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Learn how UWB is
changing the automotive

Explore the ride to
vehicle autonomy

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Connected Car

Qorvo 2nd Special Edition

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Kerry Glover, Matthew Davis,
Ali Imran Bawangaonwala,
Nicolas Layus**

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dummies**[®]
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Connected Car For Dummies®, Qorvo 2nd Special Edition

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Introduction

Technology has changed many areas of our lives, and the automobile is one of them. The technology inside today's vehicles is many times more than it was just a few years ago. Automobiles now connect wirelessly to the world around them. They have safety features like lane assistance and automatic braking, and some can even drive on their own in some situations. These new technological advancements have opened more opportunities for automobiles and consumers.

Another major change has been the growing popularity of electric vehicles (EVs). More of them are hitting the market daily, and autonomous features continue to be added year after year. EVs are equipped with software and artificial intelligence (AI) that come together to increase efficiencies and safety. All this is getting us closer to our end goal of the autonomous vehicle.

In this book, you learn about the many wireless and non-wireless technologies that are making the connected, self-reliant car of the future a reality today.

About This Book

Connected Car For Dummies, Qorvo 2nd Special Edition, consists of five chapters that explore the following topics:

- » Understanding the connected vehicle (Chapter 1)
- » Discovering the connected vehicle's technologies (Chapter 2)
- » Understanding vehicle connectivity challenges and solutions (Chapter 3)
- » Anticipating a fully connected and autonomous vehicle (Chapter 4)
- » Ten key connected car takeaways (Chapter 5)

Foolish Assumptions

It has been said that most assumptions have outlived their uselessness, but we assume a few things nonetheless!

Mainly, we assume that you're a technical engineer, design architect, technology leader, sales professional, technical marketing manager, or investor in the technological market sector. As such, this book is written for somewhat technical readers, but if you're not technical don't be alarmed — we explain most of technical terms and concepts.

If any of these assumptions describes you, then this book is for you! If none of these assumptions describes you, keep reading anyway. It's a great book, and when you finish reading it, you'll know a quite a few things about the connected car of the future!

Icons Used in This Book

Throughout this book, we occasionally use special icons to call attention to important information. Here's what to expect:



REMEMBER

This icon points out information you should commit to your non-volatile memory, your gray matter, or your noggin — along with anniversaries and birthdays!



TECHNICAL
STUFF

You won't find a map of the human genome here, but if you seek to attain the seventh level of NERD-vana, perk up! This icon explains the jargon beneath the jargon!



TIP

Tips are appreciated, never expected — and we sure hope you'll appreciate these tips. This icon points out useful nuggets of information.

Where to Go from Here

There's only so much we can cover in 48 short pages, so if you find yourself at the end of this book, thinking, "Where can I learn more?," just head to www.qorvo.com.

IN THIS CHAPTER

- » Seeing what makes a vehicle “connected”
- » Understanding the organizations driving the connected automotive market
- » Identifying the technologies inside the connected vehicle
- » Discovering how 5G and IoT will influence the connected automotive technologies

Chapter 1

Understanding the Connected Vehicle

In this chapter, you discover what a connected vehicle is and what organizations are influencing the technologies. You also find out how the next generation of automotive technologies will change vehicle connectivity.

What Is a Connected Vehicle?

Vehicles have had built-in electronics for decades, handling various internal functions such as digital speedometers and odometers, warning lights controlled by computer-tracked sensors, and digitally tuned radios. However, only recently have onboard computers been able to talk and listen to other devices outside that closed system.

In simple terms, a *connected vehicle* is one that can share data with devices and their users via software and network connections. A connected vehicle can interact with smartphones, local infrastructure manufacturers, and nearby vehicles, depending on its features and capabilities.

A BIT OF HISTORY

The first car communication systems, which were telephones, were connected to the public switched telephone network (PSTN) in the United States in 1946. Mobile telephone equipment had already been used internally within the Bell Laboratory System experimentally as far back as World War II, using mobile radios from Western Electric Corporation on type 28 VHF equipment. In the 1940s, the Emergency Radiotelephone Service was established in New York using the AM 30–40 megacycle band. The Federal Communications Commission (FCC) and Bell companies envisioned two forms of mobile telephone services in those days: highway and urban. Both would use very high frequency (VHF) and frequency modulation (FM).

By the 1950s, manufacturers like Motorola and General Electric had developed operator-dialed services for the general public's cars. Car phone service became more popular in the 1970s with a new car radiophone service network built on technology that connected with the car's battery and used signals attached to telephone networks. Such car phones were built into the car; you couldn't easily take them with you when you exited the vehicle. Analog cell service in 1984 and then digital service in the 1990s made personal cellphones affordable — and made the built-in car phone nearly obsolete.

Because people didn't need built-in car phones anymore, technological development shifted toward building special-purpose communications into vehicles. In 1996, the first production-equipped connected cars were made by General Motors with the introduction of OnStar. This telematics system first enabled voice calls to a call center that contacted emergency responders in the case of accidents when an airbag was deployed. In Europe, as of 2018, a similar service called eCall was mandated to be in every new vehicle (as part of the telematics control unit, or TCU).

As more sophisticated onboard computer systems are being designed — with more innovations and features released each year — vehicles are becoming more intelligent. For example, the advanced driver assistance system (ADAS) in many modern vehicles provides drivers with advanced collision warning and even lane-following capabilities. Electric vehicles (EVs) are also very

complex, and many of their systems are computer controlled. These onboard computer software systems are wirelessly updated as needed to keep the system working at top efficiency.

As communication systems continue to evolve, automobile electronics developers are envisioning additional ways to improve driving experiences and save lives. For example, Intelligent Transportation Systems (ITS) proposes a method for traffic lights to broadcast their current and future states so vehicles can anticipate when a traffic light will change. You can find more on ITS in the “Identifying the Organizations” section, later in this chapter.

Autonomous vehicles

Another key system that has been envisioned for years is one that would enable vehicles to communicate with each other — in other words, vehicle-to-vehicle (V2V) communications. Why would that be useful? Well, the ultimate vision for connected vehicles is autonomous driving, where the vehicle drives by itself. Autonomous vehicles are a reality today, but they’re still very expensive. But, like many of our electronic devices, costs decrease as they become more prevalent in the market.

Hundreds of autonomous vehicles are already working in major industries like mining. As of 2021, Caterpillar’s autonomous trucks safely hauled more than three billion tons of material in just seven years of operation.

The success of autonomous vehicles in the mining industry gives some hope for the obstacles faced with autonomous cars. Here are just a few examples of autonomous vehicles in operation:

- »» Waymo, the autonomous driving tech company owned by Alphabet, launched an autonomous taxi service in San Francisco in 2021.
- »» In 2023, the world’s first self-driving bus service was launched in Scotland.
- »» In 2023, the world’s first self-driving commercial passenger ferry began operating in Stockholm, Sweden. The ferry is powered entirely by electricity.

Telematics

In today's vehicles, black-box technologies are using wireless communications to increase safety and improve the automotive passenger experience. This black box has been given the name *telematics* for its combination of telecommunication and informatics.

Over the past decade, the automotive industry has gone through profound changes. One of the main changes has been the addition of wireless connectivity technologies. These wireless technologies in and around the telematics unit have played a significant role in the automobile's communications inside and outside the vehicle, as shown in Figure 1-1.

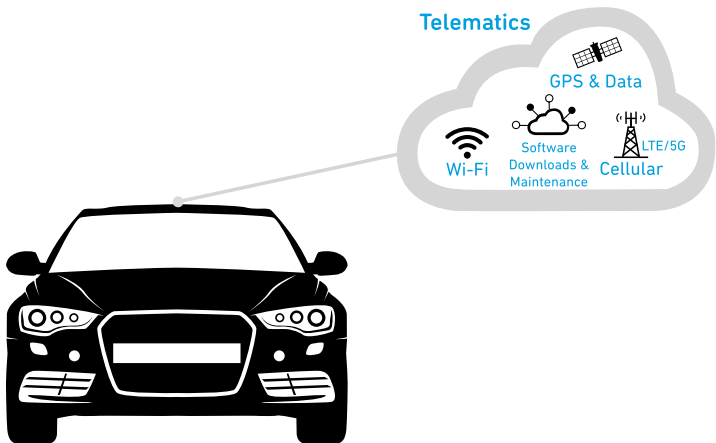


FIGURE 1-1: A diverse connected vehicle ecosystem.

Consumers and manufacturers alike have seen and benefited from the many conveniences and safety features when wireless technologies have been introduced inside and outside the vehicle. For example, the latest cars can use Bluetooth and Ultra-Wideband (UWB) in the key fob or a smartphone to lock or unlock the vehicle.

The trend of using wireless technologies for features inside and around the car will only increase as consumers demand more connectivity, safety, and convenience while using their vehicles.

C-V2X and DSRC

The cellular industry is beginning to influence and collaborate with vehicle manufacturers. Both parties understand that by using 4G Long-Term Evolution (LTE), 5G, and soon 6G, cellular vehicle-to-everything (C-V2X) communications will be a reality.

C-V2X is an umbrella term that encompasses all 3rd Generation Partnership Project (3GPP) vehicle-to-everything (V2X) technologies. 3GPP is a collaborative effort among telecommunication organizations to develop global standards. The V2X part encompasses any communication from within a vehicle to any network or device outside the vehicle.

Figure 1-2 shows how C-V2X communications will work. Communication will occur in two ways — one direct and the other indirect. Direct communications won't go through the network, while indirect *will* use the network.

