

All-band GNSS receivers enhance positioning, navigation, and timing performance. Here's how.

Harness the full spectrum of signals broadcast by GNSS constellations to meet demanding customer expectations in terms of accuracy, robustness, reliability, and more.

Abstract

As GNSS / GPS technology continues to evolve, the next frontier in driving the adoption of positioning, navigation, and timing (PNT) solutions will involve extending the benefits of all-band GNSS to a growing range of markets and applications. This white paper outlines how a new generation of powerful, compact all-band GNSS modules raises performance across key metrics, improving accuracy, GNSS availability, and convergence times while also streamlining production and logistics, future-proofing solutions, fortifying security, and reducing the total cost of ownership.

White paper: All-band GNSS receivers enhance positioning, navigation, and timing performance. Here's how.

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Executive summary



For over four decades, GNSS / GPS technology has continuously evolved, enhancing accuracy and reliability, and enabling ever more sophisticated positioning, navigation, and timing (PNT) applications. Over the past years, this evolution has been spurred on by the continual introduction of new satellite signals covering an expanding frequency spectrum.

Modern multi-band GNSS receivers capable of tracking signals across all available frequency bands have greatly enhanced PNT performance, enabling sophisticated applications. However, their high cost has largely restricted adoption to high-value sectors, including surveying and heavy machinery in construction and mining.

This white paper explores the benefits of a new generation of compact all-band GNSS receivers designed to meet the needs of key applications, including unmanned ground vehicles, unmanned aerial vehicles, heavy machinery and precision farming, automotive navigation systems, and industrial timing and synchronization.

After presenting the satellite signals broadcast by all major global and regional satellite systems, the white paper outlines how all-band GNSS receivers enhance performance across key commercial metrics beyond accuracy, reliability, and robustness, including streamlined production, simplified logistics, and enhanced security and integrity.

Critically, the capacity of all-band GNSS receivers to track all frequency bands used by GNSS satellites ensures that they can be upgraded to access emerging services, such as Galileo's high accuracy service (HAS) and Japan's centimeter level augmentation service (CLAS). This makes all-band GNSS receiver modules key enablers of mass market adoption of these services.

As all-band GNSS receivers emerge as the ideal positioning platform for future-focused applications, u-blox continues to drive technology adoption by developing positioning hardware that is accessible for high-performance, mass-market applications.

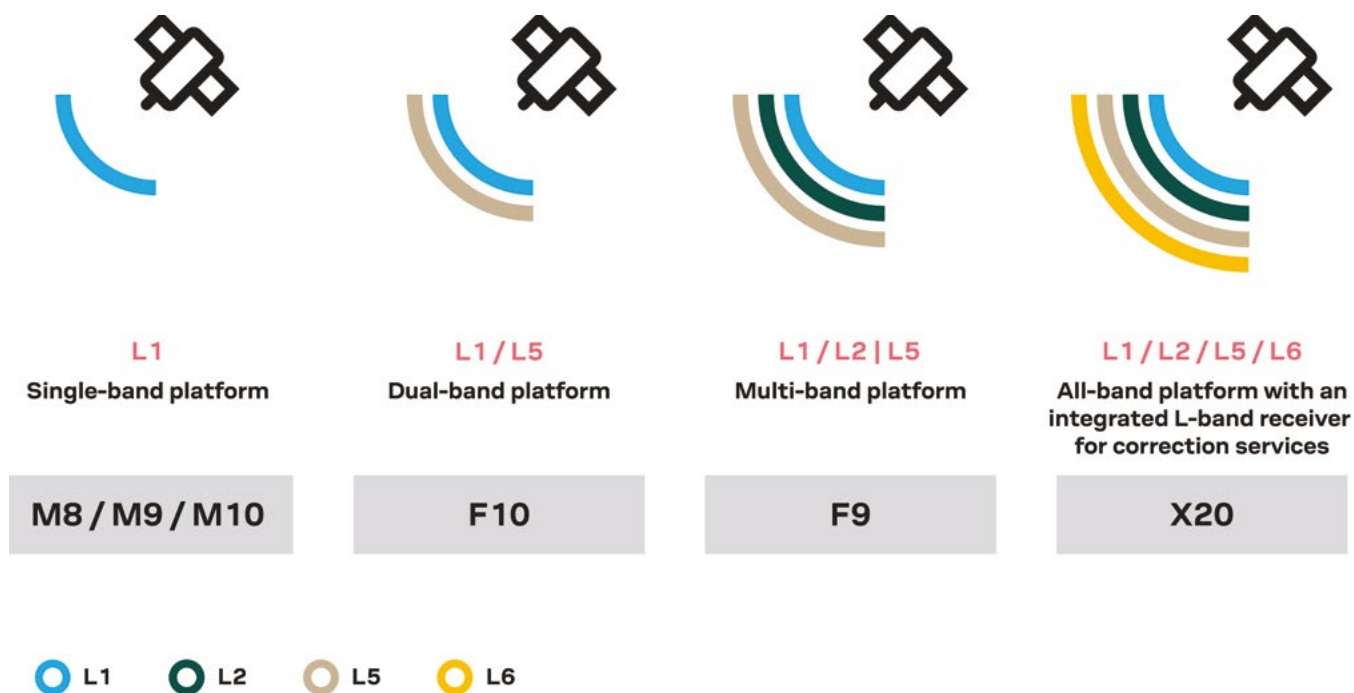
All-band GNSS: bringing the best available GNSS performance to new use cases

