The Definitive UWB Primer

Ultra-wideband technology is more amazing than you thought.

While the term "ultra-wideband" (UWB) has been increasingly popping up in trade journals and news articles, it seems as if people are still a little fuzzy on what exactly it means. The Ultra Wide Band Alliance (UWBA), a non-profit organization dedicated to speaking on behalf of UWB technology manufacturers, implementers, and users, decided to create this primer to better explain what UWB can do, how it does it, and its growing importance in the global technology ecosystem.

A Short History of UWB

All radio-based technologies like to trace their lineage back to Gugliemo Marconi, but UWB can legitimately lay claim to that distinction as Marconi's spark gap transceiver from 1896 was impulse radio (IR) UWB technology. Long before technologies like Wi-Fi[1], Bluetooth[2], near-field communication (NFC), and Global Positioning Satellite (GPS), UWB was used in military applications, particularly for radar and military communications to play an important role in stealth operations and precision ranging.

By the late 1990s, the commercial potential of UWB, specifically IR-UWB, was being realized. UWB technology became commercially viable with the publication of rules authorizing UWB in 2002 in the United States. Since then, other regional regulatory bodies around the globe have defined rulesets for UWB technology, and these rulesets continue to evolve. A feature common to UWB rules worldwide is the extremely low transmit power used, typically at or below the limit for unintentional emissions from electronic devices. This equates to about a million times less power than what is used by conventional wireless systems.

While important UWB applications began to deploy as soon as the rules allowed, the focus was largely on industrial and military uses. The mid-2000s witnessed a growing interest in the use of UWB technology in consumer applications, initially for high-throughput data communications and later for location tracking. A major boost in popularity occurred in 2020 with the publication of a global standard, IEEE Std 802.15.4z. Now present in many consumer products, UWB is included in almost every car and smartphone. Standards such as IEEE 802.15.4 continue to evolve, accelerating UWB adoption across industries.

Since UWB technology is relatively new in the consumer space, and because it fundamentally differs from other wireless technologies, there's a lot of misunderstanding of what it does and how it works. This paper lays out the benefits and examines some common misconceptions about UWB technology. Our goal is to ensure that policymakers, technologists, and global electronics stakeholders who play a part in evolving the UWB industry have the most up-to-date information.

[1] Wi-Fi is a registered trademark of the Wi-Fi Alliance.
[2] Bluetooth is a registered trademark of Bluetooth SIG, Inc.

What is UWB?

UWB is a digital wireless technology that behaves differently than other methods of wireless communication. UWB emits short pulse signals rather than continuous wave signals, which enables applications to locate and sense objects with extremely high precision. UWB can also transmit large quantities of data very fast, which can improve consumer audio, VR, and AR experiences.

UWB is permitted for unlicensed use, meaning that UWB devices can operate in allowed frequencies without the need for a frequency or site-specific license. Unlicensed devices are limited in the amount of power radiated by their antennas and must not interfere with licensed devices or services.

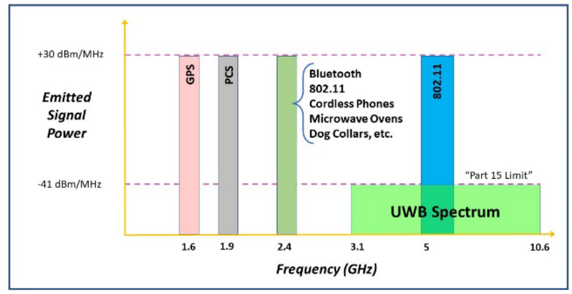


Figure 1. UWB allowed frequencies and power limit in the U.S.

UWB uses a wide bandwidth, typically about 500 MHz or larger. Although the frequencies in which UWB is allowed to operate vary by country, the most common allowed frequencies are between 6 and 9 GHz.