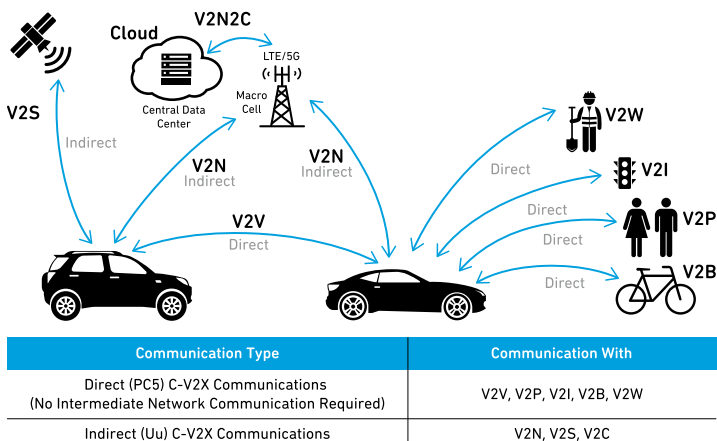


FIGURE 1-2: C-V2X communications.

From an infrastructure V2X point of view, there are two individual ways vehicles will connect: C-V2X and dedicated short-range communications (DSRC). Some countries have decided to use C-V2X, whereas others are using DSRC. In both DSRC and C-V2X, each radio broadcasts the vehicle's location, speed, acceleration, and other status elements, while simultaneously listening to other broadcast messages.

Here are some of the high-level differences between DSRC and C-V2X:

- » DSRC uses the 802.11p wireless standard, while C-V2X uses the cellular standards.
- » A DSRC radio can't communicate with a C-V2X radio and vice versa.
- » The DSRC's radio frequency (RF) range is typically 300 meters, but some installations can go higher if required. C-V2X has 20 percent to 30 percent more range than DSRC because it uses cellular standards.
- » C-V2X performs better than DSRC if obstructed.

Although differences in performance between DSRC and C-V2X do exist, both have been proven adequate for basic safety applications.

Identifying the Organizations

The idea of vehicles sharing information and working together to make transportation safer, greener, and more enjoyable is truly compelling. That vision is being realized via ITS, which applies sensing, analysis, control, and communication technologies to improve safety, mobility, and efficiency using a wide array of applications. Its aim is to provide services related to different modes of transport and traffic management, enabling users to be better informed and make safer, more coordinated, and smarter use of transport networks. Moreover, ITS's goal is to reduce traffic congestion, lessen transportation's environmental impact, and significantly reduce fatal traffic accidents.



REMEMBER

The ITS 5.9 GHz spectrum band has been set aside by governments worldwide to enable communications among vehicles.

One key reason for advanced V2V communication is to reduce deaths, injuries, and economic losses resulting from motor vehicle crashes. To reduce fatalities, organizations such as the U.S. National Highway Traffic Safety Administration (NHTSA), the U.S. Department of Transportation (DOT), the European Telecommunications Standards Institute (ETSI), and the Society of Automotive Engineers (SAE) have all proposed V2V communication systems, as well as defined standards for their implementation.



Currently, SAE and ETSI provide standards for V2X direct communications. These standards provide a high-layer protocol exchange and a separate lower layer of data transport. These standards support two data transport protocols: C-V2X and DSRC (see “C-V2X and DSRC,” earlier in this chapter).

The NHTSA publishes a V2V communications report that provides update readiness of V2V technology by application and lists the initial and envisioned use cases for ETSI and SAE. Early use cases focus on road safety and efficiency. New and advanced use cases that address high levels of automation have been introduced by organizations such as 3GPP, the 5G Automotive Association (5GAA), and Fifth Generation Communication Automotive Research and Innovation (5GCAR).

In the ITS 5.9 band, dedicated frequencies that are not subject to interferences are used for V2V communication. In this band, C-V2X can support low-latency connections over short ranges without involving the cellular network. Both C-V2X and DSRC use the global navigation satellite systems (GNSS) to determine the vehicle’s position and to synchronize communications between vehicles and the roadside infrastructure. C-V2X and DSRC can coexist in the same ITS 5.9 GHz spectrum, but based on recent data published by 5GAA, C-V2X is significantly more reliable.

Here are the main organizations associated with driving ITS implementation.

»» **Global System for Mobile Communications Association (GSMA)**

is an association industry organization that represents the interests of mobile network operators globally. More than 750 mobile operators are full GSMA members, and more than 400 companies in the broader mobile ecosystem are associate members. The GSMA collaborates with mobile operators, automakers, suppliers, industry associations, and regulators to foster the connected vehicle market’s growth through a unified approach to security, regulatory, and infrastructure solutions.

»» **5GAA** was created in 2016. This global, cross-industry organization of companies from the automotive, technology, and information and communication technology (ICT) sectors develops end-to-end solutions for future mobility and transportation services. Since its inception, 5GAA has rapidly

expanded to include key players with a global footprint in the automotive, technology, and telecommunications industries.

- » **ETSI-ITS** is a standards body for vehicle telematics and communication, encompassing V2V and vehicle-to-infrastructure (V2I) interactions.
- » **European Automotive and Telecoms Alliance (EATA)** is a commissioning body that intends to jointly develop and strengthen digital initiatives for connected and autonomous mobility.
- » **CAR 2 CAR Communications Consortium (C2C-CC)** is a consortium partnership among original equipment manufacturers (OEMs) like General Motors (GM), Hyundai, Volkswagen, and Volvo, supported by associate members from tier suppliers. C2C-CC focuses on wireless communication applications for all vehicles across borders and brands.
- » **Automotive Electronics Council (AEC)** is a U.S.-based organization that establishes qualification standards for components in the automotive electronics industry: AEC-Q100 for active components and AEC-200 for passive components.
- » **Institute of Electrical and Electronics Engineers (IEEE)** defines the 802.11p standard for wireless access in vehicular environments (WAVE), including DSRC devices in vehicles and roadside units (RSUs). It's an amendment to the popular 802.11 wireless networking standards.

The coordinated approach to V2X development of these organizations will help advance and materialize the connected and ultimate autonomous vehicle around the world.

Discovering In-Vehicle Wireless Technologies

The evolution of technology has propelled many market areas, including the connected automobile environment. As automakers, standards bodies, alliances, associations, and other stakeholders continue to collaborate, we will see many more innovative automotive products and services.

Inside the TCU

A central system called the TCU controls these products or services. The TCU is an onboard device that contains the wireless connectivity electronics. It collects telematics data from the car, such as location, speed, and engine data, by connecting with several onboard subsystems via data and control buses. It also provides eCall capability, Wi-Fi, and Bluetooth networking (see Figure 1-3).



REMEMBER

eCall is a European emergency-call system for vehicles that provides rapid assistance in case of a traffic accident with the goal of saving lives.

The TCU contains functional blocks for sensing, positioning, data storage, and processing. One of these blocks within the TCU is the *network access device* (NAD), which consists of circuitry needed to secure cellular communications (such as LTE, 5G, and soon 6G).

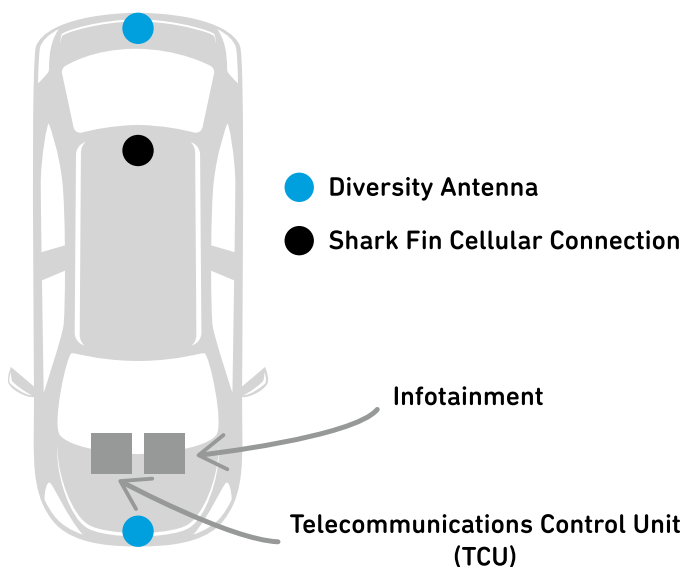


FIGURE 1-3: Automotive TCU, infotainment, and antennas.

The cellular connections located in the shark fin connect to the NAD in the TCU. As shown in Figure 1-4, the NAD is located inside the TCU, along with several other wireless blocks.

