qorvo

The Future of Automotive

Design Guide

MOUSER ELECTRONICS

Contents

Qorvo offers a broad portfolio of automotive solutions for V2X, Wi-Fi, SDARS, UWB, eCall, LTE, and 5G. These solutions are developed in close alignment with multiple chipsets in use by the leading module makers and are designed to support long automotive lifecycles. In addition to meeting ISO/TS 16949 certification, Qorvo performs AEC-Q100 and AEC-Q200 testing to ensure products meet stringent automotive industry requirements.

RF and Power Technologies Help Build Connected, Energy-Efficient Automobiles

Rodney Hsing Sr. Director of Global Distribution, Qorvo

The connected car is here, and it is powered by a diverse array of wireless communications technologies that must coexist effectively to ensure the safety and reliability of our mobile world. And it is not just higher levels of connectivity automotive consumers are after. As the electric vehicle (EV) revolution continues to gain momentum, demand for increased energy efficiency continues to rise. As a global leader in radio frequency (RF), power, and related technologies, Qorvo is helping customers solve their most difficult automotive design challenges. Our RF technology supports seamless operation across multiple communications standards, while our SiC (silicon carbide) technology delivers the perfect blend of power-related benefits for today's connected EVs.

Qorvo's products are used in the design of automotive antennas, car chargers/power adapters, infotainment, light electric vehicles, electric vehicles, and telematics that connect the car to the cloud.

Our solutions include connectivity products for 802.11p, automotive Wi-Fi, Satellite Digital Audio Radio Service (SDARS), GPS and Long Term Evolution (LTE), plus DC/DC converters and modular power management integrated circuits (ICs). In addition, for light electric vehicles, where efficient power use is critical, we offer intelligent motor controllers. Our power management solutions help to solve the challenge of having an increasing number of devices in every vehicle.

With multiple device options and the promise of higher efficiency and faster switching speeds, our Gen 4 Silicon Carbide Field Effect Transistor (SiC FET) devices enable design flexibility, yielding potential savings in cost, size, and energy, while maintaining generous design margins and circuit robustness. In addition, their ability to be safely driven with standard Si Insulated Gate Bipolar Transistor (IGBT), Si FET, and SiC FET drive voltages reduces design complexity for easy implementation.

Qorvo also offers a full suite of products that enable a reliable vehicle-to-everything (V2X) link in the Telematics Control Unit (TCU) and antenna. This product suite provides V2X communications, allowing a car to communicate with the world around it. Information from sensors and other sources travels via low-latency, high-reliability links, paving the way to fully autonomous driving.

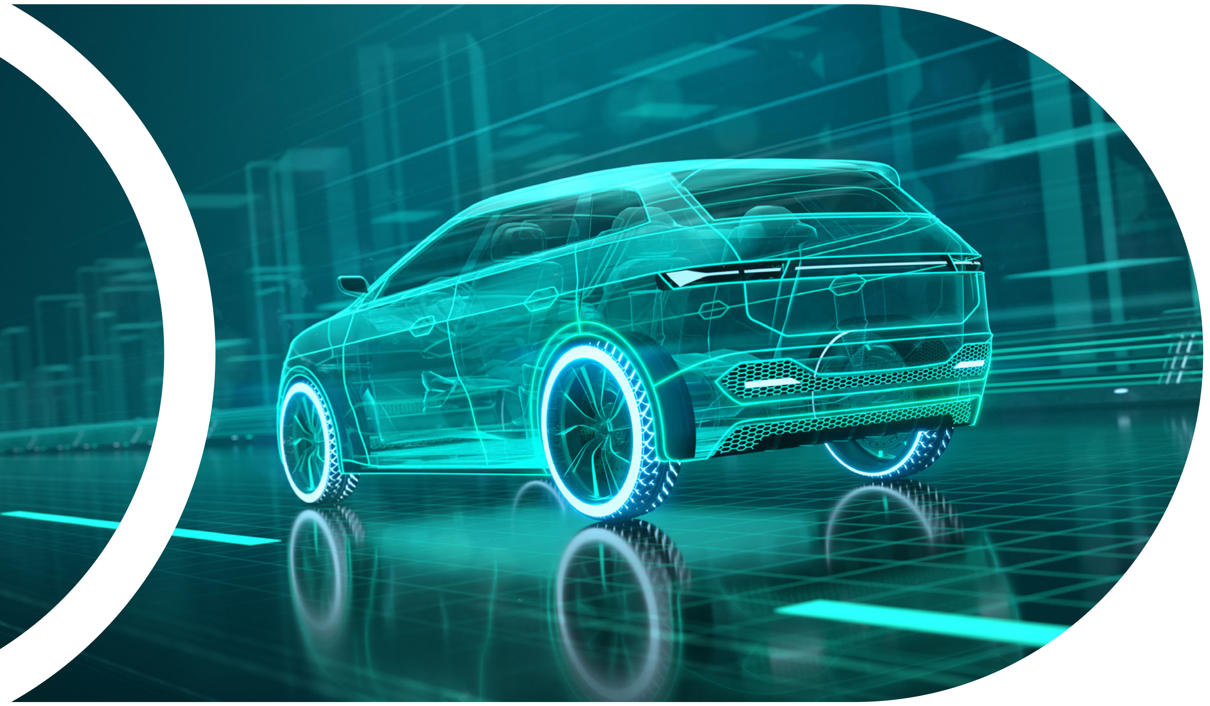
Qorvo's Ultra-wideband (UWB) technology is designed to enhance advanced driver assistance systems (ADAS) and connected autonomous vehicle (CAV) sensor suites, potentially saving lives by helping to avoid collisions. In 2021, we introduced the first integrated broadband antenna routing switch that enables Emergency Calling (eCall) for automobiles. The switch allows a primary cellular link to be switched to other antennas within the car to ensure reliable connectivity with life-saving services during an accident.

Qorvo's innovation in automotive products is delivering safety, reliability, efficiency, and user enjoyment. We perform AEC-Q100 and AEC-Q200 testing to ensure our products meet the challenging requirements of the automotive environment, enabling automobile manufacturers to rapidly bring new solutions to market.

We offer next-generation solutions that Connect, Protect and Power people, places, and things—faster and further with greater reliability.

Qorvo is all around you – making a better, more connected world possible.

A Tech Evolution Underway: V2X Architectures



Steve Taranovich for Mouser Electronics

3GPP intends to use 5G in V2X applications and the automotive front-end module (FEM), with significant advantages over current dedicated short-range communication or other C-V2X proposals.

Emerging vehicular networking applications, such as V2X, and use cases will need stringent Quality of Service (QoS) requirements in terms of latency, data rate, reliability, and communication range. Technologies often used in ultimately developing an autonomous vehicle center around three types of sensors: Camera, radar, and LiDAR. However, vehicle-to-everything (V2X), another existing wireless technology, can significantly add value to autonomous vehicles. V2X refers to high bandwidth, low latency, reliable communication between a broad range of transport and traffic-related sensors. 5G mobile networks will provide connectivity for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. The automotive front-end module (FEM) will be one of the most important enabling solutions in next-generation technology, leading to the overall success of Cellular-V2X (C-V2X).

In the following, we will discuss how the 3rd Generation Partnership Project (3GPP) intends to use 5G in V2X applications with significant advantages over current dedicated short-range communication (DSRC) or other Cellular-V2X (C-V2X) proposals.

A Technology Evolution is Coming

Future Intelligent Transportation System (ITS) services are widely accepted from a communication technology perspective. This will ultimately lead to autonomous driving and require a high level of connectivity in vehicles via advanced communication technology such as 5G V2X. After many years of research driven by academia and industry and the delivery of mature technology enablers for 5G, 3GPP is drafting the standard for 5G V2X, starting with Release 16.

Let's first look at the definition of V2X. This vehicle-to-everything technology is a two-way communication that enables the transmission of information between an automotive or electric vehicle and any surrounding entity that might affect that vehicle. V2X applications will have a significant impact on safety and convenience well before full autonomy becomes a reality by enabling less gridlock, reducing environmental impact, and adding more vehicle comforts for drivers and passengers.

5G, coupled with V2X, will enhance vehicle and pedestrian safety. Added capabilities include vehicle notification and control for approaching emergency vehicles with distance/direction information, pedestrians crossing in a crosswalk (traffic lights/signals will be controlled or extended for safety and during unexpected events, and identification) and avoidance of pedestrians darting into traffic. Notification of its location and distance will be sent when an accident is near. Things such as school bus notifications, including unloading/loading school children in the area, will keep pedestrians safe.

Cellular-vehicle-to-everything (C-V2X) is a subset of V2X. It will supplement line-of-sight (LoS) sensors such as cameras, radar, and LiDAR for non-LoS awareness, which is critical for safer driving. C-V2X will also enable broader sensing coverage than LoS sensors and is the foundation for vehicles to communicate with each other and everything surrounding them. 3GPP started standardization work of C-V2X in Release 14 in 2014. It is based on LTE, as the underlying technology. Specifications were published in 2017.

The types of transfer communications capabilities being used include vehicle-to-infrastructure (V2I), vehicle-to-network (V2N), vehicle-to-vehicle (V2V), vehicle-to-pedestrian (V2P), and vulnerable road users like cyclists, vehicle-to-device (V2D), and vehicle-to-grid (V2G) (**Figure 1**).

The automotive industry is also pursuing ways to reduce the costs for On-Board Units (OBUs) that will support 5G V2X while avoiding/minimizing any vehicle price increases.

5G and V2X

5G will make V2X easier, faster, and more reliable. The main difference between a 5G and V2X framework can be summarized as follows:

- 5G, like any radio mobile service, uses an infrastructure called base stations in which the landscape is divided into individual cells, widely overlapped, and managed by proper antenna systems.
- V2X, like any wireless service, exhibits a more flexible structure, where small antenna-device systems, called hot spots, assure best-effort connections by using a solid co-operation strategy.

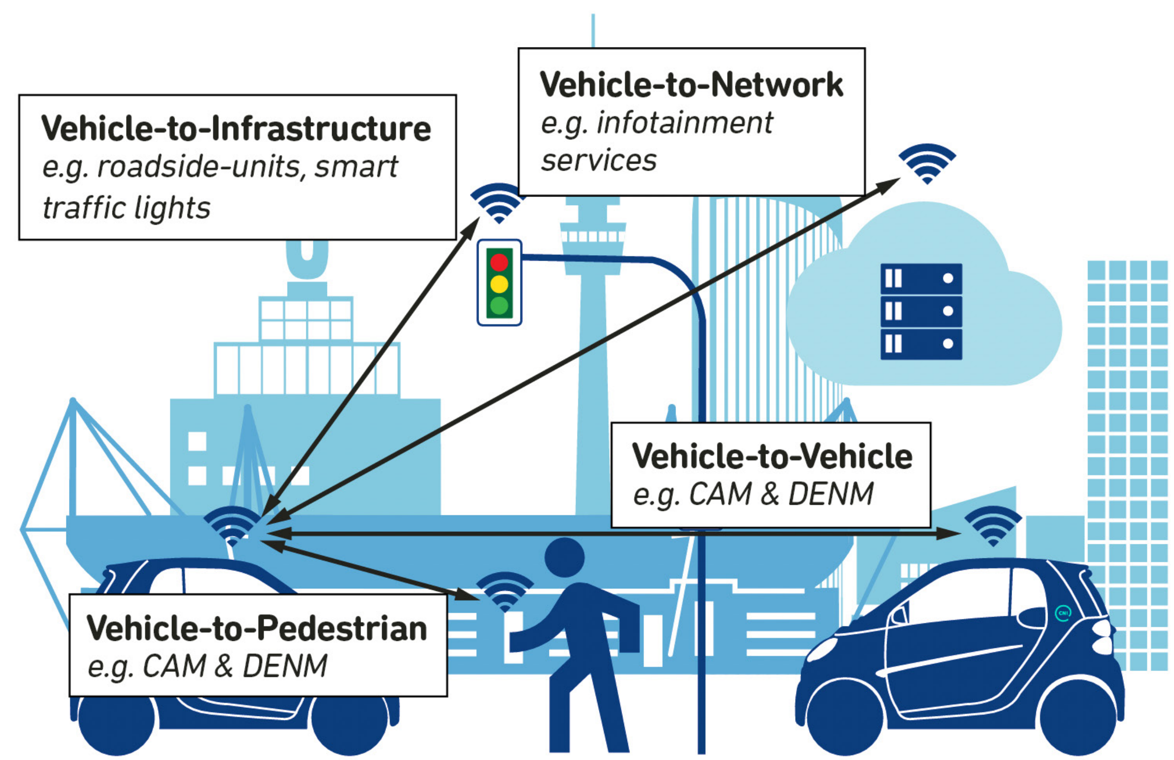


Figure 1: The main C-V2X use cases: Vehicle-to-Vehicle (V2V), Vehicle-to-Pedestrian (V2P), Vehicle-to-Infrastructure (V2I), and Vehicle-to-Network (V2N). V2X safety messages may include Cooperative Awareness Messages (CAM) and Decentralized Environmental Notification Messages (DENM) in Europe or Basic Safety Message (BSM) in the US. (Source: Performance Analysis of C-V2X Mode 4 Communication Introducing an Open-Source C-V2X Simulator 07/23/2019 by Fabian Eckermann, et al. TU Dortmund)

Qorvo has developed one of the most critically important modules for the success of V2X technology

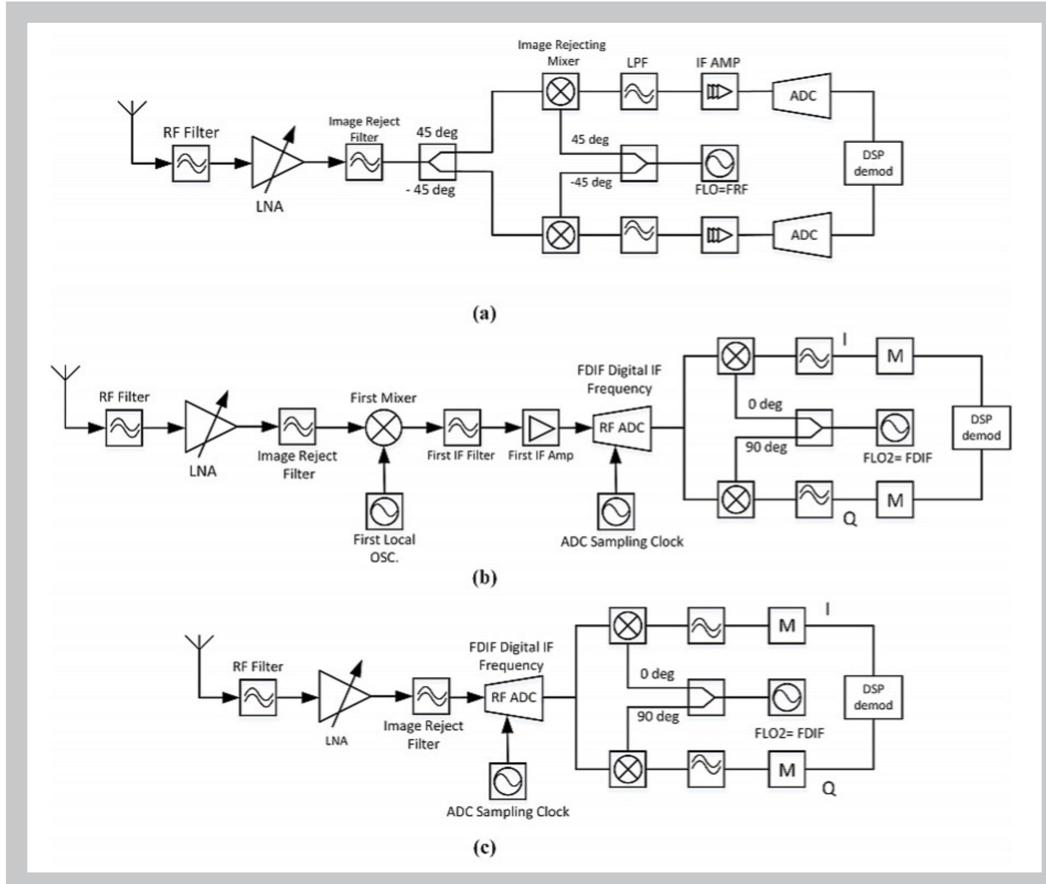


Figure 2: This block diagram shows three types of radio architectures for a C-V2X sampling receiver. (Source: IEEE)

The C-V2X receiver

Like other wireless communication technologies, the C-V2X technology is designed with analog and digital building blocks. One of the key analog and mixed-signal parts of the C-V2X design is the radio, which is designed with many high-frequency analog components in the receiver chain (**Figure 2**).

Figure 2 demonstrates three different radio architectures for sampling receivers: a) Baseband, b) IF, and c) RF. The RF analog-to-digital converters (ADCs) will determine the type of receiver the designer chooses—a, b, or c—depending on the input frequency.

The automotive front-end module (FEM)

Qorvo has developed one of the most critically important modules for the success of V2X technology—the front-end module (FEM), which is a part of the Qorvo connected car portfolio.

Qorvo's V2X connected car portfolio contains chipset-agnostic solutions for vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-pedestrian (V2P), and vehicle-to-network (V2N) communications.

