QPF5100Q

QPF5100Q Ultra-Wideband (UWB) Key Fob Solution

Abstract

This application note provides guidance for developing an automotive key fob using the Qorvo® QPF5100Q Ultra-Wideband (UWB) System-on-Chip. It describes the device's functional architecture, reference design, and system integration considerations, including component selection, PCB layout, and power management techniques. Performance data and validation results are also presented to illustrate design benchmarks and real-world operation. The note demonstrates how the QPF5100Q enables secure digital key applications for passive entry and automatic ignition through precise ranging, low-power operation, and fast wake-up within an AEC-Q100 qualified solution.

1. Introduction

This application note outlines a key fob design for secure wireless vehicle access using Qorvo's automotive-qualified QPF5100Q Ultra-Wideband (UWB) System-on-Chip (SoC). It provides integration guidelines with emphasis on UWB radio performance, power efficiency, and compliance with automotive standards.

In this design, the QPF5100Q serves as the Ultra-Wideband (UWB) ranging engine, enabling precise two-way communication with the vehicle for hands-free entry and start authorization. Its centimeter-level ranging accuracy ensures that the vehicle unlocks only when the authorized key fob is within the valid proximity zone. This provides robust protection against relay and spoofing attacks, offering significantly greater security than current short-range wireless technologies (such as Bluetooth), since UWB determines true distance using time-of-flight (ToF) measurement rather than signal strength.

Qualified to AEC-Q100 Grade 2 standards, the QPF5100Q delivers robust performance across wide temperature ranges and in challenging automotive environments. Its low power architecture supports always-on operation with minimal current draw, which is essential for battery-powered key fobs. Compliance with IEEE 802.15.4z and Car Connectivity Consortium (CCC) Digital Key standards ensures secure, interoperable operation across vehicle platforms.

The QPF5100Q integrates an advanced UWB transceiver and a single-core Arm® Cortex®-M33 microcontroller, allowing ranging, timing, and security functions to run entirely on-chip without external processing. Basic ranging and presence detection are supported with a single receive channel, utilizing antenna and polarization diversity to ensure robust localization performance across varying user orientations and environments. This high level of integration simplifies hardware design, reduces component count, and shortens development time for compact and efficient key fob solutions.

2. High Level Solution Block Diagram

The block diagram illustrates a typical UWB digital key topology based on the Qorvo QPF5100Q, implemented in a two-node configuration consisting of the vehicle and the key fob. The vehicle may incorporate up to eight UWB anchors, six being common and two the practical minimum, often integrated into the roof-mounted "shark-fin" antenna assembly or equivalent locations. The key fob contains the companion UWB module. Together, these nodes establish a secure wireless link that allows the vehicle to accurately determine its distance to the key fob, enabling passive keyless entry and engine-start functionality. Fig. 2-1 shows the key-fob solution block diagram.

