

# EMI SHIELDING SOLUTIONS USING STAINLESS STEEL FILLED THERMOPLASTIC COMPOSITES

*James J. Fagan, Constant W.L. Peek*

*General Electric Plastics*

## Abstract

With the increasing amount of onboard electronics and microprocessor-controlled systems on automobiles it is important that the electronic sub-assemblies (ESAs) in a vehicle are designed to be electromagnetically compatible (EMC). Design for electromagnetically compatibility can be achieved in a number of ways, including the use of enclosures or housings with shielding capabilities. There are a variety of enclosure design options to provide shielding to help meet EMC requirements, including the use of conductive thermoplastic composites that offer intrinsic shielding. This paper will present information on GE Plastics LNP\* Faradex\* melt process able stainless steel filled thermoplastic composites and their potential for use as electromagnetic shields. Shielding models, product performance features along with design and processing information critical to achieving effective shielding will be discussed.

## Background and Requirements

It is clear how critical the need for electromagnetic compatibility is, when considering the electronic systems that contribute to the control and safe operation of an automobile. If airbag, cruise control, anti-lock braking, and other electronically controlled assemblies are adversely affected by electromagnetic radiation, the operator's control of the vehicle, not to mention safety, could be compromised. Mandated by safety and reliability requirements, legislative, and agency standards, today's automotive onboard electronic sub-assemblies (ESAs) must be electromagnetically compatible (EMC). This means they must not emit interfering electromagnetic signals, and be immune to external interfering signals. These emissions and immunity performance requirements apply to radiated as well as conducted signals. Additionally electromagnetic compatibility standards require ESAs to be immune to potential electrostatic discharge events. Although there are no harmonized international standards and legislated requirements vary throughout the world, there are several recognized standards of conformance as outlined in Figures 1 and 2 [Lit. 1]. Most OEM's have developed their own internal standards that allow them to meet the requirements of all the geographic markets into which they sell. It is important to note that compliance testing, is carried out on two levels, one for the individual ESA and the other for the whole vehicle. Regardless of whether the ESA is being tested or the whole vehicle, both types of evaluation are done at a system level under actual operating conditions or simulated conditions designed to represent worst-case conditions. Ultimately, it is the on-vehicle results that are the most important as these results reflect future product performance when it passes into possession of the end-user. However since the cost of testing on-vehicle is significantly higher than for an individual ESA, most suppliers and OEMs conduct the majority of their tests on the ESA and then select a small representative range of vehicles on which to perform their final whole-vehicle EMC tests. It is typical then that a line-fit ESA will likely undergo two series of EMC testing, once for the standalone ESA and a second time on-vehicle.

AUTOMOTIVE STANDARD	ISSUE DATE(S)	APPLICABLE GEOGRAPHIC REGION	TESTS COVERED
95/54/EC	1995	European Union	Radiated emissions and immunity
CISPR-12	2001	Global	Radiated emissions
ISO 10605	2001	Global	ESD
ISO 11451	1994-2001	Global	Radiated immunity
SAE J551	Various	North America	Various

Figure 1. International Automotive Standards for Whole Vehicle Testing

AUTOMOTIVE STANDARD	ISSUE DATE(S)	APPLICABLE GEOGRAPHIC REGION	TESTS COVERED
95/54/EC	1995	European Union	Radiated emissions and immunity
CISPR-25	2002	Global	Radiated and conducted emissions
ISO 7637	1995-2003	Global	Transient immunity
ISO 10605	2001	Global	ESD
ISO 11452	1995-2002	Global	Radiated immunity
SAE J1113	Various	North America	Various

Figure 2. International Automotive Standards for Component Testing

To meet the requirements of the EMC standards referenced above, electronics systems designers will often employ a combination of techniques. This typically starts with component selection, circuit design and board layout, and can also include the use of shielded cables, as well as noise filtering and suppression devices such as ferrites or clamps (common mode chokes). In addition to designing the electronics to be quiet and immune, designers will also use electromagnetic shields to block or attenuate radiated and conducted signals from being emitted from and or from penetrating to a defined space. These shields isolate the circuitry from its surrounding environment. They can consist of component-specific shields (cans), as well as enclosures or housings, which shroud circuit boards or entire systems.

## Comparing Alternative Shielding Enclosure Solutions

When considering the use of an enclosure as a shield for providing protection from EMI/RFI there are a variety of design approaches including, fabricated metal designs, foil liners, and various metallization coating techniques applied to plastic enclosures as well as the use of conductive thermoplastic composites that offer intrinsic shielding.

Fabricated metal designs including die-casting, machined components and progressive stamped sheet metal are approaches offering electromagnetic shielding performance. However they do have drawbacks including, susceptibility to corrosion and weight disadvantages. Furthermore the need to perform secondary manufacturing steps in order to incorporate design features and assemble components to create complex geometries can mean higher manufacturing costs and longer manufacturing cycle times.

Application of metallization treatments to the surface of plastic substrates (via spray coating, vacuum deposition or electroplating) offers a means of delivering electromagnetic shielding performance. However the extra manufacturing steps can extend cycle times and negatively

impact WIP inventories. Furthermore, there can be significant costs associated with fixtures, tooling and masking needed to properly handle and coat parts. Critical to shielding performance is achieving uniform coating thickness. This can be a challenge on parts with deep draws or complex internal features where line of sight challenges exist. Additionally scratches and coating delamination can compromise shield performance. Lastly the environmental health and safety costs (EHS) costs associated with these coating processes due to control and handling of hazardous chemicals, emissions, and waste can be significant.

Conductive thermoplastic composites utilize a variety of conductive fillers including carbon powders and carbon fibers, silver coated glass beads and fibers, nickel coated carbon fibers, and stainless steel fibers. When well dispersed in a thermoplastic matrix, relatively small amounts of the SS fibers with the proper aspect ratio will provide shielding against electromagnetic waves without any post treatment steps needed. The very small diameter fibers when uniformly dispersed create an electrically conductive network that acts like a Faraday cage. This permanent shielding property is in most cases more cost effective and much more durable than any post treatment of plastic parts. While the molded parts are robust and require no secondary treatments, achieving optimal shielding effectiveness requires the right balance of fiber dispersion while minimizing attrition.