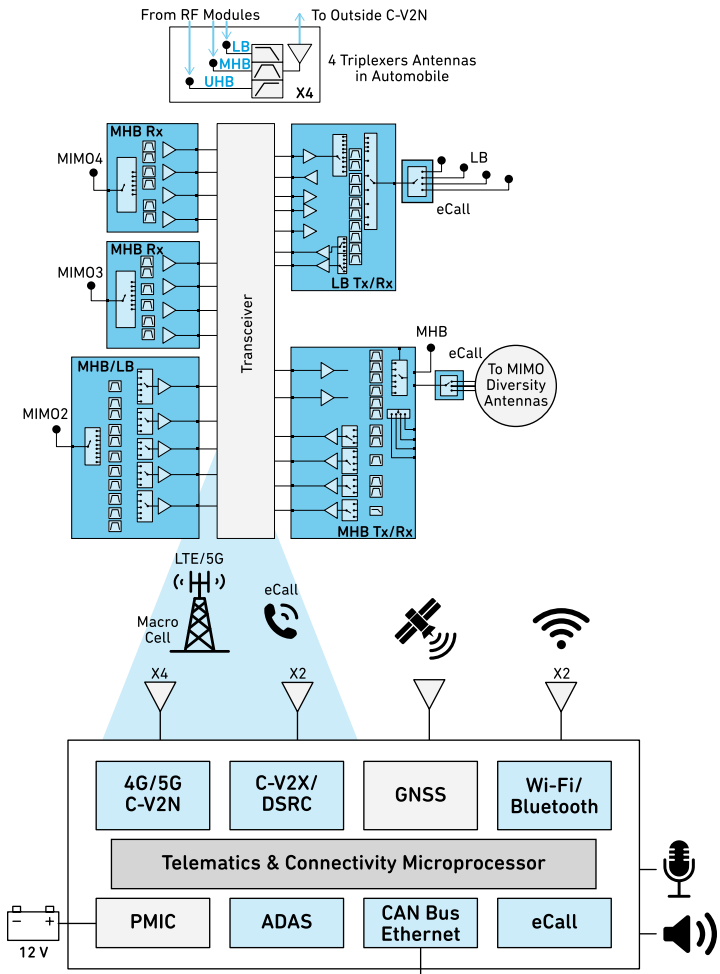


FIGURE 1-4: NAD block diagram (top) and TCU with NAD (bottom).

Wireless technologies

The automotive industry is already using wireless technologies, as you can see by looking at today's modern vehicles. These technologies play roles in telematics, infotainment systems, driver assistance, ADAS, vehicle diagnostics, and vehicle security and safety.

Automakers realized early on that using wireless technologies such as Bluetooth and Wi-Fi would help them offer convenience, comfort, and improved safety. Since then, new wireless technologies have been added to the development arsenal, like UWB.

For example, as shown in Figure 1-5, Wi-Fi provides over-the-air (OTA) data transfer to enable software updates and seamless transitions from the driver's smartphone to the car they're driving. Additionally, both Wi-Fi and UWB provide new and innovative safety and security solutions like Digital Key keyless entry and presence detection.

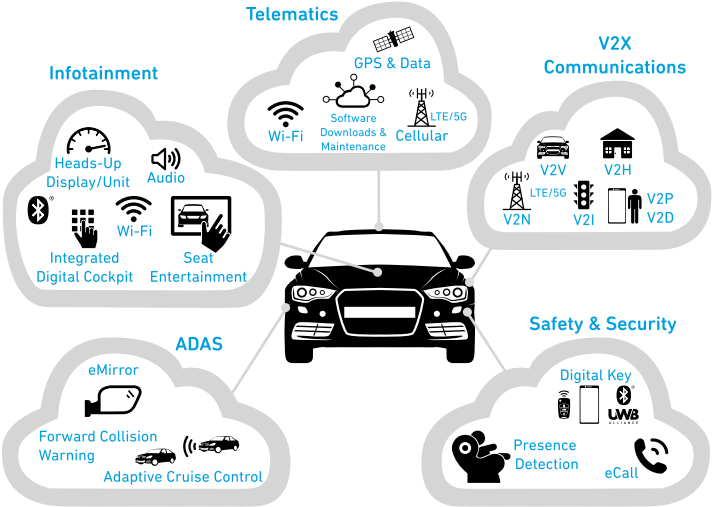


FIGURE 1-5: Automotive wireless technology applications.

The introduction of 4G LTE made V2V, V2I, vehicle-to-pedestrian (V2P), and vehicle-to-network (V2N) telematics services possible. 5G has increased these services and optimized them for lower-latency data services, creating movement toward the ultimate goal of autonomous driving.

Today's ADAS system uses several technologies, such as a camera's Light-Detection and Ranging (LiDAR), long-range radar, short/medium-range radar, and ultrasound. These technologies enable applications such as park assist, rear collision warning, blind-spot detection, cross-traffic alert, adaptive cruise control,

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lane assist and departure warning, and emergency braking/collision avoidance.

Continual collaboration of the automakers, alliances, standard bodies, and other stakeholders will further develop wireless technology services and applications. These collaborations will result in an ecosystem that will eventually lead to the next generation of autonomous vehicles.

IN THIS CHAPTER

- » Identifying the major connected vehicle wireless technologies
- » Examining some wireless use cases in a connected vehicle
- » Learning how PMICs improve power management

Chapter 2

Discovering Connected Vehicle Technologies

Emerging technologies are transforming the global driving experience and are set to revolutionize it further in the near future. This chapter surveys many of these technologies to help you understand how they increase safety and security in and around the vehicle.

Exploring Automotive Wireless Technologies

Previous-generation automobiles used cables for connections such as CD/DVD players and USB ports for smartphones and memory sticks. Today, Wi-Fi, Bluetooth, cellular (Long Term Evolution [LTE] and 5G), and Ultra-Wideband (UWB) technologies enable low-latency, hands-free connectivity. Today's vehicles can communicate with dealerships for over-the-air (OTA) system updates or service information, using these wireless technologies.

The following sections explain the technology behind some of the current and next-generation wireless technologies for automotive systems.

The 5.9 GHz spectrum

Worldwide, the 5.9 GHz band has been designated for automotive safety communications. The key uses are for wireless communication from vehicle to vehicle (V2V), vehicle to infrastructure (V2I), and vehicle to pedestrian (V2P).

Even though all nations agree on that band, the rules about how the band will be segmented for use in intelligent transportation systems vary. Table 2-1 outlines the major differences. Figure 2-1 summarizes these differences graphically.

TABLE 2-1 Automotive Frequency Spectrum by Country

Country	Spectrum (MHz)	Allocated Bandwidth (MHz)
Australia	5855–5925	70
China	5905–5925	20
Europe	5855–5925	70
Japan	755.5–764.5 and 5770–5850	9 and 80
Singapore	5875–5925	50
South Korea	5855–5925	70
United States	5895–5925	30

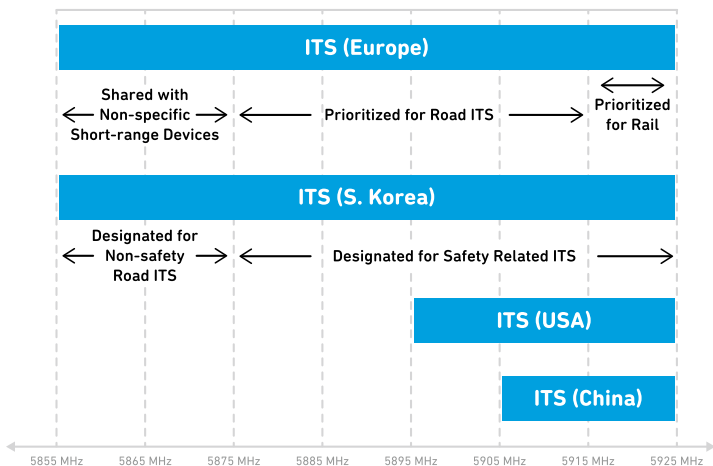


FIGURE 2-1: Automotive frequency spectrum by country.



The frequency range of 5850 to 5925 MHz was reserved decades ago by the United States and European Union (EU) regulatory bodies to allow wireless access in vehicular environments (WAVE) communications from V2V and V2I. This band was originally used by dedicated short-range communication (DSRC), also known as 802.11p, but due to lack of utilization, the Federal Communications Commission (FCC) in the United States has reduced this 75 MHz band to 30 MHz (5895–5925 MHz). The FCC has designated this 30 MHz for cellular vehicle-to-everything (C-V2X).

Figure 2-2 illustrates the EU and U.S. automotive bands and their alignment between the Unlicensed National Information Infrastructure (U-NII) bands.

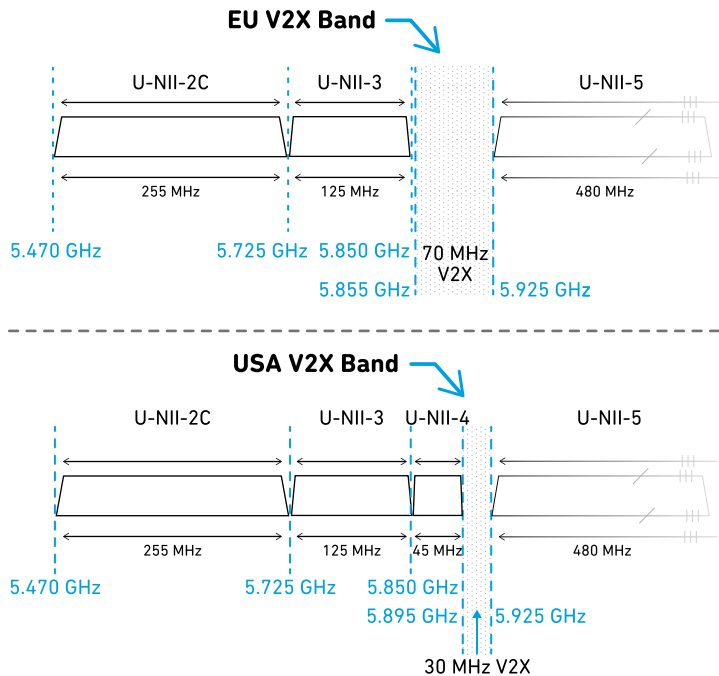


FIGURE 2-2: The EU and U.S. automotive Wi-Fi frequency spectrum.

