

How to Mitigate Spectrum Challenges Associated with V2X

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Executive Summary

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

The Foundation for Vehicular Connectivity

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

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

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

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

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

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

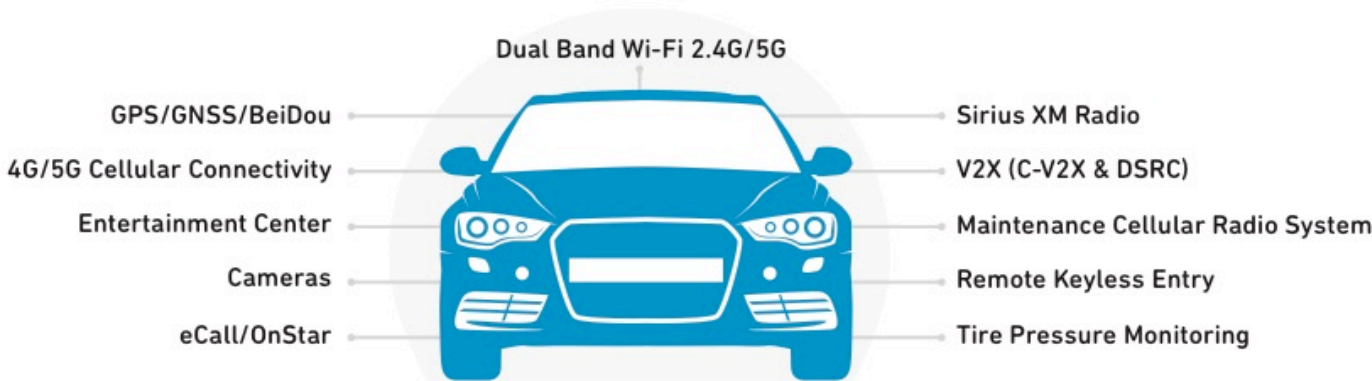
Understanding Connectivity Technologies

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

These technologies include:

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

Figure 1. Vehicular connectivity technologies.



The Coexistence Challenges of 5G and LTE

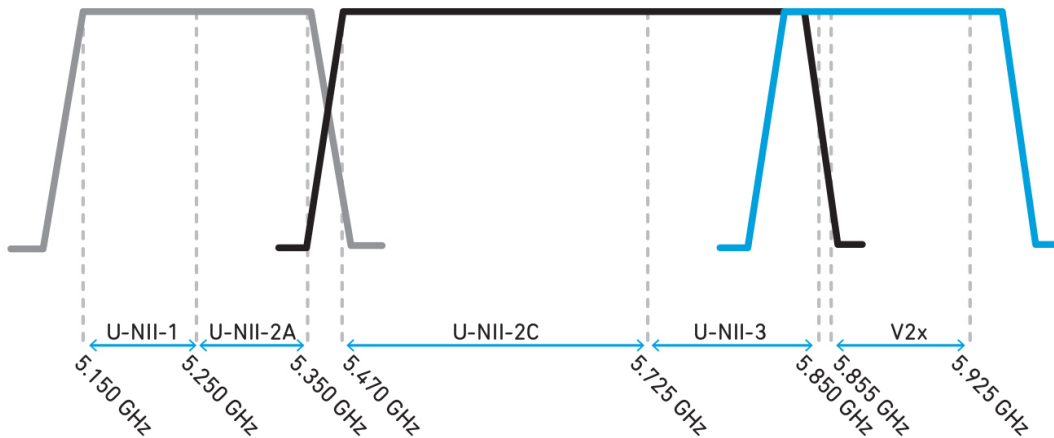
By understanding the functions/benefits of the various technologies, we can better look at coexistence challenges – specifically, compatibility with 5G and LTE.

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

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

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

Figure 2. V2X coexistence with 5 GHz Wi-Fi.



