WHITE PAPER

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Sensing Beyond Limits: Transforming User Experience with UWB Radar

Introduction

Ultra-Wideband (UWB) is already established as a leading technology for short-range, high-precision object detection and tracking, thanks to its robust time of flight (ToF) and angle of arrival (AoA) capabilities. What's less widely recognized is that the same UWB systems can also enable advanced radar sensing features – presence detection, motion analysis and even physiological monitoring. This dual capability positions UWB as a uniquely versatile solution for industries looking to combine precision location with intelligent sensing in a single, compact platform.

Radar has long been vital in aviation, shipping, and automotive safety systems. Traditional radar systems required high-power microwave signals to operate across long distances. In contrast, today's automotive radar innovations – built for short-range, high-resolution tasks – have paved the way for compact, power-efficient modules.

Now, a new set of sensing demands is emerging. Use cases like in-cabin child presence detection (CPD), driver alertness monitoring and room occupancy tracking all call for accurate, low-power detection within just a few meters. Multiple radar technologies – including frequency-modulated continuous wave (FMCW), mmWave and UWB – are addressing these needs. Among them, UWB stands out for its precision, efficiency and ability to operate in the 3.1 to 10.6 GHz spectrum.

UWB Accuracy, Range and Robustness

UWB, standardized under IEEE 802.15.4a/4z, offers high-resolution sensing and ranging with operation modes at 500 MHz, 1 GHz, and 1.3 GHz bandwidths. Built for interference resilience and low power consumption, UWB is optimized for portable and battery-powered applications. Devices equipped with UWB gain centimeter-level awareness of nearby objects or other connected devices. That's why smartphones and automotive systems are increasingly integrating UWB today.

UWB was specifically designed to address key challenges in localization – accuracy, reliability in multipath environments and energy efficiency. Its spread-spectrum design and short-duration pulses give it natural immunity to interference and allow it to function well in cluttered, indoor spaces where other technologies degrade.

For ranging applications like digital key or keyless entry, UWB uses ToF to measure the round-trip signal time between two active devices. This technique outperforms received signal strength indicator-based (RSSI) methods like Bluetooth® or Wi-Fi by directly measuring the signal propagation time, not its strength, yielding greater precision. Beyond ranging, UWB enables passive ambient sensing by transmitting radar pulses and interpreting their reflections (*see Figure 1*). This capability does not rely on a second active device. Instead, UWB systems analyze reflected energy from people, surfaces, or objects to determine motion and presence. The same pulse structure used for precise ranging can now serve dual duty in advanced radar sensing.

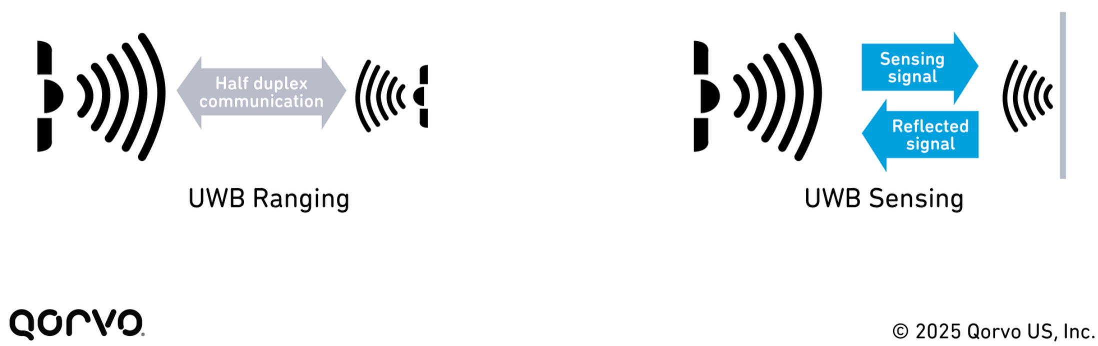

Figure 1: The difference between UWB ranging and radar sensing.

UWB Radar Sensing: How It Works

UWB radar sensing transmits short pulses and analyzes the reflected signals from surfaces and objects like people, furniture and walls. By evaluating these reflections, advanced algorithms can extract ToF and AoA data to precisely determine object distance, movement and location (*see Figure 2*).