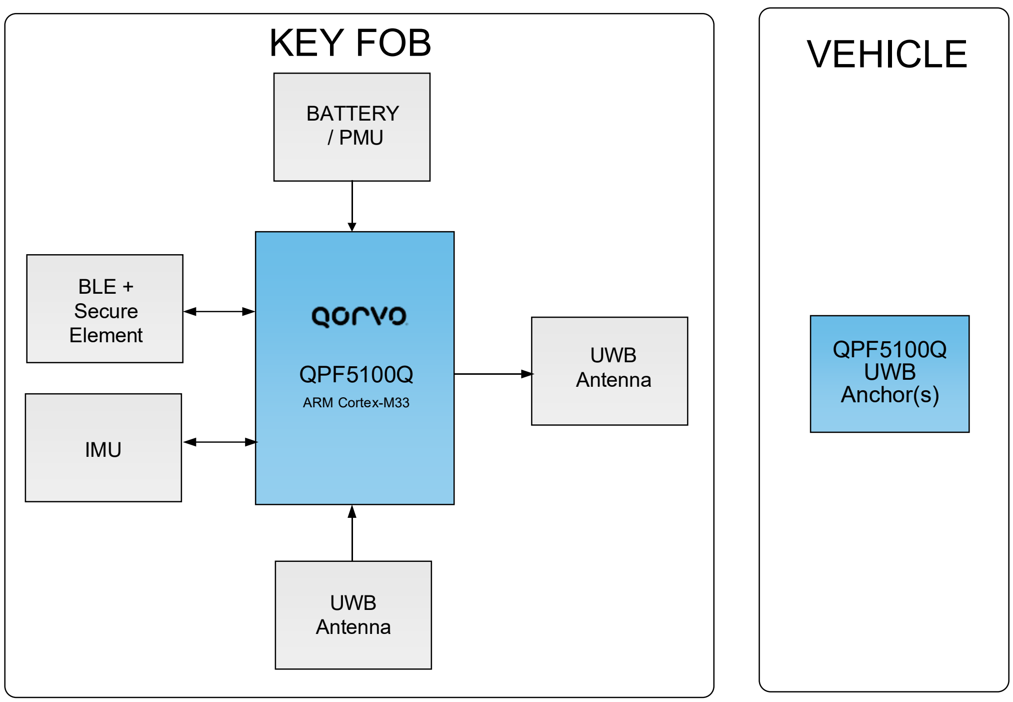

Fig. 2-1. Key fob solution block diagram

2.1.1. Functional System Overview

In this architecture, the key fob and vehicle communicate using UWB pulses to accurately measure their distance. A typical sequence begins when the key fob announces its presence over a low-power channel such as Bluetooth® Low Energy (BLE) to wake the vehicle system and exchange credentials. Once authentication is complete, the QPF5100Q UWB modules in the key fob and vehicle initiate a two-way ranging session. By exchanging precisely timed UWB pulses, each device calculates the signal time-of-flight and determines the distance between them with centimeter-level precision.

The QPF5100Q, as a fully integrated UWB System-on-Chip (SoC) with an embedded ARM Cortex-M33 processor can interface directly with an external Inertial Measurement Unit (IMU) via I²C or SPI peripheral interfaces. This enables motion and orientation data from the IMU to be processed within the SoC firmware, supporting adaptive UWB operation and enhanced localization performance. The integration allows motion aware ranging control and power optimization, such as reducing UWB activity when the key fob is stationary, without the need for an external host controller.

All UWB communication is secured under the Car Connectivity Consortium (CCC) Digital Key specification. The QPF5100Q implements the IEEE 802.15.4z High Rate Pulse (HRP-UWB) protocol with Scrambled Timestamp Sequence (STS) and AES-128 encryption to protect against relay and spoofing attacks. Each ranging frame is cryptographically protected and synchronized, ensuring that only an authenticated key fob can enable vehicle entry or ignition. From the driver's perspective, the process is seamless, the vehicle automatically recognizes when the authorized fob approaches or departs.

2.1.2. Key Components and Architecture

Each node in the vehicle key fob system consists of several core functional blocks centered around Qorvo's UWB technology. The QPF5100Q SoC serves as the primary ranging engine in both the key fob and vehicle units, managing all UWB transmission, reception, and distance calculations.

In the key fob, the SoC utilizes its integrated processor for higher level Digital Key protocol management and user commands such as lock and unlock. Two compact UWB antennas embedded in the fob's housing transmits and receives nanosecond wide pulse signals, while a small battery and power management circuit supply the system. The QPF5100Q's low-power design allows frequent ranging operation without excessive drain on the coin-cell battery. Working in concert with the Digital Key software stack, the SoC handles secure ranging, timestamping, and encryption tasks defined by DS-TWR protocol with shorter frames, forming a compact and efficient UWB module optimized for portable use. Fig. 2-3 shows example of UWB nanosecond wide pulse signal.

On the vehicle side, a corresponding QPF5100Q transceiver module connects to the central security controller or body control module through a CAN FD bus ***(Note*).*** Mounted in a location that provides broad UWB coverage, such as the roof module or cabin center, the automotive unit communicates with the key fob to determine proximity. When the fob enters a predefined secure zone (typically within 1–2 meters), the control unit can authorize door unlock or ignition enable functions. The QPF5100Q automotive qualification ensures reliable performance under extreme environmental conditions, supporting both interior and exterior installation points.