This product portfolio, providing a readily-available solution for V2X communications, includes a Band 47/Wi-Fi bulk acoustic wave (BAW) co-existence filter allowing Wi-Fi co-existence with the V2X 5.9GHz band. This capability is critical to establishing reliable links between the vehicle and its surroundings. It also includes two integrated front-end modules (FEMs), which supports C-V2X (and also DSRC systems), a digital step attenuator, a transmit/receive switch, and a low noise amplifier (LNA)

The design solutions are as follows:

- QPF1002Q: A front-end module that is optimally designed to support C-V2X systems and integrates a Power Amplifier (PA), Low Noise Amplifier (LNA), and switching in a 5.0mm x 4.0mm package
- QPF1003Q: A front-end module that is optimally designed to support C-V2X and DSRC/11p systems, integrates a Power Amplifier (PA), Low Noise Amplifier (LNA), and switching in a 5.0mm x 4.0mm package
- QPQ2200Q: A Band 47 V2X/Wi-Fi bulk acoustic wave (BAW) co-existence filter, with excellent out-of-band attenuation in the Wi-Fi UNII-3 band, prevents Wi-Fi interference V2X 5.9GHz band, enables reliable V2X links for autonomous driving, in a compact 1.1mm x 0.9mm package
- QPC6713Q: A 7-bit, 0.25dB Digital Step Attenuator: Enables fine power control necessary for compensator applications
- QPC8019Q: Features fast transmit/receive switching necessary for V2X systems

Let's take a more in-depth look at one of the Qorvo FEMs, the QPF1002Q.

The Qorvo QPF1002Q Automotive Front-End Module is an optimized solution for C-V2X (Cellular Vehicular-to-Everything) systems. C-V2X systems will sense the surrounding environment, enabling next-generation autonomy and real-time monitoring in connected vehicles. C-V2X uses the low-latency direct transmission in the 5.9GHz Intelligent Transportation System (ITS) band.

The QPF1002Q also integrates a 5GHz power amplifier (PA), Tx/Rx antenna switch, and a bypassable low noise amplifier (LNA) into one single unit.

This device features a 5.77GHz to 5.925GHz frequency range with a 28dB Tx gain, a 13dB Rx gain, and a low 2.6dB noise figure. Performance is focused on optimizing the PA for a 5V supply voltage that conserves power consumption while maintaining the highest linear output power and a leading-edge throughput. The receive path is pinned out for flexibility to enable external filtering or an LNA.

The Qorvo QPF1002Q Automotive FEM is housed in a compact 5.0mm x 4.0mm x 0.925mm laminate package and is AEC-Q100 Grade 2 qualified for automotive system applications.

The following are some key features:

- AEC-Q100 Grade 2 qualified
- 5.77GHz to 5.925GHz frequency range
- Optimized for +5V operation; +4.2V capable
- POUT = +28dBm, 10MHz linear power
- 28dB Tx gain
- 580mA Tx current
- Tx High Power and Lower Power modes
- 24dB Tx coupler
- 2.6dB Rx noise figure (includes switches)
- 13dB Rx gain
- 35mA Rx current
- -6.5dB Bypass LNA loss
- No external matching required
- 5.0mm x 4.0mm x 0.925mm laminate package
- Halogen-free and RoHS compliant

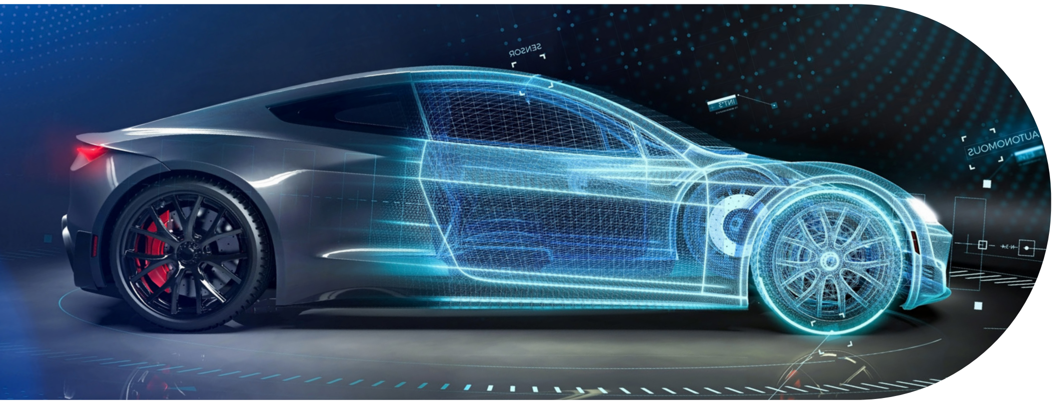
Applications are:

- ITS C-V2X
- Automotive front ends
- Automotive telematics
- Automotive infotainment

C-V2X Sidelinking

5G, Release 16, brought sidelinking to industry C-V2X with 5G New Radio (NR). This release advanced C-V2X applications such as platooning, advanced driving, extended sensors, and remote driving. Strict latency and high reliability must be guaranteed because emergency braking and collision avoidance are needed in critical driving situations. C-V2X's smallest transmission latency is at most 4ms and can be lower depending on the implementation. It is difficult to quantify reliability here, but each new release has added another group of improvements in performance and safety, which has enhanced reliability. Upcoming releases are scheduled to continue on this path of safety and reliability improvements.

The bulk of the traffic that will be carried out by short-range communications, especially in the first phase of V2X deployment, will be periodic broadcasting messages by each vehicle communicating its status and movements.



> **V2X and 5G are fast-becoming integral technologies...**

We must note that V2X applications depend on continuous, detailed location information, which can lead to privacy concerns. In a privately-owned vehicle, location traces will reveal the movements and activities of the driver, who might or might not be the vehicle owner. In short, sending and disseminating V2X user location information might be a privacy concern for the owner and driver of the vehicle.

In dense traffic areas, available channel resources will saturate and lead to an increase in packet losses. This could endanger driver and passenger safety. Congestion-control algorithms were examined and defined to modify specific parameters before these conditions reached critical levels. However, instead of looking at specific algorithms, researchers examined the Wi-Fi standard approach (IEEE 802.11p) versus the standard cellular approach (sidelinking LTE-V2X as defined by 3GPP as part of C-V2X in Release 14).

In the final analysis, it was decided that LTE-V2X was able to achieve better performance than IEEE 802.11p, under low channel loads, if it has a superior physical layer performance. When under low channel load levels, the MAC has a lower impact on performance than does the physical layer. Thus, it was determined that IEEE 802.11p outperforms LTE-V2X when the channel load increases, even in the case of having a lower physical layer performance.

The C-V2X communication technology was developed by 3GPP to enable direct communications among vehicular user equipment (VUE) over the sidelink, also named PC5 interface. C-V2X sidelink is the first wireless system to introduce distance as a dimension at the physical layer. This will enable a uniform communication range across widely varying radio environments for both LoS and non-LoS.

In short C-V2X technology includes two communication links.

1. Vehicle to Network (V2N), based on the existing cellular network (Uu)
2. Vehicle to Vehicle (V2V) direct communication link (PC5)
    - The direct communication link (PC5) mode is the main one used primary for safety and has two transmission scheduling modes: Mode 3 and Mode 4. Mode 3: Network assisted communication. C-V2X relies on the cellular network for scheduling and resource management.
    - Mode 4: Out-of-coverage/SIM-less operation. C-V2X is completely autonomous and independent from cellular network.

    Note, all C-V2X deployments are Mode 4 only. For various reasons Mode 3 is not yet viable.

Security and Privacy in V2X Communication

LTE-based V2X communication uses a high capacity, extensive cell coverage range and widely deployed infrastructure to support various vehicular communication services for safety and non-safety applications. Technical organizations such as 3GPP and Qualcomm have already prepared the roadmap toward 5G-based V2X services.

The security defined in 3GPP mainly includes confidentiality, integrity, authenticity, and resistance to replay attacks.

The full adoption of a double-key cryptosystem is advisable in the scenario of the possible solutions for automotive security and safety assurance against any cyberattack.

Other V2X applications include communication between vehicles that will augment existing methods to help with left- or right-turn assistance, emergency braking warnings, and improved situational awareness at intersections. Extending Waze concepts can control or suggest speed adjustments to account for traffic congestion and update a GPS map with real-time updates on lane closure and highway construction activity. V2X, in some form, is essential to support over-the-air (OTA) software updates for the now-extensive range of software-driven systems in your car, from map updates to bug fixes to security updates and more.

V2X safety messages can be made to include a Basic Safety Message (BSM) in US standards or Cooperative Awareness Messages (CAM) and a Decentralized Environmental Notification Messages (DENM) in a European Union (EU) standard. BSM contains position, velocity, and acceleration information and is transmitted up to 10 times per second. This message system also enables the vehicle receiving unit to predict collisions and warn the driver.

V2X Message Protection and Security

V2X and V2I communication need strong security to protect messages against fraudulent or misleading use that might lead to safety and privacy issues. Another security method is signed messages using Public Key Certificates to prevent unauthorized parties from interfering with the exchange of data and to pseudonymize the communication securely.

Public key infrastructure (PKI) consists of policies and procedures to create, manage, use, save, and revoke digital security certificates. PKI allows for the transfer of electronic information securely and goes beyond just passwords as authentication with a requirement of more rigorous identity confirmation.

C-V2X Performance in Crowded Highway Situations

The 5G Automotive Association (5GAA) ran V2X performance and functional tests in a test report entitled **V2X Functional and Performance Test Report**, in which C-V2X technology was tested for a highly-congested scenario in a laboratory setting. Even in this crowded scenario, C-V2X latency remained bounded by the 100ms latency budget configured for that scenario, which is a very positive result.

Conclusion

The FCC effectively changed the vehicle communications **Cooperative Intelligent Transport Systems (C-ITS)** market in the US via the restructuring of the 5.9GHz band.

The automotive industry must go forward on a narrowed spectrum with C-V2X technology instead of the widely used Dedicated Short-Range Communication (DSRC) spectrum. The changes announced pave the way for progress, eliminating the uncertainty caused by competing technologies.

V2X and 5G are fast-becoming integral technologies for automakers as it endeavors to commercialize fully autonomous vehicle technology in the years ahead. Ford is now making a major connected vehicle push that will generate a substantial new revenue stream with C-V2X technology. C-V2X is now featured on six models—the Ford Mondeo, Ford F-150 Raptor, Ford Evos, Ford Mustang Mach-E, Ford Edge Plus, and Ford Explorer.

Even more exciting is the effort by Ford in China as the first automaker to have C-V2X-equipped vehicles in production. These advanced-technology vehicles in China can send important information about the traffic ahead to traffic lights. This will enable manipulation of the timing of those lights to reduce congestion. V2X vehicle drivers can also receive information, including green light optimized speed advisory (GLOSA), traffic light information, red light violation warnings, and other pertinent road infrastructure details. A V2X vehicle's gauge cluster will alert drivers to maintain a certain speed range to avoid waiting at traffic lights. This will save fuel consumption and improve traffic efficiency.

More exciting vehicle advances are coming, all of which will significantly change how we drive our vehicles for the better.

Steering Clear: Vehicle-to-Everything Designs with Seamless Communication and No Interference

Ali Bawangaonwala Senior Marketing Manager, Qorvo

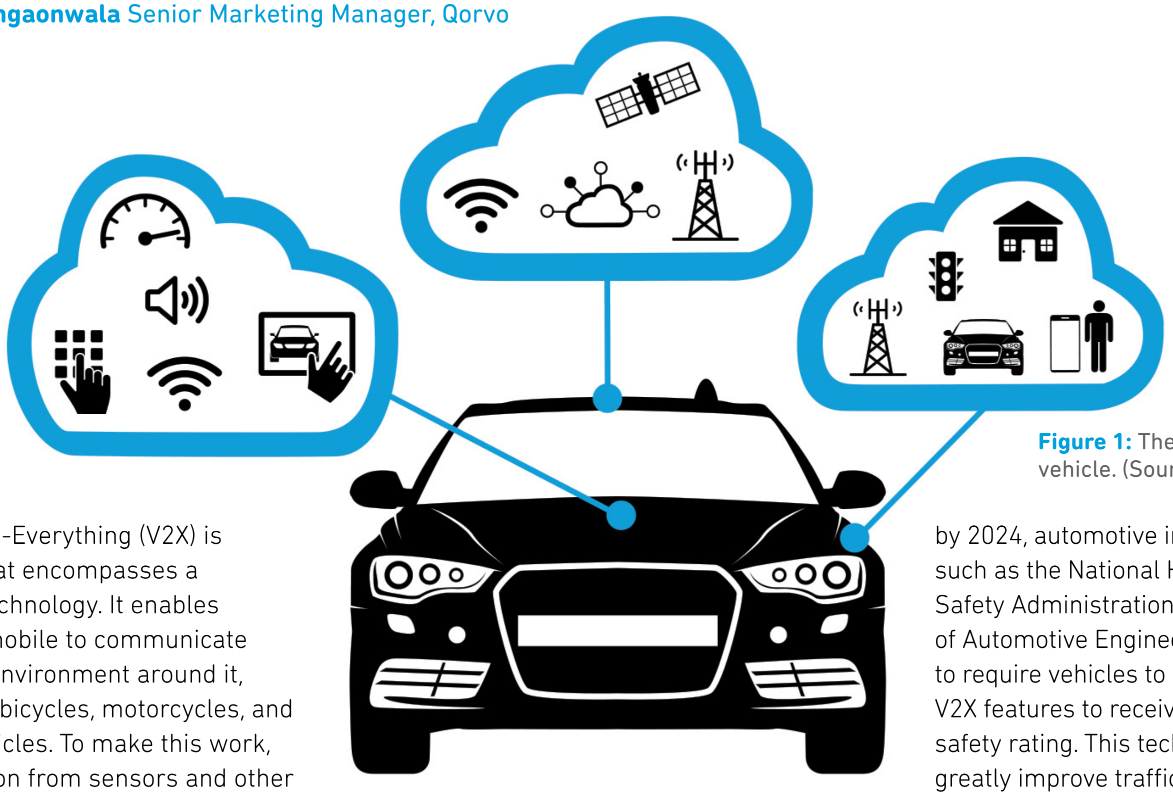


Figure 1: The connected vehicle. (Source: Qorvo)

Vehicle-to-Everything (V2X) is a term that encompasses a vehicle technology. It enables the automobile to communicate with the environment around it, including bicycles, motorcycles, and other vehicles. To make this work, information from sensors and other sources, inside and outside the vehicle, travel by means of low-latency, high-reliability links that will ultimately pave the way to fully autonomous driving. See **Figure 1**.

A major selling point for V2X communication is safety. V2X communication technology promises to lower the number of vehicle accidents, which will also lead to a reduction in associated injuries and deaths. **An NHTSA study** found that connected vehicle technology has the potential to reduce up to 80% of crashes where drivers are not impaired. In fact, by 2024, automotive industry bodies such as the National Highway Traffic Safety Administration and the Society of Automotive Engineers are expected to require vehicles to offer certain V2X features to receive a full, five-star safety rating. This technology will also greatly improve traffic management. By leveraging data from Road-Side-Units (RSUs) and On-Board-Units (OBUs), V2X technology can connect cars to other cars and drivers, pedestrians, bicyclists, and traffic lights. Information on traffic patterns, lights, and other vehicles can be relayed to the car through Wi-Fi, a cellular-connected vehicle's infotainment system, or even through an app on the driver's phone, allowing the driver to adjust to safer and more efficient driving patterns. This can lead to greener vehicle performance through the reduction of harmful CO_2 emissions, as well as lower fuel costs.

There are many components of V2X (see sidebar) "Vehicle Communications Acronyms + Meanings"). Enhancing V2X and bringing it to market is often a top priority for many car manufacturers because of the many safety benefits, as well as other communication benefits for the consumer. However, to design a robust system solution, we need to first understand the intricacies and challenges of V2X.

Cellular-V2X (C-V2X) brings several vehicle engineering challenges such as wireless coexistence caused by multiple radios inside and outside the vehicle. The new and future automobile will have many radios inside to address safety, security, and entertainment trends. These radios will lead to co-existence challenges. One obvious coexistence challenge is Dedicated Short-Range Communications (DSRC) and C-V2X (Cellular operators licensed carrier), which communicate using the same 5.9GHz band. Additionally, 4G LTE, 5G and Wi-Fi all have bands closely aligned with the 5.9GHz frequency range.

Future automobile trends

There are numerous, unique connectivity technologies in the connected vehicle, and they must not interfere with each other's signal quality to achieve seamless communication. These technologies include:

- V2X (DSRC and C-V2X) used for automobile safety
- 4G/5G cloud connectivity for in-vehicle OEM services such as remote diagnostics, over-the-air software updates, teleoperation, and more
- In-vehicle 4G/5G cloud connectivity entertainment
- Wi-Fi
- Bluetooth®
- Satellite digital audio radio services (SDARS)

V2X communication technology promises to lower the number of vehicle accidents, which will also lead to a reduction in associated injuries and deaths.

Vehicle Communications Acronyms + Meanings

Vehicle-to-Everything (V2X): A technology that allows vehicles to communicate with moving parts of the traffic system around them.

Vehicle-to-Infrastructure (V2I): Communication that allows vehicles to share information with traffic system components such as overhead RFID readers and cameras, traffic lights, lane markers, streetlights, signage, and parking meters.

Vehicle-to-Pedestrian (V2P): Communications between a vehicle and a pedestrian or multiple pedestrians within close proximity.

Vehicle-to-Network (V2N): Communication with, and access to, networks for cloud-based services.

Cellular Vehicle-to-Everything (C-V2X): Allows vehicles to communicate via mobile cellular connectivity to send and receive signals from a vehicle to other vehicles, pedestrians, or to fixed objects such as traffic lights in its surroundings.

Dedicated Short-Range Communications (DSRC): One-way or two-way short-range to medium-range wireless communication channels specifically designed for automotive use and a corresponding set of protocols and standards.

