Elerctromagnetic Compatibility Design Guide

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Electromagnetic Compatibility Design Guide

The purpose of this Design Guide is threefold:

1. It provides a basic overview of electromagnetic compatibility (EMC) theory.
2. It offers approaches to solving electromagnetic compatibility (EMC) problems, and
3. It assists in the selection of Tecknit shielding products for certain solutions.

Flow Charts are presented in Section 4 to guide the user from a perceived EMC problem to a solution with one or more of Tecknit's broad range of shielding products.

Section 1 - Electromagnetic Compatibility Overview

Electromagnetic compatibility (EMC) is the ability of an electronic system or subsystem to reliably operate in its intended electromagnetic environment without either responding to electrical noise or generating unwanted electrical noise. **Electromagnetic interference (EMI)** is the impairment of the performance of an electronic system or subsystem by an unwanted electromagnetic disturbance.

Electromagnetic compatibility is achieved by reducing the interference below the level that disrupts the proper operation of the electronic system or subsystem. This compatibility is generally accomplished by means of electronic filters, and component or equipment shielding. An example of an EMI emitter/ susceptor system is shown in Figure 1.

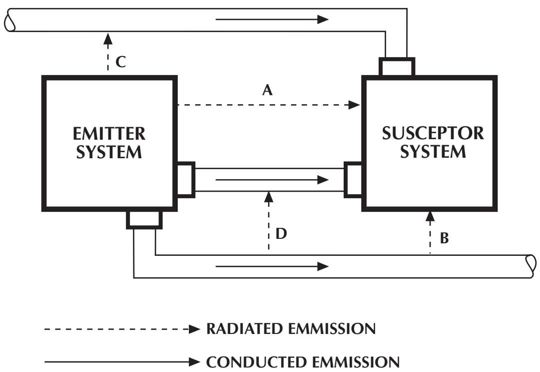


FIGURE 1
INTERFERENCE COUPLING PATHS

The emitter represents a system or subsystem that generates noise and the susceptor represents a system or subsystem that is susceptible to noise. In the real world, a system or subsystem can be simultaneously an emitter and a susceptor. The dotted lines show examples of radiated interference phenomena and the solid lines show examples of conducted interference phenomena. The arrows indicate the direction of noise transmission and coupling. Line A depicts interference coupled directly from the emitter to the susceptor through radiation paths. Line B shows that interconnect cables can also act as emitters of radiated noise. Line C shows that interconnect cables can act as susceptors and respond to noise that originated as radiated emissions. Thus, noise that originally began as radiated emission can show up in the susceptor system as conducted susceptibility. Line D represents the crosstalk problem found in interconnect cables where noise in one cable can be capacitively and inductively coupled to another cable.

Section 2 - Electromagnetic Shielding Overview

Electromagnetic waves consist of two oscillating fields at right angles (Figure 2). One of these fields is the **electric field (E-Field)** while the other is the **magnetic field (H-Field)**. **The electromagnetic wave impedance (Z_W)** in ohms is defined as the ratio of E-Field intensity expressed in **volts per meter (V/m)** to the H-Field intensity expressed in **amperes per meter (A/m)**. E-Fields are generated by and most easily interact with high impedance voltage driven circuitry, such as a straight wire or dipole. H-Fields are generated by and most readily interact with low impedance current driven circuitry such as wire loops.

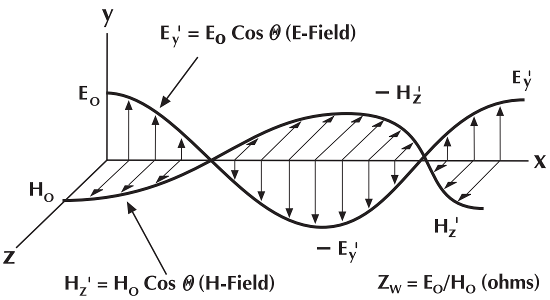


FIGURE 2
ELECTROMAGNETIC PLANE POLARIZED WAVEFORM

Any barrier placed between an emitter and a susceptor that diminishes the strength of the interference can be thought of as an EMI shield. How well the shield attenuates an electromagnetic field is referred to as its **shielding effectiveness (SE).** Therefore, shielding effectiveness is a measure of the ability of that material to control radiated electromagnetic energy. The standard unit of measurement for shielding effectiveness is the **decibel (dB).** The decibel is expressed as the ratio of two values of electromagnetic field strength where the field strengths are compared before and after the shield is in place. It is defined as:

$$\text{E-Field, } SE_{dB} = 20 \log_{10} (E_1 \backslash E_2)$$
$$\text{H-Field, } SE_{dB} = 20 \log_{10} (H_1 \backslash H_2)$$

The losses in field strength from a shielding barrier are a function of the barrier material (permeability, conductivity and thickness), frequency and distance from the EMI source to the shield.

The basic differential equations that express classical electromagnetic field phenomena and its interaction with conductive materials were developed well over a hundred years ago by J.C. Maxwell. The solutions of these differential equations are generally complex, even for simple models. This has discouraged their use in shielding analysis.

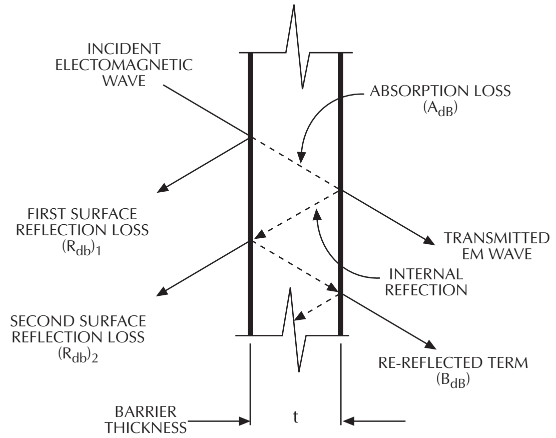


FIGURE 3
LOSSES DUE TO A SOLID CONDUCTIVE BARRIER

A simpler method for studying the effects of electromagnetic wave interaction with conductive barriers was developed by S.A. Schelkunoff in the 1930's. Using this technique, total **shielding effectiveness (SE_{dB})** of a solid conductive barrier can be expressed as the sum of the **reflection, (R_{dB}), absorption, (A_{dB})** and **re-reflection (B_{dB})** losses (refer to Figure 3). The reflection loss is proportional to the electromagnetic **wave impedance (Z_W)** and inversely proportional to the **barrier intrinsic impedance (Z_B).** The absorption loss is proportional to the **barrier thickness (t)** and **absorption coefficient of the barrier (α).** The inverse of the absorption coefficient is called the **'skin depth' (δ).** Skin depth is a magnetic property that tends to confine the current flow to the surface of a conductor. The skin depth becomes shallower as frequency, conductivity or permeability increases. Electromagnetic fields become attenuated by 1/e (natural logarithm) for every skin depth of penetration into the barrier as shown in Figure 4.
The greater the number of skin depths that exist within a given thickness of metal, the greater the absorption loss. Since the skin depth becomes shallower as frequency increases, absorption loss becomes the dominant term at high frequencies. The

re-reflection loss is strongly dependent upon the absorption loss. Just as a reflection occurs at the air to metal entrance boundary of the barrier, a similar reflection occurs at the metal to air exit boundary . For an absorption loss of greater than 10 dB, the reflection term can be ignored.

