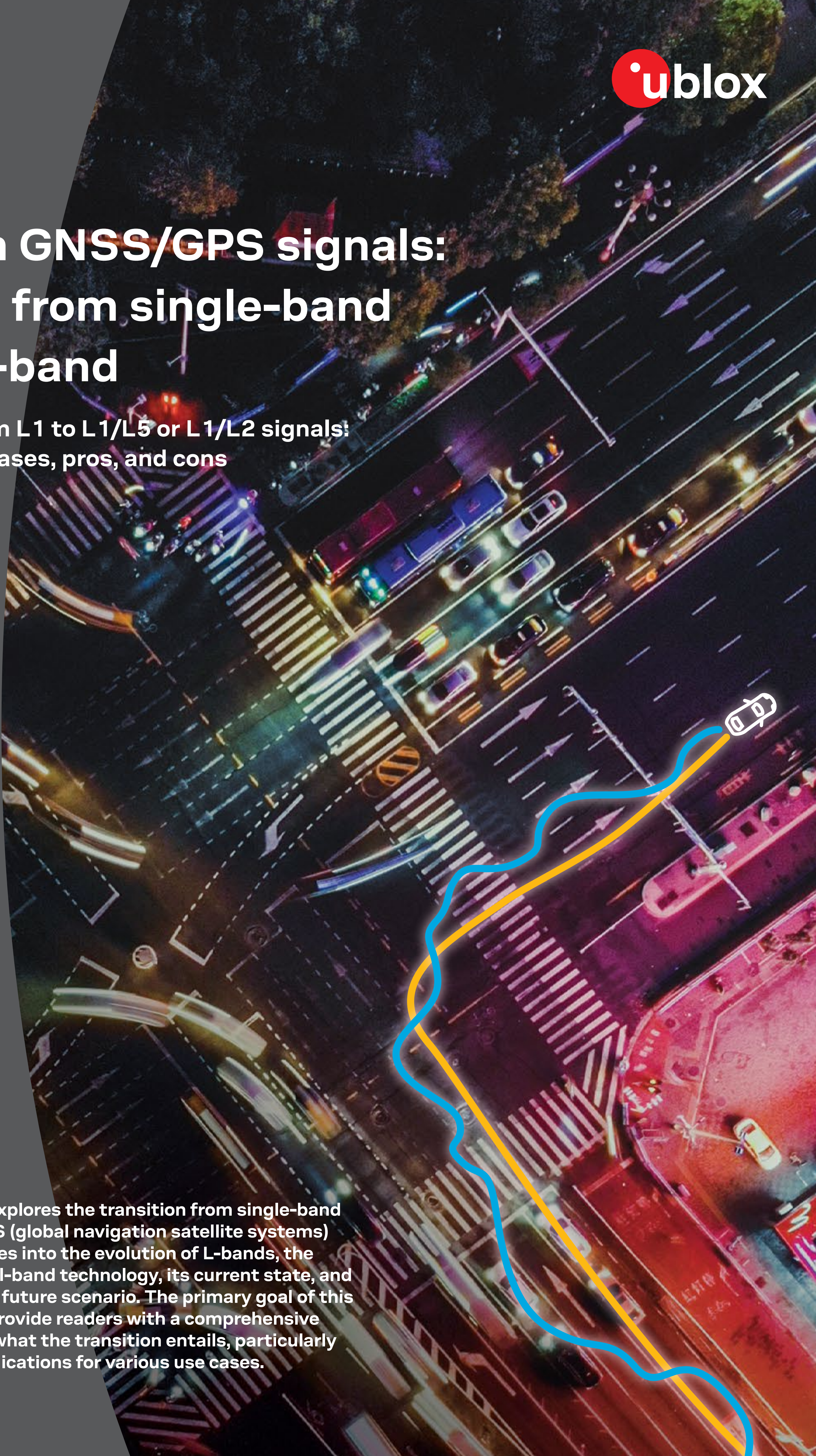
WHITE PAPER

Modern GNSS/GPS signals: moving from single-band to dual-band

Migration from L1 to L1/L5 or L1/L2 signals: context, use cases, pros, and cons



Abstract

This white paper explores the transition from single-band to dual-band GNSS (global navigation satellite systems) technology. It delves into the evolution of L-bands, the advantages of dual-band technology, its current state, and the most probable future scenario. The primary goal of this white paper is to provide readers with a comprehensive understanding of what the transition entails, particularly in terms of its implications for various use cases.