Why Qorvo should be your automotive design partner

How high-selectivity filter solutions tackle co-existence challenges

Let's examine some of the ways filter technology solutions help address V2X coexistence with Wi-Fi and cellular spectrum. Here are three of the top challenges:

- V2X and 5GHz Wi-Fi
- Wi-Fi 2.4GHz and Cellular bands 7, 40, 41
- Electronic Toll Collection (ETC) and V2X

V2X Coexistence Challenge with 5GHz Wi-Fi

As shown in **Figure 2**, the Wi-Fi 5GHz Unlicensed National Information Infrastructure 3 (UNII 3) band overlaps with the 5.9GHz V2X band. For these two radios to operate without interference, a filter is required. This filter needs to have very steep attenuated out of band edges near the 5.855GHz area to ensure the V2X and Wi-Fi UNII 3 signals do not cause communication interference. Additionally, the UNII 2C receive band noise can cause receive signal desense. Desense, in this case, is the design challenge of interference among wireless devices with multiple radios operating simultaneously. These signals could interfere and compromise the receiver's sensitivity, making it less able to receive weak signals. For example, if a transmit signal is not properly isolated from the receiver, it could interfere with the receive path signal, thus causing desense. Therefore, an additional filter is required to reduce the noise on the 5GHz receive signal.

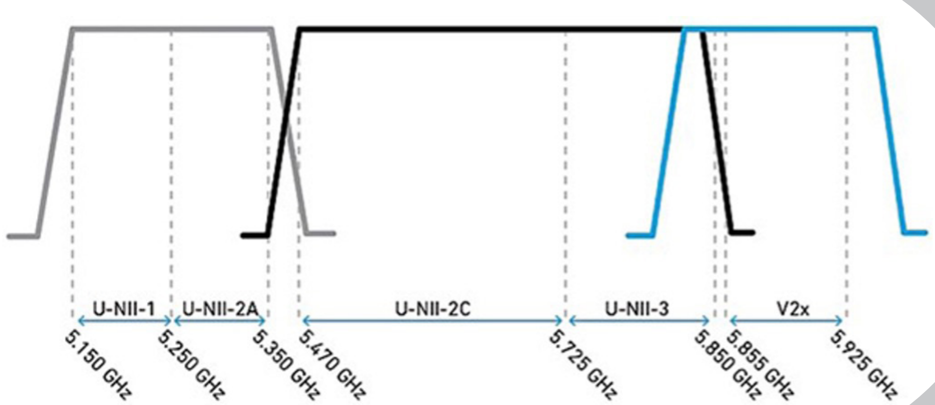


Figure 2: 5GHz automotive coexistence of V2X and Wi-Fi.

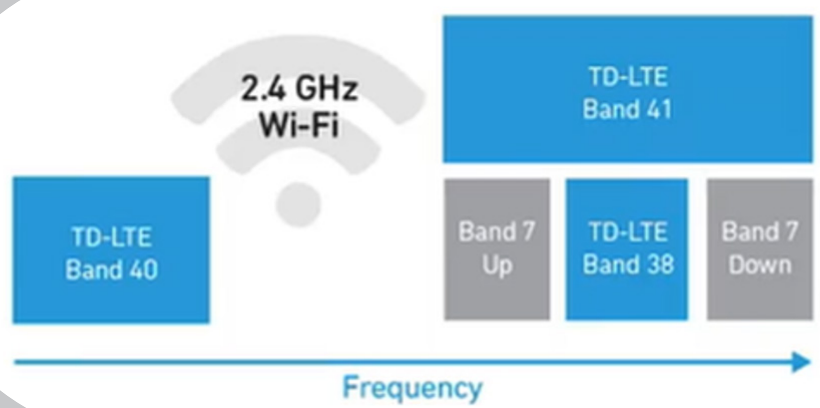


Figure 3: Coexistence between cellular and Wi-Fi 2.4GHz band.

Wi-Fi 2.4GHz Coexistence with Cellular Bands 7, 40, and 41

A second coexistence issue seen in V2X is the interference between cellular bands 7, 40 and 41 and the 2.4GHz Wi-Fi band. Shown in **Figure 3**, you can see that Wi-Fi 2.4GHz is positioned between and close to these TDD (B40 & B41) and FDD (B7) signals. When Wi-Fi 2.4 signals are transmitting and receiving in the vehicle, filters must be employed to make sure users on the cellular bands can continue communications without interruption. Again, this is achieved using BAW filter technology—both in discrete form and inside highly-integrated Qorvo modules.

V2X Coexistence Challenge with Electronic Toll Collection Radios

Beyond the above-mentioned coexistence challenges, there is the issue of V2X interfering with Electronic Toll Collection (ETC) services. ETC services in China and Europe operate very closely to the V2X bands. As shown in **Figure 4**, the European V2X band is only 40MHz from the European ETC band. The European V2X spectral emissions specification cannot be met without incorporating a notch filter at the input of the V2X front-end module, which allows the ETC to coexist with V2X.

The same issue exists in a China ETC application. The V2X China band is only 65MHz from the downlink of the ETC band. A notch filter must be employed on the front-end input to reduce spectral emissions to properly coexist. In the future, the China ETC band may likely become even closer to the V2X band because Chinese carriers are seeing possible capacity constraints due to bandwidth. Discussions on this topic are currently taking place in China.

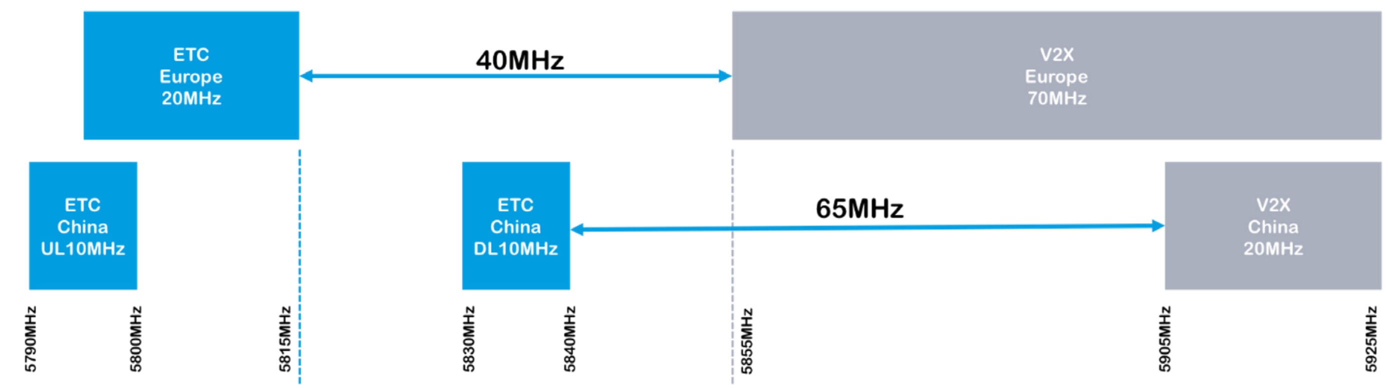


Figure 4: Electronic Toll Collection versus V2X bands.

What is the best filter technology to tackle these V2X coexistence challenges? Qorvo has helped numerous companies leverage Bulk Acoustic Wave filters for these types of applications, as we will outline below.

Bulk Acoustic Wave (BAW) filters

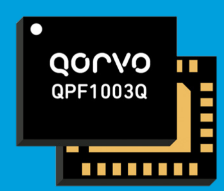
Avoiding interference in the cases outlined above calls for high-performance RF bandpass filters that can operate at high frequencies. BAW is well-suited for this high frequency operation. BAW filters also provide steep skirts to prevent signals from bleeding into adjacent bands and enable low insertion loss across the passband to sustain output power and maximize signal range.

The automotive environment requires reliable operation over the life of the vehicle, under extreme temperature and humidity as well as vibration (quartz crystal filters will not work here). Employing BAW filters in these challenging automotive conditions means engineers can now replace larger, harder-to-implement filter technology.

BAW filters uniquely possess the needed characteristics and will have all the capabilities required for the 5.9GHz band. Such filters provide the necessary steep skirts and high quality (Q) factors of up to 3,000, with a far smaller footprint than traditional ceramic or dielectric filters. BAW filters provide precise selectivity and small size and are perfectly suitable for advanced RF applications in vehicles. These filters are typically used for applications above 1.5GHz where high performance is required. Additionally, the technology is fundamentally capable of working at frequencies up to 7GHz and beyond.

A Front-end Solution

Qorvo offers BAW filter technology in discrete form and in modules. The Qorvo V2X Front-end suite has the first Band 47/Wi-Fi BAW coexistence filter that enables Wi-Fi coexistence with the V2X 5.9GHz band. This provides the ability to establish reliable links between vehicles and their surroundings. In addition, it includes two integrated front-end modules (FEMs) that support C-V2X and DSRC systems, a digital step attenuator, transmit/receive switch, and low noise amplifier. This front-end is chipset agnostic and enables a reliable V2X link with sufficient transmit linear power and excellent receive performance in a Wi-Fi environment where Wi-Fi and V2X coexists.There will be much more to come on this topic as we progress along the path of safe driving via high tech electronics innovations in road vehicles with wireless technology advancements.



How to Mitigate Spectrum Challenges Associated with V2X

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Executive Summary

Wi-Fi and 5G are recognized as enablers of autonomous vehicles. The challenge lies in how these technologies work together and co-exist—despite spectrum interference that can adversely impact vehicle operation and passenger safety. This paper discusses the technologies that support vehicular connectivity and how high-selectivity filter solutions address V2X coexistence with Wi-Fi to enable vehicular communications.

The Foundation for Vehicular Connectivity

In order for the truly autonomous vehicle to navigate without human intervention, data of all types must be shared continuously and in real time with other vehicles and the surrounding infrastructure.

This will happen using vehicle-to-everything (V2X) communication systems. V2X encompasses vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-network (V2N) and vehicle-to-pedestrian (V2P) communications.

V2X is based on 5.9GHz dedicated, short-range communications and is designed for fast-moving objects. It makes it possible to establish a reliable radio link, even in non-line-of-sight conditions. This trusted link enables drivers to be aware of hazards ahead, reducing potential automotive collisions, fatalities, and injuries.

Further, V2X will enhance global transportation efficiency and reduce CO2 emissions by warning of upcoming traffic congestion and suggesting alternative routes—with an added benefit of reducing vehicle maintenance.

Realizing the full potential of autonomous vehicles is complicated by the fact that V2X can be either C-V2X (cellular vehicle-to-everything), which uses cellular technology to create direct communication links, or DSRC (dedicated short-range communications), which is based on the IEEE 802.11p standard and was at one time the only V2X technology available.

Different auto manufacturers and countries are supporting one or the other standard; however, both utilize the same spectrum to solve the same problem, and they can co-exist.

Understanding Connectivity Technologies

In order to better understand coexistence challenges, we must look at the technologies involved in vehicular connectivity and how they function (**Figure 1**). Because each has its own characteristics, they must interact without degrading the performance of the others.

These technologies include:

- V2X (DSRC, C-V2X) for automotive safety: V2X will communicate with vehicles, roadside infrastructure, and the overall environment to improve safety and create a path to autonomous driving.
- 4G/5G cloud connectivity for vehicle OEM services: Applications for 4G/5G connectivity could include remotely diagnosing and monitoring car operations, making over-the-air software updates, performing teleoperation, and operating a fleet of shared, autonomous vehicles.
- 4G/5G cloud connectivity for in-vehicle experiences: Drivers and passengers could use this type of connectivity to enjoy new in-vehicle experiences, from augmented reality-based navigation to rear-seat entertainment and music streaming services.
- Wi-Fi for premium in-vehicle experiences and automotive dealer services: Drivers and passengers could enjoy many enhanced in-car Wi-Fi-based experiences. For example, efficient Wi-Fi connectivity throughout the vehicle could support ultra-high definition (ultra-HD) video streaming to multiple displays and enable screen mirroring from compatible devices and wireless back-up cameras. Wi-Fi could also support automotive dealer services, enabling automatic check-in, diagnostic data transfer, and software updates.
- Bluetooth®: Drivers and passengers could stream high-fidelity music via Bluetooth, as well as benefit from practical services such as using a smartphone as a key fob.
- SDARS (satellite digital audio radio services): With connectivity to satellite-based radio services, vehicle occupants are connected to their favorite radio broadcasts no matter where they are.

The Coexistence Challenges of 5G and LTE

By understanding the functions/benefits of the various technologies, we can better look at coexistence challenges—specifically, compatibility with 5G and LTE.

5G, the fifth generation of cellular technology, increases data rates, reduces latency, and enhances the flexibility of wireless services. The 5G spectrum is classified as sub-6GHz and millimeter wave.

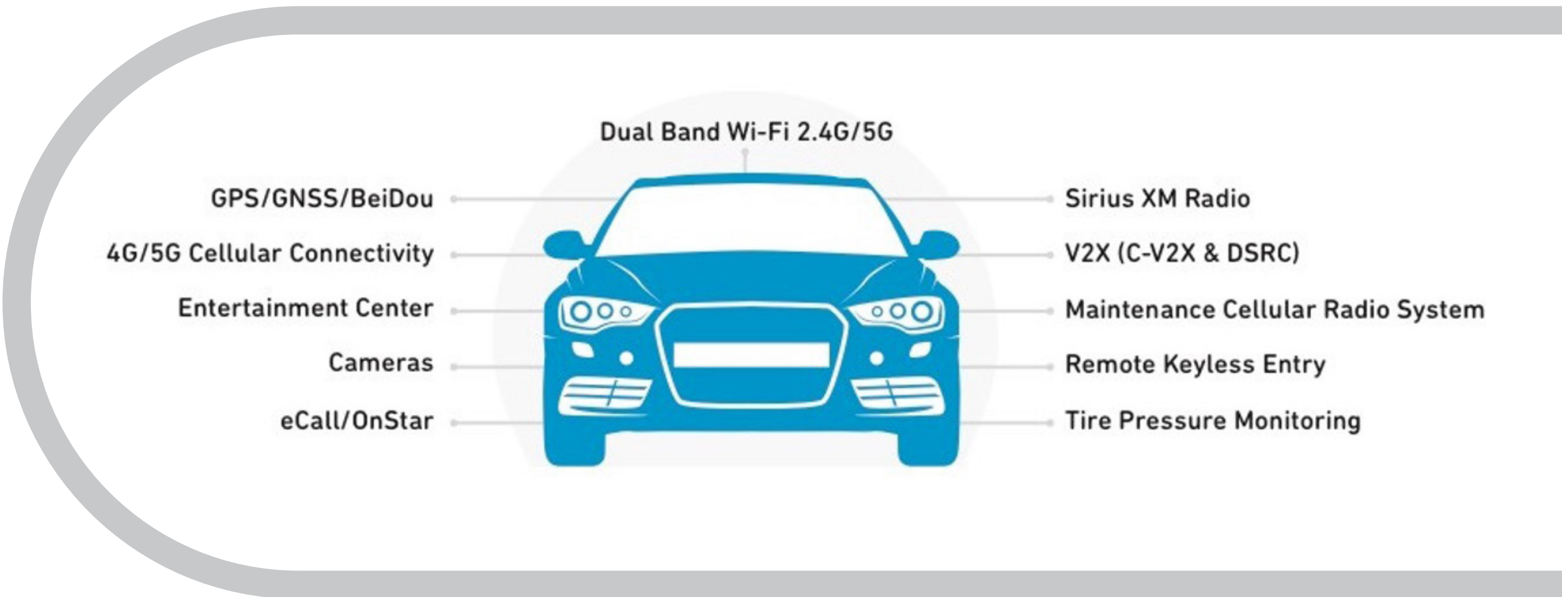


Figure 1: Vehicular connectivity technologies. (Source: Qorvo)

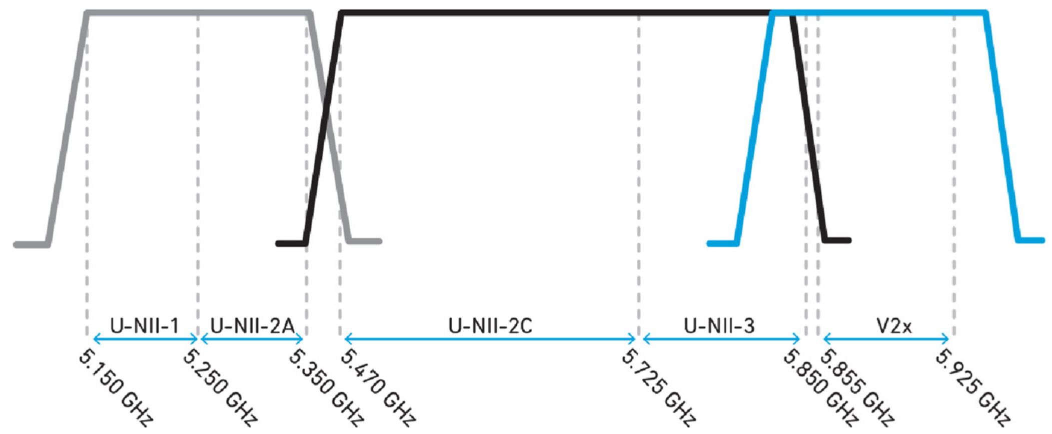


Figure 2: V2X coexistence with 5GHz Wi-Fi. (Source: Qorvo)

Wi-Fi operates in the 2.4GHz, 5.2GHz and 5.6GHz spectrum, and 2.4GHz Wi-Fi must co-exist with the LTE B40 and B41 frequency bands. 5GHz Wi-Fi enables higher data rates than 2.4GHz because more channels can be bundled together in the 5GHz band thanks to larger bandwidth. This means radio designers must use the correct filter products—those with enough attenuation in adjacent bands to deliver good receiver sensitivity—to get the full benefit of wider bands.

Another challenge is 5.6GHz Wi-Fi coexistence with V2X (**Figure 2**), when a passenger in the autonomous car is using a 5.6GHz hot spot. The only way to have a reliable V2X radio link is to ensure relatively low desense to the receiver. This is only possible with appropriate filter solutions that provide enough out-of-band attenuation to 5.6GHz Wi-Fi (**Figures 3 and 4**).

