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Automotive EMI Shielding – Controlling Automotive Electronic Emissions and Susceptibility with Proper EMI Suppression Methods

By: **John Noto, Gary Fenical, and Colin Tong**

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White Paper

As technology advances, the need to place larger numbers of electrical and electronic systems into automobiles has dramatically increased. To name a few, these systems include Control Area Networks (CAN), safety systems, communications, mobile media, infotainment systems including wireless headsets, DC motors and controllers. The physical size of these systems is greatly reduced because of the size and weight constraints involved with automotive design. These systems may be small, but it does not necessarily mean their electromagnetic emissions are too.

As the electronics systems become more complex, the wiring systems turn out to be a major cost in the manufacturing process. They turn out to be a major failure point also. The current trend is to make as many systems as possible wireless, lowering the manufacturing cost and improving the reliability of the systems by eliminating the wiring.

Placing a large amount of electrical and electronic systems into a very confined space poses the problem of keeping the Electromagnetic Interference (EMI) of these systems from interfering with each other through radiated and conducted emissions, sometimes referred to as crosstalk. If not properly controlled, the interference can cause each system to malfunction, and even fail. With most systems now fully electronic, the need to contain EMI is more vital than ever.

This White Paper discusses the various electronic systems found on automobiles, and addresses the need of containing and suppressing their EMI potential with each other through EMI shielding and ferrite solutions.

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What is EMI?

EMI is a process by which disruptive electromagnetic energy is transmitted from one electronic device to another via radiated or conducted paths, or both. In an automotive electronic system, EMI can adversely affect the performance of an integrated circuit internally, as well as that of other electronic components in close proximity.

There is a root cause to most EMI noise. In a digital system, clock pulses are generated to operate the logic. As these clock pulses are developed (typically a square waveform), they have a given rise time. The rise time, as it gets shorter, has a tendency to create a broadband energy pulse on the leading edge. This is commonly known as overshoot and ringing.

The energy present in the overshoot and ringing is the basis for generating other higher frequencies called harmonics. These higher frequencies are multiples of the clock frequency. Both odd and even multiples (harmonics) exist. In most cases, the odd harmonics (observed at 3, 5, 7, and 9 etc. times the desired or fundamental clock frequency) create most of the EMI noise problems. However, even harmonics do exist and must not be ignored.

Another EMI issue involves intentional transmitters such as mobile phones, Bluetooth® devices, and even commercial broadcast signals. The EMI of these external sources will interfere with the vehicle's electronic system when the vehicle is in close proximity to the transmitting antenna. In short, the new automotive electromagnetic environment is a very complex one involving many internal and external factors.

EMI Sources and Potential Receptors Internal to the Vehicle

EMI problems can manifest themselves as simple nuisances such as static on the radio. Or they can create a dangerous problem such as loss of control of the vehicle. Special care must be given to "mission critical" systems; especially those that deal with the control and safety of the vehicle (see Appendix). Some of these internal systems include:

- Collision avoidance radar
- Console applications
- Navigation-radio combination
- Power steering module
- Infotainment head unit
- Airbag inflator
- ECU and other module connector
- Tire pressure monitoring
- CAN Bus
- DC motors
- Ignition system
- Engine control module
- Electronic Braking Systems
- Fuel Control Systems
- Adaptive cruise control

EMI Sources External to the Vehicle

Automotive and other transportation electronics can be affected by harsh external EMI environments. Of course it is impossible to control the emissions from the external sources since EMI can be generated from power transients, radio frequency interference, electrostatic discharge, and power line electric and magnetic fields. So, the designer must provide for immunity to these threats. Proper EMI design including filtering, grounding and shielding is essential (see Appendix). If EMI is not considered at the beginning stages of the design process, it becomes more difficult and expensive to deal with it later. Some external sources of EMI include:

- Garage door opener
- Remote entry
- Cell phones
- Bluetooth devices
- MP3 players with WiFi
- Gaming systems with WiFi
- Third party navigation
- High power transmitters such as TV and radio towers

Since the transportation vehicles can go almost anywhere, the worst case situations must be assumed. Moreover, the vehicular electronics must be designed for extremely high reliability at the lowest possible cost. All these issues have to be overcome through optimal electromagnetic compliance (EMC) design and the correct EMI shielding materials selection.