White paper: Modern GNSS/GPS signals: moving from single-band to dual-band
Author: Bernd Heidtmann, Product Manager, Product Strategy for Standard
Precision GNSS, u-blox AG

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Background / Executive summary

Satellite navigation relies on receiving signals from satellites through GNSS/GPS signals broadcast in the L-band, typically within the 1-2 GHz frequency range. The L-band comprises two main sections: the lower band (from 1164 MHz to 1300 MHz) and the upper band (from 1559 MHz to 1610 MHz). Most satellite constellations transmit their data using these two band sections.

Since satellite localization technology became available for public use, the L1 frequency band in the upper L-band has been the band most devices rely on. However, this landscape is evolving at a rapid pace. Significant advancements in GNSS receiver technology are making multi-band receivers increasingly attractive and viable options for a growing number of applications.

While one might think multiple bands are a better choice for device requirements, this is not always true. In fact, the choice between a single-band or a dual-band GNSS receiver depends on the specific purpose of the positioning application.

This white paper aims to provide a comprehensive guide to positioning technology. To achieve this, it compares the differences between single-band and dual-band GNSS receivers and offers a detailed analysis of the best band combinations for specific use cases. As a result, readers will gain a thorough understanding, enabling them to make informed decisions about what bands favor their GNSS applications.

Introduction

The world of communication and positioning technologies is vast. Each available technology for this purpose serves specific use cases, depending on whether they are intended for indoor or outdoor use. In outdoor scenarios, the level of environmental congestion, whether a device operates in an open field or the heart of a city, becomes particularly relevant. The following table guides you through the accuracy of various positioning technology options and the environments in which they operate.

Positioning Technology	Position accuracy	Indoor	Campus	Urban	Rural
Cellular	< 300 m	●	●	●	●
LoRa	< 50 m		●	●	
Wi-Fi	< 5 m	●	●		
Bluetooth RSSI*	< 5 m	●	●		
Bluetooth AOA**	< 1 m	●	●		
UWB	< 1 m	●	●		
GNSS/GPS	< 1 m		●	●	●

* RSSI (Received signal strength indicator)
** AOA (Angle-of-Arrival)

Figure 1. Positioning technology vs. environment

As per the table, GNSS/GPS location technology stands out as one of the few options for precise outdoor tracking of people, assets, or vehicles. In terms of precision, GNSS outperforms the other alternatives. Another distinguishing feature is its worldwide availability. Users can access multiple satellite constellations through GNSS, providing near-100% availability for tracking with a GNSS receiver. Additionally, GNSS infrastructure (comprising satellites, ground control stations, and ground monitoring stations) is provided free of charge, offering a distinct advantage not available with other technologies.

GNSS technology relies on precise measurement of the travel time of radio waves emitted by GNSS satellites. The precision of these measurements depends on the characteristics of both the transmitter and receiver, as well as the path the signal follows.

Speaking of which, the atmosphere itself can introduce errors. Factors like changes in the ionosphere and troposphere can lead to errors that require correction.

Source of error	Expected impact on position accuracy
Ionosphere	5 m
Arrival of signal C/A	3 m
Ephemeris	2.5 m
Satellite clock error	2 m
Multipath	1 m
GNSS/GPS	1 m
Troposphere	0.5 m

Figure 2. GNSS error sources

Environmental factors can also introduce errors. Satellite signals encounter challenges in urban areas due to multiple obstacles like buildings, tunnels, or trees. Multipath interference occurs when a transmitted signal takes multiple paths to reach the receiver. This happens when the environment reflects, diffracts, or scatters satellite signals from space to the receiver, resulting in multiple versions of the same signal superimposed at different times and phases. This phenomenon can lead to delays and errors in the positioning system.

Over the past thirty years, industries such as automotive, agriculture, construction, and mining have relied on GNSS positioning applications for precise orientation and positioning. Knowing the position of an entity is pivotal not only for location but also for vehicle navigation, tracking, and other sensor data. For instance, providing real-time traffic congestion information is fundamental to helping drivers avoid delays.

These applications rely on technology that has evolved rapidly. GNSS receiver technology is progressing toward multi-band receivers with broad acceptance within the mentioned industries. The following sections thus delve into how this technology has evolved, the features provided by each signal, the benefits of dual-band systems, and their impact on various use cases.

