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2021 AUTOMOTIVE EMC GUIDE

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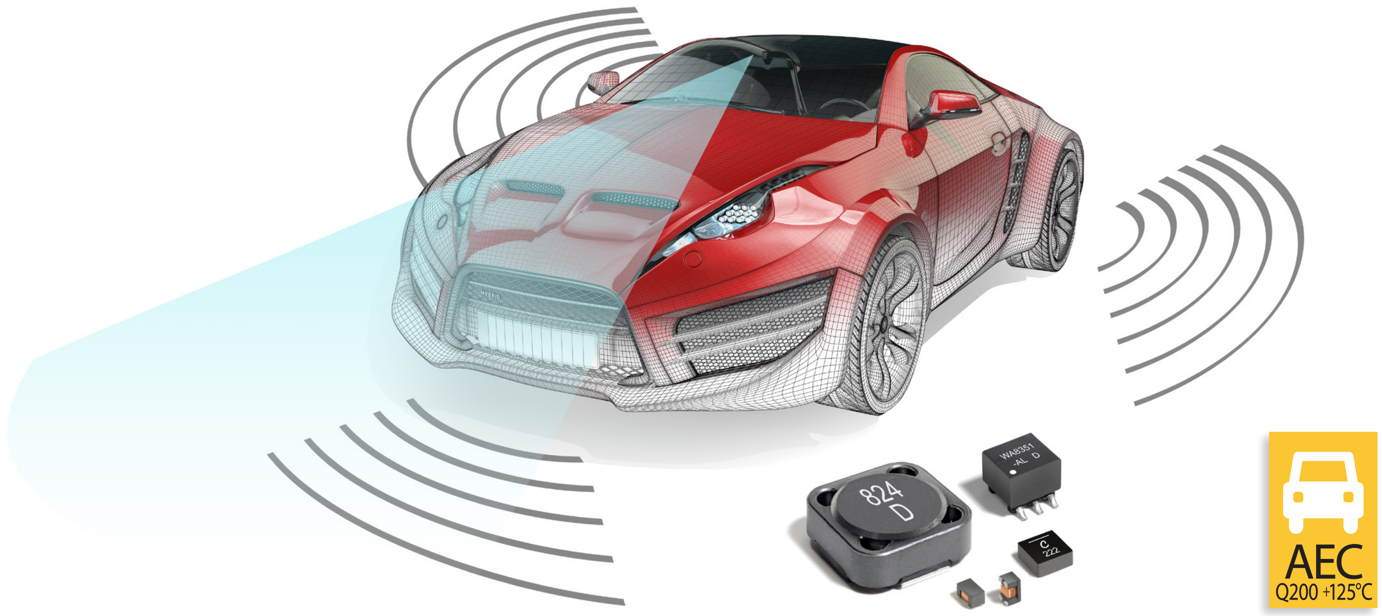
EMC EQUIPMENT MANUFACTURERS MATRIX

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									
Instrument Rental Labs	www.testequip.com		X			X		X	X	X	X	X		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
Instruments For Industry (IFI)	www.ifi.com		X							X	X				
Keysight Technologies	www.keysight.com			X		X			X			X			X
Milmega	www.ametek-cts.com/about-us/brands/milmega		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		
Teseq	www.teseq.com		X		X			X		X	X	X	X		
Test Equity	www.testequity.com		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

Advanced Magnetics for ADAS



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TOP THREE EMI AND POWER INTEGRITY PROBLEMS WITH ON-BOARD DC-DC CONVERTERS AND LDO REGULATORS

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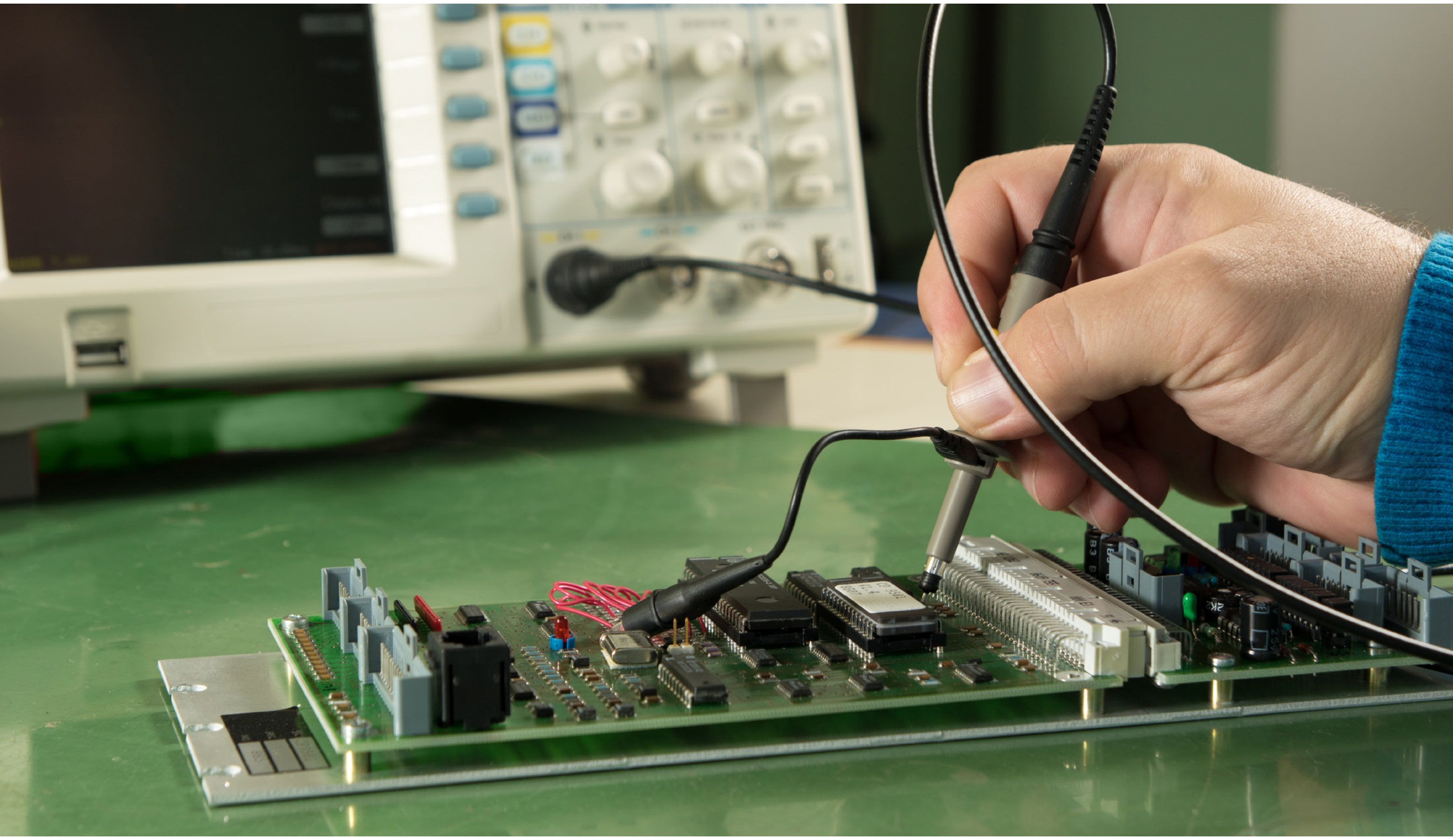
Modern devices are continuing a long-term trend of squeezing more electronics into smaller packages, while also increasing system performance, data rates and operating efficiency. Higher efficiencies are often achieved by implementing faster silicon MOSFETs or even faster eGaN FETs while size is reduced by increasing switching frequencies and replacing aluminum and tantalum capacitors with smaller ceramic devices. One result of this trend is that there is greater interaction between the disciplines of EMI, signal integrity (SI) and power integrity (PI).