Since their public introduction in the 1980s, the performance of satellite-based position, navigation, and timing (PNT) applications has been driven by a strong market demand for improved accuracy and availability. This evolution led to the proliferation of satellite signals, both through the addition of new GNSS constellations and, more recently, the expansion of satellite signals across a growing set of frequency bands. Today, GPS/GNSS signals are broadcast on multiple frequencies in the L-band ranging from 1 to 2 GHz. These are commonly broken down into the L1, L2, L5, and L6/E6 bands.

The first generation of GNSS receivers for civilian use only had access to satellite signals broadcast in the L1 band, which limited their performance in terms of positioning accuracy and robustness. These limitations restricted their ability to support more advanced applications, especially in challenging environments.

As GNSS technology advanced, the introduction of multi-band receivers represented a significant leap forward. These devices, capable of tracking multiple frequency bands, dramatically enhanced performance, enabling more sophisticated use cases.

Today, the evolution of GNSS technology has culminated in the development of all-band GNSS receivers, which extends the reach of these high-performance positioning solutions to new markets and use cases. Behind this push is a new generation of powerful, compact, and cost-effective GNSS receivers capable of leveraging the full spectrum of GNSS signals transmitted by GNSS satellites and terrestrial infrastructure. This white paper explores the potential of all-band GNSS receivers to deliver high-precision positioning, navigation, and timing for a growing spectrum of industrial, automotive, and commercial applications.



Exploring business value beyond the reach of today's technology

GNSS/GPS technology has become ubiquitous in positioning, navigation, and timing applications across industrial, automotive, commercial, and consumer markets. Offering down to centimeter-level positioning accuracy and nanosecond-level timing accuracy anywhere on the planet, it delivers unmatched value to diverse applications.

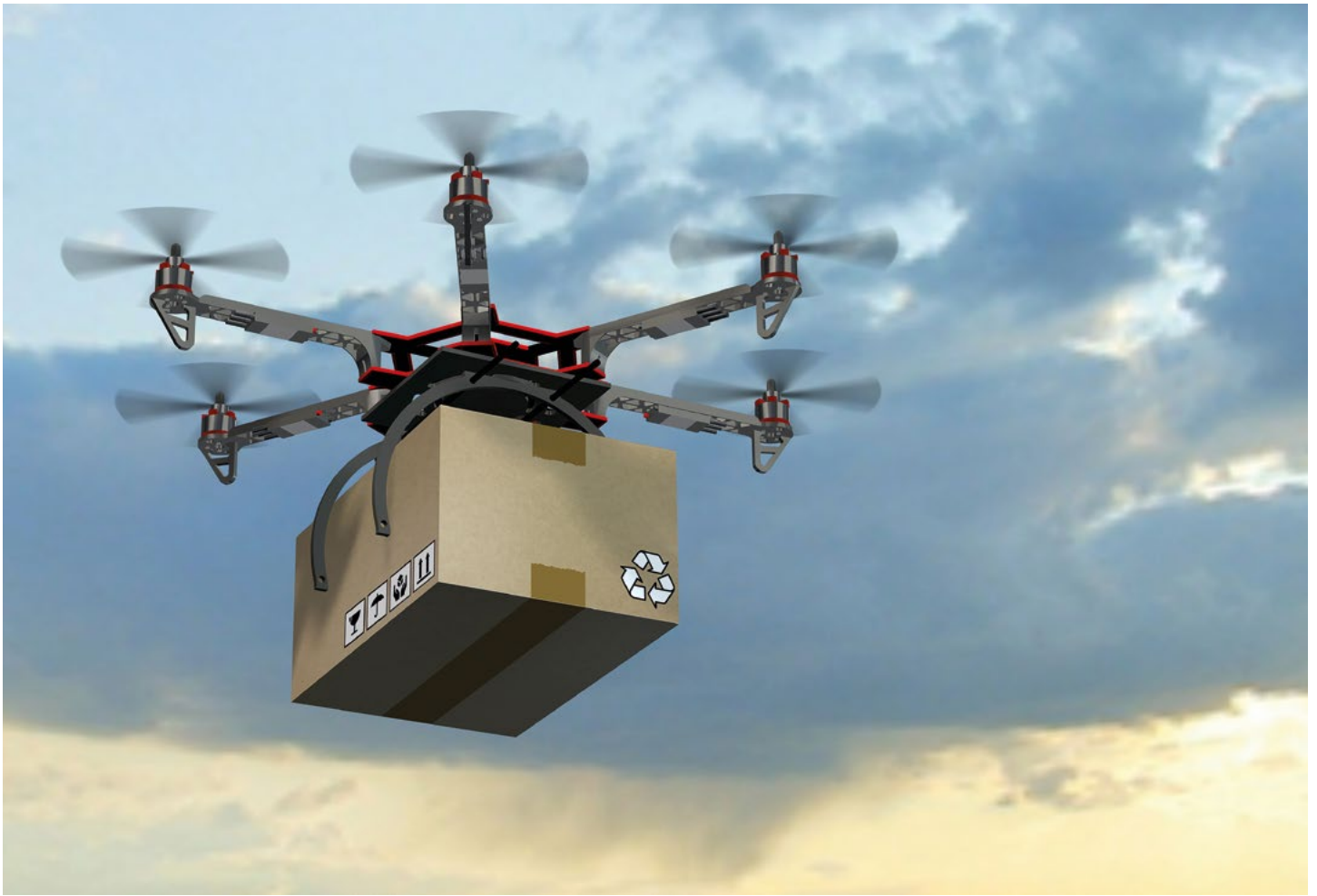
Exploiting the full spectrum of GPS/GNSS signals will unlock even greater business value for high-performance PNT applications currently relying on multi-band GNSS solutions. The use cases below demonstrate the potential benefits of all-band GNSS solutions, not only in terms of performance, but also in solution design, security, and cost of ownership.