The Equations

Advancement of automotive electronic systems has led to more and more stringent requirements for EMC and EMI shielding design. Mechanical and electrical design interfaces are challenging, especially for a new product development, in which a critical and early design decision has to be made either assuming EMC can be achieved with good electronic design to obviate the need for an EMI shield or anticipating the inclusion of an EMI shield. Moreover, the EMI shielding design should be optimized to meet the EMC requirements with the cost as low as possible. This also has increased the demand to selecting the correct EMI shielding materials and to develop new materials for EMI shielding applications [1].

Many factors must be taken into account in order to arrive at the correct solution. The equation for emissions from a basic circuit is: $E=1.316\ AIF^2/(dS)$

Where: E = field strength in µV/m, A = loop area in square centimeters, I = drive current in amps, F = frequency in megahertz, d = separation distance in meters, S = shielding ratio between source and point of measurement.

Analyzing Equation 1, it is clear that frequency is the biggest culprit because the emissions increase as the square of the frequency (F) increases. For current (I), emissions increase linearly, which is also true for loop area (A). The distance (d) is set by the test specification, and 1.316 is a constant. The system designer has no control over these last two parameters, so they must not be considered.

The equation for susceptibility is: $V_i=2\Pi AEFB/(300S)$

Where Vi = volts induced into the loop, A = loop area in square meters, E = field strength in volts per meter, F = frequency in megahertz, B = bandwidth factor (in band: B = 1; out of band: B = circuit attenuation), and S = shielding (ratio) protecting circuit.

Equation 2 indicates that the susceptibility is directly proportional to loop area (A), frequency (F), and the bandwidth factor (B). Frequency (F) is dictated by the specification and the operating environment, as is the field strength (*E*). Of course, the engineer has no control over 2π, or 300, which is the speed of light divided by 1,000,000 for this equation.

From the equations, it is possible to determine some key information. Emission levels are:

- Directly related to loop area.
- Directly related to signal current.
- A function of frequency squared.
- Inversely related to shielding effectiveness.

Susceptibility levels are:

- Directly related to loop area.
- Directly related to bandwidth.
- Directly related to the transmitted frequency and field strength.
- Inversely related to shielding effectiveness.

EMI can be reduced by a number of ways:

- Move components on the PCB.
- Add/change ground planes.
- Reduce the length of noisy PCB traces and wires.
- Match driver and return circuit traces or cable lines to cancel magnetic signals and reduce loop area.
- Add special components, i.e., inductors, capacitors, resistors, or combinations of these parts.
- Change circuit components - less noisy components.
- Add ferrite products. Ferrites will absorb the EMI energy, dissipating it as small amounts of heat, typically in microwatts.
- Use special shielding techniques.

For radiated EMI, once proper circuit layout is developed (minimize frequency, current and loop area), if the circuit still does not meet its EMI requirements, the only thing left to do is provide some sort of shielding. It is always more efficient and less expensive to deal with EMI suppression at the source. Therefore, board-level shields (BLS) are the most cost-effective and generally the most efficient type of shielding. However, it is essential that BLS be designed in at the beginning of the design process because one needs to provide for proper attachment to the printed circuit board (PCB). As good as BLS may be, it is not always the entire solution.

The enclosure of the device may have to be made of electrically conductive materials to block electromagnetic fields, e.g., foil, metal, metalized plastic, conductive fabric, etc. One approach may be to build a conductive box around the device or affected components. This involves placing the system or device that is producing the EMI into a conductive box and sealing the box. This employs EMI gaskets such as Fabric-over-Foam (FoF), CF, wire mesh, fingerstock, BLS, etc.

Used more at system level, EMI radio frequency (RF) absorbers and ferrites absorb and dissipate electromagnetic fields. The absorber sheet can be applied to the housing of the system or device creating the EMI. Ferrite chips and RF absorbers can be placed directly onto the system or device.

Shielding does little to nothing for Conducted EMI. The noise (EMI) needs to be eliminated while not eliminating the desired signals. This is generally solved by using a filter to select out the offending noise and allow through the good signals. Most filters are frequency specific. Ferrites can act as filters and absorbers.

