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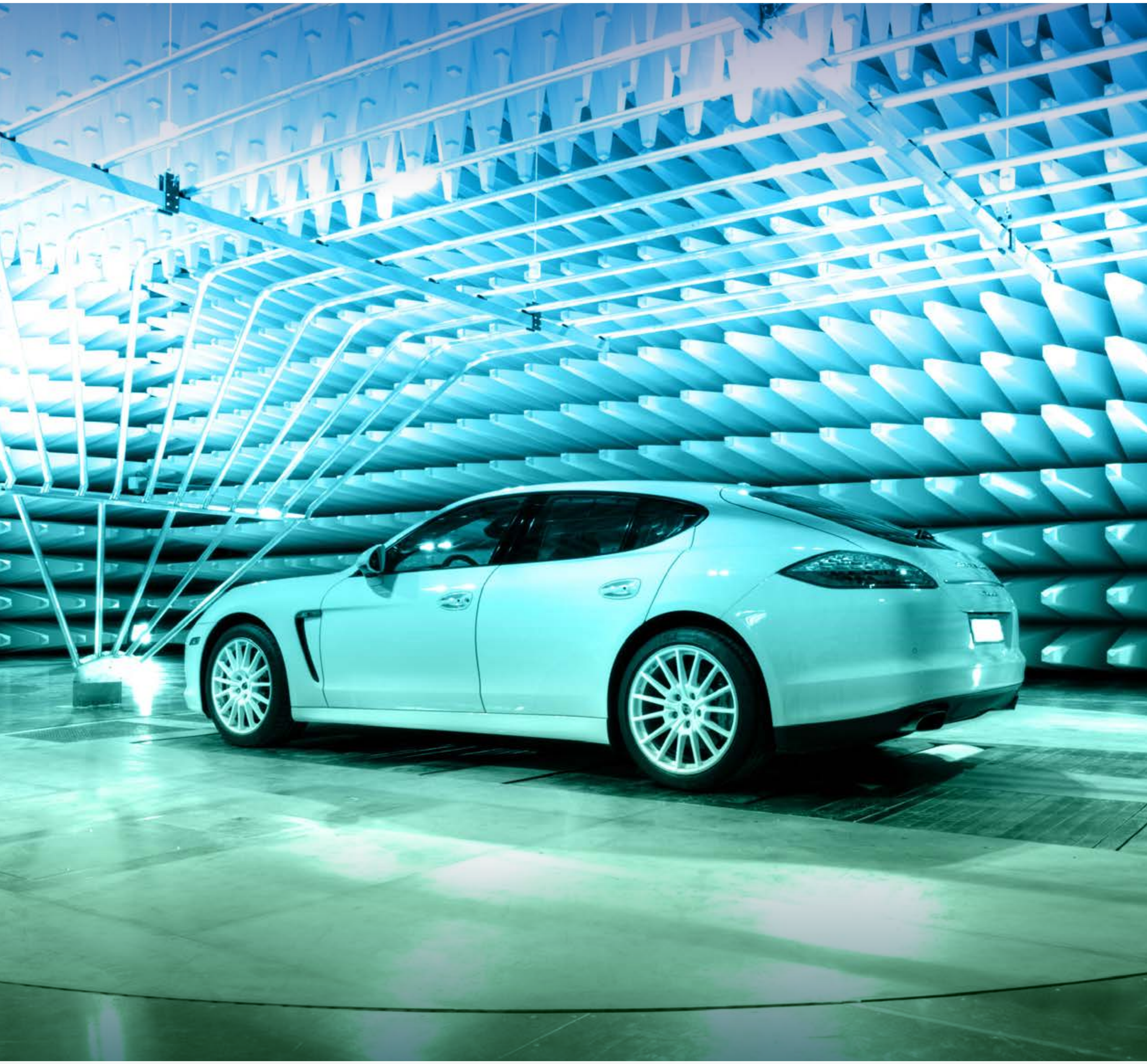
2020 AUTOMOTIVE EMC GUIDE



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INTRODUCTION

Jennifer Arroyo
Editorial Director, *Interference Technology*

Hello, and welcome to the 2020 edition of the *Automotive EMC Guide* from *Interference Technology*. We hope you enjoy the informative articles and helpful resources and references we have featured in this guide.

Mitigating issues with electromagnetic interference (EMI) is crucial in the automotive industry, especially as vehicles become more connected and include high-level and demanding electronic systems. It is now commonplace for cars to feature infotainment systems complete with wireless connectivity, and soon we will be moving toward fully autonomous vehicles that rely on radar and other RF technologies.

This year's guide features articles that center on identifying automotive EMC challenges and offering solutions. Our first article is titled "EMC/EMI Challenges for the Connected Car" by Asad Bajwa, and it focuses on the increasingly connected vehicle, which can lead to a number of EMI issues and the steps that engineers can take to reduce them.

Next, we include an article called "Overcoming 76-81 GHz Automotive Radar EMC Challenges" by Zachariah Peterson, which explains some of the challenges with automotive radar for autonomous vehicles and ways to overcome them. Rounding out our articles is "Automotive EMC" by Maurizio Di Paolo Emilio, that discusses the need for more advanced EMC design in vehicles and improved testing.

Finally, I wanted to note the new downloadable EMC guides we've produced last year. If you visit our homepage, you'll see the list of guides. Some of the more popular ones include Military/Aerospace, Testing, Wireless & IoT, and EMC Fundamentals.

Cheers,

Jennifer Arroyo
Editorial Director, *Interference Technology*
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EMC EQUIPMENT MANUFACTURERS MATRIX

The following chart is a quick reference guide of test equipment and includes everything you'll need from the bare minimum required for key evaluation testing, probing, and troubleshooting, to setting up a full in-house precompliance or full compliance test lab. The list includes amplifiers, antennas, current probes, ESD simulators, LISNs, near field probes, RF signal generators, spectrum analyzers, EMI receivers, and TEM cells. Equipment rental companies are also listed. The products listed can help you evaluate radiated and conducted emissions, radiated and conducted immunity, and a host of other immunity tests, such as ESD and EFT.

EMC Equipment Manufacturers		Type of Product/Service													
Manufacturer	Contact Information - URL	Antennas	Amplifiers	Near Field Probes	Current Probes	Spectrum Analyzers/EMI Receivers	Software Simulation	ESD Simulators	LISNs	Radiated Immunity	Conducted Immunity	Pre-Compliance Test	TEM Cells	Rental Companies	RF Signal Generators
A.H. Systems	www.ahsystems.com	X	X		X							X			
Aaronia AG	www.aaronia.com	X	X			X						X			
Advanced Test Equipment Rentals	www.atecorp.com	X	X	X	X	X		X	X	X	X	X	X	X	X
Altair	www.altair.com						X								
AR RF/Microwave Instrumentation	www.arworld.us/	X	X			X	X		X	X	X	X			X
Anritsu	www.anritsu.com					X						X			X
Beehive Electronics	www.beehive-electronics.com			X								X			
Coilcraft	www.coilcraft.com	X	X												
CST Computer Simulation Technology	www.cst.com						X								
Electro Rent	www.electrorent.com		X			X		X	X	X	X	X		X	X
EM Test	www.emtest.com										X	X	X		
EMC Partner	www.emc-partner.com							X			X				
Empower RF Systems	www.empowerrf.com		X					X		X	X				
ETS-Lindgren	www.ets-lindgren.com	X	X	X	X				X	X	X	X	X		X
Fischer Custom Communications	www.fischercc.com			X	X				X			X			
Gauss Instruments	www.gauss-instruments.com					X									
Haefely	www.haefely.com							X			X				

