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Connected Car

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Discover market opportunities and trends

Understand the future of connected vehicles

Explore the ride to vehicle autonomy

Lawrence Miller

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Qorvo Special Edition

by Lawrence Miller, CISSP

for dummies®
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Introduction

Designing today's cars is an enormously complex business. What makes them complex? Some cars have more computing power than jet aircraft, with as many as 100 programmable electronic control units (ECUs) and up to 100 million lines of code helping to run everything from the engine and powertrain to infotainment, communications, and safety and driver-assistance systems. And the complexity is only increasing as car technology rapidly advances toward more sophisticated driver-assistance systems and self-driving cars.

So, it's not surprising that the automotive sector has overtaken computers and communications as the fastest-growing market for electronics systems, according to IC Insights, which forecasts that demand for automotive integrated circuits will expand at a particularly brisk clip, experiencing 16 percent growth in 2018. To grab market share, vehicle manufacturers are adding ever more technology to their vehicle designs, and the connected car is quickly moving toward becoming the new mobile device.

In this book, you learn about the various radio frequency (RF) systems and technologies that are making the connected car of the future a reality today.

About This Book

Connected Car For Dummies, Qorvo Special Edition, consists of five chapters that explore

- The connected car visions and trends of today and the future (Chapter 1)
- Heterogeneous (mixed, varied, diverse) connectivity in the connected car, including V2X, telematics, and infotainment (Chapter 2)
- The connected car ecosystem (Chapter 3)
- Connected car RF solutions (Chapter 4)
- Key connected car takeaways (Chapter 5)

And just in case you get stumped on any acronyms or terms, there's a helpful glossary in the back of the book.

Foolish Assumptions

It's been said that most assumptions have outlived their uselessness, but I assume a few things nonetheless!

Mainly, I 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. I explain any 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, I 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 nonvolatile 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 I sure hope you'll appreciate these tips. This icon points out useful nuggets of information.

Beyond the Book

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

Where to Go from Here

With my apologies to Lewis Carroll, Alice, and the Cheshire Cat:

"Would you tell me, please, which way I ought to go from here?"

"That depends a good deal on where you want to get to," said the Cat — er, the Dummies Man.

"I don't much care where . . . ," said Alice.

"Then it doesn't matter which way you go!"

That's certainly true of *Connected Car For Dummies,* which, like *Alice in Wonderland,* is destined to become a timeless classic!

If you don't know where you're going, any chapter will get you there — but Chapter 1 might be a good place to start! However, if you see a particular topic that piques your interest, feel free to jump ahead to that chapter. Each chapter is written to stand on its own, so you can read this book in any order that suits you (though I don't recommend upside down or backward). I promise you won't get lost falling down the rabbit hole!

IN THIS CHAPTER

» Surveying the current market landscape

» Looking ahead to the future

» Enabling heterogeneous connectivity

Chapter 1 Recognizing the Visions and Trends of the Connected Car World

Drivers everywhere are quickly becoming accustomed to the increasing amount of digital technology in their cars. Many standard features have already been digitized to provide easier operation and better information, such as performance data and monitors (for example, speed, fuel efficiency, and gas tank level), climate control (heating and air conditioning), and audio (high-definition radio and CD players) — and that doesn't even scratch the surface!

In this chapter, you explore today's market and the visions, trends, and technologies that are shaping the future of the connected car.

Current Market Visions and Trends

Modern vehicles — as well as drivers' and passengers' smartphones and other mobile devices — now reach out to the surrounding world for music streamed from the cloud, real-time traffic and weather information, custom routes and navigation, and personalized roadside assistance, among other things. Other recent innovations can monitor and adjust a vehicle's position on the highway, alerting drivers if they start to drift out of their lane and slowing down if they get too close to the vehicle ahead of them. All in all, the car of today is a technological marvel.

And there's much more to come.

So, what's, uh, driving the demand for all this automotive digital technology? Several factors have contributed to the steady rise in the number and complexity of electronic modules in vehicles for several decades:

- Increasingly stringent emissions requirements and fuel-economy regulations continue to be implemented worldwide.
- Consumer appetite for convenience and safety features, such as electric seats, mirrors, cruise control, LED lighting, antilock braking (ABS), and electronic stability control (ESC) is more voracious than ever.
- Broadband wireless connectivity has connected the vehicle to a vast range of extended services, such as infotainment, real-time weather and traffic information, global positioning system (GPS) navigation, and personalized communications services (like GM's OnStar).

As vehicle manufacturers add more electronic systems to meet consumer demand and satisfy new regulations, the per-vehicle semiconductor content will continue to steadily ramp up. According to market analysis, the average semiconductor content will increase from $240 million in 2018 to $660 million in 2021, while global light vehicle production will increase from 97.2 million units to 105.1 million units over the same period, according to LMC Automotive. Events contributing to this increase will include the commercial release of 5G CAT16 (in short, Category 16 offers gigabit download speeds in ideal conditions), the dual subscriber identity module (SIM), dual active (DSDA) requirement for two radios (CAT16 + CAT6), vehicle-to-everything (V2X) dual uplink, and the increased need for bulk acoustic wave (BAW) filters for V2X applications.

TIP

Download a free copy of *5G RF For Dummies* at `www.qorvo.com/design-hub/ebooks/5g-rf-for-dummies` to learn more about 5G.

The advanced driver assistance systems (ADAS) market is one of the brightest stars in today's technology sector, with adoption rapidly expanding beyond higher-end vehicles into high-volume mainstream implementations. It's also one of the fastest-growing application areas for automotive electronics. Strategy Analytics, for example, expects that by 2021, automotive original equipment manufacturers (OEMs) will be spending more than $37 billion per year on a diverse range of assistance and safety solutions. The integration of image capture and vision processing capabilities is a critical element of ADAS designs, enabling them to offer additional and enhanced features beyond those provided by radar, Light Detection and Ranging (LiDAR), infrared, ultrasound, and other sensing technologies.

TIP

Distracted and drowsy driving is a leading cause of car accidents. A recent American Automobile Association (AAA) study found that more than one out of every six accidents can be attributed to distracted or drowsy driving. Today's in-cockpit ADAS technology can help determine if a driver is distracted or drowsy, and then alert the driver to bring his or her attention back to the driving task at hand. Additionally, by using information about the driver's head and body position provided by this same system, appropriate deployment of the airbag such as intensity and location can be implemented in crash situations.

The opportunity for vision technology to expand the capabilities of automotive safety systems is part of a much larger trend. Vision technology is enabling a wide range of products that are more intelligent and responsive than before, and thus more valuable to users. The Embedded Vision Alliance uses the term *embedded vision* to refer to this growing use of practical computer vision technology in embedded systems, mobile devices, special-purpose PCs, and the cloud — and ADAS is another exciting application for this technology.

TIP

According to the 5G Automotive Association, today, connected cars make up 12 percent of all vehicles on the road. By 2021, connected cars are projected to make up more than one-third of all vehicles on the road.

The Future's So Bright (You Must Have Your High Beams On)

Tomorrow's car will represent a step change in form and function, compared with what's being offered today. Although many have described the future in terms of the autonomous vehicle, that's just a part of the changes to come. The vehicle of the future is already taking shape in a variety of forms, although it's unlikely to reach full fruition on public streets and highways for 10 to 20 years.

Nonetheless, there will be enough innovation before then to transform the automobile. There will be new levels of connectivity between vehicles, enabling new services inside and outside the car. There will be new kinds of cars and many cars built for specific uses, such as ride-hailing and ride-sharing fleets. The culture of the automobile, including conventional wisdom about how vehicles should be owned and driven, will also change. Already, the very notion of what a car is *for* is being radically rethought.

There are four powerful global automotive megatrends behind the explosion in car data availability and its growing potential to be monetized:

- **Powertrain electrification** is being driven by stricter emissions regulations, lower battery costs, widely available charging stations, and increasing consumer acceptance. According to a McKinsey and Company report on cars, electrified vehicles (that is, hybrid, plug-in, battery electric, and fuel cell) may account for more than 10 percent of new vehicle sales by 2030, and as high as 50 percent of sales in some geographies.
- **Shared mobility** as an alternative to privately owned vehicles is growing as a mobility model. McKinsey and Company also state, by 2030, one out of ten cars sold could be a shared vehicle. This trend could spawn the rise of a market for fit-for-purpose mobility solutions as an attractive alternative to the current "one-car-for-all-purposes" model.
- **Car connectivity** will allow for new functionality and features to be offered to drivers and passengers. High-speed data and greater reliability will support new ADAS applications and effectiveness.

