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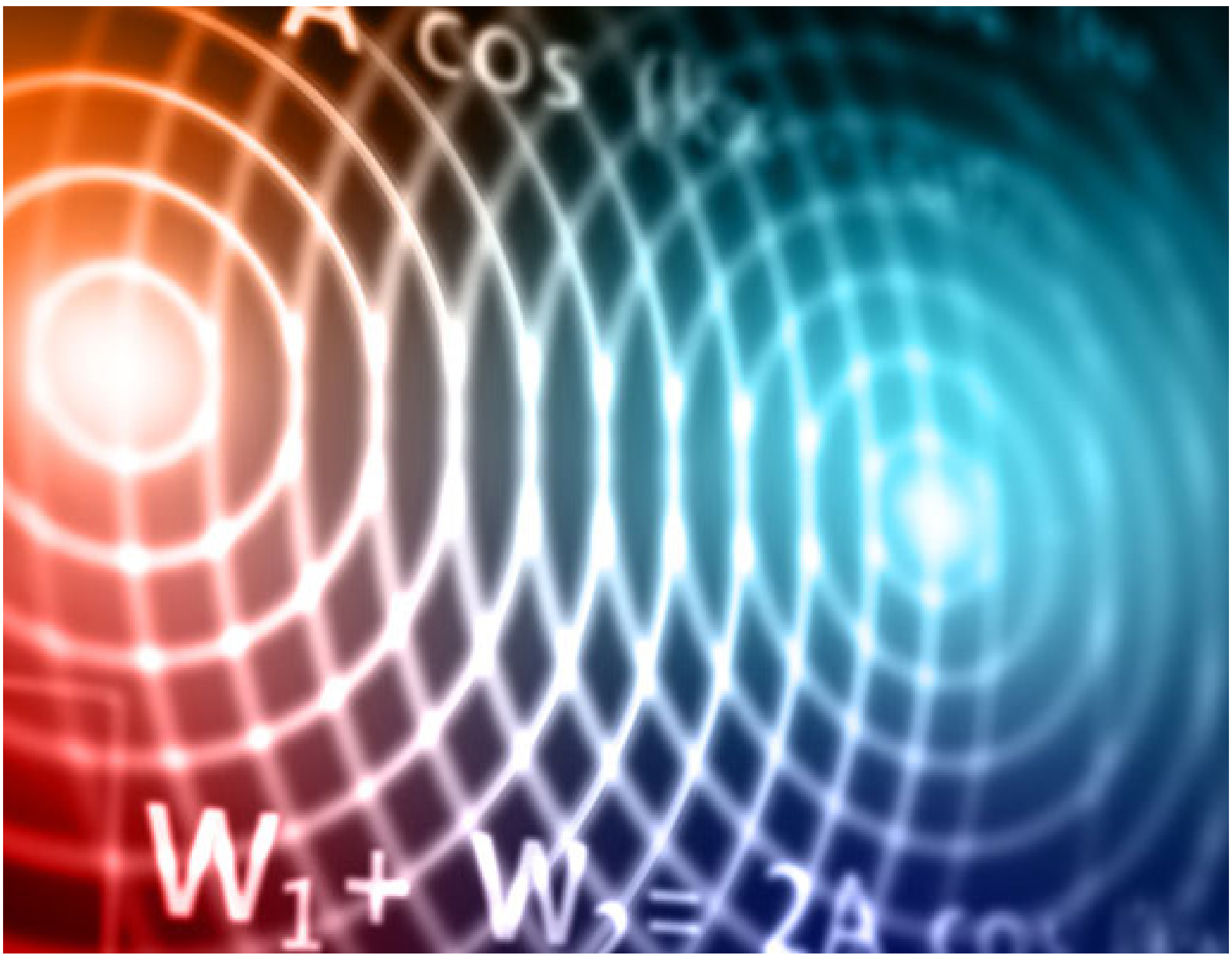
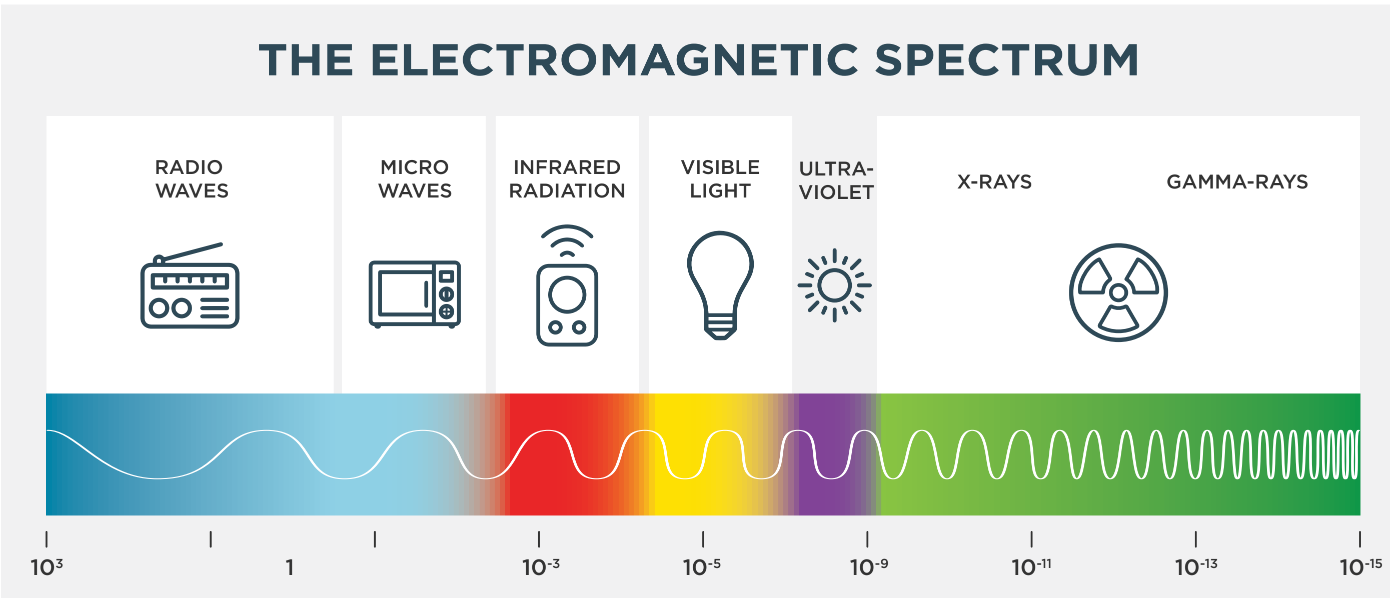
ELECTROMAGNETIC INTERFERENCE SHIELDING