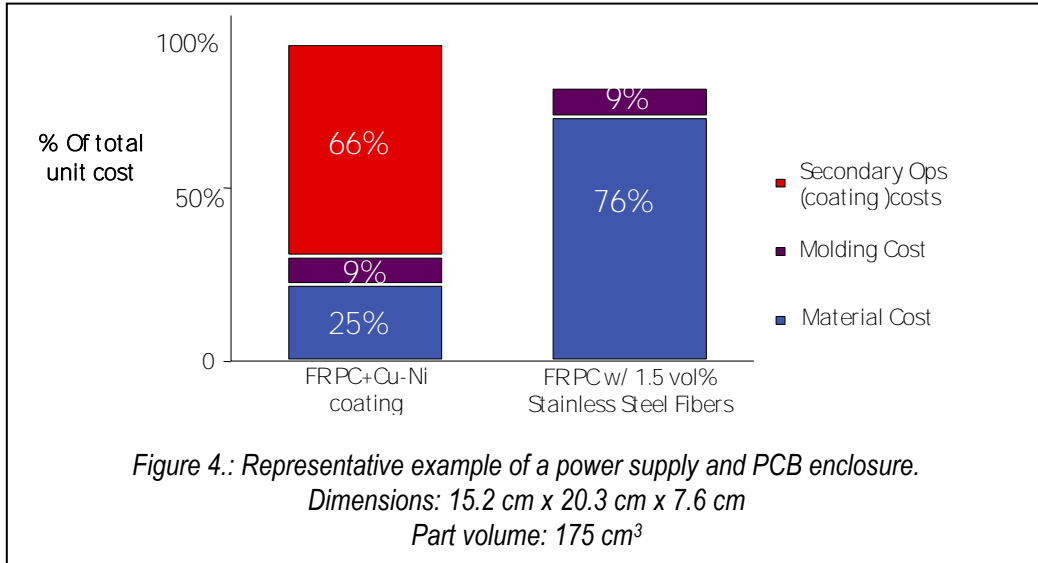
Bulk Shielding Method	Performance Metrics						Comments
	Weight Reduction	Relative Cost	Shielding Effectiveness	Recyclability	Waste Generation	Design Flexibility	
<b>Conductive Compounds</b> (LNP* Faradex* compounds)	●	○	○	○	●	●	Design sensitive. Limited shielding ability around apertures and joints. Part thickness dependent.
<b>Plating Methods</b> (Electroless and electro-plating)	●	○	○	○	○	○	Masking limitations, waste disposal, EHS issues. Tooling & fixture costs.
<b>Conductive Spray Coats</b> (Paints, zinc arc)	●	○	○	○	○	○	Masking limitations, adhesion to plastics.
<b>Metallization</b> (Vacuum, cathode sputtering)	●	○	○	○	○	○	Tooling, fixtures, masking limitations, EHS, waste disposal.
<b>Metal Enclosures</b> (Die cast, foils, stamped sheet metal)	○	●	●	●	●	○	Weight, size and lack of design flexibility for complex geometries.

Most Positive ●      Moderate ○      Most Negative ○

Figure 3. Comparative Performance of Enclosure Shielding Options

### Cost Effectiveness

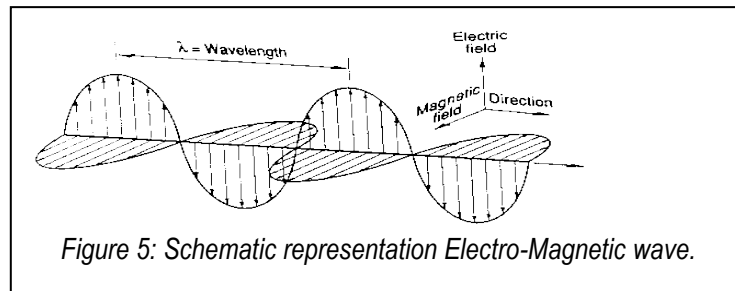
There are a variety of factors related to each design approach that contribute to the cost of producing an enclosure that will function as an effective electromagnetic shield. Such factors include; tooling costs, raw material costs, handling (such as masking, and fixturing) processing costs, packaging, transportation and inventory carrying costs. Shown in figure 4 is a comparison of a nickel on copper metallized FR polycarbonate enclosure versus a 15wt% stainless steel filled compound. As the chart shows, the intrinsically conductive compound saves about 15% per unit. It is worth noting that even though the cost of the intrinsically conductive SS filled PC is 50% greater than the FR PC, the overall cost of the intrinsic solution is 15% lower. This example does not include upfront costs of tooling and fixtures for masking or the incremental inventory carrying costs associated with servicing a secondary operation process.



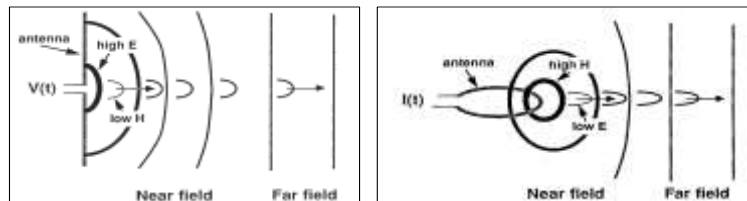
## Theory on EM-Shielding

### Electro-Magnetic Waves

Electromagnetic waves consist of two oscillating fields being magnetic and electric. These two fields are perpendicular to each other and the direction of propagation is at right angles to the plane containing these two components (see figure 5). Propagating magnetic waves always induce electric waves and vice versa. Between the two fields, energy exchange occurs [Lit. 2].



Typically electrical dipole antennas (fig.6, left) generate electrical waves that induce magnetic waves perpendicular to them. Typical examples of electric sources are antennas used in broadcasting. Loop antennas (fig.6, right) on the other hand, generate initially magnetic fields that induce electrical fields. Typical examples of magnetic sources are loop power lines and transformers.