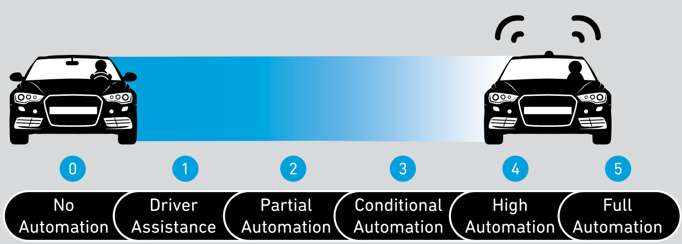
» **Autonomous vehicles (AVs)** will be the ultimate manifestation of ADAS, marking the shift from driver-assisted functionality to fully autonomous vehicle operation. Fully autonomous vehicles offer many advantages, including improved fuel economy, reduced number and severity of crashes, a safe transportation option when drivers are tired, and using travel time for entertainment and work. Autonomy will progressively transform the car into a platform from which drivers and passengers can use their transit time for personal activities, which could include the use of novel forms of media and services.

TIP

Gartner expects multiple launches of autonomous vehicles around 2020. However, the full impact of autonomous vehicle technology on society and the economy will not begin to emerge until approximately 2025. Three main areas will drive development of the autonomous vehicle market: consumer and societal acceptance, regulations, and the costs and readiness of technology. A progressive adoption scenario may imply that up to approximately 15 percent of passenger vehicles sold in 2030 could be fully autonomous, although significant differences in adoption may arise across different markets.

AUTONOMOUS DRIVING LEVELS EXPLAINED

Because no two automated driving technologies are exactly alike, in 2014, the Society for Automotive Engineers (SAE) International's Standard J3016 outlined six levels of automation for automakers, suppliers, and policymakers to use to classify a system's level of sophistication (see the figure). A crucial shift occurs between levels 3 and 4, when the driver releases responsibility for monitoring the driving environment to the system.



REMEMBER

Functional safety requirements, road and driving rules, and liability issues are in their infancy. Establishing these requirements is imperative to ensuring overall safety. Uncertainty about autonomous vehicles in the legal and insurance industries will also impact adoption.

Connective Intelligence in the Car of Tomorrow

Although many drivers today talk to their cars, the connected cars of tomorrow will talk back! Sort of. Though it's technologically feasible to stick Alexa on your dashboard today and pretend you're David Hasselhoff having a symbiotic relationship with your car while fighting dastardly criminals (well, aggressive drivers), let's focus on more practical applications for the cars of tomorrow:

- **On-vehicle intelligence:** This includes things such as intuitive instrumentation and security, immersive entertainment, machine learning, and augmented reality (like a backseat hologram telling you that you're too close to the car in front of you and you should've taken the Fifth Street bridge and now you'll never get to your mother-in-law's house in time for dinner).
- **Heterogeneous connectivity:** At a high level, this consists of three broad areas of radio frequency (RF) vehicle technology (see Figure 1-1), which I cover more extensively in Chapter 2:
  - *Vehicle-to-everything (V2X):* Connecting to the environment
  - *Telematics:* Connecting to the network
  - *Infotainment:* Connecting to the driver/passengers

The growing number of sensors in the vehicles of today and the future is a direct result of high consumer expectations. Networking is the technical path to fulfilling these expectations. Data from many systems, subsystems, and functions need to be exchanged within a complex network of electrical interfaces to increase the level of process control.

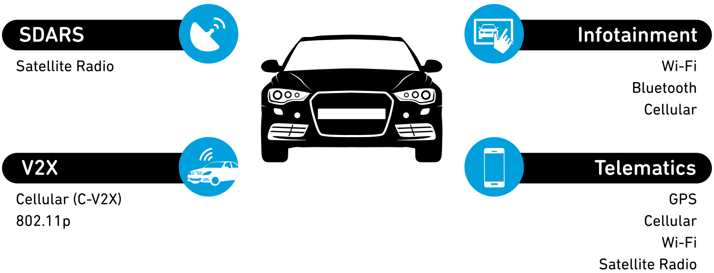


FIGURE 1-1: RF technology in the connected car.

REMEMBER

Cars generate data about how they're used, where they are, and who is behind the wheel. With greater proliferation of shared mobility, progress in powertrain electrification, car autonomy, and vehicle connectivity, the amount of data from vehicles will grow exponentially.

Networking itself has two levels:

- **On a vehicle-internal level,** networking is the strategy of interconnecting numerous electronic control units (ECUs) and sensors to facilitate new and more sophisticated functions, such as ADAS. Today, most cars have between 60 and 100 sensors. Over the next five to ten years, the number of sensors is expected to double. In other words, the number of sensors will grow beyond the number of ECUs which are integrated in modern cars. This increasingly complex network is also driven by the pressing need to increase the control quality over various car systems. For example, charge exchange, fuel injection, and exhaust gas after treatment require ever-higher control levels to meet future emissions and efficiency regulations, which limit the average fleet carbon dioxide emission per kilometer.
- **On a vehicle-external level,** networking means to integrate the vehicle into the modern digital data flow that is facilitated by wireless communication and the Internet. In a first step, cars are enabled to seamlessly link up with mobile devices, such as smartphones, to make information and apps available in the car. In a second step, however, cloud/Internet service-based information becomes available by making the car itself part of the Internet of Things (IoT). The rationale is to offer

improved driver support and an overall better traffic flow, by extending the horizon and scope of information far beyond the driver's line of sight and limited background information.

TIP

Groundbreaking changes in the connected car of the future, such as autonomous driving, will rely heavily on higher internal and external networking levels — including automotive-grade electrical interconnection and sensor technology — to achieve optimum safety, eco-efficiency, and comfort.

EDGE COMPUTING AND THE CONNECTED CAR

Edge computing-based vehicle-to-cloud solutions enable different levels of autonomous driving, including highly autonomous driving (HAD) and fully autonomous driving (FAD).

The expansion from cloud to edge computing for connected autonomous driving (AD) services is driven by the need to have more processing power closer to the vehicles to guarantee the required low latency and the need for reduced network churn with continuous access to the cloud.

Edge computing addresses these requirements by providing a different services environment and cloud-computing capabilities within the roads infrastructure, as well as access network infrastructure in close proximity to vehicles and roadside units (RSUs).

IN THIS CHAPTER

» Communicating with the environment

» Connecting to the cloud

» Interacting with drivers and passengers

Chapter 2 Understanding Connectivity in Connected Vehicles

The digital car is no longer a concept of the future. Automotive connectivity — or "connected car" applications — have now reached critical demand. The connected car is composed of multiple systems and networks that provide heterogeneous connectivity to the environment (V2X), to the cloud (telematics), and to the driver/passengers (infotainment) and more, all covered in this chapter.

V2X: Connecting to the Environment

The connected car, as depicted in Figure 2-1, fits nicely into the developing ecosystem around the IoT. Although we typically think of vehicle-to-vehicle (V2V) connectivity — with lane obstruction or automatic braking alerts, soon the connected car will be a component of a smart city, driven by a multifaceted connected infrastructure and mobile devices.

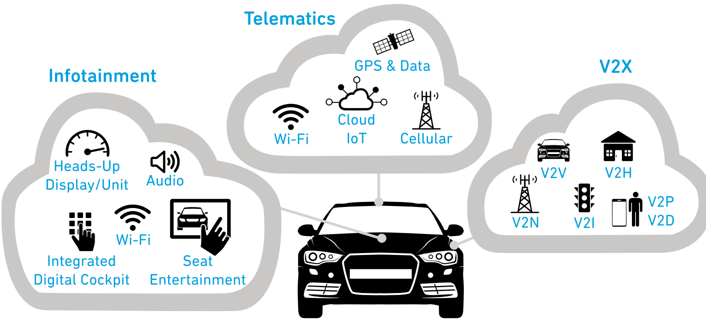


FIGURE 2-1: Heterogeneous connectivity.

Imagine traffic lights automatically changing based on traffic patterns or responding to commute demands, or your car having the capability to search several city blocks for a parking spot — all enabled by the IoT.

