WHITE PAPER

Advanced RF Filters for V2V and Other Automotive Applications

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Executive Summary

In this paper, we will discuss three key filtering challenges addressed by BAW filter technology: 802.11p in the DSRC band, LTE-Wi-Fi coexistence, and satellite radio. We will also discuss reliability and temperature stability considerations specific to automotive use.

Introduction

As automobiles acquire more digital capabilities, they are relying on a growing number of wireless technologies to communicate with the outside world. Already, many vehicles support LTE data connections and operate as small Wi-Fi hotspots. Over the next few years, the long-planned goal of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2X) communications is finally expected to become a reality, using the IEEE 802.11p standard over the 5.9 GHz Dedicated Short Range Communications (DSRC) band. This technology is expected eventually to spread to millions of vehicles across the entire automotive industry, as collision-avoidance and other intelligent transportation applications prove their value for consumers and other stakeholders such as insurance companies and government agencies.

As this connected-car trend unfolds, vehicles are increasingly using higher-frequency RF bands that are very close to bands used for other purposes, and interference between these bands has become a key concern. In many cases, there is almost no separation between bands, which makes it extremely difficult to meet regulatory requirements for reducing out-of-band emissions. The DSRC band, for example, is very close to the 5.8 GHz band used for European toll systems, while in-vehicle satellite radio services use spectrum that is separated by only a few MHz from adjacent LTE bands.

Avoiding interference in these cases requires high-performance RF bandpass filters capable of operating at high frequencies. These filters must provide steep skirts to prevent signals from bleeding into adjacent bands, and low insertion loss across the passband to sustain output power and maximize range. Filters used in automotive applications also must be able to operate under challenging physical conditions, operating reliably over the expected life of the vehicle while subjected to extremes of temperature and humidity. DSRC, in particular, also presents the challenge of delivering this performance at frequencies much higher than traditional cellular bands.

Bulk Acoustic Wave (BAW) filters uniquely possess these characteristics, and offer all the capabilities required for the 5.9 GHz band. BAW filters are acoustic filters that are built up from numerous deposited layers, including thin-film piezoelectric layers and plate-shaped electrodes. The acoustic wave travels in a vertical direction through these layers, and the resonance frequency is determined by layer thickness: thinner layers support higher frequencies. BAW filters provide steep skirts and high quality (Q) factors of up to 3,000, and are much smaller than traditional ceramic and dielectric filters. With their precise selectivity and small size, BAW filters are extensively used in smartphones and other mobile devices; those characteristics also make them suitable for advanced RF applications in vehicles. BAW filters are typically used for applications above 1.5 GHz where high performance is required, and the technology is fundamentally capable of working at frequencies up to 10 GHz and beyond.

However, manufacturing BAW filters is not easy, and the challenges increase at higher frequencies. For a BAW filter to work at 6 GHz, all the thin films in the layer stack – including the electrodes – must be very thin. Challenges arise regarding the electrical sheet resistance of the electrodes and the ability to create sufficiently smooth, uniform layers. Furthermore, the acoustic losses in solid materials tend to increase with the square of frequency. Specialized manufacturing processes are required to compensate for temperature-related frequency drift, and to ensure the required reliability.

802.11p and European Toll Systems

The 5.9 GHz DSRC band is a prime example of a band pushing the envelope of advanced RF filter technology. The frequency is higher than existing cellular bands, and the required skirt steepness is very demanding. At this frequency, losses in all parts of the transmission chain will be high, and the link budget will depend on the ability of the filter to prevent interference with other systems.

For 802.11p systems operating in this band, a key issue is coexistence with electronic toll systems in Europe. In many European countries, these toll systems operate in the 5795-5815 GHz band, and the European Telecommunications Standards Institute (ETSI) has placed tight requirements on out-of-band emissions.

To date, there has not been a workable, affordable solution that enables 802.11p systems to meet the ETSI requirements. As shown in Figure 1, solutions must provide low insertion loss across the DSRC band along with very steep skirts to avoid interference with the spectrum used by toll systems, which is separated by a guard band of only 15 MHz. Without high quality factors (Q>1,000), filters cannot meet these challenges. Simulations based on measured test structures confirm that BAW filters can exceed these requirements, and can be specified to a frequency tolerance better than 0.15 percent at this frequency.