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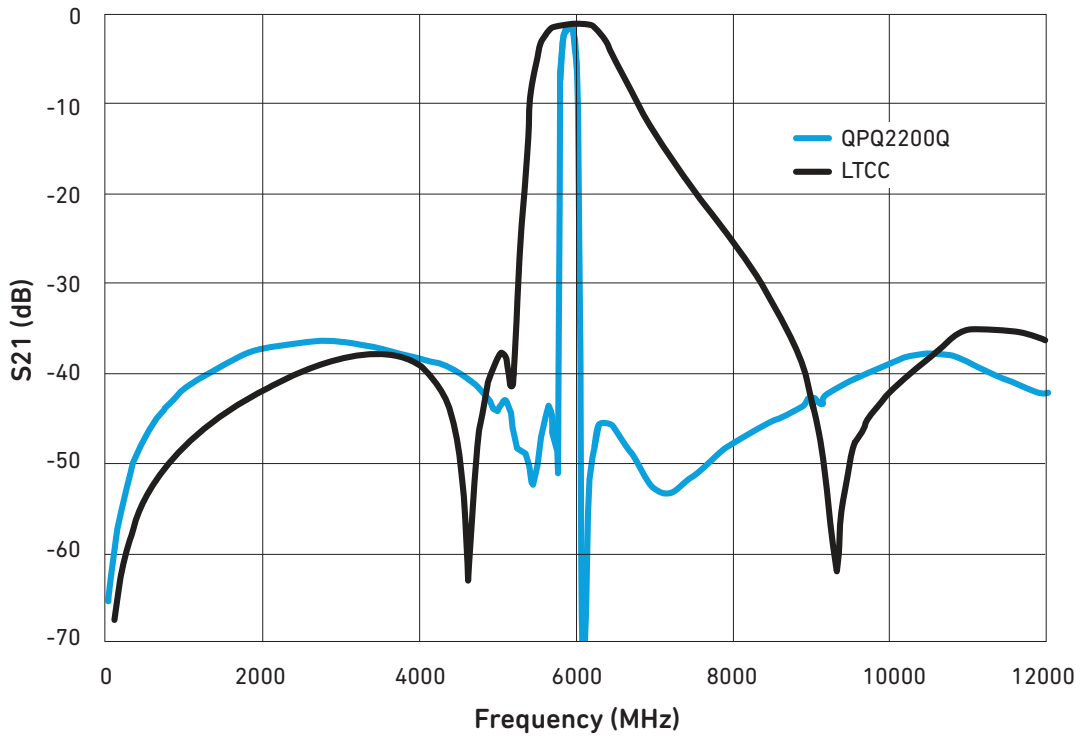
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High-performance Filtering – Why LTCC is Not Enough

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

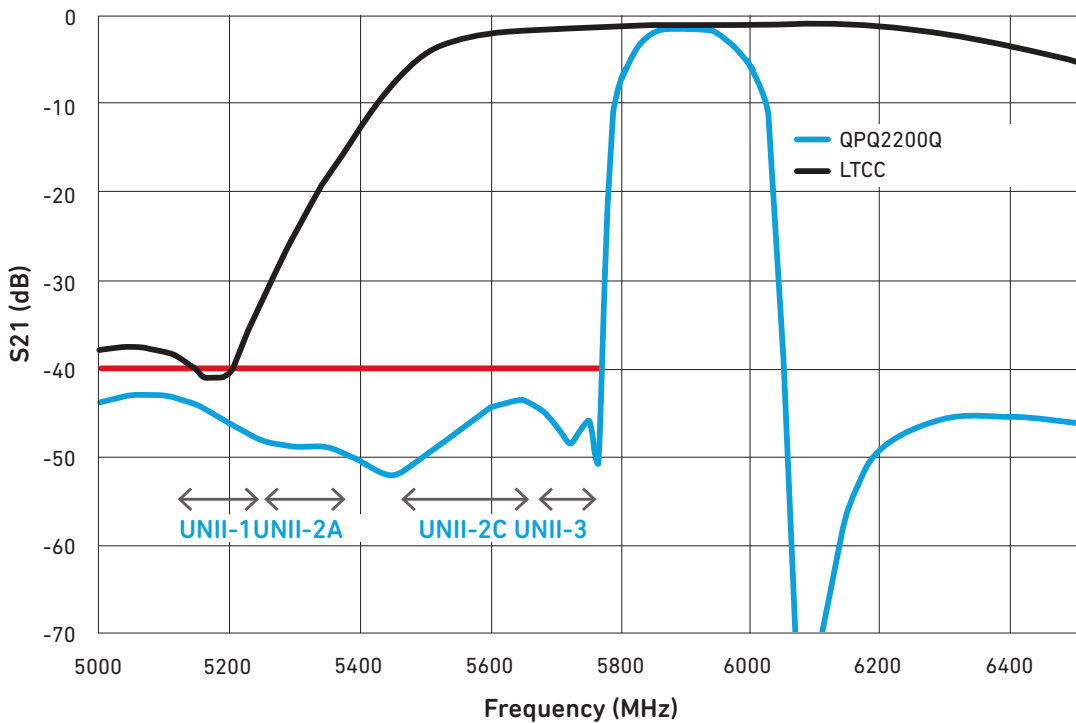
Coexistence filters help reduce interference issues from these “aggressor signals,” which can not only cause receiver sensitivity problems but also result in regulatory non-compliance. However, not all filters that claim coexistence capabilities are suitable for the job. For example, the graphic in Figure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

Figure 3. Comparison of QPQ2200Q to LTCC: Wideband performance.