EMC Equipment Manufacturers		Type of Product/Service													
Manufacturer	Contact Information - URL	Antennas	Amplifiers	Near Field Probes	Current Probes	Spectrum Analyzers/EMI Receivers	Software Simulation	ESD Simulators	LISNs	Radiated Immunity	Conducted Immunity	Pre-Compliance Test	TEM Cells	Rental Companies	RF Signal Generators
Instrument Rental Labs	www.testequip.com		X			X		X	X	X	X	X		X	X
Instruments For Industry (IFI)	www.ifi.com		X							X	X				
Keysight Technologies	www.keysight.com			X		X			X			X			X
Microlease	www.microlease.com		X			X		X	X	X	X	X		X	X
Milmega	www.milmega.co.uk		X							X	X				
MVG	www.mvg-world.com	X		X								X			
Narda/PMM	www.narda-sts.it	X	X			X			X	X	X	X			
Noiseken	www.noiseken.com							X			X	X			
Ophir RF	www.ophirrf.com		X								X				
Pearson Electronics	www.pearsonelectronics.com				X										
Rigol Technologies	www.rigolna.com		X	X	X	X	X					X			X
Rohde & Schwarz	www.rohde-schwarz.com	X	X	X	X	X	X		X	X	X	X			X
Siglent Technologies	www.siglent.com/			X		X	X					X			X
Signal Hound	www.signalhound.com			X		X	X					X			X
TekBox Technologies	www.tekbox.net		X	X			X		X			X	X		
Tektronix	www.tek.com			X		X	X					X			
Teseq	www.teseq.com		X		X			X		X	X	X	X		
Test Equity	www.testequity.com/leasing/		X			X		X	X	X	X	X		X	X
Thermo Keytek	www.thermofisher.com							X			X				X
Thurlby Thandar (AIM-TTi)	www.aimtti.com					X						X			X
Toyotech (Toyo)	www.toyotechus.com/emc-electromagnetic-compatibility/	X	X			X			X	X		X			
TPI	www.rf-consultant.com											X			X
Transient Specialists	www.transientspecialists.com									X	X		X		
TRSRenTelCo	www.trsrentelco.com	X	X			X			X	X	X	X		X	X
Vectawave Technology	www.vectawave.com		X												
Windfreak Technologies	www.windfreaktech.com											X			X

EMC/EMI CHALLENGES FOR THE CONNECTED CAR

Asad Bajwa
EMC Lab Director/Business Manager Keysight Technologies

Abstract
Our automobiles are becoming more connected and reliant on wireless connectivity, and at the same time, the number of high-compute internal systems is rapidly increasing. Like any high-speed, complex digital electronic system, automotive electronics can be both a cause of, and highly sensitive to, electromagnetic interference (EMI), and the consequences of failure can be fatal. In this article, we discuss sources of EMI, and steps engineers can take to identify, isolate, and reduce its impact.

Keywords
EMC, EMI, EMS, PXI, automotive test, connected car, test for manufacture, time domain scan, TDS, safety standards, CISPR 16-1-1, radiated emissions, conducted emissions, IEC, ANSI C62.3, radiated immunity

EMC/EMI CHALLENGES FOR THE CONNECTED CAR

In 1915, a book was published—*The Model T Ford Car: Its Construction, Operation and Repair*, by Victor W. Page [1]. It explained the "operating principles of all parts of the automobile" and extended to just 302 pages (with advertisements). How big would the book be to describe the operating principles of a modern car? Just the 100 million+ lines of code in 100+ embedded processors would fill around 10,000 books. The complexity of cars today is extreme with interconnected functional, control, safety, driver assistance, communications, and infotainment electronic systems.

The picture is more complicated when 'V2X' interactions are included: Vehicle-to-Vehicle, Vehicle-to-Infrastructure, Vehicle-to-Person, and Vehicle-to-Network. With semi- or fully-autonomous driving, complexity, and safety concerns multiply up further.

It's clear that keeping a heavy vehicle loaded with explosive fuel, or high-energy batteries safe at high speed, requires all of the on-board systems to interface correctly with no surprises. While the highest levels of engineering discipline in design can define and control the electrical and mechanical interfaces, electromagnetic effects and compatibility (EMC) are much harder to predict. The consequences of system interference can be dire—there have been reports of airbags spontaneously deploying, triggered by emergency service vehicle RF transmissions and engine management, and cruise control systems demanding 'full throttle' when subjected to EMI [2].

Robust designs are therefore necessary to ensure system EMC along with verification by simulation and test to automotive compliance standards.

A COHERENT APPROACH TO TEST THROUGH INTERNATIONAL STANDARDS

While good design practices and use of EMC/EMI simulation tools can minimize an electronic system's EMI susceptibility and emissions, performance is often affected by the installation conditions and interconnections with other equipment. With components, modules, and sub-systems sourced from multiple tiers of suppliers, individual EMC performance can only be characterized under agreed 'standard' conditions, which may not match the intended EMC/EMI environment. Compliance at all component, module, and system levels, though, is a good starting point.

The ultimate goal is to achieve certification of the vehicle to relevant standards, including EMC, with an 'E' mark, mandatory in the EU and other countries that have signed up to the scheme. The E-mark is applied to components, separate technical units (STU), and electrical sub-assemblies (ESA) as well as the complete vehicle. For most countries, the relevant automotive EMC standard is United Nations regulation ECE R10, currently at revision 5, which also covers EMC requirements for electric (EV) and hybrid-electric vehicles (HEV). For the U.S., the Society of Automotive Engineers (SAE) and automotive OEMs set the standards. These generally reference international standards for EMI limits and test methods, as defined by ISO, IEC, CISPR as well as American ANSI documents. Other countries, such as India and China, have local requirements. Vehicle manufacturers have their internal standards too, often with more stringent specifications, such as Ford CS2009, Chrysler- Fiat CS-11979, or Nissan NDS02.

The automotive environment is hostile, with conducted and radiated emissions from high-power switching converters and data lines, as well as transients and dips from load dumps and current surges but new automotive technologies and operating conditions are adding to the burden, and test standards must evolve to match. For example, ECE R10 EMC requirements now differentiate between electric vehicles at charging stations or on the road. Also, the introduction of new RF technologies such as automotive radar systems at 24/77/79 GHz and 5G connectivity, which can also operate between 24 and 86 GHz require verification for compatibility with each other and existing car systems.

Applying the EMC standards and employing certification agencies to achieve E-marking for components and sub-assemblies, with supporting simulation, test documentation, and manufacturing quality control are obligatory—and necessary, as an EMC failure at the vehicle level can be extremely expensive to rectify.

THE EMC ENVIRONMENT

EMC concerns range across all the systems in automotive applications from traction motor drives in EVs to Bluetooth™ connection for infotainment, involving the whole RF spectrum from kHz to GHz (*Figure 1*).

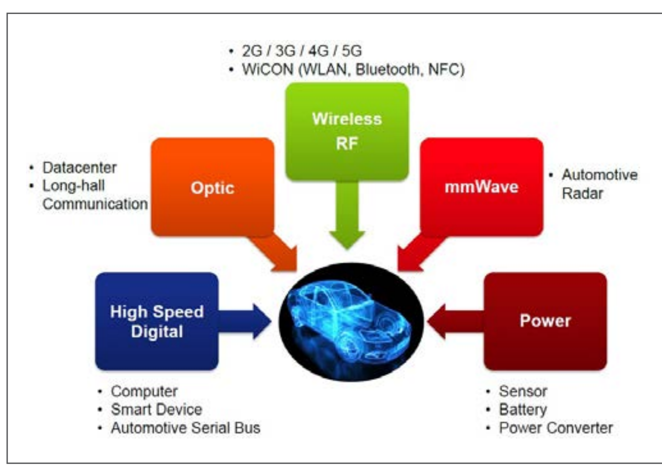

Figure 1: Automotive EMI considerations cover the whole RF spectrum. (Image Source: Keysight)

EMI is categorized into four areas, conducted/radiated emissions and conducted/radiated susceptibility, with their specific compliance standards and limits. Conducted emissions can be measured in open lab conditions, but radiated measurements require an open area test site (OATS) or anechoic chamber to eliminate spurious signals. Taking radiated emissions as an example, ECE R10 refers to CISPR 16 for broadband and narrowband emissions between 30 MHz and 1 GHz with limits, shown in *Figure 2*, for whole vehicles at 10 m (left) and ESAs/components (right). The measurement resolution bandwidth is 120 kHz.