V2X senses the environment to enable next-generation autonomy and real-time monitoring in the connected car. There are currently two key standards for V2X:

- **Institute of Electrical and Electronics Engineers (IEEE) 802.11p:** 802.11p defines wireless access in vehicular environments (WAVE) including dedicated short-range communications (DSRC) devices in vehicles and roadside units (RSUs). It's an amendment to the popular 802.11 wireless (Wi-Fi) networking standards. DSRC operates in the 5.9 gigahertz (GHz) band with bandwidth of 75 megahertz (MHz) and an approximate range of 1,000 meters.
- **Cellular vehicular-to-everything (C-V2X) cellular long-term evolution (LTE):** C-V2X is designed to support active safety and help enhance situational awareness by detecting and exchanging information using low-latency direct transmission in the 5.9 GHz Intelligent Transportation System (ITS) band for V2V, V2I, and vehicle-to-pedestrian (V2P) situations, with no need for cellular subscription or any network assistance. C-V2X is defined by the Third Generation Partnership Project (3GPP) Release 14 specifications, including PC5-based direct communications, with a clear evolution path towards 5G New Radio (5GNR).

Today, IEEE 802.11p–based products are available on the market. Many of today's vehicles are already equipped with IEEE 802.11p technology. In contrast, C-V2X is just beginning its entrance into the automotive arena. With today's cellular eco-system strength, C-V2X will most likely mature quickly (see Figure 2-2). There may be pros and cons to both technologies, but ultimately it will be a combination of consumer preference and technology that determines how well both technologies succeed in the 5G arena.

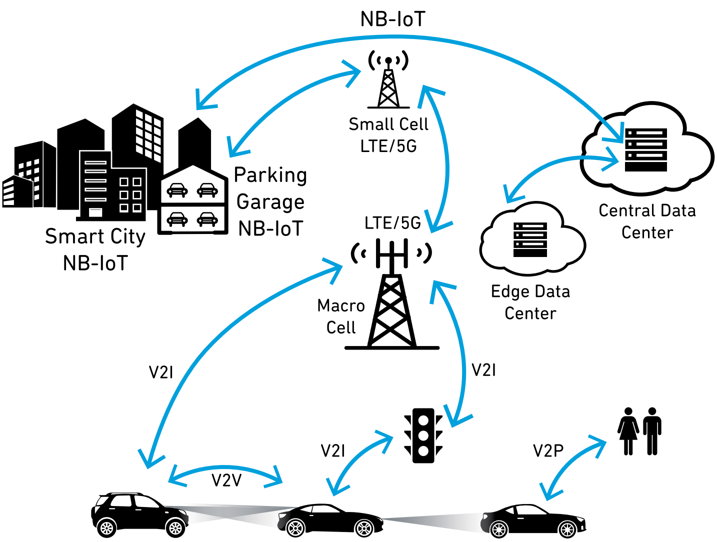


FIGURE 2-2: C-V2X communications.

Table 2-1 compares DSRC and C-V2X.

Vehicle safety is a common application for V2X, including

- **V2V:** For example, collision avoidance
- **V2I:** For example, dynamic traffic signaling
- **V2P:** For example, transmitting safety alerts to pedestrians and bicyclists
- **V2N:** Vehicle-to-network — for example, real-time traffic and weather, custom navigation, and other cloud services

V2X will also enable more efficient fleet management and platooning with V2V communications.

TABLE 2-1 DSRC versus C-V2X

	DSRC	C-V2X
Frequency Range	5.9 GHz band	5.9 GHz band
Current State	IEEE 802.11p technology used for several years	C-V2X new technology
Network Presence	Covers V2I and I2V services	Leverages cellular domain; covers V2I and I2V services
Security and Privacy on V2V/V2I/V2P	As per IEEE Wave and ETSI-ITS security services	As per IEEE Wave and ETSI-ITS security services
Can Operate Without Network Assistance	Yes	Yes

Finally, V2X is being used to enhance the capabilities in ADAS. ADAS typically employ cameras and radar sensors to provide visibility around a vehicle to a range of about 200 meters. V2X applications can share and coordinate information to extend the effective range of ADAS up to several kilometers.

TIP

LiDAR technologies such as onboard safety systems and sensors — for example, lasers, scanners, photodetector receivers, and GPS — also work alongside V2X and will be key enablers of autonomous vehicles.

Telematics: Vehicles Communicating with the Cloud

Telematics provides high-bandwidth connectivity for IoT integration and cloud services. Telematics has been used in commercial vehicles for quite some time to help businesses monitor and optimize various operational factors, such as

- Fuel consumption
- Vehicle maintenance
- Fleet utilization
- Vehicle location

- Optimum routing
- Driver behavior

Telematics in the connected car of the future will encompass all cellular standards to deliver 1 gigabit per second (Gbps) capabilities, quickly following leading smartphone capabilities.

TECHNICAL STUFF

Gigabit LTE is poised to be included in everything from smartphones and laptops to portable hot spots and vehicles. Gigabit LTE refers to LTE Category 16 (CAT16 LTE) downstream, which was introduced in 3GPP Release 12. Today's implementations have Gigabit LTE paired with LTE Category 13 uplink for uploads up to 150 Mbps. CAT16 LTE is leading to 5G low latency and higher reliability employing 256 quadrature amplitude modulation (QAM), 3x20 megahertz (MHz) carrier aggregation (CA), and 4x4 multiple input/multiple output (MIMO). QAM, CA, and MIMO are combined in various configurations for each LTE Category, resulting in their rated maximum speeds. The actual rated downlink speed achieved through this combination of technologies is not quite 1 Gbps, but close — 979 megabits per second (Mbps).

The telematics units in the car will be the primary data connection to the car, quickly demanding more data as automobile manufacturers try to match smartphone services. Mobile telecommunications carriers and vehicle OEMs will be motivated to monetize telematics data to the car, which will drive increased complexity in telematics systems. Figure 2-3 illustrates a telematics cellular front-end module (FEM).

A key advantage of telematics over smartphones is antenna performance. In automobile telematics, the antenna is typically located in the shark fin, outside the car's metal body. A smartphone located inside a vehicle means the antenna is within the metal body of the car. This degrades antenna performance, unless your dog is using your smartphone, in which case his head is sticking outside the window! Why? Because the vehicle acts like a Faraday cage — a grounded metal screen surrounding a piece of equipment, which excludes electrostatic and electromagnetic influences. To mitigate this Faraday cage effect, vehicle manufacturers are adding all telematics antennas, including cellular, to the shark fin. This allows users to connect their smartphones to the vehicle, thereby eliminating the Faraday cage effect.

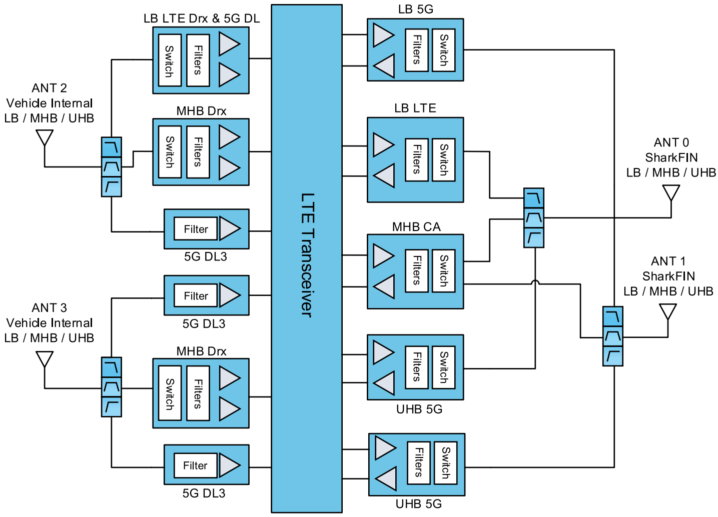


FIGURE 2-3: Telematics cellular FEM.

TIP

Automakers may be forced to support multiple carriers using Dual subscriber identity module (SIM) dual active (DSDA) technology. You learn more about DSDA in Chapter 4.

Infotainment: People Interacting with Vehicles

Today's infotainment systems allow passengers to connect outside the car as well as inside the car. Some infotainment applications include entertainment (including high-definition and satellite radio), navigation, search, and more. Key enabling protocols include Wi-Fi and Bluetooth (see Figure 2-4).