So two generic types of electromagnetic sources exist, generating either Electric- or Magnetic radiation and they influence each other through induction. As a result, the relative magnitude between the magnetic (H) and electric (E) components changes while waves propagate, because of energy exchange. [Lit. 3, 4] The ratio of E/H is called wave impedance, Z ( ) and approaches a constant. This constant is characteristic for the medium the wave travels in and is 377 for free space. The distance from the source where wave impedance becomes constant is known as the Far field transition. This transition point is positioned at approximately one sixth of the wavelength ( $= \lambda / 2$ ) and from this point the wave can be considered as plane wave. In summary, it can be stated that the characteristics of an Electro-Magnetic wave depend on the nature of the source, the distance from the source and the medium it travels in.

## Shielding Theory

In principle, any barrier placed between an emitter and a receiver, that diminishes the strength of the interference, can be seen as an EMI – shield. How well the shield attenuates an electromagnetic field is defined as the Shielding Effectiveness (SE) The standard unit for SE is the decibel (dB) and is expressed as the ratio of the values for the electro-magnetic field strength, before and after the shield. SE of a shield is defined as the Logarithm of the ratio of the energy of the incident wave and the energy of the transmitted wave [Lit. 2]. In equation 1 and 2, the calculation for Shielding Effectiveness is given for H and E fields.

$$\text{E-field, SE} = 20 \text{LOG} \frac{E_1}{E_2} \quad (\text{Equation 1})$$

$$\text{H-field, SE} = 20 \text{LOG} \frac{H_1}{H_2} \quad (\text{Equation 2})$$

Where:

*E1=Electric strength of incident wave (V/m)*

*E2 =Electric Strength of the transmitted wave (V/m)*

*H1=Magnetic strength of incident wave (V/m)*

*H2 =Magnetic Strength of the transmitted wave (V/m)*

*SE = Shielding Effectiveness (dB)*

This indicates that when the field strength is reduced by a factor 10, the shielding level is 10dB; a reduction by a factor 100 is equal to a shielding of 20dB.

## Transmission Line Approach

The transmission line theory, widely used in physics and electronics has been applied by Schelkunoff [Lit. 5] to understand shielding phenomena. According to Schelkunoff, the total shielding is a combined effect of three elements (fig. 7.):

Reflection (R);

Absorption; (A)

Secondary Reflections (B)

The three contributing factors are part of the Vaseka-formula [Lit.6], given in equation 3.

$$SE = R + A + B \quad (\text{Equation 3})$$

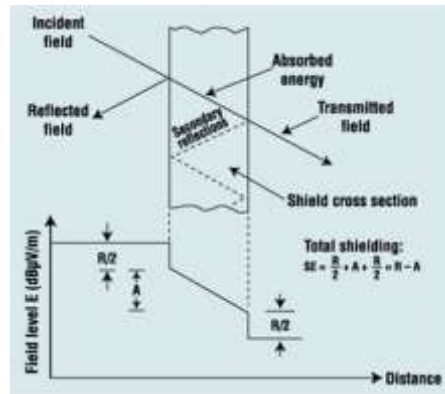


Figure 7: Model illustrating reflected, absorbed and re-reflected EM signal

From equation 3 it can be seen that reflection loss, absorption loss and secondary reflection determine the total shielding performance of a barrier. In principle secondary reflections are also part of the equation but they only become a significant factor when the absorption is smaller than 10dB.

## Reflection

In previous sections wave impedance,  $Z$  ( ) has been defined. According to theory, the bigger the difference between the wave impedance in air ( $Z_1$ ) and the wave impedance in the shield ( $Z_2$ ), the larger shielding by reflection [Lit. 4, 7]. This theory is analogue to the reflection of sound waves on a barrier, where the mismatch in density of two media determines the magnitude of reflection. In equation 4 and 5, the relationship between wave impedance and reflection is derived.

$$R = 20 \text{LOG} \frac{Z_1}{4Z_2} \quad (\text{Equation 4})$$

Where:

$Z_1$  = Impedance of the incident wave ( )

$Z_2$  = Impedance of wave in the shield ( )

$R$  = Reflection (dB)

$$Z_2 = \sqrt{\frac{\mu^*}{\sigma}} \quad (\text{Equation 5})$$

Where:

$\mu$  = Magnetic permeability of the sheet (V s/ A m)

$\sigma$  = Conductivity of the sheet (S/m)

$\omega = 2\pi f$  (Hz.)

$f$  = Frequency of the wave

It becomes clear that wave impedance in a shielding material is directly related to the conductivity of the material. The higher the conductivity, the lower the impedance. Typically, electric fields have high impedance, meaning a significant “impedance mismatch” with the conductive barrier. Magnetic fields have low impedance, similar to the impedance of the conductive sheet. As a consequence, there is little impedance mismatch and therefore very little reflection loss.

In summary it can be stated the Electro-magnetic Shielding from reflection is high when:

The source is a low frequency electrical dipole or a high frequency magnetic dipole ( $Z_1$  is high)

The conductivity of the sheet material is high ( $Z_2$  is low)

### Absorption

Absorption in a shield occurs because the conductivity and permeability of the shield prevents transmission of the wave. The term used to quantify attenuation by absorption is “skin depth”. Skin depth ( $\delta$ ) is defined as the distance an EM-wave needs to travel be reduced to 37% ( $1/e$ ) of its’ original power. The relevant relationships for shielding through absorption are given in equation 6 and 7. [Lit. 4, 8]

$$A = 20 \log e^{\frac{t}{\delta}} \text{ (Equation 6)}$$

Where:  $t$  = Shield Thickness (m)

$\delta$  = Skin depth

$A$  = Absorption (dB)

Skin depth is determined by:

$$\delta = \sqrt{\frac{2}{\mu * \sigma}} \text{ (Equation 7)}$$

Where:  $\mu$  = Magnetic permeability of the sheet (V s/ A m)

$\sigma$  = Conductivity of the sheet (S/m)

$f$  = Frequency of the wave

From equation 7, it can be seen that skin depth depends on frequency and sheet conductivity. In table 1, an illustrative example is given on the dependency of skin depth on frequency for copper and Aluminium [Lit. 7].

Table 1: Skin depth vs. frequency for Copper / Aluminum.