When determining the correct ferrite solution to an EMI problem, many issues must be taken into account: frequency, signal current (intended), noise current, and if the signal and noise currents are the same frequency. Many ferrite properties are frequency dependent. Other considerations are:

- Current
- Amp - Turns of Signal Current
- Amp - Turns of Bias Current
- Core Saturation
- Part Size
- Common Mode or Differential Mode Solution
- Temperature
- Permeability vs. Temperature
- Impedance vs. Temperature
- Curie Temperature
- Single or Multi-Line
- Isolation Resistivity

EMC Design

EMC can be achieved from different design levels, such as from chip level integrated design, PCB, module or enclosure, and interconnect to software control. Different design techniques have been developed for various EMI problems, depending on the particular system, its electronic design, and the type of interference source.

For instance, EMC design techniques for power transients need to provide primary transient protection on all module input power lines, plus secondary protection such as filtering at the circuit level. The load dump transient is usually the biggest concern.

Designing noise tolerant software is also very effective in controlling susceptibility to power line transients. The design techniques for radio frequency immunity are to keep the unwanted energy from reaching vulnerable circuits. This requires high frequency filtering on both power and I/O cables which act as antennas, plus careful circuit layout and circuit decoupling. Cable and module shielding are also effective, but are not popular in vehicular designs due to the costs.

The design techniques for electrostatic discharge (ESD) are to limit damage by transient suppression or high frequency filtering on I/O and power lines, and to limit upsets by local filtering and decoupling, careful circuit layouts, and perhaps even shielding. Many of the design techniques for EMI emissions and immunity work equally well for the indirect ESD effects due to the transient electromagnetic fields.

The design techniques for power line fields are usually instrumentation oriented, and include local shielding and filtering of the most critical circuits. The design techniques necessary for EMI emissions and immunity also minimize this threat. This is normally not a serious threat.

The design techniques for radiated emissions are to suppress the emissions at the source by careful circuit layout, filtering, and grounding, or to confine the emissions by shielding. For automotive designs, the emphasis has usually been on suppression and careful circuit layout, since shielding is costly and difficult for most high volume automotive products. Nevertheless, shielding use is increasing in vehicular applications.

Selecting Proper Materials

Many factors affect the proper selection of RF gasket materials. The following list identifies some of the key issues that must be considered. The list has been developed over many years and includes essential considerations for choosing RF gasket materials to ensure that the materials achieve their advertised specifications. The list includes:

- Operating frequency
- Materials compatibility
- Corrosive considerations
- EMC compliance specification (SAE, FMC, GM, etc.)
- Operating environment
- Load and forces
- Cost
- Attenuation performance
- Storage environment
- Oil and fuel resistance
- Cycle life
- Shielding, grounding, etc.
- Electrical requirements
- Materials thickness / alloy
- Space and weight considerations
- Product safety
- Recyclability

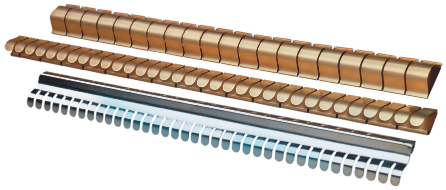
Shielding

Shielding, which is noninvasive and does not affect high-speed operation, works for both emissions and susceptibility. It can be a stand-alone solution, but is more cost-effective when combined with other suppression techniques such as filtering, grounding, and proper design to minimize the loop area. It is also important to note that shielding usually can be installed after the design is complete. However, it is much more cost-effective and generally more efficient to design shielding into the device from the beginning as part of the design process. It is important to keep in mind that the other suppression techniques generally cannot be added easily once the device has gone beyond the prototype stage.

The use of shielding can take many forms, from RF gaskets to BLS. An RF gasket provides a good EMI / EMP seal across the gasket-flange interface. The ideal gasketting surface is conductive, rigid, galvanic-compatible and recessed to completely house the gasket.

A device housed in a metal case is generally a good candidate for RF gasketing materials. When electrical and electronic circuits are in nonconductive enclosures, or when it is difficult or impossible to use RF gasketing, BLS provides the best option for EMI suppression. A properly designed and installed BLS can actually eliminate the entire loop area because the offending or affected circuit will be contained within the shield.