High-performance Filtering – Why LTCC is Not Enough

An ever-increasing array of features is adding to the number of different radios in automobiles, and today there are as many as five radios in a single vehicle (i.e. V2X, 4G/5G, Wi-Fi, Bluetooth, SDARS). This means that multiple radio transceivers are operating in close proximity to each other in different frequency bands. If the transmit power of one RF chain exceeds the power level of the signal reaching a nearby receiver, this can cause receiver sensitivity issues.

Coexistence filters help reduce interference issues from these "aggressor signals," which can not only cause receiver sensitivity problems but also result in regulatory non-compliance. However, not all filters that claim coexistence capabilities are suitable for the job. For example, the graphic in **Figure 3** compares the performance and system impact of a B47 bulk acoustic wave (BAW) filter with a low temperature co-fired ceramic (LTCC) broadband filter.

... today there are as many as five radios in a single vehicle...

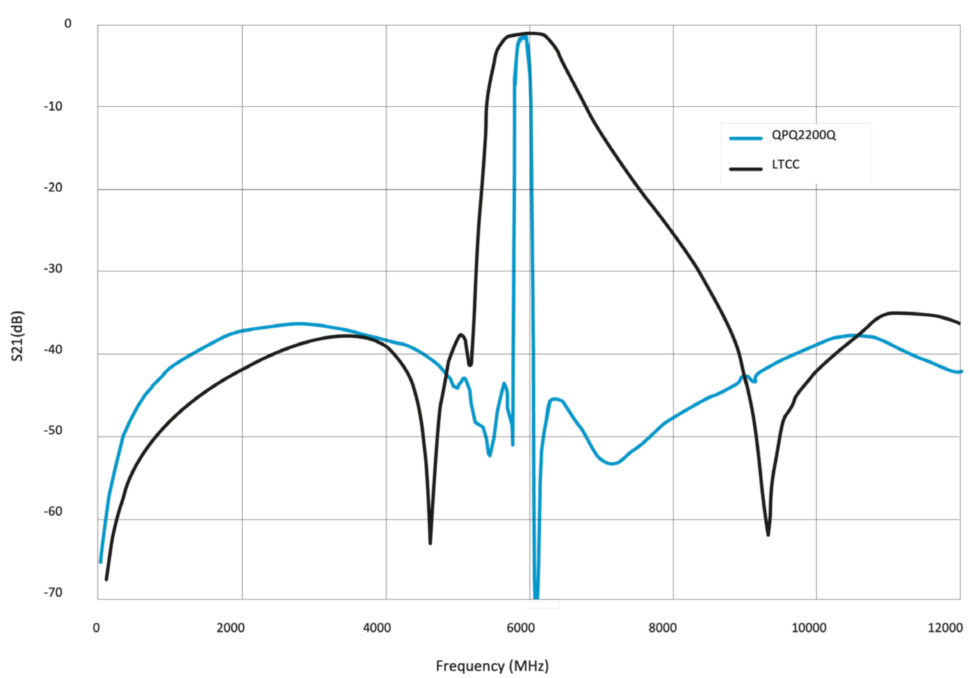


Figure 3: Comparison of QPQ2200Q to LTCC: Wideband performance. (Source: Qorvo)

The LTCC is filtering only broadband frequencies. The B47 BAW filter offers similar insertion loss as the LTCC filter, but also provides high rejection of the 5GHz UNII 1-3 bands. The B47 BAW filter can replace the LTCC filter on the Tx/Rx path, or it can be placed on the Rx side only. **Figure 4** illustrates how the LTCC filter provides no rejection of the UNI-3 band and poor rejection in the UNII-2 and UNI-1 bands.

Next, let's look at the comparison of LTCC vs. B47 V2X coexist filter from a systems and implementation standpoint. **Figure 5** compares V2X—Wi-Fi antenna isolation needed in order to achieve a 1,000-meter V2X link. The plot to the left shows a V2X system (TCU + active antenna) with only an LTCC filter on the Tx path and requiring greater than 80dB antenna isolation, which could be difficult to achieve in practice. The plot to the right shows a V2X system with a B47 V2X coexist filter in the TCU and active antenna requiring only 15dB antenna isolation in order to achieve a 1,000-meter V2X link. If design/systems engineers can achieve >20dB antenna isolation, they may need only one V2X coexist filter in the active antenna. Besides in-car Wi-Fi, there is another use case to be considered when deciding on filtering solutions, whether the car has built-in Wi-Fi capability or not, and that is when the antenna isolation is dictated by the passengers using Wi-Fi hotspots in their mobile phones.

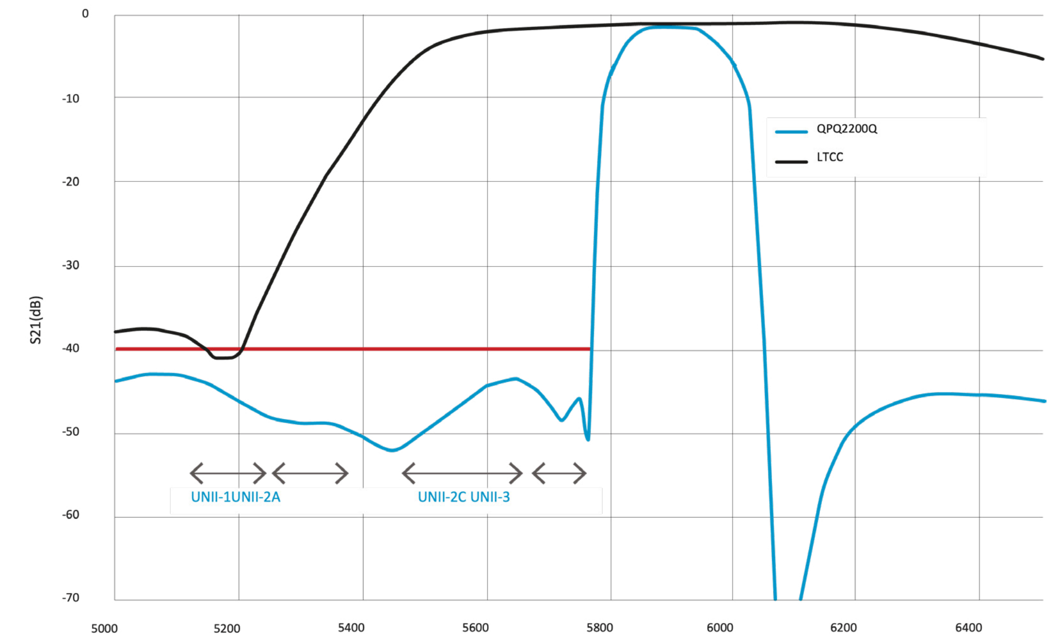


Figure 4: Comparison of QPQ2200Q to LTCC: B47 BAW filter rejects 5GHz UNII 1-3 bands. (Source: Qorvo)

Qorvo's filter products use patented BAW technology optimized to address complex selectivity requirements, from 1.5GHz up to 6GHz in standard footprints. For example, the Qorvo QPQ2200Q filter is the world's first filter to address coexistence of V2X with 5.6GHz Wi-Fi for autonomous vehicles. Another example is the Qorvo QPQ2254Q 2.4GHz Wi-Fi filter, designed to enable coexistence with LTE B40 and B41. These filters also offer a smaller footprint than ceramic filters, which adds to design flexibility.

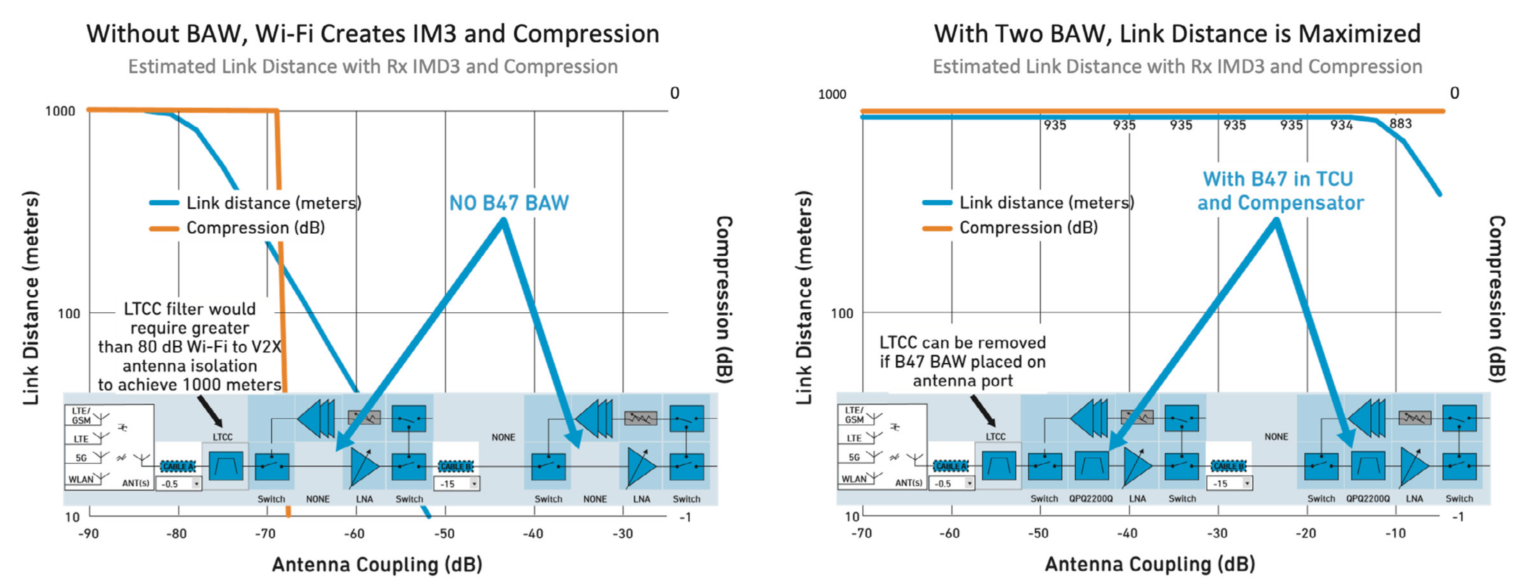


Figure 5: V2X—Wi-Fi antenna isolation needed to achieve a reliable V2X link: QPQ2200Q B47 vs. LTCC. (Source: Qorvo)

Yet even BAW band pass filters are not a complete solution to coexistence issues in the V2X environment. We must also consider the essential role played by notch filters. While the band pass filter discussed above provides adequate out-of-band rejection, Qorvo's QPQ2230Q notch filter "notches out" Rx band noise in the V2X band on the 5GHz Wi-Fi path, thus preventing Rx band noise from coupling back into the V2X system and causing desense issues, as illustrated in the

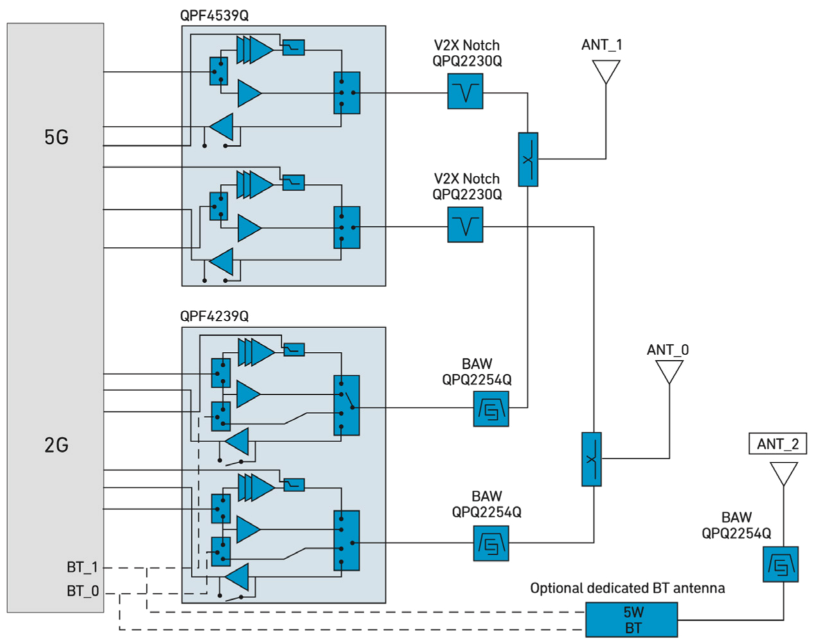


Figure 6: Wi-Fi front-end with a V2X notch (QPQ2230Q) on the 5GHz path.

system calculator (**Figure 6**). **Figure 7** illustrates that there will be up to 18dB desense in the V2X receiver if the notch filter is not used on the 5GHz Wi-Fi path vs. almost zero desense with a well-designed notch filter leveraging the benefits of BAW technology.

Another critical challenge that needs careful attention is that V2X needs to coexist with electronic toll collection (ETC). The problem here is that the ETC spectrum (for Europe it is 5795-5815MHz, for China it is 5790-5800MHz UL, 5830-5840MHz DL) is too close to the V2X spectrum (for North America and Europe 5855-5925MHz, for China 5905-5925MHz), as shown in **Figure 8**.

One way to address this issue is by notching out the ETC spectrum with a properly designed filter on the V2X path. Let's look at Europe. **Figure 9** illustrates a comparison of spectrum emissions mask with and without the notch filter at the input of V2X FEM. The plot to the left shows that the spectrum emissions from the output of the PA cannot pass the ETC spec of -65dBm/MHz, and hence V2X cannot coexist with ETC unless it is addressed in the ETC radio or through some software mitigation methods. The plot to the right shows that V2X can coexist with ETC if a well designed notch filter is inserted in the V2X radio.

Now, let's look at the state of the spectrum for China (**Figure 10**). Again, as can be seen from the plot to the left, ETC cannot coexist with V2X unless it is addressed in the ETC radio. The plot to the right shows spec compliance with margin to ETC spec of -65dBm/MHz, if a well-designed filter is used in the V2X radio.

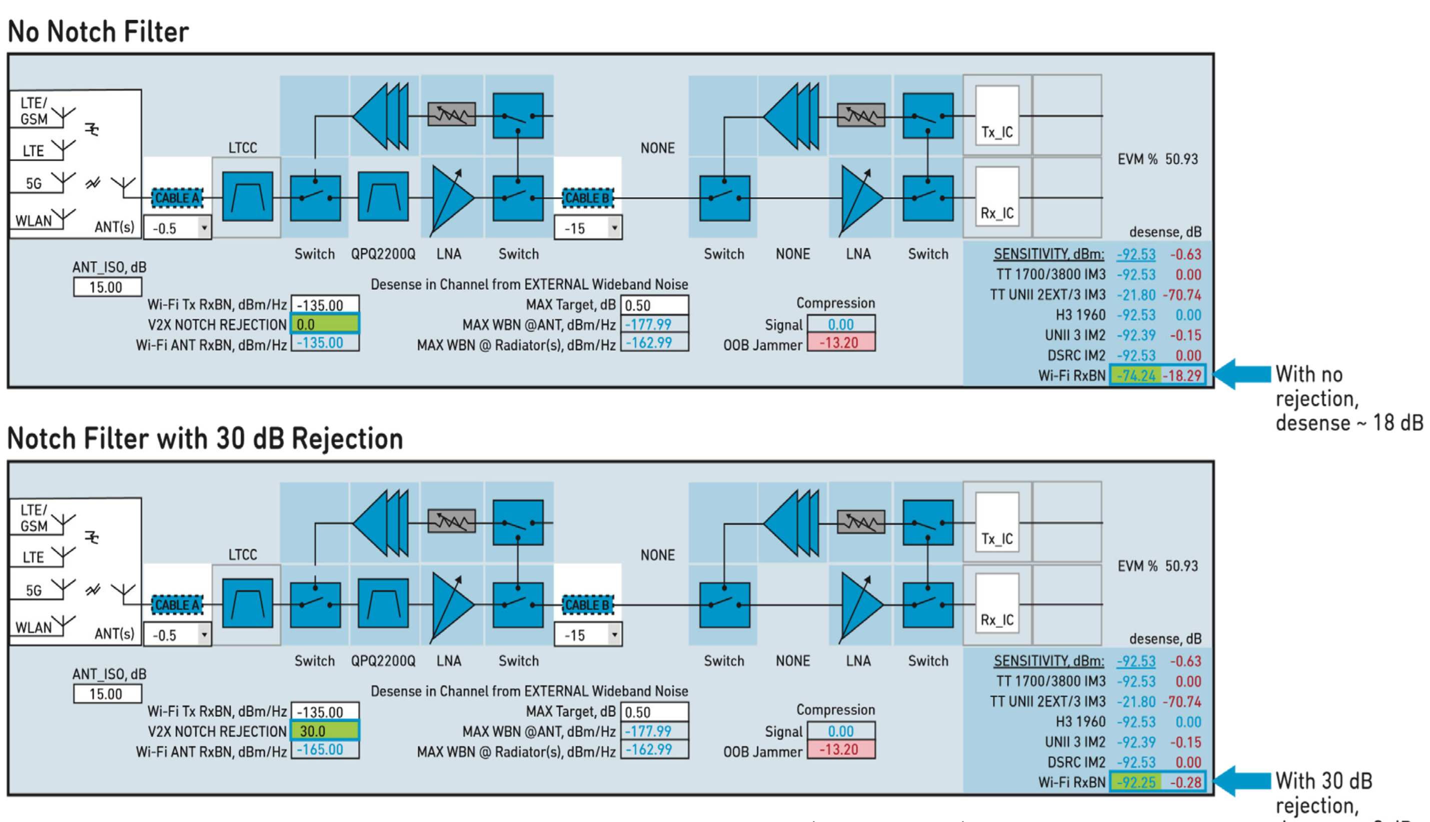


Figure 7: Rx band noise and desense with and without QPQ2230Q notch filter. (Source: Qorvo)