The Benefits of UWB

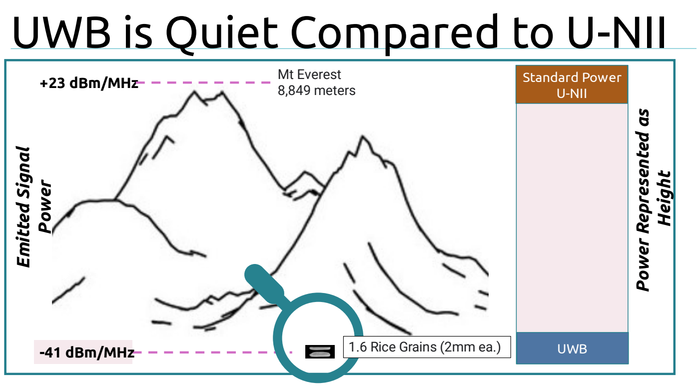
The unique technical characteristics of UWB make it beneficial for many applications and use cases. While multiple technologies play in the radio frequency eco-system, UWB does certain things extremely well and it is worth enumerating:

UWB is the king of coexistence

One of the unique advantages of UWB technology is its ability to coexist with other wireless technologies without interfering. The reason UWB technology can coexist with other wireless technologies is that it is virtually undetectable. Its transmission power is extremely low relative to other wireless technologies. UWB signals operate at levels below the unintentional radiation limits of other wireless technologies, and thus operate in the general ambient RF noise level, making UWB invisible to other devices. In real-world and lab tests, conducted to measure UWB transmissions and their impact on other wireless technologies, UWB consistently has been shown to not create interference.

A common question raised by some is whether the wide bandwidth emissions of UWB will interfere with the narrower bandwidth of other RF systems. The entire wide bandwidth of a UWB signal is required to be limited to operation below the unintentional radiation limits of all other RF technologies and emitters. With all UWB signals operating at or below the ambient RF noise floor level, it is clear why there have been no reports of device interference despite the long history of UWB operation.

A study conducted by the UWB Alliance with an independent 3rd party in 2023 showed no measurable impact on Wi-Fi 6E access points[3]. Up to 8 UWB devices simultaneously operated near Wi-Fi 6E access points and routers, and no changes to up or downlink throughputs were detected.



Despite having millions of devices in operation for over twenty years, there has never been a claim of interference attributed to a UWB device.

However, UWB devices can be overwhelmed by devices transmitting at extremely high power levels. IMT transmissions are even more powerful than U-NII (e.g., Wi-Fi) transmissions. IMT base stations can transmit at 3,280 watts (+65 dBm) per MHz under part 27 limits. This is 44.2 billion times more powerful than a UWB transmission. These comparisons show how large the differences are when comparing linear power spectral density instead of dBm/MHz, (i.e., dBm is a logarithmic scale that makes orders of magnitude look small).

While UWB is proven to coexist with other technologies operating at higher power levels, such an extreme difference as this would be disruptive to the substantial number of deployed UWB devices.

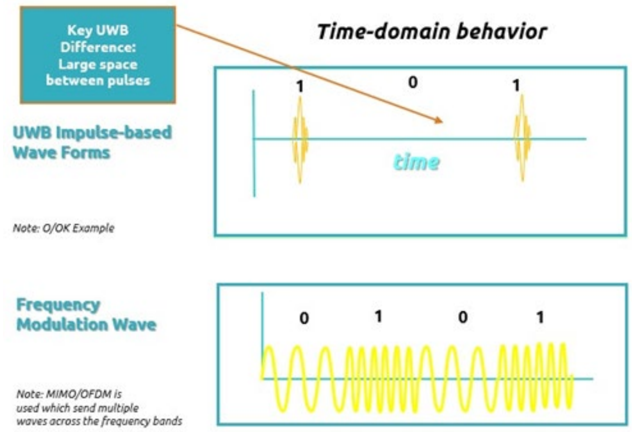
UWB is fundamentally different

While UWB, Wi-Fi and Bluetooth are all wireless radio frequency (RF) communication technologies, UWB is quite different from other RF technologies. UWB operates within a much wider frequency range and operates by sending exceedingly short ultra-low power pulses. This makes it especially resistant to multi-path and self-interference, two areas that limit the performance of the other traditional carrier-based RF technologies.