Note*: The CAN-FD (short for Controller Area Network – Flexible Data Rate) is a communication system used primarily in vehicles and industrial equipment to allow microcontrollers and devices to communicate with each other without a host computer.*

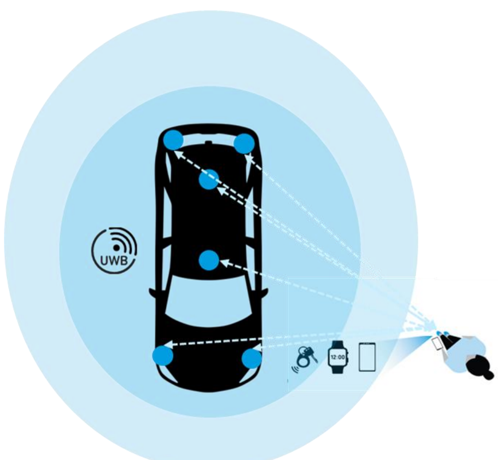

Fig. 2-2. Example of vehicle x6 UWB anchor placements for 360º ranging coverage

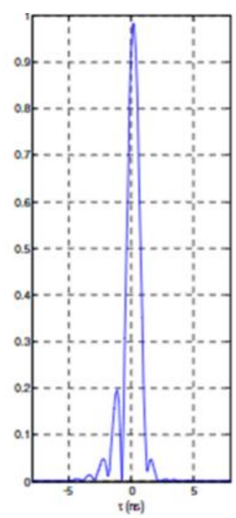

Fig. 2-3. Example of UWB nanosecond wide pulse signal

The QPF5100Q supports the IEEE 802.15.4z One-to-Many DS-TWR protocol. In its simplest configuration, a single SoC in the vehicle communicates with one in the key fob to measure distance. For enhanced functionality, such as directional detection or in-cabin localization, multiple SoC modules can be positioned at different locations on the vehicle (for example, front, rear, or sides). By comparing range and timing data from these multiple anchors, the system performs Double-Sided Two-Way Ranging (DS-TWR) and zone localization, enabling it to determine whether the fob is near the driver's door or inside the cabin. QPF5100Q's flexible firmware and software architecture support such multi-anchor configurations, allowing automakers to scale from basic to advanced digital key systems using a common hardware platform. Fig. 2-2 illustrates an example of vehicle x6 UWB anchor placements for 360° ranging coverage.

Overall, this architecture places the QPF5100Q at the center of the secure UWB link between the vehicle and key fob. Its integrated transceiver, timing precision, and on-chip processing deliver the accuracy and reliability required for next-generation keyless entry and start systems, providing drivers with seamless convenience and robust RF security.

3. Key Fob Application Circuit & System Requirements

3.1.1. Key Fob Application Circuit Example

A representative key fob design based on the Qorvo QPF5100Q UWB SoC illustrates how a compact, battery powered digital key can be realized with minimal external circuitry. By leveraging the QPF5100Q's high level of integration, including its embedded microcontroller, the design achieves optimized power efficiency and a reduced component count. The following sections describe the reference schematic's primary building blocks and outline the function of each key subcircuit, along with notes on alternative configurations to accommodate different design requirements. Fig. 3-1 shows QPF5100Q key fob application circuit diagram.