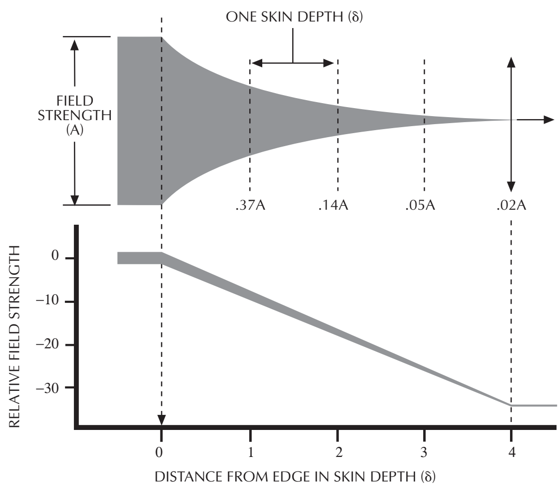


FIGURE 4
ABSORPTIVE LOSSES AS A FUNCTION OF SKIN DEPTH (δ)

The barrier intrinsic impedance is a function of the barrier relative permeability (μ_r), relative conductivity (σ_r), and frequency (f). The wave impedance is a function of the absolute permeability (μ_o) and absolute permittivity (ε_o). Two other important factors in the shielding equation are the distance (r) from the source of electromagnetic energy to the barrier, and wavelength (λ). Wavelength is related to the propagation velocity ($C = 3 \times 10^8$ m/sec) and the frequency (f) as follows: $\lambda = c/f$. When the source to barrier distance is less than about one sixth of the wavelength of the frequency of the electromagnetic energy ($\lambda/2\pi$), the field is called the 'near field'. When the source to barrier distance is greater than $\lambda/2\pi$, the field is called the 'far field'.

The distance between the source and barrier is important in determining the reflectivity factors in the near field for E-Fields and H-Fields. For E-Fields the reflection loss in the near field increases as the separation between the source and shielding barrier decreases and as frequency decreases. For H-Fields, on the other hand, the reflection loss in the near field increases as the separation between the source and shielding barrier increases and as the frequency increases. For absorption, the losses are independent of the near field/far field condition and are the same whether the wave is predominantly an E-Field, H-Field or a plane wave, which is an electromagnetic wave in which all points normal to the direction of propagation are in phase or parallel to one another or going in the same direction.

Summarizing:

- **Absorption:** Absorption increases with increase in frequency of the electromagnetic wave, barrier thickness, barrier permeability, and conductivity.
- **Reflection:** As a general rule, above 10 kHz, reflection increases with an increase in conductivity and a decrease in permeability.
- **Reflection - E-Field:** Increases with a decrease in frequency and a decrease in distance between the source and shielding barrier.
- **Reflection - H-Field:** Increases with an increase in frequency and an increase in distance between the source and shielding barrier.
- **Reflection - Plane Wave:** Increases with a decrease in frequency.

The solution of shielding effectiveness equations for solid conductive barriers, which considers the barrier as an infinite plane of finite thickness, usually results in shielding levels much greater than practically achieved with an actual shielded enclosure. This is due to barrier finite dimensions and discontinuities, which are a necessary part of a conductive cabinet design (e.g., seams, cable penetrations and air vents). Barrier thickness required to meet mechanical strength requirements generally provides adequate shielding effectiveness. The barrier material and shielding treatments of seams, penetrations and apertures are the more important design considerations. In Appendix A is a ranking of materials with respect to relative conductivity, relative permeability, absorption loss, and, reflection loss. Shielding treatments, including those manufactured by Tecknit, are discussed in the following sections of this Design Guide.

Section 3 - Electromagnetic Compatibility Design

EMC design should be an integral part of any electronic device or system. This is far more cost effective than the alternative, that is, attempting to achieve EMC on a finished product. The primary EMC design techniques include electromagnetic shielding, circuit filtering, and good ground design including special attenuation to the bonding of grounding elements.

Figure 5 presents a recommended methodology to good EMC design of a device or system. A hierarchy is presented in the form of a pyramid. First, the foundation of a good EMC design is simply the application of ***good electrical and mechanical design*** principles. This includes reliability considerations like meeting design specifications within acceptable tolerances, good packaging and comprehensive development testing.

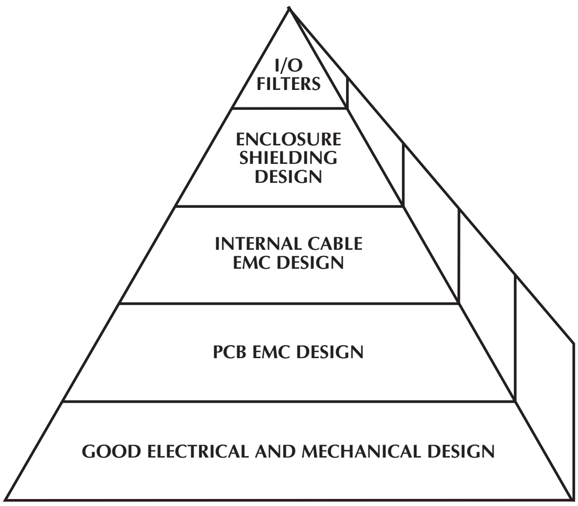


FIGURE 5
EMC DESIGN PYRAMID

Generally, the engine that drives today's electronic equipment is located on a printed circuit board (PCB). This engine is comprised of potential interference sources, as well as components and circuits sensitive to electromagnetic energy. Therefore, the ***PCB EMC design*** is the next most important consideration in EMC design. The location of active components, the routing of traces, impedance matching, grounding design, and circuit filtering are driven, in part, by EMC considerations. Certain PCB components may also require shielding.

Next, internal cables are generally used to connect PCBs or other internal subassemblies. The ***internal cable EMC design***, including routing and shielding, is very important to the overall EMC of any given device.

After the EMC design of the PCB and internal cables are complete, special attention must be given to the ***enclosure shielding design*** and the treatment of all apertures, penetrations and cable interfaces. Finally, consideration must be given to ***filtering of input and output power and other cables.***

The following sections look at each of these important areas and provide practical EMC design guidelines.

PCB DESIGN

When designing a PCB, the design goal is to control the following:

1. emissions from the PCB circuitry,
2. susceptibility of the PCB circuits to external interference,
3. coupling between PCB circuits and other nearby circuits in the device, and
4. coupling between circuits on the PCB.

This is accomplished primarily by paying special attention to the board layout and design, minimizing impedance discontinuities, and, when possible, by using low amplitude signals.

If clock frequencies above 10 MHz are used, in most cases it will be necessary to use multilayer design with an embedded ground layer. If this is cost prohibitive for your product, use guardbanding, that is, grounds on each side of signal traces.

Components should be located such that noisy and sensitive circuits can be isolated. Keep clock traces, buses and chip enables separate from I/O lines and connectors. Clock runs should be minimized and oriented perpendicular to signal traces. If the clocks go off the board, then they should be located close to the connector. Otherwise, clocks should be centrally located to help minimize onboard distribution traces. Input/output chips should be located near the associated connectors. Output circuits should be damped with a resistor, inductor or ferrite bead mounted close to the driver. Circuit types (i.e., digital, analog, power) should be separated, as well as their grounds. Tecknit offers a variety of shielding components especially suited for PCB shielding applications including a comprehensive line of conductive elastomers. See Section D of the Tecknit Shielding Products Catalog.

For high frequency design, the layout should be treated as a signal transmission environment, necessitating that impedance discontinuities be minimized.

Good decoupling practices should be used throughout the PCB; use bypasses liberally. Typically, this will be a 0.1 to 1.0 microfarad ceramic capacitor. Bypass capacitors should be mounted close to the IC.

Minimize power bus loop areas by routing the power bus as close as possible to its return. Power lines should be filtered at the PCB interface.

INTERNAL CABLE DESIGN

Internal cabling should be minimized as much as possible. When cables are required to connect assemblies and PCBs, the lengths should be minimized. Long service loops can be disastrous. If PCBs are properly designed, the requirement for shielding of internal cabling will be minimized. However, if it is found that cable shielding is required, the technique used to ground the shield is critical to the attenuation afforded by the shield. Cable shields should not be used as signal returns. For certain unbalanced circuits, coaxial cables are often used. In this case the 'shield' of the coaxial cable is intentionally used for signal return. In this application, the shield is not intended for attenuation of electromagnetic energy emanating from the center conductor. If the circuits at each end of a coaxial cable are designed properly, the coaxial cable should not radiate. However, if circuit impedances are not properly matched and the coaxial cable does radiate, another shield must be added to the cable (triaxial). This outer ground would be then bonded to the chassis ground.