Frequency	Copper (mm)	Aluminum (mm)
10Khz.	0.66	0.84
100Khz.	0.20	0.28
1Mhz.	0.07	0.08
10Mhz.	0.02	0.03
100Mhz	0.01	0.01

From table 1, it becomes clear that skin depth is high at low frequencies, which is the reason that shielding against near field magnetic radiation is difficult. For near field electric fields at low frequencies, the reflection caused by “impedance mismatch”, compensates for the low absorption.

From equation 6 and 7 it appears that Shielding from absorption is high if skin depth is small. This occurs when:

- Conductivity is high;
- Magnetic Permeability is high;
- Frequency is high;
- Wall thickness is high;

From this, it appears that absorption is the dominant mechanism of shielding when the material is solid and “electrically thick”, which means that the shield thickness is significantly larger than the skin depth.

### **Final Remarks on Transmission Line Theory**

If the Schelkunoff’s shielding theory is translated to actual system parameters, the total shielding depends on:

- The electrical conductivity of the shield;
- The magnetic permeability of the shielding material;
- The wall thickness of the shield;
- The frequency of the impinging wave;
- The distance from the source;
- The type of electromagnetic source;

Wave frequency, source distance and source type are typically determined by the electronic system and not easily influenced on enclosure level. Section thickness and material properties magnetic permeability and electrical conductivity are factors that can be accounted for in shield design. Typically the achievable shielding effectiveness under far field conditions at 3.0mm for a stainless steel filled thermoplastic composite is 40-60dB depending on frequency.

### **Design Considerations**

The theory on Electro-magnetic shielding assumes infinite shields without discontinuities. Holes, joints and other discontinuities will affect total Shielding Effectiveness. Shield thickness is also an important design consideration. Because EMC performance and compliance is a systems level evaluation, it is important to understand how these factors affect shield performance and its overall contribution the overall design approach. These factors are important to consider regardless of the shield material. We will speak to these factors generally, and as they relate to the performance of stainless steel filled thermoplastic composites.

#### **Wall Thickness:**

A well-known measure for shielding performance is “square resistivity”(R<sub>s</sub>), determined by the volume conductivity ( ) and the material thickness (t),  $R_s = 1/ \sigma t$  [Lit. 4]. Under far field conditions, the square resistivity is a direct measure for the shielding effectiveness and can be expressed by equation 8.

$$SE = 20 \cdot \text{LOG}(1+188.5/R_s) \quad (\text{Equation 8})$$

From this predictive equation it appears that thicker wall sections (with equal conductivity)

will lower the square resistivity, and as a result increases the shielding effectiveness. In addition to the fact that thinner walls will reduce the effective thickness of the shield, in stainless steel filled thermoplastic composites, thin wall sections also increase the risk of fiber breakage during injection molding. This can occur during the filling and forming process where pressure and shear stress on the heterogeneous melt can be as high as 15,000 psi. Parts with thinner walls will result in higher stresses on the heterogeneous melt front. To minimize the potential for attrition in the molding cavity a wall thickness of .080" (2mm) is recommended. Generous radii on corners and gradual wall thickness transitions are recommended to minimize fiber attrition during filling and forming of the molded part. The effect of wall thickness on shield attenuation performance is shown in figure 8 below.

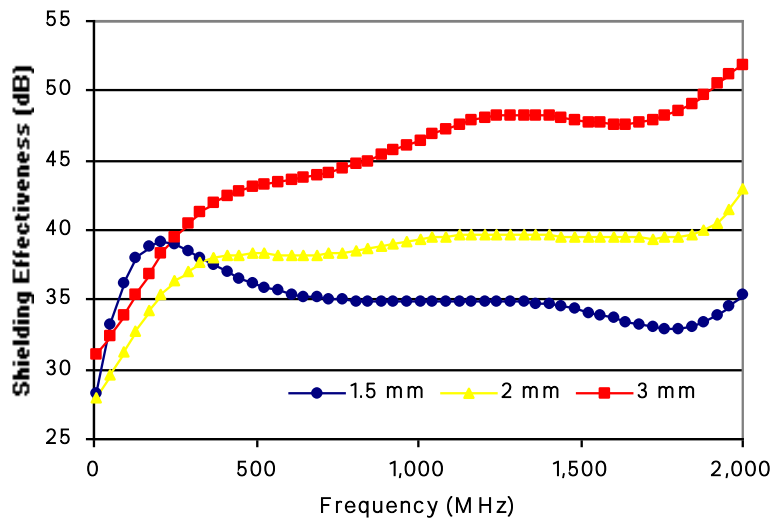


Figure 8: 1vol% stainless steel filled polycarbonate tested at different wall thickness per ASTM D4935

## Joint Design

Electromagnetic signal leakage between mating surfaces at joints or seams is the main reason why overall shielding effectiveness of the enclosure is reduced. Leakage occurring at joints due to poor continuity is referred to as a “slot antenna”. Since part of the shielding effectiveness results from induced currents, flowing through the shield, performance not only depends on the materials resistivity, but also on minimizing the resistance to these induced current flows at these joints or seams. A parallel circuit of a capacitor and a resistor can represent this opposition, or contact impedance (Fig 9).

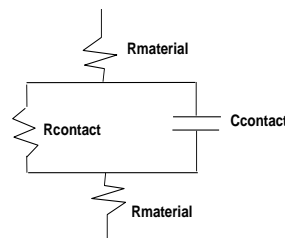


Figure 9. Electrical Circuit Model for a seam or joint

Since the overall volume loading of the conductive matrix is typically low, the electrical contact between mating surfaces is typically not continuous, and in effect, there is a “hole” in the conductive shield around the object being shielded. This is often further complicated by the desire for a good surface appearance, which results in a “resin rich” surface, at the joint “burying” the conductive fibers beneath the skin of the part. This results in high impedance at the part joint interface. Increasing the area of contact via lap joints, or tongue and groove joints can reduce the contact resistance. At higher frequencies (>150 MHz.) increasing the contact area will also reduce the capacitive coupling of the joint. Shielding at lower frequencies (<150 MHz.) is less sensitive to capacitive coupling effects. Under these circumstances good electrical contact between the parts (minimizing contact resistance) is essential. Other techniques to reduce the contact resistance are use of interference fits, ultrasonic, or vibration welding, use of self-tapping screws, and conductive gaskets.

