QPF5100Q

Vehicle Cabin Intrusion Detection

1. Introduction

Modern vehicle security systems are expected to detect unauthorized access to the passenger cabin while maintaining extremely low standby current and a very low false alarm rate. Conventional intrusion detection systems typically rely on perimeter-based sensing such as door switches and glass-break detectors, or volumetric sensing using ultrasonic or passive infrared technologies. Although widely deployed, these approaches can be susceptible to thermal gradients in hot cabins, airflow from HVAC systems, acoustic disturbances, mechanical vibration, and environmental noise. In addition, they may struggle to detect stationary or concealed occupants once inside the vehicle.

Ultra-Wideband technology provides a fundamentally different sensing mechanism. By transmitting nanosecond-scale pulses across bandwidths of up to 500MHz in the 6.5 to 8GHz spectrum, UWB systems achieve centimeter level range resolution and precise time-of-flight measurement. When applied to radar-based sensing within a vehicle cabin, UWB enables the formation of a spatial representation of reflective objects inside the vehicle and continuous monitoring of that representation for change. Because vehicles may remain parked for extended periods, the sensing solution must operate with extremely low average current while maintaining detection reliability. The QPF5100Q integrates the required RF, processing, security, and vehicle communication functions to enable such a system within a compact automotive-grade device.

2. System Operating Principle

When the vehicle transitions to the locked state, the QPF5100Q captures a baseline Channel Impulse Response (CIR) representing the static interior environment. This baseline includes reflections from seats, dashboard structures, steering wheel, windows, headliner and fixed trim components. Under stable conditions, this impulse response remains highly repeatable.

After baseline acquisition, the system enters a periodic monitoring mode in which short UWB radar pulses are transmitted, and updated CIR frames are captured. Each new frame is compared to the stored baseline. Deviations in amplitude or timing indicate the presence of new reflective objects or motion within the cabin volume. These deviations may result from a window being smashed, a door being opened, a person entering the vehicle, or movement between seats.

Two principal detection mechanisms are implemented. Motion detection identifies significant amplitude variations between consecutive CIR frames and is effective for detecting gross body movement or rapid intrusion events, such as the one depicted in Figure 2-1

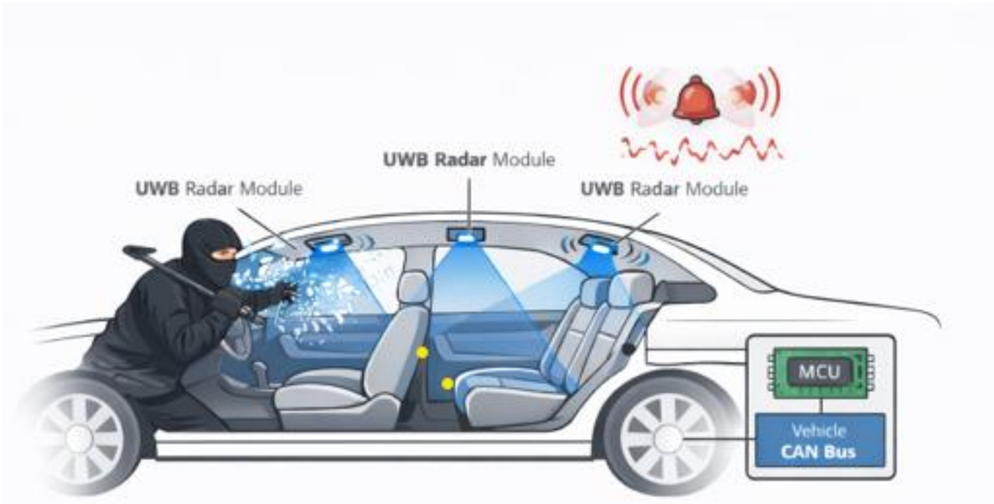

Figure 2-1. Detecting Gross Body Movement or Rapid Intrusion

Micro-motion detection analyzes slow periodic modulation in the impulse response caused by breathing or subtle body shifts, allowing detection of intruders attempting to remain stationary, as depicted in Figure 2-2.

