites to track improves overall robustness and availability. With so many satellites to choose from, a problem with any one satellite or constellation for any reason – noise, interference, masking, or failure – allows one to drop that faulty satellite or constellation and continue operation with the functioning ones.

Beyond the technical advantages, there are business reasons to adopt a dual mode receiver. If you are selling your product into Russia and some Eastern Europe countries, additional taxes will be levied on products not using GLONASS. Moreover, there are several countries that do not want to use the GPS system because it is controlled by the US military. For exporting to these areas, using a dual mode receiver may be a requirement, not an option.

Testing Multi-GNSS

So if you are now convinced of the advantages of a dual-mode receiver, how do you choose one, integrate and test it? Dual-mode receivers fall into two main classes: those which calculate their GPS and GLONASS navigation solutions separately and those that combine all the range measurements from both systems and solve for position in the aggregate. The latter type usually produces the best results.

To test these receivers, it's important to have the latest generation of GNSS simulators that operate in multi-mode and synchronize the GPS and GLONASS signals together. Most simulators today simulate all three segments of the GNSS system: the Sky Segment (the satellites), the Control Segment (the ground control stations that keep the satellites accurate and synchronized), and the User Segment (where the receiver resides). Simulators simulate the movement of the User Segment, called its Trajectory by adjusting the relative time delays of each satellite signal in realtime to reflect what that receiver would see if it were moving. In this way, a receiver in a lab connected to a simulator can experience the same conditions as if it were moving dynamically. Often the most challenging performance characteristics of a receiver are related to how it will operate under dynamic conditions of high velocities or accelerations, so it is important to test for this.

To realistically test a fully integrated type GPS+GLONASS receiver, the calculations for the user's trajectory must be simultaneously and accurately applied to both constellation simulations. The orbital parameters of each satellite following the rules for each constellation must be applied so the composite relative delays are accurately simulated. The satellite signals from the simulator must be fully integrated and synchronized to ensure you are getting the advantages you planned on from the chosen dual mode receiver. Testing GPS separately from GLONASS will not measure all the true improvements described earlier. Synchronization must occur at the nanosecond level or better because a 1 nS error equates to approximately 1 foot or 0.3 meter position error. Simulators with accurate internal time bases are extremely important because everything about GNSS position accuracy comes from measuring time delay. In some high accuracy situations, it can be necessary to use an external atomic clock reference for the simulator's time base. Consider this in choosing your simulator, as the live GNSS signals run on atomic clock time references so maybe your test equipment should too.

Fully integrated, multi-mode, accurate GNSS simulators, with optional external atomic time references, are available today, such as the Spectracom GSG product line. In choosing test equipment for your navigation system, make sure it handles multiple GNSS systems. The better ones are designed for working with all the various GNSS signals, and have the ability to be upgraded in the future. It may seem unlikely that you could "futureproof" your investment in test equipment as how does anyone really predict the future? When it comes to satellites systems, these are designed many years before they become operational, so the signal specifications are known well in advance of their launch. The Galileo system has been defined and finalized for several years now. The new GPS signals which will be available in the next few years are all defined and are being implemented in satellites being built today. The one exception to this is the Chinese Compass/Beidou system whose specifications are being released very slowly. However, the general expectation is that its specifications will be released widely to the public soon so Compass can gain the worldwide acceptance that the other GNSS have.

Conclusion

There are powerful advantages to using GPS+GLONASS receivers in any system that uses GPS data in critical applications. And those advantages can be realized right now. In addition, as other GNSS systems come on line in the next few years – Galileo and Compass in particular – the advantages of using multi-GNSS will even get stronger. The results will be better accuracy and better continuous tracking under all kinds of harsh and diverse conditions as seen in the automobile.

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