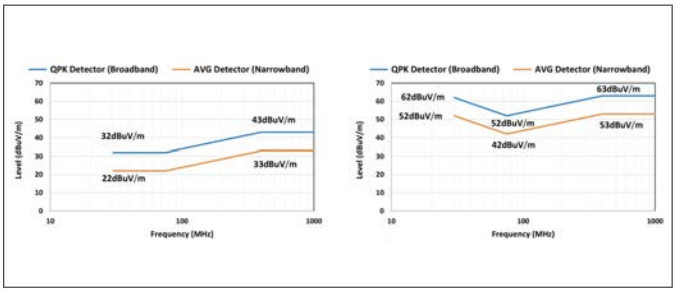

Figure 2: Limits for radiated interference according to ECE R10 from CISPR 16 from vehicles (left) and ESAs/components (right).

U.S. specifications might reference ANSI standards ANSI C63.2 and C63.4 for emissions measurement methods and instrumentation respectively, covering the range 9 kHz to 50 GHz.

Key to the measurement of conducted and radiated emissions is an EMI receiver conforming to the CISPR 16 requirements. Specific characteristics needed are a selectable signal detection method and measurement resolution bandwidth (RBW)—the ability of the measurement to separate spectrum components. RBW varies between the standards and can be between 9 kHz and 1 MHz. EMI receivers provide several options for signal detection as defined by CISPR 16: based on the applicable standard, either a 'peak', 'quasi-peak', or 'average' detector is selected, each with different detection time constants to more-or-less attenuate random or non-repetitive components of the measured signal. Quasi-peak, for example, is weighted according to the repetition rate of the signal, and the receiver must dwell at the measured frequency to allow the detector to evaluate this parameter. Peak, however, is an almost instantaneous measurement so dwell time is less and will always show a higher response than quasi-peak or average, so if limit lines are met with peak detection, then all is well. If peak detection fails the limits, there is no choice but to use quasi-peak and average to try to show compliance—a very slow measurement with traditional receiver designs.

NEW RECEIVER TECHNIQUES REDUCE MEASUREMENT TIMES DRAMATICALLY

New receiver techniques, however, can make the quasi-peak and average sweep times much faster. The advantages are: improved measurement accuracy, better repeatability, better filter shape factor, and ability to take a Fast Fourier Transform (FFT) of the digital signal, which, in turn, allows a 'Time Domain Scan' (TDS). This technique can speed up quasi-peak and average detection sweeps dramatically by dwelling only once at the bandwidth of the FFT operation. This encompasses hundreds if not thousands of RBW values and speed is enhanced further by reduction in number of total scans, requiring fewer local oscillator steps and associated re-lock delays.

CONCLUSION

Evaluating EMC between a huge range of disparate systems in automotive applications is a daunting task. The stakes are high for OEM time-to-market, and user safety is a higher priority still. Using a PXE series of EMI receivers guarantees best measurement accuracy at the fastest speeds backed up by a test and consulting service that supports users all the way from initial design to full regulatory compliance testing.

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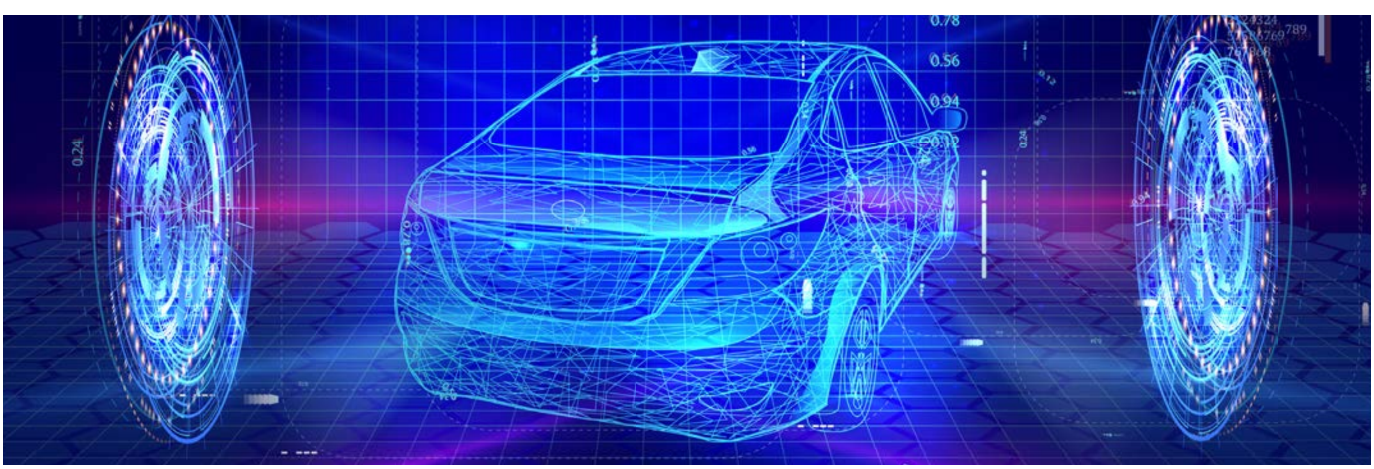
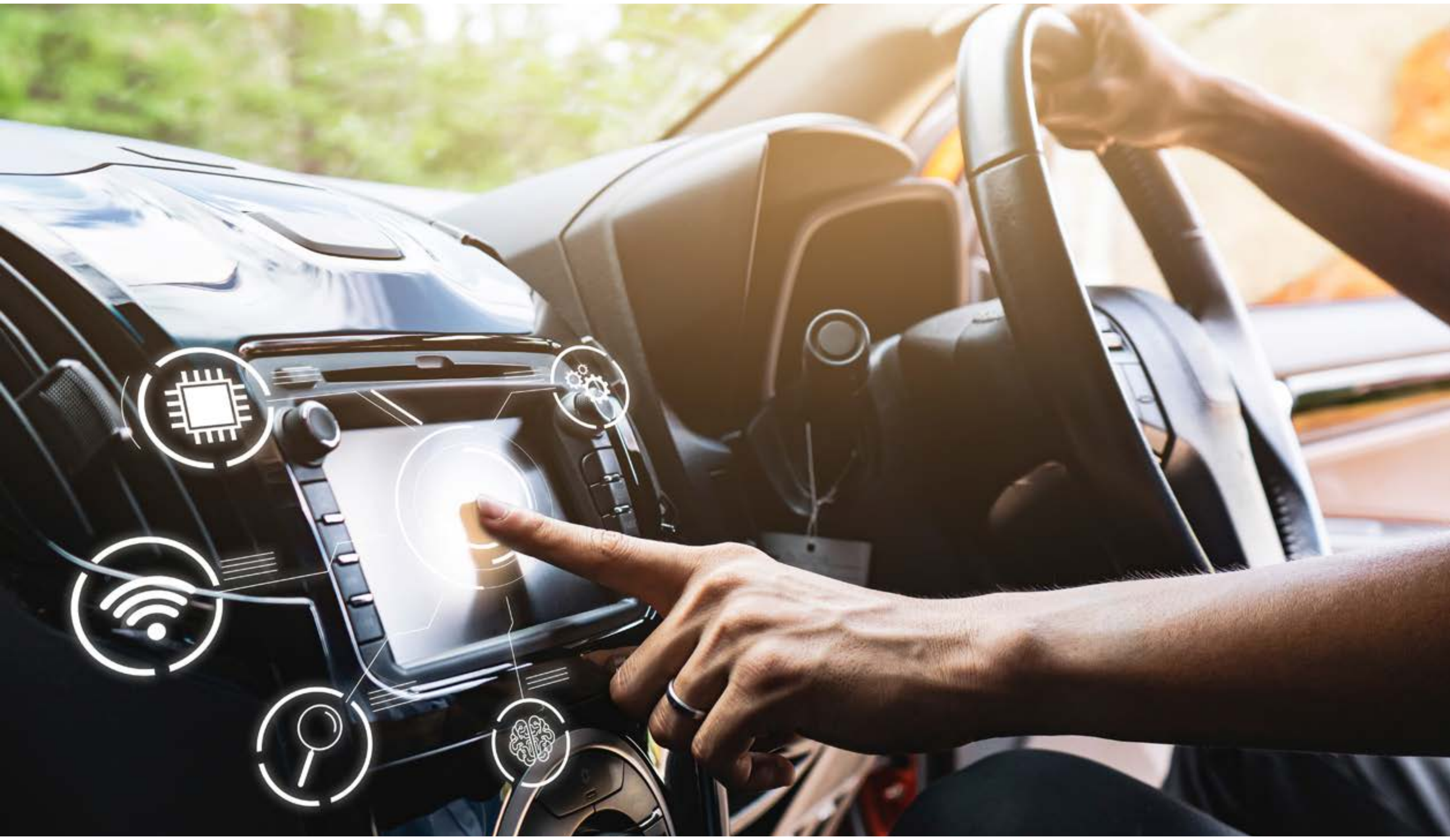