In the Tecknit EMI Shielding Products Catalog, knitted wire mesh and metal foil tapes can be found which are specifically designed for harness and cable shielding, as well as grounding applications.

ENCLOSURE SHIELDING DESIGN

The enclosure must be designed with shielding in mind. If PCBs and internal cabling are properly designed, the need for enclosure shielding will be minimized. However, if it is found that enclosure shielding is required, designing the enclosure to permit the application of shielding treatments will minimize the level of the shielding design and associated cost.

A shielded enclosure should be fabricated from materials that possess the desired physical and electrical characteristics, including resistance to adverse environmental conditions. Discontinuities degrade the shielding and their design is critical in maintaining the desired levels of shielding effectiveness, providing the possibility of electromagnetic coupling through the openings and seams. The efficiency of the coupling depends upon the size of the hole or seam in relation to the wavelength of the interference. Any openings in an enclosure can provide a highly efficient coupling path at some frequency. As the aperture increases in size, its coupling efficiency increases.

A good rule of thumb to follow in general design practice is to avoid openings larger than λ/20 for standard commercial products and λ/50 for products operating in the microwave range. Since most EMI coupling problems are broadband in nature, the frequency of concern would be the highest threat frequency within the bandwidth envelope. Figure 6 shows λ/20 and λ/50 aperture sizes over the frequency range 100 kilohertz (kHz) to 10 gigahertz (GHz).

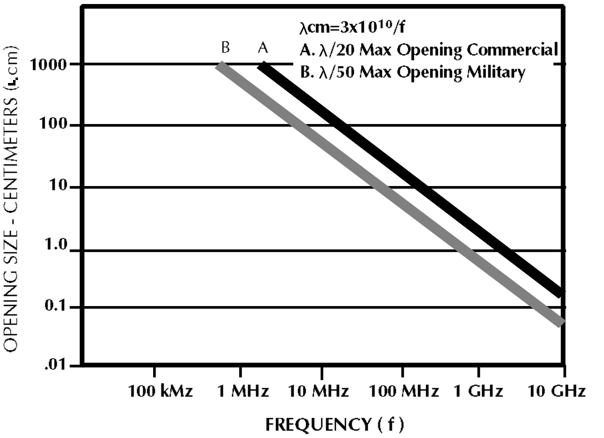


FIGURE 6
MAXIMUM SIZE OPENING AGAINST THREAT FREQUENCY

When it is necessary to specify an opening larger than λ/20 or λ/50, protective measures, such as the products manufactured by Tecknit, may be required to reduce the coupling which the aperture introduces. See Section 4 for application solutions.

Electromagnetic energy leakage through an aperture is dependent upon two factors:

1. the longest dimension, (d), of the aperture
2. the wavelength of the radiating field.

For wavelengths less than two times the longest aperture dimension, the electromagnetic energy will pass freely through the opening without being attenuated. For wavelengths equal to twice the opening, the shielding is zero. The frequency at which this occurs is called the cutoff frequency (f_c).

f_c = C/2d, where C is the propagation velocity of electromagnetic waves

For wavelengths greater than two times the maximum dimension, the attenuation is expressed as :

$R_{dB} = 20 \log \lambda/2d$, where $2 > d > t$ (t = material thickness)

Apertures affect both the reflection and absorption terms. The reflection term is lowered as a result of an increase in the barrier impedance relative to the wave impedance. This increase in barrier impedance is caused by leakage inductance, which is related to the dimensions of the aperture and the spacing of the radiating circuits from the aperture. A good approximation of the net shielding is to assume 0 dB shielding at the cutoff frequency and a linear increase of 20 dB per decade in shielding as the frequency decreases. The maximum possible shielding effectiveness, of course, is equal to that calculated for a solid barrier without an aperture. However, this does not consider the effects of the noise source in close proximity to the aperture. As long as the potential EMI source is spaced at least as far away as the largest dimension of the aperture, this approximation will hold true.

When a noise source is closer than the largest dimension of the aperture, a reduction in shielding can be expected. Deriving the shielding requirement in this situation can be very complicated. As an approximation, the effective cutoff frequency is reduced proportionally to the ratio of the distance from the aperture:

$$f_c = (C/2d)(r/d) \text{ and}$$

$$R_{dB} = (20 \log \lambda/2d)(r/d), \text{ where } \lambda/2 > d$$

The presence of more than one aperture of the same size in a solid metal barrier has the effect of reducing the total effective shielding. The amount of shielding reduction is dependent on the spacing between any two adjacent apertures, the wavelength of the interference and the total number of apertures. If the adjacent apertures have the same maximum dimension and are spaced at least a half wavelength apart, the shielding reduction is minimal and can be considered zero for practical purposes.

As the apertures are brought closer together ($s<2\lambda$), they no longer behave independently as single apertures. The reduction in shielding due to multiple apertures is approximately proportional to the square root of the total number (n) of equal sized apertures.

$$R_{dB} = 20 \log \lambda/2d - 20 \log n^{1/2},$$

where n = number of apertures

$s < \lambda/2 > d > t$

s = edge to edge hole spacing

These relationships apply to knitted or woven wire screen material if the wires make good contact at each crossover or intersection.

Nonmetallic Enclosures

Many commercial electronic devices are packaged in enclosures of plastic or other nonconductive materials. If the devices must rely on enclosure shielding for EMC compliance, these enclosures must be treated with a conductive material to provide shielding. Metallizing techniques for this application include vacuum deposition, electroless plating, arc spray, and conductive spray ‘paint’. The latter is the most frequently used technique which is really a paint-like slurry of metal particles in a carrier. These conformal coatings are loaded with very fine particles of a conductive material such as silver, nickel, copper and carbon. For example, Tecknit manufactures a highly conductive acrylic and polyurethane paints filled with silver particles. Surface resistivities as low as 50 milliohms per square are attainable for a one mil coating thickness. The lower the surface resistivity of the conductive coating, the greater the shielding effectiveness. Shielding effectiveness levels of 60 dB to 100 dB can be achieved.

Windows

Often, large-area openings are required for viewing displays, status lamps and device operating status.

When shielding of these large areas is required for EMC purposes, several options are available: (a) laminating a conductive screen between optically clear plastic or glass sheets; (b) casting a mesh within a plastic sheet; and (c) applying an optically clear conductive layer to a transparent substrate.

Refer to Section E of the Tecknit EMI Shielding Products Catalog for application and performance data on EMI shielding windows.

Seams

In the design of seams, the goal should be to achieve complete conductive contact along the entire length of the seam. In cases where this is not practical, special attention must be given to:

1. Seam Overlap: The two surfaces of the seam form a capacitor. Since capacitance is a function of area, seam overlap should be made as large as practical to provide sufficient capacitive coupling for the seam to function as an electrical short at high frequencies. As a good rule to follow, the minimum seam overlap to spacing-between-surfaces ratio should be 5 to 1.

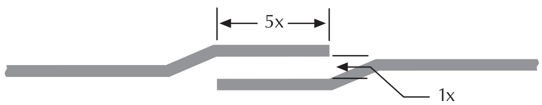


FIGURE 7
SEAM OVERLAP AND SPACING

2. Seam Contact Points: Along the entire length of every seam there should be firm electrical contact at intervals no greater than $\lambda/20$ for most commercial devices and $\lambda/50$ for microwave devices. This contact can be obtained by using pressure devices such as screws or fasteners, grounding pads, contact straps across the seam, or conductive gaskets. Tecknit manufactures foil tapes, thin elastomer gaskets, conductive caulks and various other products which can be used in this application.