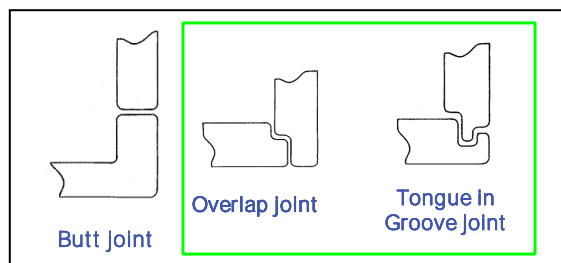


Figure 10. Enclosure joint designs

### Aperture Design:

Holes and slots in an enclosure are another potential source of EMI leakage. Apertures and other discontinuities in a shield force currents to flow along an alternative path. This effect increases the total resistance of the shield and will reduce the overall effectiveness of the electromagnetic shield. The further the current is deflected (as measured by the size of the aperture) the greater the decrease in shielding effectiveness is. Furthermore, holes and slots can act like windows for electromagnetic radiation to escape or penetrate the shield. Leakage through an aperture is affected by the size of the aperture, the wavelength/s of the field/s being shielded, and by the orientation of the plane in which the aperture exists in relation to the plane of propagation of the electromagnetic field. The use of many small holes allow for less leakage than a large hole of the same area see Figure 11. Predictive models illustrate that in general the hole size should not exceed  $\lambda/50$ . Generally it is also recognized that leakage is dependent on the frequency of the wave (higher frequency waves leak easier than lower frequency) and aperture size. Rules of thumb suggest the largest dimensions of aperture should be minimized, i.e. narrow, short, deep slots are better than long, wide shallow slots.

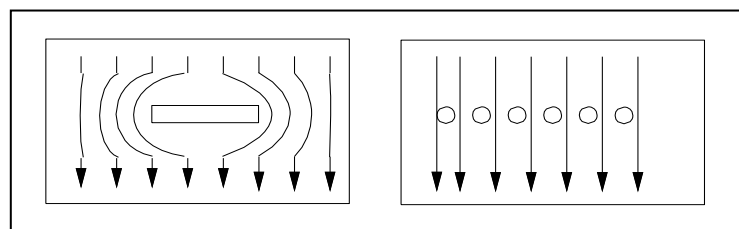


Figure 11. Disruption of induced current flows as a result of aperture size and geometry.

## Thermoplastic Materials with Improved Conductivity

In their natural state, without any additives or modifiers, almost all commercial plastics are electrical insulators, meaning that their resistance to electron passage is extremely high (generally  $>10^{15}$  ). This specific property has allowed the application of thermoplastic materials in connectors and other applications that require insulating materials.

However, in order to broaden the application field of thermoplastic materials, ways to enhance the conductivity of plastics have been developed. In table 2, the different classes within the conductivity spectrum are displayed.

Table 2: Identified Classes of conductivity for materials

Conductivity Class	Surface Resistivity, ( /Sq)
Insulation	$>10^{12}$
Antistatic	$10^9-10^{11}$
Electrostatic Dissipation (ESD)	$10^4-10^6$
Electromagnetic Interference (EMI)	$10^1 - 10^2$
Conductive	$<10^1$

While metals are in the conductive range, the subclasses antistatic, ESD and EMI are generally known as semi-conductors. Through modification, thermoplastic materials can be shifted from insulative, into a more conductive class. The most common methods can be divided into three categories: chemical additives, inherently dissipative and conductive polymers and conductive fillers. Within the scope of this discussion, we will include comments on inherently dissipative and conductive polymers and conductive fillers.

### Inherently Dissipative and Inherently Conductive Polymers.

Inherently dissipative polymers are copolymers that contain two or more blocks. A typical example is polyethylene oxide (PEO), shown in Figure 12. The oxygen atom in the chain, adds a polar character to the chain, which allows the polymer to attract and interact with both water and ions. Conduction occurs when ions hop or jump from oxygen to oxygen, thus traveling along the chain length [Lit. 9].

Typically, an IDP is mixed with a resin, like polypropylene at appropriate to reduce the resistance to the  $10^9$ - to  $10^{12}$ - range. Similar to the mechanism for chemically, modified antistatic materials the mechanism of an IDP is based on using the conduction associated with the movement of ions and charged species.

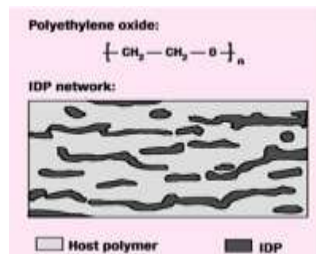


Figure 12: An IDP (PEO) in a polymer matrix

Different than IDP's were the additive creates the conductive path, with inherently conductive polymers, ICP's the polymer chain provides the conductive path for the electrons.

This is caused by a dramatic change in polymer architecture. A typical example of a conducting polymer is polyacetylene (Fig. 13) containing both single and double bonds. In particular, the single and double bonds must alternate within the structure.

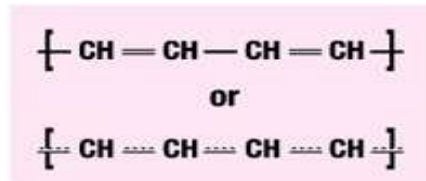


Figure13: The chemical structure of Polyacetylene.

This so called "conjugated system" allows the extra electrons of the double bonds to move throughout the system. In order to ensure that the conjugated polymer conducts electricity, it must first be doped. This step includes adding an oxidizing or reducing agent, a chemical that removes electrons from or add electrons to the polymer.

ICP conductivity can reach as conductivities as high as  $10^4$  S/cm ( $10^{-4}$  -cm resistivity). However, typical conductivity is in the range of 1–100 S/cm. The first generation of intrinsically conductive polymers did not achieve great commercial success. These polymers tended to be insoluble, very hard to process, and extremely sensitive to environmental conditions. However, several more-recent polymers have been developed that exhibit much greater stability and show the promise of commercial success.