OVERCOMING 76-81 GHZ AUTOMOTIVE RADAR EMC CHALLENGES

Zachariah Peterson
Altium



OVERCOMING 76-81 GHZ AUTOMOTIVE RADAR EMC CHALLANGES

The dream in the automotive industry is fully autonomous driving, even in poor weather conditions. This requires synchronization of multiple sensor systems, as well as real-time processing of data from these systems. Current radar systems operating at ~24 GHz (K-band) are prevalent in new vehicles with ADAS systems, and there will be an inevitable shift to state-of-the-art 76-81 GHz radar systems to support autonomous vehicles. These systems already present EMC challenges that must be addressed at the board level, intra and inter-vehicle levels, and signal processing level.

Given the EMC and EMI challenges that arise within a single radar module, between radar modules, and between multiple vehicles, how can systems designers ensure multiple nearby vehicles can be sufficiently resolved by an autonomous vehicle? Here, we'll take a look at the current EMC challenges that arise in vehicles with FMCW radar systems and some future directions systems, and how board designers can overcome these challenges.

CURRENT AUTOMOTIVE RADAR EMC CHALLENGES

Moving to the 76-81 GHz range provides a number of benefits compared to K-band radar. These include broader available bandwidth, lower attenuation, more focused beams, and longer range. As is well known, moving to higher frequencies increases on-board crosstalk and radiated EMI. As newer vehicles will use multiple module for long-range and short-range radar, as well as wireless systems at other frequencies for V2X communication, there are some particular design challenges that systems designers should consider to ensure proper target detection. Particular EMC problems become more apparent as multiple radar-equipped vehicles occupy roadways.

Mixed signal interference. This is primarily a board-level challenge that requires proper stackup design, layout, routing, and grounding techniques. In newer commercially available 24 GHz and ~76 GHz radar modules, you'll find that the digital and RF sections are sometimes separated into different boards within a single module. This requires proper grounding, routing, and layout to prevent EMI between analog and digital portions of the module.

Separating digital and analog sections into different boards is a natural choice as it does not significantly increase the footprint, while it effectively allows you to have two stacked signal layers (analog and digital) on different boards. Some current radar modules use coplanar waveguide routing on the surface layer to the Tx and Rx series-fed patch antenna (SFPA) arrays to provide sufficient high frequency isolation from other sections of the board.

Multiple vehicles operating in the same frequency band. This is a major EMC challenge in automotive radar design, which arises when multiple vehicles with radar operating in a similar frequency range interfere with each other. Consider a situation with two radar-equipped vehicles (Car A and Car B) operating in the same frequency band. The radar signal from Car B can be received by Car A, which masks detection of any true targets that would otherwise be detectable by Car A. Car B's radar will also cause multiple false targets to be seen by Car A. Car A will then have the same effect on Car B. The logic here can be extended up to any number of vehicles. A recent extensive study by the NHTSA[1] looked at the effects of radar congestion in multiple scenarios, and the results provide significant insight into the effects of interference between radar modules on different vehicles. These results are also extremely useful for newer ADAS designers as they provide some important examples of target tracking in different situations.

This particular EMC challenge is difficult to solve at the PCB level, but it has been addressed at the signal processing level. This is the same EMC challenge that occurs with K-band radar emitters used by DOT to monitor real-time traffic flow in many major cities. Civilian radar detectors overcome this interference problem with traffic sensor rejection (TSR) filtering. With multiple radar-equipped vehicles, this same type of interference problem between radar modules can cause false alarms if not addressed.

The inelegant TSR filtering solution used in radar detectors was to delay the alert time of the K-band radar sensor by more than the radar burst duration; the sensor would only alert the driver if a longer radar burst was detected. This works fine when you know the duration of transmitter's radar (approximately 1.5 s for real-time traffic sensors), but it becomes ineffective when you have multiple vehicles transmitting radar pulses at unpredictable times. The current solution involves placing an anti-aliasing filter on the Rx side of the signal chain before the signal is sampled with an ADC.

Distinguishing multiple targets. Once false targets from other interfering radar systems are suppressed, the true targets need to be sufficiently resolved. This is primarily a pulse design and signal processing challenge. In terms of pulse design, a designer needs to try and maximize the detection resolution, while balancing maximum unambiguous range and velocity. Determining heading is a simple matter of beamforming with an antenna array and just requires tracking the angle at which the beam was emitted, thus it will not be discussed in more depth here.

A radar frame emits multiple FMCW pulses, typically with linear chirp. The beat frequency between the transmitted and received pulses tells you the position of the downrange target, and changes in the beat frequency over time will tell you the velocity. Note that, without velocity detection, the motion of a vehicle will distort the range estimation due to Doppler shift, so proper range estimation requires a corresponding velocity estimation.

It is possible, both with short and long-range radar, that multiple vehicles interact with the emitted beam and produce an echo within the duration of a single chirp in the radar frame. When multiple targets are present, multiple echoes from each target need to be distinguished with some signal processing steps. While position could be distinguished from time-of-flight measurements, followed by calculating the time difference between multiple echoes to determine relative velocity, a more elegant (and accurate) solution involves applying orthogonal fast Fourier transforms to each received chirped echo in a frame. This gives you a 2D grid of range vs. Doppler shift measurements for each vehicle, which can then be converted into a range vs. velocity grid. Although some processing still needs to be done to eliminate the interference for multiple vehicles.

Finally, the signal can be cleaned up with a constant false alarm rate (CFAR)[2] algorithm, and peaks in a velocity vs. range vs. intensity graph can be detected using a standard peak detection algorithm. An example showing the results provided by CFAR for distinguishing two vehicles is shown in *Figure 1*.

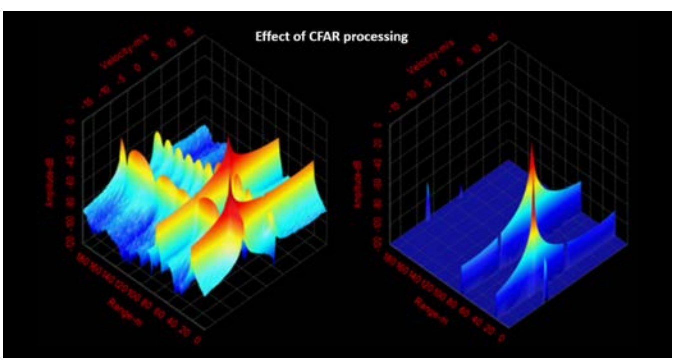


Figure 1: Resolving the range and velocity of true targets with a CFAR algorithm. [2]

Note that, without CFAR processing and peak detection, it may appear that there are actually four vehicles, as can be seen from the four intersections in the left graph. This important signal processing algorithm produces the traces seen on the right graph, telling us the range and velocity.