Metal RF Gaskets (Fingerstock) and Spring Contacts



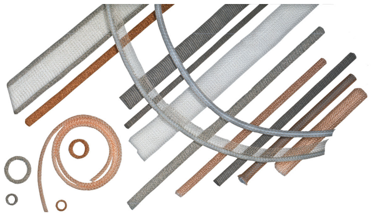
Metal RF gaskets are made from various materials. The standard product is offered in Beryllium-Copper, but phosphor bronze and stainless steel are also available. Custom designs are available to meet specific applications.

The metal must be conductive and have good spring properties. The metal RF gaskets generally have the largest physical compression range and high shielding effectiveness holding steady of a wide frequency range. CuBe is the most conductive and has the best spring properties. They can be easily plated for galvanic corrosion considerations.

Fingerstock and spring contact products are ideal for high cycling applications requiring frequent access. Hundreds of standard shapes are available, as well as cut-to-length and modified standards. Fingerstock and spring contacts offer superior performance at elevated temperatures, often a concern in automotive applications.

In response to increasing environmental concern regarding disposal of beryllium, other alloys such as RCC (Cu-Ni-Sn), Cu-Ti, Phosphorus bronze, and stainless steel are gaining preference over BeCu in some applications. However, the use of these alternatives is progressing slowly because of their inferior performance combined with the expense of developing new tooling and new design for performance improving.

Wire Mesh and Knitted Gaskets

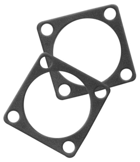


Wire mesh gaskets are a very versatile and are a proven style of shielding. Wire mesh gaskets have a great variety of uses with several popular types to choose from depending on shielding or environmental requirements. Knitted gaskets can be made from a variety of metal wires, including monel, tin plated-copper clad-steel or aluminum. They are cost-effective for low cycling applications and offer high shielding effectiveness over a broad frequency range. They are available in a wide variety of sizes and shapes with the knit construction providing long lasting resiliency with versatile mounting options. They are also available with a bonded elastomer gasket for moisture and dust sealing often a concern in automotive applications. Popular product lines include all mesh, which is the most economical gasket for low cycling applications and is designed to offer the highest levels of attenuation.

Conductive cloth knit offers close-knit stitch of the metalized nylon, providing a highly effective EMI shield, as well as a smooth, soft surface. CuBe Mesh offers superb resiliency for consistent, point-to-point contact requiring the lowest compression forces among all other shielding materials and configurations.

Elastomer Core Mesh is an optimum solution for combining excellent shielding performance with a high degree of elasticity.

Oriented Wire



Oriented wire is a conductive elastomer in which individual conductive wires of either Monel or aluminum are impregnated into solid or sponge silicone. Oriented wire provides EMI protection and seals against moisture or rain on cast or machined surfaces.

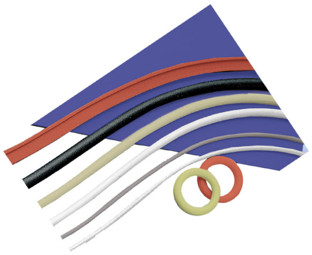
Fabric-over-Foam (FoF)

FoF EMI gaskets offer high conductivity and shielding attenuation and are ideal for applications requiring low compression force. The FoF profiles are available in a UL 94V0 flame retardant version and offer high abrasion and shear resistance. Typical FoF EMI gasket applications include shielding or grounding of automotive electronic equipment seams and apertures.

There are a wide range of shapes and thickness to meet any design need. Depending on the shape and FoF materials, compression of the gasket from 30% to as high as 75% can be allowed; thereby accommodating the tolerances of the system.

There are a wide range of enclosure materials and operating environments, so material compatibility is critical for reliability. A wide range of materials is available to design a solution for the application. Custom sizes and shapes can be designed to meet the application requirements, along with special purpose pressure sensitive adhesives and other features.

Electrically Conductive Elastomers



Conductive elastomers are ideal for automotive applications requiring both environmental sealing and EMI shielding. Compounds can be supplied in molded or extruded shapes, sheet stock, and custom extruded or die-cut shapes to meet a wide variety of applications. Conductive elastomers provide shielding effectiveness up to 120dB at 10GHz. Conductive extrusions offer a wide choice of profiles to fit a large range of applications.

