oneNav

The Next Generation of Mobile GNSS

Introducing the oneNav Pure L5 Mobile GNSS Receiver

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Introduction to the 5th generation of Mobile GNSS: oneNav Pure L5 GNSS

GNSS receivers first reached the commercial domain in the early 1980s. They were bigger than your average carry-on suitcase, weighed more, and consumed so much power that they needed to be plugged into an outlet. But technology advanced quickly and by the mid-1980s commercial GNSS receivers were appearing in survey and marine markets.

Gen 1: The first generation of truly mobile receivers were L1 C/A code only, usually with very narrow front-end bandwidths of 2-5MHz and were typically found in ruggedized handhelds used by outdoor enthusiasts for hiking and sailing. These first-generation architectures began appearing in mobile phones in the late 1990s, and were the key technology in enabling E911.

Gen 2: The second generation of mobile receivers added GLONASS satellites beginning in approximately 2010 when the GLONASS system became modernized and reliable. These receivers had to have wider bandwidths on the order of 20-30MHz in order to support the GLONASS FDMA signals at a slightly offset frequency from GPS L1. However, both the GPS and GLONASS signals were utilized in a narrow band signal processing methodology.

Gen 3: The third generation of receivers added support for the Galileo system launched by the European Union and started appearing in mainstream cellphones in the 2014 timeframe. These phones still retained a single frequency front end in the L1 band but had separate digital processing chains for all 3 satellite systems.

Gen 4: The evolution to the 4th generation took some time as it added 2 new capabilities: 1) the ability to process the Beidou signals and 2) support for a single sideband L5 receiver where Beidou, Galileo and GPS all have modernized signals. Throughout this paper, we will refer to all signals from all constellations (L5, E5 and B2) in the 50MHz band centered at 1192MHz as "L5" for simplicity's sake. Despite having been available in other markets earlier, these receivers only first appeared in phones in 2019 because of the added size, power, and complexity of supporting a dual band receiver in a mobile phone. Many expected that this would be the final generation of GNSS for cell phones as it seemed to have covered all the bases.

However, at oneNav we recognized several problems with these 4th generation receivers:

1. A dual frequency front end was a huge burden on many phone models, especially with the rise of 5G.
2. The L1 band still had reliability issues with jamming and interference but was needed to aid the acquisition of the L5 signals.
3. The receivers only supported a single sideband at L5 and were not utilizing the full capability of the L5 band to further enhance sensitivity, improve accuracy, and mitigate the impact of multipath.

As a result, oneNav set out to build a fifth generation of GNSS receivers for mobile consumer products that had the following key characteristics:

1. A single frequency design that only uses the modernized, wideband signals at L5.
2. An acquisition engine sophisticated enough to acquire L5 signals directly.
3. A navigation engine that utilizes Artificial Intelligence/Machine Learning (AI/ML) techniques to fully exploit all the signals in 50MHz wide band at L5, in order to increase accuracy by greatly reducing multipath errors.

Why L5 is so important for consumer devices

Every GNSS user in every segment benefits from using the new, modernized signals in the L5 band. L5 signals are more accurate, more reliable, and are currently available in sufficient numbers to support all user segments. A quick overview of the major advantages of L5 over L1 is presented below.

1. Signal structure (narrow correlation peak) accuracy

The GPS L1 has a chipping rate of 1.023 MHz, while the modernized signals in the L5 band have a ten times higher chipping rate of 10.23 MHz. This means that the correlations peak of L1 covers 293m, while an L5 peak covers only 29.3m. This yields inherently more precise measurements as well as effectively eliminating multipath distortions from any reflection that exceeds 29m.

2. Wide bandwidth (multipath mitigation) accuracy

Multipath mitigation ability is directly proportional to bandwidth. By having a larger bandwidth, signal observables contain additional information that can be used to determine reflections that are present in the combined received signal. By identifying these reflections, they can be corrected, and the signals can be used in the solution rather than eliminated due to measurement uncertainty. In addition, because our wide bandwidth captures both the A and B channels, we increase our resistance to multipath fading since the signals have different fading patterns.

3. Pilot codes (longer coherent integration increasing SNR)

The original GPS L1 CA code has a single component with a data bit every 20 milliseconds, while the modernized signals in the L5 band have two quadrature components: a data channel with the data symbols and a pilot channel without data symbols. The European Galileo and the Chinese BDS versions have a 2nd sideband with two more quadrature components enabling a second data and pilot channel. Since these pilot channels have no data bits, they enable longer coherent integration which greatly enhances the sensitivity of the receiver. Combining these multiple components also provides additional sensitivity in acquisition mode.

4. Multiple constellations and signals with common signal structure

The signals in the L1 band were mostly designed in the 1970s and each system uses its own modulation scheme. When the L5 signals were being defined by different countries across the globe, the UN OOSA (Office of Outer Space Affairs) set up the ICG (International Committee on GNSS) that allowed the countries to discuss designs that would facilitate interoperability through conferences and working groups. This led to a relatively common baseline across all systems that eliminates the HW and SW complexity in L1 receivers as each system required its own digital processing core.