Unmanned ground vehicles (UGVs):

Multi-band GNSS solutions	All-band GNSS solutions
<p>Unmanned ground vehicles operate in some of the most challenging signal environments, leveraging multi-band GNSS receivers and GNSS correction services to achieve decimeter-level positioning accuracy. Such high-precision positioning solutions typically comprise a multi-band GNSS receiver and a subscription to the locally relevant correction data stream, often delivered over cellular networks.</p>	<p>All-band GNSS receivers promise to increase the availability, robustness, and security of UGV positioning solutions by harnessing satellite signals emitted in all frequency bands. The ability of all-band GNSS receivers to track all signals, including global GNSS correction data, using a single unit further increases flexibility in solution design, production, certification, and global distribution.</p>
<p>Opportunities</p> <ul style="list-style-type: none">✓✓ Maximum availability by exploiting all available GNSS signals✓✓ Increased solution robustness and faster convergence✓✓ Globally valid correction service for high precision positioning✓✓ Enhanced resilience due to independence from vulnerable IP-based corrections✓✓ Globally applicable solution offering simplified production and logistics✓✓ Simple, affordable position solution packaged in a single unit	





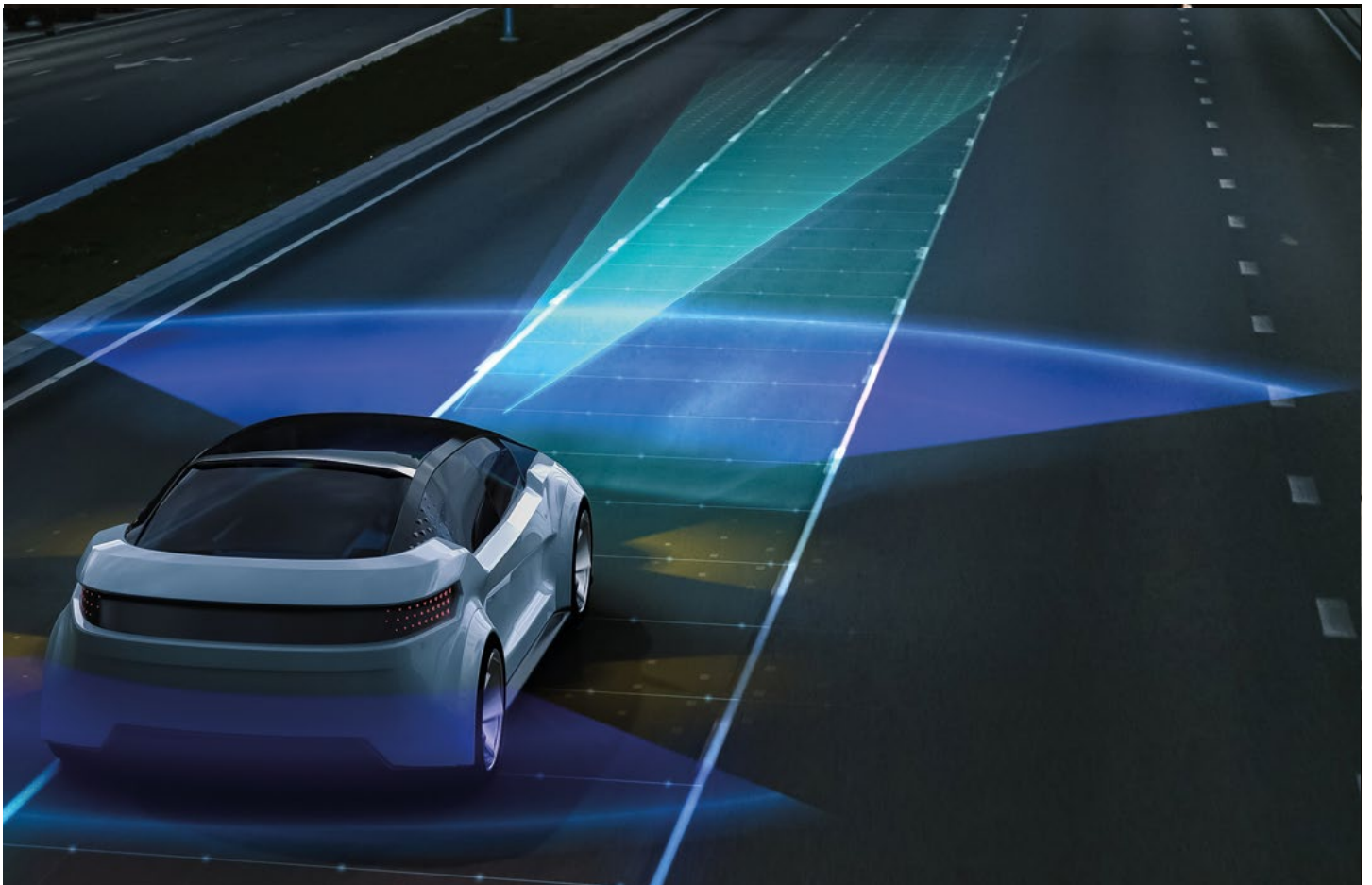
Unmanned aerial vehicles (UAVs):