Figure 2-2. Detecting Subtle Body Shifts, Concealed Intruder

When deviations exceed predefined thresholds and persist across a temporal validation window, the QPF5100Q confirms an intrusion event and communicates this condition to the vehicle's Body Control Module over CAN-FD. The alarm system may then be triggered while radar monitoring continues.

3. High level Solution Block Diagram

The intrusion detection module is centered on the QPF5100Q automotive UWB SOC. The device integrates an impulse radio transceiver, dual RF receivers, a 32-bit Arm® Cortex®-M33 microcontroller unit with TrustZone® security, a digital baseband processor, hardware encryption, and a CAN-FD controller within a single automotive-qualified package.

In contrast to a gesture-based kick sensor system, which monitors a localized region beneath the rear bumper, a cabin intrusion system monitors the entire cabin compartment. The UWB antenna is therefore positioned to provide volumetric coverage of the cabin rather than directional short-range sensing outside the vehicle.

Figure 3.1 below illustrates the main components and connections of a QPF5100Q based UWB vehicle cabin intrusion detection application.

Power is derived from the vehicle's 12V supply and stepped down to 3.3V using an automotive-qualified DC-DC buck converter. An external CAN-FD transceiver connects the SOC to the vehicle network. Additional optional sensors, such as an accelerometer or acoustic glass-break detector, may be integrated for sensor fusion and false-alarm mitigation, although the UWB radar can operate as a standalone volumetric sensor.