UWB is designed for use cases that require high precision location awareness, fast data transfer, and extremely low latency. UWB has vastly different physical properties that make it more suitable for some uses compared to other RF technologies. It is widely used for secure real-time distance and location determination because the very short-duration pulses enable exceedingly accurate measurement of range (distance) instantaneously. Due to an extremely low duty cycle (the UWB pulse is typically not present 98% of the time) and extremely low transmit power, interference potential is negligible to non-existent. This has enabled millions of UWB devices to operate concurrently with other RF technologies for years without a single interference claim.

[3] Ultra-Wideband (UWB) Aggregation and Co-existence of Wi-Fi 6E Operating in the Presence of UWB https://uwballiance.org/wp-content/uploads/2023/05/UWBA-Interference-Testing-Report-April-2023-corrected-final.pdf

A UWB transmission emits far less power than the power transmitted by Bluetooth or Wi-Fi. This difference can range from 10's of thousands to millions. Not only is the amount of energy put "into the air" by UWB much lower, but the time during which energy is in the air is much less. The UWB signal comprises a series of pulses instead of a continuous signal. The continuous waves of other RF technologies are susceptible to wave physics that include additive, subtractive, fading, and distortion of the waves, which can diminish the quality of received signals.



Like UWB, Bluetooth is used in applications that require wireless data exchange over short distances. However, being a continuous wave carrier-based technology Bluetooth is subject to limitations in device density and performance. Although it is popular and convenient for consumer-grade electronics, it is extremely difficult to obtain full-quality audio and impossible to obtain the high-precision location performance provided by UWB. Professional broadcast/theatrical communications or precision asset management is not possible with Bluetooth due to its significantly lower bandwidth. Latency measures and audio quality have recently improved for Bluetooth but are far from accomplishing the sub 3 ms latency that is possible with UWB.

Wi-Fi, on the other hand, is a high-data-rate wireless technology used primarily for connecting devices to the Internet through wireless routers. Wi-Fi, like Bluetooth, is also a continuous wave technology subject to device density, performance, and self-interference issues. Of course, Wi-Fi has its advantages, especially regarding performance over longer or less line-of-sight applications. If one were to visualize the best RF technology for various uses in a home, Wi-Fi is designed to cover a "whole house" (or even outside the house or garage). In contrast, Bluetooth and UWB are more applicable to shorter-range "whole room" approaches.

UWB applications are growing exponentially

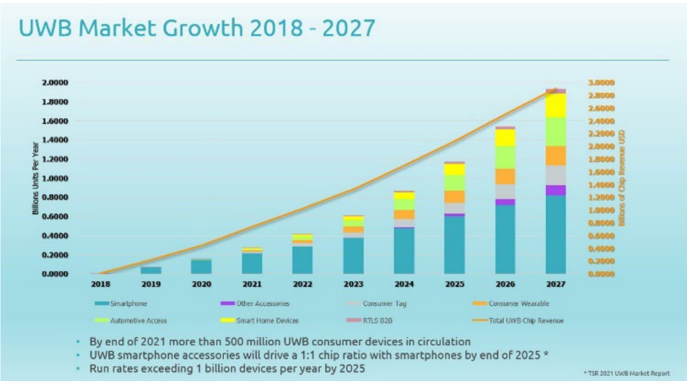
UWB technology has a wide range of applications that continue to expand. These include asset tracking, indoor positioning, automotive radar systems, smart home devices, and even healthcare applications, such as vital sign monitoring.

UWB is also excellent for a multitude of consumer entertainment applications that require low latency, low power, and high data rates. For example, low latency, high polling rate gaming devices, high-definition audio headsets, and wireless speakers.

Now existing in most high-end smartphones, the availability of UWB is spurring innovation to develop new applications that previously were not possible. A similar wave of innovation began in 2004 when Bluetooth was widely available in mobile phones. The same is now happening with UWB. AirTags and

SmartTags are examples of how smartphones leverage UWB for tracking and finding objects, but this is just the beginning.

Because of its low energy consumption, accuracy, and lack of interference with other types of RF, UWB is also an excellent ‘supporting technology’ when used in conjunction with other methods to enhance performance. For example, AirTags and SmartTags use Bluetooth for detecting nearby objects and use UWB for determining the precise location of objects.



