




Whitepaper

Transportation



EMC challenges in connected cars

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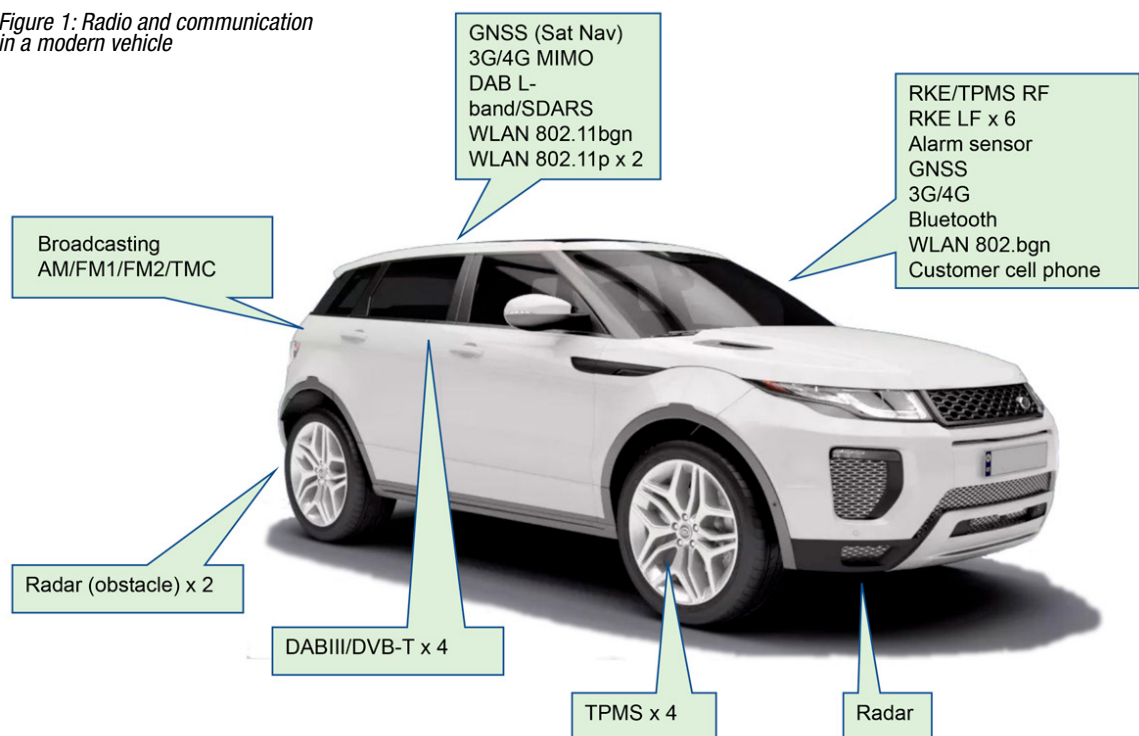
New vehicles contain a dazzling array of electronics. Trends such as the 'connected car', driver assistance systems and the move towards semi or fully autonomous vehicles are creating a huge demand on the electronics industry. However, with so many electronics systems within close proximity to each other, the potential for EMI problems is dramatically increased. Many of these autonomous systems make decisions that can have life-changing consequences. For example, interference to ultrasonic Advanced Driver Assistance Sensors (ADAS) from cellular radio signals needs to be eliminated at all costs. The challenges of EMI are compounded in electrically powered vehicles with high current systems in the drive train potentially creating significant transients throughout the vehicle.

In this whitepaper we explore some of the EMI/EMC challenges present in modern vehicles and how new automotive innovations will need robust and resilient protection methods. The whitepaper will highlight some of the sources of EMI and introduce some of the basic steps engineers need to take to limit its impact. These will include inclusion of passive EMI filtering networks using inductors, common-mode chokes and capacitors, together with off-the-shelf filtering and suppression components.