Multi-band GNSS solutions	All-band GNSS solutions
<p>Unmanned aerial vehicles generally operate in open-sky signal environments, combining multi-band GNSS receivers with GNSS correction services to achieve decimeter-level positioning accuracy.</p>	<p>All-band GNSS receivers will benefit UAVs by bringing in more frequency bands and greater protection against intentional and unintentional RF interference. Access to a globally valid correction service, integrated into the all-in-one module, will radically simplify solution design, production, certification, and global product rollout.</p>
<p>Opportunities</p> <ul style="list-style-type: none"> ✓✓ Maximum availability by exploiting all available GNSS signals ✓✓ Increased solution robustness and faster convergence ✓✓ Globally valid correction service for high precision positioning ✓✓ Enhanced resilience due to independence from vulnerable IP-based corrections ✓✓ Globally applicable solution offering simplified production and logistics ✓✓ Simple, affordable position solution packaged in a single unit 	

Heavy machinery and precision farming:

Multi-band GNSS solutions	All-band GNSS solutions
<p>PNT solutions in construction and mining machinery, as well as precision farming vehicles, rely on multi-band high-precision GNSS receivers and IP-based GNSS correction data. Often used in remote regions with irregular cellular data reception, they may require locally generated GNSS reference data transmitted from a nearby base station via UHF to achieve the centimeter-level accuracy required by the application.</p>	<p>In addition to simplifying the design of positioning solutions used in heavy machinery and precision farming use cases, all-band GNSS solutions let users access new GNSS signals and services as they become available. These include GNSS correction data delivered via satellite, such as the Galileo high accuracy service (HAS), transmitted by Galileo satellites over the L6/E6 frequency band.</p>
<p>Opportunities</p> <ul style="list-style-type: none"> ✓✓ Maximum availability by exploiting all available GNSS signals ✓✓ Increased solution robustness and faster convergence ✓✓ Easy access to commercial and emerging free correction services, including HAS ✓✓ Enhanced security by exploiting all available GNSS signals ✓✓ Simple, affordable position solution packaged in a single unit 	





Automotive positioning systems:

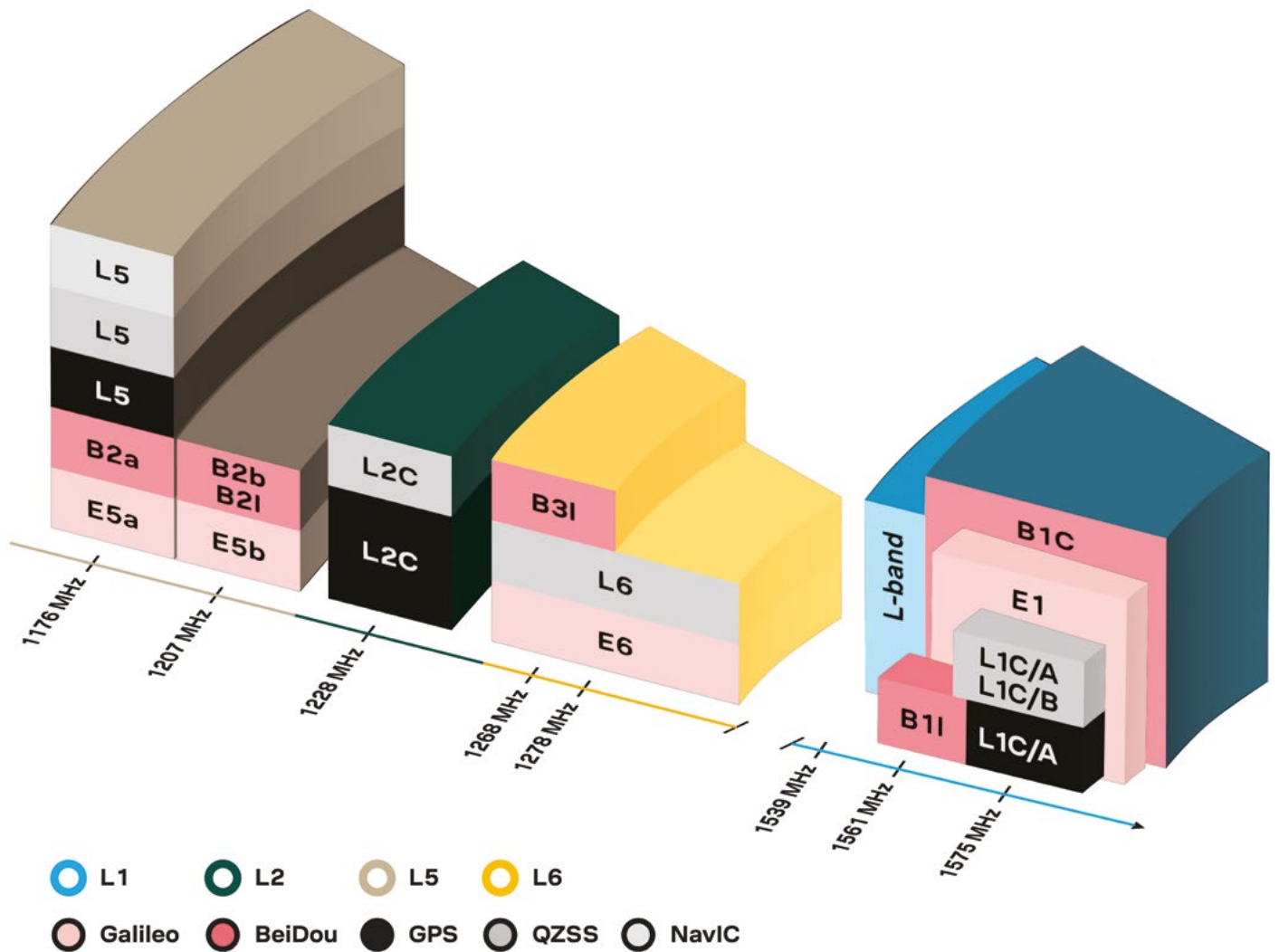
Multi-band GNSS solutions	All-band GNSS solutions
<p>GPS/GNSS solutions used in automotive navigation systems typically comprise multiple hardware components and subscriptions for geographically relevant GNSS correction services. Common challenges include poor service availability in remote areas with unreliable cellular coverage, managing correction data subscriptions when entering new geographical markets, high expectations regarding security, and costs that hinder mass market adoption.</p>	<p>By packaging all the components of the positioning solution into a single unit, all-band GNSS simplifies solution design. Exploiting all available satellite signals, including satellite-broadcast correction data, paves the way for GNSS correction services offering global high precision GNSS performance. Increased redundancies and access to encrypted GNSS signals provide the highest protection against jamming and spoofing.</p>
<p>Opportunities</p> <ul style="list-style-type: none"> ✓✓ Globally valid correction service for high precision GNSS ✓✓ Increased solution robustness and faster convergence ✓✓ Globally applicable solution offering simplified production and logistics ✓✓ Superior scalability of satellite broadcasting for high-volume applications ✓✓ Enhanced security by exploiting all available GNSS signals ✓✓ Simple, affordable position solution packaged in a single unit 	

Network infrastructure and time sync:

Multi-band GNSS solutions	All-band GNSS solutions
<p>Today's multi-band GNSS timing receivers provide time synchronization within five nanoseconds in typical macrocell environments. However, due to ongoing network densification, 5G networks are becoming increasingly reliant on street-level installations, creating new challenges for GNSS signal reception.</p>	<p>Modern all-band GNSS timing receivers address cell site challenges by leveraging a larger number of available signals and offering improved timing accuracy. This provides the necessary performance margins to enable reliable network synchronization, even in more challenging site locations. Complemented by the latest security features, they are ideal for critical infrastructure applications.</p>
<p>Opportunities</p> <ul style="list-style-type: none">✓✓ Globally applicable solution offering simplified production and logistics✓✓ Enhanced security by exploiting all available GNSS signals✓✓ Simple position solution packaged in a single unit	



Understanding the GNSS frequency bands behind today's PNT solutions



L1 band: 1559-1610 MHz

Most commonly referenced as centered around 1575.42 MHz, the GNSS L1 band encompasses signals from all global GNSS constellations, spanning from 1559 to 1591 MHz (including GLONASS, up to 1610 MHz). Since GPS was first developed, the GPS L1 C/A signal has been the primary signal for civil GNSS navigation and timing applications.