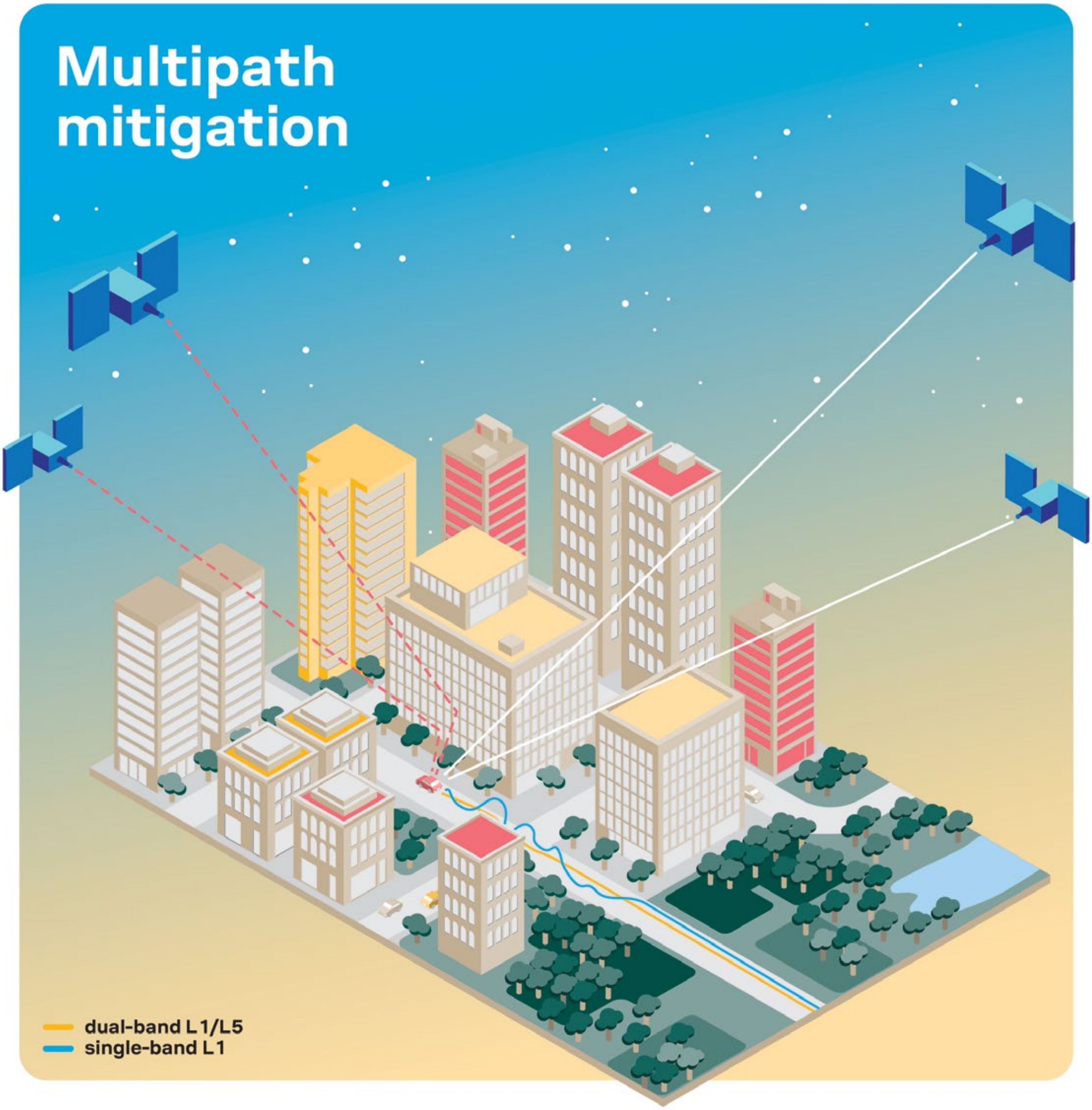

Figure 3. Larger GNSS position errors in an urban multipath environment

Satellite signal bands evolution

Since 1983, when President Ronald Reagan allowed the commercialization of GPS technology, civilians have been using the L1 band. It is the oldest GPS signal, and most navigation applications still use it today.

Although the GPS satellite constellation was the first to use the 1574 MHz band, other satellite systems have adopted similar frequencies over time to ensure interoperability. For instance, China's third generation BeiDou navigation satellite system, BDS-III, also employs the L1 frequency for transmitting navigation signals.

L2 was the second frequency band accessible to civilians in satellite navigation systems. It operates at a lower-frequency signal with the capacity to penetrate through clouds, trees, or urban obstacles like buildings. Users employ it simultaneously with L1 frequencies since the infrastructure is entirely in place.

L5 is the latest GNSS signal available for civilian use. At present, the U.S. Air Force, the National Space Defense Center (which oversees the GPS program), and the European Space Agency are in the process of completing the ground segment to make it fully operational.

