Advanced Connectivity Architecture for 5G-V2X and DSRC

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Abstract

The present-day wireless connectivity architecture in a commercial vehicle might be suitable up to the standard Level 2 of automated driving. However, it is still questionable if it will fulfill the performance requirements for Level 3 and above. In this context, we present future connectivity architecture for autonomous vehicles. It is based on the remote radio head (RRH) concept using a software-defined radio (SDR). The new architecture can provide twofold gains. On one hand, it can fulfill the performance requirements of future use cases, and on the other hand, it enhances reliability by facilitating the use of multiple wireless access for a given service. We provide an example of how two wireless access technologies can be implemented using this architecture. The overall approach is to exploit the power of softwarization, which aligns with the future of in-car computing technologies.

Introduction

The focus of this article is on the wireless connectivity architecture in an ever-evolving connected vehicle. For this purpose, we have selected related services and provided their brief description. Most of these services have two-way communications and rely on multiple/hybrid wireless communication standards or multiple frequency bands, mainly to ensure reliability and quality of service. Designing an RF system for covering multiple bands and multiple wireless standards for vehicle connectivity is a very challenging task. First, we will discuss the challenges of designing vehicle connectivity units using a conventional RF approach. This helps us to develop an understanding that the realization of some of these services is suboptimal in many aspects (for example, radio performance). Learning from the drawbacks of conventional RF design has led us to a new architecture for commercial vehicle radio connectivity units. This new architecture is based on the RRH concept. In the article "Enabling 5G and DSRC V2X in Autonomous Driving Vehicles,"[1] we introduced a sub-6 GHz, 4-channel multiband SDR-based transceiver RF IC, the ADRV9026. Here we extend the discussion from that article with an example that uses the RRH concept and a single SDR RF IC, from which we can build a dual-band V2X connectivity unit for 5G and DSRC. This unit will not only provide enhanced radio performance, but it will also enable the implementation of advanced coordination and cooperation algorithms for V2X wireless access.

An Account of Wireless Systems and Technologies for Connected Vehicles

Services in a modern vehicle, such as infotainment, navigation, communications, and broadcast, require wireless access systems. The RF spectrum range for the systems delivering these services is very broad, from 90 MHz (broadcast radio) to 5.9 GHz (V2X and Wi-Fi). Future systems are targeting frequencies corresponding to millimeter waves (for example, 5G mmWave, 24 GHz to 29 GHz). Figure 1 illustrates multiple wireless systems that are used to deliver a single service.

A commercial radio connectivity unit provides the interface between the application space and the corresponding wireless systems. The following list highlights the functions and the frequency bands of operation for some of these wireless systems:

- **GNSS/GPS:** Provides location services and positioning information. It often provides service to other wireless systems for synchronization. There are multiple regional standards and allocated frequency bands ranging from 1176 MHz to 1602 MHz.
- **Cellular 2G, 3G, 4G, and 5G:** Used for voice and data services such as telematics, infotainment, over-the-air updates, and V2X communications. It covers a huge number of cellular bands and channels from 300 MHz to 5.9 GHz.
- **Wi-Fi:** For multiple applications including over-the-air updates, diagnostics, and data download. Different regions have different allocations of bands and channels specified for internal and external use. Most common are the channels in the 2.4 GHz and 5.8 GHz bands. In Japan, some channels are allocated in the 5 GHz band.
- **ITS-G5/DSRC:** For V2X communications, the 70 MHz spectrum is allocated in 5.9 GHz in most of the regions in the world.
- **Radio Broadcast:** From 90 MHz to 240 MHz, there are different channels and bands in different regions. Please note that broadcast systems could also be covered by a radio connectivity unit, but usually they are implemented separate from the two-way communication systems.

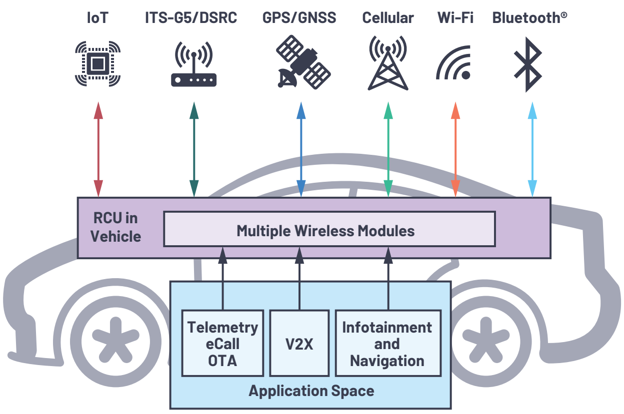


Figure 1. Major wireless systems in a vehicle.

Classical Implementation of Complex RF Systems

Due to all of the wireless systems present in a vehicle, it is evolving like a smartphone on wheels. However, there is a huge difference between a smartphone and vehicle user equipment (UE) when it comes to the implementation of functionalities. Consider an example of 4G cellular system implementation architecture in a commercial vehicle. In Figure 2a, a wideband antenna covering 4G bands is put on the outer side of the body of the vehicle, usually on the rooftop. The antenna is connected to a coaxial transmission line cable that runs through the body of the vehicle to the control unit hosting the 4G module.