### Conductive Fillers.

Perhaps the oldest and best-known method of making a plastic electrically conductive is to load the resin with a conductive filler to make a composite. In literature, two basic mechanisms for conduction in systems consisting of conductive fillers in a non-conductive matrix, are proposed conduction through electron tunneling and through percolation. The two mechanisms are displayed in Figure 14 [Lit. 10].

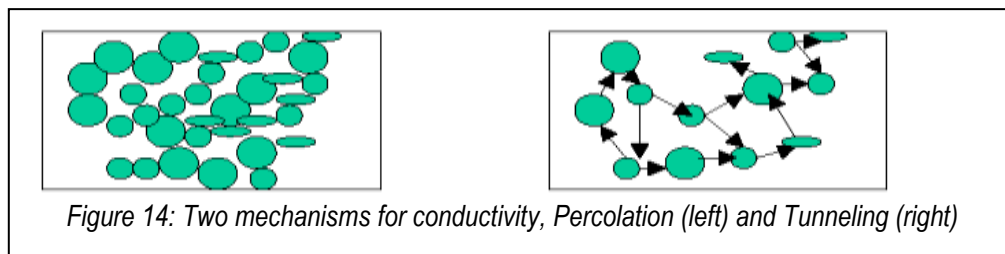


Figure 14: Two mechanisms for conductivity, Percolation (left) and Tunneling (right)

Electron tunneling is the effect that results when applied current polarizes the conductive system causing the electrical resistance to drop by charge effects. As currents, especially high currents continue to be applied polarized particles might migrate and further coalesce. This mechanism requires certain mobility of the conductive particles.

Since the mobility of conductive particles in most thermoplastic systems is limited, percolation is the dominant mechanism. This implies that particle-particle contact is required for a good conductivity. Figure 15 gives a simplified view of this percolation transition.

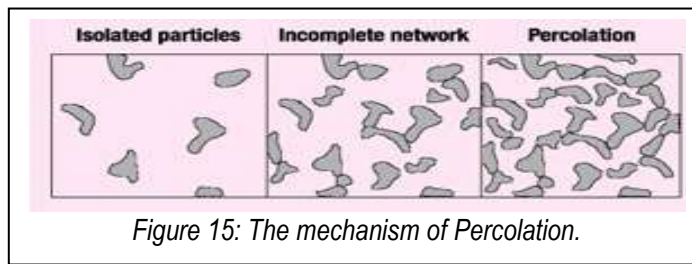


Figure 15: The mechanism of Percolation.

At low filler loadings, the filler particles act like conductive islands in the insulating resin. As filler volume increases, the conductive particles become more crowded and the probability for contact between the conductive particles becomes larger. Finally, at the percolation threshold, the majorities of particles are in contact with each other and form a continuous network. An electrical charge can now pass through the composite without encountering the high-resistance polymer resin. Additional filler loading beyond the percolation threshold does not greatly reduce the resistance of the composite. A typical Percolation curve is displayed in Figure 16.

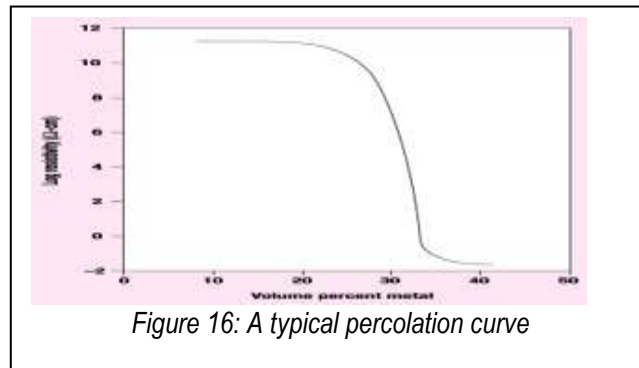


Figure 16: A typical percolation curve

Particle conductivity, loading level, and particle shape are the three key factors, determining the final conductivity of the thermoplastic composite.

The shape of the particle plays a critical role in determining at what volume % percolation will occur. The more structured the filler, the more likely it is to contact a nearest neighbor and form a continuous network. Perfectly spherical fillers will percolate at higher volume loadings, compared to fillers with a high aspect ratio such as carbon fibers or stainless-steel fibers. Stainless steel fibers typically have an aspect ratio >500.

For this reason and the fact that their inherent conductivity is high, Stainless steel fibers are extremely effective conductive fillers, which can even be used in EMI shielding applications. Figure 17, shows a microscopic picture of stainless steel matrix.



Figure17: Stainless Steel Fiber Network.

In figure 18, the shielding performance of stainless steel fiber modified compounds is displayed. Depending on the fibre loading and thickness of the shield, values of >50dB can be achieved under far field conditions.

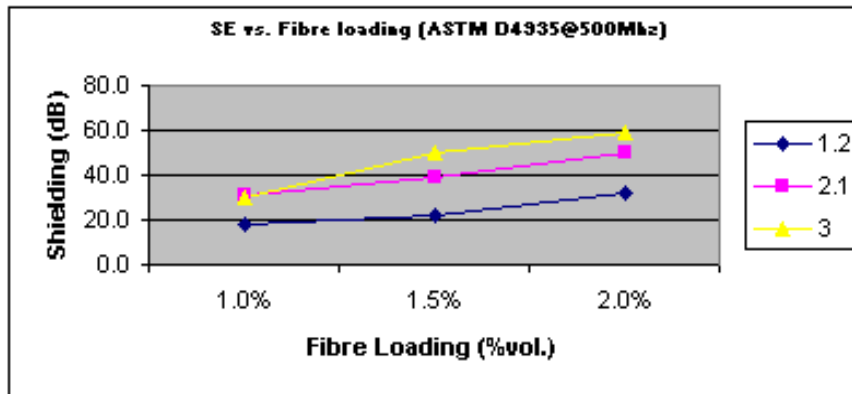


Figure 18: SE vs. Fiber Loading at various wall thicknesses (in mm)

### Material Characteristics of Stainless Steel Modified Compounds.

We have seen that stainless steel fiber modified compounds have the capability to provide shielding at relatively low volume % loading levels. In addition to understanding the electrical and magnetic properties of the shield material, consideration of other material performance characteristics must be accounted for in the material selection process. As a full explanation of these other performance attributes is beyond the scope of this paper, brief overview will be provided here.