Conductive elastomers come with many different material choices, and elastomer-conductive filler combinations are available. Conductive fillers include, but are not limited to:

- Carbon (C)
- Passivated aluminum (IA)
- Silver-plated aluminum (Ag/Al)
- Silver-plated copper (Ag/Cu)
- Silver-plated glass (Ag/G)
- Silver-plated nickel (Ag/Ni)
- Nickel-coated carbon (Ni/C)
- Silver (Ag)

Elastomer options include:

- Silicone rubber
- Fluorosilicone rubber
- Ethylene propylene diene monomer (EPDM)
- Fluorocarbon rubber, Viton, or Fluorel

Form-in-Place (FiP)

Form-in-Place (FiP) EMI gaskets can be dispensed onto any conductive painted, plated, or metallic surface of an electronics enclosure that requires environmental sealing, has complex or rounded surfaces, or has miniature devices requiring a precision gasket; thus, protecting the enclosure against internally and externally radiated interference and environmental elements.

FiP gaskets allow for more critical packaging space for board-level components. Room temperature curing gasket materials eliminate the need for costly heat curing systems because single-component compounds eliminate ingredient mixing, thus shortening production cycles. They have shielding effectiveness in excess of 70-100 dB to 18 GHz.

Board-Level Shielding (BLS)

If done well, PCB level shielding can be the most cost-efficient means of resolving EMI issues. The approaches involve proper shield selection and optimal circuit design including partitioning, board stack-up, as well as high-frequency grounding of the board and filtering techniques. As mentioned previously, if these techniques are designed-in at the initial stage, minimal impact to schedule and cost can be accomplished [1].

A properly designed and installed PCB shield can actually eliminate the entire loop area because the offending or affected circuit will be contained within the shield. For instance, board layout affects EMI control greatly. Noisy components can sometimes be moved away from sensitive areas. When the layout arrangement is not enough, some form of shielding is required to isolate the EMI source from other components and the local space. In fact, if PCB shields are considered early during the design stage, sections of the PCB can be used as part of the shield. PCB shields can be designed for maximum efficiency and minimum size. Generally, shielding on a PCB is typically some form of conductive cover mounted over one or more components.

There has been a variety of board-level shielding products available, such as metal can, conductive plastic cover with conductive paint, plating or surface coating. In some applications, a shielding barrier separates board components to prevent crosstalk. Shielding cans, cover and other barriers must be grounded. This can be done using board traces and other nearby conductive surfaces. In addition, heat can be an issue when using PCB shields. Ventilation is usually an adequate way to address this problem. However, if ventilation does not provide enough heat dissipation, PCB shields are available with integral heat sinks or other thermal dissipation systems.

As a low cost, and most common shielding method, a variety of board-level metal can-type shields have been used to eliminate EMI radiation from entering or exiting sections of a PCB. This method has primarily employed solder-attached perforated metal cans being attach and soldered to the ground trace on a PCB directly over the electrical components that need to be shielded. The can-type-shields are often installed in a fully automated fashion via a surface mount technology process at the same time the components themselves are installed onto the PCB using wave soldering, or solder paste and a reflow process. Such cans offer very high levels of shielding effectiveness, are typically very reliable, and are widely used in the industry.

BLS metal cans can consist of tin or zinc plated steel, stainless steel, tin-plated aluminum, brass, copper beryllium, nickel silver or other copper alloys. Among these materials, tin plated cold rolled steels have been most commonly used for board-level shielding due mainly to their excellent mechanical formability, environmental compliance, and relative low cost. Plating may be specified to improve corrosion resistance and shielding performance of a shield while tin plating is often used to enhance solderability preservation. However, tin whisker growth has been a major concern for tin plated cold rolled steels, and has caused increased limitations in board-level shielding applications. Nickel silver is expected to be the preferred alloy for the majority of board-level shielding applications, taking the place of tin plated steels and other copper alloys. This kind of alloy exhibits excellent corrosion resistance, outstanding aesthetic qualities, and good solderability in its natural state. The fact is that the nickel silver has not been used widely for board level shielding because of its high price and increased manufacturing cost.

