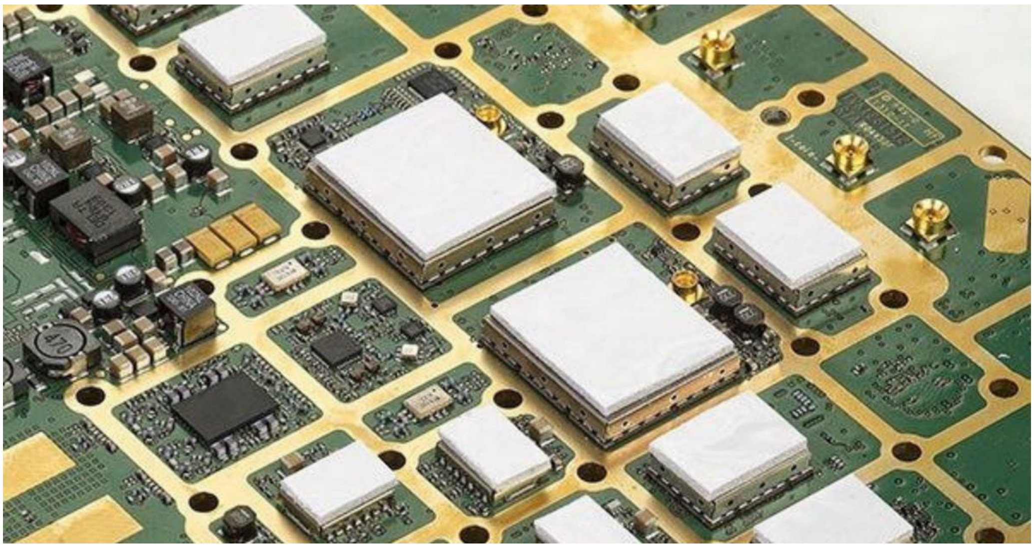
INTRODUCTION TO EMI SHIELDING



Source- Modus Advanced

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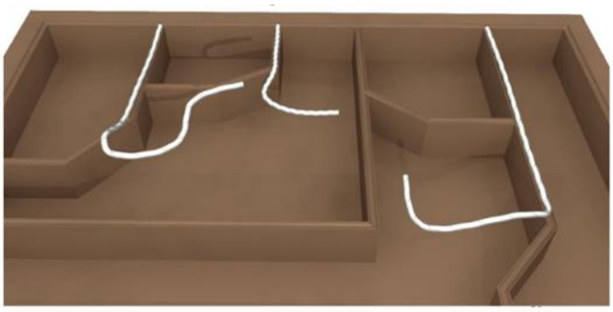
Introduction to EMI Shielding

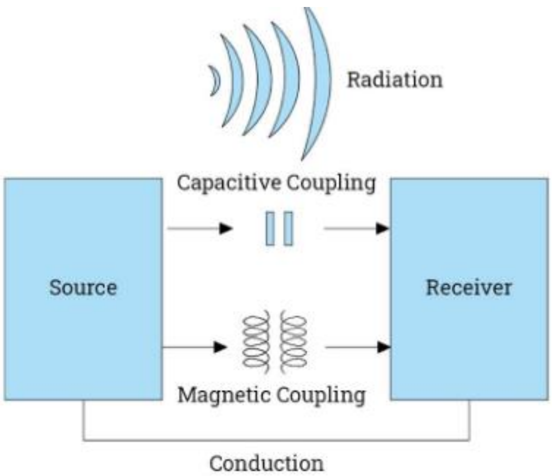
EMI shielding is a technique of creating a barrier that prevents leakage of strong electromagnetic fields that can interfere with sensitive devices and signals. They can be installed to isolate the electromagnetic field source or as an enclosure of the device that needs protection. Electromagnetic interference, or radio frequency interference (RFI), is a problem for most electronics since it can decrease the performance of the circuit or even cause it to fail. Electronics deal with small voltages and currents that an electromagnetic field can easily disrupt.



Installing an EMI Gasket

What is Electromagnetic Interference (EMI)?

Electromagnetic interference (EMI) is the coupling of signals from one system to another. There are three components to creating an EMI: the source, path, and receiver. The two systems are the source and the receiver. The source is generally the external circuit or phenomenon that creates the disturbance, which can be naturally occurring (lightning, auroras, cosmic microwave background, and solar flares) or artificial (cellular networks, AM/FM radio waves, power transmission lines, measurement and control devices). The receiver, or the victim, is the sensitive signal or device in which its output signal is distorted by the interference. The path is where signal coupling occurs, which can be through four modes.



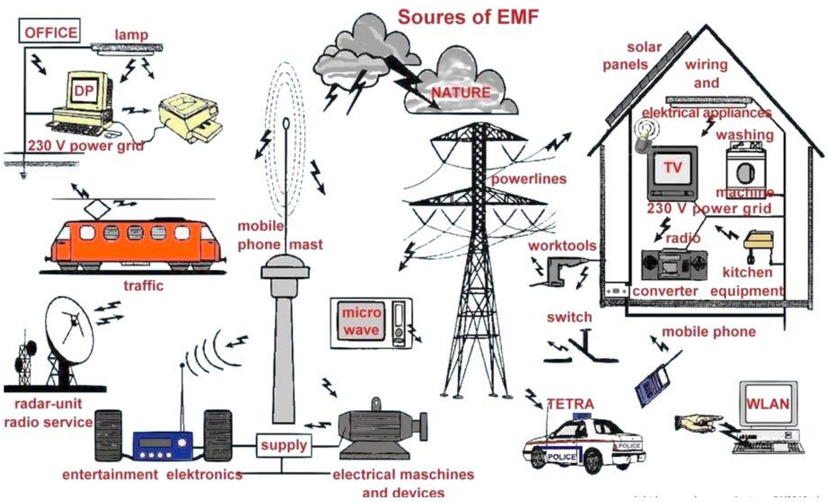
EMI Shielding (EMF Shielding)