Now, let's focus on the RF front end (RFFE) in the receiver RF path. After filtering the bands, the low noise amplifier (LNA)—with a very low noise figure (NF) and high gain—amplifies the incoming RF signal. After single or multiple stages of amplification, the signal is fed to the 4G module for baseband and higher layer processing. After the 4G protocol stack, the data goes to the application processor. Now, if we do a simplified RF analysis of this architecture, we find out that the overall RF chain has very poor noise performance. The signal loss in a coaxial cable is proportional to the signal frequency and the length of the cable. Hence, due to the cable loss, the combination of the cable and LNA will result in a lower signal-to-noise ratio. Additionally, we know from noise cascade analysis that the NF of the complete RF chain is overweighted by the NF of the first component in the RF signal chain. Hence, even an LNA cannot overcome this problem. To save cost and to reduce weight, normally a lighter cable is selected, which unfortunately adds to the RF problem. The overall noise performance could be improved by bringing the RF front-end components closer to the antenna, but the impact of the coaxial cable will be present in the system.

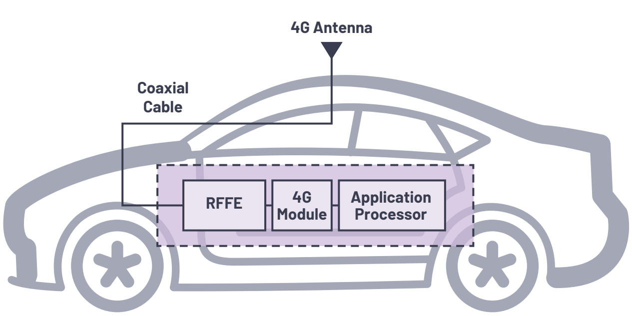
We skip the details of the transmit RF path where you must do proper amplification of the signal before transmission. However, we emphasize the fact that any transmitting device connected to a cellular network must also get the approval of the network operator. Hence, proper design is required in both receive and transmit RF paths.

In Figure 2b, we outline how other wireless systems are normally implemented. This is to demonstrate how much coaxial cable is used to connect relative antennas and how much RF signal loss (attenuation in dBM) occurs in each system. This loss increases rapidly if we have multiple antennas for a single system. In addition to that, achieving synchronization among the signals on multiple antennas and running them through the coaxial cable is not an easy task. Moreover, in the case of 5G mmWave frequencies (24 GHz to 29 GHz), the RF signal loss in the coaxial cable will be higher than the sub-6 GHz frequencies.

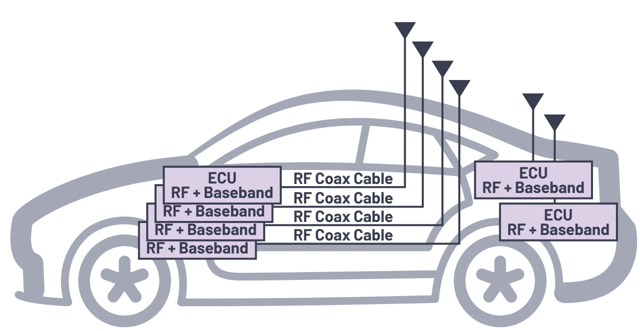
Remote Radio Head (RRH) Architecture for Vehicle Connectivity

The concept of RRH is well established and in use for base station implementations to overcome the problems caused by the coaxial transmission line cables. The strategy is to transport the digital signal instead of the RF signal. For this purpose, the RFFE and the transceiver (RF IC) is moved closer to the antenna. The RF signal is converted into digital I/Q bits that are transported using a high speed digital data link. Further processing of digital data is done in the general-purpose baseband processing pool. We propose that similar RF architecture can be used in the vehicle. Figure 3 depicts this architecture where coaxial cables are replaced by a high speed link. Moreover, for the conversion of RF signal into digital I/Q samples, we propose using an RF IC that transforms RF to bits and vice versa. These bits are transported between the RF IC and the baseband processor by the digital link (for example, gigabit Ethernet). Further processing is done by the application processor. These processors could be hosted by a radio connectivity unit or by a centralized computing platform. Computational resources and the trend of centralized computing in a vehicle are increasing at a great pace,[2] hence a gradual change toward this architecture is well aligned with the future computing architecture in vehicles.

Keeping only the RF-to-bits functionality close to the antenna has two-fold gains. First, only the minimum required transformation to avoid RF signal loss will be done close to the antenna where space and power is already a problem. Second, the requirements on the digital high speed link will be relaxed in terms of data rates.



(a) 4G-LTE Example User Equipment Implementation Using a Coaxial Cable



(b) Implementation of Several Other Wireless Systems Using a Similar Architecture

Figure 2. Classical architectures for cellular wireless connectivity and other wireless systems.