TOP THREE EMI AND POWER INTEGRITY PROBLEMS WITH ON-BOARD DC-DC CONVERTERS AND LDO REGULATORS

Introduction

EMI is a measure of the electromagnetic emissions produced by the high-speed current and voltage signals the system creates. Power integrity is a measure of the power quality at the device that being powered. This means that the power supply voltages must be maintained within the allowable operating voltage range of high-speed devices.

Devices, such as modems, reference clocks and low noise amplifiers (LNAs) are all sensitive to noise on the power rails, which results in timing jitter, spurious responses reduced data channel eye openings, and degraded signal-to-noise ratio (SNR). This too, is a measure of power integrity.

The power supply itself is a noise source and the noise sources generated by the power supply must be kept from propagating through the system.

This article discusses the three most common causes of EMI and power integrity issues while providing tips for how to avoid or minimizes them in your design,

1. **Ringing** on switched waveforms causes broad resonant peaks in the emission spectrum.
2. **DC-DC converters generate noise** at the switching frequency, and because of high speed switching devices, can generate broadband switching harmonics well into the GHz.
3. **Power plane resonance** in DC-DC converter or LDO regulators due to high-Q capacitors resonating with power planes.

Ringing and Radiated Emissions

Any ringing on the switched waveform (fairly common) can lead to broadband resonances in the resulting RF spectrum. Resonant frequencies resulting from DC-DC converters or low dropout (LDO) linear regulators can be as low as a few kHz while resonance due to the PDN with switching devices, such as MOSFET's can be in hundreds of MHz or higher.

The harmonic energy resulting from this switching is "captured" by the PDN and device resonances, evident as ringing in the time domain. The current and voltage of this ringing produces EMI. The magnitudes of the ringing and EMI are related to the quality factor (Q) and characteristic impedance of the resonance and the harmonic energy produced by the switching.

As an example, the switching waveform on a DC-DC buck converter demo board was measured with a Rohde & Schwarz RTE 1104 oscilloscope and Rohde & Schwarz RT-ZS20 1.5 GHz active probe (*Figure 1*).

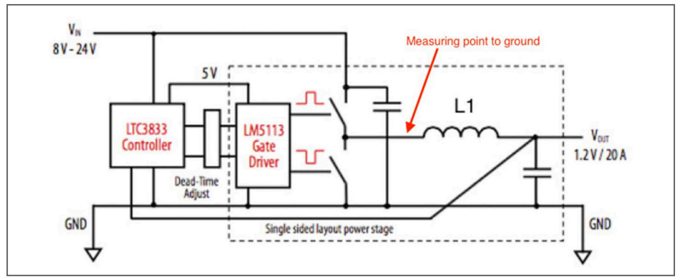


Figure 1. Diagram showing the measuring point at the switch device junction (on the left side of L1) to ground return.

There was a very large ringing superimposed on the switched waveform of 216 MHz. This can be seen clearly in *Figure 2*.

A Fischer Custom Communications F-33-1 current probe was used to measure both the input power cable common mode current (violet trace) and output load differential mode current (aqua trace). See *Figure 3*. Note the broad resonant peaks at 216 MHz (*marker 1*) and the second harmonic at 438 MHz (*marker 2*).

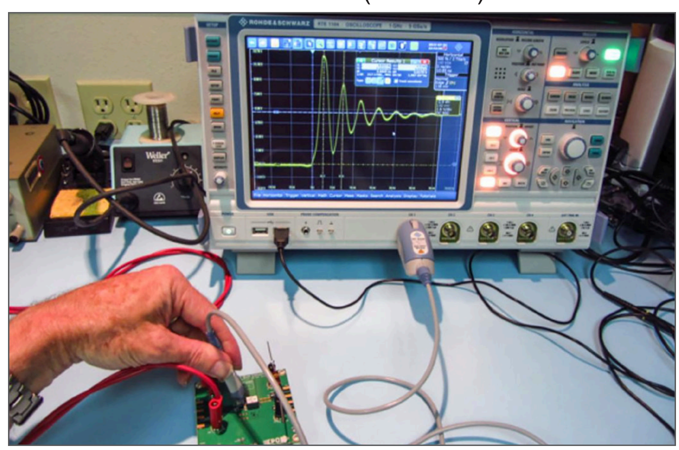


Figure 2. Measuring the rise time and ringing on a DC-DC converter. Notice to strong ringing at 216 MHz.

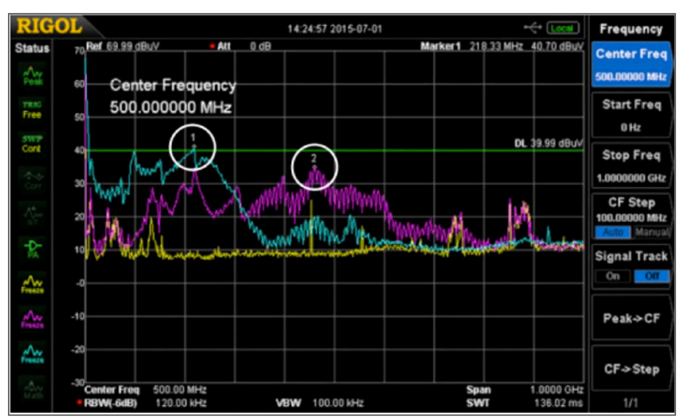


Figure 3. Resulting resonances from the 216 MHz ring frequency (marker 1) and second harmonic at 438 MHz (marker 2).

Remediation Tips - There are several ways to improve the design to minimize the resonances, ringing and therefore EMI. Since the energy is related to the switching frequency, rise time of the switching, characteristic impedance, and Q of the resonances, these factors are also the paths to mitigation.

- Slower edges will degrade operating efficiency but reduce high frequency energy
- Careful PCB design and capacitor selection will minimize the characteristic impedance and Q
- Keep traces short and wide and dielectrics thin.
- Keep all the switching circuitry on one side of the board, preferably with a thin dielectric to the respective ground return plane.
- Use of a snubber circuit, damping of resonances using controlled ESR capacitors, or redesign of the inductor for lower leakage inductance.

For additional detail on measuring ringing refer to *Reference 1*.

Fast edges create broadband noise at GHz frequencies
Today's on-board DC-DC converters use switching frequencies as high as 3 MHz. This is an advantage because it allows for physically smaller inductor and filter components, as well as increased efficiency. However, the fast edge speeds create broadband harmonic energy. The bandwidth of this harmonic energy is related to the voltage and current rise time. A 1ns edge speed can produce harmonic energy up to 3 GHz, or more.

These broadband harmonics are the cause of radiated emissions failures and also can affect the receiver sensitivity of any on-board telephone modems or other wireless systems, such as GPS. *Figure 4* shows how a typical DC-DC converter circuit can be characterized using an H-field probe connected to a spectrum analyzer.

It's also possible to connect the probe to an oscilloscope and hold it near each DC-DC converter to get some idea of the ringing, if any, without disturbing the circuit.

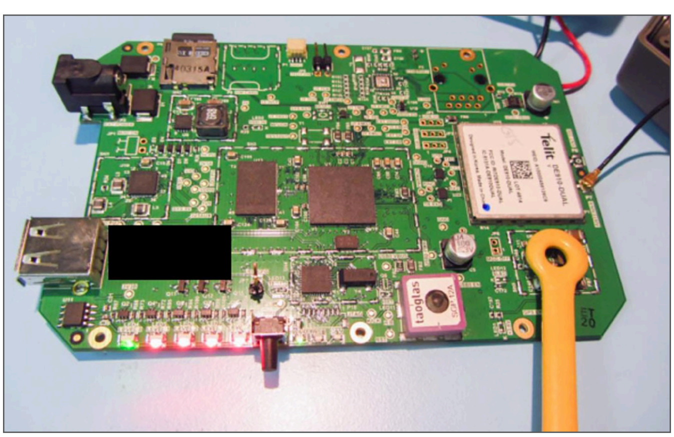


Figure 4. Probing DC-DC converter noise sources on a typical wireless device.