- **Conducted EMI:** This is caused by the presence of a conductive path between two circuits where stray signals or currents can travel. Conducted EMI can be classified as common-mode or differential-mode. In the common mode, the stray current from the two systems travels in the same direction through a grounding connection, which serves as a common return path. In the differential-mode, the unwanted current flows across the two systems in opposite directions through the power supply lines and is independent of the ground.
- **Radiated EMI:** Radiated EMI propagates through the open space between the source and the receiver. A source emits an electromagnetic wave that is unintentionally transmitted to a circuit. Conductors such as cables and circuit board traces can act as antennae that can transmit and receive an external electromagnetic wave.
- **Capacitive EMI:** This occurs between two conductors in a system that has very close proximity, typically less than a wavelength apart. This tiny space creates a parasitic capacitance, where the electric charge is stored and transferred through charge differentials. The charge differentials are created by the electric fields emitted by the conductors. The parasitic capacitance becomes a pathway for transferring stray signals.
- **Magnetic EMI:** This is the same as capacitive coupling, which occurs at close distances. Signal transfer is done by creating a current across another conductor through electromagnetic induction. This is possible when the current in the first conductor changes or oscillates.

Types of EMI

EMI can be classified according to the duration of the interference. Types of interference are continuous and pulse interference. A continuous interference is a type of EMI where the source continuously emits the unwanted signal. Continuous interference is generally characterized as low energy and low frequency. Continuous interference includes radio frequencies, electromagnetic field leaks from industrial equipment, power transmission lines, etc. On the other hand, pulse, intermittent, or transient interference is an EMI that occurs only in a short duration. The definition of its duration varies from each application, but the usual is less than a period of one AC cycle (1/60 Hz = 16.67 milliseconds). Pulse interference is characterized by high bursts of energy, which can be repetitive or random events. Repetitive is usually artificial, making it predictable in terms of amplitude and duration. Random events can be artificial and naturally occurring, such as lightning strikes, power surges, electrostatic discharge, and so forth.

Another classification of EMI is by the length of the wave bandwidth of the disturbance, which can be narrowband or broadband. The definition of the two depends on the bandwidth of the signal on the receiver, termed the resolution bandwidth. A narrowband disturbance has a bandwidth of less than or equal to the receiver, while a broadband disturbance has greater bandwidth.



Importance of EMI Shielding

Every day, new innovations are flooding the commercial market with new conveniences that are designed to make life easier. This wide array of electronics has the potential to damage and interfere with each other unless they are shielded properly. EMI shielding aims to isolate the energy of a device so that it does not affect what is around it and blocks external energy from attacking. Every new electronic device emits some amount of electromagnetic energy and has zero resistance to EMI.

With an understanding of the nature of EMI, it is clear that it can affect its surroundings in various ways. It can affect electronics that are in contact (conducted EMI), in close proximity without contact (capacitive and magnetic EMI), and even over large distances (radiated EMI). Along with the progress of the information age, the increased usage of electronics for data processing and communication creates considerable pollution to the electromagnetic wave spectrum, on top of the other disturbances caused by electrical transmission and distribution systems and natural phenomena such as lightning strikes and solar flares. Below are some effects of EMI.

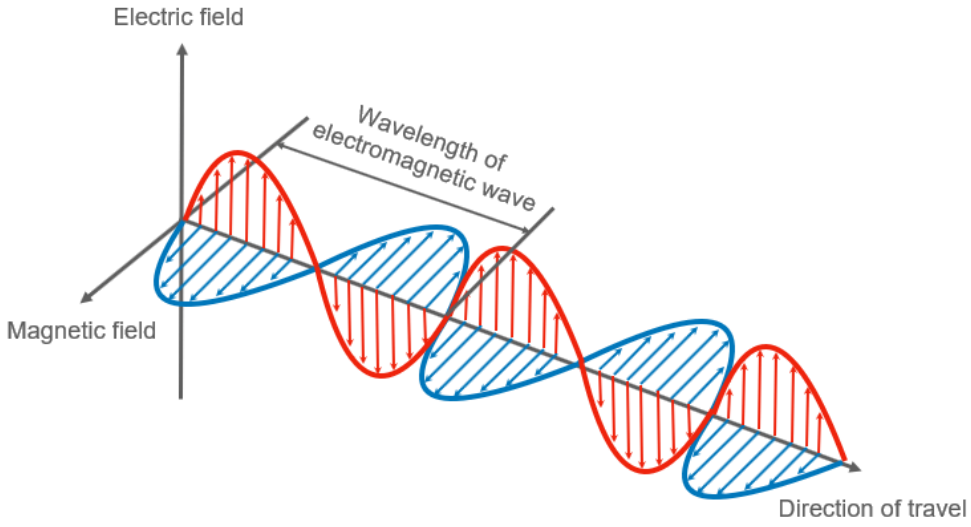
- Jammed or distorted signals received by communication devices
- Sudden power outage, power fluctuations, and electrical fast transitions (EFT)
- Total electronic circuit failure or damage
- Decreased life and performance of electronic systems
- Electric shock and burns
- Potential ignition source

EMI & Environmental Connector Seal Source – Spira-emi

International organizations developed electromagnetic compatibility (EMC) standards to address these problems. EMC is the property or characteristic of equipment to operate correctly in an electromagnetic environment without generating or transmitting electromagnetic energy to other equipment. International EMC standards are stipulated by the International Special Committee on Radio Interference (CISPR), a part of the International Electrotechnical Commission (IEC), and the International Organization for Standardization (ISO). In the United States, EMC standards are managed by the Federal Communications Commission (FCC).