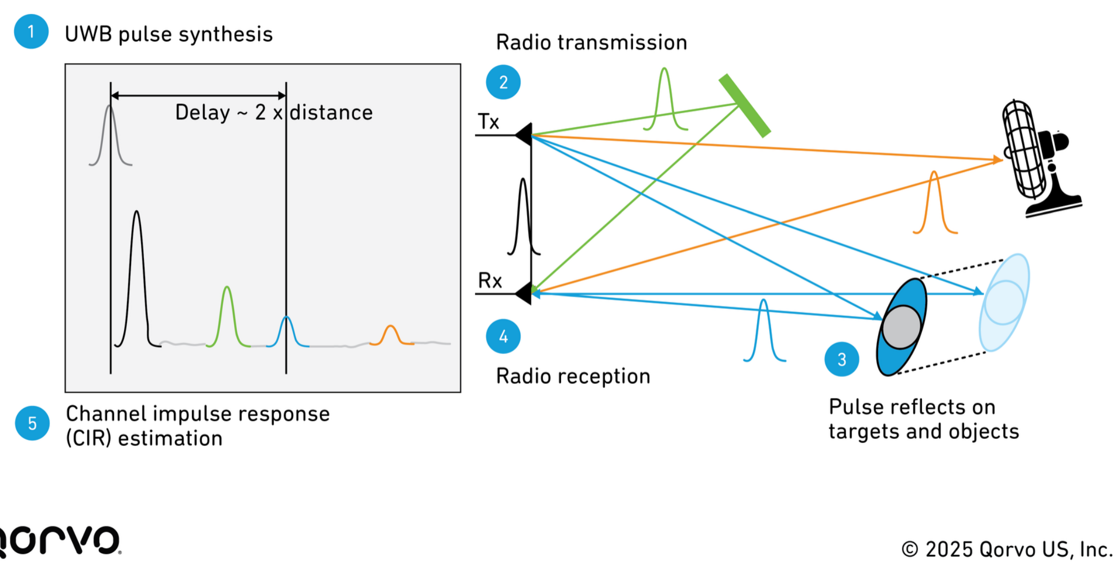

Figure 2: UWB radar transmits and receives multipath signal reflections.

UWB radar transceivers operate by transmitting a known sequence of short pulses. As these pulses interact with objects in the environment, they are reflected, absorbed or scattered. The receiver performs a cross-correlation between the known transmitted signal and the received signal to generate a channel impulse response (CIR). This CIR represents the combined effect of all the propagation paths that the pulse traverses. Each path contributes to a distinct component, and together they form a time-domain signature of the environment. The channel impulse responses represent the time domain summation of the multiple path signal components received at the receiver. Unless there is a requirement for interoperability, for instance if the transmission is shared with a FiRa or car connectivity consortium (CCC) frame, a monostatic radar, one with the transmitter and receiver in the same location, can adopt a modulation scheme and communication protocol optimized for the application.

A CIR is not static. When observed over multiple frames captured over time, it evolves in response to environmental changes. *Figure 3* illustrates how a time-series collection of CIR frames forms a CIR matrix. Post-processing algorithms can be applied to this matrix to filter out static reflections – such as those from walls or furniture – leaving only dynamic signals associated with motion. The CIR can be processed using time-domain or frequency-domain analysis to extract meaningful data about object distance, movement and AoA. In this way, even micro-movements like a person's breathing can be isolated and identified.

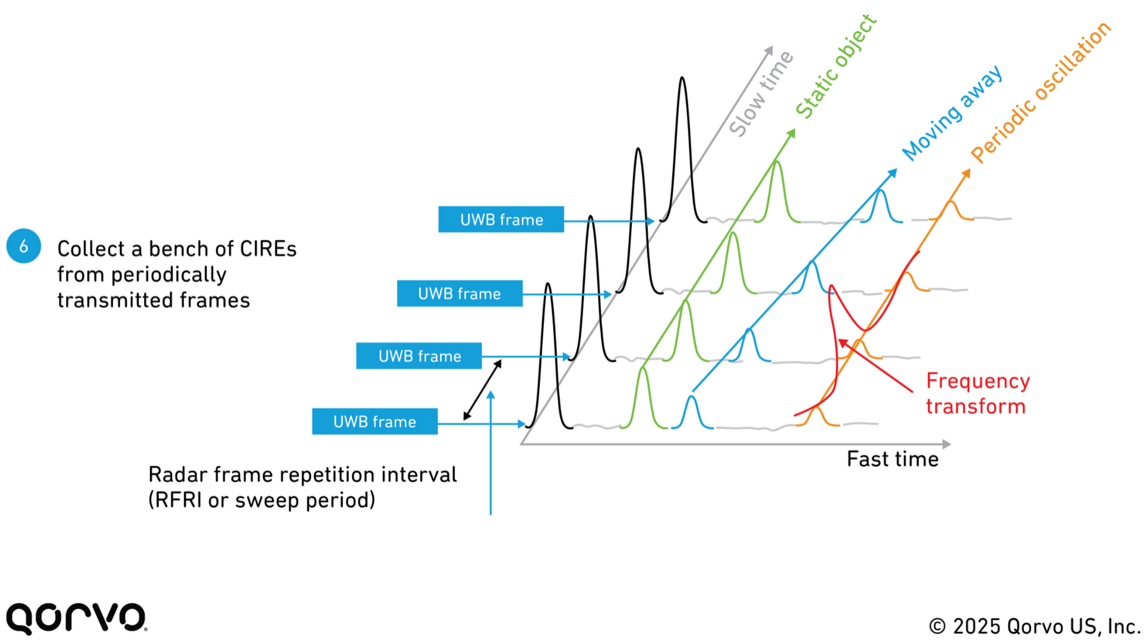

Figure 3: UWB radar collects bench of CIREs and analyzes signal variations.