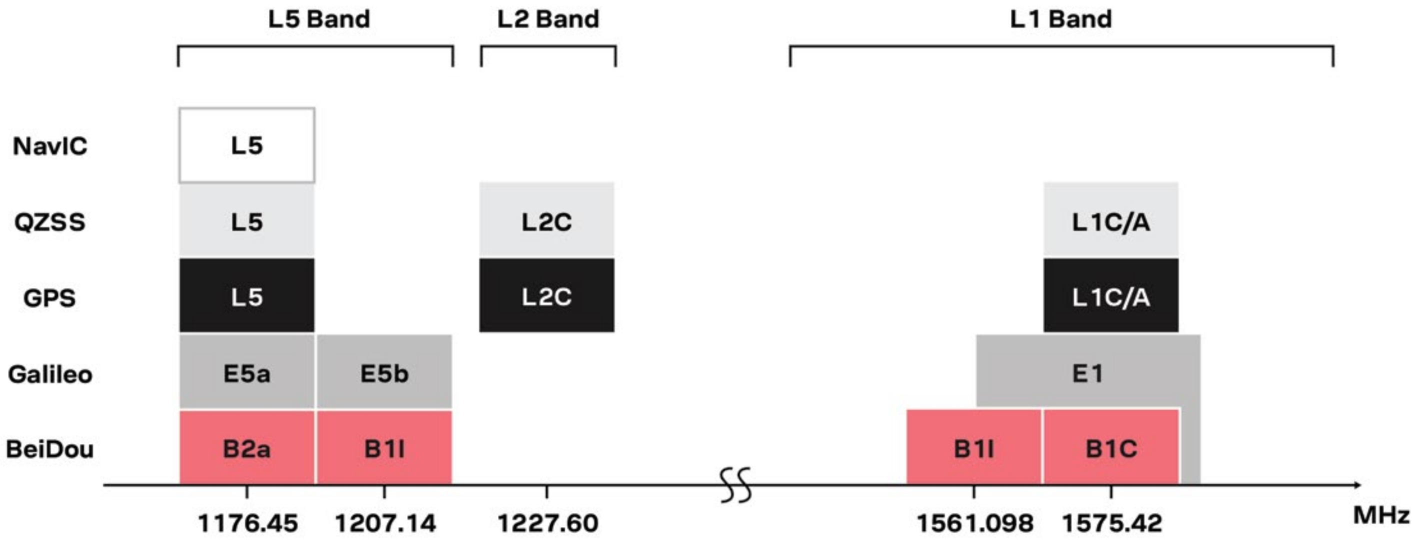

Figure 4. L-band constellations and frequencies

As of 2023, the L1 band offers global coverage. The GPS, Galileo, and BeiDou satellite systems use it for transmission. Depending on the satellite generation and constellation, satellites can transmit on the L1 band alone or on a combination of L1, L2, and L5 bands.

Each satellite constellation has a nomenclature for the frequencies it uses. For simplicity, we will refer to them as L1, L2, and L5 going forward. Hence, bear in mind this extends beyond GPS definitions.

So far, as the figure above shows, most major satellite constellations offer dual-band. Still, several countries aiming for an independent positioning system are currently developing satellite technologies to meet connectivity and communication demands.

Signal characteristics and value for users

The table below provides a summary of the key characteristics of the L-band frequencies, including their availability, accuracy, and pros and cons.

GNSS band	Fast signal acquisition	Signal availability	Interference immunity	Position accuracy	Multipath resistance	Weak signal tracking
L1	●●●	●●●	●●	●	●●	●●
L2	●	●●	●	●●●	●●	●●
L5	●	●	●●●	●●●	●●●	●●●

Figure 5. Civil L-band characteristics

Civilian L1 signals typically comprise two main components: the Coarse/Acquisition Code (C/A) and the navigation message.

Coarse/acquisition code (C/A code). A digital signal spreads GPS signals over a wider frequency band, making the signal more resistant to interference. This is the signal most mass-market applications use. C/A code is only available on L1.

Navigation message. It carries satellite information, including ephemeris, ionosphere modeling coefficients, clock bias parameters (satellite clock deviation), almanac, health status, and further data.

The L1 band remains the primary frequency for civilian GNSS applications. Its widespread compatibility with all major GNSS constellations and fast signal acquisition are outstanding.

Over time, L2 combined with L1 has gained popularity for precise positioning, while L5's improved multipath and interference resistance make it a promising option for urban applications.

New frequencies are currently under deployment, such as L6. As of January 2023, Galileo is implementing the High Accuracy Service (HAS). It is the first service that, through the E6-B signal, provides free-of-charge precise point positioning (PPP) corrections worldwide.

Dual-band benefits

Using multiple satellite bands and constellations simultaneously improves the quality of the output of the GNSS receiver. The following are some of its benefits.