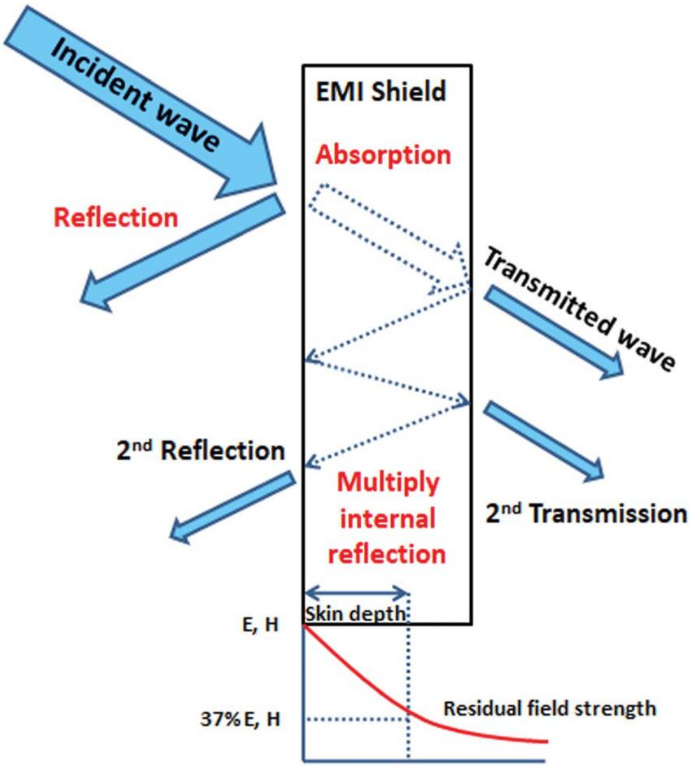
Mechanisms of EMI Shielding

EMI shielding is one of the methods of achieving EMC aside from grounding, filtering, and bonding techniques. This involves creating enclosures with the appropriate material, structure, and form to alter the path of most undesired electromagnetic waves coming into or out of the equipment. The path is altered by absorbing or reflecting the electromagnetic wave through conductive or ferromagnetic materials.



Electromagnetic Wave

An electromagnetic wave consists of an electric component and a magnetic component. Both travel at the same frequency and are perpendicular to each other. A conductive material blocks the electric components, while a material with high magnetic permeability blocks the magnetic components. Since a component of an electromagnetic wave cannot exist without the other, it is enough to protect one component. When it comes to EMI shielding, there are different mechanisms involved to filter out each. Enumerated below are the three mechanisms of EMI shielding.

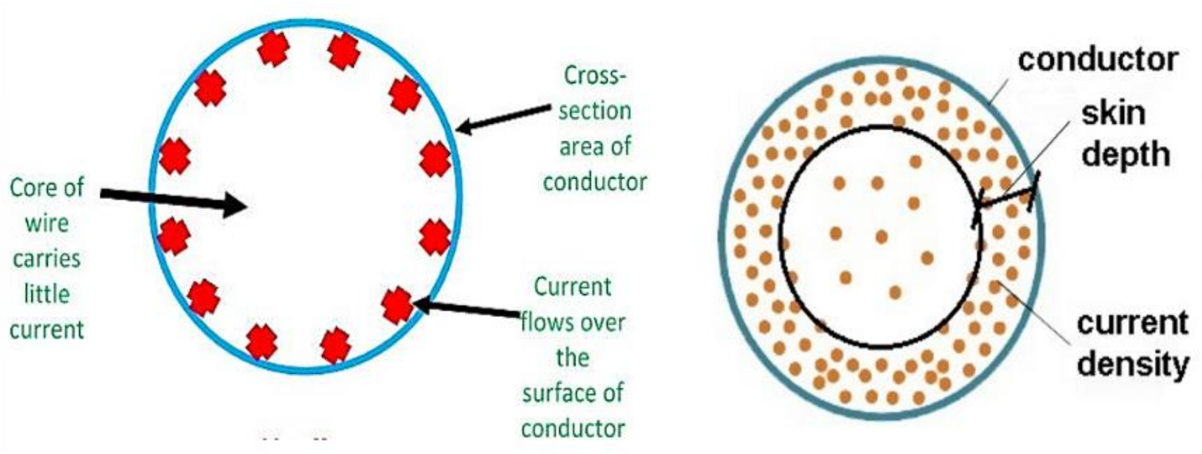


Mechanisms of Shielding

Reflection of the EMI

The main mechanism of EMI shielding is reflection, which attenuates the electric component of the EMI. In order to achieve EMI reflection, the material must have mobile charge carriers. This means the material used for shielding must be conductive. The incoming electromagnetic wave interacts with the mobile charge carriers present in the conductive shield. This interaction causes the charges to flow and redistribute along the conductor creating an opposing electromagnetic field. The electromagnetic field generated by the redistribution of charges cancels out the external magnetic field. In this mechanism, the higher the conductivity of the material, the better the shielding characteristics.

The problem with this mechanism is that a discontinuity on the enclosure that is larger than the wavelength of the external electromagnetic field will defeat its shielding properties. Thus, the sizes of holes and openings in the enclosure design are minimized. However, this is not possible for higher electromagnetic wave frequencies. The only way to counter this in high-frequency EMI is through the use of filtering devices.

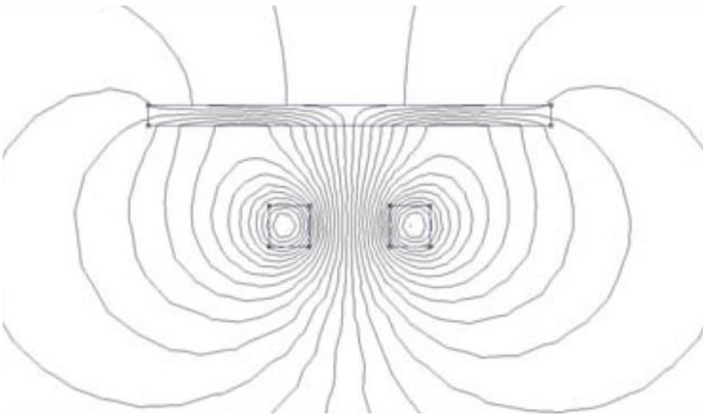


Skin Effect

Another problem is the skin effect, which is seen in AC circuits. When AC flows through the conductor, the charges accumulate at the surface or the top-most layers of the conductor, increasing the current density in that area. The inner section is used less, which lowers the conductivity and ultimately, the performance of the shield. This effect is highly evident in high-frequency electromagnetic waves. A solution for this is to increase the conductor's surface area, thereby increasing the effective conducting cross-section. Another solution is by electroplating the surface with a highly conductive material at the surface such as silver.