Real-Time Insight with Phase Detection

Some UWB radar systems offer phase coherence across successive CIR measures. This allows them to track minute periodic movements, like human breathing, by observing phase variation over time. These phase shifts are not easily detectable using amplitude analysis alone but can be captured using frequency domain tools such as fast fourier transforms (FFT) as shown in *Figure 4*.

Phase coherence makes UWB radar well suited for vibration analysis, presence confirmation and other use cases where consistent, subtle motion is the key indicator. Even in noisy RF environments, the coherence of periodic motion allows FFT-based analysis to average out the noise and isolate meaningful activity.

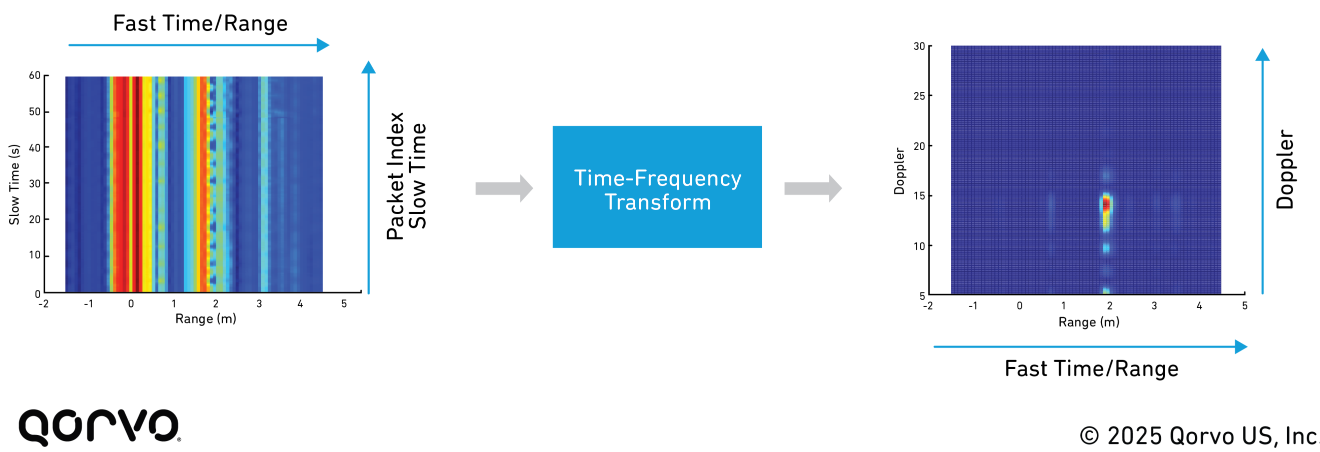

Figure 4: How time-frequency transformation is used to extract signal from noise.

CIR and System Architecture

A limitation of monostatic radar is energy leakage between the transmit and receive antennas (illustrated in *Figure 5*). Some of the transmitted energy leaks directly into the receiver path and this leakage, also known as crosstalk, can mask early reflections and create a blind zone near the antenna. A simple solution to mitigate this involves adjusting the transmit and receive gain settings to avoid saturation. While this method is less complex, it comes with the trade-off of reduced range coverage. To optimize performance, the system should dynamically select a short-range or long-range profile based on the specific use case. More advanced approaches may employ noise cancellation techniques or high dynamic range receiver designs that suppress or remove the effects of crosstalk without compromising performance.

The accuracy and resolution of UWB radar systems are determined by the signal's bandwidth and its power spectral density (PSD), both influenced by pulse width and pulse shape. Narrower pulses improve resolution, enabling distinction between objects located close together. A 500 MHz bandwidth pulse, as specified in IEEE 802.15.4a/4z systems, typically results in 2 nanoseconds of pulse width and approximately 30 cm of spatial resolution. This level of precision is suitable for most consumer and industrial radar applications. Clean, Gaussian-like pulse shapes reduce confusion caused by pre- or post-lobe oscillations in targets discrimination operation.