The advent of more advanced chip technology is upon us, and major chip manufacturers have recognized the unique value UWB adds to their device offerings. Manufacturers now offer chips that utilize UWB right alongside Wi-Fi and Bluetooth. Each RF technology has its own unique advantages, and a complete wireless device is one that is designed to maximize the advantages of each. With the integration into multi-radio chipsets, UWB is now no more limited than Wi-Fi or Bluetooth.

UWB is used across almost every electronics segment

UWB is increasingly being used in a wide range of industries for different applications all of which benefit from UWB’s unique technical characteristics:

- **Audio:** Broadcast and entertainment professionals are switching to UWB to deliver the full audio bandwidth with low latency needed to meet audio performance requirements
- **Automotive:** Secure keyless entry systems in cars, detection of children and pets left behind in cars, advanced driver-assistance systems for object avoidance
- **Commercial**: Secure hands-free building access, indoor navigation assistance, and automatic adjustment of lighting, heating, and ventilation to save energy and create a more comfortable environment
- **Healthcare:** Tracking medical equipment, staff, and patients within hospitals, monitoring patient vitals
- **Home:** Smart home automation, device tracking, keyless entry and access control, home security, augmented reality and gaming
- **Industrial and Manufacturing:** Tracking assets, personnel, and equipment for workflow optimization and safety

UWB Use Cases (Grouped by volume)

High Volume	Medium Volume	Lower volume
"Point and shoot" to initiate broadband	Smart Industrial Automation and Control	Sports monitoring and tracking
Keyless entry: Vehicles, Home and Office	Contactless vital sign and fall detection	Tank level
AR/VR	Vehicle and personnel proximity (safety)	Body Area Network
Wide dynamic range low latency audio	Robotic consumer device	GPR (Ground Penetrating Radar)
Child left behind in vehicle safety seat	RTLS Industrial asset tracking tag	
Secure payment systems	Social distancing/contact tracing	
Phone "find it" apps: tag, peripheral devices	Building material analysis device	

- **Internet of Things:** Communication and data transfer in IoT devices
- **Robotics**: Accurate positioning and localization, improving the efficiency of robotic systems
- **Search and Rescue:** Detect and locate people trapped in debris following natural and man-made disasters

The versatility of UWB, with its ability to provide high data rates and precise location information in short-range communication, makes it suitable for a wide range of industries beyond consumer electronics. Its applications continue to expand as technology advances, cost comes down, and new use cases emerge.

UWB is an established technology standard

UWB has been around for over two decades and has been used in various applications, including military and industrial uses, long before it gained attention in consumer devices. The establishment of standards has played a crucial role in promoting the adoption of UWB technology since 2007. Standards provide a common framework ensuring interoperability, reliability, and compatibility among UWB devices. In 2019 UWB was first used in mobile phones, spurring further awareness of the technology in consumer applications and accelerating other innovative uses across industries.

Standards, technical specifications, and certification programs have played a pivotal role in shaping the UWB landscape, facilitating its integration into various industries, and ensuring a consistent and reliable experience for users worldwide. Standardization efforts continue to evolve as technology advances, contributing to the ongoing success and expansion of UWB applications.

- **IEEE 802.15.4** is an industry standards group that specifies UWB physical (PHY) and medium access control (MAC) layers. Task Group 4ab is currently expanding the usefulness of the 802.15.4 technical standard for a wider variety of UWB applications.
- **ETSI ERM TGUWB** is the industry body that requests changes to UWB regulations in Europe and drafts the Harmonized Standards on which product compliance testing is based.
- **AES SC-02-02-B** is a task group within the Audio Engineering Society (AES) that is defining a new standard for UWB audio.
- **Omlox/PROFIBUS** is a standard that enables manufacturing applications to use location data from multiple wireless location technologies and manufacturers, including UWB, through standardized APIs.
- **Connected Car Consortium (CCC)** Digital Key standard allows mobile devices to authenticate and share digital keys that leverage UWB securely for the automotive industry.
- **The Connectivity Standards Alliance** is defining an open standardized communication protocol to enable interoperability between mobile devices, wearables, and access control readers that use multiple RF technologies including UWB.
- **FiRa** defines UWB test specifications for ranging applications and provides a UWB product certification program.