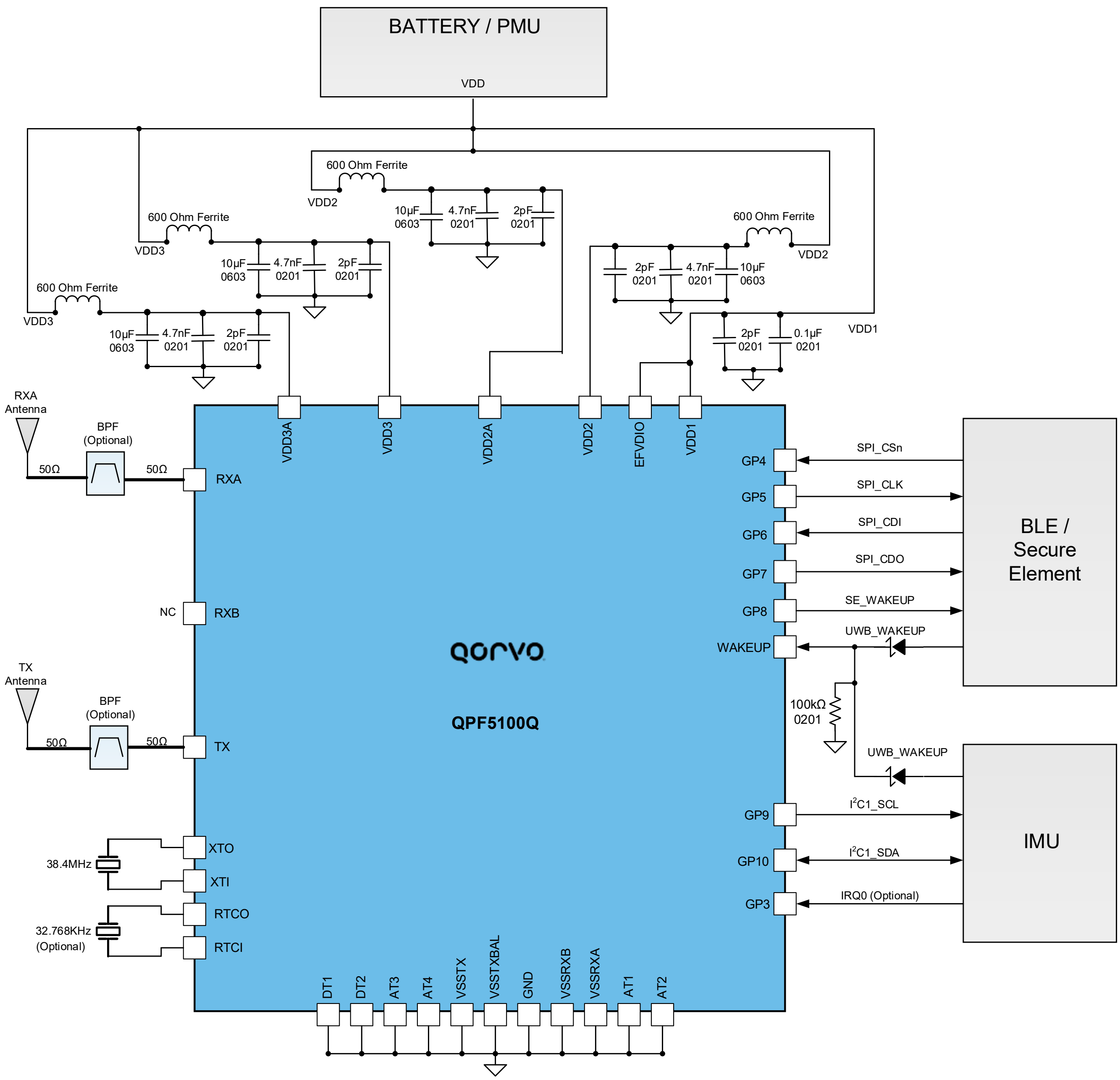

Fig. 3-1. QPF5100Q key fob application circuit diagram

3.1.2. Battery Supply and Power Management

A small coin-cell battery, such as a 3 V CR2032, powers the key fob. Its output is regulated by a buck-boost converter plus capacitor bank at its output to provide a stable 2.5–3.3 V supply for the UWB SoC and peripherals. The QPF5100Q is optimized for this voltage range and includes internal regulators for its core logic, reducing the need for external power management components.

The power circuit should incorporate both high-value and small-value decoupling capacitors placed close to the SoC's supply pins to minimize voltage dips during UWB transmit and receive bursts. An optional 32 kHz crystal can provide a low power timing reference for sleep and wake scheduling.

Power management design must minimize quiescent current in idle mode while supporting brief high-current pulses during UWB activity. The QPF5100Q typically draws about 0.8 µA in deep sleep, approximately 25–35 mA during transmission, and up to 70–90 mA in peak reception. The buck-boost converter and battery must handle these current bursts without excessive voltage droop, which requires a low-ESR (Equivalent Series Resistance) power source and proper decoupling.

By combining aggressive duty cycling with efficient burst power delivery, the system target is to achieve up to two years of operation from a single coin-cell battery.

3.1.3. RF Antenna and Matching Network

The UWB antenna is critical because the system uses the transmitted and received pulses directly to calculate the time of flight. Any pulse distortion coming from group-delay variation or a low fidelity factor immediately impacts ranging accuracy.

Key fob designs usually rely on compact PCB printed antennas or small chip antennas. These antennas need to offer wideband matching, stable radiation patterns, and good efficiency. In practice, printed UWB antennas for fobs typically achieve efficiency around the –1 dB range over the band of operation.

Because UWB antennas are wideband by design and usually optimized for 50 Ω operation, they normally do not require a dedicated matching circuit. The antenna is generally connected directly to the RF port, with only a short transmission line. Adding matching components typically narrows the bandwidth and can worsen group-delay behavior, so they are avoided.