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

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

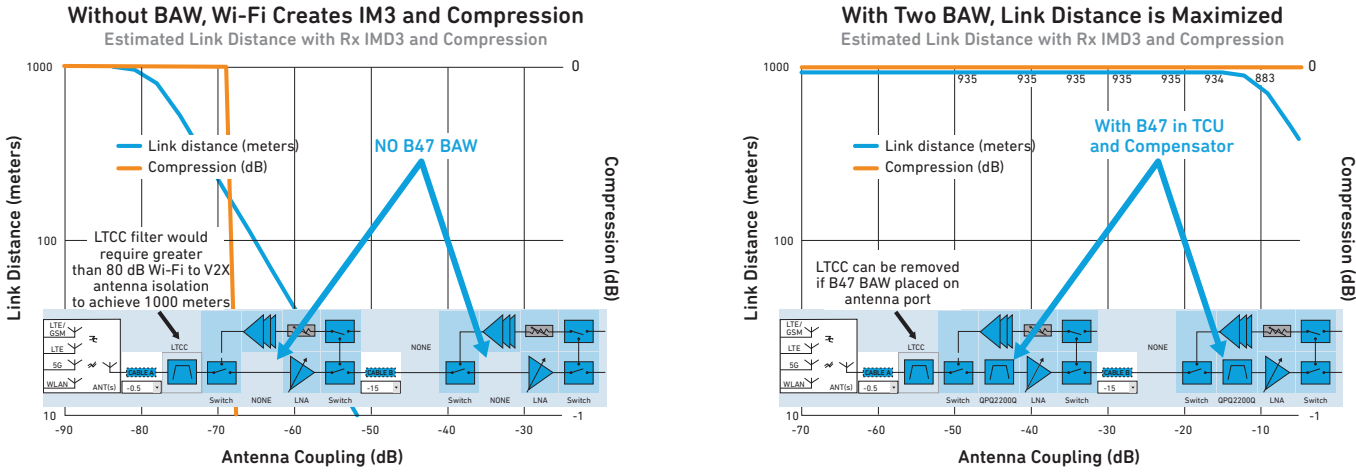


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Next, let's look at the comparison of LTCC vs. B47 V2X coexist filter from a systems and implementation standpoint. Figure 5 compares V2X – Wi-Fi antenna isolation needed in order to achieve a 1,000-meter V2X link. The plot to the left shows a V2X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

Figure 5. V2X – Wi-Fi antenna isolation needed to achieve a reliable V2X link: QPQ2200Q B47 vs. LTCC.



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

Yet even BAW band pass filters are not a complete solution to coexistence issues in the V2X environment. We must also consider the essential role played by notch filters. While the band pass filter discussed above provides adequate out-of-band rejection, Qorvo’s QPQ2230Q notch filter “notches out” Rx band noise in the V2X band on the 5 GHz Wi-Fi path, thus preventing Rx band noise from coupling back into the V2X system and causing desense issues, as illustrated in the system calculator (Figure 6). Figure 7 illustrates that there will be up to 18 dB desense in the V2X receiver if the notch filter is not used on the 5 GHz Wi-Fi path vs. almost zero desense with a well-designed notch filter leveraging the benefits of BAW technology.