Absorption of the EMI

This is the secondary mechanism of EMI shielding which acts on the magnetic component of the EMI. To achieve EMI absorption, the material must have electric and magnetic dipoles. These are materials with high dielectric constant and high magnetic permeability. In the presence of an external magnetic field, the magnetic field lines are cut since they tend to travel through the material. An enclosure with this property absorbs the magnetic ane electric field lines by creating a pathway within itself. However, a problem in using these materials is that they do not have high conductivity. Thus, they are less efficient in protecting from the electric component of the electromagnetic wave.



Magnetic Field Shielding

Part of the absorption mechanism is weakening of the incoming electromagnetic wave through eddy currents. This is observed when the electromagnetic wave is oscillating at a high frequency, which induces currents within the conductor. The eddy currents create their magnetic field that opposes the external magnetic field. Materials with high electric conductivity create stronger eddy currents.

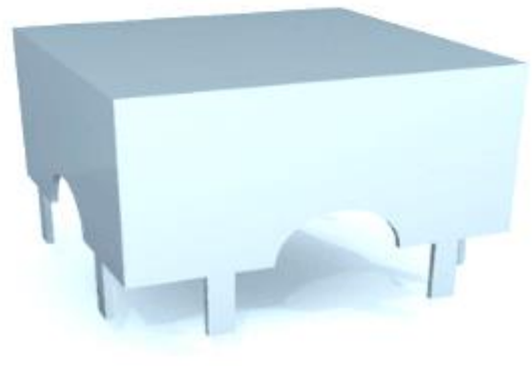
Shielding with Multiple Reflections

This is another mechanism observed in composite materials with large interfacial areas or surfaces with porous structures. Shielding is achieved by having multiple reflecting boundaries for reflecting the electromagnetic wave. This results in the scattering of electromagnetic waves.

Materials for EMI Shielding

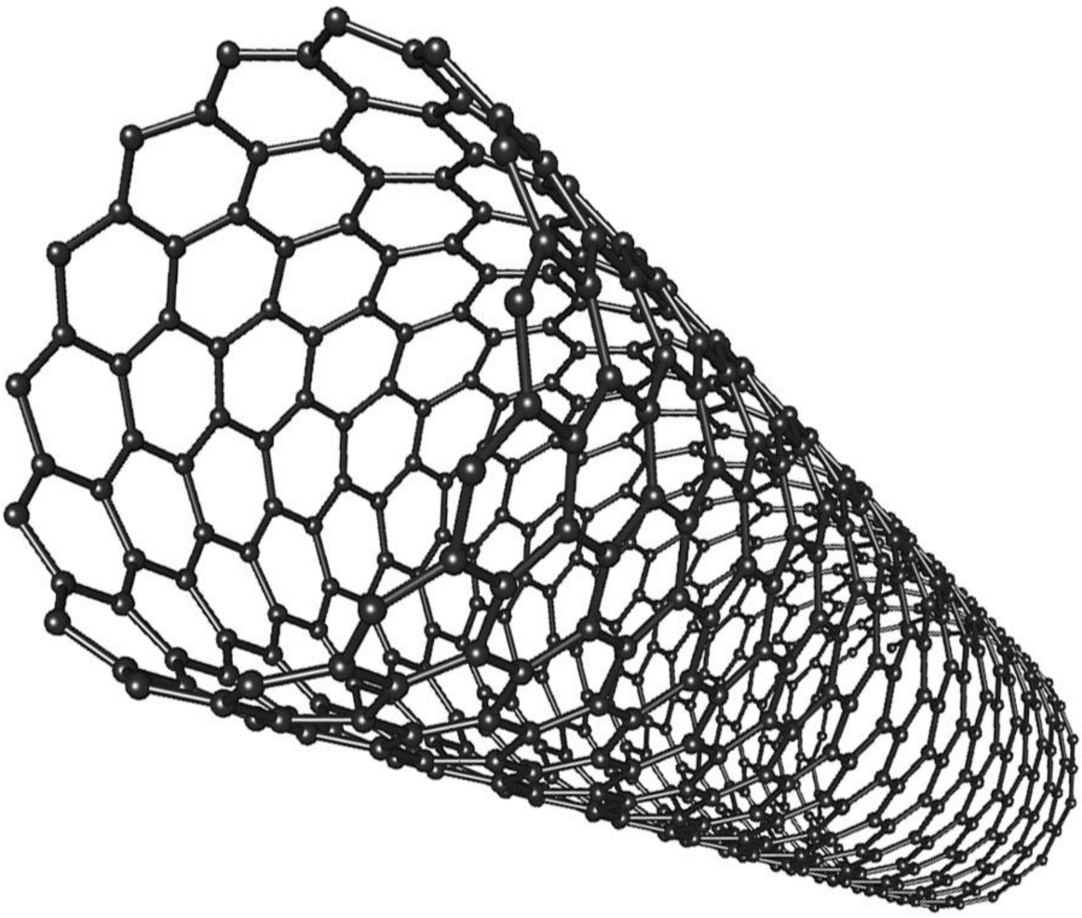
The previous chapter discussed the mechanism of EMI shielding and the desired properties of materials necessary to achieve it. Two main properties achieve EMI shielding: electrical conductivity and magnetic permeability. Below are some of the materials that demonstrate these properties.