If the seam surfaces are conductive and mate tightly, an electrical short is provided. To ensure a tight seam design, conductive gasketing along the entire length of the seam may be used. Conductive gasketing should be considered in the following cases:

1. Total enclosure shielding requirements exceed 40dB.
2. Enclosures with seam openings greater than $\lambda/20$.
3. Threat/emission frequencies exceed 100 MHz.
4. Machined mating surfaces are impractical.
5. Dissimilar materials are used on the mating surfaces of the seam and the device is designed to operate in severe environments.
6. Environmental (e.g., dust, vapor) seals are necessary.

Tecknit manufactures a wide variety of conductive gaskets for a broad range of applications, see the Tecknit Catalog.

When using gasketing materials to attain a satisfactory EMI shield, as well as proper environmental seal, be aware that gaskets are subject to both minimum and maximum pressure limits to achieve a proper electromagnetic seal. The greater the pressure applied to the gasketed joint, the better the apparent environmental and EMI seal. However, should the pressure exceed the maximum pressure limit of the gasket, permanent damage to the gasket can occur. This damage may decrease pressure across the seam and degrade both the environmental and EMI shielding characteristics. Wherever possible, use gasket compression stops or grooves to limit compression to the maximum recommended values.

Penetrations

Enclosure penetrations may be categorized as (a) those through which a conductor is passed, and (b) those through which a conductor does not pass. An example of the former is a cable interface port, and examples of the latter are air vents and holes for dielectric shafts.

Generally, to maintain the shielding integrity of the enclosure at cable penetrations, electronic filters or shielded cables must be used. Tecknit manufactures wire mesh and foil tapes which can be used for cable shielding purposes. See Section A in the Tecknit Catalog.

To maintain the shielding integrity of an enclosure with feedthroughs for non-conductive shafts or air vents, waveguide theory may be applied. A metal tube may be used for non-conductive shafts as shown in Figure 8. This tube may be treated as a waveguide to determine its 'shielding' characteristics. The attenuation (A) characteristics of an individual waveguide below the cutoff frequency (fc) is a function of the depth to width ratio (d/w). As the depth to width ratio increases, so does the shielding.

For circular waveguides, the following relationships apply:

$$f_c = 1.76 \text{ x } 1010/w_{cm} = 6.92 \text{ x } 109/w_{in}$$

$$A_{dB} = 32 \text{ d/w}$$

For rectangular waveguides, the following relationships apply:

$$f_c = 1.5 \text{ x } 1010/w_{cm} = 5.9 \text{ x } 109/w_{in}$$

$$A_{dB} = 27.3 \text{ d/w}$$

As discussed above, air vents that attenuate electromagnetic energy can generally be designed using multiple small holes in a metallic enclosure. However, in some cases where adequate attenuation can not be achieved in this manner, for example, when the noise source is close to the air vent, a honeycomb waveguide design may be used as shown in Figure 8. These waveguide air vent panels are available from Tecknit. See Section F in the Tecknit Catalog.

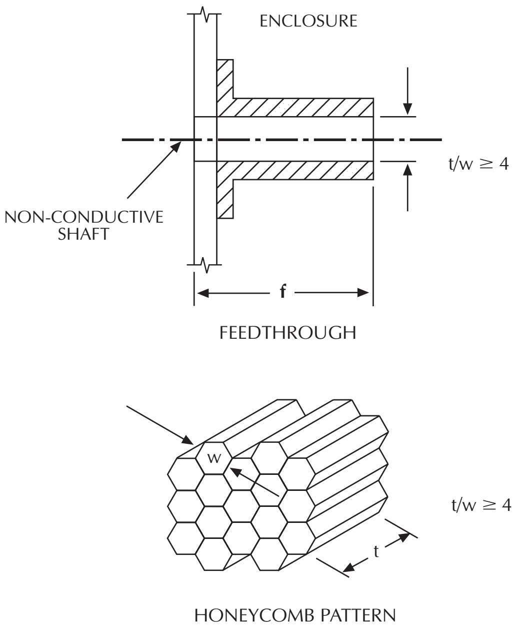


FIGURE 8
WAVEGUIDES BEYOND CUTOFF

FILTERS

Generally, to suppress power line and signal line emission, some form of filtering is required. Filter attenuation is highly dependent upon source and load impedances. Manufacturers' data is generally published for 50 ohm source and load impedances while actual impedances are generally reactive and vary considerably over the frequency range of interest. While there are methods for determining the actual impedances, these values are usually unknown. Hence, the selection of filters through mathematical computation is usually impractical.

An alternative approach is that of impedance mismatch. That is, if a filter mismatches its source and load impedances, minimum transfer of signal (EMI) power will occur. If the source impedance is high, the filter input impedance should be low, or shunt capacitive. If the source impedance is low, the filter input impedance should be high, or series reactive. The same mismatch should exist between the load impedance and the filter's output impedance.

Another consideration is whether the EMI is common mode or differential mode, where common mode refers to noise voltages on two conductors referenced to ground, and differential mode refers to a voltage present on one conductor referenced to the other. In many cases both types of EMI must be attenuated.

Virtually all off-the-shelf power line filters are designed to handle common mode noise, and many provide both common and differential mode filtering. Without conducted emission test data, it is generally difficult to determine the interference mode of the equipment and thus the type of filter required.

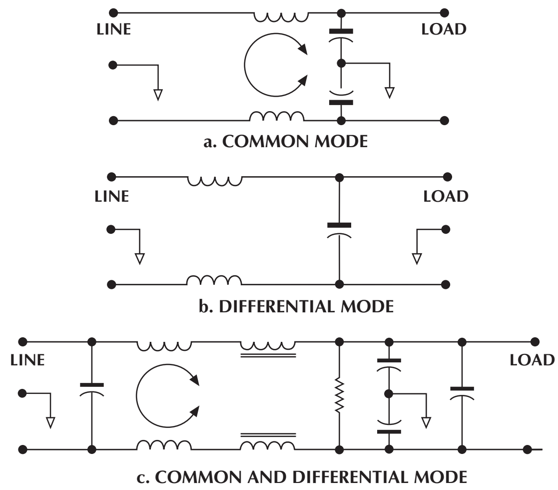
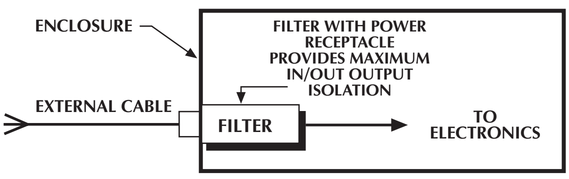


FIGURE 9
EXAMPLE OF FILTER TYPES

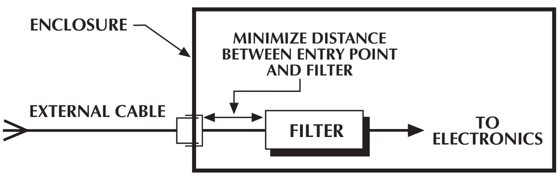
Some knowledge of basic filter design is helpful in selecting which filter type to try first. Where common mode filtering is required, line-to-ground capacitors and common core inductors should be used.

Where differential mode filtering is required, line-to-line capacitors and discrete series inductors should be used. Figure 9 illustrates examples of both filter types. Most filter manufacturers, given some knowledge of a particular device and the EMI problem, can assist in selecting a suitable filter. The only way to be sure that a filter will reduce EMI to compliant levels is to test the equipment for conducted emissions, and be prepared to try several different filters. This trial-and-error approach may be unscientific, but in most cases proves to be the fastest, most cost effective, and minimum risk approach.

The installation of a filter is extremely critical. Filter case-to-frame ground connections must have low impedance over the frequency range of the filter, input-to-output leads must have maximum physical isolation, and, in the case of power line and I/O line filters, the filtered lines must be as close as possible to the enclosure entry point (see Figure 10).