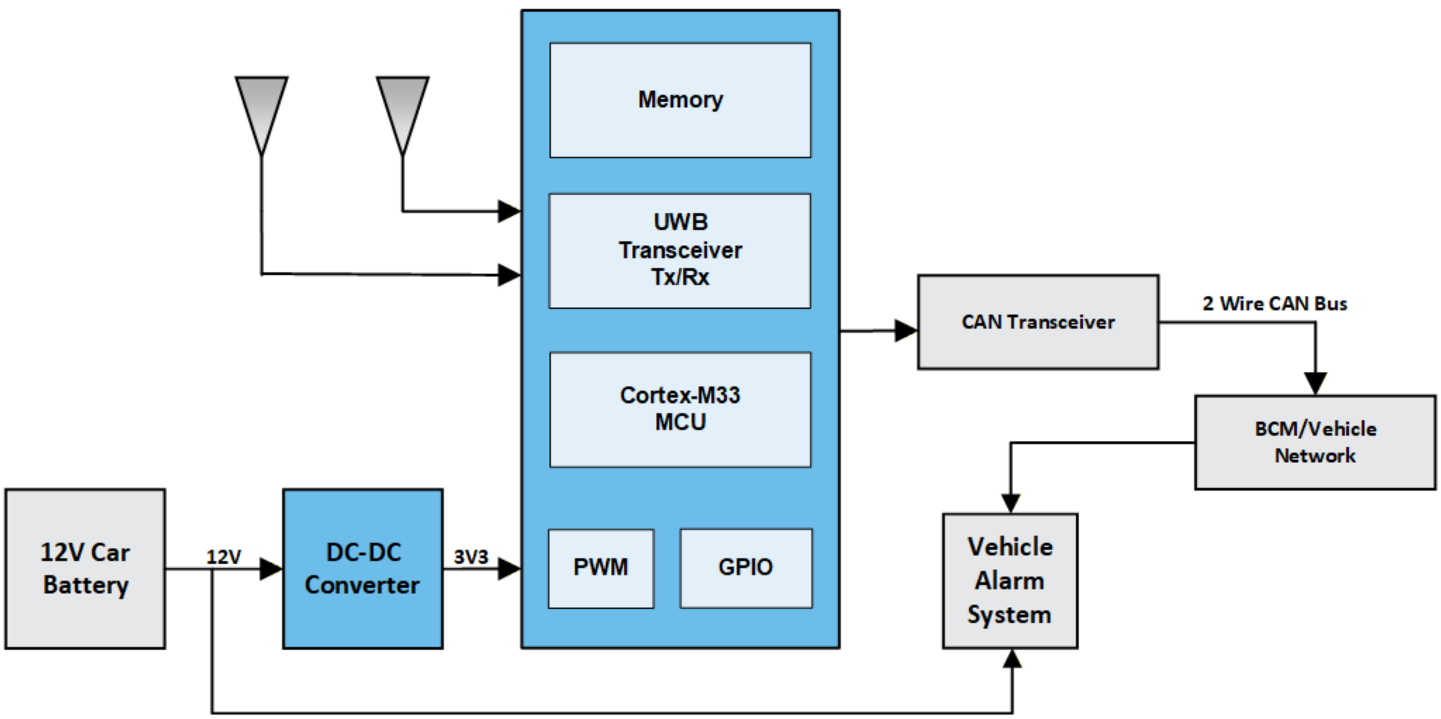

Figure 3-1. Implementation of QPF5100Q for Vehicle Cabin Intrusion Detection

4. Antenna Design and Placement

The UWB antennas are a critical element of a vehicle detection system because they directly determine sensing coverage, detection reliability, and robustness to multipath. The system relies on detecting reflections and small variations in signal paths caused by occupant presence or intrusion events, which place a strong requirement on stable antenna performance across the full operating band and throughout the vehicle cabin.
In an automotive design, the antenna must balance compact size, wide bandwidth, and a radiation pattern that reliably covers the occupant compartment. UWB operation typically spans the 6.5 GHz to 8 GHz range, and the antenna should maintain good impedance matching across this bandwidth (for example, VSWR ≤ 2:1 or return loss better than -10 dB) to ensure efficient signal transmission and consistent sensing performance.

The TX–RX isolation is critical to reduce transmit signal leakage into the receiver path, which can saturate the receiver front-end and degrade sensitivity. To achieve robust occupancy and/or intrusion event detection performance, TX–RX isolation of approximately 30 dB or greater is recommended. This is typically achieved through a combination of antenna placement, physical separation, orientation, and RF front-end isolation.

Linear-polarized antennas are generally preferred for in-cabin UWB sensing because they provide predictable propagation and stable reflection characteristics within the highly reflective vehicle interior. Circular polarization may be used in certain configurations; however, reflections within the cabin can alter polarization characteristics, which may impact detection consistency. Maintaining stable radiation characteristics and antenna orientation is therefore important.

The radiation pattern should be selected to match the sensing volume of the cabin. A broad, downward-facing radiation pattern is typically used to provide coverage across the vehicle cabin. Moderate directivity can be beneficial to concentrate energy within the occupant region and improve signal-to-clutter performance. Depending on system requirements, suitable antenna implementations include wideband printed or planar antennas for broad coverage, or patch-style antennas and antenna arrays for more controlled field-of-view.

Because the antenna is integrated into a complex vehicle environment, nearby structures and materials, including trim components, housings, wiring, and metallic elements, can detune the antenna or distort the radiation pattern. Antenna performance should therefore be verified in the final installation environment using impedance measurements and system-level RF validation. Adjustments to antenna matching or placement may be required to compensate for installation effects.

The diagram below provides an example of radiation pattern coverage for a headliner-mounted antenna configuration, illustrating a downward-facing beam oriented toward the seating area. This type of placement enables effective coverage of the vehicle cabin while minimizing signal blockage from interior structures

Support for antenna selection, integration, and validation is available through Qorvo engineering support channels.