3GPP and C-V2X

The 3rd Generation Partnership Project (3GPP) is a collaborative effort between telecommunication organizations to develop global standards, with C-V2X as a term for all 3GPP vehicle-to-everything (V2X) technologies.

The 3GPP standards are not static. As shown in Figure 2-3, the road map clearly establishes goals for future standard updates.

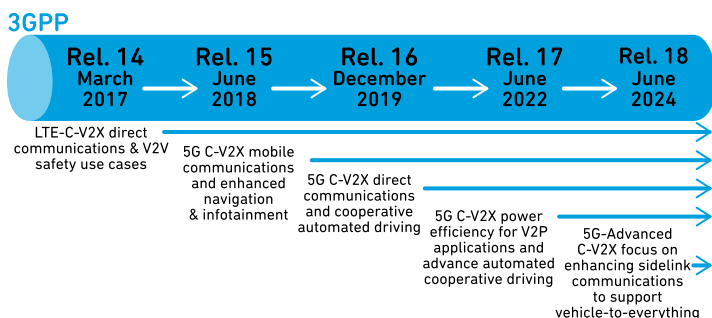


FIGURE 2-3: 3GPP release use case road map.



TIP

Learn more about 5G in Qorvo's *5G RF For Dummies* book, available at www.qorvo.com/design-hub/ebooks/5g-rf-for-dummies.

Wi-Fi

Wireless connectivity is increasingly vital in differentiating vehicles, as manufacturers integrate advanced Wi-Fi-enabled infotainment systems for a social, connected, and safety-focused cockpit experience. Premium vehicles often come with Wi-Fi, linking the car and devices to the cloud, with ongoing updates to the latest Wi-Fi standards for future-readiness. Modern connected cars generate about 25GB of data per hour, a figure expected to reach tens of terabytes with further sensor and service additions and the advent of autonomy. A significant portion of this data is cloud-uploaded for analytics.



TECHNICAL STUFF

Wi-Fi brings tri-band capability up into the 6 GHz realm to aid in fast terabyte levels of data for telematics or for downloading new firmware without interference or network congestion. However, Wi-Fi is limited because vehicles must be close to a Wi-Fi network access point to operate. The newer Wi-Fi standards in automobiles have extended RF range to help cars leverage external Wi-Fi roadside infrastructure to upload data and enhance the connectivity link.

The Internet of Things

The global transition to 5G is in full swing, with more than one billion connections. 5G has been mostly used to expand the smartphone and fixed wireless access markets. However, as expected, 5G has reached well beyond these areas to cover many more applications. One area 5G is merging with is the growing Internet of Things (IoT) arena.

Automotive IoT is the integration of gadgets, sensors, cloud computing, applications, and other components into vehicles to function as a complex ecosystem for the connection of cars, predictive maintenance, fleet management, insurance, and more.



TIP

Learn more about the IoT in Qorvo's *Internet of Things For Dummies* book, available at www.qorvo.com/design-hub/ebooks/internet-of-things-for-dummies.

In the automotive market, IoT will further expand 5G to improve road safety, solve traffic congestion problems, and reduce pollution and energy by improving fleet management. The IoT sensors in and around the vehicle will advance sensing technologies to gather more information about the vehicle and its surroundings. The technology also automates payments for fueling, electric vehicle (EV) charging, tolls, and more.

5G Reduced Capability (5G RedCap) is a new 5G standard, launched in 2022, that aims to meet the requirements of IoT devices that need smaller, less complex, lower-cost radio-frequency (RF) solutions with longer battery life than existing 5G wireless technology options. 5G RedCap has been defined in the 3GPP Release 17. The areas of market interest in 5G RedCap will be in the IoT areas of wearables, industrial wireless sensors, and video surveillance.

From an automobile perspective, 5G RedCap is likely to be used in applications served by 4G (commonly deployed in entry-level connectivity, dashcam solutions, and vehicle diagnostic sensors, as well as sensors that monitor the condition of assets in transit), such as tracking devices, charging stations, micro-mobility, and battery-powered sensors.

5G RedCap promises to broaden the 5G ecosystem, creating more connections. As shown in Figure 2-4, it fills the gap between low-power wide-area (LPWA), enhanced mobile broadband (eMBB),

and ultra-reliable low-latency communications (URLLC), simplifying 5G integration in IoT applications. These 5G RedCap modules will be low cost with lower power consumption, something that the 5G standard can't offer.

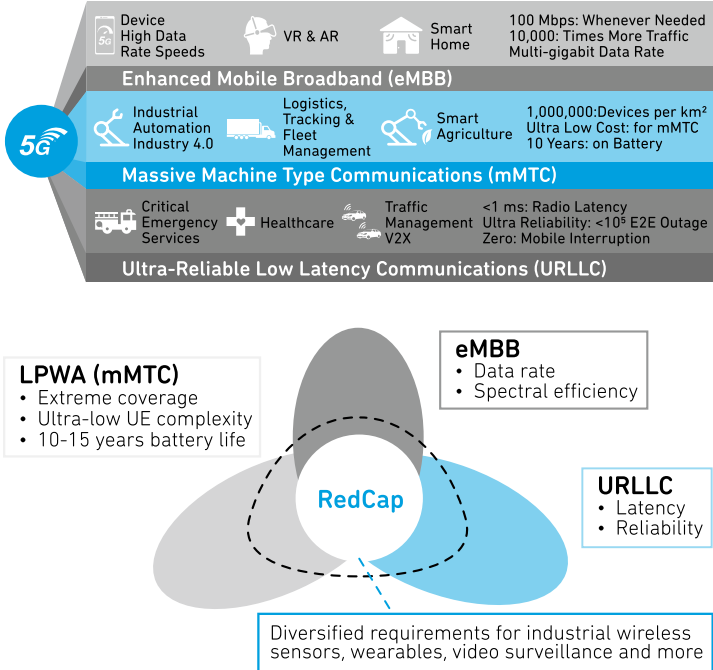


FIGURE 2-4: RedCap in the 5G landscape.

Predictive edge analytics

Predictive edge analytics is integral to mobile edge computing (MEC) deployment in vehicles. It involves collaboration among mobile network operators, original equipment manufacturers (OEMs), service providers, app developers, internet providers, and road transportation authorities. This technology enables low-latency, reliable applications that swiftly alert drivers to road hazards and provide early warnings about adverse traffic.

Bluetooth and Ultra-Wideband

Several low-energy wireless sensors and communication devices are inside and on a vehicle. One that has been around for some

time is Bluetooth, along with its lower-power variant Bluetooth Low Energy (LE). Bluetooth is a short-range wireless standard commonly used to connect a smartphone to the infotainment center. It provides two-way Short Message Service (SMS) communications and navigation smartphone syncing. Bluetooth LE is commonly used inside the key fob.

UWB is another low-power wireless technology being seen more in the automotive industry. It uses two-way ranging to determine the distance between two UWB transceivers. It's used in UWB anchors, key fobs, and for smartphone keyless entry called *Digital Key*.



A Digital Key application that runs on a smartphone (or smartwatch) and imitates the functions of a key fob uses both Bluetooth LE and UWB. When Bluetooth LE connects with the vehicle, it executes the Digital Key messaging. Then it exchanges the Digital Key ID using public keys and verifies the user has a valid ID. Next, the system initializes the UWB transceivers, telling each the assigned time to transmit their scrambled timestamp sequence signal. This process repeats each time the user enters or leaves the vehicle, as shown in Figure 2-5. UWB ranging includes a security feature designed to ensure that no third party can spoof the transmission and create an incorrect distance measurement. This ranging process relies upon the secure Advanced Encryption Standard (AES) protocol.

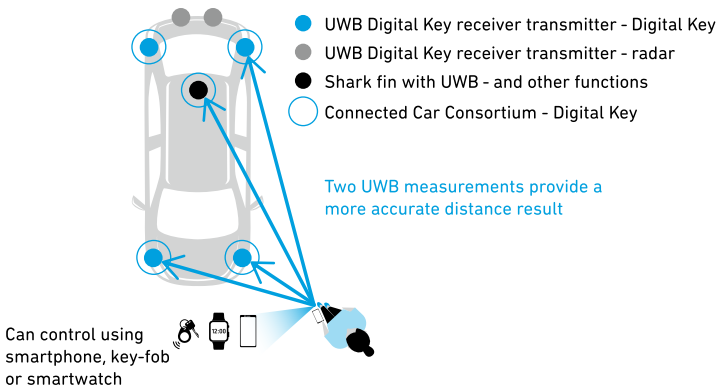


FIGURE 2-5: A UWB Digital Key scenario in high-end automobile.



TIP

Learn more about Digital Key in Qorvo's e-guide available at www.qorvo.com/design-hub/ebooks/ultra-wideband-ccc-digital-key.



TIP

New UWB technology can prevent heat-related incidents in cars by identifying occupants, such as unattended children, through channel impulse response (CIR) variations. This system can identify the presence of passengers, monitor heartbeats or breathing, and alert vehicle owners if a child is left in a hot vehicle, as shown in Figure 2-6.

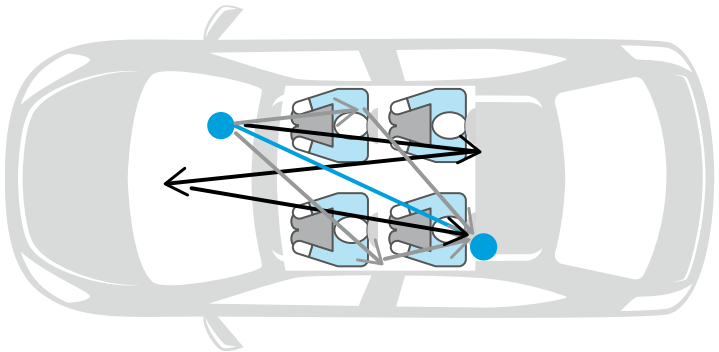


FIGURE 2-6: UWB internal occupancy scenario.