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

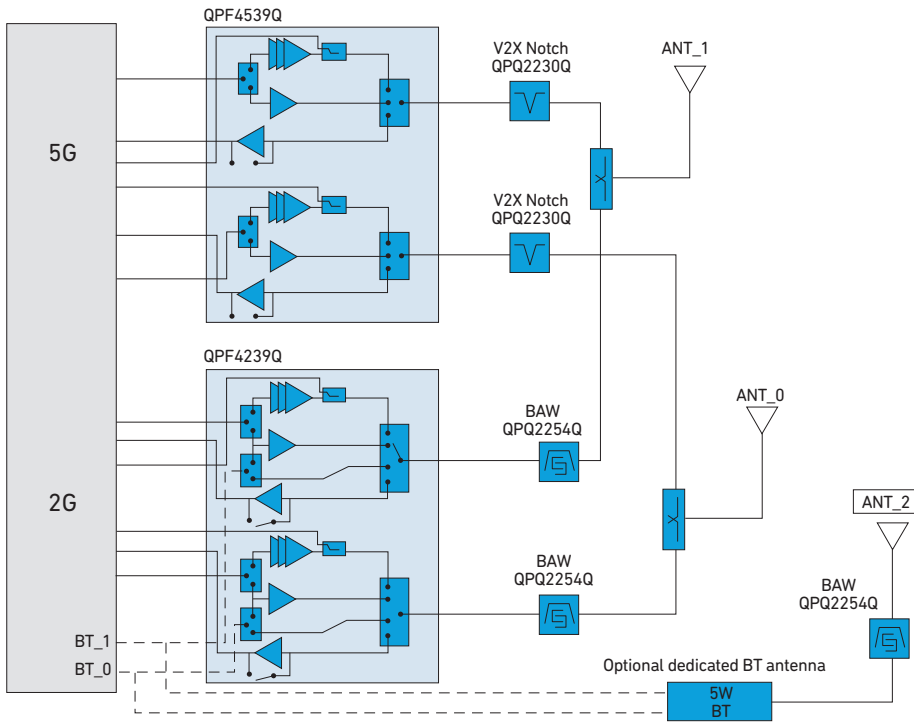
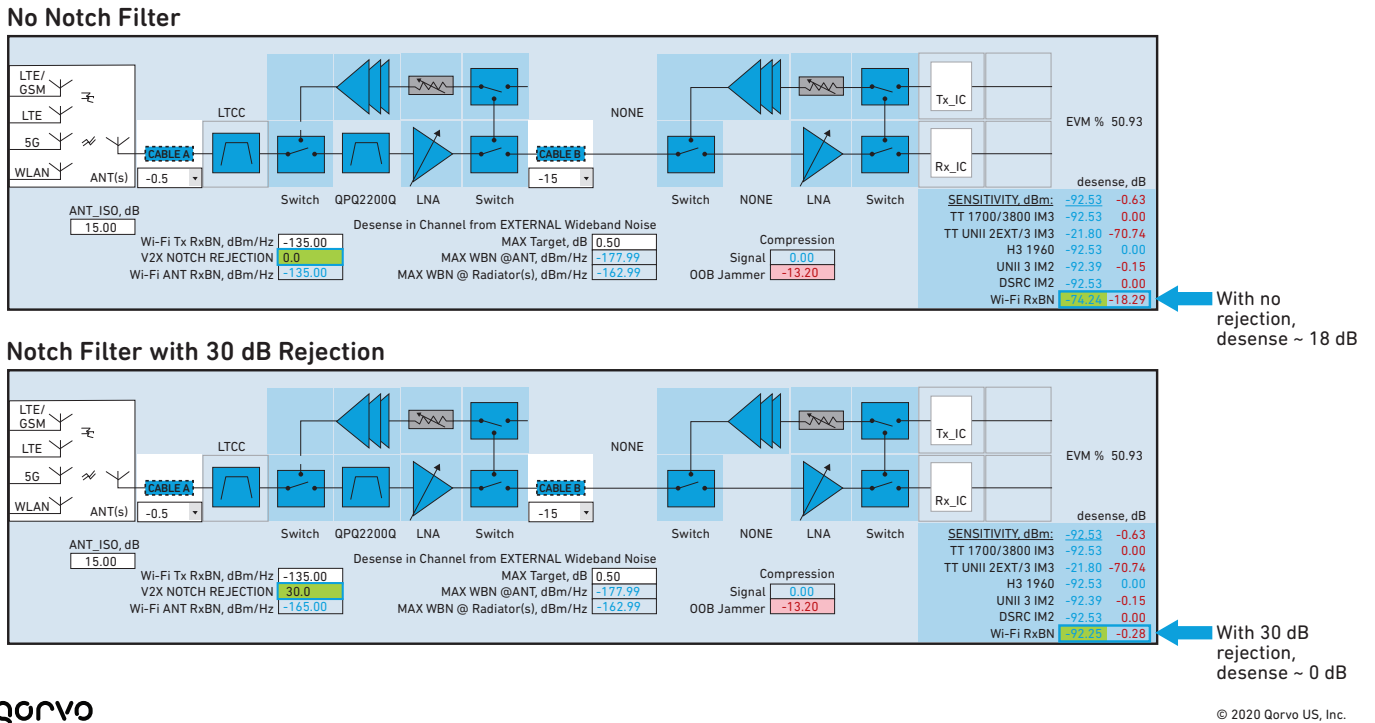
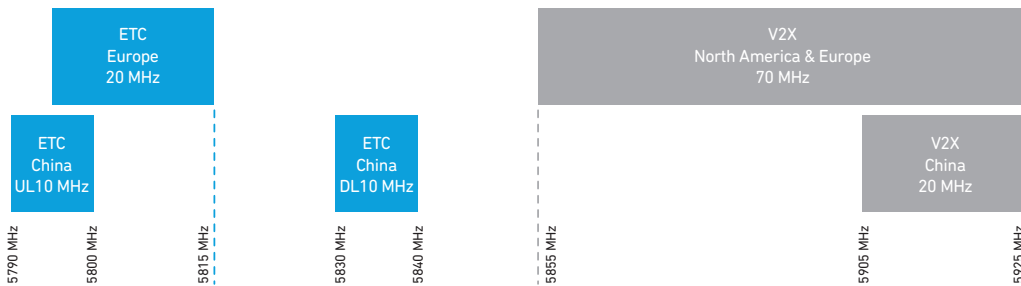