- **Metals:** Metals are the first choice for cheap and simple EMI shielding. Their properties such as electrical conductivity, magnetic permeability, strength, and ductility make them suitable for shielding structural materials. Silver has the best electrical conductivity with good corrosion resistance, making it the most efficient electric field attenuator. The downside of using silver is its relatively high cost compared to other metals, which is why it is used as an alloying component or surface coating through electroplating. Balancing the cost and shielding efficiency, copper and aluminum are the most widely used metals for EMI shielding. The electrical conductivity of copper is almost the same as silver, while that of aluminum is 40% less. Carbon steel alloys such as mild carbon steel and ferritic stainless steel, and iron-nickel alloys such as Mu-metal, Permalloy, and Supermalloy are common materials used for magnetic shielding. The most popular is Mu-metal which has a relative permeability of 100,000 at 1kHz.



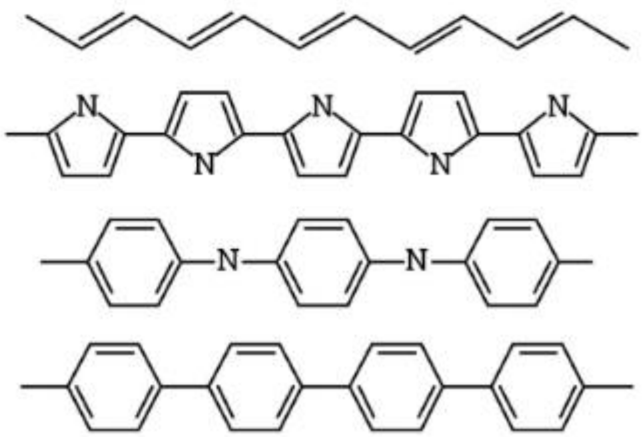
Metal EMI Shield

- **Carbon Allotropes:** Carbon allotropes are forms of carbon, such as exfoliated graphite, graphene, carbon fibers, and carbon nanotubes. They are used as filler materials for EMI shield composites. They are effective filler materials due to their intrinsic strength and conductivity. They mainly operate through the multiple reflection mechanism of shielding. Exfoliated graphite is widely used as EMI shielding gaskets due to its flexibility and ability to flow on the surface irregularities of the sealing surfaces. They have a highly porous structure that promotes EMI absorption. Graphene, carbon fibers, and carbon nanotubes are used as filler materials due to their high aspect ratio. They are commonly embedded in polymers, ceramics, cement, and metals to create rigid structures. For high-frequency shielding applications, graphene and carbon nanotubes are mostly used because the dimension of these materials is lesser than the skin depth. This makes them better conductors than metals in the GHz range.



Carbon nano Tube

- **Intrinsically Conducting Polymers (ICPs):** These are special polymers that can conduct electricity within themselves without the need for additional conducting materials. They are desired because of their light weight and processability. ICPs can conduct electricity between atoms due to the conjugated bonds (alternating single and double bonds). This enables the delocalization of π-electrons (loose electrons), which act as mobile charges. The electric conducting property of ICPs can be modified through doping or de-doping. Popular ICPs are polyaniline (PANI) and polypyrrole (PPy). The use of ICPs is still under development since several problems exist concerning their mechanical and chemical stability. They are more extensively used as components to composites containing metal nanoparticles and carbon filaments.



Alternating Single & Double Bonds ICPs

- Silicone: Silicone is not a conductive material but can be used for EMI shielding by having metal embedded in it. Since it is a flexible material, it can be cut and shaped to fit any type of EMI shielding. Additionally, silicone has become widely used because it is resistant to sunlight and water and can tolerate a wide range of temperatures. This aspect of its properties has made it an ideal solution for hot and cold environments such as aerospace. Most EMI shield silicone has a nickel graphite content and is effective at shielding radio frequencies between 20 Hz and 10,000 Hz.

- **Foam:** The type of foam used for EMI shielding is carbon foam, which is lightweight, high temperature tolerant, and has adjustable thermal and electrical properties. The two types of carbon foam are graphitic and non-graphitic. Non-graphitic foams are stronger, can be used as a thermal insulator, and cost less.
  Graphitic foam is made from petroleum, coat tar, or synthetic pitch and is more expensive to produce. Due to the expense of production, graphitic foam is in limited supply but is widely used for EMI shields. Used as an EMI shield, it is capable of shielding radio frequencies from 100 Mhz up to 20 GHz without any metal component.

Foam is an ideal material for EMI shielding due to its flexibility and adaptability. These characteristics have made it a popular choice for EMI shields. Additionally, foam lasts longer in extreme and harsh conditions, weighs very little, and does not rust or corrode. Foam is the most environmentally friendly of the many materials used to make EMI shields.

- **Foil:** Foil tape contains thin pieces of conductive metal, such as copper or silver, with an adhesive to cover a device and shield it from electromagnetic waves. The tapes are flexible, form-ffitting, and an easy and convenient method for shielding equipment. Like all tape, EMI shielding tape can be cut, shaped, formed, and configured to fit any size device without adding to its weight, making it an ideal EMI solution. It is a cost-effective, practical, and versatile material that provides excellent protection without incurring any waste.

- **Fabric:** Although EMI fabric may seem to be traditional fabric, it is used like textile fabric in EMI protection and has physical properties like conventional fabric. The substrate of EMI fabric is nylon or polyester that has been interwoven with metal. The flexibility of EMI fabric makes it possible to engineer it so that it can be effective in a wide variety of conditions and applications. EMI fabric is not the strongest form of EMI protection, but it is ideal for conditions where a moderate amount of protection is required. Since EMI fabric has a metal content, it tends to get surface corrosion in certain conditions.