UWB can be used for a short-range radar system to continuously monitor nearby vehicles' positions. In a system like the one in Figure 2-7, a transmitter and a separate receiver can create a histogram. By analyzing the histogram and extracting the time of arrival of the first peak, it can obtain the line-of-sight reflection from an object and determine the distance to that object, thus implementing a short-range radar. Using this UWB radar will enable vehicles to warn the driver if other vehicles get too close. The applications advantage of this scenario is that it doesn't require UWB sensors in other vehicles.

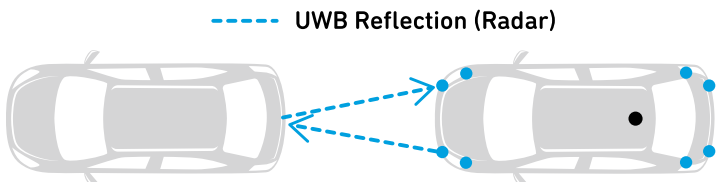


FIGURE 2-7: A UWB short-range radar scenario.



TIP

Learn more about UWB in Qorvo's *Ultra-Wideband For Dummies* book, available at www.qorvo.com/design-hub/ebooks/ultra-wideband-for-dummies.

And those two examples are just a small sample of what's on the horizon. A multitude of UWB technology applications are possible, such as EV charging alignment, car lot vehicle location, automated parking, parking garage secure payment, passenger service pickup identification, pedestrian location road safety, and more. Figure 2-8 summarizes a few of these graphically.

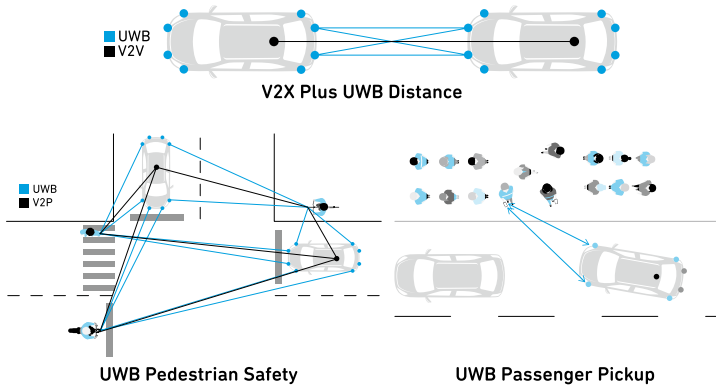


FIGURE 2-8: UWB application scenarios.

Changing the Driving Experience

Today's driving experience is changing before our eyes. Every day, we see new wireless technology applications being applied to the vehicle and the infrastructure around it — with the goals of road safety, efficient transportation, and autonomous driving.

Traffic light alerts

DSRC and V2X technology enable vehicles to communicate wirelessly, providing various features. For instance, the 2022 Lincoln Adventurer uses V2X to anticipate traffic light durations, advising drivers on safe intersection crossing with visual and audible alerts. Additionally, manufacturers like Ford have integrated C-V2X systems into their vehicles, allowing communication between vehicles, pedestrians, and traffic management systems.



REMEMBER

C-V2X-enabled vehicles can talk directly to each other without going through a cellular tower. They notice non-CV2X vehicles but won't communicate with them.

Collision avoidance

Collision avoidance is a major sought-after solution. C-V2X vehicles will broadcast their unique identity, position, speed, and direction to other vehicles and the traffic management infrastructure system. This onboard system will also combine other C-V2X data to create a map of its individual surroundings to determine if there are any potential collision possibilities in real time. It can also help avoid these potential collisions by braking or accelerating.

Fast wireless DC charging

Wireless charging technology, already prevalent in mobile phones, is now being adopted in the automotive industry. The emergence of new EVs is bringing brand-specific plugs for direct current (DC) fast charging, complicating cable and adapter use. Wireless charging stations simplifies this by eliminating the need for these accessories.

This technology relies on resonant magnetic induction to transfer energy between a pad on the ground and another under the floor of a compatible EV. The pad is around a meter square, while the car's pad is a smaller device under the car. Therefore, alignment to attain efficient charging is a must. Engineers are working out the industry standards on this technology using Bluetooth LE and UWB's precision location technology.

eCall

eCall is a European emergency-call system for vehicles. It provides rapid assistance in traffic accidents. It aims to save lives, mitigate injury, and reduce property damage in vehicle accidents. eCall relies on first-generation cellular services — 2G and 3G. As of 2018, eCall systems were mandatory in all cars and vans sold in the EU.



REMEMBER

Here's how it works. When an accident happens, the sensors on the vehicle activate an emergency call. The system automatically phones the European emergency service 112 call center and sends details of the accident's location via Global Positioning System

(GPS). Then the emergency dispatch center sends the appropriate assistance to the location.

Antenna damage can compromise eCall's effectiveness, but this issue can be resolved by switching between the vehicle's multiple antennas. As Figure 2-9 illustrates, the vehicle has various RF pathways and requires complex switching for eCall. High-performance broadband antenna switches can enable the primary cellular signal to automatically switch to an undamaged antenna in case of an accident, ensuring connectivity for emergency services. This antenna electronics integration enhances mobile connectivity in vehicles, helping to save lives.

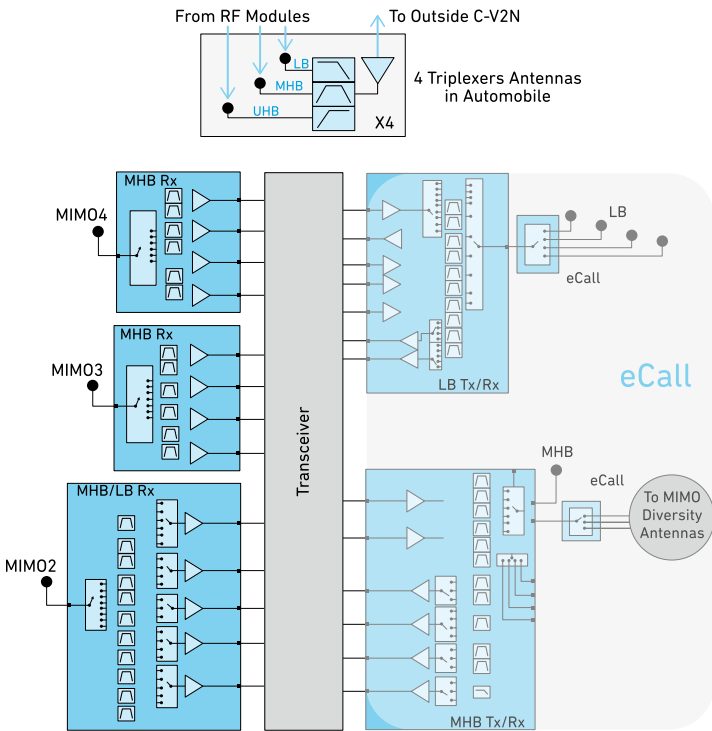


FIGURE 2-9: eCall system architecture in a network access device (NAD).

Intelligent speed assistance

In 2019, the EU also mandated the implementation of *intelligent speed assistance* (ISA) in all new vehicles starting in 2022. ISA is

an in-vehicle safety system that warns or prevents drivers from exceeding the legal speed limit. ISA always displays the current speed limit within the vehicle and can also restrict acceleration to maintain compliance, either manually or automatically.

Over-the-air updates

Consumers have been getting OTA updates on their smartphones and computers for many years, and it's now common in vehicles. The always-connected automobile of today requires software fixes and upgrades, like any other computer, as part of its regular maintenance. Automobile manufacturers are seeing the advantages of doing these updates OTA rather than having the owner bring the automobile into the garage. This saves money and time for both the consumer and manufacturers.

OTA updates come in two forms: software and firmware. Software updates commonly address non-safety issues like slow touchscreens, while firmware updates target critical systems like autopilot. Today, many vehicles lack firmware update capabilities due to system complexity, but this is changing as vehicles increasingly use complex gateway chips for communication between sensors, actuators, computers, and the cloud.

Another key advantage of OTA updates is that they will enable manufacturers to roll out enhancements and upgrades to its systems — unlike in the past, when the vehicle you bought would have the same features you purchased with it. With OTA updates, this limitation goes away, and your vehicle will improve over time, just like your phone.

Improving Power Management

Power management integrated circuits (PMICs) encompass various control mechanisms and play a critical role in managing system power across many applications.

Although there are PMICs in combustion engine vehicles, EVs drive most of the market. In EVs, PMICs help increase efficiency and reduce draw on the battery. PMICs have become increasingly crucial to manage all the voltage variations in these components. A typical PMIC includes linear regulators like low-dropout

regulators (LDOs) and single or multiple switching DC-to-DC converters (such as Buck and Boost).

The rise in EVs is boosting power management due to the growing adoption of connectivity and advanced driver assistance system (ADASs). ADAS technology adds more electronics to vehicles, increasing the power load. PMICs are vital for regulating this power usage, ensuring thermal efficiency and supporting various applications like infotainment systems.