Group delay stability is also important. Variation on the order of ±100 ps keeps pulse distortion under control and maintains a good fidelity factor. Higher ripple stretches the waveform and degrades time of flight measurements.

Placement near the PCB edge with a clean keep-out area is important for stable radiation. Metal parts, ground planes, batteries, or fast digital traces too close to the antenna reduce omnidirectionality, lower efficiency, and increase group-delay ripple. Antenna symmetry is also beneficial: a more symmetrical environment around the antenna helps maintain a balanced radiation pattern and reduces pattern tilt or nulls. For this reason, placing the antenna at the center of the PCB edge rather than offset to one side generally gives more uniform coverage and better overall UWB performance.

Omnidirectionality is important for calibration. Antennas with narrow radiation peaks or deep nulls calibrate well only within a limited angular range. A uniform pattern gives more consistent performance regardless of how the user holds the fob.

Polarization also matters. Most compact designs use linear polarization because it fits small PCB layouts, but it is sensitive to orientation differences with the vehicle antennas. Circular polarization improves orientation robustness, but compact CP antennas in the UWB band are harder to implement and often trade away efficiency or bandwidth. The final choice depends on the mechanical constraints and expected user handling.

Some designs add a UWB band pass filter on the Rx antenna for coexistence reasons. A BPF on Tx is not required on QPF5100Q variants with embedded LPF which generally meet the spectral mask and harmonic regulations without external filtering but may be required on chip variants without Tx filter. Figure 3-2 shows QPF5100Q UWB Dual Antenna CH5, CH9 2D Radiation Pattern example.

Qorvo has a dedicated team of antenna experts that can provide UWB antenna design consultation services upon customer request.

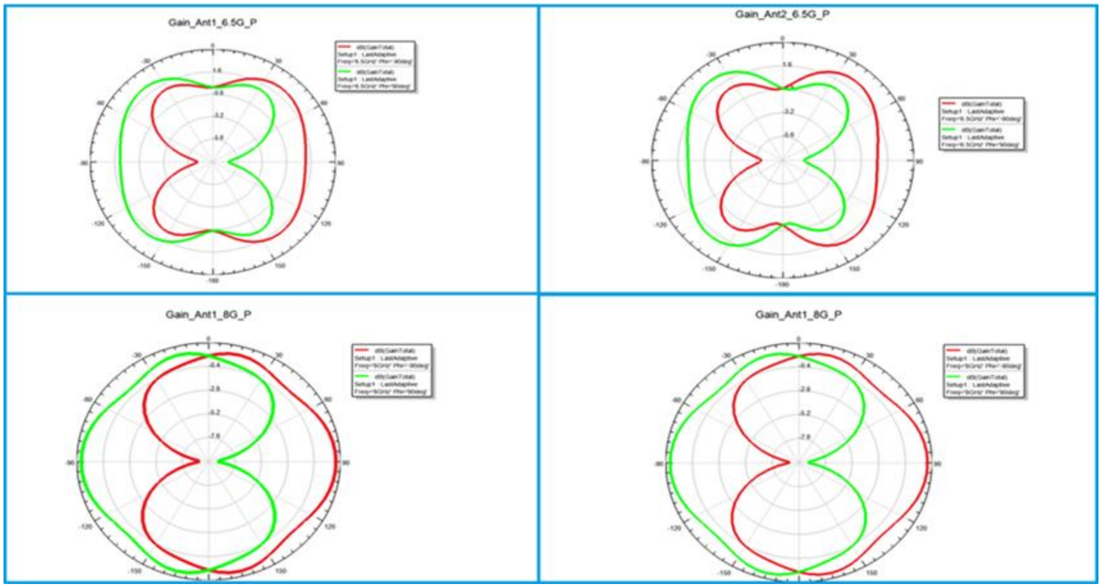

Figure 3-2: QPF5100Q UWB Dual Antenna CH5, CH9 2D Radiation Pattern

3.1.4. Component Selection & Tolerances

Designing an automotive-grade UWB key fob requires careful selection of external components to ensure stable operation across temperature, voltage, and lifetime conditions. All components should be automotive-qualified to AEC-Q standards and rated for operation from –40°C to +105°C in alignment with Grade 2 requirements.