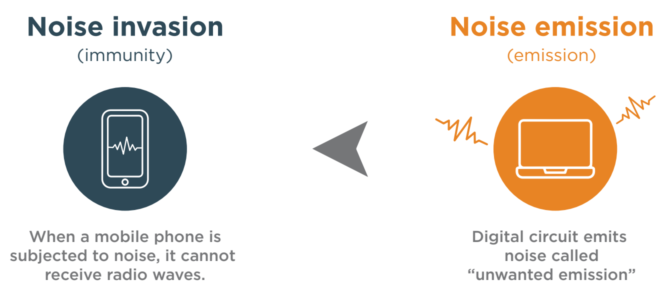
A Key Component of Engineering Design Trends, Insights, and Design Considerations



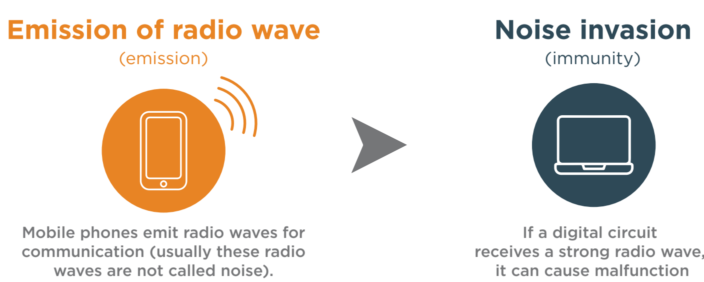
Introduction

Electromagnetic interference (EMI), also known as radio frequency interference (RFI), results when an outside source causes noise or interference in an electrical path or circuit. Shielding is necessary to prevent EMI from causing electronic devices to malfunction. Such malfunctions can range from the innocuous — an odd noise on a car radio — to the serious — an accident related to failing safety equipment.





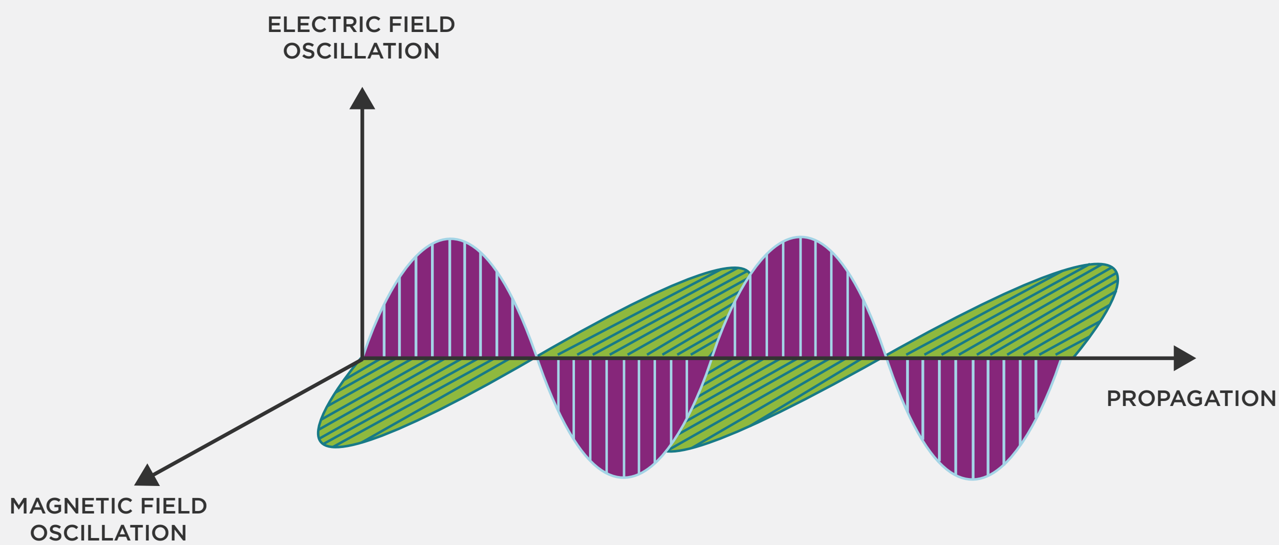
(a) When a PC becomes the source of noise