When these signal processing steps are taken together, we now have a system that is robust against interference from other vehicles. The remaining consideration for systems designers requires selecting the appropriate components that are robust against some common signal integrity problems in RF systems.

Suppressing intermodulation products. 5G designers are already familiar with passive intermodulation, and the same effect can occur in amplifier stages used in RF signal chains for frequency modulated signals. The third-order intermodulation products are the most important as they lie closest to the FMCW bandwidth, although other odd-order products will be present and can lead to interference in wideband signal chains. If you aren't using an SoC with an integrated amplifier, or you are designing your own amplifier as part of a signal chain, you'll need to suppress intermodulation products created on the Tx side from interfering with the Rx side.

As higher frequency radar systems use relatively wideband amplifiers and ADCs, intermodulation products can propagate into the Rx side as crosstalk and reduce the usable range in a radar module system. This is particularly problematic with power amplifiers on the Tx side, which typically run near saturation. This is another problem that should be addressed at the board level and circuit level. A higher order filter on both sides can be used for intermodulation product suppression, while eliminating interference requires sufficient isolation between the Tx and Rx sides of the RF signal chain.

LOOKING TO THE FUTURE OF AUTOMOTIVE RADAR

Although we already looked at the signal processing and layout challenges in automotive radar systems and modules, we still haven't considered EMI from the rest of the vehicle. Strong electromagnetic fields in electric cars leads to EMI that increases the noise figure in an FMCW radar module, which can reduce the maximum available range based on the required SNR value.

Greater innovation in automotive radar that provides higher spatiotemporal resolution with a large number of Tx/Rx modules in new vehicles requires suppressing EMI or avoiding it altogether. 5D radar imaging is likely to become the state-the-art method for gathering 3D images of nearby vehicles with high spatial resolution, as well as Doppler and time tracking. This technique is already well-known among the medical community for gathering spatially resolved hyperspectral images. These images then need to be gathered within some solid angle (i.e., angular resolution) and then reconstructed extremely quickly.

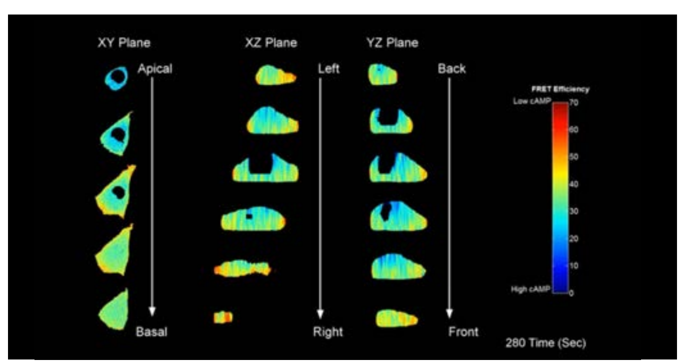


Figure 2. Example results from 5D radar imaging. Note that these images are actually dynamic; they change over time as a target is tracked.[3]

At the radar module and ECU levels, all signals required for MIMO radar must be phase and frequency synchronized so that a coherent beam can be constructed for angular resolution with a phased array antenna. SoCs and embedded signal processing within radar modules aid in synchronization for beamforming, but synchronization among multiple radar modules is already critical for preventing interference between modules on a single vehicle. In the process of locating and tracking vehicles in the nearby environment, a significant amount of data gets generated and must be sent to an ECU. Sending this data throughout a vehicle with coaxial or twisted pair cabling incurs losses and makes them susceptible to high frequency EMI from other systems. One can expect that data sent throughout a vehicle will reach gigabit levels as more ADAS modules are placed in new vehicles.

Much like the telecommunications industry has done, this motivates a move to fiber for vehicular radar systems and for moving data around a vehicle. Using fiber with radar systems is a natural choice (i.e., radio over fiber) to eliminate susceptibility to EMI within a vehicle. Note that fiber does not have to be limited for signal routing in a radar system; fiber can be used for in-vehicle networking as it provides higher bandwidth and data rates while eliminating interference problems that will continue to arise in new vehicles. Radar transceiver module proofs-of-concept that are built with COTS components are already being reported.[4] The schematic below shows a module built on the AWR1243 radar transceiver module from Texas Instruments.

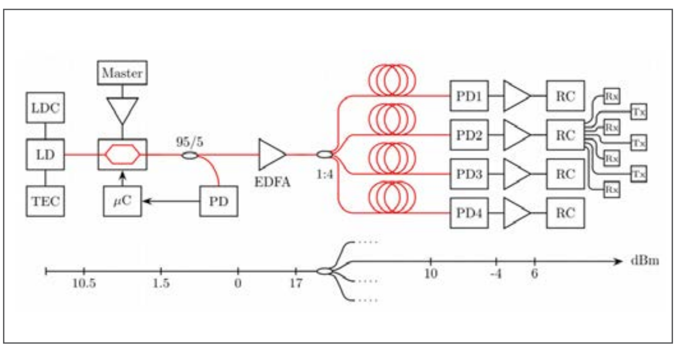


Figure 3: Proof-of-concept for a microwave photonic radar module for use in the 76-81 GHz band. The total link gain for the electrical signal from the master output to the RC input is zero, including electrical-optical and optical-electrical conversion, and all pre and post amplifiers. LDC: laser diode current controller, LD: laser diode, TEC: temperature controller, μC: microcontroller, PD: photo diode, EDFA: Erbium-doped fiber amplifier, RC: radar chip.[4]

In addition to the AWR1243 transceiver IC, this proof-of-concept module uses COTS components and can be easily integrated into a small radar module. The use of photonic circuits eliminates the intermodulation problems and many mixed signal interference problems noted above. If there is a shift to microwave photonic systems at the radar module level, expect this to coincide with greater use of fiber for in-vehicle networking.

FINAL THOUGHTS

This particular EMI/EMC challenge is currently being solved primarily with signal processing, appropriate component selection, and layout to produce accurate angle-resolved range and velocity estimates for nearby vehicles. The move to fiber and further advancements in microwave photonics-based radar systems represents a significant opportunity for innovation in this space. Obviously, any new mmWave system must pass EMC checks before it hits the market, and generalized in-lab test procedures are being developed for evaluating high frequency automotive radar systems.[5] The next advance in automotive radar my come in the form of partially coherent radar systems.[6] Prepare to see more innovation in the design, processing, and testing arenas as these systems proliferate new vehicles.

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Zachariah Peterson has an extensive technical background in academia and industry. He conducted his Physics M.S. research on chemisorptive gas sensors and his Applied Physics Ph.D. research on random laser theory and stability. Prior to working in the PCB industry, he taught and conducted research in optoelectronics and photonics at Portland State University. His background in scientific research spans topics in nanoparticle lasers, electronic and optoelectronic semiconductor devices, environmental systems, and financial analytics. His work has been published in several peer-reviewed journals and conference proceedings. He founded Northwest Engineering Solutions, a PCB design and embedded development firm, in 2017. He currently writes technical articles on PCB design for Altium and a number of other ECAD companies. He has also previously written on 77 GHz Radar for Automotive PCBs: Routing and Signal Integrity.

AUTOMOTIVE EMC

By Maurizio Di Paolo Emilio, Ph.D

AUTOMOTIVE EMC

INTRODUCTION

The rapid development of the automotive industry and the trend towards autonomous vehicles and ADAS systems continue to drive the need for more sophisticated EMC design and test scenarios for the automotive industry. Vehicle platforms become increasingly much more complex with electronic devices that need a reliable function without impacting security or communication infrastructure.

The increase of electronics in automotive systems has not just foreseen a radical change in control systems with ECUs, but also in the communication, information, security and mobile entertainment systems in vehicles. It is important that all the electronic devices of a vehicle are electromagnetically compatible and do not interfere with the systems outboard.