5. Stronger signal transmission

The satellites now in space that transmit L5 signals are significantly evolved from the original satellites built in the 1970s. In particular, they are far more power efficient due to better solar arrays, larger batteries and significantly improved transmitter efficiency. The result is that power can be used to transmit additional signals and at higher power while still conforming to international coexistence requirements. Each component of the modernized signal can be at least 0.5dB stronger than L1 CA, and the combination of all four components can be 6 dB stronger. This results in faster acquisition times and better coverage in dense urban environments.

6. Lower BER and cross correlation

The original L1 C/A code used a simple parity bit scheme for error detection only. The modernized signals switched to a much more robust system of convolutional encoding that adds more robustness to error detection and also adds the ability for error correction. In addition, modernized signals added a secondary code that is used to ensure that the correct satellite is being detected and not cross correlated with another satellite with a much stronger signal. The combination of a longer primary code and secondary coding leads to a reduction in cross correlation by more than

13dB. Cross correlation in L1 receivers can inhibit detection of weaker signals by 10% when a strong satellite is present: (jamming 100Hz out of each 1kHz of BW). These techniques enhance the reliability of the L5 measurements which prevent position errors which occur with L1 measurements.

7. Cleaner band with less interference

The L5 band is centered 400MHz lower in frequency than L1 in the heart of the ANRS (Aeronautical Navigation Radio Services) band which is protected worldwide for navigation purposes. This means no communication bands which can cause interference are present, nor can they ever be added. Furthermore, the L1 band is situated in frequency band that has significant harmonic interference from certain cellular bands, which causes major issues for handset developers. As a result, the L5 band has much less RF interference and much far fewer jamming issues.

8. Signal availability

The GNSS systems in the L5 band have seen significant build out in the last few years to where there are now 66 satellites transmitting operational signals in the L5 band. As a rule of thumb, individual systems declare full operational capability (FOC) at 24 satellites. Both Galileo and Beidou are complete which accounts for 48 signals, plus 12 GPS Block IIF, plus 3 GPS Block III, and 3 QZSS to get to the total of 66 signals. Also, for most commercial operations, using more than 12 satellites in the solution provides very little benefit in terms of accuracy and robustness. There are more than enough L5 satellites today and more GPS III satellites are being launched regularly.

Why not just use a current L1/L5 solution?

The benefits of L5 are clear. That's why many GNSS suppliers have started building L1/L5 solutions, and they are starting to appear in smartphones. It seems to be quite a natural progression to add an L5 receiver chain on top of an existing L1 solution and be able to reap the benefits. But there are a number of reasons why bringing along the legacy L1 solution could actually be having a negative impact on the overall solution.

1. Extra receive chain

Using a dual band solution requires having a second, separate RF receive chain for each band. That means 2 antennas as well as an extra set of amplifiers and filters. These take up space, consume power and cost money at the handset level. Since the L5 measurements are more accurate, many receivers turn off L1 to save power in tracking mode. Why incur the size, cost and power of L1 just for acquisition? These can be at a premium in 5G handsets and wearables, and eliminating them provides more flexibility without giving up any performance when using the oneNav solution.

2. Interference and Jamming

The L1 band has significantly more issues with interference and jamming than L5. This is because several cellular bands are at nearly exactly ½ of the L1 frequency and therefore the transmitters are actually putting out signal harmonics that can jam the L1 receiver. Furthermore, there are more 2nd and 3rd harmonic combinations that can also impair the L1 reception and they are closer to the L1 signal than the comparable ones at L5. Finally, the L5 band is a protected band worldwide for navigation and there are no nearby interferers unlike Ligado Networks (former Lightsquared) in the L1 band. This problem is especially concerning since if the L1 signal cannot be acquired, then the receiver cannot use that information to acquire the L5 signals. Having a clean L5 band that can't be acquired because L1 is jammed is a major reliability problem.

3. No benefit to navigation accuracy

Because the L5 signals are stronger and more accurate, once they are acquired, there is no need to use the L1 signals in the navigation solution. They have more noise and more multipath and therefore DEGRADE the solution, so most suppliers ignore L1 measurements once L5 has been acquired. Some receivers use the L1/L5 combination to reduce ionospheric errors, but these can easily be corrected in connected devices using readily available global data services that provide the same level of accuracy for reference networks.

Introducing the oneNav Pure L5 wideband receiver

Based on the above, it would seem clear that the ideal solution would be a pure L5 solution that provides all of the benefits of L5 without the downsides of L1. In this case, LESS IS MORE. Unfortunately, no one is offering such a solution in the marketplace today and that is what motivated us to develop the oneNav Pure L5 receiver. Leaving L1 behind and focusing solely on building an L5 receiver from scratch that can acquire L5 directly and resolve multipath to the 1-2 meter level is a highly challenging task. Here are several of the key innovations that have allowed oneNav to build such a unique product.

Optimized L5 acquisition engine

Building an acquisition engine for the L5 signal is a huge mathematical task. Since the codes are 10X longer and have a 10X faster chipping rate, it's a 100X more difficult search problem. oneNav has created an engine that is optimized for that problem without using 100X more silicon or 100X more power by developing a customized array processor that tackles the L5 acquisition problem using a more GPU like approach. In this way, we are able to maintain TTFF without an oversized engine and without any assistance from L1.