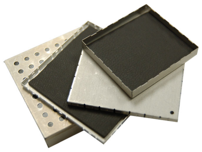
To alleviate the tin whisker growth concern and provide relatively low cost board-level shielding products, some environmentally friendly composite plating steels, such as chromate-free electrogalvernized steel (ZE-38) and ECO-TRIO steel, have been developed and have emerged as promising board-level shielding materials. They are cold rolled steels coated with environmentally friendly composite or alloyed coatings which provide good solderability, high resistance to whisker generation, relatively high surface conductivity, and satisfactory corrosion resistance [2].

As the design and realization of lightweight shields to reduce EMI with sensitive automotive electronic apparatus and systems is a challenge, there have been some attempts to improve the shielding performances of light materials such as plastics and composites by the insertion of conductive meshes in the substrate, the use of conductive additives and fillers prior to injection molding, and the use of conductive coatings. Among these techniques the use of conductive coatings are most promising.

Similar kinds of PCB shields have been made by a thermoformed polycarbonate foil, which is coated by a thin layer of tin or other metals before or after thermoforming. Due to the great formability of polycarbonate and to the good ductility of the metal coating, the shielding foil can be used to make covers and caps with different shapes and features, and can be mounted onto PCBs in order to reduce EMI and radiated emissions. These kinds of shields can provide shielding effectiveness of around 60-80 dB in the frequency-range from 30 MHz up to 2.0 GHz. Using these techniques offer great potential for forming low cost, lightweight shields [1].

Combination Shielding Products

Combination shields offer two or more technologies combined into one convenient form. These combination shields were developed to address the growing cost of redesign. Combination products offer reduced part count, improved performance, and size reduction.



There are multi-compartment shields to cover multiple board areas simultaneously. These shields are made by molding conductive elastomer walls onto metal shield cans to provide any compartment geometry needed. In addition, even more complex applications involve welding spring contact/fingerstock to shield cans to seal compartments in ultra-low profile applications.

Some popular combination shields include the Microwave Board-Level Shield, which is a combination of a microwave absorber with board-level shielding and will absorb or suppress high-frequency interference, enabling the board to be more effective at high frequencies.

To address applications where heat needs to be removed and where board-level shielding is also required, thermal interface materials are incorporated with board-level shields. Adding a gap filler material with high thermal conductivity between the electronic component and board-level shield cools the component by transferring heat efficiently to the shield, which acts as a heat spreader.

Ferrites

Suppression of EMI has become a major concern in the transmission, reception, and processing of electronic signals and data. Ferrite materials exhibit varying magnetic properties depending on the frequency at which they are excited. In electronic applications, the relation of the magnetic loss to frequency is used to design the equivalent of band pass filters, attenuating high frequency interference where the material's losses are high, yet passing lower bands where data is carried.

By changing the composition of ferrite, it is possible to enhance attenuation in selected frequency ranges. A family of ferrites with varying compositions allows for the optimal type selection of the application, as well as cable core, SMT common mode, differential mode and other configurations is available.

An extensive line of ferrite products for signal line and EMI filtering applications is available. Products include ferrite cable cores, connector plates, unique common mode chokes, CAN-Bus chokes, high current thru hole and surface mount components, chip beads, surface mount inductors and toroid inductor cores. Nickel-zinc ferrite parts are used extensively in the suppression of electromagnetic interference.

There are wide band transformer and filter cores, and manganese-zinc and nickel-zinc ferrite toroids range in initial permeabilities from 16 to 10,000. These products are used primarily in pulse transformers, isolation transformers, dataline and power filters, and ground fault interrupters. Parts are available bare or coated.

Conclusion

Proper EMI design considerations are essential from the beginning stages of the device. There are a myriad of EMI sources and receptors in today’s automobiles and in the environment in which they must operate. Today’s automobiles are an impressive and complicated electronic platform. They will only get more sophisticated and complex as time goes on. The control of electromagnetic interference is essential. Not only because there are mandatory requirements, but also for the proper functionality of the entire system. Devices installed into automobiles and devices brought on board by passengers must not interfere with each other. This is especially true for the safe operation of the vehicle. The achievement of complete electromagnetic compatibility is essential.