(b) When a PC becomes the victim of noise

As technology evolves, EMI shielding becomes increasingly important. The looming impact of the fifth generation of wireless technology (5G), the extending reach of the Internet of Things (IoT), and the growing electrification movement all have implications for EMI shielding. EMI shielding, as a key component of engineering design, should be considered at all levels of design from the PCB layout to the enclosure. Engineers are faced with an array of shielding options to suit their needs at each design stage and for each application, be it commercial, energy, defense, or others. This paper aims to give engineers a look at what technological advances will challenge current approaches to EMI shielding and provides a detailed overview of the materials currently on the market.

ELECTROMAGNETIC WAVE



Market Dynamics and Trends

IoT and 5G

The Cisco Internet Business Solutions Group (IBSG) defined the IoT as the point in time when more "things or objects" were connected to the internet than people[ii]. By IBSG's estimation, the IoT was born around 2010 when the world's population was 6.8 billion and the number of devices per person connected to the internet was 1.84[ii]. Since then, the IoT has steadily crept into our world — both personally and professionally. In our homes, it is becoming more common to control lighting and HVAC or to watch surveillance video footage of our front doors from our smart phones. Similarly, in our places of employment, the IoT allows for the connectivity of machines, vehicles, and systems.

5G has been considered by some to be a key enabler for IoT technology[iii]. With 5G comes the promise of faster data transmission as well as increased connectivity. The introduction of 5G to industry will create significant advances in the IoT. As a wireless network, industrial 5G will benefit from the elimination of cables within that environment, leading to greater flexibility and improved production layout. The very high speed of 5G is expected to eliminate lag and to improve productivity.

Compared to frequencies for previous generations, frequencies in the 5G network have increased. In the United States, among the four major mobile carriers, frequencies in the second phase of 5G rollout range in the mid-band from 2.5GHz to 3.7GHz[iv]. In Europe, regulators identified the 3.4-3.8GHz band as suitable for 5G, and it is the main frequency band for 5G. Higher frequencies in the millimeter wave bands 24GHz up to 86GHz are required for higher data rates. Even higher frequencies are expected as 5G advances. Compared to 4G, 5G with its high frequencies and high data rates will require many more base stations.

Increases in data speed lead to commensurate increases in noise and heat. Greater connectivity supporting more wireless devices results in more signals and increased connector heat. All of these changes related to 5G place greater emphasis on appropriate EMI shielding, and as 5G evolves, engineers will need to meet the challenges of designing for faster data speeds, increased connectivity, and higher frequencies.

Electrification

In addition to the challenges posed by 5G and the IoT, the growing trend in electrification is presenting engineers with challenges from EMI. Government initiatives for alternatives to the internal combustion engine are driving a boost in the electrification of vehicles — from personal vehicles to long-haul trucks, delivery vans, farming equipment, and aircraft[v].

By design, the electric vehicle represents a large amount of electrical content confined to a space. The battery in an electric vehicle is one potential source of EMI. The all-electric vehicle has electromagnetic fields between the two battery packs (traction and auxiliary), the DC/DC converter, and other system components. Other types of electric vehicles — hybrid electric, plug-in hybrid electric, and fuel cell electric — have an auxiliary battery, making them EMI susceptible as well. When considering EMI shielding for electric vehicles, the engineer must also keep in mind the heat and flammability associated with the battery. As with an increasing number of non-electric vehicles, electric vehicles may house navigation systems and safety applications, such as advanced driver assistance systems, that also rely on uninterrupted RF signals, representing additional areas for EMI[v].

Beyond the electric vehicle itself are related EMI concerns. Electric charging stations (ECS) represent a source of EMI due to the presence of AC and DC magnetic fields. The onboard electronics of the ECS require shielding from EMI as well. Additionally, the electric vehicle is susceptible to external sources of EMI ranging from common household items like garage door openers and cell phones to less frequently encountered sources like solar storms and high voltage power lines[v].