Today, all major global GNSS systems - GPS, Galileo, BeiDou, and GLONASS - broadcast navigation

signals in the L1 band, which is also used by satellite-based augmentation system (SBAS) and regional systems to enhance accuracy and integrity.

The L1 band continues to evolve as GNSS systems introduce new modernized signals, such as the GPS L1C signal. Representing a significant leap in signal design, the L1C signal, currently broadcast by six satellites, is expected to be fully operational with at least 24 satellites by the end of the decade.

Frequency Band	GPS	GLONASS	Galileo	BeiDou	QZSS	NavIC
L1/E1	<p>L1C/A: Standard Positioning Service (SPS)</p> <p>L1C: PNT Service, in development</p>	L1OF: Standard Precision Signal	<p>E1: Open Service (OS), Public Regulated Service (PRS), Search and Rescue (SAR), Open Service Navigation Message Authentication (OSNMA)</p>	B1C and B1I: Basic Navigation Services	<p>L1C/A, L1C/B, L1C: PNT Service, Signal Authentication Service</p> <p>L1S: Sub-meter Level Augmentation Service (SLAS), DC Report</p> <p>L1Sb: SBAS Transmission Service</p>	L1: Standard Positioning Service, in development

Table 1: Summary of the civil GNSS signals and their services broadcast in the L1 band.

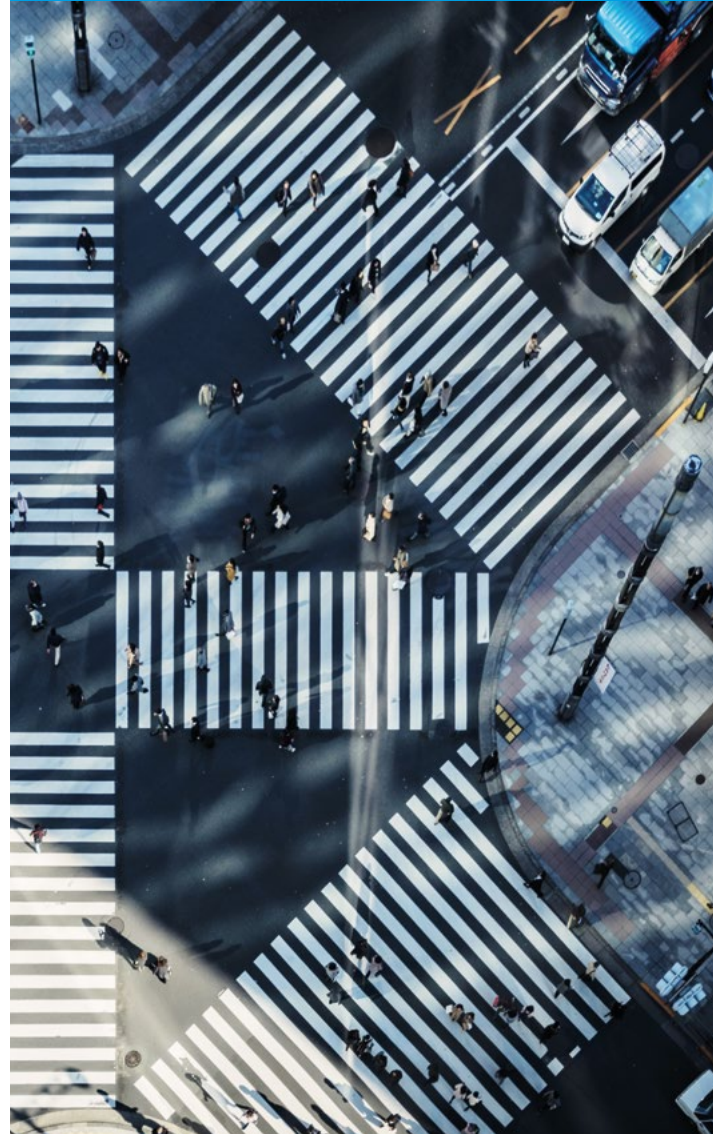
L2 band: 1215-1252 MHz

The L2 band, centered around 1227.60 MHz, is primarily known for its use by the GPS system but also accommodates signals from other GNSS systems, including GLONASS and QZSS. GPS L2 signals have been instrumental in improving the accuracy of GNSS applications through dual-frequency operation, which enables more precise ionospheric error correction and enhances signal penetration through clouds, trees, and urban obstacles.

Since its introduction, the GPS system has broadcast the L2 P(Y) code for military use in this band. Advanced civilian receivers have exploited this military signal using a codeless tracking method. In its modernization program, the U.S Space Force introduced the L2C signal as a second civilian GPS signal to meet commercial needs, rendering the codeless tracking of the military signal obsolete.

GLONASS transmits signals in the L2 frequency band at slightly higher frequencies, contributing to the need for an extended frequency range. The QZSS system, which enhances GNSS performance over Japan and the Asia-Oceania region, also broadcasts its L2C signal in the L2 band.

Together, these systems make the L2 band a critical component for advanced GNSS applications. The modernization of GPS, with the gradual deployment of the L2C signal, promises enhanced capabilities and robustness in the years to come.