Figure 5 shows the resulting measurement of a couple DC-DC converters. The yellow trace is the ambient noise floor of the measurement system and is always a good idea to record for reference. The aqua and violet traces are the two converter measurements. Note that both produce broadband noise currents out to 1 GHz, with the convertor in violet out to beyond 1.5 GHz. Note the violet trace is 20 to 50 dB higher than the ambient noise floor.

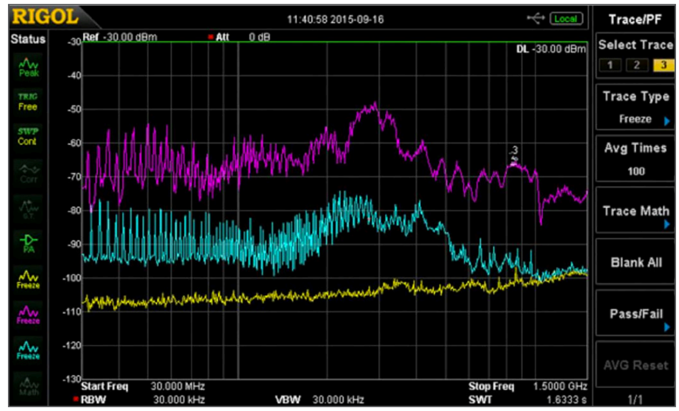


Figure 5 - In this example, we're looking from 30 MHz to 1.5 GHz to generally characterize the spectral emissions profile of a couple of on-board DC-DC converters. Both will potentially cause interference to mobile phone bands in the 700 to 950 MHz region. The one with the violet trace is over 30 dB above the ambient noise level in the mobile phone band.

Remediation Tips – To reduce the risk of self-interference to on-board mobile phone modems and wireless systems, the product design must start off with EMC in mind and with no corners cut.

This will consist of:

- A near perfect PC board layout
- Filtering of DC-DC converters
- Filtering of any high frequency device
- Filtering of the radio module
- Local shielding around high noise areas
- Possibly shielding the entire product
- Proper antenna placement

The PC board layout is critical and is where most of your effort should reside. An eight or ten layer stack-up will provide the most flexibility in segregating the power supply, analog, digital, and radio sections and provide multiple ground return planes, which may be stitched together around the board edge to form a Faraday cage. Care must be taken to avoid return current contamination between sections – especially in the ground return planes. For wireless products, the power plane for the radio modem section should be isolated (except via a narrow bridge) from the digital power plane. All traces to this isolated plane should pass over the bridge connecting the two. This can provide up to 40 dB of isolation between the digital circuitry and radio.

It is vital that the power and ground return planes be on adjacent layers and ideally 3-4 mils apart at the most. This will provide the best high frequency bypassing. All signal layers should be adjacent to at least one solid ground return plane. Clock, or other high-speed traces, should avoid passing through vias and should not change reference planes.

Power supply sections should be well isolated from sensitive analog or radio circuitry (including antennas). Be aware of primary and secondary current loops and their return currents. These return currents should not share the same return plane paths as digital, analog, or radio circuits. Remember that high frequency return currents want to return to the source directly under the source trace.

For more details on resolving DC-DC converter noise issues with wireless radio modems, refer to *Reference 2.*

PC Board Plane Resonance and the Effect on Radiated Emissions

Noise propagation in a simple system can be represented by three elements, the voltage regulator, the printed circuit board planes with decoupling capacitors (PDN) and the device being powered (load).

Each of these three elements is comprised of resistive, inductive and capacitive terms. Even "noise free" low dropout (LDO) regulators can be highly inductive (*Reference 3*). The resistive, inductive and capacitive terms can resonate amplifying the noise signals created by the power supply and the load as they travel across the PDN creating EMI. The harmonics of the switching frequency and the switch ringing discussed earlier excite these PDN resonances (*Reference 4*). As stated previously this noise can degrade and interfere with on-board wireless modems, as well as resulting radiated and conducted emissions.

A short video helps explain the basic principles of PDN design (*Reference 5*). The radiated EMI of a LTC3880 DC-DC converter measured near the input plane using an H-field probe is seen in *Figure 6*.

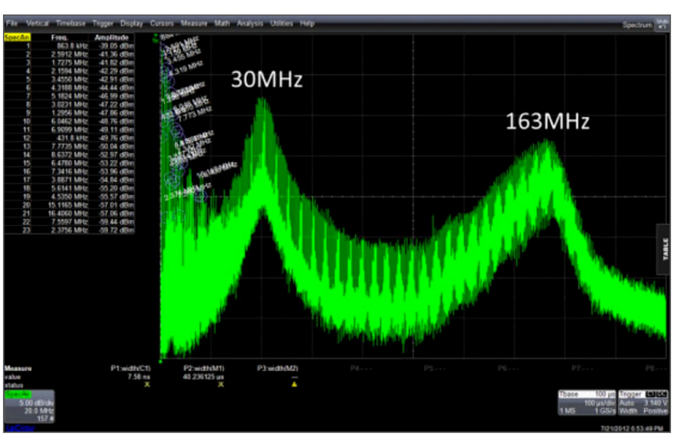


Figure 6. Spectrum analyzer display showing the 30 MHz and 160 MHz resonances detected near the input power connections of a DC-DC converter.

The 163 MHz is attributed to the ringing of the switches as seen in *Figure 7*. This ringing is caused by the inductance of the upper MOSFET bond wires, pins and circuit board planes, ringing with the lower MOSFET and PC board capacitance.

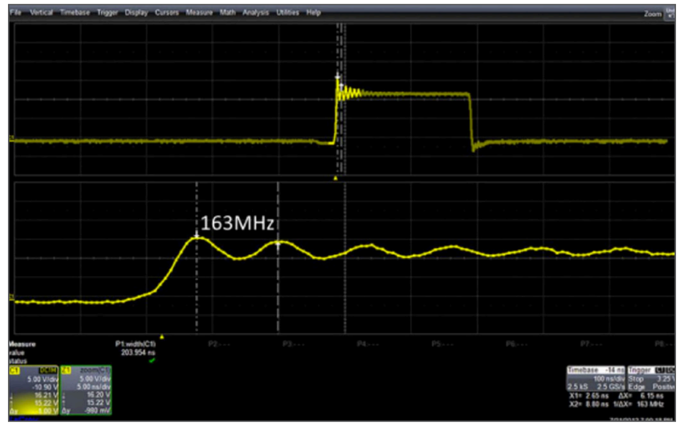


Figure 7. The 163 MHz EMI is easily explained by the ringing at the switch device, as discussed earlier.

The input ceramic decoupling capacitor resonates at approximately 30 MHz, as seen in *Figure 8* and results in the large 30 MHz EMI signature.

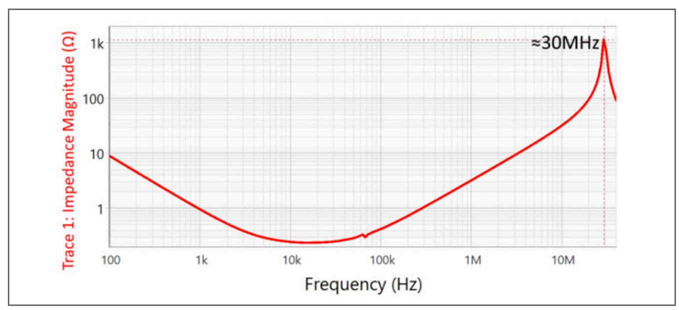


Figure 8. The larger 30 MHz emission is identified as a printed circuit board resonance using an H-field probe and confirmed by a 1-port reflection impedance measurement at the input capacitor.

The input power plane section of the DC-DC converter (measured in *Figure 6*) is shown in *Figure 9* with schematic representations of the component, PC board and external connections.