Single frequency simplified architecture

As noted previously, the pure L5 architecture completely eliminates the need for a second RF chain. Furthermore, since all the L5 signals were designed to be interoperable as a result of international cooperation, the DSP architecture can be harmonized. Rather than having independent correlation engines, the oneNav L5 engine uses common hardware (the customized array processor) for signals from all GNSS systems. This greatly reduced hardware and software complexity and provides flexibility in implementation.

Increased sensitivity for acquisition and tracking

The L5 signal has a modernized signal structure that allows for increased sensitivity for both acquisition and tracking. In acquisition, combining multiple components from both sidebands increases total signal energy resulting in improved sensitivity. In tracking, the pilot channel allows for longer coherent integration to maintain signal lock in difficult environments including enhanced resilience from fading. Since the oneNav architecture is wideband, all parts of the L5 signal can be combined for maximum performance. In this way, there is significantly more signal strength coming off the satellite in L5 vs L1. That means in the same environment, the L5 signals appear stronger.

Improved time to an L5 based fix

Current dual band receivers first get a fix on L1 and then begin the acquisition process on L5. By doing the L5 acquisition directly, we skip the entire process of acquiring and navigating using L1, which saves time. The L5 measurements are more accurate and therefore the time to an L5 based fix is critical.

Increased acquisition reliability

The L1 signal structures are outdated. They do not have the longer primary codes and the secondary codes like modernized signals on L5 that mitigate many of the reliability problems associated with cross correlation, jamming and spoofing. In difficult conditions, using these unreliable signals can even cause the L1 acquisition to take longer and produce incorrect results.

Improved tracking and measurement

a. The L5 signals are inherently more accurate as discussed previously but they also hold more information in the full bandwidth. The Galileo and BDS signals have both an A and B channel which when used together produce significant improvement in tracking sensitivity as well as improved measurement accuracy.

b. Using the full bandwidth allows a more sophisticated channel estimation than a simple pseudo range measurement that is common in other receivers. The oneNav receiver determines a representation of the full channel impulse response (CIR) using unique signal processing of the satellite signal, which allows better multipath correction by the navigation engine.

c. Since there are multiple signals contained within the L5 wideband signal, we gain advantages from channel diversity as well. These signals are separated by about 30 MHz which provides further resilience against multipath, especially at low speeds common for pedestrians.

AI/ML enhanced navigation engine

a. The oneNav enhanced measurements are processed by a cloud connected Navigation Engine that uses advanced AI/ML techniques to further improve navigation accuracy. The inference engine and navigation algorithms that produce the final navigation output run on the mobile device, while the learning engine resides in the cloud. This allows the mobile device to operate even when temporarily disconnected from the cloud.

b. The Navigation Engine uses sophisticated ML techniques to 1) predict if the received signal is Line of Sight (LOS), and 2) predict the measurement error caused by multipath. These techniques require the extra information contained in the CIR and the correlation function from the oneNav measurement engine. Combined with data from building models, the propagation model of the urban canyon can be learned and used to resolve multipath and improve positioning accuracy. The oneNav Cloud service uses this model to allow reflected signals to be used correctly in the navigation solution rather than being excluded due to their multipath content.

c. The Navigation Engine uses a sophisticated pattern matching-based positioning algorithm that combines the pseudorange measurements and the environment's 3-D building map model to enhance the positioning accuracy in deep urban canyons.

Integrating the oneNav receiver into your product

The oneNav receiver was designed from the beginning as a licensable IP core rather than a discrete silicon solution. oneNav provides a complete solution, including all the firmware and an RF front end reference design from antenna all the way to A/D converter. This allows customers to determine how to best bring the oneNav advantages to their products. The IP core can be integrated into a larger ASIC such as a modem or an SOC. It could also be implemented as a discrete silicon solution if desired. The RF could be combined into any of these solutions or implemented with other RF components in the system. The measurement and position engine firmware can be run on a dedicated CPU or shared in either the same or different CPUs. This methodology allows the customer to decouple the GNSS capability from other functionality and implement in whatever silicon process or partitioning that is most effective for the application and do the system integration that is optimal for that application.

The IP core is implemented to be both process independent and scalable. With oneNav support, the core can be customized to provide an optimal balance of size, power and GNSS performance that is specific to the application. The core has build time scalability to support different memory sizes and clock speeds to support different performance requirements. For example, trading off search size and speed with silicon area may be different for different applications. The measurement engine supports run time scalability that allows optimization of power and performance depending on prevailing signal conditions as well as host application requirements. Furthermore, an integrated GNSS core means that GNSS performance can be maintained across multiple platforms and silicon generations providing consistency of measurement and positioning performance needed to maintain system reliability and fusion.

In summary, the oneNav Pure L5 Wideband Receiver is the next generation, the 5th generation, of GNSS for mobile consumer products. This high-performance receiver based on a modern design and modern signals provides a best in class receiver that will set the standard for GNSS products in cellular, wearable and IOT products.