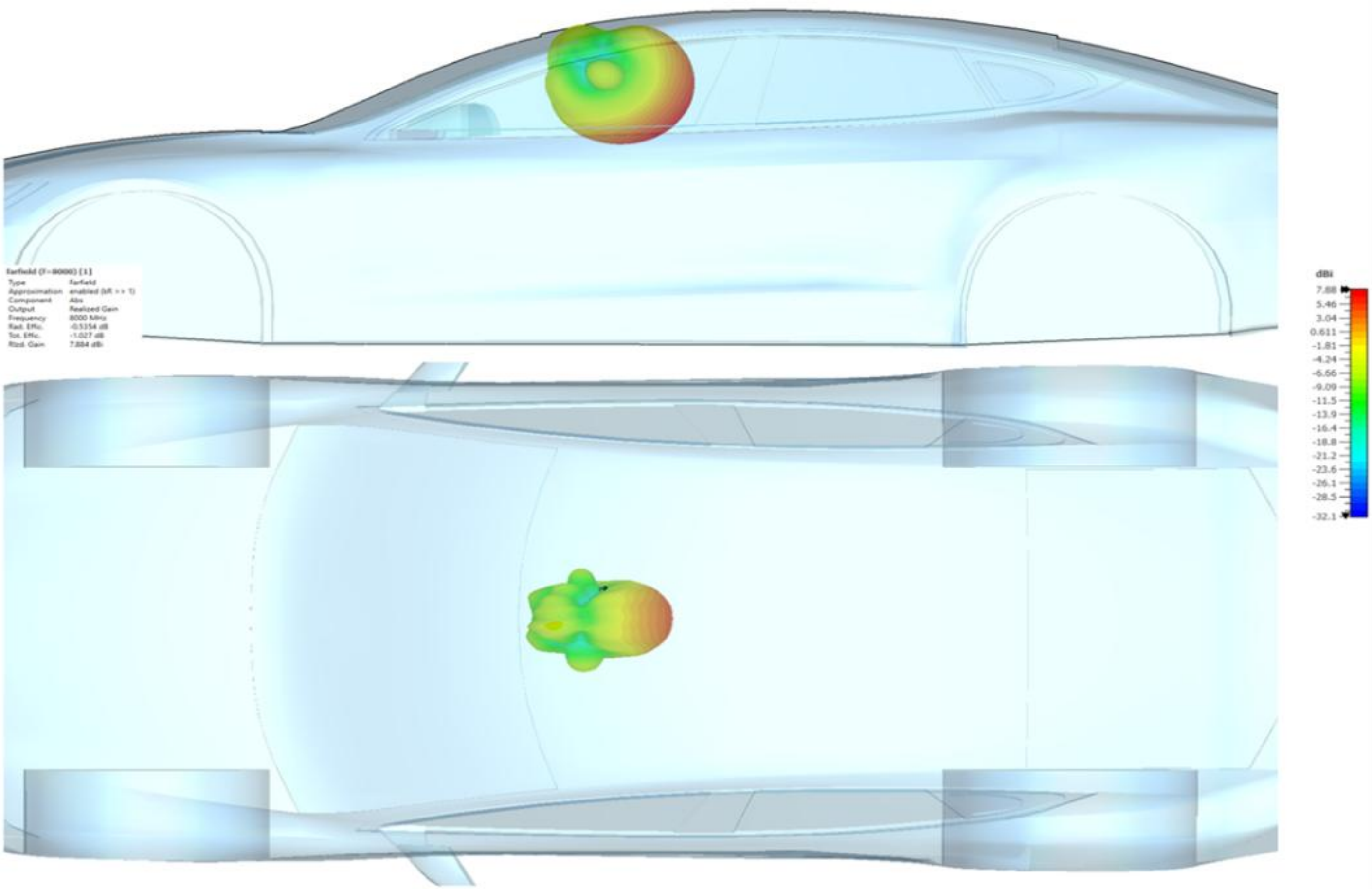

Figure 4-1. Radiation pattern of a two-element patch antenna array

5. Conclusion

Implementing cabin intrusion detection using UWB CIR radar provides a robust and technically advanced alternative to conventional volumetric sensors. By continuously monitoring the spatial impulse response of the vehicle interior, the system can detect both gross motion and subtle micro-movement while maintaining low false alarm rates and environmental immunity.

The QPF5100Q integrates transceiver, secure processing, and vehicle communication interfaces in a single automotive-qualified device, enabling compact and energy efficient implementation. With careful attention to antenna placement, power management, signal processing, and PCB layout, automotive designers can develop a reliable next-generation cabin intrusion detection system suitable for modern vehicle security architectures.

6. Reference/Links

QPF5100Q-PK090 HW Design Guide

QPF5100Q Datasheet – QPF511Q-PK020

Revision History

Revision	AUTHOR	Date	Description
A	Alan Molley	1st September 2026	Initial draft

Contact Information

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Important Notices