Ever since cars and electronics have coexisted, there have been compatibility issues. In the 70's you could tell a passing vehicle with a faulty 'condenser' as it wiped out AM reception on your Motorola radio from the unsuppressed contact breaker arcing. Today, latest-model cars are mobile data centers with easily more than a hundred processors running 100 million lines of code. Electronics is packed into every available space, from door mirrors to headlining with a mile or more of interconnecting cabling. Much of the car is electronically controlled, from the trivial adjustment of 'mood lighting' through essential features such as door locks, to critical drive-by-wire functionality where brake, accelerator and even steering can be just digitised inputs to a microcontroller which in turn drives motors and actuators. All the while, signals are being received from external sources for GPS location, cell phones, tire pressure monitors, broadcast entertainment and more. Data is also transmitted through Wi-Fi, Bluetooth to portable media devices, 3G/4G LTE for internet connectivity and radar for collision avoidance. Figure 1. Plans for the future include the 'IoMT, the 'Internet of Moving Things' where your car will 'talk' to other vehicles using Car-to-Car (C2C) communication and to roadside traffic signals and message boards using Car-to-Infrastructure (C2I) to get a view of traffic conditions and potential hazards. C2C and C2I will use an automotive-specific version of Wi-Fi, IEEE802.11p. In Europe, all this comes under the heading of Cooperative Intelligent Transport Systems and Services (C-ITS) [1]. In the US the National Highway Traffic Safety Administration (NHTSA) is making proposals for an equivalent Vehicle to Vehicle (V2V) communication system.

Inside the vehicle, data is transferred using a whole range of buses and protocols, sometimes at very high rates. The bus might be CAN (Controller Area Network) for routine functions or MOST™ (Media Oriented Systems Transport) protocol for multimedia and FlexRay™ for critical controls such as braking and steering. Increasingly Ethernet connections are being used with a particular two-wire unshielded cable which promises savings in the weight of wiring compared with shielded multi-conductor cables. This could amount to 100 pounds (45kg) in a typical modern car if Ethernet were the 'backbone' communications system. Unshielded cables are a cost and weight saving but require careful consideration when EMI is concerned.

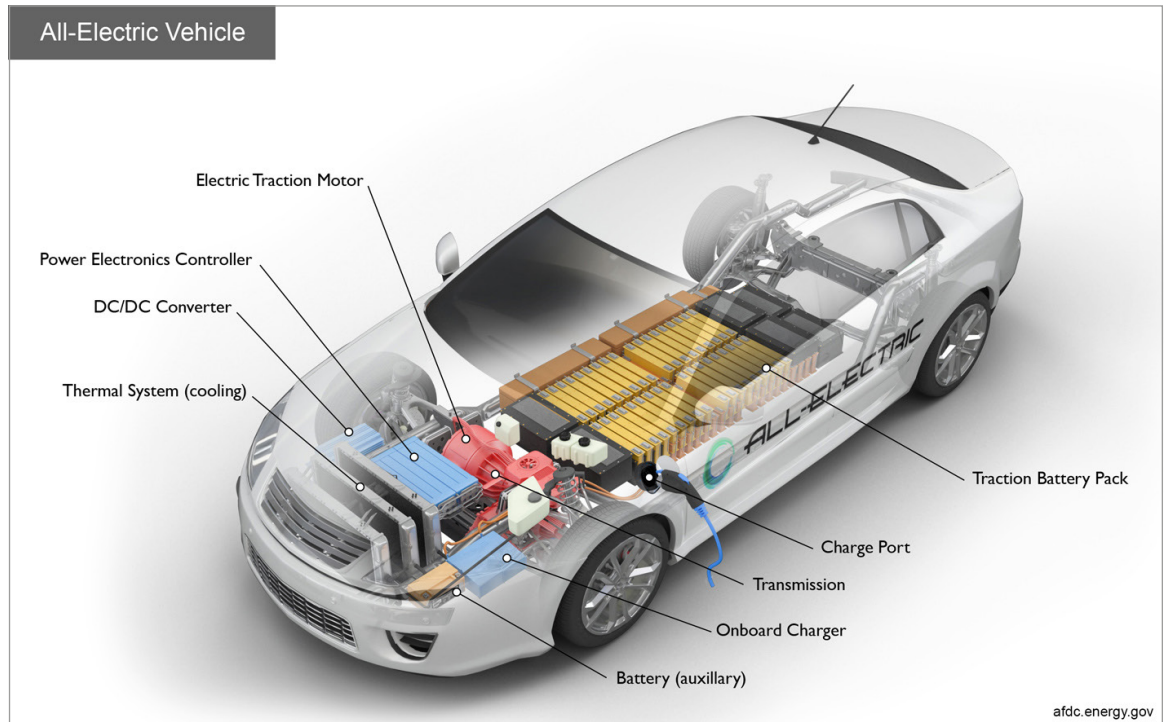
Figure 1: Radio and communication in a modern vehicle