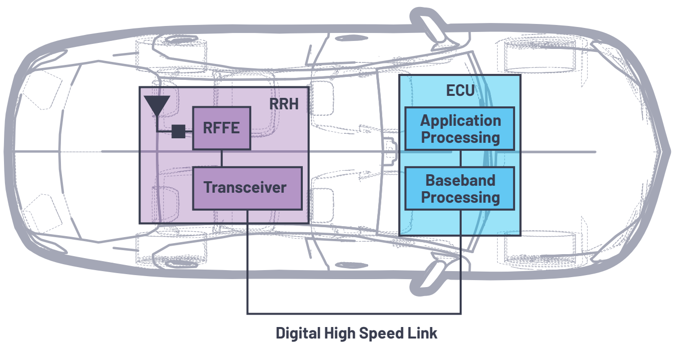


Figure 3. Future connectivity architecture.

RRH and SDR-Based V2X Implementation

We can enhance the benefits of RRH architecture by using a multiband RF IC. The V2X communications service is a perfect example to exploit this combination. As mentioned in the article "Enabling 5G and DSRC V2X in Autonomous Driving Vehicles," V2X service can use two different wireless access technologies: one is based on DSRC/ITS-G5 (IEEE 802.11p), and the other is based on cellular technology (C-V2X), be it 4G-LTE or 5G. It can use both access types in a coordinated/cooperative manner to guarantee required reliability and safety. A single-chip multiband V2X system could be designed with the help of the newly introduced RF IC, ADI's ADRV9026. Figure 4 shows that the ADRV9026 could be integrated into the RRH, which could be placed on the rooftop antenna box. It contains four main transmit and four main receive channels, each with the possibility of maximally four independent digital datapaths to the baseband processor. Using the advanced local oscillator architecture, the ADRV9026 can transmit and receive simultaneously in multiple frequency bands below 6 GHz. Using the V2X wireless access management (WAM) function, both wireless access types can efficiently share 70 MHz in the 5.9 GHz band allocated (in most regions of the world) for V2X service.

In line with the future trends, we have assumed that centralized computational resources are available in the vehicle (see Figure 4). Baseband processing, modem protocol stacks, and application processing could be implemented using the centralized platform. The ADRV9026 complies with the JESD204B and JESD204C[3] protocols for serial data transmission and reception. Off-the-shelf cables are available,[4] which can be used to transport 10 Gbps at up to 1 m. In case more flexibility and data rates are required, one can use any processing hardware to convert the JESD-based serial data into any other suitable format—for example, gigabit Ethernet or PCIe.

As shown in Figure 4, we have allocated two transmit and two receive channels each for DSRC V2X and 5G cellular. The 5G can use the two channels for full 5G communications including the Cellular V2X service. With two channels, a 2 × 2 MIMO scenario could also be implemented. Unlike current architectures, it requires that the modems for each wireless standard are implemented in the centralized computing platform. The I/Q samples of respective wireless standards are processed by their software modems. We anticipate that such a change could be challenging to adopt for current generations. However, with the advent of softwarization and virtualization, we will be ready for it.[5]

Conclusion

We have highlighted the classical vehicle connectivity architecture where each wireless system is implemented individually by installing antennas, cables, RF processing hardware, and software processing hardware. Based on the qualitative analysis, the negative impacts on service performance due to the classical architecture are presented. With the help of the RRH concept and dual-band RF IC, a new architecture approach for vehicle connectivity was proposed. We see multifold benefits for this architecture, such as:

- Reduction in the use of coaxial cables, thus enhancing RF performance and radio link reliability.
- Compliance with the software architecture of future vehicles.
- The ability to manage some new features through software updates.
- Multiple standards could be realized with a single RF IC.
- Enhanced control of quality of service guarantee.
- Better coordination possibility for services applying multiple wireless standards.
- Ready to adopt new wireless standard implementations in future vehicles such as 5G mmWave.

Our approach provides higher performance (which is required by automated driving scenarios) and the possibility of multiple wireless systems being implemented with a common hardware. We have shown that V2X service, which is essential for automated driving use cases such as platooning and teleoperated driving—both requiring high reliability in wireless connectivity—could exploit the benefits of this architecture.

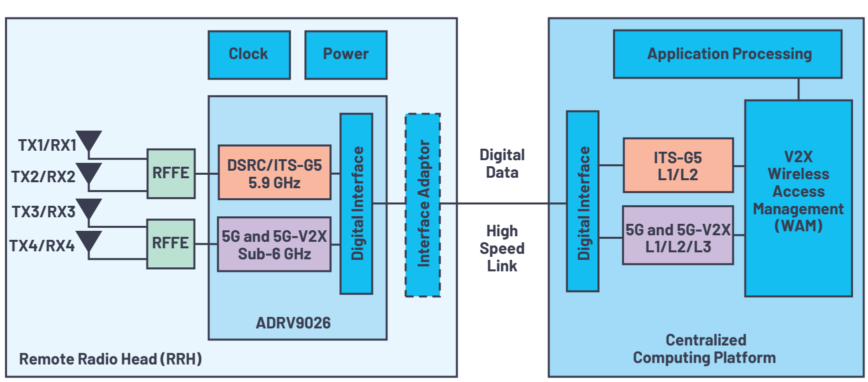


Figure 4. Advanced 5G and V2X connectivity using SDR-based RRH architecture.

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