Wi-Fi hot spots in the car will be the primary connection that will enable a multi-user interface similar to home Wi-Fi networks today. Wi-Fi will deliver 1 Gbps data via the telematics unit in connected cars, to be used by all occupants of the car. The heavy use of Wi-Fi hot spots and new implementations of V2X will also create new safety challenges in the connected car. For example, V2X and 5 GHz Wi-Fi will have significant spectrum co-existence challenges that will need to be addressed using innovative filter products.

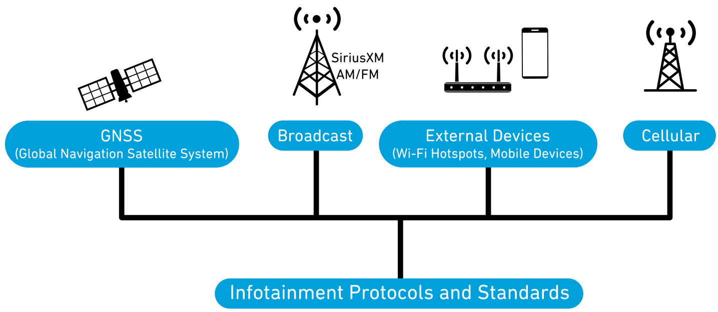


FIGURE 2-4: Infotainment connectivity.

Filter products reduce out-of-band interferences between radio frequency (RF) bands such as cellular, Wi-Fi, Bluetooth, and so on. Many of these bands are very close to each other and filtering is required to manage interference between systems. For example, within the 2.4 GHz Wi-Fi band, there is an increased potential for interference with cellular communications, like band 41 in the 4G LTE band. RF designers use coexistence filters to address the potential for transmitted Wi-Fi signals to desensitize LTE receiver reception, and for LTE signals to interfere with Wi-Fi communications. Bulk acoustic wave (BAW) filters are very effective at meeting these requirements.

TIP

To learn more about RF filters, download a free copy of *RF Filter Technologies For Dummies* and *RF Filter Applications For Dummies* at `www.qorvo.com/design-hub/ebooks/filters-for-dummies`.

Filters also aid in providing a safety factor. Proper bandpass filters mitigate interferences between bands such as the cellular LTE band 13 and the public safety band used by the United States public safety services. Without these filters, safety services could be interrupted.

As more vehicle and network services are added, design challenges will follow. The vehicle is becoming crammed with many RF signals, increased data processing, and more functionality. Negotiating the intricate balance between each of these within the vehicle will be discussed further in Chapter 4.

IN THIS CHAPTER

» Exploring connected vehicle data and services

» Examining new opportunities and use cases

» Leveraging RF semiconductors in the connected car

Chapter 3
Looking at the Vehicle Communications Ecosystem and RF — Not Just the Shark Fin

The idea of vehicles sharing information and working together to make transportation safer, greener, and more enjoyable is truly compelling. The technologies associated with this concept, collectively known as Cooperative Intelligent Transportation Systems (C-ITS), promise to reduce traffic congestion, lessen the environmental impact of transportation, and significantly reduce the number of lethal traffic accidents. The positive impact on safety alone makes C-ITS worth considering. According to the World Health Organization (WHO), roughly 1.25 million people died in 2015 due to traffic accidents, with an associated governmental cost of about 3 percent of gross domestic product (GDP).

In this chapter, I explore the connected vehicle and vehicle data, opportunities and use cases, and RF semiconductors in the connected car.

Connected Vehicles and Data

Vehicles are transforming from individual, self-contained transportation-focused objects to sophisticated, Internet-connected endpoints, often capable of two-way communications. The new data streams generated by modern connected vehicles drive innovative business models such as usage-based insurance, enable new in-vehicle experiences, and build the foundation for advances in vehicle technology such as autonomous driving and V2V communication.

As discussed in Chapter 2, there are two main approaches to the connected and future autonomous vehicle. One technology is based on the IEEE 802.11p standard, and the other will leverage existing LTE cellular infrastructure — C-V2X. Figure 3-1 shows how both methods intermingle and connect. Ultimately, they both connect to the LTE/5G infrastructure network, but they do it differently.

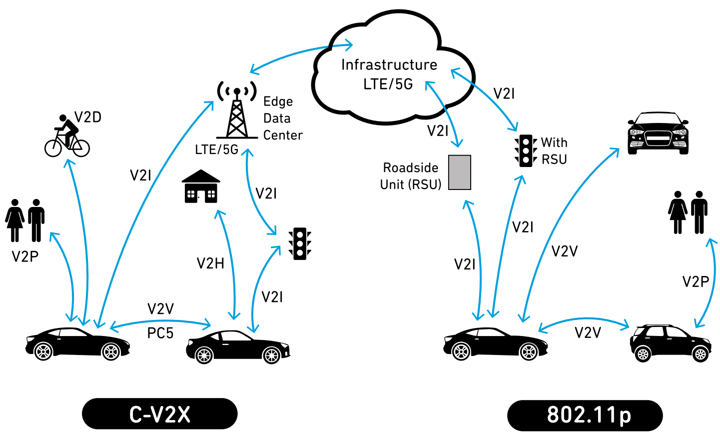


FIGURE 3-1: C-V2X and IEEE 802.11p connections.

Connected vehicle data is composed of a broad set of sensor and usage data (see Figure 3-2) such as the following:

- **Vehicle location:** GPS coordinates, speed limit, accelerometer, compass orientation.
- **Drivetrain metrics:** Drive status, engine revolutions per minute (RPM), engine temperature, fuel level, and fault codes.

- **Vehicle environment status:** Cabin/external temperature, rain detection, and humidity.
- **Custom sensors:** Cameras, third-party tracking services including payload temperatures, location, speed, and damaging impacts.
- **Over-the-air (OTA):** Automobile companies are providing software updates to infotainment, security systems, and so on via OTA, instead of bringing the auto to the service center.

FIGURE 3-2: Connected vehicle data and services.

TIP

Today's vehicles can produce up to 560GB of data per day. Future autonomous vehicles may produce more than 4,000GB of data per day. Companies such as Google, insurance agencies, and car manufacturers are already looking for innovative new revenue opportunities from processing and analyzing this continuous stream of data from the vehicle.

Opportunities and Use Cases

The digital revolution is driving a revenue redistribution across the value chain, with traditional telecom services shrinking in favor of digital services. Within digital services, connected things (for example, cars, homes, and buildings) and media (for example, infotainment in cars) could represent approximately 30 percent of the digital pie by 2020, according to Delta Partners, a leading advisory and investment firm for the telecom, digital, and media industry.

The ecosystem is still emerging, but many players are already trying to establish themselves in the connected car value chain. Examples include telcos such as AT&T, Verizon, and Telefonica, over-the-top (OTT) providers such as Google and Apple, platform providers such as Jasper and Airbiquity, original equipment manufacturers such as BMW and Audi, integrators such as Accenture and Tech Mahindra, and specific machine-to-machine (M2M) vertical service providers such as OnStar. These players are offering a range of services to both consumers and businesses, including in-car and out-of-car services (see Figure 3-3).

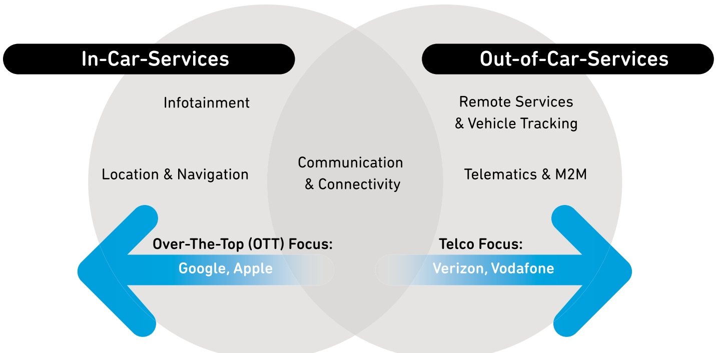


FIGURE 3-3: Connected vehicle use-cases and opportunities.