Higher signal availability. L5 signals transmit at a lower frequency, which implies a better range and, as a result, they provide improved penetration. For dual-band receivers operating on this band, this capability translates into higher signal availability in areas with obstructions, such as buildings or trees, which either attenuate or reflect the signals.

Higher position accuracy. As mentioned earlier, atmospheric conditions affect signals traveling through the atmosphere, causing signal delays. However, the GNSS receiver can compute the position more accurately when accessing more information. Receivers with access to signals from two or three different frequency bands, utilizing advanced algorithms to compute this information, can correct these atmospheric delays.

Signal security improvement. The system's resilience and availability increase by mitigating interference effects such as jamming or spoofing attacks. The receiver can switch to the other frequency band in case one is compromised by such attacks.

Fast signal acquisition. When switching on a GNSS receiver, the L1 band has an advantage over the other bands: a shorter time duration to compute first position information (TTFF = time to first fix). This is a crucial indicator to save power and increase the performance of devices using a GNSS receiver. Acquiring signals in the L2 or L5 band typically takes much longer than in the L1 band.

For the above reasons, industrial-grade dual-band GNSS receivers provide an L1/L2 or L1/L5 band combination. As we will later explore, both options offer advantages when considering specific use cases.

L1/L5 band vs L1-only

Besides the general improvements in signal availability, position accuracy, and signal security, L5 holds an advantage over L1 when considering **weak signals**, which occur when foliage in the forest or a car window attenuates the signal.

Suppose a device's antenna lacks sufficient gain. In this scenario, the L5 band can be instrumental in maintaining functionality even under weak signal conditions. This helps ensure continued positioning availability and accuracy in challenging environments, surpassing what a receiver relying solely on the L1 band could achieve. The algorithms employed for position calculations are differentiators in the quality of products available in the market.

Tests comparing L1-only against L1/L5 receivers in urban areas have demonstrated that L1/L5 receivers provide better accuracy but only in the presence of **multipath signals**. This differs in open spaces, where both L1 and L1/L5 receivers show similar accuracy results.

Figure 6. Car drive test in an urban environment comparing L1 vs. L1/L5 band GNSS

Despite the mentioned benefits of L1/L5 dual-band receivers, we can point out two main disadvantages: increased power consumption and the current operational status of the L5 signal. L1/L5 dual-band receivers consume more power than single-band receivers, which could pose challenges for battery-powered devices. Additionally, it is important to note that, as of today, L5 is not fully operational on GPS and Galileo. Given its operational status, users must carefully consider how to design products based on the L5 band.

L5 signal operational status	2023	2024	2025
GPS	Unhealthy	IOC	FOC
Galileo	IOC	FOC	FOC
BeiDou	FOC	FOC	FOC

Unhealthy   IOC: Initial operational capability   FOC: Full operational capability