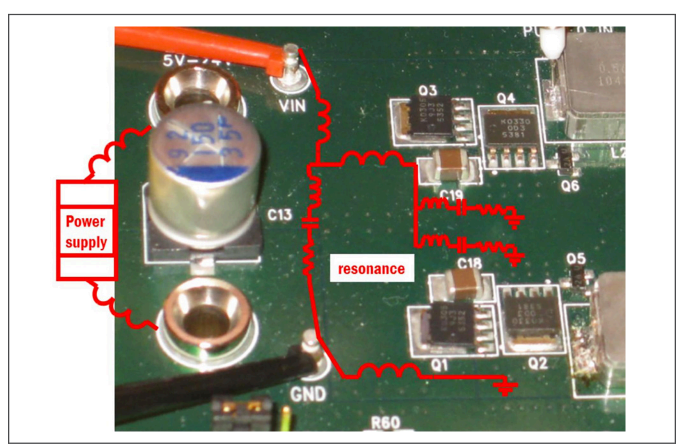


Figure 9. The power plane section of the DC-DC converter (measured in Figure 6) with schematic representations of the component, PC board and external connections.

A very simple simulation example can be used to illustrate these impedance resonance effects. Consider a simple DC-DC converter as shown in *Figure 10*.

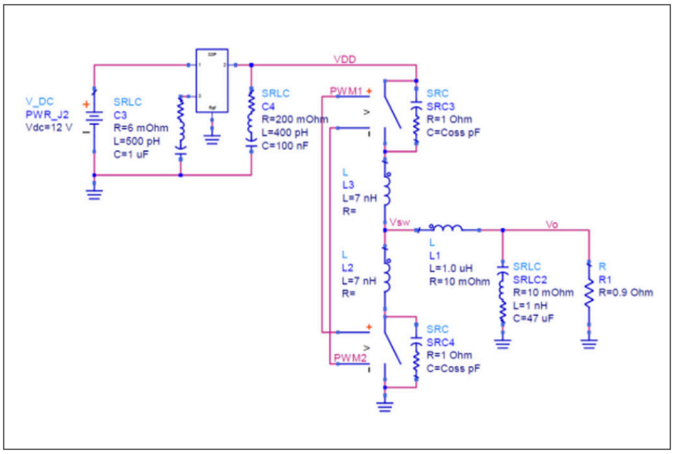


Figure 10. A simple DC-DC converter for illustration of plane resonance EMI. The "FET" switches include lead inductance and drain capacitance (Coss). A small PC board and two ceramic capacitors are included.

Designers frequently place the FET switches on one side of the board with power entry on the opposite side of the PC board. The small PC board plane used in this example has power entry through a pair of pins and no interconnect inductance is added to connect power to the PC board. A large 47 µF ceramic capacitor is placed on the top side of the PC board, while a smaller, 0.1 µF ceramic capacitor is placed very close to the FET switches on the bottom side of the PC board. Two parallel vias connect power and ground from the top side of the PC board to the bottom side as seen in *Figure 11*.

The simple model is used to simulate the harmonic current in the input connector, which is directly related to conducted and radiated emissions. Two simulations are performed; one with low ESR ceramic capacitors and the other with a lower Q controlled ESR ceramic replacing the 0.1 µF capacitor close to the FET switches. Both simulations are shown together in *Figure 12*.

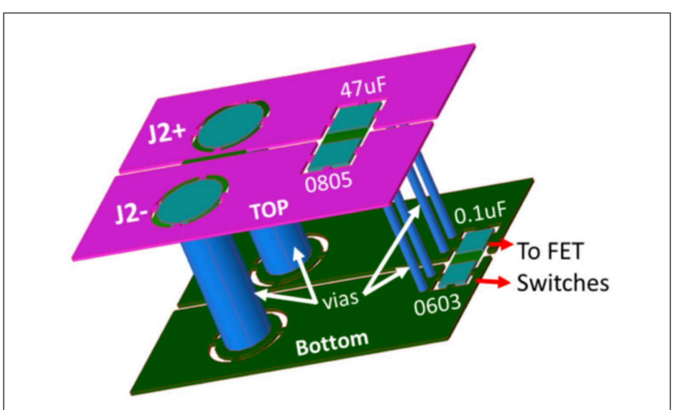


Figure 11. The large round pins on the left are the input power connector, J2. The larger capacitor on the top side is an 0805 sized 47 µF and the smaller capacitor on the bottom side is an 0603 sized 0.1 µF.

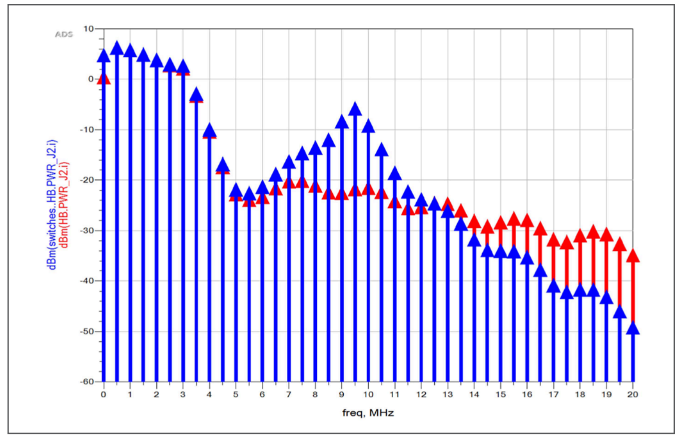


Figure 12. Spectral simulation of the input power lead shows the high Q ceramic (10 mΩ blue) has a clear peak near 10 MHz that is eliminated using a controlled ESR ceramic (200 mΩ red)

The simulated impedance, measured at the smaller capacitor in *Figure 13* shows the corresponding plane resonance with a clear 10 MHz peak using the high Q ceramic capacitor (blue) and the peak is eliminated using the controller ESR ceramic capacitor (red).

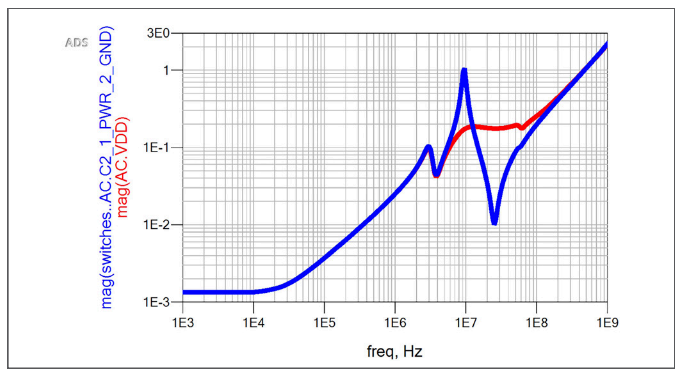


Figure 13. The simulated impedance at the 0.1 uF capacitor using high Q ceramic (10 mΩ blue) and a controlled ESR ceramic (200 mΩ red)

Remediation Tips – To minimize PDN resonances, the complete system of voltage regulator, PDN and the load need to be carefully balanced. Damping resistance must be included to eliminate or minimize the existence or Q of resonances. This will consist of:

- Short, wide power planes
- Keep the layout as small as possible to minimize inductance
- Thinner PC board dielectric layers, closer to the surface
- Incorporate EM simulation to identify and minimize PDN resonances
- Keep capacitors on one side of the PC board to the extent possible
- Low-Q or ESR controlled capacitors reduce Q
- Choose voltage regulators and output capacitors for good control loop stability
- Don't place cutouts or holes in ground plane layers below the power plane

- Ferrite beads are a very common cause of PDN resonances
- Be aware of inductive interconnects bringing power to the system.

Printed circuit board design and decoupling is critical and "rules-of-thumb" generally don't work well in high speed circuits. The design of the circuit board and capacitor decoupling always involves trade-offs, but the impacts on resonances need to be weighed carefully. A multi-frequency harmonic comb generator can be extremely helpful for quickly identifying PDN resonances (*Reference 3*).