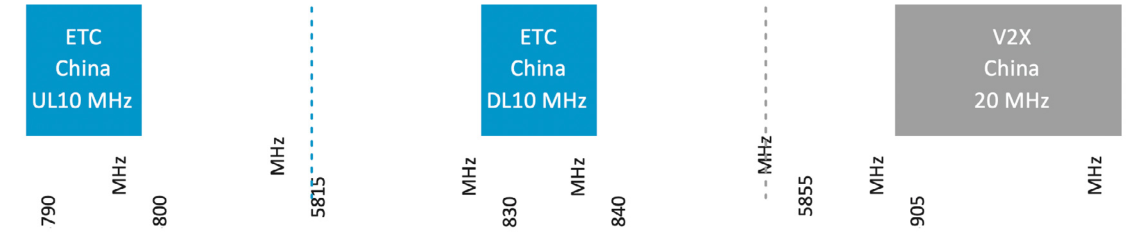


Figure 8: Global ETC spectrum coexistence with V2X. (Source: Qorvo)

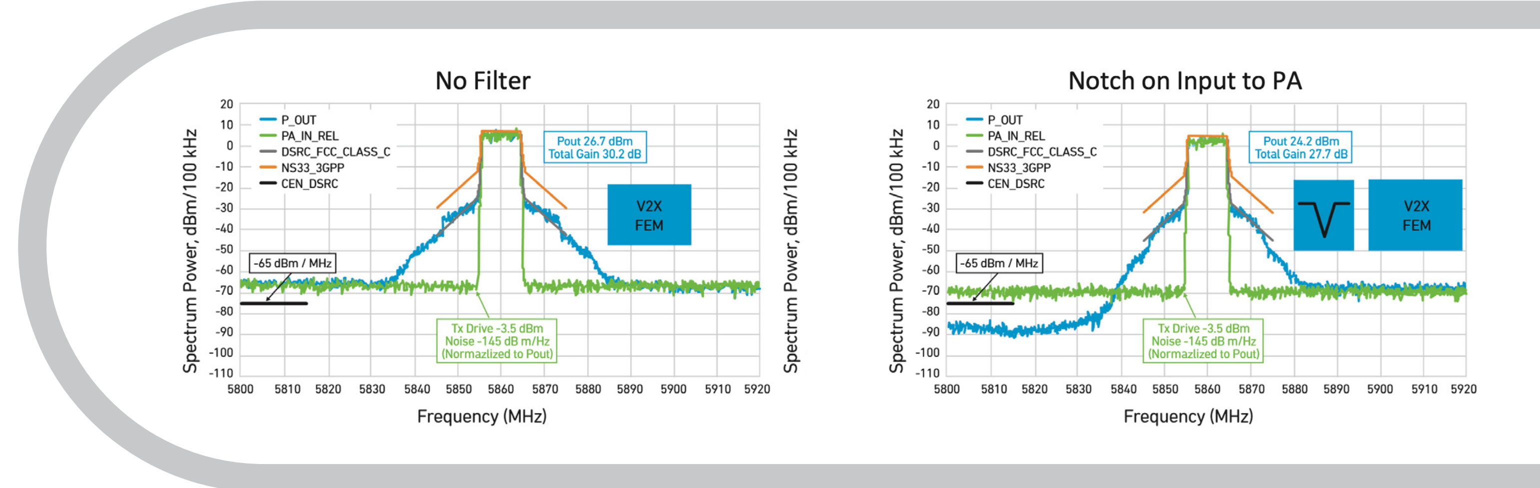


Figure 9: Europe: Comparison of spectrum emissions mask—with and without ETC notch filter. (Source: Qorvo)

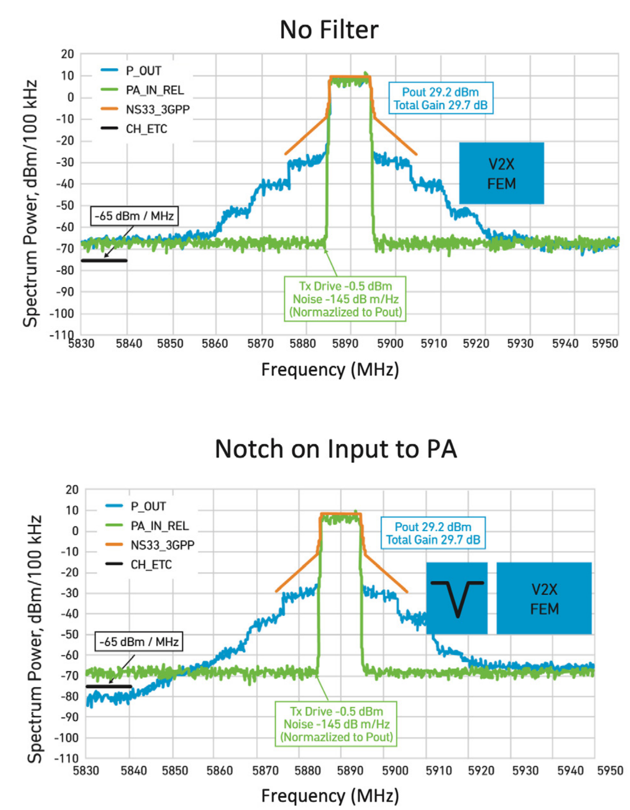


Figure 10: China: Comparison of spectrum emissions mask—with and without ETC notch filter. (Source: Qorvo)

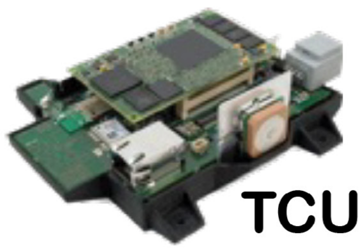
Two of the parameters that characterize high-performance filter products are the resonator qualities, i.e. quality factor (Q) and coupling factor (k2). High Q is necessary to minimize insertion loss, while high k2 enables wider bandwidth. Technology advances at the resonator level have helped improve insertion loss and high selectivity performance with wider bandwidth filter products at frequencies up to 6GHz.

Conclusion

A combination of high-Q band pass and notch filters offers the most complete solution to coexistence challenges in the design of autonomous vehicles. Based on the data discussed above, LTCC filters are not true coexistence filters and do not work in the unique automotive environment where Wi-Fi and V2X are situated next to each other.

The seamless coexistence of all the technologies on the connected car spectrum, enabled by advanced BAW band pass and notch pass filtering solutions, will ensure that our increasingly mobile world is safer, more reliable, and more enjoyable.

Qorvo Automotive Solutions



Telecommunication Control Unit (TCU)

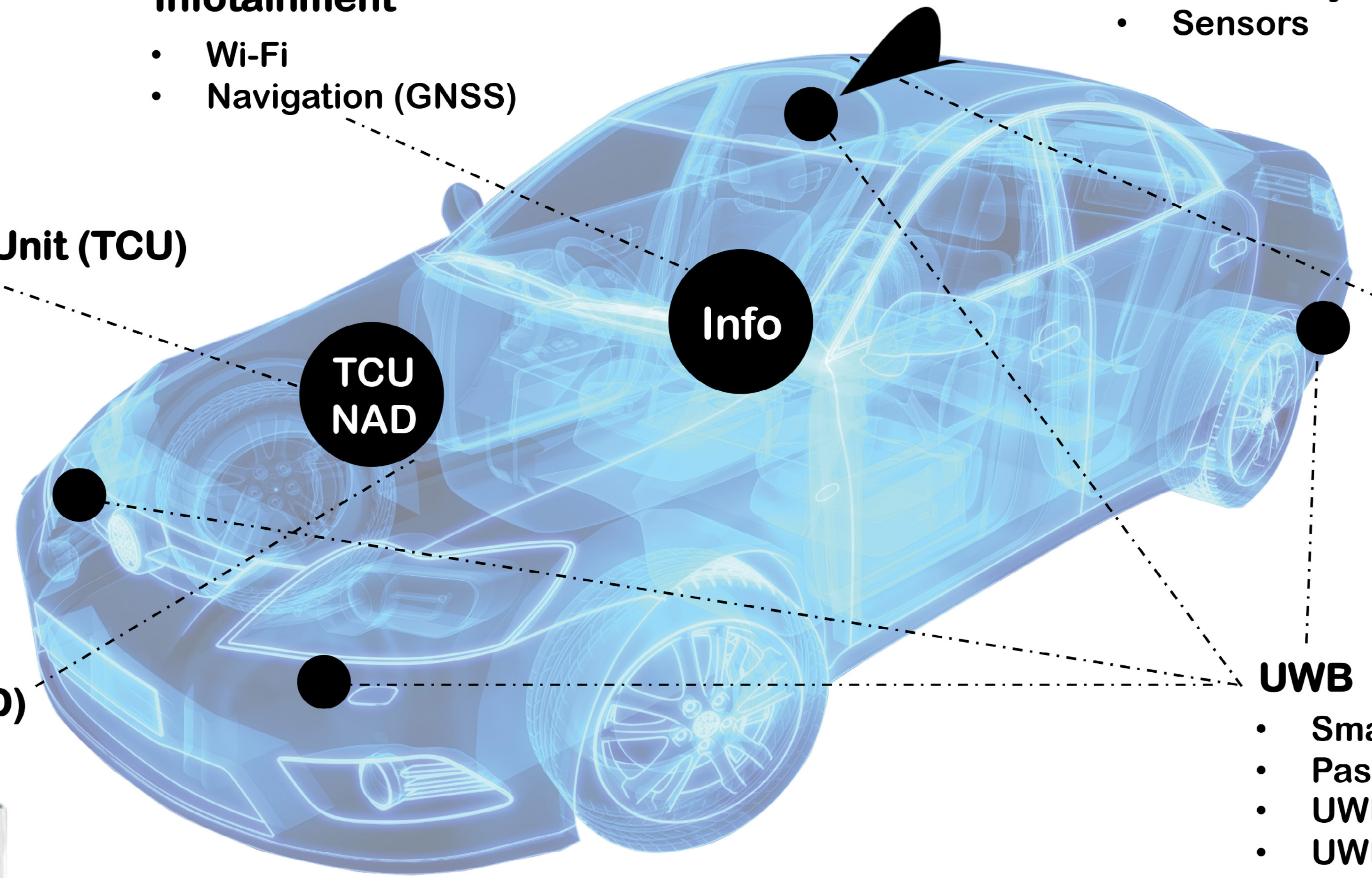
- Wi-Fi module
- V2X – DSRC/C-V2X
- BAW filters (co-existence)
- eCall switches
- Bluetooth® technology
- GNSS

Infotainment

- Wi-Fi
- Navigation (GNSS)

Other Solutions:

- USB charger/control
- EV battery charging
- Sensors



Antenna

- SDARS (SiriusXM)
- V2X compensator
- Antenna tuners
- Switches
- mmWave

Network Access Device (NAD)

- LTE MHB PAMiD
- LTE LB PAD
- 5G FEMs
- APT modulator
- Switches

UWB

- Smart car access
- Passenger detection
- UWB inside car
- UWB in key fobs

Qorvo offers a full portfolio of automotive solutions, with both active and passive devices to meet the challenging requirements of the automotive industry. We have connectivity products for 802.11p, automotive Wi-Fi, SDARS, GPS, and LTE, plus a wide range DC/DC converters and modular power management ICs. In addition, for electric vehicles, we offer intelligent motor controllers and EV battery charging solutions. AEC-Q100 and AEC-Q200 testing is performed on many products to ensure they are ideally suited to the automotive environment.

View Qorvo's portfolio on Mouser.com

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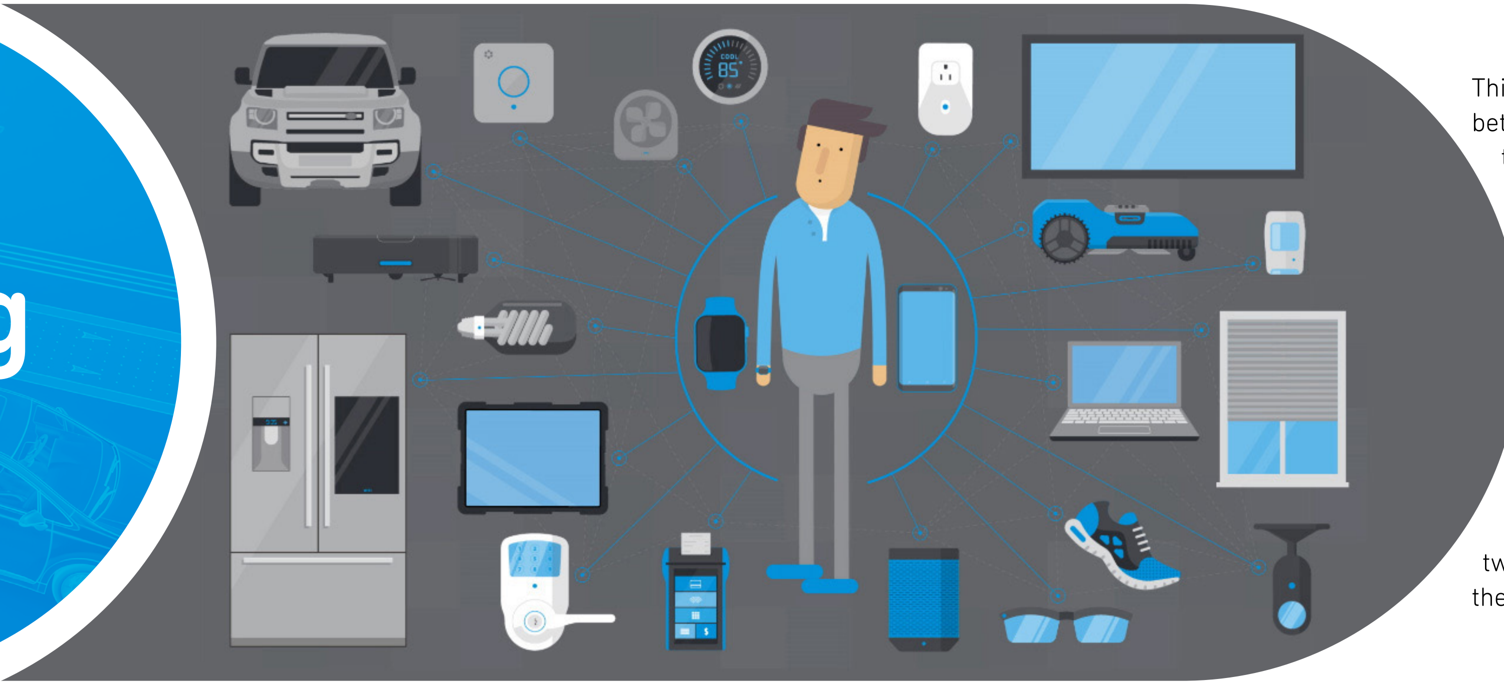
A Far Superior Automobile Using UWB Technology

Jean-Jacques DeLisle for Mouser Electronics



Imagine a distance/location and communication wireless technology that is both small and cost-effective while delivering centimeter accuracy in real-time. This is Ultra-Wideband (UWB).

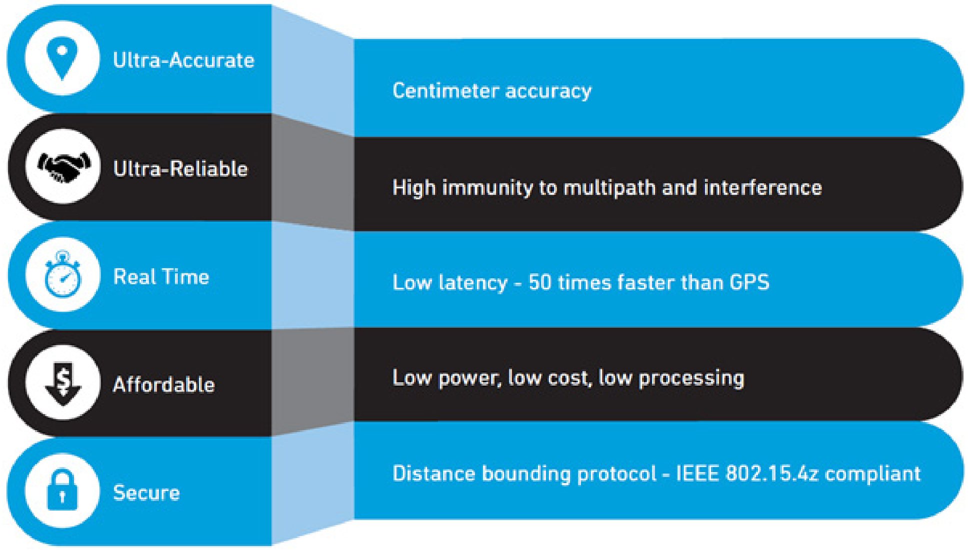


Figure 1: UWB in a nutshell. (Source: Qorvo)

Introduction

Wireless location/distance sensing and secure communications are the backbone of the latest convenience, performance, security, and safety features of emerging automotive systems from consumer to fleet vehicles. Autonomous driving and augmented driver assistance features are increasingly in demand. However, there are limitations to familiar short-range relative location sensing technologies for automotive applications, of which the most significant are:

- The latency/location update rate
- Location accuracy, and
- Security of the accompanying communication

A recently reinvented technology, Ultra-Wideband (UWB), is poised to substantially enhance short-range relative location sensing, secure communication between vehicles, and develop many previously infeasible advanced automotive features.

What is UWB?

Ultra-Wideband (UWB) is a wireless standard based on IEEE 802.15.4z that is designed to provide micro-location and secure communication. UWB is also designed to be superior to many of the existing wireless standards regarding reliability, location accuracy, location latency/update rate, and security while being affordable and compact. Additionally, due to the nature of UWB's physical layer protocol, UWB communications and location sensing are highly immune to multi-path and interference, all while using minimum energy (**Figure 1**).