Figure 7. Operational status of L5 band constellations as of October 2023

L1/L2 vs L1/L5

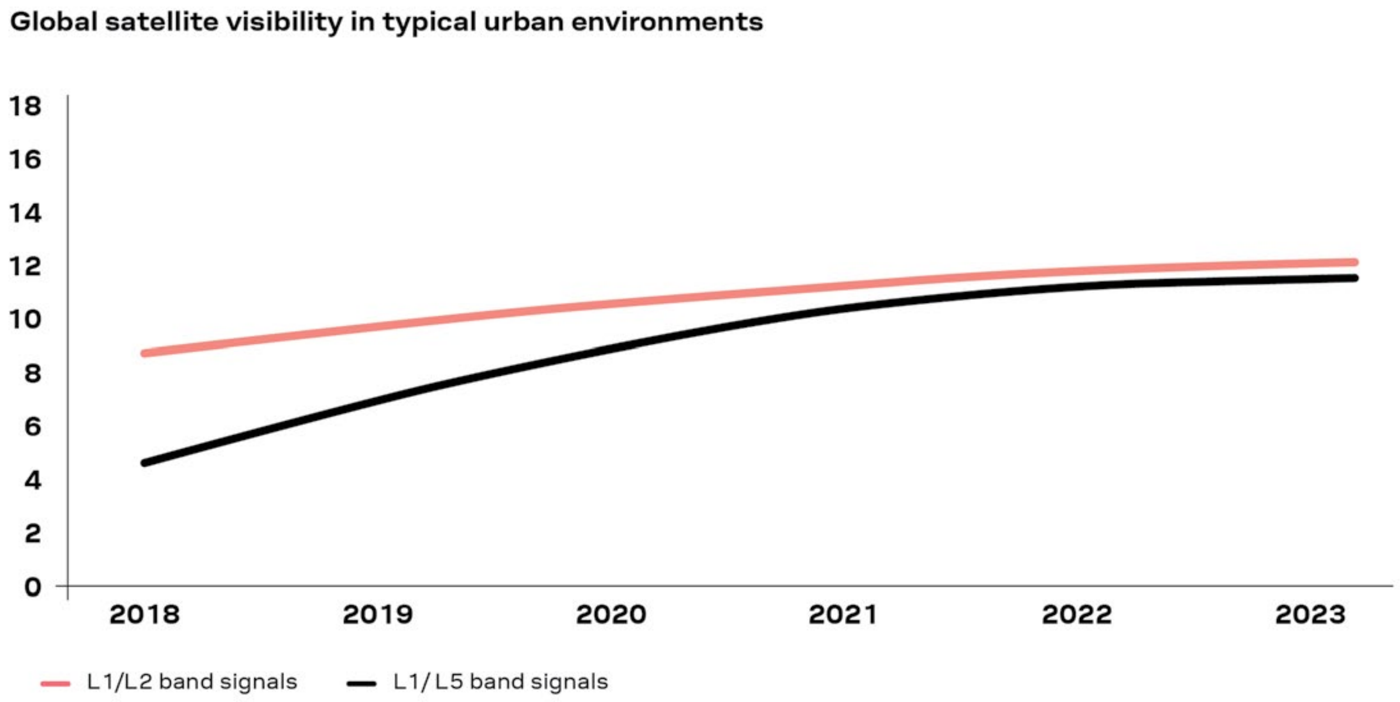

Figure 8. GNSS visibility over time

Through the lens of test results, both multiband solutions can enhance position accuracy and reliability compared to L1 setups.

Unlike non-RTK systems, which can operate with fewer visible satellites, RTK GPS systems need more satellite visibility. Therefore, L1/L2 band products have proven themselves in high-precision applications supported by RTK (Real-time kinematics) to achieve cm-level position accuracy.

L1/L5 systems offer distinct advantages compared to an L1/L2 design, particularly in terms of multipath mitigation and performance in environments with weak signals.

Many systems have been verified to perform exceptionally well when using L1/L2 band GNSS receivers. With the full operability of BeiDou, Galileo, and GPS in the L5 band, however, we can expect a shift toward the use of L1/L5 in the immediate future.

Key differentiators	L5	L2
Better multipath mitigation	●	
Higher signal availability		●
Better weak signal handling	●	

Figure 9. GNSS L5 and L2 band key differentiators

Selecting the appropriate frequency bands for every application

The tale is more complex than simply stating that multiband receivers outperform single-band receivers. The choice between the two strongly depends on specific use cases and their respective requirements. So, let's explore which solution is more suitable for each application.

Asset tracker. Asset trackers are low-power, battery-powered devices that operate for extended periods without battery replacement or recharging. Since dual-band receivers consume more power than single-band receivers, and GNSS typically powers down between two location requests, these devices benefit from single-band receivers. Asset trackers usually require a position accuracy within a 10 m range, a requirement that an L1 band tracker can easily meet.

Wearables. Like asset trackers, wearables are low-power devices, although they can be recharged more frequently. It's also important to consider whether the device will be used in an urban or open environment. Additionally, wearable users have certain expectations regarding the accuracy of reported positions and tracking distance. Considering these factors, the L1 band is suitable for low-power, cost-effective positioning solutions for wearables, especially for simple applications like sports watches or animal trackers with certain accuracy.

More complex applications, such as smartphones that allow users to access mobility services or require PPP information (for instance, avoiding being on the wrong side of a street) would be better suited to an L1/L5 device. This choice applies to both urban and rural areas.

Vehicle tracker. Most vehicle tracking applications require sub-10-meter position accuracy, which an L1-only GNSS can serve well. More advanced applications, such as crash recorders that demand trustworthiness and high accuracy, should rely on an L1/L5 dual-band receiver.

Commercial UAVs. The choice between a single or dual-band drone receiver depends on the specific objectives of the use case. Single-band receivers are an excellent choice for consumer devices. On the contrary, dual-band receivers are essential for real-time PPP applications that demand high accuracy, like drone light shows. These receivers are also crucial for surveying applications, particularly when photogrammetry is involved. In such scenarios, L1/L2 receivers are renowned for their performance. Real-time precision ensures accurate data capture on-site, while post-processing enhances the final model by improving the dataset.

For fast and accurate standstill heading, a crucial characteristic for drones, dual-band receivers outperform single-band receivers.