Progress toward connected cars and autonomous vehicles is being spurred by four interrelated trends:

- Radically new technology at lower prices
- New high-tech entrants driving faster innovation
- New mobility concepts and increasingly urban customers
- Evolving regulatory and policy constraints

All these trends are leading to changes in what cars are and how they're used. They also explain why automakers have been investing so heavily in connected technologies, new ride-sharing services, and other transportation options (for example, Toyota's investment in Uber, Volkswagen's investment in Gett, and GM's investment in Lyft). Finally, it explains the entry into the market of data-centric data players such as Google, Apple, and Alibaba, all of which are well attuned to the changing demographic of the driving (and nondriving) public.

One area of ADAS that is seeing a particularly significant increase in interest from OEMs is the use of in-cockpit cameras to monitor the driver. As semi-autonomous and autonomous driving takes hold, a big hurdle will be alerting the driver when he or she needs to take control of the vehicle. The internal cockpit driver monitoring system will perform this function. Strategy Analytics sees the potential for more than 2.5 million cameras to be used in such applications in light vehicles produced in 2021, with further growth accelerating beyond that as autonomous technologies become more widely applied and regulators and safety bodies focus on driver distraction issues. Strategy Analytics has identified two main factors behind this trend:

- **As mainstream ADAS technologies increasingly appear in mass-market vehicles, the pressure is on to develop ever-improved solutions for premium car brands and models.** By monitoring the driver, for example, automated interventions can be specifically tailored to the driver's attentiveness. This response customization both reduces the likelihood of false warnings when the driver is engaged and improves responses when the driver is distracted.
- **There is large and growing industry interest in the migration of ADAS technologies into increasingly autonomous vehicles.** One of the key challenges here is managing the handover between autonomous and driver-controlled states. Without accurate information as to how engaged the driver is at any particular point in time, a smooth handover is almost impossible.

Image perception, understanding, and decision-making processes have historically been achievable only using large, heavy, expensive, and power-draining computers. This has restricted computer vision's usage to a few niche applications like factory automation. Beyond these few success stories, computer vision has mainly been a field of academic research over the past several decades. However, with the emergence of increasingly capable processors, image sensors, memory, and other semiconductor devices, along with robust algorithms, it has become practical to incorporate computer vision capabilities into a wide range of systems, including ADAS designs.

RF Semiconductors in Vehicles

The increase in electronic communications systems inside the automobile has grown extensively. As shown in Figure 3-4, there are multiple RF front-end (RFFE) chains and antennas within a vehicle such as Wi-Fi, cellular, Bluetooth, and others. Additionally, some standards noted in Figure 3-4 have more than one or two antenna signal paths.

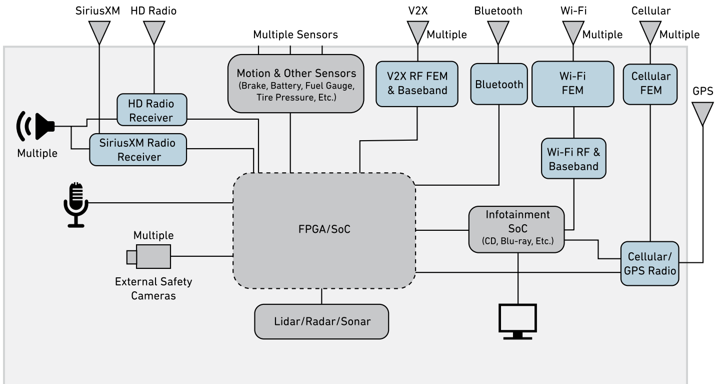


FIGURE 3-4: RF technology has enabled the connected vehicle.

Many of these RF chains contribute to the new vehicle system intelligence. This system intelligence begins with gathering data from sensors, cameras, and onboard connections providing important data and services. RF components such as amplifiers, switches, filters, and highly integrated modules add important functionality to the vehicle processing and communications systems. As we head toward a more autonomous vehicle, these systems and their functionality will become more complex. In addition, new RF chains such as millimeter wave (mmWave) will migrate onto the vehicle, providing more than three times the accuracy and data transfer rates of today's systems. This will enable designers to implement more intelligent onboard communications and sensing to help the vehicle detect and avoid other vehicles, people, objects, and devices.

REMEMBER

Just as the cellular technology market has evolved with many stops, starts, and turns, so too will the vehicle of the future transform markets. Customers will influence automotive designs, regulatory agencies will control and shape technologies, and the LTE/5G connected world around the vehicle will continue to advance. RF design engineers fraught with meeting the market needs will need to balance performance and opportunity within their applications.

IN THIS CHAPTER

» **Tackling RF performance challenges**

» **Addressing vehicle quality standards and technical system requirements**

Chapter 4
Exploring Connected Vehicle RF Challenges and Solutions

Today's smartphones have more computing power than all of NASA had back in 1969 when it landed two astronauts on the moon. And what do we do with all this raw computing power in our hands? Send smiley winking emojis to our BFFs, of course!

Modern vehicles have even more computing power and technological complexity than smartphones. Thus, interference between technologies and RF signals in modern vehicles is a constant challenge for design engineers. To ensure all these technologies can coexist, RFFE modules require precise filtering, PA performance, and PA efficiency to work cohesively. In addition, these components must be able to perform under harsh environmental conditions to meet stringent vehicle quality standards. Finally, system requirements for CA and DSDA technology create still more challenges.

In this chapter, we discuss various RF design challenges and solutions.

Understanding Performance Parameter Challenges

Key RF-related performance parameter challenges include

- Receiver sensitivity
- Linearity
- Selectivity
- Thermals and robustness

Receiver sensitivity

Receiver sensitivity indicates how faint an input signal can be and still be successfully received by the receiver. The lower power level the receiver can receive, the better the sensitivity of the receiver. Sensitivity in a receiver is normally defined as the minimum input signal required to produce a specified signal-to-noise ratio (SNR) at the output port of the receiver.

Receiver (RX) sensitivity is one of the key specifications of any radio receiver in wireless communications. A receiver's sensitivity indicates its ability to pick up low-level signals. Because signal levels are directly proportional to the distance from their source, a system with low sensitivity means that you have an optimal range of reception. That is, more receiver sensitivity equals longer range.

TECHNICAL STUFF

Sensitivity in a receiver is defined as the minimum input signal required to produce a specified output signal with a required signal-to-noise ratio (SNR). It can be calculated by multiplying the thermal noise floor with the RX noise figure (NF) and the minimum required SNR. Lower noise figure means better performance.

In a vehicle, several factors can lead to higher noise figure or SNR challenges than in other applications. These challenges include the following:

- Lengthy RF coax cabling in some vehicle applications can cause increases in noise figure and signal loss.
- Extreme temperatures or temperature shifts in RF cables and components can cause increases in noise figure and compromise the performance of RFFE devices.

To mitigate the noise figure caused by the loss in lengthy cables, designers use low-noise amplifiers (LNAs) and try to place the RFFE closer to the antenna. This reduces the cable length, thereby improving system NF, as well as reducing cable insertion loss.

High Q, low loss RF filters assist in mitigating the effects of temperature shifts. They also help reduce link budget insertion loss and adjacent band interferences.

TECHNICAL STUFF

Higher Q or *quality factor* indicates a lower rate of energy loss relative to the stored energy of the resonator. High Q RF filters have narrower and steeper stop-band skirts.

Another design consideration is frequency range. Obtaining low noise figure tends to be more difficult at higher frequencies. As cars continue to migrate toward higher frequency ranges, such as cellular and Wi-Fi, attaining noise figure specifications becomes increasingly difficult. It is unlikely that this trend will change, and the expectation is that frequency ranges will eventually extend to the mmWave ranges such as 28GHz or 34GHz. Thus, noise figure will continue to be a challenge for in-vehicle systems.

Linearity

PA linearity describes how well a PA can amplify a signal without distortion. The term refers to the essential job of an RF amplifier, to increase the power level of an input signal without otherwise altering the content of the signal.

Linearity is important for systems using any frequency modulation scheme that encodes information in the amplitude variation of the signal. In telecommunications and signal processing, frequency modulation is the encoding of information in a carrier wave by varying the instantaneous frequency of the wave. These modulation schemes range from amplitude modulation (AM) to complex quadrature (QAM) used for Wi-Fi. Modulation schemes rely on the receiver's ability to discern the differences in the signal's amplitude and phase. A linear PA is required to preserve the amplitude and phase variation in the signal. If the transmitted signal is distorted, then the receiver will have a more difficult time recovering the information encoded in the amplitude portion of the modulation. Signal degradation has a negative impact on the system's range and data rate.