This distance-measuring method is secure and distinct between the two UWB communicating radios and is immune to multi-path, as the shortest path will always be the shortest distance between the two radios.

Extending this concept further to include additional anchors distributed throughout an environment can enable real-time navigation. With multiple synchronized anchors in space, the exact position of a tag in 3D space can be determined using Time Difference of Arrival (TDoA) or Reverse TDoA (RTDoA).

Suppose a UWB tag is equipped with multiple antennas. In that case, the Phase Difference of Arrival (PDoA) can be used to calculate the relative position of the two devices by determining the distance and the bearing of the communication radios.

How Does UWB Work?

UWB uses extremely wideband and short pulses (~2 nanoseconds) with very sharp rise/fall times to encode data using binary phase-shift keying (BPSK) and/or burst position modulation (BPM). Two consecutive impulse radio (IR) signals are used in UWB to represent a symbol and can be within one of the chirp-intervals (Tc) that is within a time frame (Tf). The use of time-hopping code allows for the accurate determination of the position of a signal in a single dedicated time frame, which minimizes the chance of interference between two UWB systems (**Figure 2**).

Each UWB communication is timestamped. Timestamping allows for the use of the Time-of-flight (ToF) of the signals between two radios to calculate the distance between the two radios, point-to-point (P2P) Two-Way Ranging (TWR).

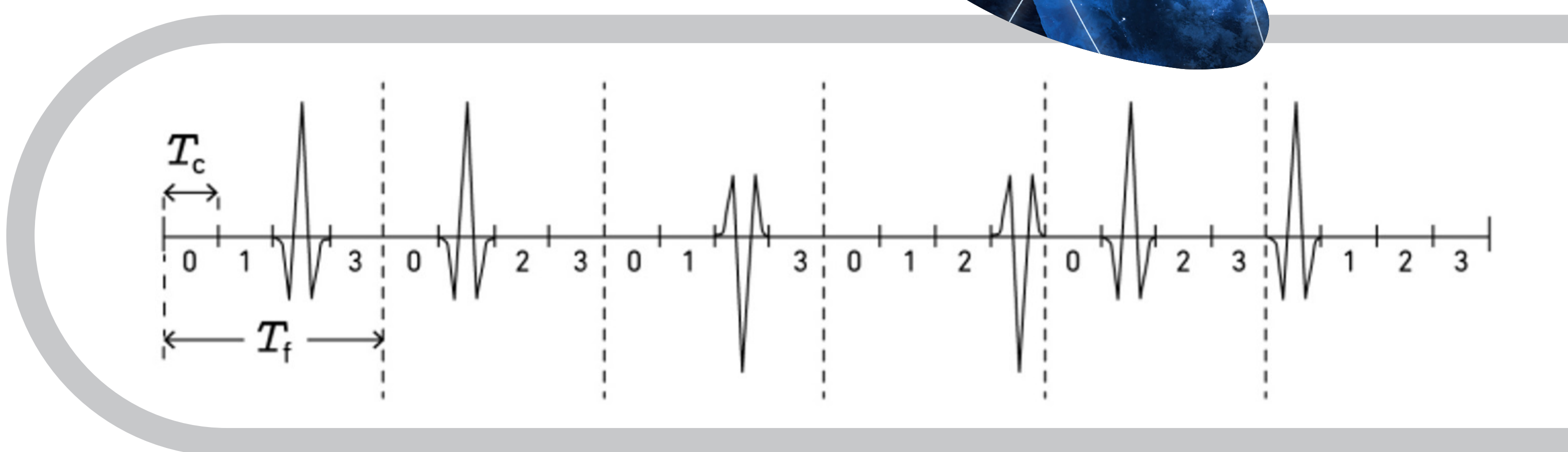


Figure 2: UWB transmits information using short sequences of extremely narrow pulses. (Source: Qorvo)

Overview of Current Location Technologies

There are five different approaches to distance/location measurements using modern wireless communication: RFID, Wi-Fi, Bluetooth, GPS, and UWB. RFID, Wi-Fi, and Bluetooth use RSSI to calculate distance. RSSI is a measure of the relative signal strength between a transmitting and receiving radio, which can be used to approximate the distance, given specific knowledge of the channel. Another method is GPS, which measures ToF between a user device (UE) and several time-synchronized satellites to determine the distance from each satellite, which can be used to calculate the 3D position relative to the satellite constellation. Lastly, there is Qorvo's IR UWB ToF technology (**Figure 3**).

The main difference between these methods and Qorvo IR UWB ToF is that the UWB approach uses extremely wideband frequency signals that are extremely short in time. Narrowband ToF systems use short pulses, but only over a narrow frequency band. Wi-Fi, Bluetooth, and RFID also use ToF, but are also limited in bandwidth and aren't capable of producing extremely short pulses with sharp rise/fall times (clean edges) compared to UWB (**Figure 4**). The ultra-wideband bandwidth of UWB means that the signal energy is distributed over the entire ultra-wide frequency band, which means that the protocol is comparably immune to interference at any given frequency. The incredibly sharp rise/fall times and the brief time of the UWB pulses minimize the impact of multi-path interference and enable very accurate time measurements, resulting in enhanced accuracy.

TECHNOLOGY	Qorvo UWB Alliance	Bluetooth	WiFi	RFID	GPS
WHERE USED					
ACCURACY	Centimeter	1-5 meters	5-15 meters	Centimeter to 1 meter	5-20 meters
RELIABILITY	★★★★★ Strong immunity to multi-path and interference	★☆☆☆☆ Very sensitive to multi-path, obstructions and interference	★☆☆☆☆ Very sensitive to multi-path, obstructions and interference	★★★★★	★★★☆☆ Very sensitive to obstructions
RANGE / COVERAGE	Typ. **70m** Max **250m**; Typ. 250m² per anchor	Typ. **15m** Max **100m**; Typ. 25m² per beacon (for 2m accuracy)	Typ. **50m** Max **150m**; Typ. 100m² per access point (for 5m accuracy)	Typ. **1m** Max **5m**; Typ. 25m² per reader	N/A
DATA COMMUNICATIONS	☑ up to 27Mbps	☑ up to 2Mbps	☑ up to 1Gbps	☒	☒
SECURITY (PHY LAYER)	★★★★★ Distance-Time bounded protocol	★☆☆☆☆ Can be spoofed using relay attack	★☆☆☆☆ Can be spoofed using relay attack	★☆☆☆☆ Can be spoofed using relay attack	N/A
LATENCY	★★★★★ Typ. <1ms to get XYZ	★☆☆☆☆ Typ. >3s to get XYZ	★☆☆☆☆ Typ. >3s to get XYZ	★★☆☆☆ Typ. 1s to get XYZ	★★★☆☆ Typ. 100ms to get XYZ
SCALABILITY DENSITY	★★★★☆ >10's of thousands of tags	★★☆☆☆ Hundreds to a thousand tags	★★☆☆☆ Hundreds to a thousand tags	★★★★★ Unlimited	★★★★★ Unlimited
POWER & BATTERY	5nJ/b TX · 9nJ/b RX **Coin Cell**	15nJ/b RX/TX **Coin Cell**	50nJ/b RX/TX **Lithium Battery**	**Passive**	**Lithium Battery**
TOTAL COST (infrastructure, tag, maintenance)	$	$	$$$	$$$	$$$

Figure 3: Comparison of various wireless location and communication standards. (Source: Qorvo)

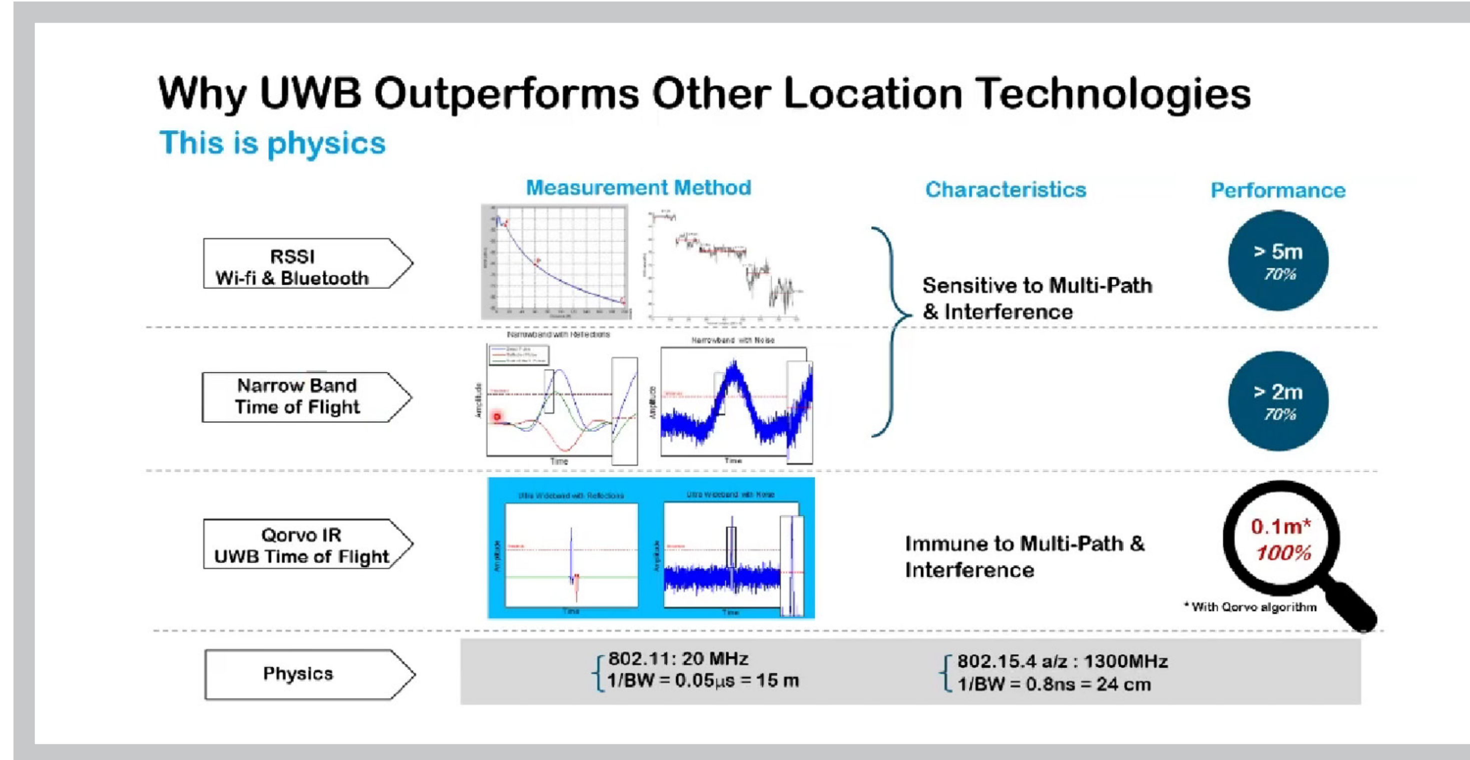


Figure 4: Comparison of the distance/location between RSSI, Wi-Fi, Bluetooth, Narrowband ToF, and Qorvo IR UWB ToF. (Source: Qorvo)

These reasons are why UWB can achieve centimeter accuracy between two devices over a relatively far distance compared to Bluetooth, Wi-Fi, and RFID. Moreover, UWB is a communication protocol with a maximum throughput of 27Mbps, which is superior to all other protocols except Wi-Fi. The very short pulses and fast distance/position calculations mean that UWB allows for real-time distance/location tracking with sub-ms speeds for 3D tracking, which is approximately 100 times faster than GPS. Additionally, UWB tags and anchors are low-cost and power-efficient enough to be massively scaled, which is also supported by the protocol and hardware.

UWB For Automotive Applications

It shouldn't be a surprise that legacy remote keyless entry (433MHz car dongles/key fobs) are not the most secure solution for preventing unwanted entry into automobiles. Several well-known exploits to these devices can sometimes allow access or even control of an automobile. Hence, the Car Connectivity Consortium (CCC) has developed a new standard that leverages UWB to create a much more secure remote keyless entry method.

In fact, the CCC's UWB standard uses the same type of security used in credit cards. US, Japanese, and European car manufacturers are already adopting this UWB standard, with ongoing efforts to encourage adoption with Chinese car manufacturers. In Q3 of 2018, the CCC adopted high-rate pulse UWB (HRP-UWB), which drives the interoperability between Automotive and Mobile manufacturers to enable Mobile as a Key-fob.

The first use case for automotive UWB is Passive Entry/Passive Start (PEPS), which uses NFC in phase 2 and UWB and Bluetooth Low Energy (BLE) in phase 3 of the CCC Conform Access System PEPs initiative.

An additional use case is leveraging the short-range radar capability of UWB to provide a new class of safety requirements as Intrusion and Passenger detection, or for easy trunk access, by detecting people and objects inside and outside of a vehicle. UWB radar technology is sensitive enough that it can be used to detect human breathing and even differentiate between adults and infants. Not only could this help prevent small children and infants from being left unattended in vehicles, but it could also be used to alert driver protection systems if a driver falls asleep or is otherwise incapacitated.

Figure 5: Emerging and potential future automotive UWB use cases. (Source: Qorvo)

Another is the use of UWB to provide secure Autonomous Electric Vehicle Wireless Charging, which would enable a UWB electric car to be driven to a wireless charging zone and automatically share credentials and enable the charging transaction (**Figure 5**).

Automotive UWB Hardware & Software

The first emerging automotive UWB application is the Digital Key (DK) Car Access System, which enables a phone with UWB to connect to a UWB-equipped car for remote keyless entry, but on a much more secure level. DK technology uses an authorization server to provision a phone with car access using private keys. The initial key exchange is done through the phone and car Secure Elements (SE), enabling autonomous car access without needing a cloud connection (**Figure 6**).

Using a high-end car as an example for a PEPs system, a phone, or keyfob with the necessary UWB, BLE, NFC, and electronic SE (eSE) electronics (pre-provisioned) can be used to access a car that is also equipped with compatible hardware and SEs. In this example, each UWB transceiver

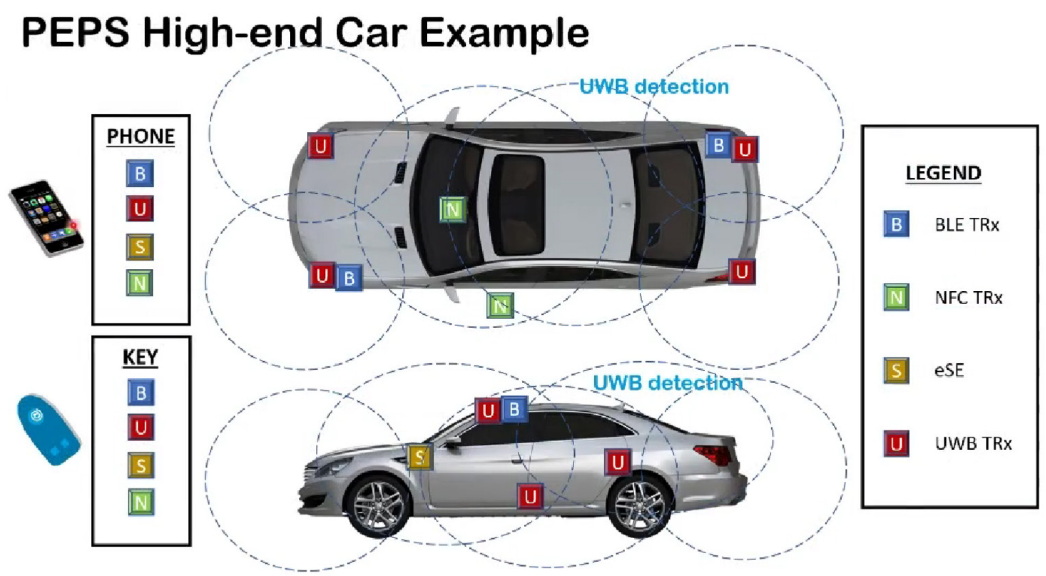


Figure 6: PEPS high-end car hardware example. (Source: Qorvo)

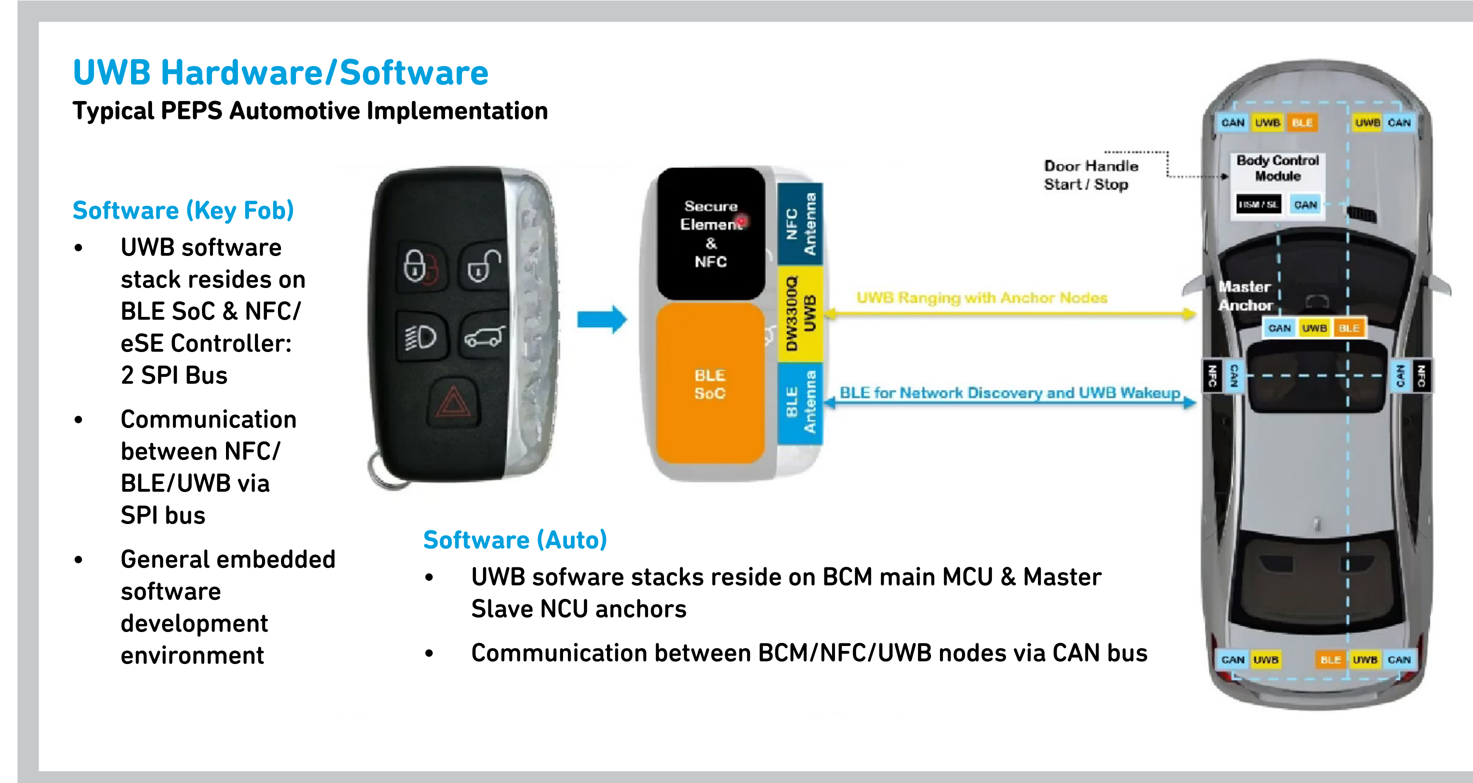


Figure 7: Example PEPS Automotive Hardware Implementation. (Source: Qorvo)

(TRx), otherwise known as a UWB anchor, in the vehicle provides a bubble of coverage that can enable secure access once a BLE handshake is performed (**Figure 7**).