Passive Components:
Use high-stability capacitors and resistors that maintain performance over temperature and time. Multi-layer ceramic capacitors should employ low-drift dielectrics such as X7R or C0G, while inductors and resistors should have tolerances of 5 percent or tighter to ensure consistent electrical behavior. Timing-critical parts, including the 38.4 MHz crystal and any PLL loop filter components, must provide precision on the order of ±15 ppm at +25ºC and ±25 ppm over temperature for crystals and ±5 percent or better for RC elements to keep UWB signals within specification. QPF5100Q can operate with a low cost 38.4 MHz crystal, due to the integrated on-chip programmable load capacitance (CDAC) for frequency trimming. Table 3-1 summarizes reference clock requirements.

Table 3-1. Reference clock requirements (38.4 MHz, 25ºC, VDD1,2,3 = 3.3 V)

Parameter	Min.	Typ.	Max.	Units
Crystal oscillator reference frequency		38.4		MHz
System Frequency Tolerance			+/-15	ppm
SSB phase noise power density @ 1KHz offset			-132	dBc/Hz
SSB phase noise power density @ 10KHz offset			-145	dBc/Hz

Voltage and Current Ratings:
Select all parts to withstand the maximum operating voltages and currents expected in the design. Decoupling capacitors on the 2.5-3.3 V supply should carry a voltage rating at least twice the battery voltage, typically 6.3 volts or higher for a 3-volt system. Inductors used in the RF matching and choke networks must support short, high-current UWB pulses while maintaining low equivalent series resistance to avoid excessive heating or loss of performance.

Environmental Reliability:
Choose components designed for automotive temperature, vibration, and humidity conditions. Crystals, connectors, and sensors should match the QPF5100Q's –40°C to +105°C operating range so that the complete system remains reliable under cold-start, hot-soak, and other extreme environmental stresses.

3.1.5. Variant and Alternative Configurations

The reference design assumes the QPF5100Q operates as a standalone UWB solution running both the Radio Physical Layer (PHY) and application firmware. However, the architecture is flexible, and several configurations can be adapted to meet different system requirements.

Standalone UWB SoC:
This is the standard configuration. The QPF5100Q manages all UWB communication and application tasks internally using its single MCU core, eliminating the need for an external host controller. This approach offers the simplest hardware design, lowest power consumption, and smallest footprint, making it ideal for compact key fobs dedicated to UWB-based digital key operation.

UWB with Low-Power Companion Radio:
Some key fob systems incorporate a secondary low-power radio interface, such as Bluetooth® Low Energy (BLE), to support long-range discovery or wake-up functions before UWB ranging begins. In this configuration, the QPF5100Q handles precision ranging and secure distance measurement, while the companion radio enables initial proximity detection or wake-up signaling at longer distances. This combination balances responsiveness with power efficiency without requiring the user to manually activate the fob.

4. Figures of Merit and Design Benchmarks

In a UWB-enabled automotive key fob, the Qorvo QPF5100Q demonstrates performance characteristics that align closely with the requirements of passive entry, periodic beaconing, and secure digital key operation. Validation results show that the device maintains high radio precision with exceptionally low average current consumption. Table 4-1 summarizes the key metrics for this use case, including test conditions, typical performance values, and their relevance to system-level goals.

Table 4-1. Figures of merit

Metric	Measurement Conditions	Typical Values / Range	Relevance to Key Fob Goals
Ranging accuracy	Line-of-sight, 6.5 GHz channel, calibrated setup	±6 cm	Enables secure discrimination between “inside” and “outside” vehicle positions
Receiver sensitivity	6.8 Mbps	~–95 dBm	Reliable detection of weak signals at extended range for early fob detection
Data rate range	Configured per IEEE 802.15.4z	0.85 Mbps to 62.4 Mbps	Flexibility between low-power polling and fast ranging sessions
Deep sleep current	Standby mode, 3.0 V supply	~0.8 µA	Extends battery shelf life when fob is idle
Active TX peak current	TX burst, nominal 3.0 V supply	~25–35 mA	Defines short-term load on coin cells during unlock ranging
Active RX peak current	Continuous RX, nominal 3.0 V supply	~70–90 mA	Important for dimensioning duty cycle in periodic beaconing
Wake-up time (sleep→active)	Deep sleep to TX-ready	<3.5 ms	Ensures responsiveness for rapid polling and fast unlock
Operating temperature	Automotive Grade 2 qualification	–40°C to +105°C	Guarantees reliability in harsh outdoor and in-cabin conditions

These metrics form the foundation for system design. Ranging accuracy in the range of 6 centimeters enables the vehicle to enforce location-based security by distinguishing whether the key fob is inside or outside the vehicle boundary. Receiver sensitivity near –95 dBm ensures reliable polling and communication even when the fob is up to ten meters away, such as in a driveway or garage environment.