CASE 1 - FILTER WITH BUILT-IN RECEPTACLE



CASE 2 - FILTER WITHOUT BUILT-IN RECEPTACLE

FIGURE 10
FILTER INSTALLATION

Connector pin filters and ferrite beads are also very effective, especially on I/O line and for high frequency (>100 MHz) attenuation. One must be cautious that the capacitor and ferrite impedances do not affect intended signal characteristics.

BONDING AND GROUNDING

In the preceding sections, references were made to the importance of good low impedance ground connections for shielding and filtering. Grounding is probably the most important, yet least understood, aspect of EMI control. Often, 'ground' connections are made without appropriate attention to the ground conductor impedance at the frequencies of interest. As a result, the performance of enclosure shielding, cable shielding or filtering may be degraded, and the erroneous conclusion made that the 'shield' or 'filter' design is incorrect.

When we use the word "ground", we are generally speaking about a reference point. In most cases, the best place to begin is with the green safety wire of the AC power cable, assuming the device is not battery powered of course. Since safety organizations require that the safety ground be connected to the chassis, the green wire is generally attached to the chassis immediately upon entering the enclosure. This is good practice for EMI control as well since this 'safety ground point' will also serve as the primary point of reference for all other ground connections. The goal is to maintain a very low impedance path between this point and any other ground connection point in the device.

Thus, 'bonding', or maintaining a low impedance connection between mating conductive parts, is an important part of a good ground scheme. This requires that mating parts of enclosures not be painted, the ground straps not be attached to painted surfaces, and, perhaps, in corrosive environments, special attention be given to the use of dissimilar metals to preclude the effects of galvanic action. The goal is to maintain, as close as practical, a single potential 'safety ground' system.

Signal returns should generally be attached to safety ground at one point (single-point ground concept) to avoid ground loops. The term generally is important to note here since, in some cases, it might be found that a multi-point ground approach yields better results. Trial-and-error may be required. Printed circuit board design should also employ a single-point ground approach to maintain isolation of different circuit types as previously discussed. The best approach is to develop a ground diagram showing all ground connections, using different symbols for ‘safety’, ‘analog’, ‘digital’, and ‘rf’ grounds. This will help to highlight potential problems such as ground loops and common ground paths for different circuit types.

Figure 11 illustrates the concept described above. This is an ideal condition. However, in many cases it is necessary to connect returns from one PCB to another or one circuit type to another. This results in ground loops. To minimize the potential EMI threat, the following approaches can be taken:

1. use balanced differential circuits when possible,
2. minimized loop areas, and
3. run hot and return leads next to each other.

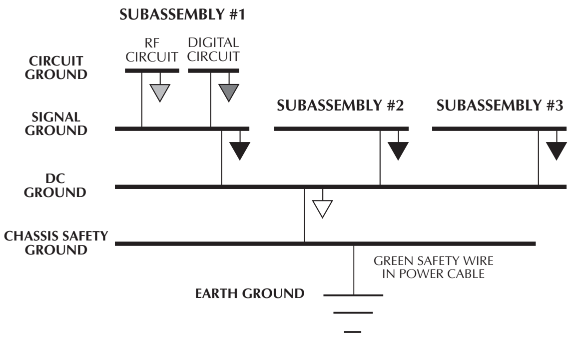


FIGURE 11
EXAMPLE OF DEVICE GROUND DIAGRAM

Section 4 - Problem Solving & Flow Charts

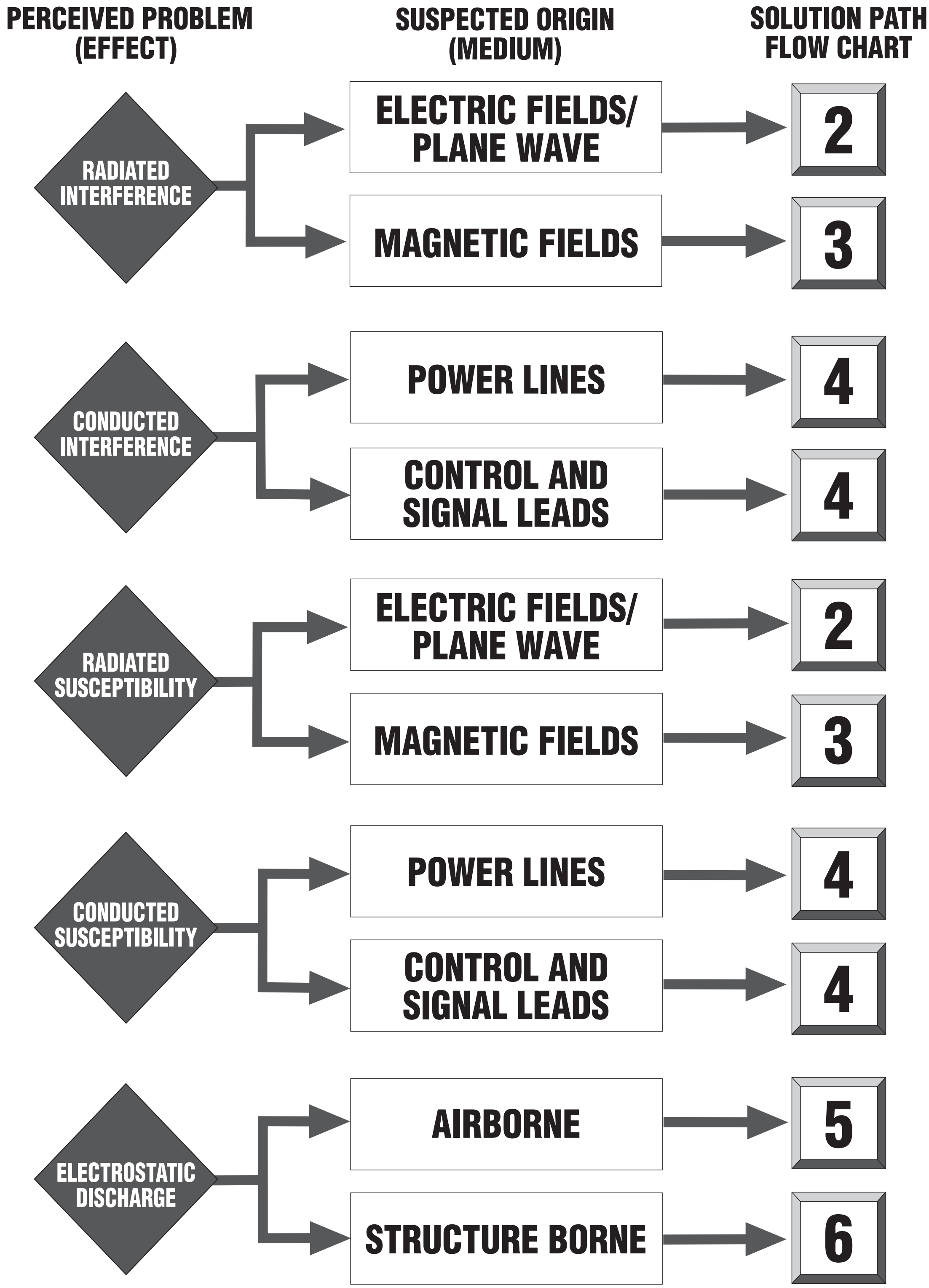
In the event that a device or system exhibits EMC problems or non-compliance with applicable EMC requirements, a methodology for finding a solution is set forth in Solution Path Flow Charts 1 through 6. EMC problems can be categorized as :

- **Radiated Interference**
- **Conducted Interference**
- **Radiated Susceptibility**
- **Conducted Susceptibility**
- **Electrostatic Discharge**

Chart I is a guide from these Perceived Effects to Solution Paths shown on Charts 2 through 6. Each solution path is a logical guide through the various EMC design issues discussed above, which apply to the particular effect. Certain solutions are shielding products such as those manufactured by ***TECKNIT.*** These are identified and referenced to the specific section of Tecknit's EMI Shielding Products Catalog where detailed application and performance data can be found. Contact your TECKNIT representative for further assistance.