Summary

As you can see, designing DC-DC converters, LDOs, and PDNs with today's high-speed technology nearly always requires careful circuit design, adequate filtering, simulation of the PDN, very careful circuit board layout, and use of controlled-ESR filter capacitors. Poor designs can result in:

- Ringing in power supply switches (or other fast-edged digital switching) resulting in associated radiated or conducted emissions resonant peaks at the ring frequency and harmonics.
- High frequency broadband noise well beyond 1 GHz, resulting in self-interference to radio modems.
- Poor stability and resonances in un-damped power distribution networks, leading to instability, spectral resonances, and associated radiated and conducted emissions.

References

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FIVE STEPS FOR SUCCESSFUL AUTOMOTIVE EMC DESIGN

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EMI/EMC behavior of devices has become a major quality benchmark all over the world. The automotive industry follows several standards and stringent limits. Advancements in technology, customer requirements, along with harsher fuel emissions regulations, have resulted in the need to place more electrical and electronic systems into vehicles. In turn these resulted in the need of using electromagnetic compatible systems in the vehicle to avoid cross coupling between the systems and causing non-compliances or customer dissatisfaction.

FIVE STEPS FOR SUCCESSFUL AUTOMOTIVE EMC DESIGN

What makes automotive EMC special?
Electronic systems in automotive involve in safety critical functions which include engine management, braking control, and airbag deployment, to name a few. Also, the automotive industry has seen a new generation of on board electronics for driver assistance devices and entertainment. Having the mobility of automobile, it can be exposed to different electromagnetic environments, from electromagnetically benign locations to electromagnetically harsh environments like airports with high radar fields.

Almost all automobiles today have sensitive AM/FM/DAB radio receivers (or perhaps even a land mobile VHF/UHF radio), so emissions from digital circuits are one of the biggest EMI problems facing today's designer of vehicular electronics. Most of the time the problem is annoying, but in the case of emergency vehicles (police, fire, ambulance), jamming a radio receiver could be life threatening. As a result, most vehicle manufacturers now require suppressing the offending emissions to extremely low levels. In short, automotive emission requirements are aimed at protecting on board receivers (CISPR 25) and immunity requirements are very stringent to protect the safety critical on-board devices. Major Original Equipment Manufacturer (OEMs) had come up with their own standards which are more stringent than regulatory requirements. This make it essential for the suppliers to be fine tuning the EMC design best to suit the market.

EMC control - Vehicle level or Electronic Sub Assembly (ESA)
Understanding the fact that all major OEMs use electronics sub assemblies from more than one supplier for integrating in the vehicle, it is required by all major OEMs that the ESA fulfills the emission and immunity requirements. It can un-doubtfully say that making the ESA compliant to respective standards shall increase compliance possibility at the vehicle level testing, but, over the years it is proved that failure at vehicle levels are not completely avoided by making ESA compliant to EMC.

The article aims to provide a brief understanding for suppliers intended to produce products compliant and acceptable to Tier 1 OEMs.

I. UNDERSTAND THE REQUIREMENT

The automotive industry is a good example of responsible 'EMC regulation'. Country specific legal requirements are limited to generic clauses in the form of directives (for Europe) or FCC – Part 15 (United States). In addition to legal requirements, customer-based requirements are established by OEMs. Requirements of Tier 1 OEMs vary with each other in terms of standard followed, test limits and test type. A standardized test specification that cover major OEMs are far from reality even today [R1]. For radiated and conducted emissions of ESA, OEMs use CISPR25 as guideline and for regulatory purpose at vehicle level emission results, CISPR12 is used. For immunity measurements the ISO 11452-series is referenced for ESA and ISO 11451 series is referenced at the vehicle level. These standards apply to vehicles powered by internal combustion engines, as well as hybrid and electric vehicles. Test distances and methods required to validate a product's performance are detailed in these standards. Some of the OEM specific standards, such as standards issued by General Motors, Ford and Fiat Chrysler requirements are available in the public domain. It is of utmost importance that product manufactures (of ESA) shall be aware of the OEMs they are targeting, and the respective levels of emission and immunity to be achieved.

Vehicle Level		Electronic Sub-Assembly	
Emission Standards	CISPR 12, EN 55012	Emission Standards	CISPR 25, EN 55025
Immunity Standards	ISO 11451-2 (Radiated Immunity)	Immunity Standards	ISO 11452-2 (Radiated Immunity)
	ISO 11451-3 (On Board Transmitter Immunity)		ISO 11452-3 (TEM Cell Method)
	ISO 11451-4 (BCI Method)		ISO 11452-4 (BCI Method)
	ISO 10605 (ESD)		ISO 11452-5 (Stripline)
			ISO 11452-7 (Direct RF Power Injection)
			ISO 11452-9 (Portable transmitter)
			ISO 10605 (ESD)

Table 1 - Automotive EMC Standards Overview

II. INCLUDE EMC IN DESIGN

It is often observed that EMC is taken into consideration at the final phase of the project, either after experiencing a compliance failure or at final sample stage. EMC design from the earliest stages of the project leads to easy implementation and cost-effective design approaches. When designing an electronic circuit, it is necessary to take several precautions to ensure that its EMC performance requirements can be achieved. Methods that can address EMC during the design are optimized as:

- Component selection and frequency selection
- PCB design for minimum radiation
- Cabing & Shielding

A. Component selection and frequency selection
For many automotive electronic systems, the embedded

microcontroller is the only high-speed source of EMI on the board. If one can confine the selection of the component having lower emission profile and higher immunity performance, the EMC performance can be improved. Always ask for EMC compliance data for microcontrollers or passives used in the design. A detailed view EMC performance graphs will help to identify the advantages and shortcomings of the components. Preparing a 'frequency table' (such as shown in *Table 2*) that list out the fundamental frequency and the dominant harmonics associated with each component would be a handy tool for better understanding of the circuit for design. Better design shall use frequencies that will not interfere constructively.

IC Reference	Radiated Emission Level	Radaiated Immunity Level	Fundamental Frequency	Harmonic Frequency (1st, 3rd, 5th , 7th, 9th , 11th)	EMC Remarks

Table 2 - Component selection - Frequency check

B. PCB design for minimum radiation

Clocks & Harmonics: The primary sources of emissions from microcontroller based automotive systems are the clocks and other highly repetitive signals. A non-sinusoidal periodic waveform is composed of a fundamental frequency plus harmonic frequencies. The harmonics of these signals result in discrete narrowband signals that are typically within the VHF and UHF radio ranges. These harmonics are easily radiated by cables, wiring and printed circuit boards. The amplitude of square wave harmonics in digital systems decreases at the slowest rate (20 dB/decade) as frequency increases, and therefore are a rich sources of high frequency harmonics. Any conductor will act as an efficient antenna when it's physical dimensions exceed a (1/20) fraction of a wavelength. This shows that for a 300 MHz signal, a PCB trace of 5 cm can act as antenna. The design shall take care in avoiding PCB trace length comparable to the wavelength of the signal carried through it.

Spread Spectrum Clocking (SSC): Radiated emissions are typically confined in a narrow band centered around clock frequency harmonics. By uniformly distributing the radiation over a band of a few MHz, regulatory measurement levels (in a 120 kHz bandwidth at frequencies below 1 GHz and in a 1 MHz bandwidth at frequencies above 1 GHz) will be reduced up to 8 dB [R2].