EV considerations

In conventional fuel-driven cars, the main sources of EMI are relatively low level with the highest currents associated with battery discharge on cranking during which sensitive electronics can be disabled or held reset. With electric vehicles, the world of high-power electric motors and their drives is introduced with associated EMC challenges. A DC bus from the battery is switched at high frequency to generate variable AC for the motors for traction and further switched-mode converters down-convert the bus to 12 or 24V for ancillary equipment and the rest of the electronics in the car. Figure 2. The DC switching operation is typically performed by IGBTs at relatively low frequency to maintain efficiency but newer technology devices are being introduced such as Silicon Carbide (SiC) switches which can operate at much higher frequencies with good efficiencies. The consequent effect of this is to considerably reduce the size of other passive components such as magnetics and capacitors, in turn reducing cost and weight. The penalty is EMI at higher levels and higher frequencies, but not just emanating from the power converter itself; the batteries, cabling and motors all act as antennas to some extent with sometimes unexpected characteristics: batteries for example may be a few milliohms impedance at DC but 10 ohms at 100kHz where power converters often operate [2].

Figure 2: Powertrain in an electric vehicle (source – USDoE)

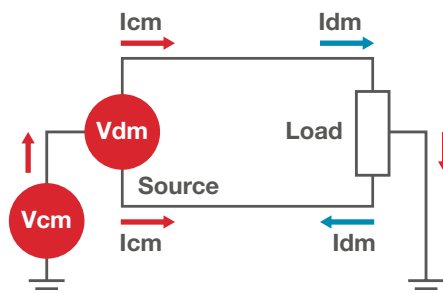


EMI Consequences

It's clear that there are many car systems that can generate and be susceptible to electrical interference both from internal and external sources. There have been reported incidents of airbags spuriously operating, triggered by RF transmissions from emergency service vehicles and cruise control and engine management systems demanding 'wide-open throttle' when subjected to EMI [3]. In another example it's reported that "holding certain types of cell phone close to the steering wheel exposes the circuit which ignites the explosives that deploy the air bag to RF fields at about 1.8GHz and well over 100V/m, while automotive EMC testing is only necessary up to 1GHz and 24V/m" [3]. The interference could be unintended or even deliberate, with security researchers already demonstrating that the most high-profile of electric cars could be 'hacked' to remotely manipulate critical systems such as brakes [4]. This vulnerability was immediately patched but the potential for disastrous consequences is a serious concern for manufacturers. What is certain though is that there is plenty of scope for 'nuisance' events such as information display resets or reduction in communications quality and reliability.

EMI categories

Figure 3: Common mode and differential mode noise currents



EMI falls into distinct categories: conducted and radiated emissions and conducted and radiated immunity. Susceptibility to Electrostatic Discharge (ESD) is included as well, although not an electromagnetic effect. Emissions from the vehicle have to be considered for their effect on internal systems, on other cars and the environment generally. Similarly, conducted EMI can come from the outside world through charging stations as well as from internal systems. Radiated EMI can also originate from the car's own communication systems as well as externally from other road users or from high power sources such as broadcast transmitters.