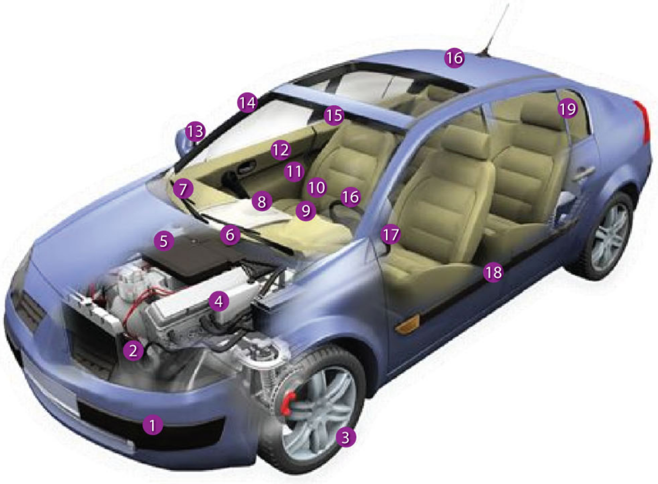
If the device does not meet its EMC requirements, then shielding is generally the only solution. There are many possible shielding solutions and products. Proper product design and shielding selection is essential for efficient cost-effective operations. If the designer is unfamiliar with shielding techniques and available products, it is advisable to contact a shielding manufacturer that provides services such as trained field application engineers.

References

[1] C. Tong, *Advanced Materials and Design for Electromagnetic Shielding.* Roca, USA: CRC Press, 2009.

[2] C. Tong. Environmentally friendly composite coating steels for board level shielding applications. Proceeding of 2010 Asia-Pacific Symposium on Electromagnetic Compatibility & Technical Exhibition on EMC RF/Microwave Measurement & Instrumentation. April 12 to 16, 2010. Beijing, China.

Appendix
Automotive Systems, EMI Sources, and EMI Solutions



AUDIO, ENTERTAINMENT, AND CONNECTIVITY

Description	Number
Audio / Radio, CD – BLS, Fabric-Over-Foam, Metals / Fingerstock / Spring Contacts, Impedance Modules, Differential Mode Chokes, Chip Inductor Beads	8
In-Car Entertainment – BLS, Fabric-Over-Foam, Metals / Fingerstock / Spring Contacts, Differential Mode Chokes, Chip Inductor Beads	8
Satellite Radio & Navigation – BLS, Metals / Fingerstock / Spring Contacts, Differential Mode Chokes, Chip Inductor Beads	16

BODY SYSTEMS

Description	Number
Motor Drive Controls – BLS, Ground Contacts, Ferrite Rods & Bars	12
Keyless Entry – BLS, Ground Contacts, Ferrite Rods & Bars	12
Lighting / Exterior – BLS, Ground Contacts, Ferrite Rods & Bars	13

CHASSIS AND STEERING SYSTEMS

Description	Number
Power Modules – BLS, Ground Contacts, Common Mode Chokes, High Current Chokes	2
Power Steering / EPS, RPHS, Belt Drive – BLS, Ground Contacts, Differential Mode Chokes, Chip Inductor Beads	16

ELECTRICAL / ELECTRONIC ARCHITECTURE

Description	Number
Motor Drive Controls – Ferrite Rods & Bars	7, 14, 19
Power Modules – Common Mode Chokes, High Current Chokes	7, 14, 19

INTERIOR SYSTEMS

Description	Number
Power Modules – BLS, Ground Contacts, Common Mode Chokes, High Current Chokes	10, 11, 18
Motor Drive Controls – BLS, Ground Contacts, Ferrite Rods & Bars	7, 10
Climate Control – BLS, Ground Contacts, Differential Mode Chokes, Chip Inductor Beads	10
Embedded Functions in Review Mirror – BLS, Fabric-Over-Foam, Metals / Fingerstock / Spring Contacts, Impedance Modules, Chip Inductor Beads	15
TFT Screens / Clusters – BLS, Ground Contacts, Form-In-Place, Elastomers	9, 15