PMICs play a crucial role in battery management for EVs, ensuring drive range is met and charging is efficient and safe. They monitor battery cell temperature during use and charging, cutting off power if temperatures exceed set values, thereby enhancing battery performance, life span, and safety. EVs also require a rapid, efficient, and compact solution to convert alternating current (AC) from the charge station to DC for their batteries. This conversion process is illustrated in the circuitry of wall-mount and onboard EV battery chargers in Figure 2-10.

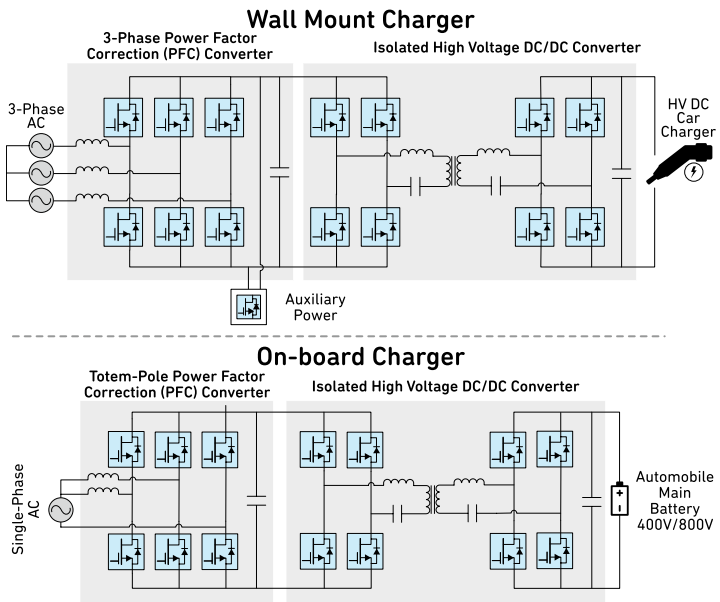


FIGURE 2-10: Wall mount and onboard EV charger/converter using silicon carbide (SiC).

EVs convert DC from the battery to AC to power the motors for various functions like wheel movement and window operations. These require high-power, high-current switches. Figure 2-11 features a Qorvo-designed SiC traction inverter circuit module that efficiently powers motor application in vehicles, ensuring optimal torque without tire skidding and motor overstress from battery heat.

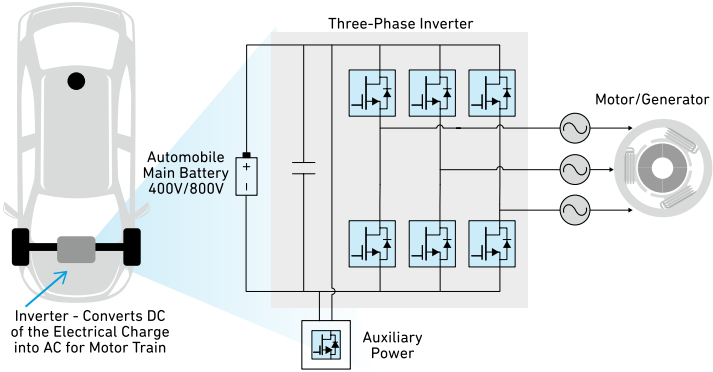


FIGURE 2-11: An EV traction inverter circuitry using SiC.

IN THIS CHAPTER

- » Understanding the challenges of connectivity and C-V2X applications
- » Exploring spectrum and the challenges it sometimes brings
- » Learning how to use RF filters to attain coexistence

Chapter 3

Understanding Vehicle Connectivity Challenges and Solutions

In this chapter, you learn what design challenges engineers face in the automotive cellular vehicle-to-everything (C-V2X) space. Although challenges exist, there are ways to mitigate or completely resolve wireless issues using new and innovative technology solutions. In this chapter, you explore both the challenges and how to resolve them with unique design methodologies and technologies.

Mitigating V2X Spectrum Challenges

As we explain earlier in the book, several wireless technologies are poised to enable vehicle-to-everything (V2X) and autonomous vehicles. These standards offer the potential for many automotive safety enhancements, but they also present some coexistence challenges that may adversely impact vehicle operation if not addressed.

The V2X vehicle standard is based on a 5.9 GHz dedicated short-range communication. It works for both fast-moving objects (cars) and non-line-of-sight applications. It can also work with either C-V2X, using cellular technology to create direct communication links, or dedicated short-range communications (DSRC), which is based on the Institute of Electrical and Electronics Engineers (IEEE) 802.11p standard. Different automotive manufacturers and countries support one or the other standard. However, both use the same spectrum to solve the same problem and must coexist with each other, as well as with other data transmission standards such as Wi-Fi, cellular, Ultra-Wideband (UWB), and Global Positioning System/Global Navigation Satellite System (GPS/GNSS). Figure 3-1 summarizes the various wireless transmissions in and around a connected vehicle.

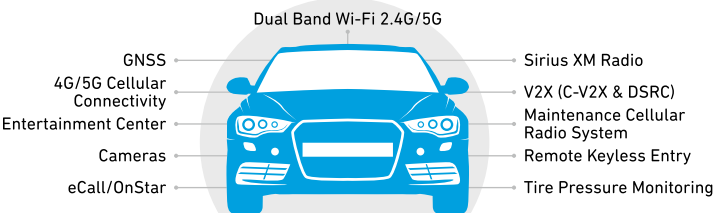


FIGURE 3-1: Vehicle connectivity technologies.

Wi-Fi operates in the 2.4 GHz, 5.2 GHz, 5.6 GHz, and 6 GHz spectrum. As shown in Figure 3-2, the 2.4 GHz frequency band must coexist with Long-Term Evolution (LTE) 40 and 41 frequency bands, and the 5 GHz and 6 GHz frequency band must coexist with the automotive 5.9 GHz band spectrum. To ensure a reliable V2X radio link, a low desense is required on the receiver end.



TECHNICAL STUFF

Desense is a degradation in receiver sensitivity. It can occur when there is a noise source that a device in the radio itself may generate. High-isolation radio-frequency (RF) filters are used to isolate the individual signal paths to prevent a signal or noise from occurring on another pathway in the radio.



TIP

Learn more about RF filter technology in Qorvo's *RF Filter Technology For Dummies* book, available at www.qorvo.com/design-hub/ebooks/filters-for-dummies.

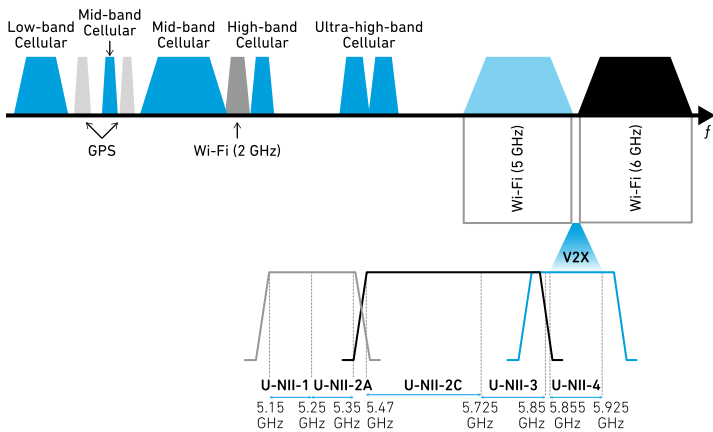


FIGURE 3-2: Wireless frequency spectrum of automotive, Wi-Fi, and others.

To ensure coexistence, it's essential to provide the appropriate RF filtering with enough out-of-band attenuation in the 5.6 GHz Wi-Fi band and the 5.9 GHz automotive band. With the many new features inside the vehicle using radios like V2X, 4G/5G, Bluetooth, Satellite Digital Audio Radio Service (SDARS), UWB, and Wi-Fi, multiple radio transceivers are operating at the same time in close proximity. If one RF transceiver power level signal reaches a receiver nearby, this can cause receiver sensitivity issues. These coexistence filters can assist in preventing this from happening. Figure 3-3 shows a band 47 bulk acoustic wave (BAW) RF filter response that provides sufficient out-of-band attenuation in the Wi-Fi bands. This attenuation will enable the system to mitigate interference caused by Wi-Fi Unlicensed National Information Infrastructure (U-NII) 1–3 bands.



Let's look at a scenario with an in-car Wi-Fi system using desense mitigating BAW filters. As shown in Figure 3-4, the V2X Wi-Fi antenna isolation needs to achieve a 1,000-meter V2X link as shown on the left horizontal axis. The measurement in Figure 3-4 shows a V2X system (telematics control unit [TCU] and active antenna) using a low-temperature co-fired ceramic (LTCC) filter before the active antenna *without* band 47 BAW filters and

the same measurement *with* band 47 BAW filters. Using band 47 BAW filters, a V2X TCU system with an active antenna can achieve the appropriate isolation to meet the goal of a 1,000-meter V2X link, as shown with the blue and dark gray measurement lines.

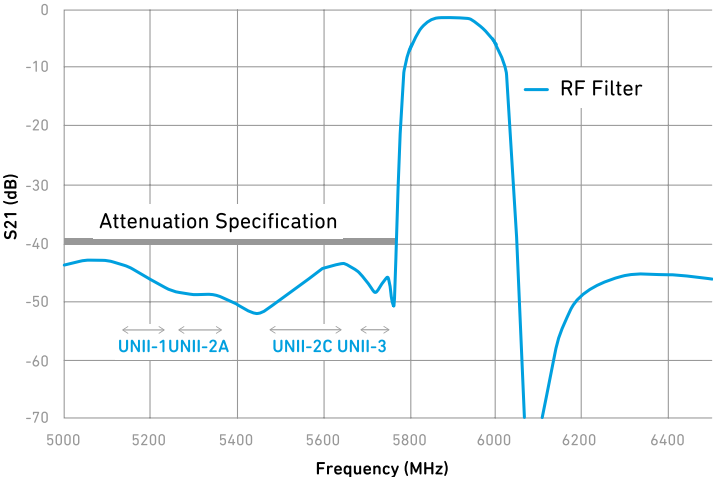


FIGURE 3-3: RF filter response mitigating desense on an automotive application.