The new wireless communication paradigms applied to the automotive sector require high performance electronic systems that operate at high bitrates and, therefore, at high frequencies according to the operating environment. Each of these new sub-systems must comply with the electromagnetic compatibility (EMC) standards. Furthermore, the integrity of the signals, the transmitted and processed data streams are critical aspects. Miniaturization of electronic products is a must and, as a consequence, manufacturing tolerance can be no longer neglected. Variations in nominal design parameters cause irregular behaviours that negatively affect the EMC and signal integrity and power (SI / PI) aspects.

SIGNAL INTEGRITY

Historically, engineers have used signal integrity testing (SI) as a key part of design and development of new systems and for maintaining standard qualifications. With today's increasing demand for higher system throughput and reduced latency in cloud computing, customers are increasingly designing low-loss laminate materials with more stringent design specifications and tolerances for impedance control.

The integrity analysis continues to evolve by combining simulation models with instrumentation to include detailed measurements of non-uniform trace structures, vias, packages and connectors. As the PCBs become more complex, the lines between the different scopes of analysis become blurred. The concepts of signal and power integrity are closely related. Power integrity problems in a project can actually appear as signal integrity problems. That's why performing signal integrity analysis is important for creating reliable designs, as well as for understanding and resolving possible problems encountered in the laboratory.

Digital projects traditionally have not been suffered of problems associated with the loss of a transmission line that can have significant consequences on the transmitted data. At low speeds, the frequency response has low influence on the signal. However, as speed increases, high frequency effects take over and even shorter lines can suffer of interferences such as crosstalk and reflections. In this case, the characteristics of a circuit can be determined as a function of parasitic impedances, which become prevalent along a transmission line.

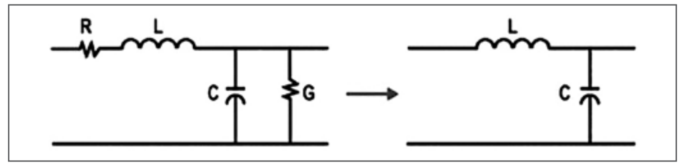


Figure 1: Circuit model of a transmission line (on the left) and approximation to the first order (on the right)

An example of circuit model is shown in *Figure 1*. The impedance plays an important role determining a perfect match of the transmission path of the signal and therefore effects on the quality of the signal. A mismatching between the line, source and load impedances determines a reflection of the signal with consequent energy loss and signal degradation. At high data rates this can cause overshoot of the signal, undershoot and stepped waveforms, which produce signal errors.

The mismatch of impedance can be overcome through the use of circuit schemes with simple parallel (see *Figure 2*) and more complex RC terminations in which a resistor-capacitor network provides a high-pass filter to remove low-frequency effects but passes the high-frequency signal.

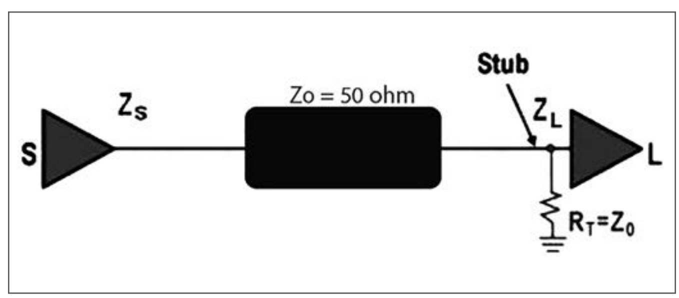


Figure 2: Parallel termination circuit diagram

Losses in the high frequency signal transmission line make difficult for the receiver to interpret the information correctly. The following two causes of losses in a transmission line are due to the transmission medium:

- **Dielectric absorption:** high frequency signals excite the molecules in the insulation, reducing signal level. Dielectric absorption refers to the PCB material.
- **Skin effect:** high frequency signal current tends to travel on the conductors with an increase in the self-inductance of the material. The effective reduction of the conductive material causes an increase

in resistance and, therefore, the attenuation of the signal (*Figure 3*). The density of alternating current J in a conductor decreases exponentially from its value on the surface J_s according to depth d from the surface:

$$\delta = \sqrt{\frac{2\rho}{\omega\mu}}\sqrt{\sqrt{1+(\rho\omega\varepsilon)^2}+\rho\omega\varepsilon}$$

Where ρ is the resistivity of the conductor, ω is the angular frequency, μ is the magnetic permeability, ε is the permittivity of the material.

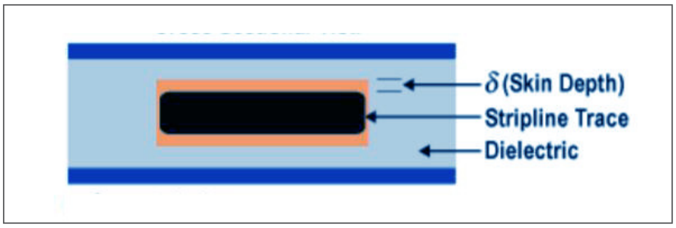


Figure 3: PCB section. The current route is orange. In blue is the ground plane and in celestial is the dielectric of the material. The copper PCB trace is highlighted in black.

CMOS circuits are very popular in many automotive sectors, due to their high speed and very low power dissipation. An ideal CMOS circuit dissipates energy only when it changes state and when the capabilities of the node need to be charged or discharged. In general, a CMOS requires an average of 10 mA and emission limitation techniques are focused on peak voltage and current values rather than average.

The rising current from the power supply on the chip's pin is a primary source of emission. By placing a bypass capacitor near each power pin, this problem is limited. Larger capacitors provide strong current peaks, and tend to react badly to high-speed demands. Very small capacitors can react quickly to demand, but their total charge capacity is limited and can quickly run out. The best solution for most circuits is a mix of different sizes of parallel capacitors, perhaps 1-μF and 0.01-μF in parallel.

One area in which automotive designers are interested is in the AM radio band. Most every car is equipped with radios, which has a very sensitive and high gain tuneable amplifier from 500 kHz to 1.5 MHz. Many switching power supplies use switching frequencies within this same band, which leads to problems in automotive applications. As a result, most devices use switching frequencies above this band, often at 2 MHz or higher.

AUTOMOTIVE STANDARD

The automotive industry and the car manufacturers have the aim of satisfying a variety of requirements regarding electromagnetic compatibility (EMC). For example, two requirements must ensure that electronic devices do not emit excessive electromagnetic interference (EMI) or noise and are immune to noise emitted by other systems. Automotive systems have several receivers installed around the car. The IEC Commission has formulated international standards to protect them. The international standard for this electromagnetic noise is formulated as CISPR 25, and the power supply on board is required to meet this standard (*Figure 4*).

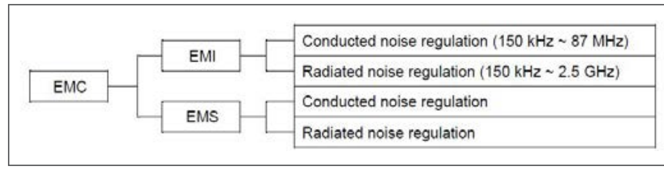


Figure 4: Electromagnetic noise

Automotive standards that relate to electromagnetic compatibility (EMC) are mainly developed by CISPR, ISO and SAE. CISPR and ISO are organizations that develop and maintain standards for international use. The CISPR 25 and ISO 11452-2 standards form the basis of most other standards.

CISPR 25 is a standard with different test methods. It requires that the level of test electromagnetic noise is being performed is at least 6 dB lower than the lowest measured levels. Another standard of testing is the ISO 11452-4 Bulk Current Injection (BCI) to check if a component is negatively affected by the narrow band electromagnetic fields. The test is performed by coupling noise directly in the wiring with a current probe.