#### Mechanical Properties;

This includes tensile, flexural and impact properties. As well as long-term performance characteristics such as creep and fatigue resistance. Stainless steel fibers provide no real boost in strength or stiffness properties and most mechanical properties of the compound are similar to that of the base resin. Impact properties typically are reduced by the presence of the fibers, but impact modifiers can add back some of the toughness and ductility that is lost. Products having increased toughness as well as improved stiffness or heat resistance are available.

#### Environmental Resistance;

This includes heat resistance and chemical resistance. As with mechanical properties, heat resistance is not affected by the presence of stainless steel fibers as it is with other types of structural fibers (glass or carbon), so the short term and long term thermal capabilities of these composites is a function of the base resin selected. The chemical resistance of these composites is also a function of the base resin.

#### Physical Properties;

Typically the density of these composites will increase by up to 10% do to the inclusion of the stainless steel fibers. Because the volume % loading of stainless steel fibers is low, both moisture absorption and CTE are typically comparable to the base resin of the composite.

#### Aesthetics;

Different than carbon modified compounds stainless steel fiber modified compounds are

colorable to an extent. Although fibers might appear at the surface of light colors, color ability is a feature available with these composites.

## Shielding Measurements

As discussed previously, when addressing EMC standards electronics systems designers are concerned about overall system compliance. As such they will typically employ a combination of techniques to achieve electromagnetic compatibility including electromagnetic shields. In order to effectively incorporate a shield as part of an overall design, it is important to understand the shield materials electrical conductivity and characteristic shielding performance. Two methods of characterizing these properties are discussed below.

### Bulk Conductivity

A known method for determining the resistance of a sheet sample is the “Four-point”-method. (ISO 3915) The method measures the square resistance ( $R_s$ ), which is defined as the resistance from one side of a square material sample to the other. The square resistance is determined using four electrodes (Figure 19).

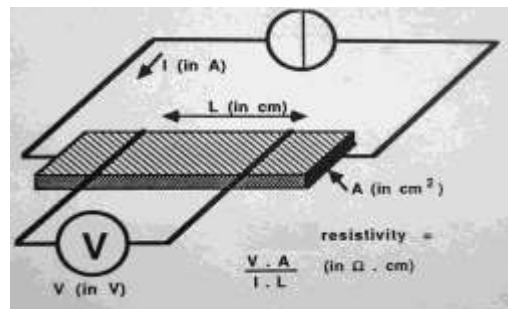


Figure 19: The four-point measurement setup.

From equation 9 it can be observed that  $R_s$  is independent from the sample area dimensions, so is  $R_s$  a typical material property and has a direct relationship to Shielding Effectiveness, ref equation 8[Lit. 5].

$$R_s = \frac{l}{*l * t} = \frac{1}{*t} \quad (\text{Equation 9})$$

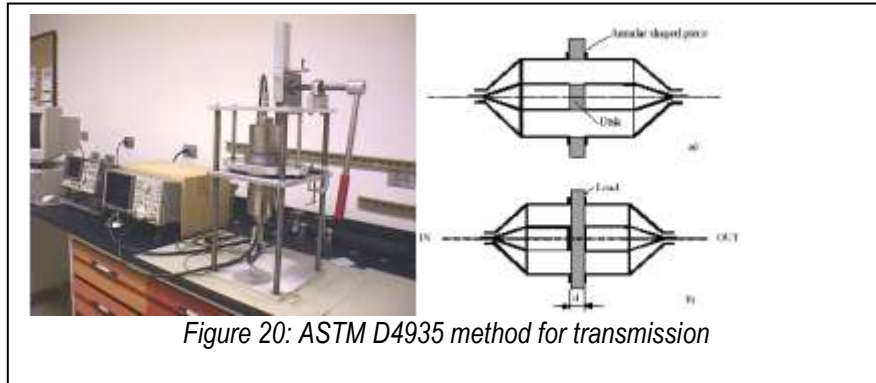
For materials like metal, having a homogeneous conductivity throughout the sample this method is effective and reliable. However, for materials having a conductive network embedded in a “non-conductive” matrix, the method is less suitable due to the presence of a “non-conductive” surface layer.

### Far Field EMI-shielding (ASTM D4935)

The only standardized method for characterization of base materials is ASTM D4935. The method is suitable for measuring heterogeneous materials and reports shielding effectiveness (SE) of a planar material, exposed to a plane, far field Electro-magnetic wave. Typically, the measurement is conducted over a frequency range 30MHz.– 1.5GHz. The apparatus for

performing this test is shown in Figure 20.

The method is method suitable for various kinds of materials and shows good precision and accuracy [Lit. 11, 12]. ASTM D4935 is a good method to support product development efforts and as a comparative method for evaluating the performance of different shield materials.



## Processing of Stainless Steel Modified Compounds

In general Stainless Steel Modified compounds can be processed like unfilled resins on conventional molding machines. However, mild processing conditions are preferred to prevent fiber attrition and to ensure the optimal shielding properties. General recommendations for Injection Molding of Stainless Steel Fiber Modified composites include:

- Melt and Mold temperatures are set relatively high;
- Plasticizing is performed gently;
- Injection pressures are minimized.

Recent studies highlight how proper processing conditions are critical to achieving optimal Shielding Effectiveness. Using a 400 ton injection-molding machine (Engel HL400) 400\*300\*3mm plaques were molded with variable backpressure, plasticizing speed, injection speed, barrel temperatures and gate dimensions. The study was performed on stainless steel modified Polycarbonate and the results are graphed in Figure 21.