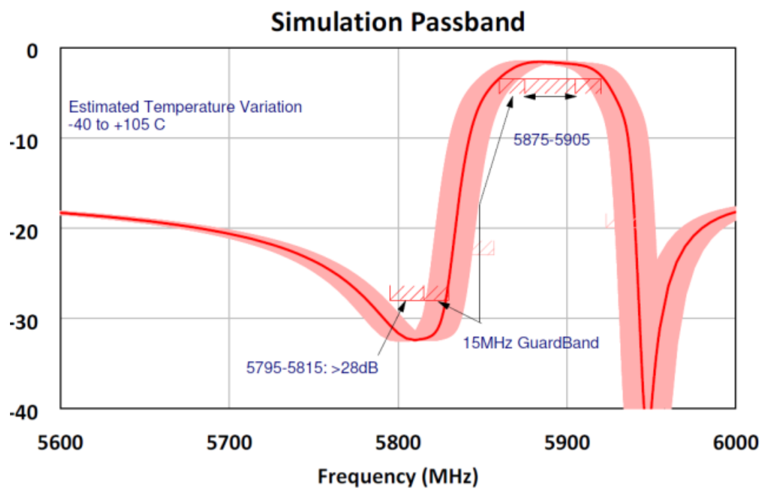

Figure 1. Simulation showing required performance of 802.11p BAW filter to avoid interference with European electronic toll systems

Automotive filters must meet these exacting requirements across a broad temperature range. Temperature drift – the shift in filter frequency response as the temperature changes – has become a major obstacle when trying to avoid interference between closely spaced bands. The problem is particularly acute with automotive applications, since specifications typically require an operating temperature range from -40 C to +105 C. Vehicles are driven in conditions ranging from extreme summer heat to snow and ice, and filters are often in locations subjected to even greater temperature variation and heat stress, such as rooftop aerials or engine compartments.

BAW filters are inherently less sensitive to temperature change than other acoustic filters, but even so it may be impossible to meet the stringent requirements for DSRC systems in Europe with traditional BAW manufacturing processes. Solving the problem requires advanced processes that create filters with a much more stable response to temperature variation. Temperature drift is caused by the fact that typical filter materials soften as the temperature rises; the effect can be counteracted by adding silicon dioxide (SiO_2), which exhibits the opposite response, stiffening with rising temperature. This temperature compensation can reduce temperature drift to near-zero, resulting in BAW filters with a temperature coefficient of frequency (TCF) of 0 ± 2 ppm/C.

Satellite Radio and the WCS Band

Satellite radio is another case where even standard BAW filters are not capable of meeting requirements, and temperature-compensated BAW filters are needed. The satellite digital radio audio service (SDARS) band is sandwiched between the uplink and downlink bands of FDD-LTE Band 30, which operates in the Wireless Communications Service (WCS) spectrum (Figure 2). Only a 5 MHz guard band exists on each side of the SDARS spectrum. To enable satellite radio services to operate while protecting the adjacent WCS band from interference, a fully temperature-compensated BAW filter with near-zero TCF is needed. The filter is embedded in the vehicle's antenna.

Figure 2. The satellite radio/LTE Band 30 coexistence challenge.

Wi-Fi/LTE Coexistence

Wi-Fi and LTE communications often must coexist in vehicles, requiring both to be able to operate simultaneously without interference. Many models now act as Wi-Fi hotspots, funneling data to and from the outside world via an LTE data connection. People in the vehicles may also simultaneously be using these technologies on their mobile devices.

The biggest challenges are coexistence between 2.4 GHz Wi-Fi and LTE Bands 40 and 41. Band 40 is a TDD-LTE band used in China. Band 41 is used both in China and the United States. Band 7, predominantly used in Europe, is also close to the Wi-Fi spectrum. There is only a miniscule 1 MHz guard band between LTE Band 40 and Wi-Fi channel 1, and the same gap between Wi-Fi channel 14 and LTE Band 41. The use of temperature-stable BAW filters has enabled coexistence between Wi-Fi and both bands with minimal need to sacrifice bandwidth.

Reliability

Reliability is a key issue for filters used in automobiles, which have a much longer working life than other devices such as smartphones. Automotive filters therefore should be tested and audited to a much greater extent than for other commercial applications. The Automotive Electronics Council AEC-Q200 quality standard for passive components (such as filters) includes stringent stress tests for stability under high temperatures and temperature changes; resistance to humidity; and mechanical stresses such as shock, vibration, and board flex.

Conclusion

RF interference rejection will become ever more challenging as wireless devices of all types proliferate, more wireless bands are allocated at higher frequencies, and global spectrum management remains a fragmented process. Temperature-compensated BAW filters such as Qorvo's NoDrift™ and LowDrift™ filters offer temperature stability along with high quality factors and steep skirts, enabling BAW technology to meet the most challenging requirements of the automotive industry. Achieving good performance and manufacturability with BAW is not easy; it requires superior process control and unique knowledge of materials science. Manufacturers of filters for automotive applications should also demonstrate proven reliability under temperature and environmental stress.

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