Conducted interference, in the form of extraneous communication signals or noise is further split into 'common mode' (CM) and 'differential mode' (DM). DM interference is between connections and their intended current return path. CM interference appears on electrical connections with respect to the local ground or chassis and can be difficult to identify and control. Figure 3. The move to increased plastic and carbon fiber panels in cars means that the metal shell cannot necessarily be seen as a screening 'cage' or even a low impedance overall ground. Actual current paths for ground return currents have to be considered carefully to avoid generation of CM interference.

Standards

There are specific standards dictating the levels of EMI emissions and immunity for vehicles along with testing methods. These include ISO (International Standards Organisation), CISPR (International Special Committee on Radio Interference) and SAE in the US with much cross referencing between each other and to other established standards such as the IEC 61000 series.

ISO 11451-xx standards relate to vehicles and ISO 1142-xx and ISO 7637-xx relate to components. Similarly, US SAE J551-xx relate to vehicles and SAE J1113-xx to components. CISPR 12 [4] sets limits and test methods for radiated EMI affecting communications equipment away from the vehicle while CISPR 25 [5] relates to on-board receivers and mandates testing of components within the vehicles separately as well as whole-vehicle susceptibility. Although CISPR 12 is used by regulatory agencies, CISPR 25 is more used as an engineering standard by vehicle manufacturers. The standards were originally intended specifically for internal combustion engines but are generally being updated to include references to electric vehicles.

Vehicle manufacturers often have their own internal standards though, with more stringent requirements, such as Ford CS2009, Chrysler- Fiat CS- 11979 or Nissan NDS02.

EMI Mitigation at source

All vehicle manufacturers try to design-in good EMC performance and powerful multi-physics simulation tools are available to attempt to predict performance. In practice, as well as mandating good emissions and susceptibility performance from components and modules, interconnections, grounding and shielding need to follow best practice but with awareness that compromises may be necessary, particularly when cost and weight are factored in. With electric vehicles, the problem is particularly acute with the high currents involved. It might seem obvious to use the metal chassis as a return; this would be cheaper and lighter than having a dedicated cable but almost certainly worse from an EMI standpoint.

In switching power converters, edge rates can be controlled to minimise the spectrum of emissions and topologies chosen that naturally have lower emissions without sacrificing efficiency. Latest techniques using 'resonant conversion' are favoured at the expense of some complexity, although when a 'holistic' approach is taken, any extra expense can be offset by savings in filtering elsewhere.

Filters to slow data edges can be provisioned and balanced-pair data cabling used for minimum radiation and pick-up. Screens are a mixed blessing – they are effectively protecting signals but can also provide unwanted return paths for power or other signals if not terminated carefully. Fiber-optics are an ideal but expensive solution and are used in some MOST installations.

Differential and common-mode chokes in signal and power lines can be beneficial but need to be combined with capacitors to shunt away interference – if EMI is just blocked with the high impedance of an inductive filter, it generates a voltage which can then be coupled elsewhere as interference. Filters can also interact to produce unwanted resonances and voltage peaking so need to be designed carefully with appropriate damping and controlled input/output impedances.