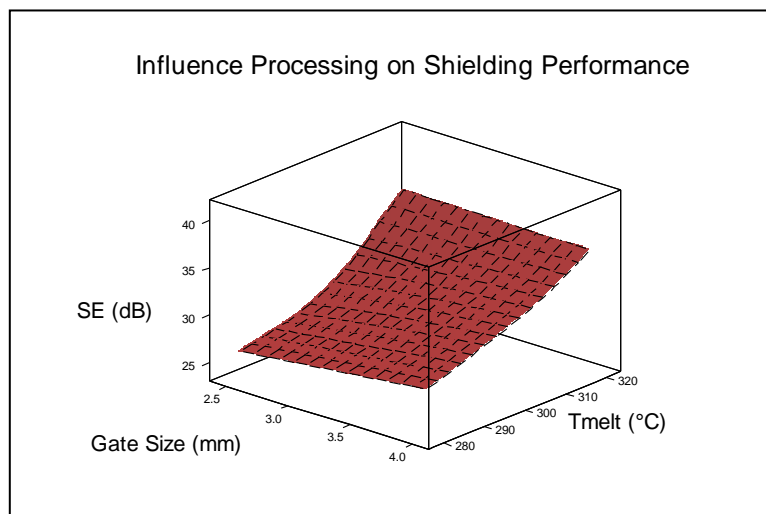


Figure 21: Study Illustrating Processing Variable Influences

Review of the graph highlights how processing temperature influences shielding effectiveness. This is because at elevated temperatures the viscosity of the composite melt is reduced and the required pressures to process the material are reduced resulting in reduced fiber attrition and an optimum stainless steel fiber network.

The result of proper molding conditions that optimize dispersion and minimize attrition can be seen in the SEM image below in figure 22.

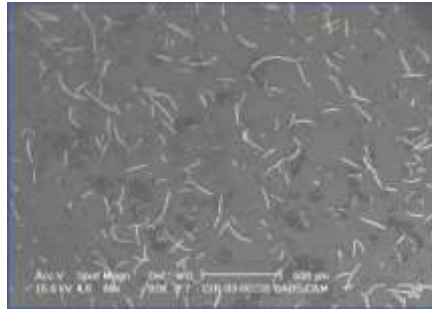


Figure 22.

Another area of investigation was the effect of using hot runner systems during injection molding of stainless steel fiber filled composites. Hot runner systems are commonly used to reduce cycle times and reduce material consumption by eliminating runner scrap. Figure 23 shows the shielding effectiveness (SE) performance for an ABS-based material processed using three different types of hot runner delivery systems.

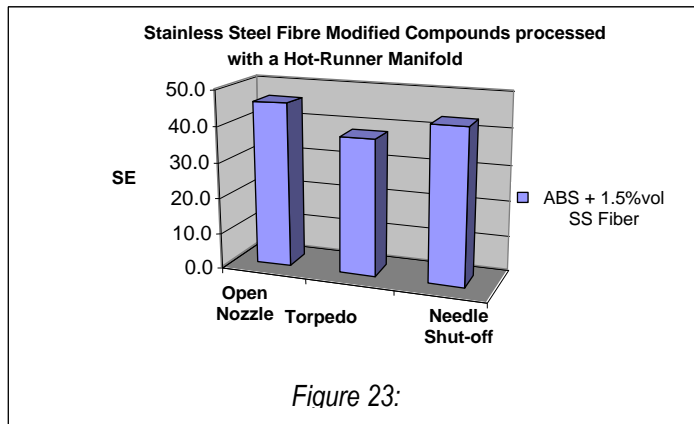


Figure 23:

It can be observed that reasonable performance is measured for the hot runner with the open nozzle and with the needle shut-off valve. However parts molded through the torpedo shaped hot runner show significantly less shielding effectiveness. This results from the fact that the torpedo design, by nature increases the internal shear condition during molding resulting in fiber attrition. These results show that stainless steel fiber modified compounds can be processed on tools equipped with hot runners, as long as hot runner selection is performed properly.

## Conclusions

Through both theoretical explanation and practical application and testing it has been demonstrated that melt processable stainless steel filled thermoplastic composites can function as effective electromagnetic shields. As such they offer electronics and compliance engineers a solution path for achieving electromagnetic compatibility (EMC) in a variety of automotive electronics applications. The inherent benefits of working with thermoplastics including design flexibility, potential for parts consolidation, weight reduction and corrosion resistance combined with the intrinsic conductivity feature provides potential productivity and cost advantages. Continued investigation into understanding absorptive and reflective attenuation effects, methods for reducing contact impedance at seams and joints and ongoing refinements of compounding and injection molding processing parameters will lead to performance enhancements that will help broaden the usefulness of these composites and expand the range of applications that they can support.

## References

1. O'Hara, Martin, "Automotive EMC testing", Interference Technology, 2004 Annual EMC Guide, Test Equipment-Automotive pp. 1-9 (2004).
2. Chromerics Corporate Literature, *EMI Shielding Design*, available through [www.chromerics.com](http://www.chromerics.com):
3. Björklöf, D., *Shielding for EMC*, ETL SEMKO, available through [www.ce-mag.com](http://www.ce-mag.com)
4. *Faradex DSM & Conductive literature, Introduction to Faradex*, (1999).
5. Schelkunoff, S.A., *The Impedance Concept and its Application to Problems of Reflection, Refraction, Shielding and Power absorption.*, BSTJ 17, (1938), 17-49.
6. Vaseka, G.J., *Theory, Design and Engineering Evaluation of Radio Frequency Shielded Rooms.*, U.S. Development Centre, Johnsville (PA), Report NADC-EL-54129, August, (1956).
7. Clark, T.L., et al, *The Marshall Space Flight Center Electromagnetic Compatibility Design and Interference Control (MEDIC) Handbook*, Marshal Space Flight Centre, (January 1995)
8. White, D.R.J, *A Handbook on Electromagnetic Shielding Materials and Performance*, DWCI, USA, (1980)
9. Grob, M.C., et al, *Permanent Antistats: New developments for Polyolefin applications*, Ciba Specialty Chemical inc., (1999).
10. Ritter G. W, *Electrical Current Effects on Conductive Eposies*, Proceedings of the 22<sup>nd</sup>, Annual Meeting of the Adhesion Society, 56-59, (1999).
11. ASTM D4935-99, "Test Method for Measuring the EM Shielding Effectiveness of Planar Materials", American Society for Testing and Materials, W-Conshoocken (PA), (1999).
12. Badic M., *The Failure of Coaxial TEM Cells ASTM Standards in HF-range*, Research Institute for Electrical Engineering, Bucharest, Romania.