Frequency Band	GPS	GLONASS	Galileo	BeiDou	QZSS
L2	L2C: Enhanced civilian service, P(Y) code: Precise Positioning Service	L2OF: Standard Precision Signal	-	-	L2C: PNT Service

Table 2: Summary of the GNSS signals and their services broadcast in the L2 band.

L5 band: 1164-1210 MHz

The GNSS L5 band, centered around 1176.45 MHz, represents one of the most advanced and robust frequency bands in use today. This band and its signals have quickly been adopted by GNSS users, including those in consumer electronics and low-power GNSS receivers requiring a moderate boost in accuracy and availability.

The introduction of the L5 band marks a significant step forward in GNSS technology, offering enhanced capabilities for critical applications that demand the highest levels of precision and reliability. The deployment of L5 signals across various GNSS systems is ongoing, with the goal of achieving full global coverage in the coming years.

The L5 band is specifically designated for safety-of-life applications, such as aviation, where high accuracy and reliability are paramount. The band encompasses signals from multiple GNSS systems, including GPS, Galileo, BeiDou, and the regional QZSS and NAVIC systems.

The GPS L5 signal, introduced as part of the GPS modernization efforts, is designed to provide superior accuracy and signal integrity, particularly in challenging environments. It operates alongside the Galileo E5a and E5b signals, as well as the BeiDou B2a and B2b signals, which enhance the GNSS infrastructure within this frequency range. Additionally, QZSS and NAVIC, which support GNSS performance in their respective Asia-Oceania regions, also transmit their L5 signals within this band.

Frequency Band	GPS	GLONASS	Galileo	BeiDou	QZSS	NavIC
L5/E5	L5: Open PNT service (pre-operational status)	-	E5a: Open Service (OS) E5b: Open Service (OS), Commercial Service (CS)	B2a and B2I: Basic Navigation Services B2b: Basic Navigation Services, Short Message Service (SMS), International Search and Rescue Services, and PPP services	L5: PNT Service, Signal Authentication Service L5S: Positioning Technology Verification Service	L5: Standard Positioning Service (SPS)

Table 3: Summary of the GNSS signals and their services broadcast in the L5 band.

L6/E6 band: 1260-1300 MHz

The latest frequency band to be added is the L6 band, centered around 1278.75 MHz. Increasingly recognized for its role in advanced GNSS applications, particularly those requiring high precision and specialized services, the L6 band encompasses signals from several GNSS systems, including Galileo, BeiDou, and QZSS.

Located within this band, the Galileo E6 signal is used to enable the system's high-accuracy services (HAS) and emerging encrypted services. BeiDou's B3I signal strengthens the broader GNSS ecosystem by providing an additional layer of accuracy and redundancy.

In the Asia-Oceania region, the L6 band's L6E signal enables augmentation services including centimeter accuracy service (CLAS), a regional PPP-RTK service over Japan's mainland, and

multi-GNSS advanced demonstration for original coordinate alignment (MADOCA), a regional precise point positioning (PPP) service that currently covers the Asia-Pacific region but could expand into a global PPP service.

The L6 band has rapidly emerged as an essential band for high-end GNSS applications that require advanced capabilities, such as enhanced precision and integrity. As these systems continue to evolve, the L6 band will play an increasingly significant role in advanced navigation applications, particularly in timing and high-precision domains, with expected adoption in automotive applications.

Frequency Band	GPS	GLONASS	Galileo	BeiDou	QZSS
L6/E6	-	-	E6: Galileo High Accuracy Service (HAS)	B3I: Basic Navigation Services	L6D: Centimeter Level Augmentation Service (CLAS) L6D and L6E: Multi-GNSS Advanced Orbit and Clock Augmentation - Precise Point Positioning (MADOCA-PPP) L6E: Signal Authentication Service

Table 4: Summary of the GNSS signals and their services broadcast in the L6/E6 band.

L-band: 1520-1559 MHz

The L-band provides seamless worldwide connectivity and is used to transmit high-accuracy services to GNSS receivers in industrial automation applications, precision agriculture, and maritime applications. It supports critical safety-focused applications with specialized

augmentation services, such as differential corrections and integrity information. As such, the L-band serves as a foundational spectrum for future GNSS innovations, enabling scalability and greater precision for advanced technologies like autonomous driving.



All-band GNSS enhances performance across key commercial metrics

Thanks to a confluence of technological developments, satellite-based positioning receivers capable of concurrently tracking all available GNSS signals are poised to bring their benefits to mass-market applications. By harnessing data from all frequencies broadcast by orbiting satellites, these compact, easy-to-integrate all-band GNSS modules

match the precision and accuracy provided by today's premium positioning and timing solutions. At the same time, they enhance performance across key commercial metrics by streamlining production, simplifying logistics, drastically reducing total cost of ownership, and adding tangible value in the field.



Streamlined production

Because all positioning functionalities can be housed in a single unit featuring a built-in L-band receiver, this setup simplifies access to high-performance positioning, leveraging GNSS correction services broadcast by satellite or terrestrial network infrastructure.