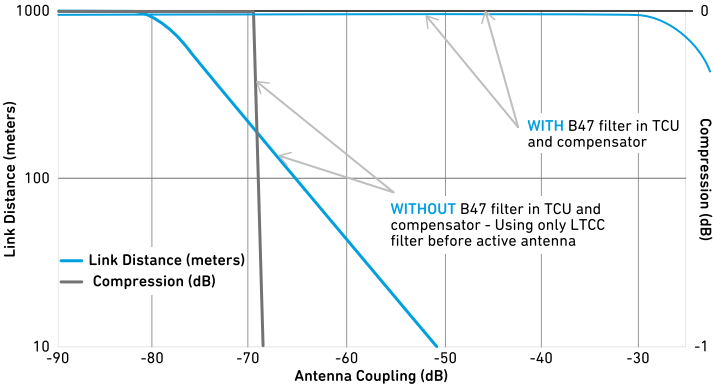


FIGURE 3-4: Measurement comparison with and without BAW filters in a V2X antenna system.

The block diagram in Figure 3-5 shows the system used to achieve the preceding antenna coupling response.

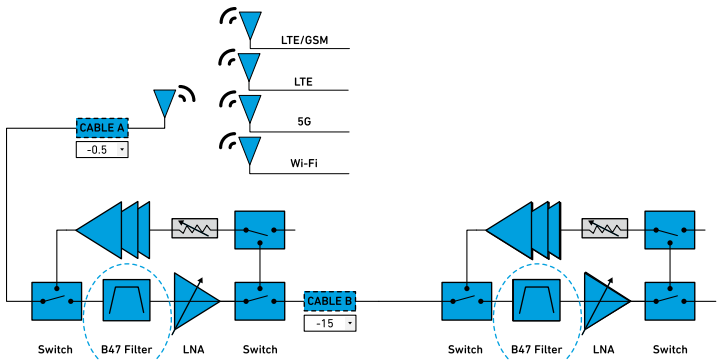


FIGURE 3-5: Block diagram showing B47 BAW filters to maximize V2X link distance.

These in-vehicle Wi-Fi scenarios require not only band-pass filtering, but sometimes notch filters as well. Although the band 47 band-pass filter provides adequate out-of-band rejection on the transmit side, notch filters may also be required on the receive path to reduce noise in the V2X band of 5 GHz. These notch filters can prevent received band noise from coupling back into the V2X system and causing desense issues. The notch filters shown in Figure 3-6 provide an almost zero desense.

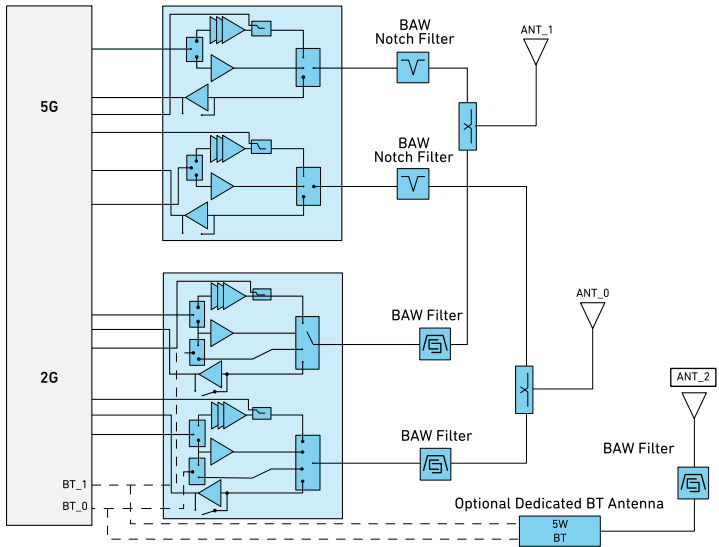


FIGURE 3-6: Filters used on a V2X Wi-Fi front end on a 5 GHz path.

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IN THIS CHAPTER

- » Seeing how 5G and IoT will affect the connected vehicle
- » Understanding where the connected vehicle is heading
- » Identifying the technology enablers of the autonomous vehicle

Chapter 4

Anticipating a Fully Connected and Autonomous Vehicle

In this chapter, you see how 5G and the Internet of Things (IoT) are opening new opportunities for connected vehicles. We also speculate on what the connected vehicles of the future will be like and when fully autonomous vehicles will hit the marketplace.

Exploring the Impact of 5G and IoT on Connected Vehicles

5G and IoT are exploding into the wireless marketplace. 5G is covering large areas of the world; by some predictions it will cover up to 65 percent of the world's population and encompass much of the mobile data traffic by 2025. It's little wonder, then, that the automotive industry sees 5G as a way to achieve its future vision of autonomous driving.

As noted in Chapter 2, Release 15 marked the beginning of 5G cellular vehicle-to-everything (C-V2X) mobile network communications and its resulting enhancements in navigation and infotainment. 5G will play a critical role in providing ultra-reliable low-latency communications (URLLC), ensuring reliable connections and fast communications in the automotive industry. It's continuously being refined, and its capabilities are expanding with each new 3rd Generation Partnership Project (3GPP) standard release.

5G and the mobile industry body 3GPP have helped enable communications between vehicles and roadside infrastructure. It does so by leveraging the comprehensive coverage of secure and already well-established cellular networks.

5G's real-time data enhances C-V2X by working with vehicle sensors and roadside infrastructure for road safety. It complements radar, Light-Detection and Ranging (LiDAR), and other sensor technologies, helping drivers maintain safe distances and navigate bad weather and road conditions. This data surpasses human sensing and cognitive abilities, enabling C-V2X to provide advanced intelligence and features like collision avoidance, platooning, cooperative driving, pedestrian protection, emergency support, and hazard detection.

Another advantage of using the cellular network is its secure wide area and short-range connectivity. This makes it versatile and cost-effective for automakers and wireless providers. With the added benefit of cellular security and densification, automakers and wireless providers can deliver massive economies of scale. With the large-scale compliance collaboration between standards bodies like 3GPP, Global System for Mobile Communications Association (GSMA), and so on, this helps 5G catapult the auto industry into a well-connected ecosystem.



REMEMBER

With the help of 5G, more connectivity and services can be achieved. Here are some of the ways 5G will meet these new connections and services:

- » **Advanced positioning:** Mobile networks already have positioning services available. 5G will further enhance spot accuracy in areas of poor Global Positioning system (GPS) coverage like Global Navigation Satellite System (GNSS), like in tunnels or underground parking. Moreover,

PC5 (device-to-device communication) will also be used for positioning. This leverages the direct communication capabilities of 5G and makes ranging between devices possible. It will further enhance the reliability and robustness of the positioning framework within 5G.

- » **Network slicing:** Network slicing is a tool for separating network resources to provide a more consistent communication service. It can be applied for data traffic flows within a given network slice and provides the foundation for dynamic selection, enabling traffic steering and separating services for devices.
- » **Multi-access edge computing:** This technology provides service where low latency is required. It will be used in collision avoidance and collective awareness applications. It may also be a key enabler for autonomous driving functionality, such as automated valet parking.
- » **Vulnerable road user (VRU) protection:** This system is positioned in C-V2X to address the rising number of pedestrian and bicyclist traffic fatalities around the world. The 3GPP specification in smartphones supports direct vehicle-to-pedestrian (V2P), vehicle-to-bicycle, and vehicle-to-motorcycle communications and will also be addressed in C-V2X in Release 17. It enables warnings to smartphones or vehicles, alerting them to potential hazards.

Looking Ahead

The connected vehicle is on the verge of several simultaneous evolutions:

- » It's moving away from fuel-based to electric power.
- » It's becoming more wireless.
- » It has more electronic devices than ever before.
- » It has more advanced telematics and infotainment systems and sensors.
- » Manufacturers are now collaborating with several business entities to increase the number of features on a vehicle.

To meet the demands of all these services and new features, automotive manufacturers must change their supply chain collaborations. Traditionally, automakers collaborated mostly with tier-one suppliers. But today, the ecosystem of automotive features and services has changed — with higher levels of complexity — creating a broader ecosystem involving multiple entities.

Automotive customers are demanding more complex services well beyond the infotainment system. To meet these demands, automotive manufacturers are collaborating with many wireless technologies, real-time analytics, and operating systems. Collaborating with suppliers well versed in these new technologies enables the automotive manufacturers to share the burden.

When Will We See Autonomous Vehicles?

As you may expect, North America, China, and Europe will likely be the first to see autonomous vehicles on public roads, followed by Japan, South Korea, and Australia.

But when, exactly, will that be? The short answer is: We don't know. Autonomous vehicles are on the horizon, but several hurdles must be overcome. There are many complex, interrelated capabilities that must all be working reliably — and working together. These capabilities can roughly be divided into two categories:

- » **Advanced safety automated driving** with sensor signal sharing, dynamic intersection management, dynamic cooperative traffic flow, automated valet parking, data sharing of dynamic objects, complex interactions, tele-operated driving, and cooperative maneuvers.
- » **Safety traffic efficiencies** including intersection safety, VRUs (addressing the rising number of pedestrian and bicyclist traffic fatalities), cooperative maneuvers, collective awareness, collaborative adaptive cruise control (ACC), dynamic cooperative traffic flow, and data sharing of dynamic objects.