Signal Integrity and Electromagnetic Compatibility

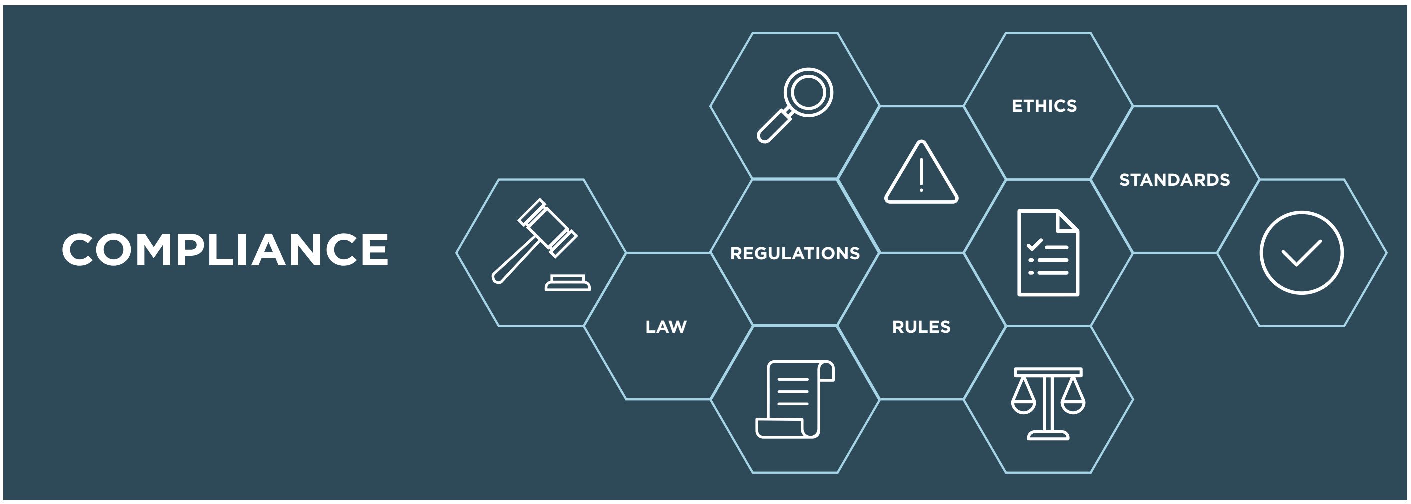
Signal integrity and electromagnetic compatibility (EMC) can be considered two separate yet related components of engineering design, each warranting a unique set of requirements. Signal integrity is a measurement of quality between a driver and a receiver. To maintain signal integrity, one must ensure that timing margins are met and that signals remain within voltage thresholds so that send and receive devices are not damaged. Unlike with EMC, there are no standards governing signal integrity. The main requirement for proper signal integrity is that the final product functions correctly in its intended application[vi].

Use of simulation tools is important in developing products with good signal integrity. Inexpensive and easy to execute, signal integrity simulation can reduce the risk of failure, can enable what-if analysis in early design stages, and can provide information that justifies later stage design changes. In essence, simulation can help verify the effectiveness of design changes and can reduce time to market[vi].

EMC, by definition, means that equipment can function satisfactorily within its electromagnetic environment without creating intolerable electromagnetic disturbances for other equipment in the environment[vii]. To resolve EMI at its source, electronics engineers will consider good board layout, filtering, grounding, and signal integrity in their design. EMC mandates that products are designed using criteria established within government standards or market-driven emissions and immunity standards. To meet EMC, circuit board layouts must be printed properly to limit the flow of unwanted common mode current to wires connected to the product. Sophisticated testing is utilized to ensure that these currents meet established limits. For Class B radiated emissions testing, for example, a 5mA common mode current measurement will result in failure[vi].

Compared to simulation for signal integrity, simulation for EMC is expensive and difficult to perform. Rather than using simulation to test for adequate EMC, engineers are better served by designing with EMC in mind and laying out circuit boards to achieve EMC[vi]. Other techniques to reduce EMI include use of proper grounding and EMI filtering or shielding[viii]. Testing products under the electromagnetic environments cited in relevant EMC standards is also important[viii].

Compliance with EMC Standards



Designing for EMC is becoming increasingly important as technology advances. With 5G specifically, all new systems will need to meet EMC legislation, and RFI shielding of the enclosures and components will be a requirement. EMC is regulated by numerous bodies across the world, and each industry sector has specific EMC standards[viii]. Although not exhaustive, **Table 1** lists common EMC standards by application[viii]. A more comprehensive list, published by Interference Technology, can be found at https://learn.interferencetechnology.com/2022-emc-testing-guide/. As a best practice, design engineers should consult the appropriate guidance in their region and industry before beginning a project.