Figure 4: Edge rates of power converters can be in the nanosecond range

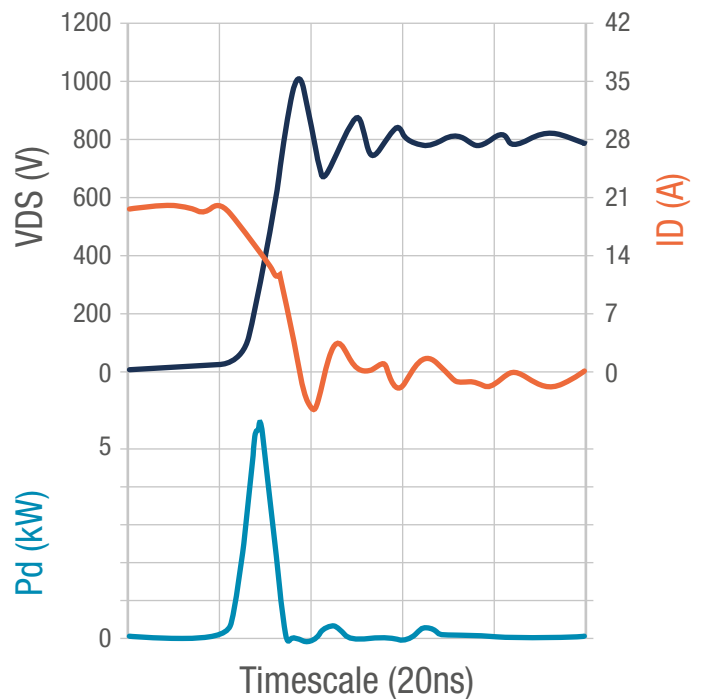
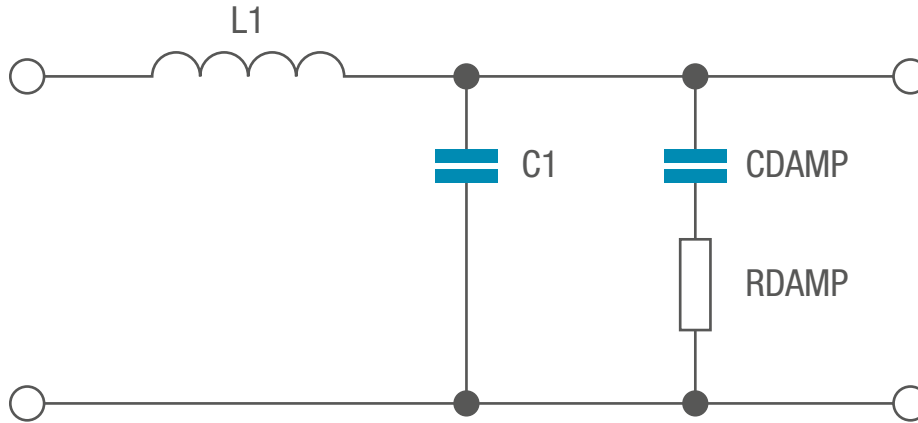


Figure 5: Filters may need damping to avoid instability



Transient limiters have their place as well in the form of varistors, clamp zeners or simply diodes on analog or digital inputs to clamp the signals to the rail voltages as a maximum. Varistors are low cost but do have a wear-out mechanism with stress so cannot be relied on to maintain performance over long periods. Individual system modules assembled into a car will have been evaluated for their EMC performance individually but will produce quite different performance with 'real-life' inputs and outputs – this is where whole-vehicle testing is vital.

Given that there are an almost infinite number of permutations of interference types, levels and effects though, a pragmatic approach is taken to determine what is the worst that can happen using FMEA (Failure Mode and Effect Analysis) and mitigate the effects with a hierarchy of fail-safe mechanisms. In the 'wide-open throttle' case already mentioned for example, the relevant actuator could be de-powered then fuel cut to the engine if there is no response. All critical communications will have error correction as standard.