Power efficiency is equally critical. The QPF5100Q’s sub-microamp deep-sleep current enables the device to remain idle for extended periods, waking only when motion is detected by the Inertial Measurement Unit (IMU) or when vehicle polling occurs. Although active transmit and receive bursts draw tens of milliamps, they are extremely brief, keeping the long-term average current in the tens-of-microamps range. This balance supports multi-year battery life under typical automotive polling conditions.

Fast wake-up latency, typically <3.5 ms from deep sleep to transmit-ready state, provides a seamless user experience. When the vehicle initiates a ranging request, the fob responds almost instantly, enabling immediate unlock as the driver approaches. Similarly, rapid transmit-receive turnaround allows two-way ranging to complete within milliseconds, ensuring precise time-of-flight measurements and consistent centimeter-level accuracy.

Finally, the QPF5100Q's automotive qualification and wide temperature tolerance ensure stable performance under harsh environmental conditions. Whether exposed to sub-zero cold or high cabin temperatures, the device maintains secure ranging accuracy and reliable wake behavior. Collectively, these benchmarks confirm that the SoC meets both the technical and experiential expectations of modern digital key systems, delivering precise, secure, and power-efficient operation in a compact key fob form factor.

5. Summary

The Qorvo QPF5100Q has been validated as a highly capable Ultra-Wideband System-on-Chip for automotive key fob applications, offering an integrated feature set that simplifies design while meeting the accuracy, security, and efficiency requirements of next generation digital key systems. By combining the UWB transceiver and single-core microcontroller within a single automotive-qualified package, the device eliminates the need for multiple chips and external switching components. This integration reduces board complexity and footprint, enabling compact, battery efficient key fob designs that comply with stringent automotive standards.

From a performance standpoint, the QPF5100Q delivers centimeter-level ranging accuracy and sub-microamp deep-sleep current, supporting both secure localization and extended battery life. Testing demonstrates a ranging precision of approximately ±6 cm under typical conditions, allowing the vehicle to reliably determine whether a key fob is inside or outside the cabin. While active transmit and receive currents peak in the tens of milliamps, the device's deep-sleep capability maintains average consumption in the tens-of-microamps range. Combined with a wake-up time under 3.5 milliseconds, the QPF5100Q enables a seamless user experience in which the vehicle unlocks instantly as the driver approaches. Table 5-1 summarizes key performance parameters for this use case, including design aspects, QPF5100Q benefits and relevance to key fob use.

Table 5-1. Summary key performance parameters

Design Aspect	QPF5100Q Benefit	Relevance to Key fob Use
Integration	Single-chip UWB SoC with embedded MCU and RF front-end	Reduces BOM and PCB size, simplifies design and validation
Ranging performance	±6 cm accuracy under LOS conditions	Provides secure location-aware access and digital key functionality
Deep Sleep Current	<0.8 µA	Extends battery shelf life when key fob is idle
Wake-up latency	<3.5 ms from deep sleep to active	Guarantees instant unlock response to vehicle polling
Automotive qualification	AEC-Q100 Grade 2, –40°C to +105°C	Reliable in harsh outdoor and in-cabin environments

By uniting precision, efficiency, and robust integration, the QPF5100Q serves as a proven platform for secure digital key implementations. Designers can adapt the reference circuits and layout guidelines to specific form factors, select automotive-grade passives that maintain performance across temperature and time, and validate antenna tuning in situ to ensure compliance with emission and sensitivity targets. Qorvo supports this process with evaluation kits, design guides, and application assistance to help teams accelerate development and meet OEM and regulatory specifications.

In conclusion, the QPF5100Q exemplifies how UWB technology can be deployed effectively in compact, battery-powered automotive key fobs. It balances high-precision ranging with low-power operation, integrates all essential RF and digital resources, and satisfies the rigorous reliability standards of the automotive sector. The result is a secure, responsive, and energy-efficient foundation for digital key systems that align with the next generation of connected vehicles expected to enter the market over the next 3 - 5 years.

Revision History

Revision	Author	Date	Description
A	Stuart Williams	23 Jan 2026	Initial Draft

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Important Notices