Blocking Materials for EMI Shielding

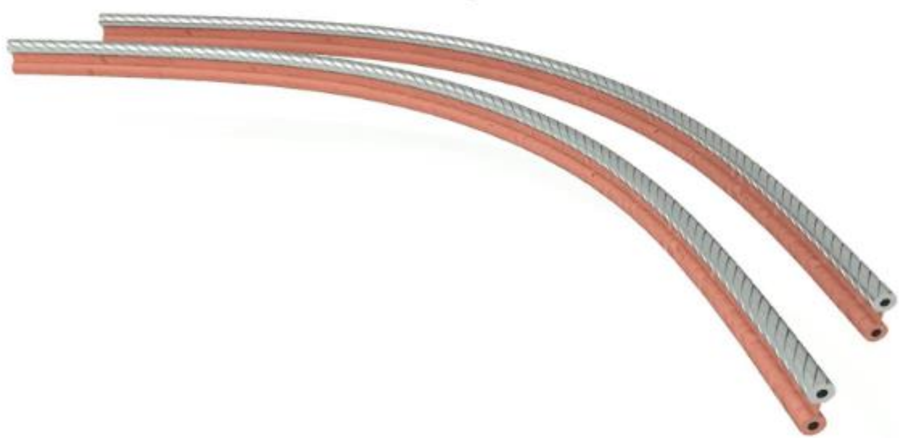
- **Green Tourmaline:** Green tourmaline is a crystal material that can overcome electromagnetic sensitivity and lessen its effects. It blocks EMFs by energy transformation by absorbing and converting negative energy into positive energy. Green tourmaline acts as protection but does not eliminate the effects of EMFs.
- **Black Tourmaline:** Black tourmaline absorbs the negative energy of an EMF and its electromagnetic waves to create a ground effect for the protected device. It has a high concentration of iron, which is especially good at absorbing and harmonizing EMFs. Black tourmaline enhances the electrical field around a device and makes it more grounded as a hindrance to radiation in the surroundings.
- **Orgonite:** Orgonite protects against the harmful effects of EMF radiation from cellphones, laptops, and televisions by neutralizing the radiation. It operates independently without the need for external excitation, such as batteries. Its energy remains active when it is placed under pressure.

EMI Shielding Design

EMI shielding can be considered the most cost-effective method of EMC compatibility since it decreases the use of intra-equipment devices to manage undesired signals. Achieving EMC through shielding depends on two factors: the structural or form design and the materials used. A simple EMI shield design is a Faraday cage made of conductive materials such as copper. The EMI shield design depends on the characteristics of the electromagnetic environment within which the equipment must reliably function. Below are some design considerations in constructing an EMI shield.

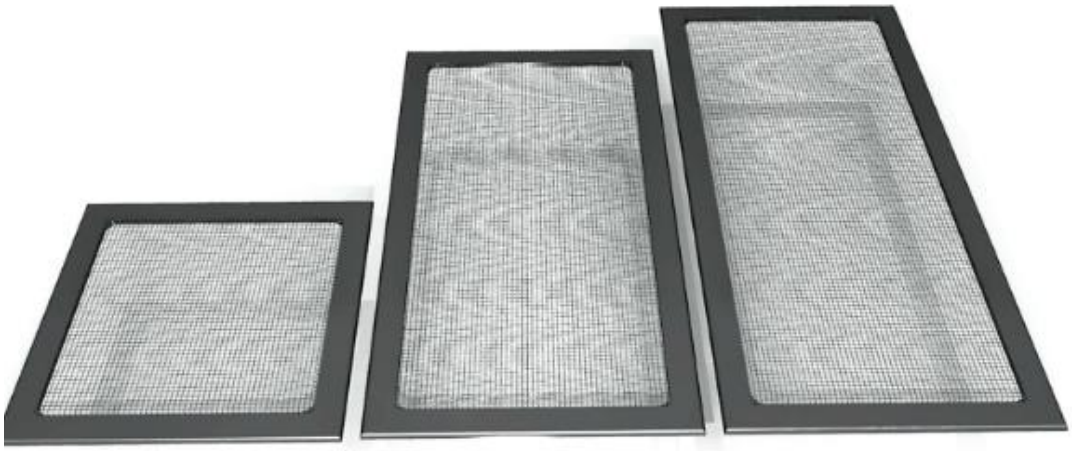
Structural Design

- Discontinuities must be minimized to control leakage of radiated EMI.
- Sufficient bonding of enclosures must be created at every seam and discontinuity to have a homogenous conductive surface. There should be metal-to-metal contact done through welding, brazing, or soldering.
- Generally, similar metals are bonded to prevent galvanic corrosion.
- The poorest electrical bond will determine the shielding effectiveness of the enclosure.
- In case permanent bonding is not possible, ensure that the chosen fastening method exerts enough pressure to maintain contact.
- For uneven surfaces, it is best to use an EMI shielding gasket. EMI shielding gaskets are commonly used for enclosures with removable panels, drawers, and covers. The gaskets fill in the gaps to provide continuous electrical contact between surfaces. The following properties must be considered in selecting an EMI shielding gasket:
  - High resilience, strength, and toughness;
  - High conductivity;
  - Corrosion resistance.



EMI Sealing Gasket

- The shielding gaskets must have the least thickness possible without compromising their strength.
- The shielding gasket should be compressed only with sufficient pressure. Shielding effectiveness only improves up to a certain limit.
- The mating surfaces of the enclosures must be free from contaminants such as oil, moisture, rust, and dirt.
- Cable penetrations can degrade shield integrity. In the case of conductors penetrating the shield, appropriate filters must be used. Filters allow the construction of intentional discontinuities in the enclosure by letting wanted signals or currents pass while suppressing the unwanted noise. They are composed of electronic components such as resistors, inductors, and capacitors to create desired impedance discontinuities.
- Shielded cables are used for signal lines penetrating shielded enclosures. These cables are grounded to the outer shield of the enclosure.



EMI Shielded Vents

- For ventilation and moisture drainage, the openings must be small to avoid decreasing the shielding efficiency. The size of the opening must be smaller than the operating wavelength.
- In case minimizing the hole-size is not possible, shielded screens must be used.