Table 1: Common EMC Standards by Application/Industry[viii, ix]

Application/Industry	EMC Standard
Aerospace, Defense, and Marine equipment	DEF STAN 59-411 MIL-STD-461 MIL-STD-704 MIL-STD-1275 MIL-STD-1399
Automotive components	IEC CISPR 25 ISO 11451 ISO 11452 ISO 7637 SAE (multiple numbers)

Application/Industry	EMC Standard
Commercial equipment	FCC Part 15 class B IEC 61000-6-1 (generic) IEC 61000-6-3 (generic)
Industrial devices	FCC Part 15 class A IEC 61000-6-2 (generic) IEC 61000-6-4 (generic)
Medical devices	IEC 60601-1-2
Power station and substation equipment	IEC 61000-6-5
Process control and measurement equipment (<1000 V AC, 1500 V DC)	IEC 61326-1
Switch gears and control gears (1000 V AC, 1500 V DC)	IEC 60947-1
IEC: International Electrotechnical Commission; ISO: International Organization for Standards; SAE: Society of Automotive Engineers; FCC: Federal Communications Commission	

EMC Testing

EMC must be addressed before any electronics product comes to market, regardless of industry or application[ix]. EMC testing measures a product's RF emission levels and its immunity to RF emissions. Results from the testing environment will give engineers an indication of whether the product will produce EMI in the real world[x].

There are three main steps to EMC testing:

1. **Identify the appropriate standards**. As previously stated, applicable standards vary across products, applications, and geography. Either contact a test house and ask which standards apply or fully research the standards yourself before beginning any testing activities.

2. **Perform pre-compliance testing**. To ensure that your product is fully immune to EMI and meets standards for energy emissions before formal testing, you will ideally want to test within an anechoic chamber or an RFI shield enclosure. Fully EMC compliant testing equipment, such as EMI receivers, can be rented for these purposes. Detailed instructions for setting up pre-compliance testing in house, an overview of the necessary equipment, and a supplier guide are available at **https://learn.interferencetechnology.com/2022-emc-testing-guide/**.

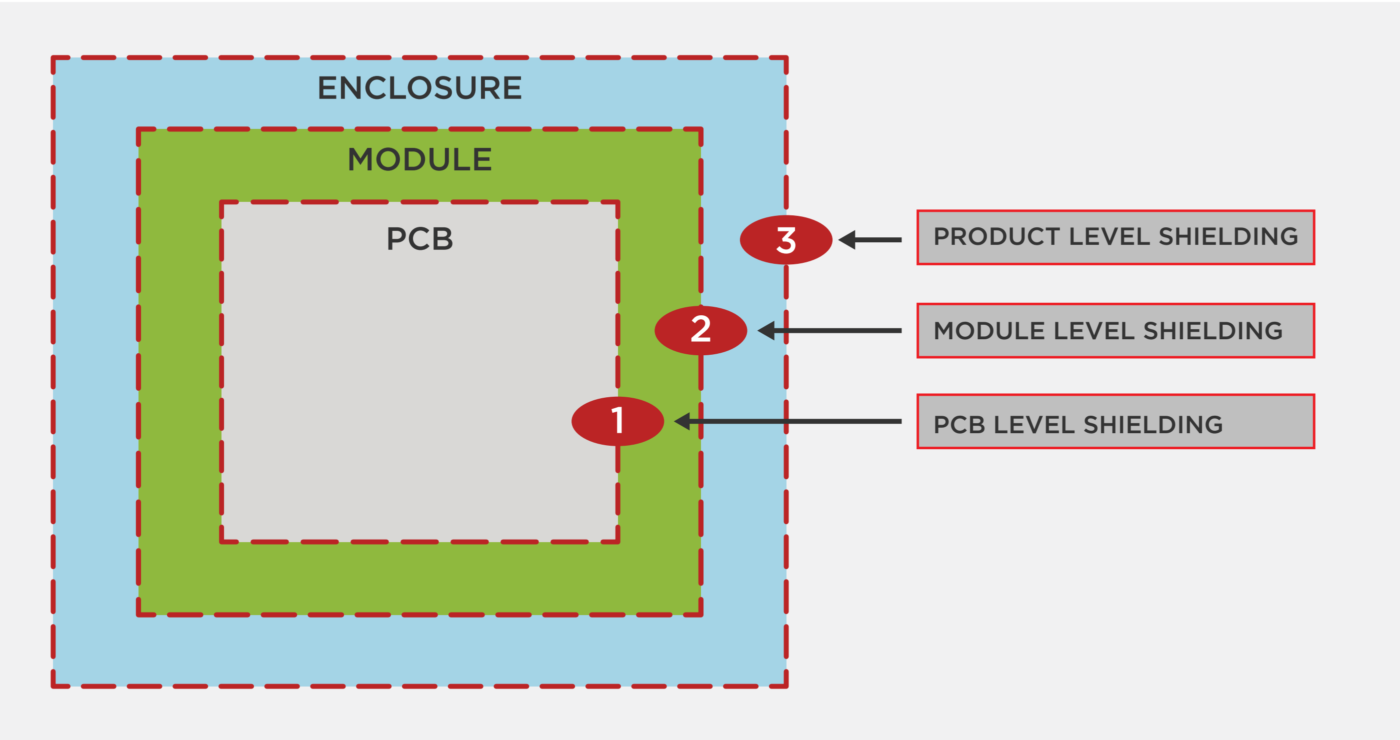
3. **Select an EMC test lab**. Make sure that the lab you select is accredited by A2LA for ISO/IEC 17025. Crucial when placing your product in market, this accreditation will validate your testing. Expect a lag of at least several months when booking the lab and plan your pre-compliance testing accordingly[x].