Ultimately, it's impossible to know when full automotive autonomy will become a reality. We can only make an educated guess. Many of the predictions are aligned with when technical

innovations on or around the vehicle like the ones listed earlier will reliably take hold. In any case, the following six levels are the steps to full autonomous driving as defined by the Society of Automotive Engineers (SAE), which will enable vehicles to transport drivers and goods in all normal conditions:

- » **Level 0:** No automation. Driver is involved with eyes, hands, and feet.
- » **Level 1:** Driver assistance. Driver is involved with eyes and hands.
- » **Level 2:** Partial automation. Driver is partially involved with eyes.
- » **Level 3:** Conditional automation. Driver is not involved but remains on standby.
- » **Level 4:** High automation. Driver is present but need not be awake and aware.
- » **Level 5:** Full automation. No driver is needed.

Figure 4-1 provides a graphical representation of these levels.

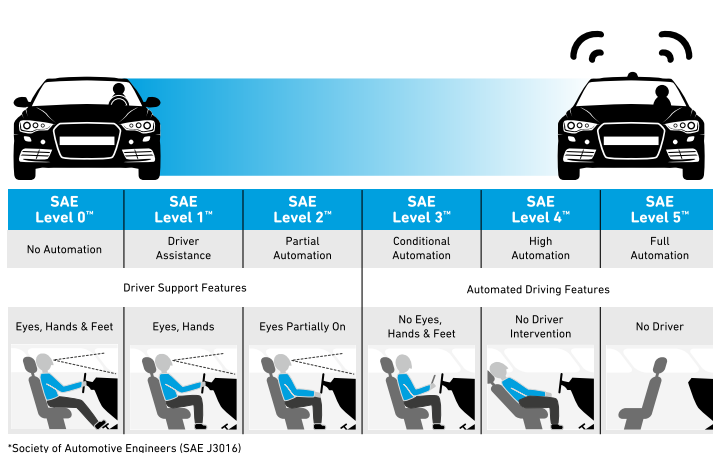


FIGURE 4-1: Automated driving levels (SAE J3016).

Based on most predictions of autonomous driving, not all vehicle travel will convert to autonomous. Some human-operated vehicles will still exist. Moreover, it will probably take decades for fully autonomous vehicles to penetrate the market.

These factors are expected to affect the penetration rate of the autonomous vehicle:

- »» The speed of technology development
- »» The results of testing in actual road situations
- »» Local and regional regulatory approval
- »» The costs of both the vehicle and the reliability of the connected ecosystem
- »» The travel preferences of consumers
- »» Infrastructure developments and public policies

Realistically speaking, optimists predict that by 2030, autonomous vehicles will be sufficiently reliable and affordable to displace human driving. But most optimistic predictions are made by those individuals with financial interests or disruptive technologies in the industry. They tend to ignore all the other considerations mentioned earlier, like the legal and regulatory approvals, the public policies, the infrastructure required, and the reliability in mixed urban traffic. Autonomous driving will happen at some level, but a lot of variables from many entities will need to be resolved before that can happen.

Chapter 5

Ten Key Takeaways

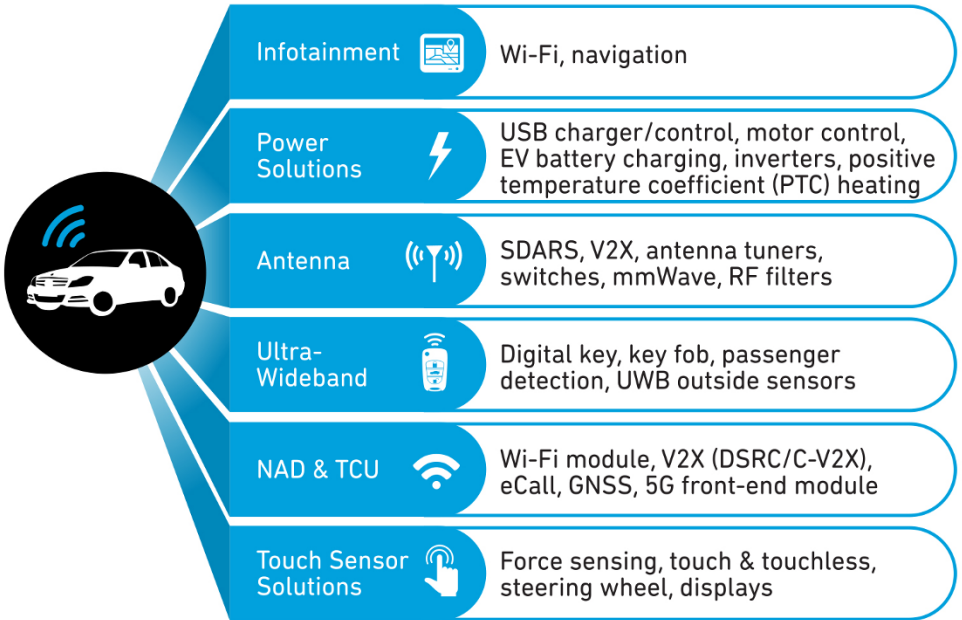
Here are ten important takeaways to remember about the connected car:

- » Cellular vehicle-to-everything (C-V2X) is an umbrella term that encompasses all 3rd Generation Partnership Project (3GPP) vehicle-to-everything (V2X) technologies. It includes any communication from within a vehicle to anything outside the vehicle.
- » From an infrastructure V2X point of view, there are two ways our vehicles will connect: C-V2X and dedicated short-range communications (DSRC). Some countries have decided to use C-V2X; others are using DSRC.
- » Intelligent Transportation Systems (ITS) 5.9 GHz spectrum band has been set aside by governments worldwide to enable vehicle communications between each other.
- » The 5G Automotive Association (5GAA) is a global, cross-industry organization of companies from the automotive, technology, and information and communication technology (ICT) sectors working together to develop end-to-end solutions for the future mobility and transportation services.

- »» The telecommunications control unit (TCU) is an onboard device that wirelessly links the vehicle to cloud storage or other vehicles through V2X standards over a mobile network. It collects telematics data from the car, like location, speed, engine data, and so on.
- »» The network access device (NAD) is an electronic onboard vehicle device that enables drivers to have a safe and enjoyable ride. It provides drivers with information about anticipated events, such as predictive maintenance, accident prevention, and telematics.
- »» The advanced driver assistance system (ADAS) provide drivers with advanced collision warnings and even lane-following capabilities.
- »» In the vehicle, many wireless technologies are working simultaneously. To ensure the coexistence of these technologies/ standards, radio frequency (RF) filters are used to isolate the individual signal paths, with high-isolation RF filters being used to prevent a signal or noise from occurring on another pathway in the radio.
- »» eCall is a mandated European emergency-call system for vehicles that provides rapid assistance in traffic accidents. It saves lives, mitigates injury, and reduces property damage.
- »» 5G Reduced Capability (RedCap) is key in this Internet of Things (IoT) evolution. RedCap aims to meet the requirements of IoT devices that need smaller, less complex, lower-cost RF solutions with longer battery life than existing 5G wireless technology options. RedCap has been defined in the 3GPP Release 17. The advantage RedCap provides for IoT manufacturers is that it builds on the 5G network but with lower RF complexity and cost.

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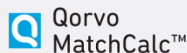


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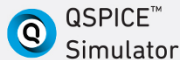
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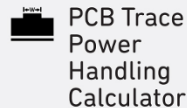


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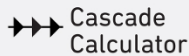
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Modelithics®
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DESIGN TOOLS



PCB Trace Power Handling Calculator



Cascade Calculator



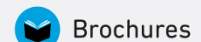
RF Impedance Matching Calculator



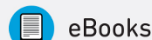
Block Diagrams



Blogs



Brochures



eBooks



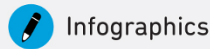
Videos



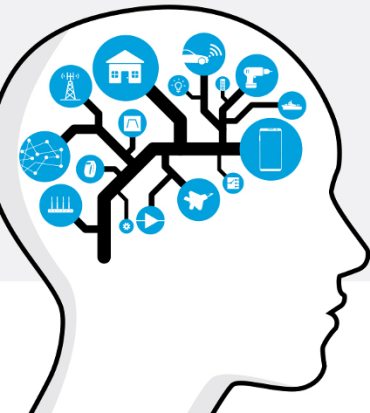
Technical Articles



White Papers



Infographics



Learn how the connected car is evolving toward autonomy

The connected car is here and becoming more intertwined into our everyday lives. It now connects to all our mobile devices, the home, IoT and the cellular-based networks instantaneously and continuously. The growth trend of connectivity in vehicles will persist, primarily driven by convenience and safety advantages. To enable these connections, technology such as Ultra-Wideband (UWB), cellular, Wi-Fi, Bluetooth and Matter are all being leveraged. With the addition of all these technologies and wireless standards, engineers need ways to navigate the complexity of coexistence, high-level of consistency and reliability required for vehicles. This book will help provide some level of that guidance.

Inside...

- Understand how the connected vehicle communicates
- Learn the technologies behind the connected vehicle
- Discover how UWB technology enables next-generation vehicle communication
- Learn the best way to navigate connectivity challenges in vehicle design
- Learn the secret of autonomous vehicles

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