UWB is far more than just short-range communication

Although there are numerous highly effective short-range UWB solutions on the market, UWB is also an important technology for critical safety and positioning applications at both short and longer distances. Child presence detection in vehicles, secure access control, and smart home applications are examples of UWB applications that utilize short-range use of the technology. In contrast, important critical applications such as search and rescue operations, autonomous vehicles, and outdoor positioning systems employ additional infrastructure or technical methods that allow longer-range use of UWB technology.

Some UWB systems can communicate across distances exceeding 100 meters. It seems counterintuitive that a UWB radio can communicate at the same distance as other technologies, (e.g., Bluetooth) using as little as 1/10th of the power consumption. The result of spreading energy over a wide bandwidth, the nature of UWB signals, and other factors such as coherent coding make this possible. The precision with which the time of flight can be determined remains extremely high even at distances over 100m with some implementations.

UWB uses power super-efficiently

UWB is used in power-constrained applications including car key fobs, mobile phones, tracking devices, RTLS infrastructures, and smartwatches. The brief pulses of typical UWB transmissions allow for months or even years of use on a typical coin cell battery. In contrast to traditional wireless transmitters that constantly emit radio waves to carry the information, the duty cycle of UWB transmitters is exceptionally low since they transmit extremely short pulses (several nanoseconds) and stay silent for a relatively long time. Those with prior radar experience often assume power consumption levels much higher than what can be achieved with UWB. Power consumption on par with less feature-rich sensing modalities like Passive Infrared Sensors (PIRs) for certain applications is unimaginable to most customers familiar with, for example, mmWave radar.

Continuous transmission, used with both Wi-Fi and Bluetooth, consumes power at a higher rate than non-continuous transmissions used by UWB. This is the case with Bluetooth using GFSK in which a frequency wave is constantly modulated. Similarly, modern Wi-Fi uses OFDM-based modulation that combines several waves on various frequencies. Both technologies use far more power than needed to accomplish the same communication.

Energy consumption also applies to wireless receivers. Many wireless technologies typically require receivers with complex equalizers to mitigate channel impairments or clean receiver chains to deal with overly complex modulation schemes (e.g., 1024 QAM). The complex structure of such receivers requires higher power consumption than UWB receivers.

UWB is inherently more secure

UWB is inherently secure even though it operates over a broad frequency range. UWB can easily be designed with robust security features taking advantage of the latest encryption methods, making it more secure than other wireless technologies. Two UWB technical characteristics uniquely enhance UWB security:

1. UWB is a pulse technology with an extremely short pulse duration. This prevents an attacker from decoding and modifying the transmitted signal, and
2. UWB signals are difficult to detect, due to the pulsed nature and extremely low power, operating below the ambient RF noise floor.

The unique capabilities of UWB make it particularly useful for enhancing security in some applications. Dedicated standards such as IEEE 802.15.4z have been developed and are commonly implemented to make UWB more robust and secure.

Security benefits have led to the wide adoption of UWB for secure access to vehicles, buildings and even payments. New payment capabilities integrated into smartphones and watches are using UWB. Unlike payments that use Near Field Communication (NFC) and RFID, UWB does not require tapping your smartphone or watch on a screen. Payments made using UWB offer higher accuracy, robust security, and faster transaction speeds. Enhanced security via UWB is possible due to its very precise distance measurements, which can identify and differentiate between intended users and imposters.

UWB's cost is comparable

UWB technology has become more accessible and cost-effective as the supply from and competition among UWB chip manufacturers has increased. Many consumer and industrial products now incorporate UWB without significantly increasing the overall cost. While the unit cost of UWB is currently marginally more expensive than other technologies such as Bluetooth, it's important to consider total life cycle cost when comparing wireless technologies. Factors such as device battery life, infrastructure deployment cost, infrastructure complexity, and infrastructure maintenance cost all contribute to total life cycle cost. Because UWB uses far less energy than other wireless devices, the useful life of battery-powered UWB transmitters is relatively long, minimizing expensive replacement costs and maximizing environmental benefits.

Moreover, with the most recent addition of UWB to multi-radio chipsets, the cost to implement UWB is becoming equal to any other RF technology.