Current Loop: Another key source of emissions is current flow. As processor speeds increase, the current requirement of the processor increases. Current flowing through a loop generates a magnetic field, which is proportional to the area of the loop. Loop area is defined as trace length times the distance to the ground plane. As signals change logic states, an electric field is generated from the voltage transition. Thus, radiation occurs because of this current loop and the voltage transition. The following *equation (1)* shows the relationship of current, its loop area, and the frequency to EMI (E-field): Since the distance to the ground plane is fixed due to board stack up requirements, minimizing trace length on the board layout is key to decreasing emissions.

$$\text{EMI (V/m)} = k\ IAf^2 \qquad (1)$$

Where:

k = constant of proportionality

I = current (A)

A = loop area (m^2)

f = frequency (MHz)

Decouple Power Line: Whenever a digital circuit switches, it also consumes current at the switching rate. These pulses of power current will radiate as effectively as pulses of signal current. These switching peak currents cause more radiation since the power levels are usually much higher than those on an individual signal line. For devices with multiple power and ground pins, each pair of pins should be decoupled. High frequency capacitors in the 0.01–0.1 μf range should be installed as close as possible to the device V_{CC}. Also, high frequency capacitors (0.001 μf typical) shall be placed on the input and outputs of all on-board voltage regulators. This will protect these devices against high levels of RF energy and will also help suppress VHF parasitic oscillations from these devices. Keep the capacitors close to the devices, with very short leads.

C. Cabing & Shielding

Radio Frequency Immunity: The design method for better immunity to radio frequency is to avoid unwanted energy reaching vulnerable circuits. This requires high frequency filtering on cables (both power and I/O) which act as antennas and a careful circuit layout and circuit decoupling. To prevent coupling, noise carrying cables shall be placed away from chassis seams. Ferrite beads can be used to attenuate common mode noise on I/O cables. Provide adequate grounding for all cables. Both ends of cables shall be grounded to chassis ground.

The system case acts as shield and reduces EMI by containing EMI radiation. Effectiveness of the shield depends on the material used and the discontinuities in the case. Cable and module shielding are effective but are not popular in vehicular designs due to the costs.

III. REVIEW FOR EMC GUIDELINES

In the above section multiple EMC design methods are mentioned, it is important to suitably select the best possible methods based on the design considerations and cost impact. For better implementation, EMC design reviews shall be conducted at the sample stage. Introduction of front loading enables us to confirm the EMC design effect from the first prototype step and to reduce time for EMC improvement countermeasure at later stages. EMC review, hand in hand with design stage, helps to have a robust EMC design by ensuring major EMC checks are in place.

Structure of EMC design review- The EMC design review shall include the hardware circuit designer, PCB designer, mechanical designer, software designer and persons responsible for cable / interfaces. A detailed check for – Hardware selection, PCB guideline implementations, cable / interface connections must be performed at each review and the potential EMC challenges shall be noted.

EMC design review can look for answers to important question like,

1. How severe are the EMC challenges for the circuit under design?
2. What should be the focus of the EMC design – PCB or at interface cables.
3. Is shielding of cables / critical circuits a possible solution?
4. Do we need an EMC simulation for a cost-effective implementation?
5. A facility for EMC pre-compliance is available or can be developed.

IV. PLAN FOR PRE-COMPLIANCE

Performing pre-compliance EMC testing avoids the risk of product failure and eliminates costly re-testing after design. EMC troubleshooting using near field probes for emission measurement are common nowadays, but for automotive device where the emission requirements are too stringent and immunity levels are too high, an exposure to actual test levels and setups is necessary to understand any pitfalls in design before final compliance testing. There are organizations having in-house equipment capable for automotive emission and immunity measurement, and these organization benefit from easy access and quick fix to EMC threats during design stage itself.

A. Common mode current measurement:

Measuring common-mode currents from cables can give an estimate of the radiated emission values, as radiated emission from cable is directly proportional to the common-mode current in that cable. We can use below equation to find out the amount of E-field emission.

$$E = \frac{12.6 \times 10^{-7}(f \times l \times \text{Icm})}{r}$$

Where E is the e-field strength in uV/m, Icm is in micro amps, f is in MHz, r (distance from Antenna) & l (Length of the harness) are in meters. Common mode current can be measured with a high frequency clamp-on current probe and a spectrum analyzer / EMI Receiver.

A generic test setup for emission measurement for automotive devices using a LISN, current probe, and spectrum analyzer / EMI receiver is shown below.

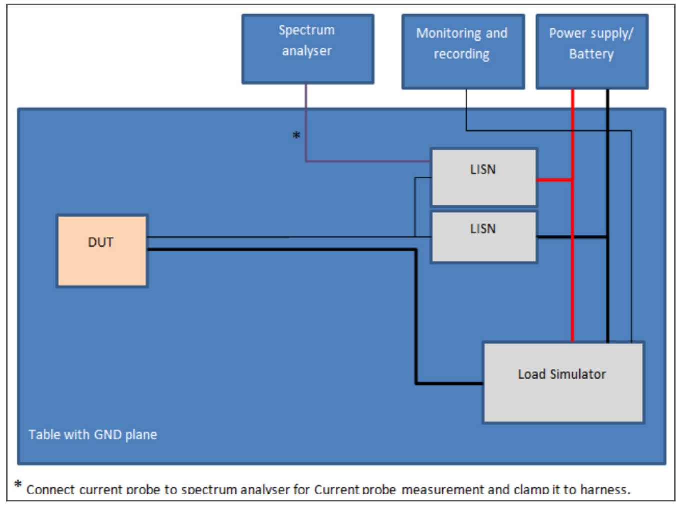

Figure 1 - Conducted emission test setup.

B. 1m Radiated Emission test

Radiated emission testing can be performed as part of pre-compliance measurement with proper calibrated antennas if we can control or reduce the reflection of the emitted field. This can be achieved by keeping the DUT away from reflective surfaces. A lot of trial and error measurement may be required to build this setup in an internal lab. Small broadband antennas are the best choice for 1m EMC testing. A bi-conical antenna (30 – 200 MHz) and a small log periodic antenna (200 – 1000 MHz) are suitable for this kind of measurement. Active antennas are the other option for this kind of test. The antenna needs to be placed 1m from the DUT. Connect the antenna to a spectrum analyzer and take measurements. A reference measurement with an approved lab can give a bench mark for the internal pre-compliance measurement. However at least a 6dB correction factor may be required with respect to an approved lab. Cost effective pre-compliance for radiated emissions can be made by the "Golden Product method" [R4] where the correction factors for the environment and equipment of pre-compliance measurement can be identified by comparing with a Golden sample whose radiated emissions behavior is already available from a test lab.

C. Pre-compliance Immunity testing

Measuring radiated immunity for automotive products without an anechoic chamber will be difficult to do as the fields are very high and it can interfere with the system around and with licensed radio services. Alternative ways to do this are to use hand held radio transmitters and place close to the device under test to check if these can cause any performance degradations. The BCI (ISO 11452-4) test in a small shielded room or shielded box can be used for understanding the immunity performance of the device up to 1 GHz [R3]. This is relatively less expensive than a fully installed antenna measurement.

With these methods, immunity performance of the product at different electromagnetic field levels can be observed and the product can be taken to an approved facility for further investigation and compliance testing.

D. ESD testing

ESD tests can be done in an internal lab with an ESD generator. Various models of ESD generators are available and these can be set up in an internal lab without much space and cost impact. Care should be taken to monitor the temperature and humidity of the area during the test time, as these environmental factors have impact on the static discharge.

V. SYSTEM INTEGRATION

Vehicle manufacturers are required to gain EMC approval for all vehicles. The electronic sub-assemblies, components and separate technical units are operated in full functionality for approval testing. Vehicles must not have electromagnetic emissions above the limits and must be immune to interference levels stated in the appropriate standards. Even though OEMs use sub-assemblies that have sufficient EMC robustness when tested individually, there exist a high chance that electromagnetic robustness for emission and immunity can be affected when different functional modules are integrated. These can be due to sharing of a common power supply or sharing a common communication network.