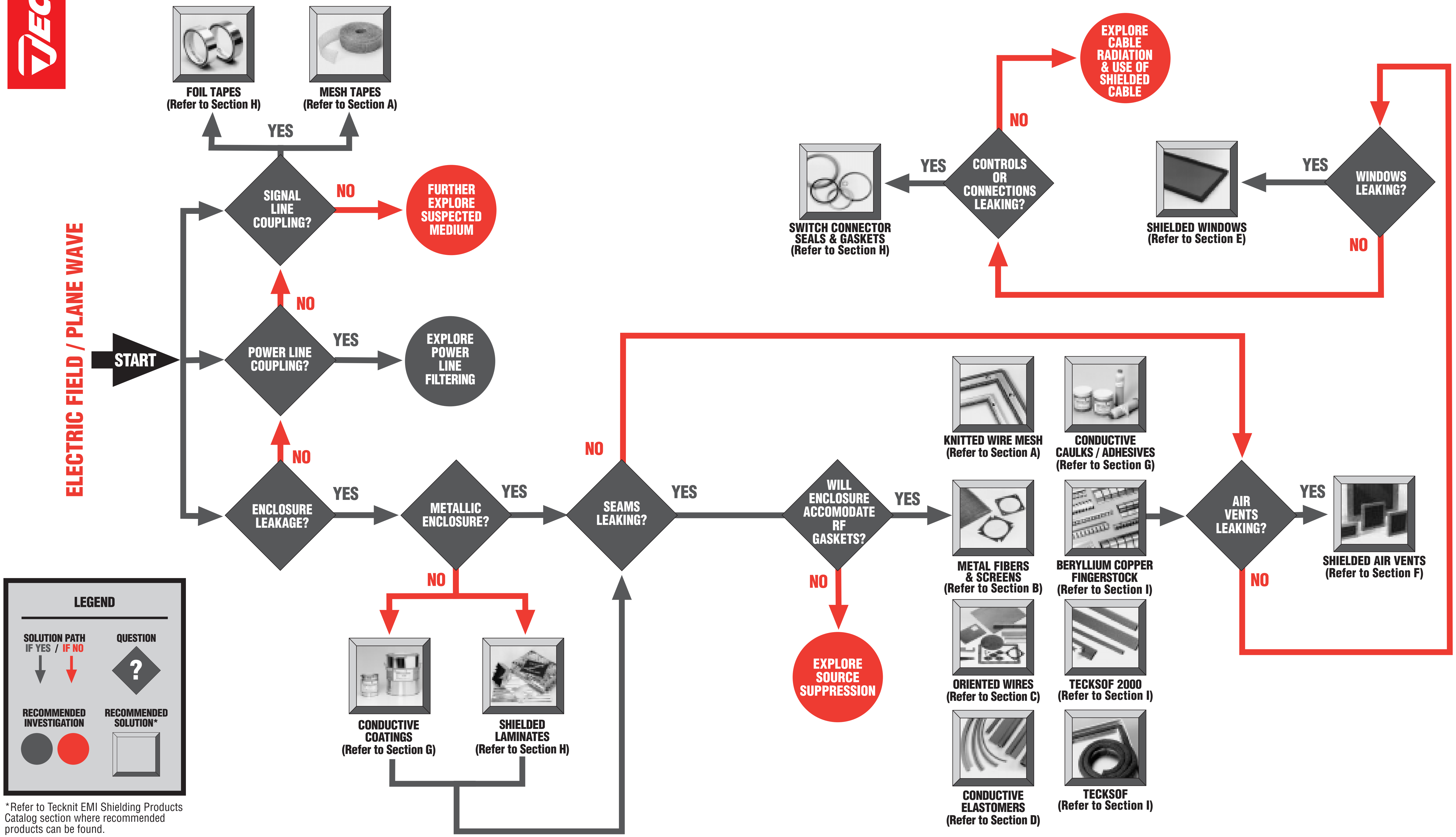
Solution Path 1

NEED HELP?
CALL
(908) 272-5500



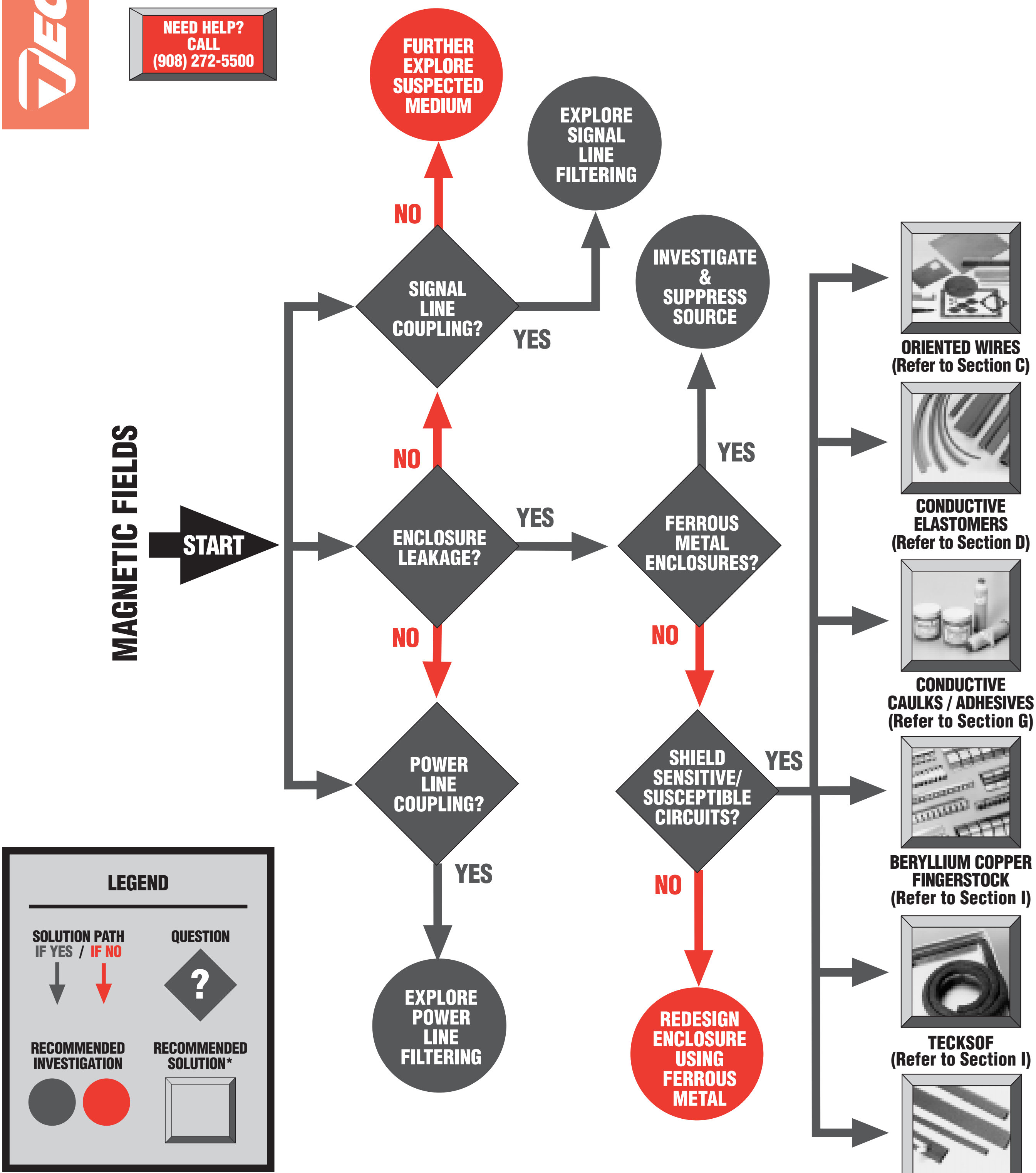
Solution Path 2 - Radiated Interference/Susceptibility