POWERTRAIN SYSTEMS

Description	Number
Powertrain Electronics – BLS, Ground Contacts, CAN-Bus Mode Chokes, Differential Mode Chokes, Chip Inductor Beads	5
Engine Control Unit & Transmission Control Unit – Multi-Hole Plates, CAN-Bus Chokes, Differential Mode Chokes, Chip Inductor Beads	5
Electronic Clutch Actuation – BLS, Ground Contacts, CAN-Bus Chokes	5
Electronic Starter Motor – CAN-Bus Chokes, Differential Mode Chokes, Chip Inductor Beads, Ferrite Rods & Bars	5

SAFETY AND SECURITY SYSTEMS

Description	Number
Active Cruise Control / Collision Avoidance / Backing Aids – Board-level Shields, Absorbers, CAN-Bus Chokes, Differential Mode Chokes, Chip Inductor Beads	1
Tire Pressure Monitoring – BLS, CAN-Bus Chokes, Ferrite Rods & Bars	3
Vehicle Stability Control – BLS, Ground Contacts, CAN-Bus Chokes, Differential Mode Chokes, Chip Inductor Beads	4
Heads Up Display – BLS, Metals / Fingerstock / Spring Contacts, Differential Mode Chokes, Chip Inductor Beads	9
Airbag Electronics – BLS, Ground Contacts, Multi-Hole Plates, Two-Hole Baluns, CAN-Bus Chokes	4
Night Vision System – BLS, Metals / Fingerstock / Spring Contacts, Differential Mode Chokes, Chip Inductor Beads	6
Driver Safety / Communications / Hands Free – BLS, Differential Mode Chokes, Chip Inductor Beads	17

About the Authors

John Noto has been with Laird Technologies for 10 years. He has a strong background in operations management, including the introduction of major EMI metals facilities in China, Czech Republic, and Mexico. Mr. Noto was formally the Inside Sales Manager for Laird Technologies' Pennsylvania facility. He is currently managing all EMI metals product lines for the Americas region. He has a BS in Business Management as well as an AS in Mechanical Design.

Gary Fenical has been with Laird Technologies for 26 years. He is a specialist in RF shielded enclosures and has been responsible for the design and / or measurement and quality control of hundreds of large-scale shielded enclosures, as well as a number of shielded equipment cabinets and housings. He was instrumental in the design and construction of Laird Technologies' state-of-the-art World Compliance Centers. Mr. Fenical has authored many articles on EMC Requirements for Medical Devices, Mutual Recognition Agreements and Guidelines; meeting the essential requirements of the EU EMC Directive. He has also authored several seminars on the EU EMC Directive, International Compliance, and Designing for EMC and EMC Requirements for Medical Devices which have been presented worldwide. He holds the patent for the invention of heat-treated beryllium-copper knitted wire mesh gaskets.

Colin Tong joined Laird technologies in 2006 as a materials specialist for the Performance Materials Division. He has been responsible for the management of metal and EMI testing labs, involvement in the development of EMI shielding materials, and supporting the manufacturing process, quality assurance, and technical service with engineering responsibility for EMI shielding products. In addition, he has almost 20 years of experience in research and development, testing and characterization, component design and processing of advanced materials, metallurgical products, thermal management of electronic packaging, as well as electromagnetic interference shields. He holds a Ph.D. in Materials Science and Engineering. His research & development activities and industrial practices have resulted in more than 30 papers, several patents, and two books. Dr. Tong is a member of the TMS, ASME, and ASM International. He received the Henry Marion Howe Medal from ASM international for his contribution to research and development on advanced composite materials in 1999.

About Laird Technologies, Inc:

Laird Technologies designs and manufactures customized, performance-critical products for wireless and other advanced electronics applications.

The company is a global market leader in the design and supply of electromagnetic interference (EMI) shielding, thermal management products, mechanical actuation systems, signal integrity components, and wireless antennae solutions, as well as radio frequency (RF) modules and systems.

Custom products are supplied to all sectors of the electronics industry including the handset, telecommunications, data transfer and information technology, automotive, aerospace, defense, consumer, medical, and industrial markets.

Laird Technologies, a unit of Laird PLC, employs over 10,000 employees in more than 39 facilities located in 13 countries.

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