Inter-system radiated emissions and immunity of ESAs within the vehicle can be improved by proper positioning of the ESA in the vehicle. It is observed that for conventional automobiles with internal combustion engines, EMC sensitive equipment are positioned away from engine section where high power and high frequency switching noise are high. CAN, LIN and FlexRay are major communication networks. When devices are connected to a shared bus network, electromagnetic noise can be controlled by proper impedance matching design.

VI. CONCLUSION

Much advancement is happening in the automotive industry. As automotive systems are more and more occupied with electronic systems and subassemblies, EMI/EMC measurements became crucial for market certification and safety. It is required that automotive suppliers are positioned well in advance for EMC achievement. The above explained the key stages of a successful EMC achievement. Time for required for product development can be reduced if we only had a harmonized method of testing worldwide and with different OEMs. One day, methods and procedures might be unified for test execution that everyone can adopt. For now, by following a common EMC requirement and include EMC in the design strategy, a robust EMC design can more likely be achieved.

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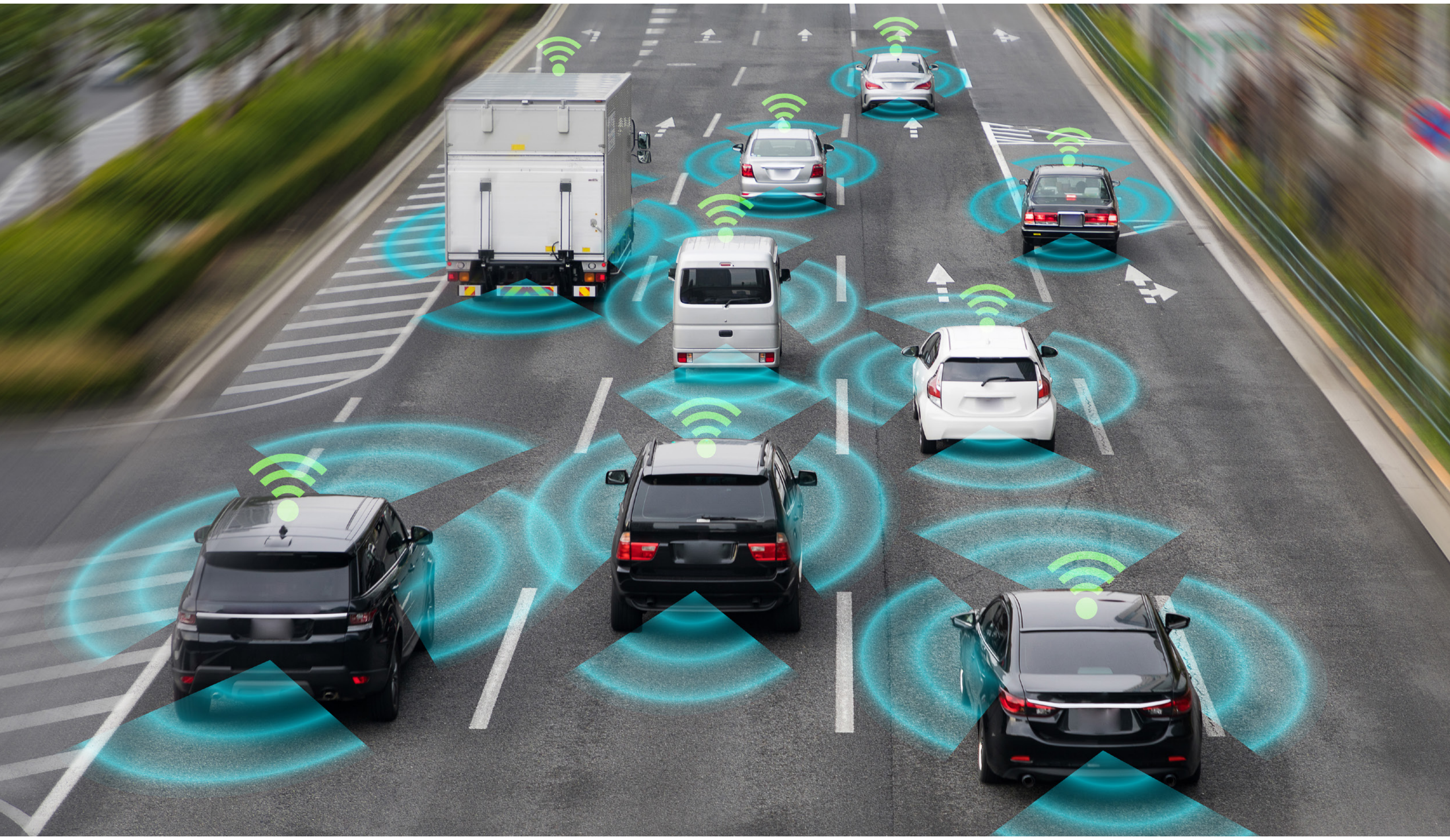
RESILIENCE IS KEY TO THE CONNECTED AND AUTONOMOUS REVOLUTION

Anthony Martin
EMC Chief Engineer, HORIBA MIRA



RESILIENCE IS KEY TO THE CONNECTED AND AUTONOMOUS REVOLUTION

INTRODUCTION

Connected and autonomous vehicles have long been hailed as the answer to safe transport. Around 1.25 million people die in road traffic accidents worldwide each year according to E&T—and driver error accounts for over 90% of those deaths[1]. In theory, the removal of the driver as the lead decision maker for vehicle control should reduce this number, with the SMMT estimating that 2,500 lives will be saved between 2014 and 2032 through the introduction of autonomous vehicles. It is imperative however, that the industry ensures that the control technology underpinning the revolution remains safe, secure and functional as autonomous vehicle development progresses.

Artificial intelligence (AI) technologies, which utilize machine learning, are at the heart of vehicle automation. There have been significant strides in the development of the basic algorithms used in machine learning in addition to an increase in the amount of quality data available. Infrared sensors, light detection and ranging (LiDAR) systems, 360° vision systems, wireless connectivity and many more data sources all combine to provide machine learning algorithms with a wealth of rich information from which to learn, optimize and grow. It is now widely acknowledged that autonomous vehicles offer the application that AI has been waiting for, and that the introduction of autonomous vehicles will be sooner than we think.

Wireless technologies and the associated benefits that they bring are an ever-increasing and indispensable part of modern society. Services such as digital radio and TV (DAB and DVB-T), GSM, 3G, 4G, Wi-Fi ,and Bluetooth are now commonplace in most executive and prestige vehicles. With demand increasing and implementation costs reducing, these technologies are becoming available across the majority of vehicles offered by manufacturers. For example, Bluetooth is common in all but the most basic entry level vehicles, and DAB and DVB-T are optional on most mid-range vehicles. Integrated GSM, 3G, 4G, 5G, and Wi-Fi technologies will be available in the next wave of models from the major high-end vehicle manufacturers, and along with intelligent transport systems (ITS), are set to deliver the much awaited ‘connected car’ and the connectivity backbone for autonomous vehicles.

For engineers though, who must look through the glossy benefits and get to the nuts and bolts of what is required to realize the change, a thorough understanding of the safety, security and functionality risks of each vehicle feature will be essential in ensuring that connected and autonomous technologies are resilient. These elements of the engineering process are inextricably linked, creating a web of intertwined and hidden risks. Security and safety systems must remain functional, whilst safety systems and functional systems must remain secure from cyber threats.

Standards form a key role in the engineering process, with ISO 26262 for functional safety and SAE J3061 for cyber security representing the state of the art for achieving high levels of system confidence. While changes are being implemented to tackle the issues surrounding connectivity and autonomy and significant work is undertaken to align the standards, even ISO 26262 Edition[2] scheduled for release in 2018 is unlikely to fully cover the requirements for autonomous vehicles. This is a reflection of the complexity of verifying the safe and secure operation of connected and autonomous vehicles rather than any inadequacy in the standards generation process.