NEED HELP? CALL (908) 272-5500



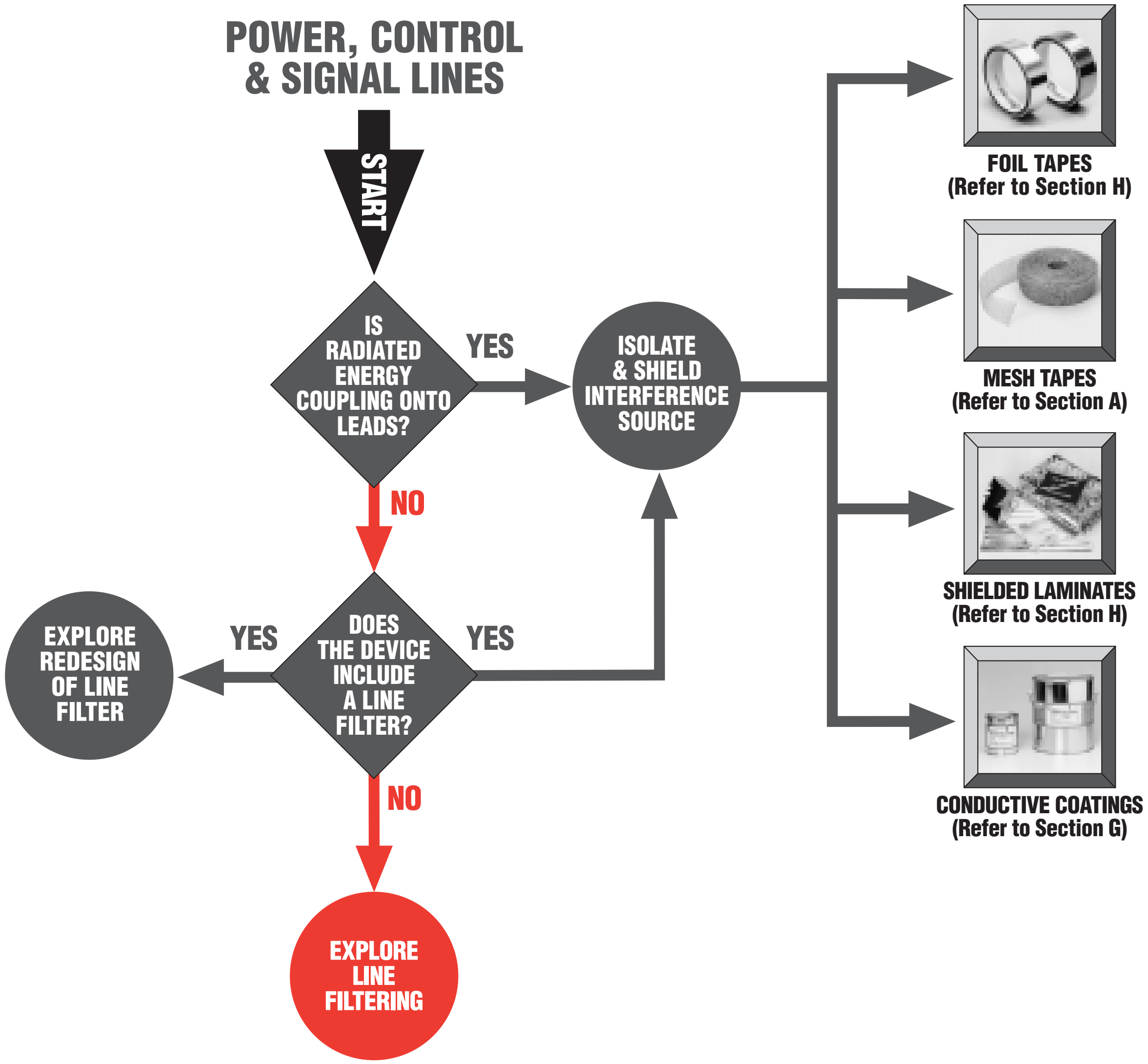
*Refer to Tecknit EMI Shielding Products Catalog section where recommended products can be found.

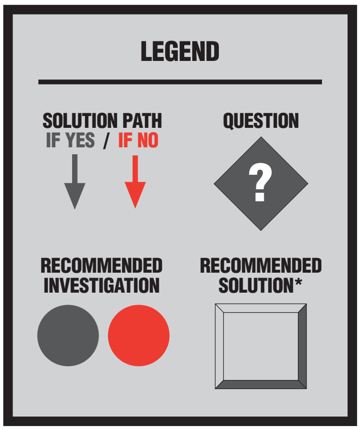
Solution Path 3 - Radiated Interference/Susceptibility



*Refer to Tecknit EMI Shielding Products Catalog section where recommended products can be found.

Solution Path 4 - Conducted Interference/Susceptibility



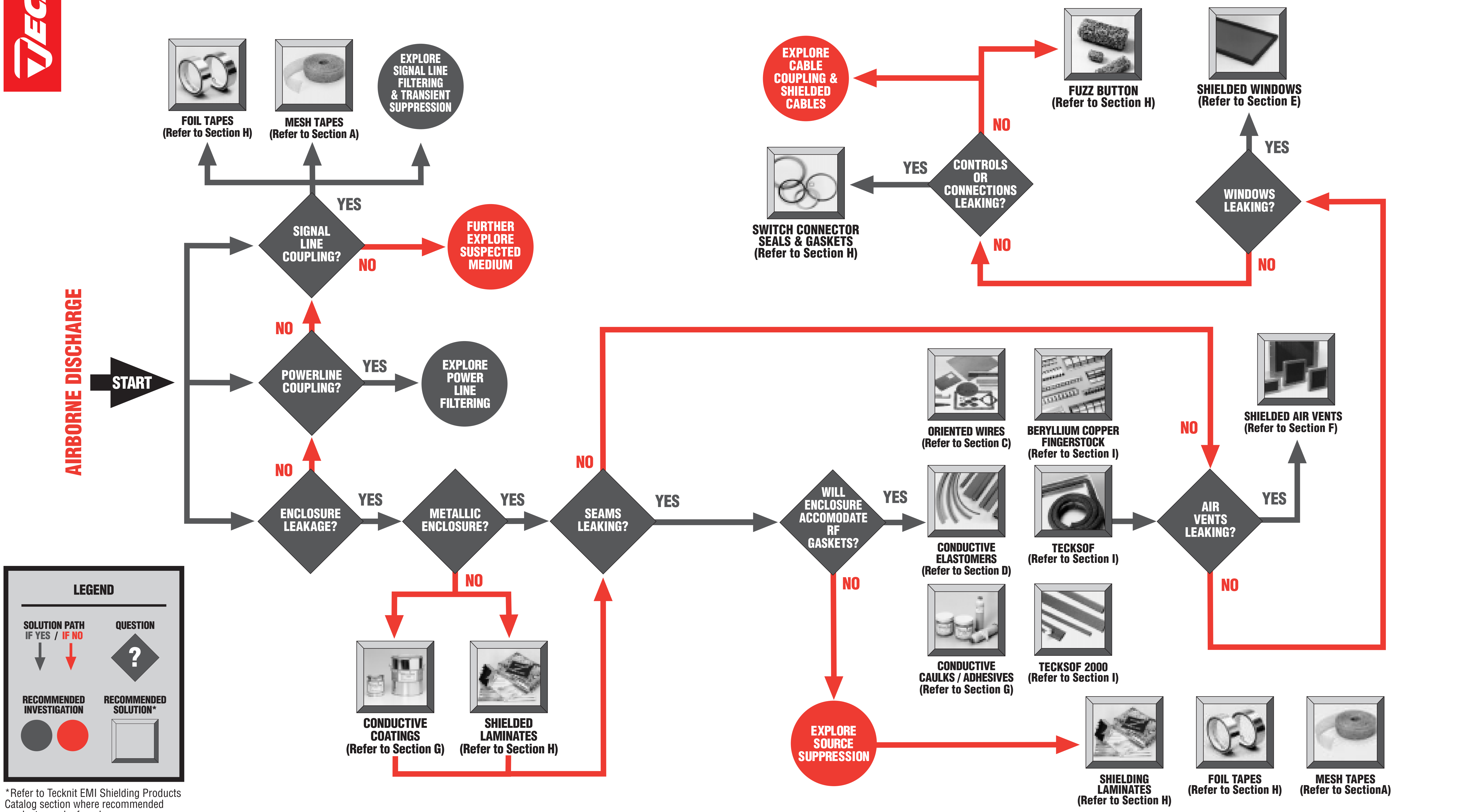


*Refer to Tecknit EMI Shielding Products Catalog section where recommended products can be found.