The received signal can include unwanted out-of-band signals with large amplitude. These unwanted signals can cause distortion products in the receiver that degrade the SNR of the desired signal, impacting range and data throughput. Filters can be used to reject these signals and reduce the linearity requirements. Therefore, linearity requirements for the out-of-band interference signals can be reduced by using a bandpass filter.

Nonlinear front-end PA systems generate spectral regrowth causing interference to adjacent channels. Spectral regrowth is a significant distortion mechanism in nonlinear devices such as PAs in wireless applications. Power level requirements, temperature, and link budget increases can all attribute to linearity issues. Using band edge filters can help attenuate nonlinear distortion from interfering with users in adjacent channels. In addition, coexistence filters on the receive side of the RFFE can also mitigate signal interference and help improve receiver band SNR.

Selectivity

Selectivity is the measure of performance of a radio receiver to respond only to the radio signal it is tuned to and to reject other adjacent signals nearby in frequency, such as another broadcast on an adjacent channel.

Vehicle wireless communication systems can be affected by several types of interference. Vehicle RF design engineers must consider both internal and external RF signals in and around the radio receiver.

Filters increase receiver selectivity by attenuating undesired signals while passing the desired signal with minimal loss. They also help mitigate adjacent band interferences. As the average number of band counts and radios in vehicles increases and the number of standards increases, leveraging advanced filter technologies such as low-drift BAW helps engineers tackle tough interference problems.

An additional consideration in wireless RFFE design on vehicle systems is heat or thermal reduction. Using high Q RF filtering reduces the impact of heat on insertion losses. As shown in Figure 4-1, using high Q low-drift filtering helps reduce interference during thermal shifts. The low temperature coefficient of frequency (TCF) of a low-drift filter helps attain low insertion loss, mitigate adjacent channel interference, and decrease link budget constraints.

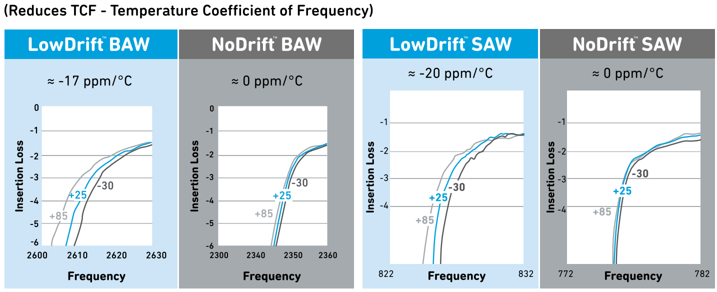


FIGURE 4-1: Optimized filter technology reduces temperature drift.

Thermals and robustness

Temperature shifts in a vehicle can be very large. Vehicle stress conditions ebb and flow between −40°C and 150°C. So, vehicle design engineers and suppliers must qualify and test their components and systems for these extreme conditions (see Figure 4-2).

Stress Conditions	Depending on Desired Temperature Grade
	Grade 0: -40 to 150°C
	Grade 1: -40 to 125°C
	Grade 2: -40 to 105°C
	Grade 3: -40 to 85°C
	Grade 4: 0 to 70°C

FIGURE 4-2: Automotive AEC requirements.

Engineers often make tradeoffs between linearity, power output, and efficiency in their system designs. Heat can degrade overall system performance characteristics such as throughput, signal range, and interference rejection. As a result, it's important to design systems that use RFFE components that mitigate heat. Using optimized, highly linear power amplifiers or front-end modules reduces overall heat.

Another key contributor to heat in vehicles is cable loss. Cable loss causes link budget increase and means the transmit (TX) RFFE PA must compensate by increasing its output power to mitigate the loss. This increase in output power increases system heat and inefficiencies.

Recognizing Other Vehicle RF Challenges

Beyond performance parameters there are two key topics to consider in vehicle RF systems:

- Creating components that meet stringent Automotive Electronics Council (AEC) vehicle quality standards
- Meeting system requirements for carrier aggregation (CA) and DSDA technology

IATF and AEC standards

As car technology rapidly advances toward more sophisticated driver-assistance systems and self-driving cars, the stakes get higher. The automotive industry has developed strict quality standards for component manufacturing and testing to ensure that increasingly complex RF components don't fail when they're embedded in electronics systems.

Manufacturers in the automotive sector typically need to meet specified industry standards throughout the manufacturing and testing process. Three key standards include the following:

- **International Automotive Task Force (IATF) 16949:** The global automotive industry standard for quality management systems. The automotive industry generally expects parts to be manufactured, assembled, and tested in IATF 16949-qualified facilities.
- **Automotive Electronics Council (AEC) Q100:** Defines standard tests for active components such as switches and PAs.
- **AEC-Q200:** Defines standard tests for passive devices such as RF filters used in Wi-Fi and cellular communications.

Some tests are unique to the automotive industry — for example, early life failure rate (ELFR), which subjects multiple samples of 800 components to temperatures of at least 125°C, and power temperature cycling (PTC), which repeatedly cycles between high (125°C) and low (–40°C and lower) temperatures.

TIP

Other tests are conducted under harsher conditions or use larger lot sizes to provide greater statistical confidence in the reliability of production components.

CA and DSDA

Carrier aggregation (CA) allows mobile network operators to combine many separate LTE carriers in order to increase the bandwidth and bit rate. Carrier aggregation is a technique used to combine multiple LTE component carriers (CCs) across the available spectrum to

- Support wider contiguous or noncontiguous chunks of intra- or inter-band bandwidth signals
- Improve network performance in the uplink, downlink, or both directions
- Increase peak data rates up to 1 gigabit per second (Gbps) peak download speed
- Increase overall capacity of networks to exploit fragmented spectrum allocations

REMEMBER

A CC is an LTE channel normally allocated to one user.

The Third-Generation Partnership Project (3GPP) Release 13 standard allows up to 32 CCs in CA implementations, which is a formidable challenge for RF designers. In the vehicle, CA will offer gigabit-class LTE connectivity. To achieve these speeds, in-vehicle modems use sophisticated digital signal processing (256 QAM) and up to 4x4 MIMO supporting up to 4x CA.

TECHNICAL STUFF

MIMO is an antenna technology for wireless communications in which multiple antennas are used at both the transmitter and receiver. The antennas at each end of the communications circuit are combined to minimize errors and optimize data speeds.

CA challenges in vehicles include the following:

- **Downlink sensitivity:** Many CA applications require architectures using RF filters, duplexers, or complex multiplexers. These RF filters help ensure isolation between the individual TX and RX paths, helping achieve system sensitivity. As more bands are added to a system and more complex filtering, such as multiplexers are used, designers must ensure individual bands works cohesively.

- **Harmonic generation:** Harmonics are generated by nonlinear components such as PAs, duplexers, and switches. Designers must be prudent in their design tradeoffs to ensure that they don't sacrifice performance over harmonic reduction.
- **Desense:** Harmonics and TX leakage cause degradation in system sensitivity, known as *desense.* Desense is the degradation in sensitivity due to noise sources, typically generated by the same device the radio is in. This creates degradation of the receiver, which prevents the desired signal from being properly detected. High switch isolation and filter attenuation can minimize interference from one signal path to the other.

TIP

To learn more about CA and LTE technologies, download *Carrier Aggregation For Dummies, Carrier Aggregation Fundamentals For Dummies*, and *5G RF For Dummies*, all available at `www.qorvo.com`.

DSDA technology uses two separate transceivers and antenna pathways for two CCs, which are both active. This enables OEMs to utilize specific contracted carrier services while offering vehicle owners the ability to add their preferred carrier. Carriers will benefit by allowing vehicle owners to add the vehicle to their family data plans. However, the tradeoff is that DSDA increases system power consumption (which increases heat) and RFFE complexity. To mitigate heat, designers must use RFFE modules that are linear and efficient.

REMEMBER

Like CA, DSDA requires robust low-drift filtering to achieve system and automaker design goals. Individual band filters, as well as complex multiplexers, become increasingly important as the number of CCs increases.

IN THIS CHAPTER

» Getting connected

» Satisfying the demand for data

» Overcoming specific technology challenges

» Driving worldwide safety standards

» Partnering with an innovative company

Chapter 5
Ten (Car) Key Takeaways

In this chapter, I give you ten important takeaways to remember about connected car technology.