It is the engineering processes within these standards, defining rigorous recommendations and regulations (throughout the product life-cycle from concept to decommissioning), that must be built upon to fully realize resilience for autonomous systems.

FUNCTIONAL PERFORMANCE

In order for connected and autonomous vehicles to function properly, we must ensure acceptable levels of performance for critical functions, such as braking, steering and acceleration. Key to this is the connected technology backbone; the broadcast systems and wireless links that enable connected vehicles to ‘talk’ to each other and to surrounding infrastructure. Data transmitted and received by vehicles will rise significantly, with vehicles using GSM, 3G, 4G, Wi-Fi, Bluetooth, vehicle-to-vehicle /infrastructure communication, and other data links and broadcast technologies.

Vehicle connectivity is improving, but not quickly enough for customers. According to J.D. Power’s 2016 Vehicle Dependability Study, the number of problems with infotainment, navigation, and in-vehicle communication systems—collectively known as audio, communication, entertainment, and navigation or ACEN—has increased and now accounts for 20% of all customer-reported problems[3].

For vehicle manufacturers, this poses a big issue as many customers will rate the quality of the entire electrical system in their vehicles based on the reception and connectivity experience that the vehicle delivers. Currently for mainstream vehicles, radio reception is the key tell-tale, but for high-end vehicles, this will extend to TV reception and interference. However, in the future customers will be armed with an increased number of diagnostic tools including data link corruption or dropouts, which will exhibit themselves as dropped phone calls, poor Wi-Fi reception or slow data rates. These will all form the tell-tale signs of electromagnetic interference issues or poor system/antenna performance. The irony is that the number of noise sources fitted to vehicles, and their proximity to sensitive antenna systems due to space constraints, are both causing an increased risk of electromagnetic issues and at the same time the means by which customers can perceive issues.

The risk of poor performance can lead to impact on the customer, such as the inability to make a phone call via the infotainment system, as well as warranty issues which lead to lengthy debates between customer, OEM and dealership. However issues will also reduce the effectiveness of vehicle features reliant on connectivity, some of which will be part of the vehicle control strategy. OEMs are acutely aware of these issues but are reliant on costly and time consuming subjective surveys to progress design development and gather data on connectivity performance issues meaning that signing off performance confidently is a challenge.

OEMs therefore require quantitative targets and meaningful performance measures for vehicle development. To meet these requirements for robust and accurate reception and connectivity assessment methods, a number of factors must be considered including; antenna performance, the level of wanted signal received by the vehicle when moving and the unwanted interference levels from the vehicle. All of these factors must be combined such that they reflect 'real-world performance', accurately simulating the vehicle occupant's experience to ensure that reception issues are identified and rated.

Connectivity is a key enabler in the future of mobility, and performance is crucial to feature functionality. Bottlenecks in connectivity must be avoided and data throughput must be maximized.

There are also many challenges ahead for electromagnetic testing of autonomous features, most of which surround the issue of system complexity. As functions are combined for co-pilot or auto-pilot features, system complexity grows rapidly. This in turn means that each system function is linked to multiple inputs from other vehicle systems. With this web of interconnectivity comes fragility, meaning fault modes are more likely. As such, test complexity increases due to the increase in stimuli for operational test modes. Efficient electromagnetic testing of autonomous features involves immersive situational testing, delivering services that use more diagnostic information, real-time vehicle data analysis, moving targets, and a number of other actuator and simulator systems.

SAFETY

Traditionally, safety has been considered to include active safety, such as anti-lock braking systems, blind spot information systems, and lane departure warning sys-

tems, as well as passive safety, including seat belts and airbags. However, with connectivity, electrification, and automation, safety has to be considered in a completely new light. First and foremost, new technologies mean engineers are having to get to grips with new systems and tools, which come with their own safety considerations. Secondly, new hazards are being created as a result of these new technologies. This includes exposure to electromagnetic energy and hazardous levels of electrical energy, potentially causing health-related issues, as well as thermal runaway, leading to thermal events, such as the release of chemicals.

System failures are another potential cause of hazards and can be caused by random hardware faults or systematic faults such as software defects. Widespread application of electronic systems in vehicles means it is especially important that safety risks are managed throughout product development. The ever increasing complexity of vehicle technology requires a coordinated approach to safety and functionality, and that the safety of security systems and the security of safety systems must be considered together. Only by undertaking coordinated, pragmatic and 'goal-based' programs can robust engineering solutions be delivered while avoiding unnecessary development rework, verification, and validation activities.

SECURITY

Increasing autonomy and connectivity has exposed us to the potential of greater levels of malicious activity in the form of cyberattacks. There are many potential threats that we face, including traditional vehicle theft, owners enhancing the performance of their own car, identity theft, or unauthorized remote access to vehicle functions. Each of these threats can have a variety of different consequences, including the financial, privacy, and operational impacts typically associated with the information security domain, as well as potential impacts upon safety and functionality.

In order to address these threats, we must use a risk-driven security engineering approach, through which appropriate security measures can be specified, designed, and implemented. Effective verification and validation is required to evaluate whether the actual level of security is as designed, and whether it is effective at preventing the relevant attacks. This involves various review, analysis, and testing activities which take several forms, including verification of correct functional behavior, proper implementation of security mechanisms, vulnerability analysis, and penetration testing to confirm the effectiveness of those mechanisms.

Due to the diverse nature of the automotive supply chain, it is essential to perform this verification for individual hardware and software components, complete embedded systems and at vehicle level, to ensure that all elements are properly integrated.

It is clear that there are still challenges on the horizon yet to be fully addressed, but with a coordinated approach to safety, security, and functionality, we will be able to better map, manage, and mitigate the risks for connected and autonomous vehicles.

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2021 AUTOMOTIVE EMC CONFERENCES

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IEEE 93rd Vehicular Technology Conference: VTC2021
April 25–28, 2021
Helsinki, Finland
https://events.vtsociety.org/vtc2021-spring/
The 2021 IEEE 93rd Vehicular Technology Conference: VTC2021-Spring will be held in Helsinki, Finland, 25 - 28 April 2021. This semi-annual flagship conference of IEEE Vehicular Technology Society will bring together individuals from academia, government, and industry to discuss and exchange ideas in the fields of wireless, mobile, and vehicular technology. IEEE VTC2021-Spring will feature world-class plenary speakers, tutorials, technical as well as application sessions, and an innovative Industry Track, which will feature panels and presentations with industry leaders sharing their perspectives on the latest technologies.

2021 IEEE International Symposium on EMC+SIPI
July 27–August 13, 2021
Virtual Event
https://www.emc2021.emcss.org/

Electric & Hybrid Vehicle Technology Show
September 14–16, 2021
Suburban Collection Showcase in Novi, MI, USA
https://www.evtechexpo.com/en/home.html
Electric & Hybrid Vehicle Technology Expo brings together hundreds of suppliers across the electric hybrid vehicle and battery industries. Come see the components and systems that make EVs and HEVs unique, including batteries, electronics, motors, inverters, power management, charging, and more. Check out the growing exhibitor list at EVT show 2021.

The Battery Show - North America
September 14–16, 2020
Novi, MI, USA
https://www.thebatteryshow.com/en/home.html
The Battery Show is North America's largest and most comprehensive advanced battery manufacturing trade show. Combined with the Electric & Hybrid Vehicle Technology Expo, more than 700 suppliers come together to showcase their raw materials, components, cell makers, testing, and recycling products and services.

Automotive Test Expo 2021
October 26–28, 2021
Novi, MI, USA
http://www.testing-expo.com/usa/
The event is America's largest vehicle and component testing and validation technology and services exhibition, featuring more than 370 exhibitors and attracting over 6,000 attendees. Visitors can expect to see the latest in ADAS testing, NVH measurement tools, test rigs, simulation packages, durability testing technologies, crash testing know-how, dynamometers, emission measurement systems and dynamic assessment tools, as well as countless service providers such as proving grounds and test facilities.

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