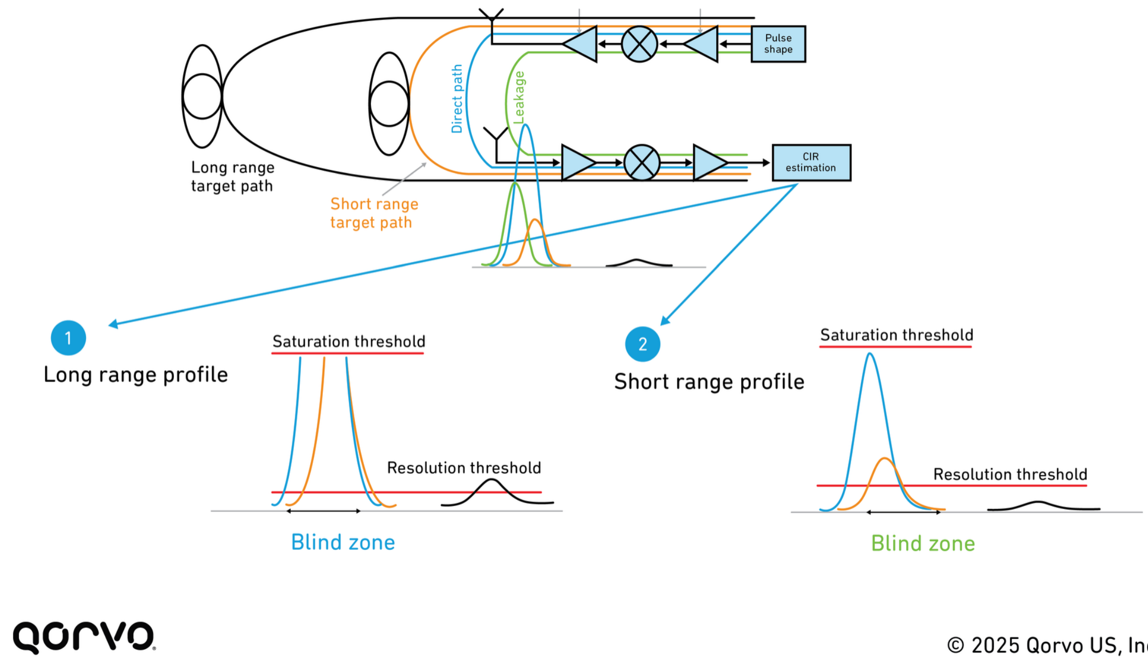

Figure 5: Potential blind zones created near antenna by crosstalk.

The performance of a UWB radar system in this context depends on multiple factors such as the power of the transmitted signal, the gain, the isolation between antennas, the shape and width of the pulse and the quality of the signal processing algorithms used to extract relevant motion signatures. However, the reflected signals of interest are usually very weak because of the inverse quartic attenuation path loss over distance experienced by monostatic radar. Achieving reliable detection and accurate target characterization depends on having a highly sensitive receiver, enabled by robust RF performance and optimized architecture.

Low Power, High Impact

UWB radar sensing consumes less than 10mW while detecting objects across several meters. This makes it ideal for always-on applications in smart home, healthcare and automotive environments. Its low-power profile helps extend device battery life while supporting intuitive, non-contact user interfaces.

The ability to detect small, periodic movements – like a chest rising with breath – makes UWB ideal for gesture recognition, vital sign monitoring and sleep tracking. These applications benefit from the fine granularity of UWB's phase and amplitude resolution, which allow detection of motion even at the sub-millimeter scale.

Metric	UWB Radar	Passive IR (PIR)	mmWave Radar
Sensing Method	Periodic Impulse Responses	Change in Infrared Radiation	Electromagnetic Wave Reflections
Range	<10 m	<5 m	>10 m
Solution Size	+	++	++*
Solution Cost	$	$	$$*
Power Consumption	<10 mW	<10mW	10s of mW
Ranging + Radar	✓	✕	✕
LOS and NLOS Sensing	✓	✕	Limited
Micromovement Detection	✓	✕	✓

*for high resolution 60 GHz radar implementation requiring additional processing

Table 1: Comparing UWB radar to other sensing technologies.

Compared to mmWave radar or passive infrared (PIR) sensors, UWB offers better power efficiency, range and typically lower implementation cost (see *Table 1*). It also performs well through obstructions like walls or furniture and in variable lighting and environmental conditions. The fact that UWB does not rely on visual input or temperature differences allows it to function effectively in situations where optical or thermal sensors might fail.

Technology That Enables Future Innovation

Whether it's child presence detection in cars, home automation triggers or healthcare monitors, UWB is enabling a new generation of responsive, low-power sensing applications and experiences. Combining centimeter-level accuracy, robust multipath immunity and low energy consumption, UWB radar capability is more than a component – it's a platform for innovation. With its dual functionality for both fine ranging and sensing, UWB continues to expand what's possible in wireless detection, helping engineers build systems that are not only smarter but more aware of the world around them.