Ground robotics. L1/L5 and L1/L2 are suitable options for high-precision positioning devices in various applications, including autonomous agricultural machinery, surveying, and construction equipment. The choice of receiver depends on the specific accuracy requirements of each piece of equipment and use case, but L1/L2 offers some advantages over L1/L5.

Suppose the equipment relies on real-time kinematic (RTK) technology. In that case, L1/L2 receivers provide greater accuracy than L1/L5 receivers because L2 has broader global coverage, whereas L5 GPS is still in the pre-operational phase. Another advantage is that L1/L2 receivers typically perform exceptionally well when integrated into multi-purpose platforms.

Heavy machine control. This segment initially deployed L1/L2 GNSS receivers with satisfactory results. Since the equipment lifecycle is longer than in other segments, the transition to L1/L5 systems will depend on the user's knowledge, experience, and early experimentation with L1/L5 equipment.

Precision timing. Before the 5G rollout, network timing was synchronized using only L1-band receivers. But with the advent of 5G services demanding higher time accuracy, devices required a second GNSS band. On top of this, factors such as GNSS signal jamming, ionospheric delay, and multipath interference affect the reliability and accuracy of timing data. Due to the increased demand for precision, the L1/L2 band combination has recently been employed to provide even more precise timing information.

Devices that combine the L1 and L5 bands can also mitigate timing challenges. L1/L5 receivers can achieve timing accuracy within 5 ns, a quarter of what a single-band receiver can provide. With GPS, Galileo, and BeiDou GNSS constellations now broadcasting L5 signals, a receiver designed to access these three constellations could potentially operate worldwide.

Automated driving cars. In automated driving, various levels of autonomy and specific scenarios entail different requirements. Automated driving applications encompass a range of scenarios and conditions that change depending on the level of autonomy. For example, a Level 2 advanced driver assistance system (ADAS) solution focuses on highway driving, while a Level 2+ extends the operational design domain (ODD) into urban environments. Level 3 ADAS solutions primarily focus on providing high integrity on highways. Finally, Level 4 and Level 5 solutions demand high integrity in all types of environments.

L1/L5 and L1/L2 receivers can achieve these diverse aims. Yet, L1/L5 offers greater resilience to multipath interference, resulting in improved reliability and navigation robustness, especially in dense urban environments. Moreover, L1/L5 is preferred when extending autonomous driving features from a highway environment (under open skies and light urban conditions) to cities located in deep canyons.

Use case	L1	L1/L5	L1/L2
Asset tracker	●		
Wearable	●	●	
Vehicle tracker	●	●	
Commercial UAV	●	●	
Ground robotics		●	●
Heavy machine control		●	●
Precision timing		●	●
Automated driving cars		●	●

Figure 10. Preferred GNSS bands used by application

Simplified integration with consistent product form factor across various band options

u-blox offers a wide range of GNSS products and services serving consumer, industrial, and automotive markets.

Based on u-blox GNSS chips, diverse module form factors are available for various use cases. Some form factors like NEO are widely recognized for L1-only in several markets but are also available in different versions supporting other band options. This allows users to easily migrate from their existing design to dual-band solutions.

	Product	L1	L1/L2	L1/L5
	Chip	●	●	●
	ZOE/MIA module	●		
	MAX module	●		
	NEO module	●	●	●
	ZED module		●	●

Figure 11. u-blox's solutions depending on frequencies

In a nutshell

Our single-band to multi-band journey is about to end. We explored the L-bands' characteristics, development, and status in the preceding lines. Additionally, we discussed the main benefits of dual-band receivers and compared dual-band versus single-band and dual-band receivers.

Going from single-band to multi-band technology will increase position accuracy and resilience to interference. It is a trend permeating all markets, especially consumer markets. We can expect most applications to follow this path in the coming years.

Choosing between L1/L2 or L1/L5 requires a more careful analysis of the situation. Today, L1/L2 receivers incorporating Galileo E5b reception, such as ublox's F9 products, provide access to a higher number of signals than L1/L5 band GNSS products. This is paramount for RTK receivers. However, with the operational launch of GPS L5, there will be an increase in the availability of GPS L5 signals. Since L5 provides a protected band and a signal with improved characteristics for reducing multipath effects (considering GPS), a transition to L1/L5 receivers seems to be a logical next step.

We discussed the most representative applications, always paying attention to present use but also considering future migrations. Currently, L1-band receivers fit many applications well, especially when low-power consumption is a critical requirement. However, if position accuracy in a multipath environment is crucial, where signal security and/or cm-level position accuracy is essential, dual-band GNSS receivers are a better option. For cases such as precision timing, commercial UAVs, and heavy machine control, L1/L2 has shown to be a reliable solution so far. Yet, a migrating tendency toward L1/L5 is looming on the horizon.