- **The connected car is beachfront real estate for service providers.** Instead of a conduit for the smartphone, the car is becoming a prime connected device in the IoT.
- **Getting attached to telematics.** The telematics attach rate will exceed 60 percent within five years, and there is a real possibility to achieve a 100 percent attach rate in under ten years.
- **So many carriers and apps, so little bandwidth spectrum.** Cars will be connected across many protocols enabling many new applications, forcing OEMs to support multiple carriers across the world with an ever-increasing frequency band count.
- **Data on the DL.** Data demand will increase dramatically in the car over the next five years, so OEMs will need to deliver competitive performance — exceeding 1Gbps downlink (DL) speeds — to leading smartphones.
- **You need Cat 16 to make the connected car purr-fect.** As evidenced in many leading smartphones, high data demand will significantly increase the RF content and complexity in the connected car. Cat 16 or greater will be required to meet the demand.

- **5G — More horsepower than under the hood of your car.** 5G sub-6 gigahertz (GHz) will be aggressively implemented in the connected car, ramping up in 2021.
- **More options (and challenges) with DSDA.** DSDA has many hurdles to overcome, but many OEMs believe it will be required, which will drive higher RF content and complexity.
- **Catch a millimeter wave (mmWave).** Radar and communication systems using mmWave will potentially enable high-bandwidth access and Gbps data rates in the connected car. However, many complex challenges — such as the need for propagation channel models, infrastructure, and communication overhead — will need to be solved before OEMs will adopt mmWave in connected car systems.
- **Safety first.** V2X will become common worldwide as governments implement more safety standards.
- **Choose a partner with a road map to the future.** Qorvo is uniquely positioned to solve the many RF challenges in the connected car of the future.

Glossary

5G New Radio (5GNR): The wireless standard for a new physical interface in 5G.

advanced driver assistance systems (ADAS): Automotive systems developed to automate, adapt, or enhance vehicle systems for safety and better driving.

AEC-Q100: Automotive Electronics Council (AEC) "Stress Test Qualification for Integrated Circuits."

AEC-Q200: Automotive Electronics Council (AEC) "Stress Test Qualification for Passive Components."

amplitude modulation (AM): A modulation technique, commonly used for transmitting information via a radio carrier wave, in which the signal strength (amplitude) of the carrier wave is varied in proportion to the waveform being transmitted.

antilock braking system (ABS): A system that prevents the wheels on a motor vehicle from locking up or skidding when the driver applies the vehicle's brakes.

augmented reality (AR): Technology that produces a composite view by superimposing high-resolution (even 3D) images on a real-world view.

Automotive Electronics Council (AEC): A U.S.–based organization that establishes qualification standards for the supply of components in the automotive electronics industry. *See also* AEC-Q100 *and* AEC-Q200.

bulk acoustic wave (BAW): A piezoelectric transducer that converts electrical signals to acoustic waves used to create filters and delay lines.

Bluetooth: A wireless technology standard for data exchange over short distances between fixed and mobile devices using short-wavelength

UHF radio waves in the 2.4 to 2.485 GHz ISM band. *See also* ultra-high frequency (UHF), gigahertz (GHz), *and* industrial, scientific, and medical (ISM) band.

carrier aggregation (CA): A technique used to aggregate carriers (known as component carriers) to achieve greater bandwidth, lower latency, and better coverage. *See also* component carrier.

cellular vehicular-to-everything (C-V2X): Builds upon existing LTE connectivity platform for automotive; part of Release 14 of the global 3GPP standard. *See also* Long-Term Evolution (LTE) *and* Third-Generation Partnership Project (3GPP).

component carrier (CC): An aggregated carrier or channel in carrier aggregation. *See also* carrier aggregation.

Cooperative Intelligent Transportation Systems (C-ITS): Technology that enables vehicles to communicate with other vehicles and infrastructure (for example, traffic signals) to provide drivers alerts about potential hazards and traffic information.

data communications equipment (DCE): A device used to establish, maintain, and terminate communications between a data source and its destination in a network. *See also* data terminal equipment (DTE).

data terminal equipment (DTE): A device that communicates with a DCE in a network. *See also* data communications equipment (DCE).

dedicated short range communications (DSRC): One-way or two-way short-range to medium-range wireless communication channels specifically designed for automotive use and corresponding protocols and standards.

downlink (DL): In satellite communications, the link from a satellite to a ground station. In cellular networks, the link from a cell site to the cellular device. In computer networks, the connection from the DCE to the DTE. *See also* data communications equipment (DCE) *and* data terminal equipment (DTE).

dual SIM, dual active (DSDA): A capability that enables support for dual cellular carrier contacts, such as the contact carrier plus one other user carrier. *See also* subscriber identity module (SIM).

early life failure rate (ELFR): A method for calculating the early life failure rate of a product, using accelerated testing, with a failure rate that is constant or decreasing over time.

edge computing: A method used to optimize cloud computing by processing data at the edge of the network, near the source of the data.

electronic control unit (ECU): Any embedded system that controls the electrical system or one or more subsystems in a motor vehicle.

electronic stability control (ESC): Technology that automatically applies braking to a vehicle's wheels individually when a loss of traction or steering control is detected and, in some systems, reduces engine power until driver control is restored.

European Telecommunications Standards Institute Intelligent Transport Systems (ETSI-ITS): A body of standards developed by the independent European telecommunications standards organization, for telematics and all types of communications in vehicles, between vehicles, and between vehicles and fixed locations.

fully autonomous driving (FAD): A vehicle capable of sensing its environment and navigating without human input. Also referred to as driverless car, self-driving car, or robotic car. *See also* highly autonomous driving (HAD).

gigahertz (GHz): A measure of bandwidth in a digital signal.

global positioning system (GPS): A U.S. government–owned global system of satellites that provide geolocation and time information on GPS receivers anywhere on or near Earth where there is an unobstructed line of sight to four or more GPS satellites.

Global System for Mobile Communication (GSM): A second-generation digital mobile telephony system that uses a variation of time-division multiple access (TDMA).

highly autonomous driving (HAD): A vehicle capable of performing all driving functions under certain conditions. The driver may have the option to control the vehicle. *See also* fully autonomous driving (FAD).

industrial, scientific, and medical (ISM) band: The parts of the RF radio spectrum that are reserved for industrial, scientific, and medical requirements. *See also* radio frequency (RF).

infrastructure-to-vehicle (I2V): I2V technologies capture vehicle-generated traffic data, wirelessly providing information such as advisories from the infrastructure to the vehicle that inform the driver of safety, mobility, or environment-related conditions. *See also* Vehicle-to-Infrastructure (V2I).

insertion loss: In telecommunications, the loss of signal power due to the insertion of a device in a transmission line, typically expressed in decibels.

Institute of Electrical and Electronics Engineers (IEEE): A technical professional organization that promotes the advancement of technology.

Intelligent Transportation Systems (ITS): Systems to which information and communication technologies are applied in the field of road transport, including infrastructure, vehicle and users, and in traffic and mobility management.

International Automotive Task Force (IATF): An association of primarily U.S. and European automotive manufacturers that works together to provide improved quality products to automotive customers worldwide.

international mobile subscriber identity (IMSI): A unique 64-bit identifier used to identify a user on a cellular network.

International Telecommunications Union (ITU): A United Nations agency responsible for coordinating worldwide telecommunications operations and services.

Internet of Things (IoT): A system of smart, connected devices.

Light Detection and Ranging (LiDAR): A system, similar to radar, that uses laser light to measure the distance to an object.

Long-Term Evolution (LTE): A telecommunications standard for high-speed wireless communication, developed by the 3GPP. *See also* Third Generation Partnership Project (3GPP).

low-noise amplifier (LNA): An electronic amplifier that amplifies a very low-power signal without significantly degrading its signal-to-noise ratio. *See also* signal-to-noise ratio (SNR).

machine-to-machine (M2M): Direct communication between devices, sensors, or other machines, without requiring human intervention.

megahertz (MHz): A measure of bandwidth in a digital signal. One megahertz is equal to one million hertz.

millimeter wave (mmWave): The band of spectrum between 30 GHz and 300 GHz.

multiple input/multiple output: Wireless communication technology in which multiple antennae are used at the source and destination and their functions (transmit/receive) are combined to reduce errors and optimize data speed.

noise figure (NF): A measure of the degradation of SNR, caused by components in an RF chain. *See also* signal-to-noise ratio (SNR) *and* radio frequency (RF).

original equipment manufacturer (OEM): A company that produces parts and equipment that may be marketed by another manufacturer.

over-the-air (OTA): Wireless communication methods used to distribute new or updated software and configuration settings, among others.

over-the-top (OTT) provider: Streaming audio, video, and other media services that are provided directly over the Internet, for example, by Google or Apple, bypassing telecommunications, cable, or broadcast television service providers.