Access to new services

As the GNSS ecosystem continues to evolve and new signals and services emerge, the ability to track signals on all relevant frequency bands future-proofs devices by ensuring they can be upgraded to leverage the latest services – such as Galileo's High Accuracy Service (HAS) and CLAS in Japan – via a firmware update.



Simplified logistics

A single device enables global deployments by delivering services across geographically fragmented markets, whether through satellite constellation coverage or GNSS correction service subscriptions.



Expanded geographical coverage of high precision positioning (HPG)

Leveraging all available satellite signals makes it possible to remove local atmospheric corrections without sacrificing accuracy. This paves the way for a high precision positioning solution with global coverage and expands geographical market reach and service availability, particularly in regions previously underserved by existing technologies.



Enhanced availability

While accuracy and precision remain comparable to those achieved with multi-band receivers, all-band GNSS receivers increase PNT service availability. Tracking more bands translates to more tracked signals, providing the highest precision even in challenging signal environments. Additional redundancies further protect against signal outages and downtime.



Increased security and integrity

Tracking signals from all GNSS constellations on all bands offers redundancies that can be exploited to increase security and integrity of the PNT service. Combined with modern security-focused services, such as Galileo OSNMA, all-band receivers are well-equipped to protect users against various jamming and spoofing threats.



Reduced total cost of ownership

The reduction of components required to implement globally applicable high-precision PNT solutions translates to a considerably lower total cost of ownership.

How next-gen solutions cost-effectively harness the full potential of GNSS signals

As highlighted in the introduction, the performance benefits of all-band GNSS receivers have, to date, only been within reach of high-value commercial applications capable of absorbing their high cost of ownership. Today, rising performance expectations for low- to medium-value applications are dovetailing with increasing cost pressure on high-value applications, leading to growing market demand for more cost-effective all-band GNSS solutions.

For the first time, a new generation of powerful, compact all-band GNSS receivers is on the horizon at a price point that makes them accessible for all high-performance GNSS applications. Key enablers include the continuous miniaturization of the receiver silicon and the integration of the L-band receiver into the GNSS module.

At the same time, GNSS antenna manufacturers are releasing products tuned to receive all relevant GNSS frequency bands, including those for GNSS correction data broadcast via satellite and terrestrial cellular data networks.



Elevate your PNT performance with u-blox



For over 25 years, u-blox has been driving the adoption of GNSS technology by pushing innovation to combine market-leading performance with the latest functionality, all at a competitive price point.

In 2018, u-blox set the benchmark for mass-market high precision positioning, becoming the leading provider of the technology with the u-blox F9 multi-band GNSS platform¹, including ANN-MB² and ANN-MB1³ antenna solutions.

Today, u-blox is again redefining expectations with its game-changing u-blox X20⁴ all-band high-precision positioning platform and the ANN-MB2⁵ all-band antenna, designed to speed up the commercialization of high-performance positioning solutions.

Bundling L1, L2, L5, L6/E6, and L-band GNSS signal reception and world-leading RTK, PPP-RTK, and PPP support for global centimeter-level accuracy into one device, it brings affordable and easy-to-integrate position, navigation, and timing to all users worldwide.

Moreover, exploiting all available GNSS signals, including new message authentication services like Galileo OSNMA, improves the ability to detect and counteract jamming and spoofing, boosting security for mission-critical applications.

To learn more about the u-blox X20 all-band GNSS platform, reach out to your nearest sales representative, fill out a project information form, or join us at our booth at an upcoming trade fair.

1. www.u-blox.com/en/technologies/high-precision-positioning

2. www.u-blox.com/en/product/ann-mb-series

3. www.u-blox.com/en/product/ann-mb1-antenna

4. www.u-blox.com/en/x20

5. www.u-blox.com/en/product/ann-mb2-antenna

About the authors

Mårten Ström, Director of Product Management for Industrial Navigation & Robotics, u-blox.

Mårten Ström has been an integral member of the Product Strategy team at u-blox Positioning since January 2015. His responsibilities encompass the oversight of u-blox's high-precision GNSS (Global Navigation Satellite System) offerings, as well as steering the company's endeavors in the Industrial Navigation and Robotics sectors.

Mr Ström has a Master of Science in Applied Mathematics, from the University of Åbo Akademi in Turku, Finland. His expertise in this field underpins his strategic role at u-blox, where he continues to contribute significantly to the company's innovative trajectory.

About u-blox

u-blox (SIX:UBXN) is a global provider of leading positioning and wireless communication technologies and services for the automotive, industrial, and consumer markets. Their solutions let people, vehicles, and machines determine their precise position and communicate wirelessly over cellular and short range networks. With a broad portfolio of chips, modules, and a growing

ecosystem of product supporting data services, u-blox is uniquely positioned to empower its customers to develop innovative solutions for the Internet of Things, quickly and cost effectively. With headquarters in Thalwil, Switzerland, the company is globally present with offices in Europe, Asia, and the USA.

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