Several basic tests are performed to assess a product's EMC. These include radiated immunity and emissions and conducted immunity and emissions. Testing for radiated immunity gauges the product's performance when it is exposed to electromagnetic energy within its environment. Testing for radiated emissions evaluates the amount of electromagnetic disturbance caused by the product. Conducted immunity testing measures the test product's response to electromagnetic energy that originates with another product and is conducted via a cable or conductor to the test product. Conducted emissions testing analyzes the electromagnetic energy that travels from the test product along a conductor to another product. A variety of specialized equipment is available for the in-house performance of each of these tests. Conducting these tests in house before sending a product to a lab for EMC certification can allow for the fine-tuning that may prevent a product from failing on the first attempt at certification[x].

Levels of EMI Shielding

From a design engineering perspective, EMI shielding should be considered at all levels — from the enclosure to the module to the PCB. A Faraday cage, or a protective structure that prevents electromagnetic radiation from entering or exiting an area, is an important component in EMI shielding at these different levels[xi].

- **Enclosure level**: EMI shielding of enclosures at all levels involves a Faraday cage to attenuate signals from within the enclosure. This minimizes signals escaping and causing interference to other equipment within the environment and can prevent outside interference from penetrating the enclosure.
- **Module level**: Module-level shielding is the shielding of active components, such as drives, displays, etc., within the electronics enclosure to protect those components from internal interference.
- **PCB level**: Shielding at the PCB level consists of shielding of individual components, such as integrated circuits, with shielding cans, for example, making a small Faraday cage for those components.

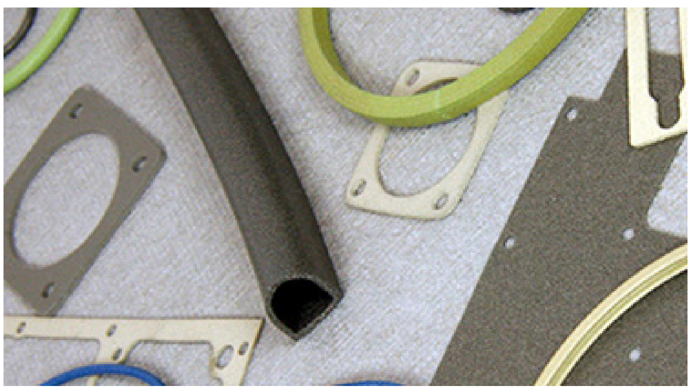


EMI Shielding Material Types

EMI shielding is available in a variety of materials to meet a broad range of needs across applications and industries. Different types of materials address different challenges to achieving an effective EMI shield. The four main types of EMI shielding materials include the following:

- Knitted wire mesh
- Electrically conductive elastomers
- Conductive fabric over foam
- Metal fingers, typically beryllium copper or stainless steel

Knitted wire mesh. Knitted wire mesh represents a cost-effective solution for EMI shielding. This type of shielding consists of multiple layers of wire, commonly Monel (alloy of nickel and copper), tin-plated copper clad steel, stainless steel, or aluminum, knitted over a core. Core materials range from silicone sponges and solid silicone to closed cell neoprene sponges. The availability of different wire mesh materials allows for galvanic compatibility with mating flanges, reducing the likelihood of corrosion. Knitted wire mesh can be fabricated in complex shapes and can be fitted to grooves as an O-ring. When bonded to a carrier, knitted wire mesh also can be mounted to a surface and will provide a dust and moisture seal. This type of shielding is well suited for cabinet doors, lids, and removeable cover plates. The shielding effectiveness of knitted wire mesh begins to decrease beyond 1GHz, necessitating the addition of more wire mesh layers.



Electrically conductive elastomers. Another cost-effective choice in EMI shielding, electrically conductive elastomers come in a range of materials for various applications. These materials include silver-plated aluminum, copper, or glass in silicone or fluorosilicone and nickel-coated graphite or pure nickel in silicone or fluorosilicone. Each of these materials offers high performance at all frequencies. Representing the most popular materials, nickel-coated graphite and silver-plated aluminum feature a low specific gravity, which makes them more cost effective than copper or nickel-based fillers. However, nickel-coated graphite is three to five times less expensive than silver-plated aluminum. Like knitted wire mesh, electrically conductive elastomers also ensure galvanic compatibility through the diversity of conductive fillers. Conductive elastomers are available in sheets, flat gaskets, or O-rings. The fluorosilicones are fuel and oil resistant, making them an ideal choice for harsh environments. The nickel-coated graphite in silicone product is also available in a flame-retardant version approved to UL94-V0 file number E344902.