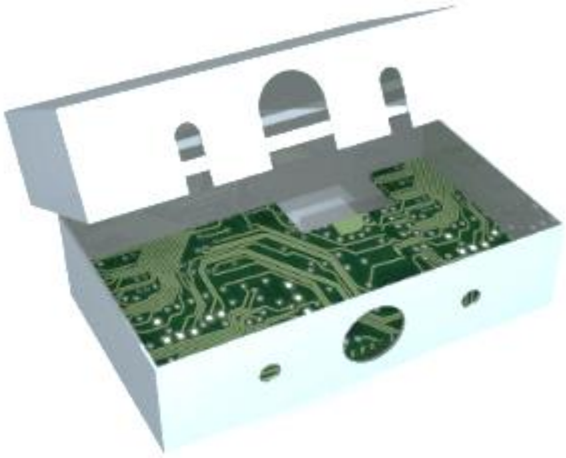
Material Selection

- The material selected depends on the relative strengths of the electric and magnetic components of the electromagnetic magnetic field.
- Low-frequency circuits are characterized by currents that provide magnetic fields, while high-frequency circuits are characterized by voltages that provide electric fields.
- Most materials suitable for enclosure construction will provide shielding against electrical fields. Typical of these materials are aluminum, copper, and silver. The predominant shielding mechanism will be signal reflection rather than absorption.
- Shielding against magnetic fields requires materials with high magnetic permeability. Typical of these materials are Mu-metal and iron. The predominant shielding mechanism is absorption rather than reflection.

Common Forms of EMI Shields

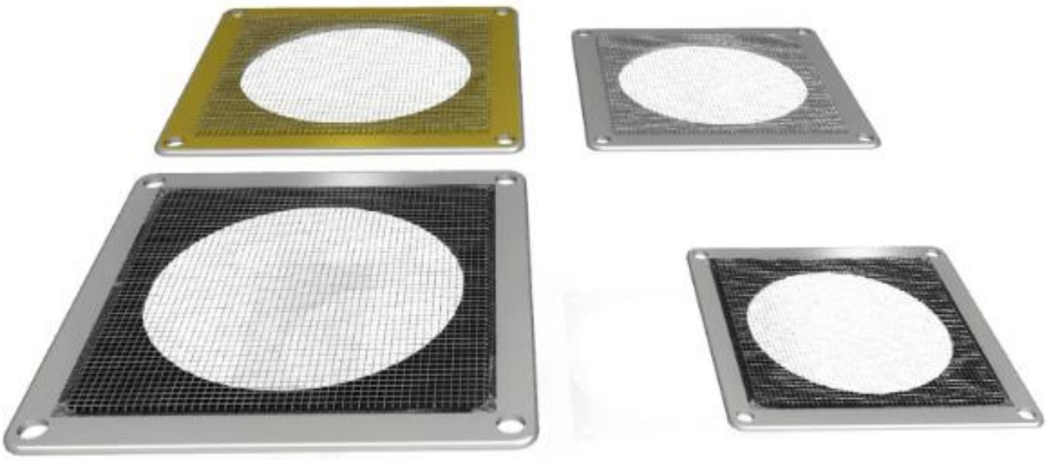
EMI shielding components have varying forms depending on the application. Below are the common EMI shields seen in the market.

- **Solid Enclosures:** Typically, metallic cases have sufficient rigidity to contain and support the device. Thus, it serves two functions. First, it acts as structural support or frame to the unit. Second, it prevents electromagnetic waves from getting into or out of the system. The enclosure is grounded so that any stray current will be diverted to ground, which minimizes the risk of electric shock.



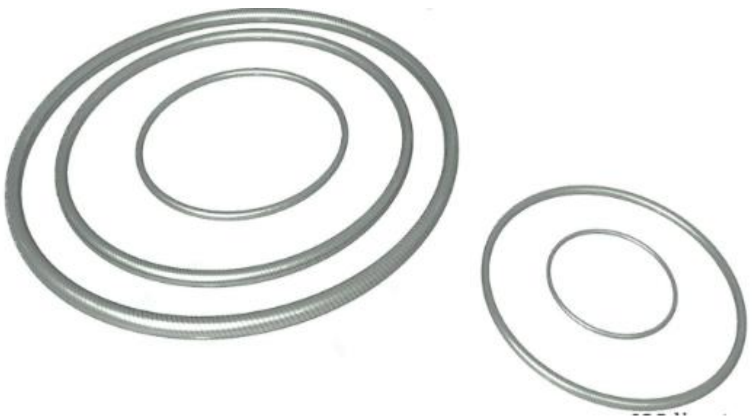
EMI Solid Enclosure

- **Wire Mesh and Screens:** These are shielding materials with penetrations or discontinuities less than the expected wavelength of the EMI. They function similarly to solid enclosures, but with the added benefit of allowing ventilation, especially for electronics that generate heat. Moreover, using wire mesh creates a translucent characteristic to an enclosure, which is useful for see-through enclosures and displays. Since the discontinuities need to be very small, they are manufactured through high-resolution processes such as photochemical etching and printing.