Once the BLE system performs network discovery and UWB wakeup, the UWB ranging and secure authentication triggers the CAN-bus system in the car to initiate the autonomous remote keyless entry mechanism. The multiple UWB anchors in the vehicle allow for precise location detection of the phone or keyfob and add security features. As a backup system, a keyfob or phone equipped with the eSE and NFC can be used to access such a vehicle while close to the vehicle's NFC tag.

UWB & V2V

Adding additional UWB sensors and combining UWB ranging with a vehicle-to-vehicle (V2V) communication link makes it possible to create a UWB area network by communicating UWB information over V2V. This could allow for secure information to be shared between or among vehicles on the road and assist fully autonomous or semi-autonomous driving or navigation systems to safely coordinate and avoid obstacles or otherwise provide alerts to a manually operated vehicle (**Figure 8**).

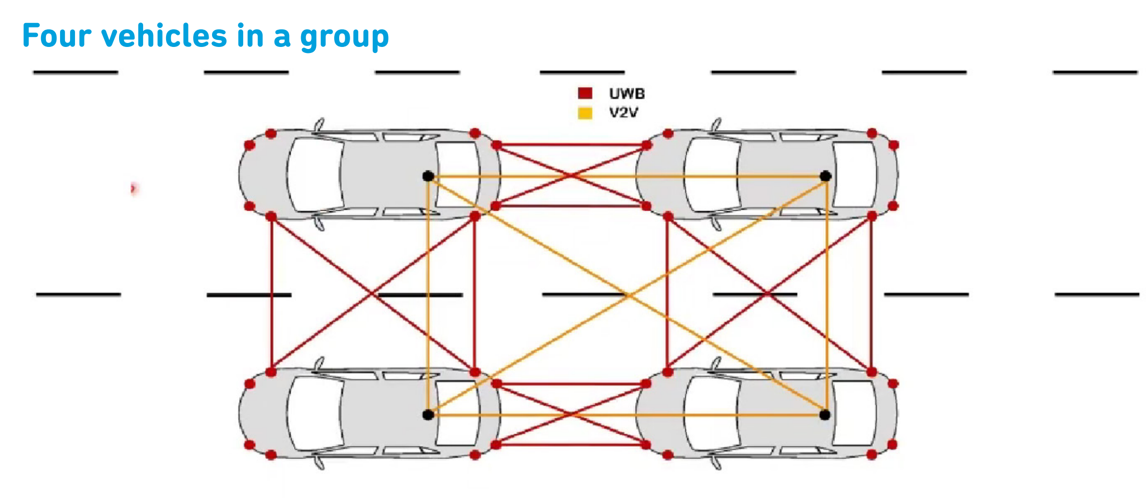


Figure 8: Sensor fusion capability using UWB and V2V communications. (Source: Qorvo)

The accuracy, reliability, and fast update rate of UWB can enable very rapid reaction times among vehicles. In some cases, UWB could even replace more expensive and computationally complex camera systems for vehicle coordination and obstacle detection (**Figure 9**).

Conclusion

Today, there is a gap in capability left open by currently-deployed automotive sensor technologies. Fortunately, there is a recently updated wireless sensing technology available to fill this gap by delivering a low-cost, high-update-rate, very accurate, compact distance/location sensing solution paired with relatively high data rate communications. UWB is poised to unleash a vast array of potential applications from V2V communications to passenger safety sensing. And the best is yet to come, as future UWB technologies will be developed as it becomes more widely spread and integrated into vehicles and smartphones.

> **... the best is yet to come, as future UWB technologies will be developed...**

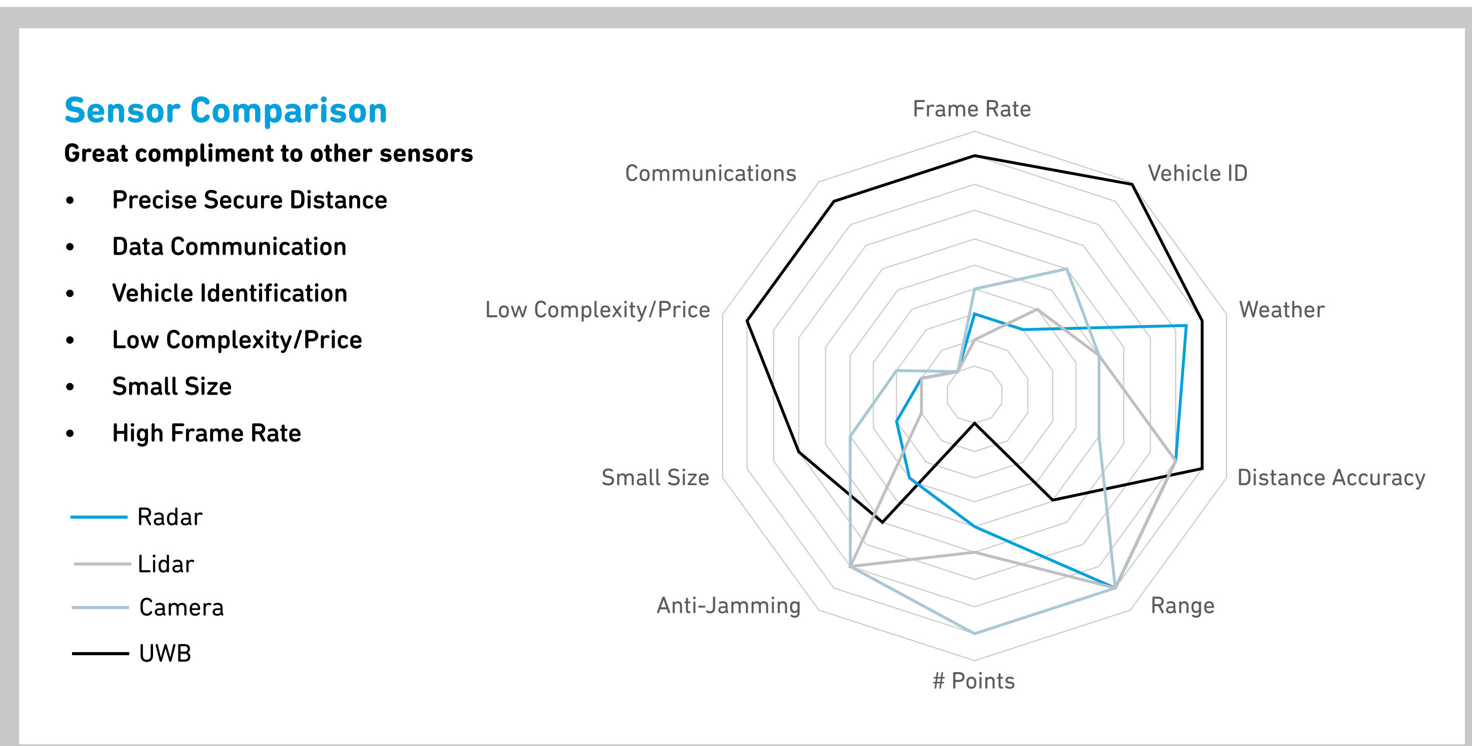


Figure 9: Comparing common automotive sensors. (Source: Qorvo)

SiC FETs in OBC Chargers
Good Things Come in Small Packages

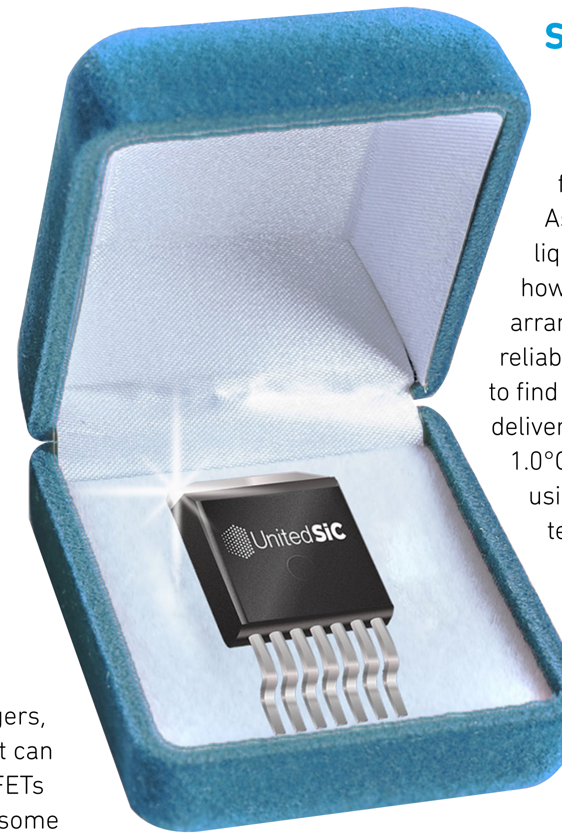
Mike Zhu Senior Product Apps Engineer, Qorvo

Semiconductor power switches in EV on-board chargers and surface mount variants can be viable up to tens of kW when SiC FETs are used. We will look at some performance figures.

Introduction

Silicon carbide (SiC) MOSFETs are firmly establishing themselves as a contender for the semiconductor switches in all stages of electric vehicle (EV) on-board chargers at power levels of 22kW and higher. The UnitedSiC (now Qorvo) SiC FETs, with their unique cascode construction of a Si MOSFET and SiC JFET, outperform IGBTs in efficiency, and are more attractive than superjunction MOSFETs. It's not just about overall converter system losses, though. Cost, size, and weight are also important factors that matter to an EV owner.

Designers have a choice of different package styles for semiconductor power switches in EV on-board chargers, including surface mount variants that can be viable up to tens of kW when SiC FETs are used. In this blog, we will look at some SiC FET performance figures.



(Source: Qorvo)

SiC FETs in OBC Chargers

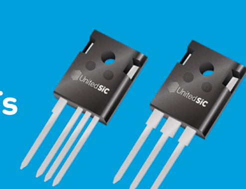
At the typical power levels seen in EVs, even with 98%+ efficiency, on-board chargers still need to dissipate hundreds of watts from a small housing in a hot environment. As a result, heatsinking is needed, often with liquid cooling. A major design consideration is how the switches connect to this heatsinking arrangement for optimal thermal transfer, yield reliability, and low assembly cost. It is common to find SiC FETs in a TO-247-4L package that delivers excellent thermal performance, around 1.0°C/W from the junction to the cooling fluid, using UnitedSiC (now Qorvo)'s wafer-thinning technology with a silver-sinter die and a ceramic isolator pad. However, a downside of the TO-247-4L package is that it needs mechanical fixing and through-hole soldering. It also has significant package inductance and limited creepage and clearance between its pins. In addition, the package has less distance between PCB pads unless the leads are 'joggled' in a complicated and expensive way.

Table 1: Comparison between D2PAK-7L and TO-247-4L. (Source: Qorvo)

Package	Die Pad (mm2)	Inductance (nH)	Creepage (mm)	Clearance (mm)
D2PAK-7L	43	3 to 5	6.7	6.1
TO-247-4L	176	10 to 15	3.9	3.9

A surface-mount alternative would seem attractive, but at the 22kW level? Actually, yes, it can be viable with UnitedSiC (now Qorvo) D2PAK-7L devices with little or no effect on performance, depending on the power conversion stage considered. Looking at the headline differences between the package styles in **Table 1** above, the D2PAK-7L wins except for die pad size, which results in an overall junction to cooling fluid thermal resistance of around 1.3°C/W for an 18-milliohm device bonded to an insulated metal substrate, about 30 percent more than the TO-247-4L package.

The practical effect of a higher thermal resistance is a higher junction temperature for given power dissipated, all things being equal, but because of the substantial assembly savings with an SMT device, perhaps lower resistance parts can be used, reducing temperature. However, if using only one SMT device reaches thermal limits—Tj becomes too high—paralleling SMT devices is a viable solution. If using two SMT devices in parallel to replace one SMT device, each of the two paralleling SMT devices should have twice the on-resistance compared to using only one SMT device. In this case, the current in each is halved, but on-resistance is doubled for each, so dissipation is half of a single part. The total dissipation of two paralleled SMT devices would be slightly lower compared to using just one SMT device with half the on-resistance. Thermally, each device would be much cooler because for the same thermal management (thermal resistance from junction to ambient or coolant), each paralleling device only dissipates half the loss of a single SMT device. So theoretically, each paralleling SMT device's temperature rise from ambient- or coolant-to-junction should also be half of a single SMT device. Apart from this, the lower package inductance of the D2PAK-7L might allow faster switching edge-rates for even lower dynamic losses.



It's useful to look at some examples of the package performance comparisons in the different stages of a typical on-board charger using the UnitedSiC online FET-Jet Calculator™. A 'Totem Pole PFC' stage is common, and an example rated at 6.6kW with 400V output, 75kHz, continuous conduction mode (CCM) was evaluated with a range of TO-247-4L and D2PAK-7L SiC FETs for the 'fast switching' leg, for a heatsink/fluid temperature of 80°C. The junction temperature differences between the two packages ranged from 3°C to 8°C depending on the class of on-resistance.

At higher power and with a three-phase AC supply, a 'Vienna rectifier' might be used with an 800V DC-link at, say, 40kHz (**Figure 1**). 750V SiC FETs can be used, and if 18-milliohm TO-247-4L and D2PAK-7L parts are compared again, the difference in junction temperature is just 3°C with 0.1% difference in 'semiconductor' efficiency. Higher on-resistance parts in this application inevitably show a bigger difference with an unworkable temperature rise for single devices, but at 22kW in a high-value product, the cost of the lower resistance parts is not a large overhead for the benefits gained.

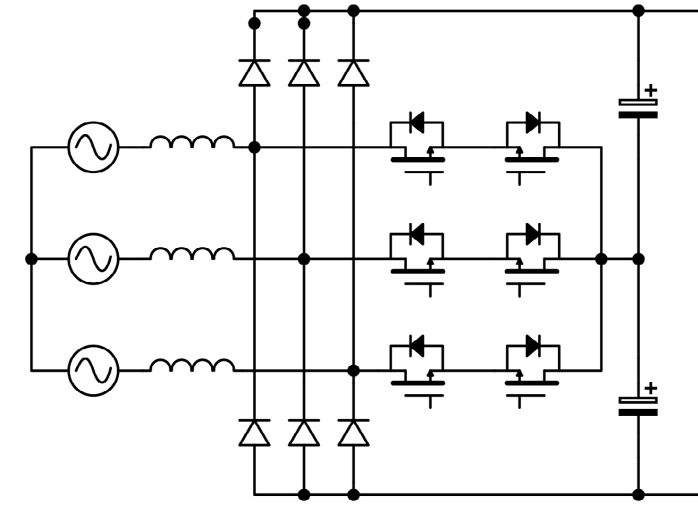


Figure 1: The image illustrates the Vienna rectifier front-end. (Source: Qorvo)

D2PAK-7Ls Can Replace TO-247-4Ls in the DC/DC Stage Effectively

The Totem-Pole PFC and Vienna rectifier stages just considered are 'hard' switching, and frequency is kept relatively low to minimize dynamic losses. The DC/DC stage in an OBC can be a resonant or 'soft' switched converter, such as the CLLC topology with a much higher frequency for small magnetics and low loss, typically 300kHz. For example, at 6.6kW with a 400V DC-link and using 18-milliohm SiC FETS, losses according to FET-Jet Calculator™ per device are 4.1W and 4.2W for TO-247-4L and D2PAK-7L respectively, and the lower inductance of the SMT package makes it a natural choice for the higher frequency used.

Moving to SMT D2PAK-7L packages is a natural progression from TO-247-4L types when total system cost is considered with minimal or no difference in temperature rise or system efficiency, especially if the electrical and mechanical ease of paralleling is factored in. As SMT devices, along with their class-leading Figures of Merit (FoM) and easy gate drive, SiC FETs are inching closer to the ideal switch choice for EV on-board charger applications.