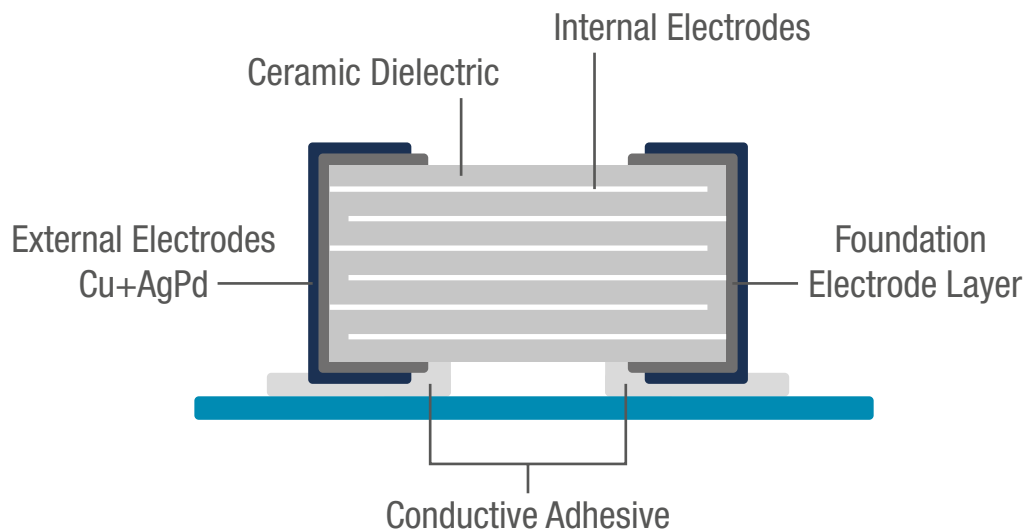
Suppression components

A starting point for suppression components is that they should be qualified to the appropriate AEC-Q standard, typically AEC-Q200 for stress immunity of passive components. The standard splits components into five grades depending on the intended application. Grade 0 is the most stringent, requiring tests from -50 to +150°C. Components at this level can be used in any automotive application, regardless of location within the vehicle. Grade 1 parts are suitable for most under-hood uses and are tested from -40 to +125°C, grade 2 parts are less stringently tested again and are suitable for use in hot spots within the passenger compartments, grade 3 is for use within most of the cabin, and down to grade 4 which is for non-automotive parts.

Components intended for automotive applications will be rated not just for the harsh temperatures but also for thermal shock and high vibration. Techniques to 'proof' component terminations against mechanical stress include 'soft' electrodes or even conductive glue, for example in the Murata GCJ, GCG and GCB series of multilayer capacitors [7]. High reliability types might also have special 'series' construction so that an internal electrode short circuit due to stress just reduces capacitance rather than causing a total end-to-end short.

Inductors can have the same protection mechanisms for the automotive environment; often surface-mount inductors and dual-winding /common mode chokes will be based on ceramic core technology for stability and high temperature performance such as those from Bourns [8] and TDK Electronics [9]. Transient and ESD protection devices are also available with AEC-Q200 qualification from suppliers such as Vishay [10].

Figure 6: Example of a glue termination for automotive surface mount component



Summary

Design for compliance with automotive EMC standards starts with system considerations, design for minimum EMI and susceptibility, simulation and careful whole-vehicle analysis. There is an armoury though of suppression and filtering components that can be utilized to ensure inter-operability between the huge range of high and low frequency control and communications systems in a modern car.

¹ <https://www.car-2-car.org>

² S. Guttowski, S. Weber, E. Hoene, W. John, H. Reichl - EMI in Electric Vehicles Fraunhofer Institute for Reliability and Microintegration

³ Radiocommunications Agency EMC awareness - <http://www.emca.org/awareness/Pages/InterferenceExamples/Automotive.htm#MobileTrans>

⁴ <https://www.bbc.co.uk/news/technology-37426442>

⁵ CISPR 12:2007 Vehicles, boats and internal combustion engines - Radio disturbance characteristics - Limits and methods of measurement for the protection of off-board receivers

⁶ CISPR 25:2016 Vehicles, boats and internal combustion engines - Radio disturbance characteristics - Limits and methods of measurement for the protection of on-board receivers

⁷ https://www.murata.com/en-eu/apps/auto?intcid5=com_xxx_xxx_cmn_bc_xxx

⁸ <https://www.bourns.com/products/magnetic-products/power-inductors-aec-q200-compliant>

⁹ <https://en.tdk-electronics.tdk.com/tdk-en/1419046/products/application-guides/automotive---epcos-brand/convenience/rear-camera-systems/inductors>

¹⁰ http://www.vishay.com/applications/automotive/48v_dcdcconverter/



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