PC5 interface: A one-to-many user equipment communication interface; part of the 3GPP LTE standard. *See also* Third-Generation Partnership Project (3GPP) and Long-Term Evolution (LTE).

power amplifier (PA): An electronic device that increases the power of a signal.

power temperature cycling (PTC): A test performed to determine the ability of a device in operation to withstand alternate exposures and high and low temperature extremes.

quadrature amplitude modulation (QAM): A modulation technique that conveys two analog or digital signals.

quality factor (Q): A measure of the selectivity of a resonant circuit described as the ratio of stored versus lost energy per unit of time.

radio frequency (RF): An electromagnetic wave frequency used in radio communication.

radio frequency front end (RFFE): A device or module that incorporates all the circuitry between the antenna and at least one mixing signal stage of a receiver and/or transmitter.

roadside unit (RSU): A computing device located on the roadside that provides connectivity support to passing vehicles.

signal-to-noise ratio (SNR): A measure used to compare the level of a desired signal to the level of background noise, typically expressed in decibels.

Society for Automotive Engineers (SAE) International: A global U.S.-based professional association and standards developing organization for engineering professional, primarily in transportation industries.

subscriber identity module (SIM): An integrated circuit used to securely store the IMSI and its related key, which are used to identify and authenticate mobile device subscribers. *See also* international mobile subscriber identity (IMSI).

Third-Generation Partnership Project (3GPP): A consortium of telecommunications industry partners that collaborate on the development of GSM, 4G LTE, and 5G standards. *See also* Global System for Mobile Communication (GSM) *and* Long-Term Evolution (LTE).

ultra-high frequency (UHF): The ITU designation for RF frequencies between 300 MHz and 3 GHz. *See also* International Telecommunications Union (ITU), radio frequency (RF), megahertz (MHz), *and* gigahertz (GHz).

vehicle-to-everything (V2X): The passing of information from a vehicle to any entity that may affect the vehicle, and vice versa.

vehicle-to-infrastructure (V2I): V2I technologies capture vehicle-generated traffic data, wirelessly providing information such as advisories from the infrastructure to the vehicle that inform the driver of safety, mobility, or environment-related conditions. *See also* Infrastructure-to-Vehicle (I2V).

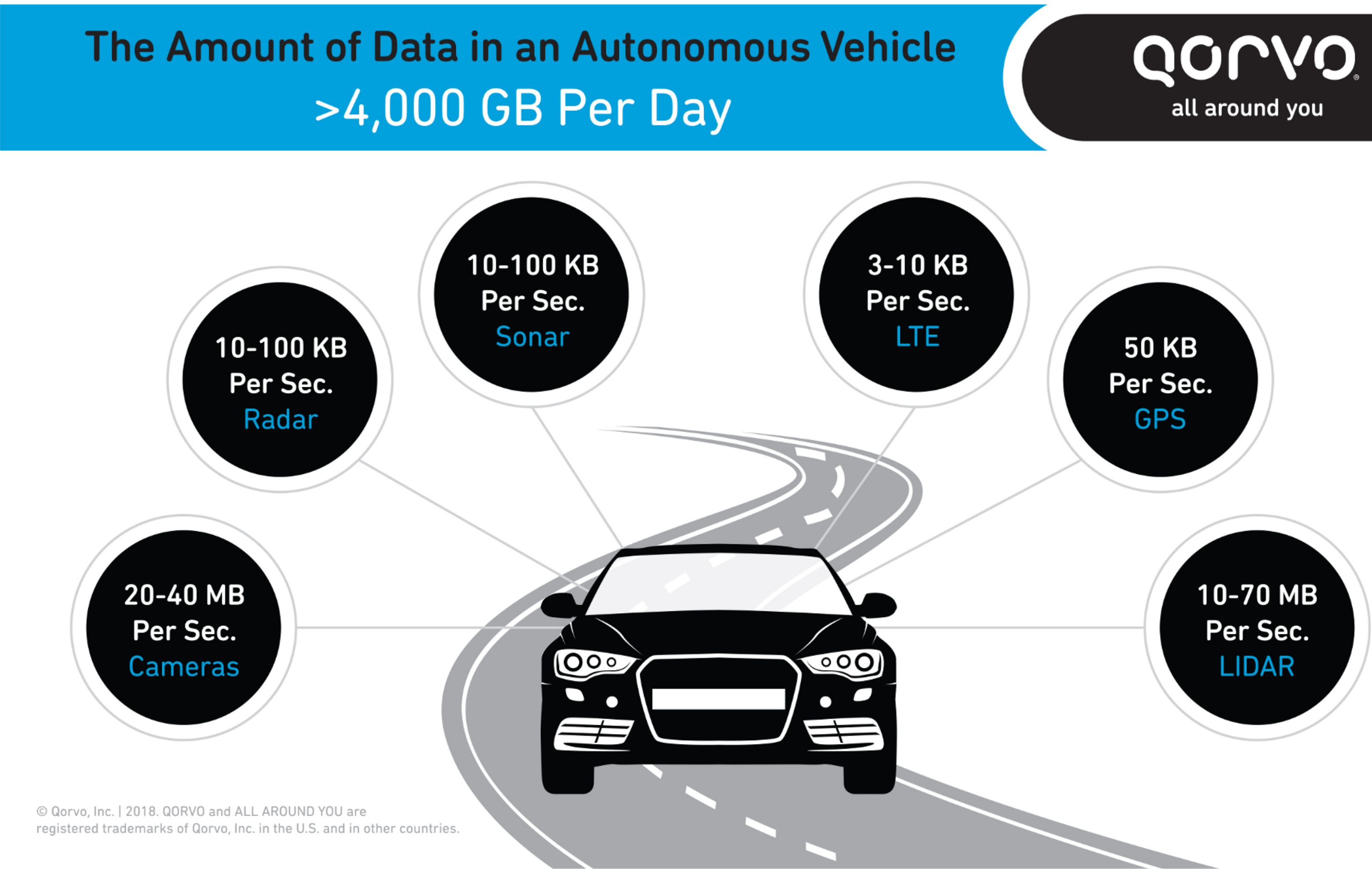
vehicle-to-network (V2N): Interconnectivity to realize communication and roaming between ad-hoc vehicular networks and other heterogeneous networks.

vehicle-to-vehicle (V2V): Comprises a wireless network where automobiles send messages to each other with information about what they're doing.

virtual reality (VR): A computer-generated three-dimensional (3D) image representation of an object or objects, which a user can interact with in a similar manner as real-world objects.

Wi-Fi: A technology used for wireless local area networking with devices based on the IEEE 802.11 standards. *See also* Institute of Electrical and Electronics Engineers (IEEE).

Zigbee: A collection of high-level communication protocols for use in small, low-power personal area networks and smart home automation.


The Amount of Data in an Autonomous Vehicle
>4,000 GB Per Day
qorvo
all around you
10-100 KB
Per Sec.
Radar
10-100 KB
Per Sec.
Sonar
3-10 KB
Per Sec.
LTE
50 KB
Per Sec.
GPS
20-40 MB
Per Sec.
Cameras
10-70 MB
Per Sec.
LIDAR

Learn about evolving connected car RF technologies

The connected car is beginning to take shape as today's consumers expect to extend their digital lifestyles to their vehicles with wireless services such as GPS satellite navigation, real-time traffic and weather info, Wi-Fi connectivity, Bluetooth integration, and more. To deliver the connected car of the future, innovative new solutions are needed to address interoperability and RF interference challenges, among others.

Inside...

- Look at the connected vehicle in a 5G world
- See how telematics will leverage edge computing
- Consider semiconductor technology and connected cars
- Understand how the connected vehicle will improve safety
- Look at RFFE challenges and solutions

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Lawrence Miller has worked in information technology in various industries for more than 25 years. He is the co-author of CISSP For Dummies and has written more than 130 other For Dummies books on numerous technology and security topics.

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