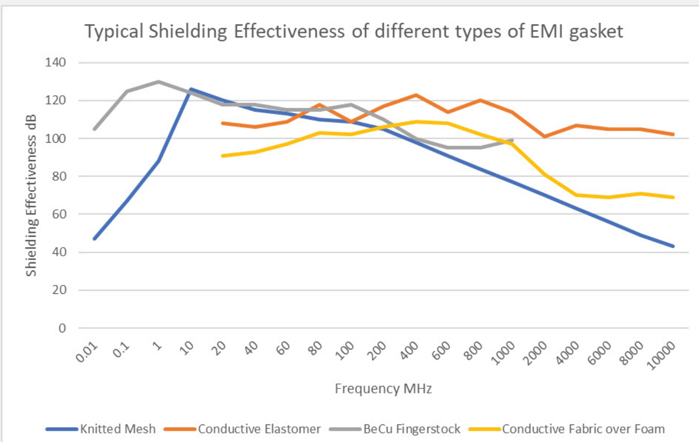
Two additional types of conductive elastomers include form-in-place gaskets and oriented wire in silicone. Form in place conductive elastomers consist of a conductive silicone in liquid form that can be dispensed directly into enclosure hardware. Materials include nickel-coated graphite in silicone and silver-plated aluminum, copper, or nickel in silicone. Form in place conductive elastomers also are available in non-conductive silicone. Form in place conductive elastomers can be well suited for small enclosures with minimum gasket land area and provide a dust and moisture seal.

Oriented wire in silicone is a flat, silicone sheet material embedded with vertically oriented Monel or aluminum wires. Oriented wire in silicone is a great shielding option for electromagnetic pulse and provides an environmental seal. Variants include solid closed cell silicone, soft solid silicone, sponge silicone, and solid fluorosilicone and different wire counts.

Conductive fabric over foam. This type of EMI shielding consists of conductive nickel/copper or silver-plated polyester or nylon fabric over a soft polyether polyurethane foam core. Conductive fabric over foam is available in many different forms, making it useful for a wide range of applications, including commercial uses. Conductive fabric over foam offers effective shielding up to 10GHz. While this type of shielding provides no water seal, it does offer a limited dust seal.

Finger stocks. With mechanical spring characteristics and high electrical conductivity, finger stock, most often made of beryllium copper, represents a useful EMI shielding choice for cabinets and doors or other areas that are frequently accessed. Various plating finishes are available to address galvanic compatibility. Finger stock is available in a wide range of solderable and unsolderable finishes with gold, silver, bright tin, bright nickel, zinc, and electroless nickel options. Finger stocks. With mechanical spring characteristics and high electrical conductivity, finger stock, most often made of beryllium copper, represents an ideal EMI shielding choice for cabinets and doors or other areas that are frequently accessed. Various plating finishes are available to address galvanic compatibility. Finger stock is available in a wide range of solderable and unsolderable finishes with gold, silver, bright tin, bright nickel, zinc, and electroless nickel options.

SHIELDING EFFECTIVENESS



KNITTED WIRE MESH

H field (magnetic) shielding 62dB @ 10Khz achievable. SE falls off after 1GHz

CONDUCTIVE ELASTOMERS

Shielding with wide frequency range, >100dB upto 10GHz E field.

FABRIC OVER FOAM

Shielding with wide frequency range, >100dB upto 10GHz E field.

BERYLLIUM COPPER FINGERS

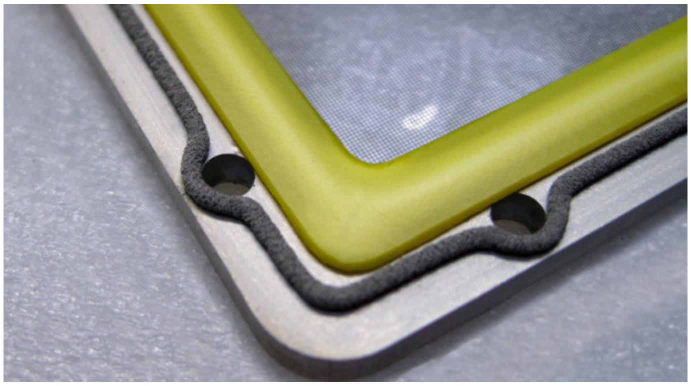
Shielding with wide frequency range, >100dB upto 10GHz E field.

Several additional options for EMI shielding include honeycomb EMI vents, EMI shielded optical windows, and EMI cable glands.

Honeycomb EMI vents. Honeycomb air ventilation panels consist of an aluminum honeycomb foil held in a rigid extruded aluminum mounting frame. The foil, formed and laminated into a series of honeycomb cells that are glued and perforated or laser welded at the join, ensures a conductive path at each join. Although the foil is conductive in all directions, to enhance EMI performance, two pieces of honeycomb polarized at 90° to each other are recommended.