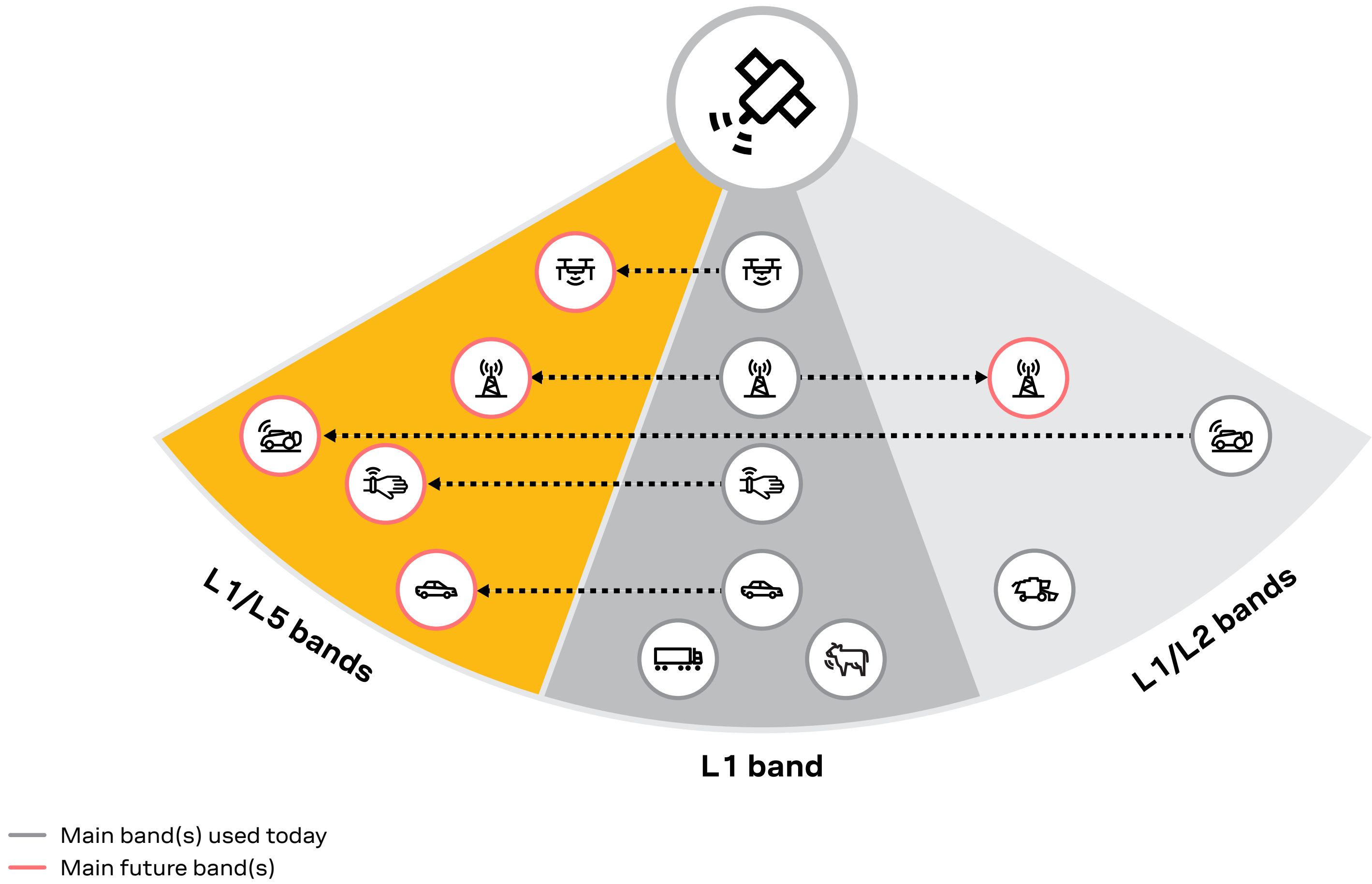

Figure 12. Use cases that will migrate to L1/L5

About the authors

Bernd Heidtmann, Product Manager, Product Strategy for Standard Precision GNSS, u-blox.

Bernd Heidtmann is Product Manager for the u-blox M10/F10 technology platform and module series. He is also a member of the Product Strategy Team within the Product Center Positioning at u-blox. Prior to joining u-blox, Bernd served as the Product Manager for RF products at Huber + Suhner. Before that, he worked in various roles in the Mobile Radio Base-Stations business at Siemens/Nokia.

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.

u-blox AG
Zuercherstrasse 68
8800 Thalwil
Switzerland

www.u-blox.com