"A surface-mount alternative would seem attractive, but at the 22kW level? Actually, yes..."

Conclusion

With standard 1700V ratings and better efficiency than IGBTs, SiC FETs are becoming more attractive than super-junction MOSFETs, firmly establishing themselves as contenders in all stages of EV on-board charging. While SiC FETs in a TO-247-4L package provide excellent thermal performance, a downside is that they require mechanical fixing and through-hole soldering. So, migrating to an SMT device like the UnitedSiC D2PAK-7L package is a natural evolution when total system cost is considered with minimal or no impact on temperature rise or efficiency. These SMT SiC FETs not only offer designers significant savings on circuit assembly but also class-leading FoM and an easy gate drive solution, making them the ideal switch choice for on-board chargers for EVs.

What Engineers Need to Know to Achieve an Enhanced eCall Automotive Design

David Watson Senior Marketing Manager, Qorvo

Engineers are always looking for the simplest solution to complex system design challenges—and eCall design in automotive applications is no different. In this article, we review how system designers are approaching designs in automobiles and how new eCall solutions can optimize the overall platform. We also share some RF design expertise and integrated solutions that help meet some of the most demanding product challenges of eCall applications.

What Is eCall?

Emergency Calling (eCall) is a European emergency-call system for vehicles that provides rapid assistance in traffic accidents. Its goal is to save lives, mitigate injury, and reduce property damage. Here's how it works: When an accident happens, an emergency call or eCall is activated automatically via the vehicle's sensors. The system then autonomously phones the European emergency service 112 call center. A phone line is established to the emergency center—sending details of the accident's exact location via GPS. Next, the emergency dispatch center sends the appropriate assistance to the location.

As of 2018, eCall systems are mandatory in all cars and vans sold in the European Union. The basic idea is to accelerate emergency response times to reduce fatalities, injuries, etc. According to Thales Group, the system can speed response time by 40% in urban areas and 50% in suburban areas. It can also reduce the number of fatalities by at least 4% and the number of severe injuries by 6%.

From a reliability standpoint, the eCall system must be flexible because, when an accident happens, power wires from the battery can be severed and electronics can be disconnected or damaged. Therefore, there needs to be backup power sources, like small batteries, for the eCall system to operate effectively and in harsh environmental conditions.

The Traditional Approach to eCalling

Traditional eCall systems have multiple switches to provide RF pathways to several antennas. These many switches require matching and power circuitry to operate, which means design times can be extensive, form-factors can be large, and RF losses can be wide-ranging. In addition, design flexibility while configuring the switch matrix can be complicated for the many antenna arrangements.

Here is a list of some challenges seen with this traditional design approach:

- The FR4-PC board material requires careful matching, which adds insertion losses and lowers performance.
- The addition of matching and power circuitry increases the system's thermal temperature, limiting overall performance.
- There is limited design flexibility when configuring the switching matrix for different antenna configurations.
- There is limited ability to have a common layout for higher-tier design models with dual SIM dual active (DSDA) versus non-DSDA.

Figure 1 shows a traditional eCall design using discrete switches. There are multiple RF pathways, which means the system engineer must meticulously match each path to optimize the design. **Figure 1** also illustrates the complexity of such a system, as each signal will require multiple digital GPIO controls (GPIO—general purpose input/output) for each path. This traditional design requires careful PC board design of splitters or the addition of external splitters to accommodate the proper layout and lower RF losses.

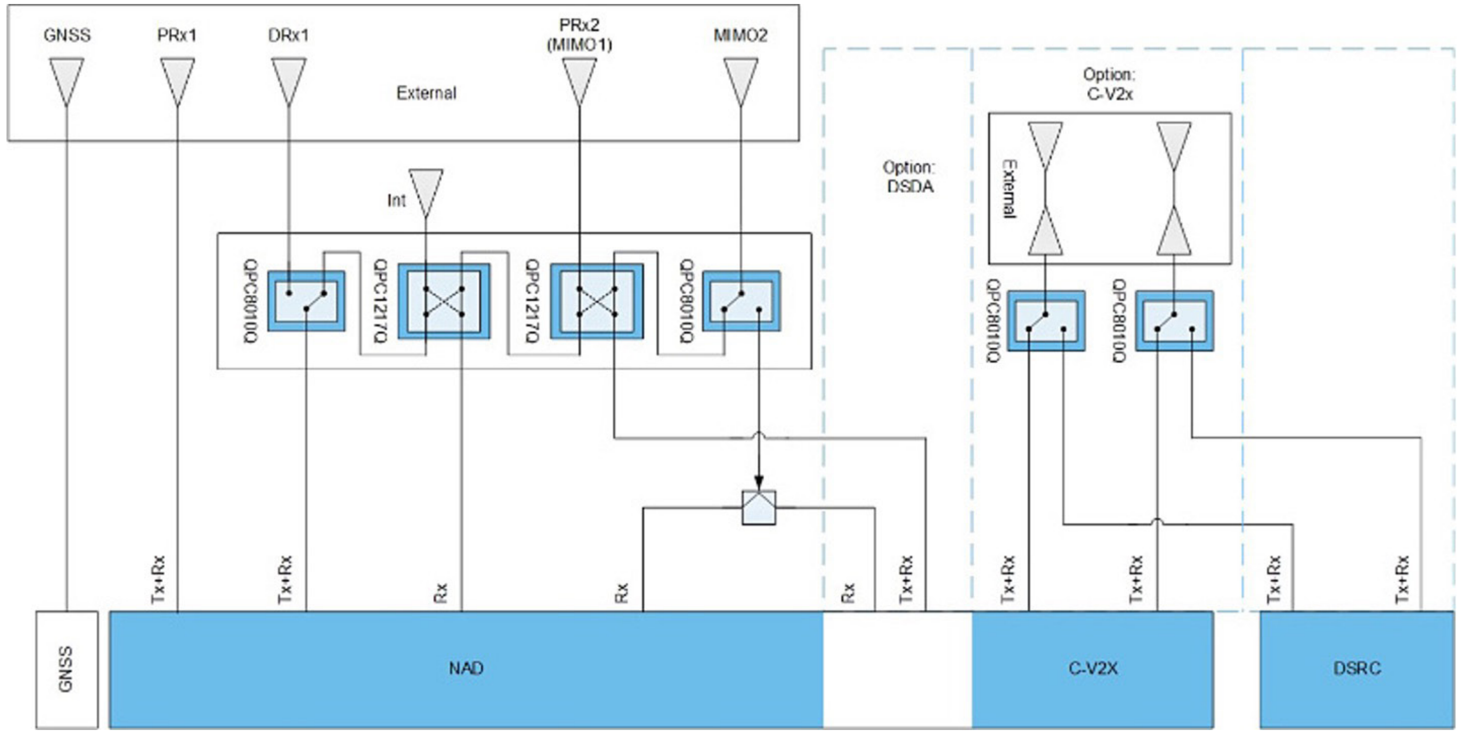


Figure 1: Example of a traditional eCall switching architecture. (Source: Qorvo)

Meeting the Challenge with Integration

Approaching the complexity problem is made easier by implementing simple integration on some of the RF pathways. This approach will obviously reduce some of the complexity, path-losses, and matching challenges, but it only gets you slightly down the design road. As shown in **Figure 2**, integrating some of the switches does help reduce matching, removes the need for many GPIO controls, replaces them with fewer MIPI (mobile industry processor interface) controls, and reduces the number of switches. Cost savings can be seen with this approach, even though this is minimal as compared to a fully integrated approach.

As shown in **Figures 3** and **4**, moving toward a fully integrated approach offers even more improvements beyond the integration shown in **Figure 2**. **Figure 3** incorporates the DSDA switch option architecture and requires less RF front-end matching, lowers the number of RF losses, uses one RFFE MIPI control, integrates all the splitters inside one package, and reduces the cost of materials and design time.

The design in **Figure 4** is similar to that in **Figure 3**, but it does not integrate the DSDA switch option architecture. However, it still requires less RF front-end matching, offering all the benefits shown in **Figure 3**.

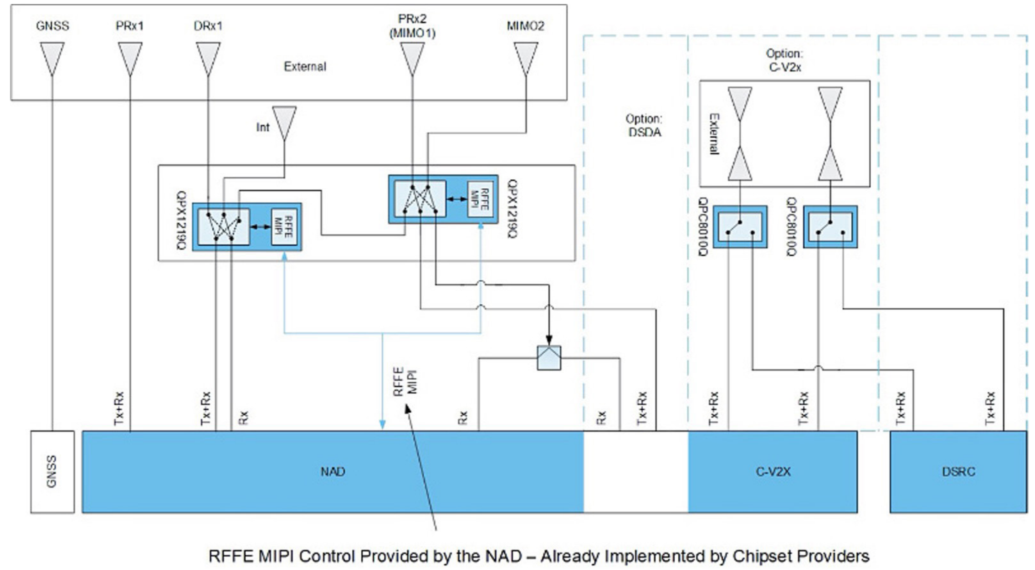


Figure 2: Example of somewhat integrated eCall switch architecture approach. (Source: Qorvo)

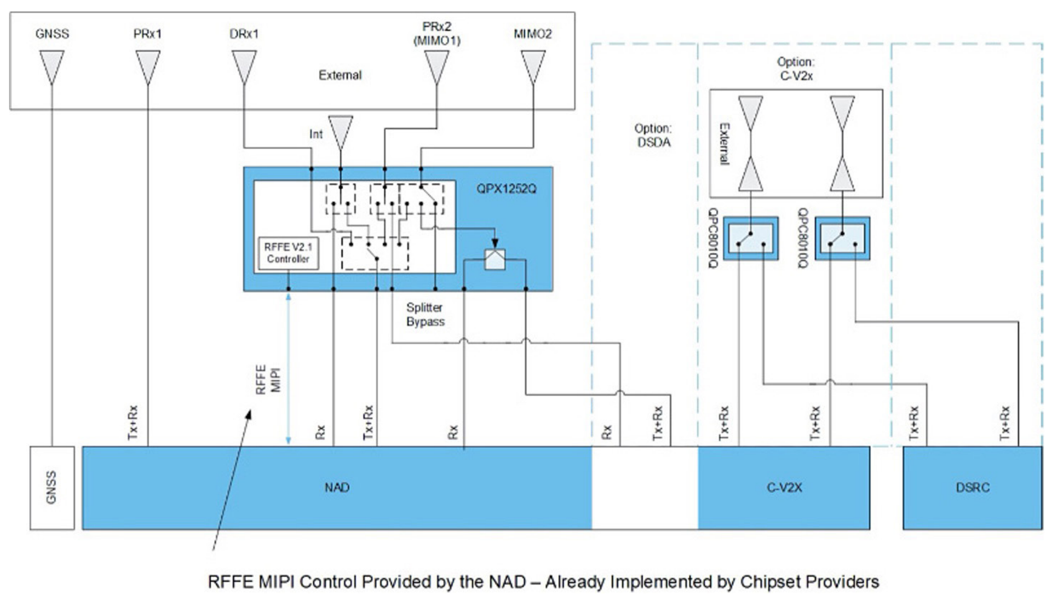


Figure 3: Example of fully integrated eCall switching architecture – using pin-to-pin optional DSDA (QPC1252Q) (Source: Qorvo).

QPC1220Q Broadband DP4T Routing Switch

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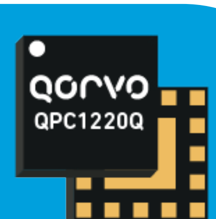

Qorvo Expands Portfolio of Automotive eCall Solutions for Improved Emergency Communications

Qorvo's high-performance broadband antenna switches for eCall are helping provide connectivity to life-saving services after an accident. The switches enable a vehicle's primary cellular signal to automatically relay—or hot switch—to undamaged car antennas to call for help.

The newest addition to Qorvo's automotive line-up is the QPC1220Q broadband, high-linearity Dual-Pole Four-Throw (DP4T) antenna routing switch, which spans the full Automotive AEC-Q100 Grade 2 operating range. It supports hot switching capability of up to + 34dBm—making it ideally suited for all Telematic Control Unit (TCU) eCall and antenna routing configurations. It also reduces insertion loss of up to 1dB, maximizing the effective power delivered to the external eCall antenna array and enabling better cellular and 5G connectivity, even in areas where signal coverage is limited.

A compact design delivers up to 35% board area savings over traditional implementations that can require four or more discrete switches, associated matching, and months of engineering resources. This simplifies and speeds board design for multimode, multi-band systems.

Using the fully integrated QPC1251Q and QPC1252Q for the eCall solution allows for a much more straightforward design—one chip does the job of five individual switches. This design approach can be used for 4G and 5G chipsets, eliminates multiple switches, lowers overall system power consumption, and allows automotive manufactures to connect primary and secondary antennas. The benefits of using either of these two highly-integrated components in a DSDA or non-DSDA solution include:

- Flexible, single-component solution
- Easy design solution enabling complex eCall antenna routing
- Eliminates multiple switches and the need for RF matching on the TCU module
- Allows for flexible switch control
- Provides excellent insertion loss and isolation performance
- Highly linear and offers low power consumption
- A broadband solution suitable for 5G applications up to 6GHz
- Integrated splitters, eliminating the need for external PC board or discrete splitters
- A fully qualified AEC-100 Grade 2 solution

"...we continue to work with customers to solve for the complex design requirements that ultimately help create best-in-class automobiles."

Electronically speaking, our vehicles are becoming more complex—essentially becoming a new mobile device. As RF connectivity infrastructure becomes more available, our vehicles will become safer and more connected to each other and to our current wireless ecosystem. Integration of antenna electronics will help accelerate this mobile connectivity. Semiconductor companies like Qorvo are working diligently with vehicle manufacturers and standards bodies to provide highly-integrated solutions that help vehicle system engineers meet the needs of next-generation designs. With our integrated approach to the eCall switching system, we continue to work with customers to solve for the complex design requirements that ultimately help create best-in-class automobiles.

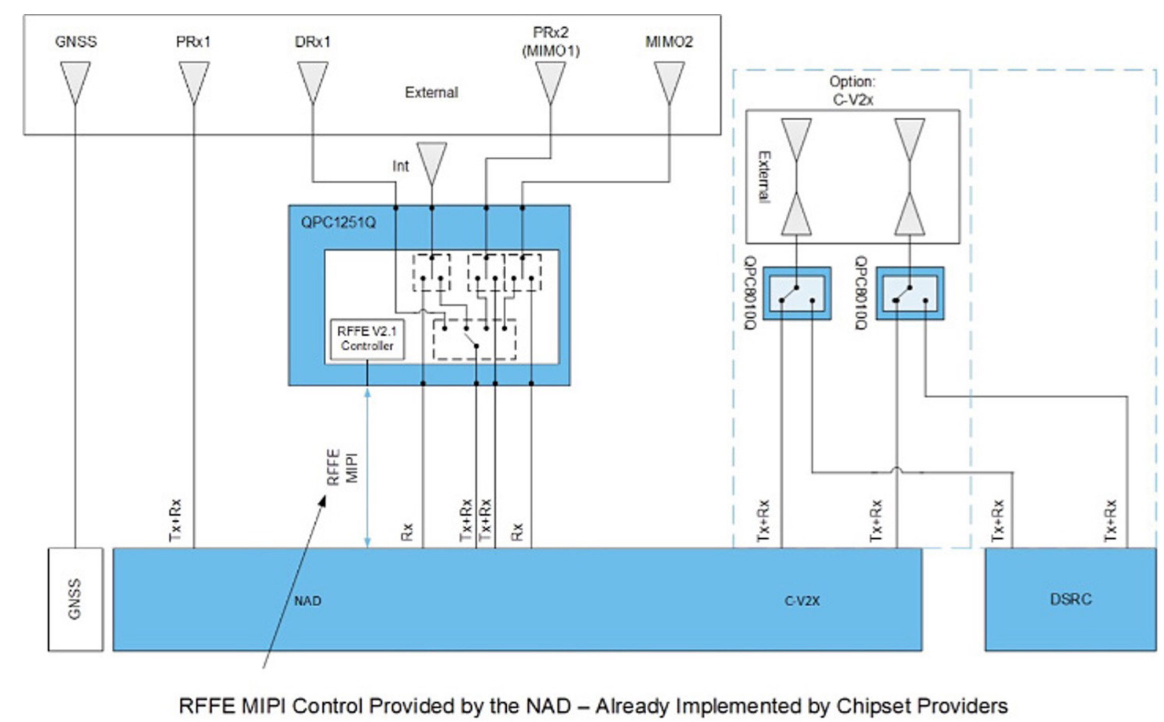

Figure 4: Examples of fully integrated eCall switching architecture – using non-DSDA (QPC1251Q) routing switch. (Source: Qorvo)

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