The frame can be supplied with an integral or separate EMI/RFI gasket and can be treated with a variety of finishes to provide corrosion protection or to improve conductivity. The principle is that of “waveguide beyond cutoff.” The honeycomb vent is a series of tubes that acts as a waveguide, guiding electromagnetic waves into or out of the enclosure, but as the tubes are long enough then it attenuates those waves. Typically, the tube should be at least three times as long as the diameter with good practice being four times. Therefore, a 3.18mm cell should be 12.7mm long. Honeycomb material is used because it offers high shielding performance, light weight, and good airflow.

Ventilation panels are designed for use in electronic enclosures where good air flow is required for cooling and ventilation but where EMC compliance must be ensured. Typical applications include electronic enclosures, air conditioning units, fan housings, EMC racks, and communication shelters.



EMI shielded optical windows. EMI shielded windows provide a high-performance EMI shield for an enclosure while maintaining optimum optical transparency. EMI shielded windows provide an EMI screen as part of a shielded enclosure that will provide protection against radiated emissions and susceptibility. Shielded windows provide good transparency for viewing display devices, such as LED and LCD, and they also can form the front panel of an enclosure to provide impact protection, contrast enhancement of displays, display color matching, anti-reflection, and anti-glare surfaces. Shielded windows can be used to provide EMI shielding on a wide range of applications, such as laptops and small display screens. In addition, large windows can provide transparent EMI shielding for architectural use, such as computer rooms, shielded rooms, MRI rooms, and secure communication cabins.

These optical windows come in two configurations:

- **Laminated window**: A very fine woven wire mesh trapped between two layers of optical substrate, which are laminated together using a polyurethane interlayer
- **Cast window**: A very fine woven wire mesh embedded in a cast substrate

EMI cable glands. Cable glands provide excellent EMI shielding for screened cables that pass through enclosure walls. Made from brass, they are available to suit different size cables. They also provide traditional strain relief for the cable.

EMC cable glands consist of four parts: the body, cap, locknut, and mesh olive. The cable entry system gland uses a wire mesh olive that consists of knitted wire mesh over a silicone core. When the cap is tightened to the body, the compression provides circumferential pressure to both the cable and gland body, giving excellent electrical conductivity between the two, to provide good RF and electromagnetic shielding.

EMI Shielding Applications

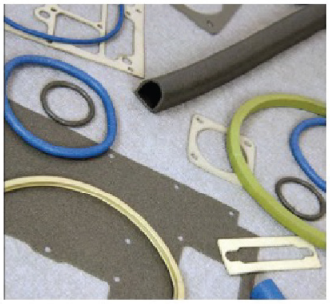
EMI shielding is necessary in a broad range of applications and industries, from aerospace and defense to data communication/IoT, automotive, and medical. Although not an exhaustive list, **Table 2** outlines the EMI shielding materials used in a number of applications and industries.

Table 2: EMI Shielding Material Types by Application and Industry

Material	Application	Industry
Knitted wire mesh	Door seals Access panel seals Areas with frequent access	Aerospace, defense, and marine Data communication Energy Industrial Medical
Electrically conductive elastomers	Industrial controls Instruments Military equipment Avionics Medical electronics Electronic equipment enclosures	Aerospace, defense, and marine Automotive Data communication Energy Industrial and commercial IoT Medical Transportation
Fabric over foam	Cabinet doors Panel gaskets Grounding contacts Card cage gaskets Connector and IO gaskets	Data communication IoT Medical
Finger stock	Cabinet doors Access panels Personnel doors in screened rooms and containers Shielded rooms Grounding contacts	Data communication IoT Medical

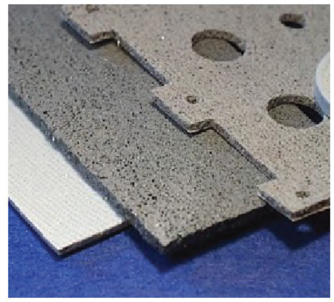
Key Takeaways

Advances in technology, including the expanding rollout of 5G and the increasing reach of the IoT, are leading to a greater need for EMI shielding. It is imperative that engineers consider EMI shielding early in the design process. From the enclosure to the module to the PCB, each level should incorporate EMI shielding. Benefits of accounting for shielding early in the process include eliminating inefficiency, avoiding costly redesign, and preventing delays in product launch. Various shielding materials are available for (TE) individual applications — each well suited for meeting different EMI challenges. TE Connectivity has a broad portfolio of EMI shielding materials and is the ideal partner can help you identify the most appropriate material for your specific project.



Conductive Elastomers

Standard silicone has excellent temperature range performance and is resistant to compression set. Fluorosilicone has superior resistance to fuel oils and solvents.



Oriented Wire in Silicone

Provides excellent shielding with EMP survivability and will also provide an environmental seal.

Knitted Wire Mesh

Knitted wire mesh gaskets provide an excellent cost-effective EMI gasket, providing shielding in the magnetic as well as electrical fields.

EMI Shielding Ventilation Panels

Made from aluminium honeycomb mounted into a frame.

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