CISPR 25 contains limits and procedures for measuring radio interference in the frequency range from 150 kHz to 1,000 MHz. The standard applies to any electronic / electrical component intended for use on vehicles, trailers and devices. CISPR 25 defines the test configuration as shown in *Figure 5* for measuring the noise of the radiation emitted by the apparatus.

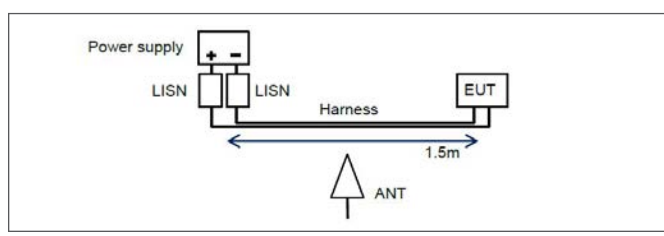


Figure 5: EMI Radiated Noise Test Configuration Example

In the case of irradiated noise measurement of 1 GHz or less, the antenna is placed in the middle of the harness. The wiring current (or voltage) (or LISN) is measured for the conducted noise. The length of the line is different from the test condition for the radiation noise. Therefore, it is important to reduce the noise source level and to prevent noise propagation along the line to reduce EMI noise.

EMC TESTING

When a magnetic field is present, a coil of conductive material can act as an antenna and convert the magnetic field into a current flowing around the wire. The small size of these loops minimizes the inductive effects of these materials. An example of this effect is when there is a differential data signal. A loop can be formed between the transmitter and the receiver with the differential lines. Another common loop is when two subsystems share a circuit, for example a display and an ECU device.

When a high-speed signal is sent through a transmission line and encounters a change in the characteristic impedance, part of the signal is reflected back and the other continues along the electrical path. Then, reflection leads to emissions.

Emissions can be caused by an interruption in the signal track or in the ground plane. For this it is necessary to avoid sharp angles on the signal track. To minimize reflections on components, it's important to use small components such as size 0402 and set the width of the track equal to the width of the 0402 component.

A recurring topic when trying to solve EMI problems is to reduce dv/dt or di/dt where possible. In this context, DC-DC converters may seem completely harmless as switching regulators are much more efficient than other linear solutions. One area in which automotive designers are not interested in creating interference is in the AM radio band. The cars are equipped with AM solutions, which have a very sensitive and high-gain tuneable amplifier from 500 kHz to 1.5 MHz. Most automotive switching supplies use the switching frequencies above this band, often at 2 MHz or higher. If the filter is not sufficient to contain this interference, it can trigger an EMI cycle over the whole circuit.

There are several ways to implement EMI noise reduction countermeasures.

Spread Spectrum Clock Generation (SSCG) is a method by which the energy contained in the small band of a clock source is spread on a larger one in a controlled mode, thus reducing the spectral amplitude of the fundamental and harmonics to reduce the emission radiated by the clock. This is obtained by modulating the clock frequency with unique shapes that allow reaching the peak of reduction of the EMI.

By varying the clock frequency on a band in a controlled mode, the time elapsed from the signal at a certain frequency is reduced, and in this way the concentration of energy at any frequency is reduced. So energy is spread on the band of frequencies that reduce the amplitude of the peak.

SSCG provides a way to reach EMC goals. It is an active solution, preserves the integrity of the clock, and can cover a wide range of frequencies. Compared to traditional methods of using passive components such as ferrite beads, RF coils to suppress EMI, SSCG uses an integrated circuit of active components to reduce the EMI peak using frequency modulation (*Figure 6*).

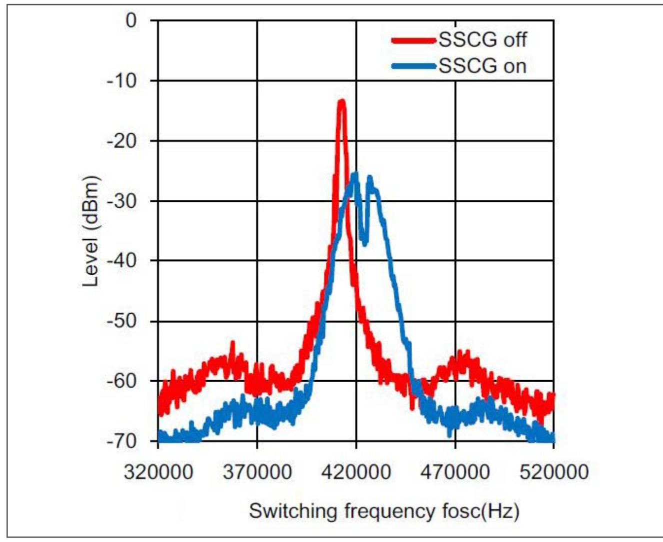


Figure 6: EMI reduction with SSCG

POWER CIRCUITS

Various electronic devices are mounted on vehicles with different power sources. Switching circuits help power management solutions but are essentially noise sources. Where it is not possible to increase the switching frequency is necessary to introduce noise suppression measures.

DC-DC switching solutions for automotive systems have a switching frequency of 2 MHz, with the exception of some devices. Therefore, there is almost no problem in the range of AM radio (from 530 kHz to 1.8 MHz) as it is below 2 MHz, but countermeasures could be requested with values above 2 MHz. In particular, high noise frequency above 30 MHz is the most important since it generates cases of interference such as to interrupt the correct functioning of a system. A diagram of the step-down DC-DC converter is shown in the following *Figure 7*.

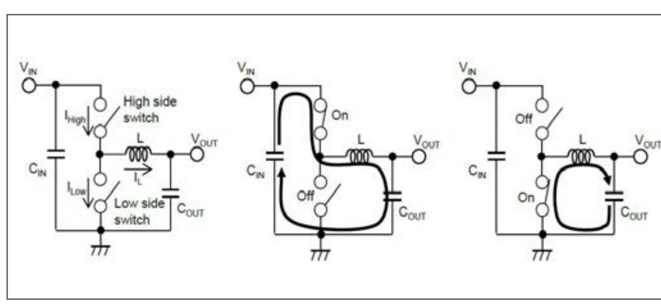


Figure 7: Step-down converter with current loop in various cases depending on the switch position

The parasitic inductance of the loop generates a high frequency voltage and therefore noise. To reduce this high frequency, it is necessary to reduce the parasitic inductance and to improve the switching response speed. Noise suppression measures are not limited to vehicles and can also be used with other industrial equipment (*Figures 8* and *9*).

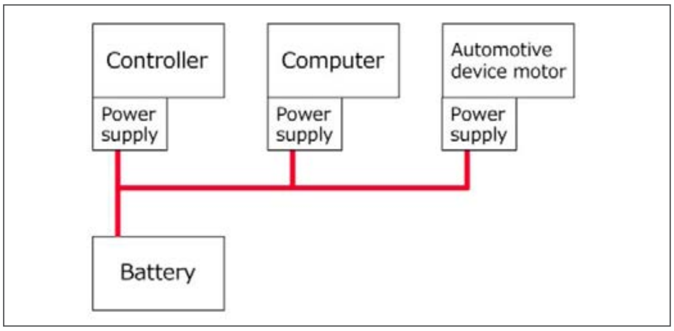


Figure 8: Automotive power system

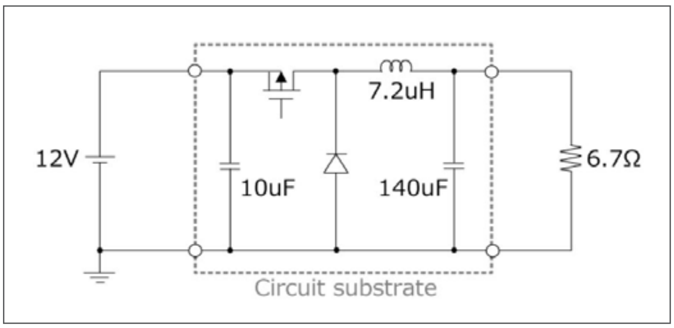


Figure 9: Model of IC DC-DC step-down

Some methods consist of using appropriate shields to suppress noise up to 20 MHz. Or insert a common mode choke coil (CMCC) immediately next to the power connector to suppress noise in common mode at 20 MHz or higher, or, an LPF near the power connector to suppress noise in normal mode at 20 MHz or higher. In *Figure 10* an implementation circuit of what has been described.