UWB is (lightly) regulated

UWB technology is subject to regulation by various regulatory authorities in many countries and is allowed to operate on a broad range of channels both indoor and outdoor. Regulatory bodies, like the Federal Communications Commission (FCC) in the United States, the Electronic Communications Committee (ECC) in Europe, the Ministry of Internal Affairs and Communications (MIC) in Japan, and the Korea Communications Commission have established rules and standards for UWB usage. These bodies establish rules of the road and guidelines that govern the use of UWB, addressing issues such as spectrum allocation, power limits, and interference mitigation. As spectrum is a limited resource and in short supply, technologies like UWB that can optimize spectrum and co-exist are needed now more than ever.

UWB excels at seeing through things

The path loss when operating through an obstacle such as a wall, window, or person is more determined by the actual frequency of operation than the method. Although there are circumstances where any RF technology may have issues operating through obstacles, some UWB devices are known for their ability to penetrate obstacles such as walls and objects.

UWB can be quite effective when performing in the presence of obstacles because it is more immune to multi-path interference that is inherent in other RF technologies utilizing continuous waveforms. While they suffer from receiving multiple reflections of the transmitted signal, UWB can exploit the information in these copies to improve its performance.

This is why, for example, UWB is extremely effective at detecting survivors buried in rubble in search-and-rescue operations. The signal pulses emitted by UWB devices penetrate various materials in the debris while reflecting off others. Because different materials and objects reflect signals differently, algorithms in the UWB devices can detect human presence, their locations, and movement.

UWB is more easily deployed than ever

Most new technologies are relatively difficult to deploy initially. In its earlier years, Bluetooth was perceived as difficult to deploy but the evolution of standards, chip components, and integration experience over time have naturally simplified the process. Bluetooth has existed for decades, allowing ample time for chip suppliers to quickly deliver turn-key solutions that make it easier for system integrators to deploy. We now see the exact same process happening with UWB, especially with the introduction of chips that include UWB alongside Bluetooth and Wi-Fi.

UWB is not inherently more difficult to deploy than Bluetooth. As UWB standards continue to evolve, as UWB chip components become more prevalent, and as system integrators gain more experience deploying UWB-based solutions, the perception that UWB is difficult to deploy will vanish.

Conclusion

Although UWB has been around since the days of Marconi over a century ago, its presence in the commercial space started in earnest in 2002 after the FCC authorized its use. Since then, UWB has been introduced in a number of applications across multiple industries. Still, UWB is not a household name yet, and there are many misconceptions about what UWB is, how it works and is different from other radio frequency technologies, and why it is an important component of the RF ecosystem.

Since 2002, much more is known about how UWB easily co-exists with all other wireless technologies, whether licensed or unlicensed. The combined experience and data of millions of unlicensed UWB devices in the market with millions of other unlicensed wireless devices (even at much higher powers) now allow a more holistic review of the pros and cons of all options to maximize the advantages of all unlicensed RF devices. Unlicensed wireless has proven its immense benefit to society and innovation. UWB has now proven its ability to co-exist and provide superior performance while supporting other wireless operations.

Regulatory agencies around the globe are charged with the task of ensuring the most efficient use of spectrum, and UWB is proving to be a valuable tool in this effort. As demand on the spectrum keeps growing, UWB and its low interference footprint offer a unique way out, allowing multiple devices to operate in the same space, in the same spectrum, at the same time.

About the UWB Alliance

The Ultra Wide Band (UWB) Alliance is a global not-for-profit organization that works to collectively establish ultra-wideband (UWB) technology as an open-standards industry. A coalition made up of vendors that either design, manufacture, or sell products that use ultra-wideband technology, the UWB Alliance aims to promote and protect the current allocation of bandwidth as well as promote the continuing globalization of the technology. As part of our mission, we advocate UWB technology and use cases to promote verticals showing the value of UWB for IoT and Industry 4.0 and to build a global ecosystem across the complete UWB value chain, from the silicon to the service. In addition, the Alliance is promoting and assuring interoperability through its work with Standards Development Organizations such as the IEEE and ETSI and then working with members to define upper layers and testing to assure compliance. For more information, please visit us at www.UWBAlliance.org.