Figure 7. Rx band noise and desense with and without QPQ2230Q notch filter.



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

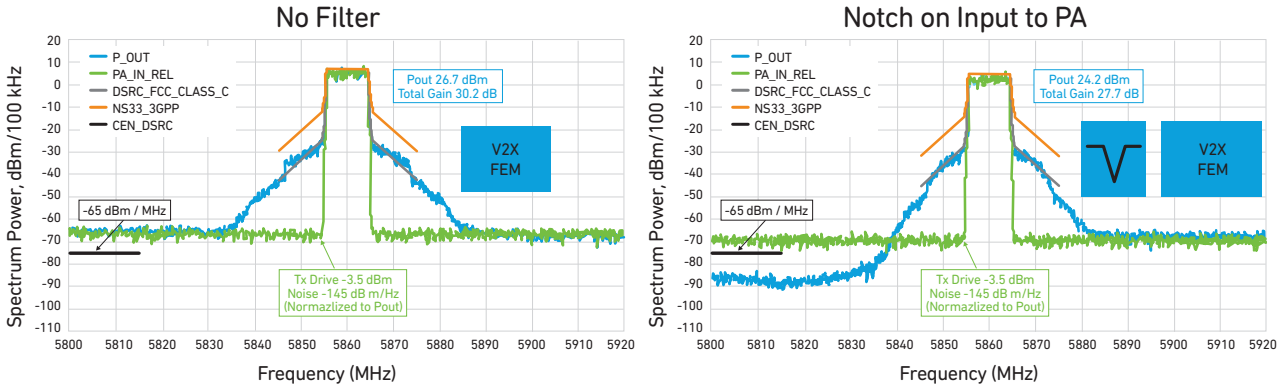
Figure 8. Global ETC spectrum coexistence with V2X.



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

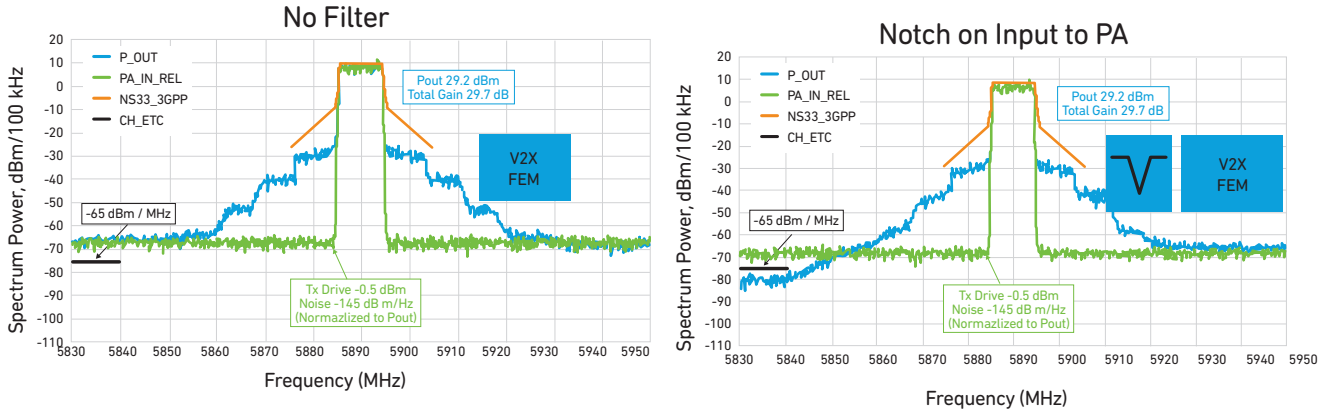
Figure 9. Europe: Comparison of spectrum emissions mask – with and without ETC notch filter.



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

Figure 10. China: Comparison of spectrum emissions mask – with and without ETC notch filter.



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

Conclusion

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

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

References

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Qorvo BAW filters: www.qorvo.com/innovation/technology/baw

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