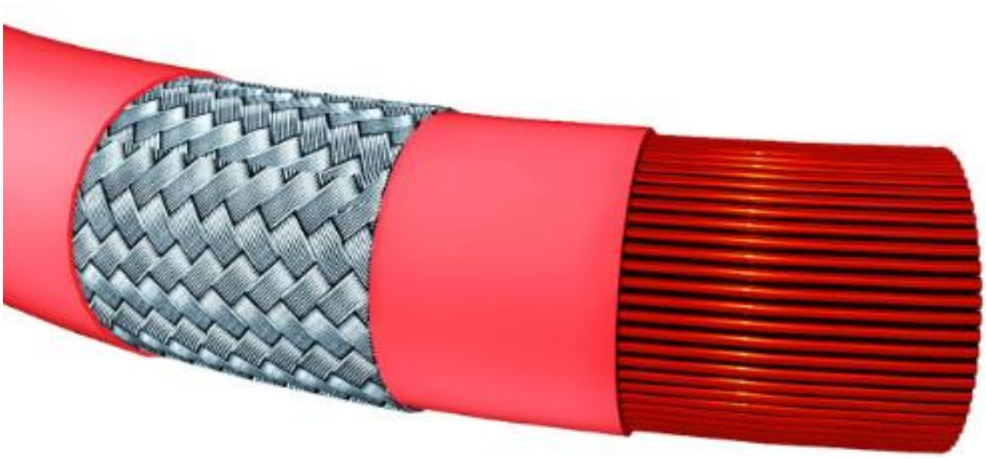
EMI Shielded Fan Filters

- **Gaskets and O-rings:** As mentioned before, the enclosures must be fully continuous without any penetrations so as not to defeat the purpose of EMI shielding. In reality, this is not the case since all enclosures must have access to the components inside. Thus, there is a continuity problem with the removable parts of the enclosure. EMI shielding gaskets and O-rings solve this problem by being able to absorb EMI, and at the same time, have the flexibility and elastic characteristics of ordinary sealing materials.



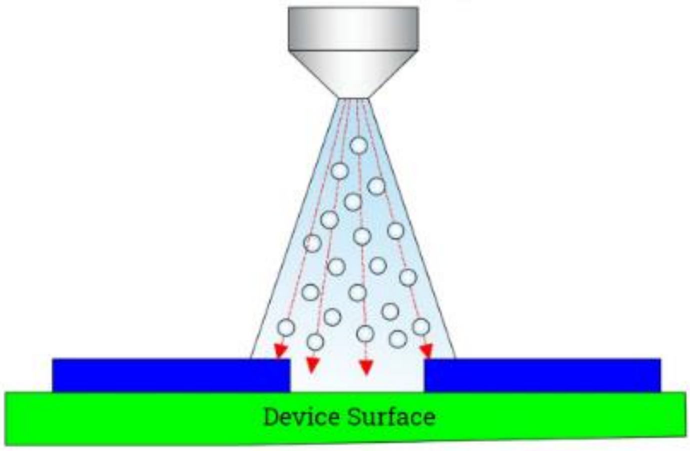
EMI Shielded O Rings

- **Cable Shielding:** These are tapes or wire braids that cover the insulated conductor of a power or instrument cable. When used in a power cable, this prevents creating electromagnetic waves that can affect nearby electronic components. When used in instrument cabling, the main function is to prevent external electromagnetic waves from distorting the signal that flows through the cable. The shielding is grounded so that any leaking current or stored electricity through parasitic capacitance is diverted to ground.



Shielded Cables

- **Coatings:** EMI shielding materials can also be coated through painting, spraying, dispensing, and electroplating. These are typically used in lightweight applications, such as mobile devices, where metallic shielding is impractical.



EMI Coating

- EMI shielding is a technique of creating a barrier that prevents leakage of strong electromagnetic fields that can interfere with sensitive devices and signals.
- Electromagnetic interference (EMI) is the coupling of signals from one system to another. It is a problem for most electronics since it can decrease the performance of the circuit or even cause it to fail.
- EMI shielding operates under three mechanisms: reflection, absorption, and multiple reflections.
- Two main properties achieve EMI shielding: electrical conductivity and magnetic permeability.
- EMI shields are available as solid enclosures, wire mesh, screens, gaskets, O-rings, cable shields, and coatings.

PCB Design Guidelines to Reduce EMI

Both conducted and radiated EMI in a PCB can come from a variety of sources, including:

- Switching devices
- Switching pulses
- High-speed digital signals
- Clock signals

Obstructions in current paths, especially in high-frequency PCBs, generates EMI and threatens the EMC of a board. At high-frequency operation, metal projections (such as heat sinks) behave as antennas radiating electromagnetic emissions. Similar to the causes mentioned above, 'n' number of factors influence the generation of crosstalk, noise, distortion, and EMI in PCBs.

Since EMI can stem from a variety of places, multiple areas on a PCB need to be considered to mitigate the negative effects of EMI. Here are some modifications to consider to increase the EMC of a PCB design:

- Minimize trace length
- Avoid routing over split planes
- Minimize the inclusion of vias
- Close routing of differential pairs
- Isolate high-speed traces
- Separate analog from digital circuits
- Separate power from control circuits
- When using ICs on a board, include decoupling capacitors near the VCC pin
- Guard critical circuits using EMI shields

EMI Shielding in PCBs

EMI shielding is often used in PCBs used in the medical, communication, and military fields. In RF or high-frequency circuits, EMI shields are often used in the input, output, and amplifier stages, as these sections are more vulnerable to EMI.

In EMI shielding, critical circuits are covered using metal shields that protect from the radiation and absorption of EMI. EMI shields isolate the encapsulated circuit or components from the rest of the board without altering its electrical connection with other components in the PCB. Designers connect the EMI shield to the ground to transfer the interferences or noises to the ground plane.

The EMI shield absorbs the internally or externally generated EMI. This absorption creates a current flow in the metal used for shielding. Since the EMI shields are connected to the ground plane, the currents generated from EMI leave the critical circuit without interfering with its sensitive signals. The effectiveness of any EMI shield depends on the shield material used, and the material choice is determined by the type of circuit and its frequency of operation.

Types of EMI Shielding

There are a few types of EMI shielding used in PCBs:

- **Component shielding:** A component shield encases a component that is either susceptible to or radiates EMI.
- **Board shielding:** A section of a board or complete board can be encapsulated inside EMI shields to prevent the detrimental effects of EMI from reaching other circuits.
- **Cable shielding:** In high-frequency circuits, the presence of parasitic reactance aggravates the effect of EMI in cables carrying analog or digital signals. Cable shielding is an excellent solution for minimizing the EMI in cables.

EMI shielding in PCBs is a great method of protection against the ill effects of radiated and absorbed EMI. A PCB design with EMI shields can increase the reliability and signal integrity of circuits.

References

www.iqsdirectory.com

www.cadence.com