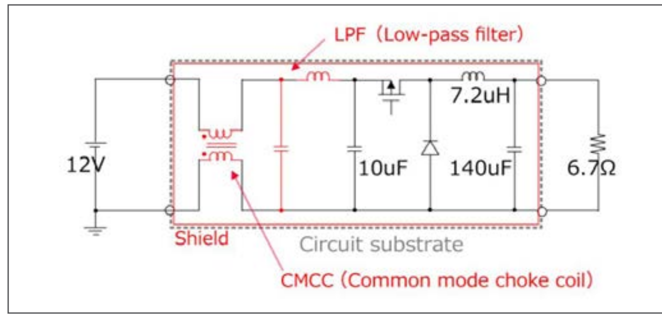
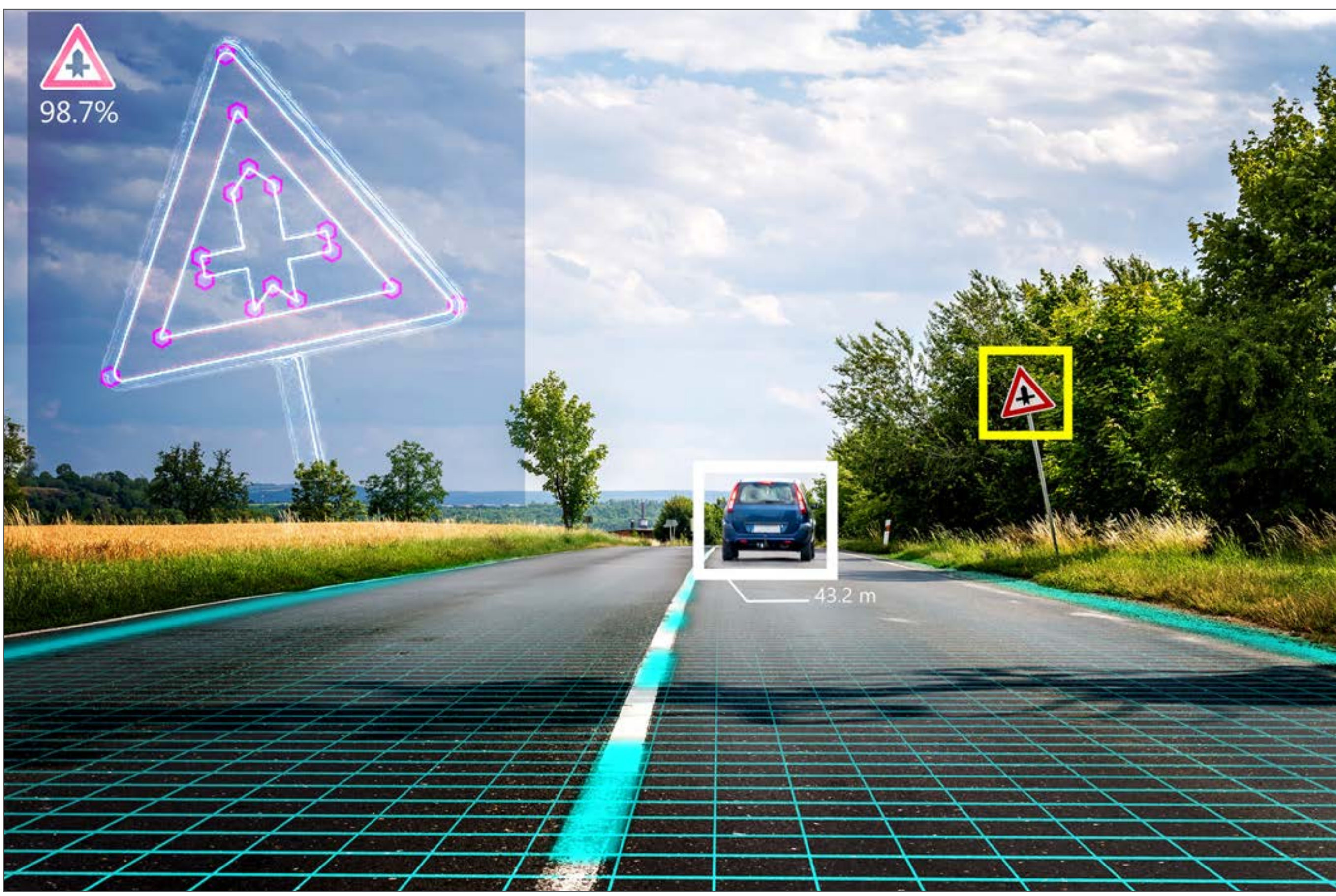


Figure 10: The circuit model of Figure 9 with noise suppression methods

CONCLUSION

Automobiles rely more on electronics: ADAS systems and self-driving vehicles; in all these there is a growing need to operate without errors without interfering with other systems in the vehicle. Through a selection of the appropriate components, materials and PCB study; engineers are able to design robust systems that enable automotive systems to operate EMI-free reliability.



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https://www.ul.com/automotive-and-mobility

Yazaki Testing laboratory
http://www.yazakiemc.com/wp/

If your test lab specializes in automotive EMC testing and is not listed, please contact: jennifer@lectrixgroup.com and we'll include you in the next issue.

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http://www.autoalliance.org

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http://www.aiag.org

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http://www.acea.be

National Automobile Dealers Association
https://www.nada.org

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https://www.aiacanada.com

Center for Automotive Research
http://www.cargroup.org

German Association of the Automotive Industry
https://www.vda.de/en

Motor Trades Association of Australia
http://www.mtaa.com.au

PUBLICATIONS

2019 Automotive EMC Guide
The guide is comprised of the latest trends in technology, EMC design, standards, and pre-compliance testing in the automotive space.
https://learn.interferencetechnology.com/2019-automotive-emc-guide/

Interference Technology Engineer's Master (ITEM 2020)
Interference Technology Engineer's Master (ITEM) is an exhaustive guide full of invaluable EMC directories, standards, formulas, calculators, lists, and "how-to" articles, compiled in easy-to-find formats.
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2020 AUTOMOTIVE EMC CONFERENCES

The following is a partial listing of major automotive electronics conferences planned for 2020. Please check conference websites for up to date information and cancellation notices. If your conference is not listed, please contact: jennifer@lectrixgroup.com

Vehicle Technology Conference (VTC)
May 25–28, 2020 (Online Only)
Antwerp, Belgium
https://events.vtsociety.org/vtc2020-spring/#
IEEE VTC will bring together individuals from academia, industry and government to discuss and exchange ideas in the fields of mobile, wireless and vehicular technology as well as the applications and services associated with such technology. Features include world-class plenary speakers, panel sessions, tutorials, and both technical and application-based sessions.

The 2020 IEEE International Symposium on EMC+SIPI
July 27–31, 2020
Reno, NV, USA
https://emc2020.emcss.org

Electric & Hybrid Vehicle Technology Show
September 15–17, 2020
Novi, MI, USA
http://www.evtechexpo.com
Electric & Hybrid Vehicle Technology Expo is the premier showcase for electric and hybrid vehicle technology and innovation. The show highlights advances right across the powertrain and across a wide range of vehicles from passenger and commercial to off-highway industrial vehicles.

The Battery Show - North America
September 15–17, 2020
Novi, MI, USA
https://www.thebatteryshow.com
The Battery Show is the premier showcase of the latest advanced battery technology.

Automotive Test Expo
October 27–29, 2020
Novi, MI, USA
http://www.testing-expo.com/usa/
This conference includes the very latest technologies and services that are designed to ensure that the highest standards are met in terms of product quality, reliability, durability and safety.

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