NEED HELP? CALL (908) 272-5500

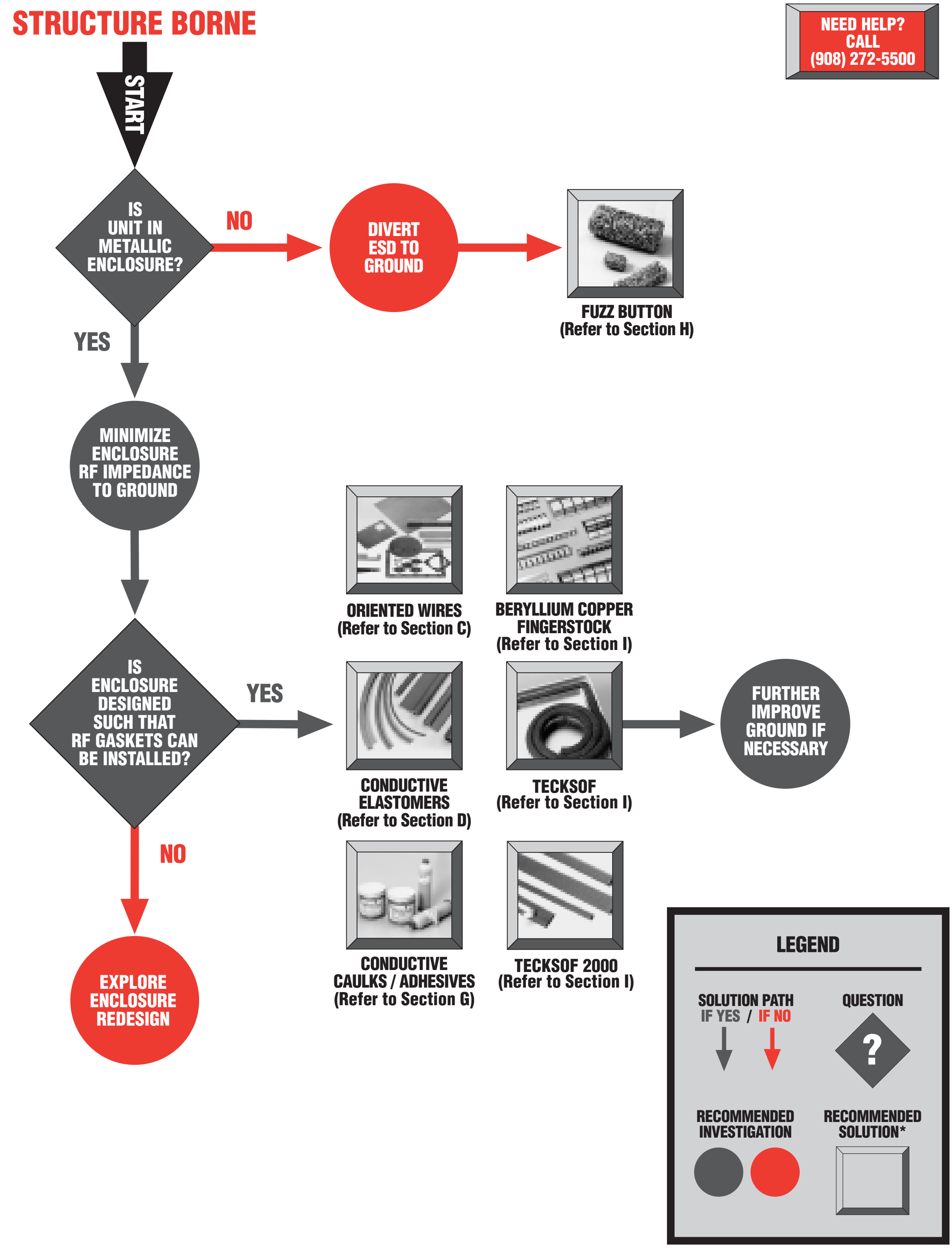
Solution Path 5 - Electrostatic Discharge (Airborne)

NEED HELP? CALL (908) 272-5500



*Refer to Tecknit EMI Shielding Products Catalog section where recommended products can be found.

Solution Path 6 - Electrostatic Discharge (Structure Borne)



*Refer to Tecknit EMI Shielding Products Catalog section where recommended products can be found.

Section 5 - Applicable National and International EMC Standards

As mentioned earlier, the primary purpose of EMC design is to ensure that an electronic system or subsystem will reliably operate in its intended electromagnetic environment without either responding to electrical noise or generating unwanted electrical noise. Other associated reasons include the following:

1. to improve product reliability,
2. to comply with contract requirements (when applicable), and
3. to comply with government regulations.

Often, contract requirements will be based upon government regulations and, if the product is intended for various countries, the requirements will generally be a worst case composite of the applicable country regulations.

EMC should be routinely considered in the design of all products which use electromagnetic energy in the operational process for the first reason listed above. Of course, where mandatory contract or government regulations apply, there is no choice.

History has shown that the government regulatory environment goes through cycles of great activity and relative calm, generally affected by technology advances. At the time of the writing of this Design Guide, for example, the government regulatory environment was quite dynamic, driven, for the most part, by the development of the **European Union (EU)** and resulting trade directives. Test procedures and limits are published for the EU by an organization called **CENELEC (European Committee for Electrotechnical Standardization)** and provide details for complying with the broad directives. Much research has been performed in the development of these procedures and limits and, thus, they have influenced worldwide regulations including those in the United States (i.e., EMC requirements found in the **Federal Communications Commission (FCC)** Rules and Regulations and **Federal Drug Administration (FDA)** EMC Guidelines).

There are many international EMC standards, too numerous to discuss in this Design Guide. However, those which are currently having the greatest impact on worldwide manufacturers, are discussed. EMC test laboratories can provide guidance in selecting the correct EMC standards for a particular product and application, and define the specific requirements.

FCC RULES AND REGULATIONS

The FCC regulates and protects communications services. Therefore the requirements address electromagnetic emission from products. However, there is a statement in the Rules which requires that a product operate in its intended environment without damage, but there are no specific requirements.

The test procedures are set forth in the Code of Federal Regulations (CFR), Title 47. Parts 15 and 18 of CFR 47 are the primary emission standards covering **intentional** and **unintentional** radiators, where intentional radiators would be radio transmitters, for example, and unintentional radiators would be computers, radio receivers, and other devices which use electromagnetic energy producing circuits to operate but do not intentionally radiate this energy, for example, for the purpose of communication. Many devices are exempt from these regulations including equipment used a) exclusively in transportation vehicles, b) as an electronic control or power system, or c) in an appliance. Also, exempt are: a) specialized medical digital devices, b) digital devices having a power consumption not exceeding 6 nW, c) joystick controllers or similar devices, and d) digital devices in which both the highest frequency generated and used are less than 1.705 MHz and which do not operate from AC power lines.

Basically, Part 18 applies to **industrial, scientific and medical (ISM)** devices designed to produce material changes due to RF or ultrasonic effects while Part 15 governs all other devices.

The Part 15 limits are summarized in Appendix B, Table B-1. The Class A and B notations refer to **Digital Devices** where Class A is equipment marketed for use in commercial, industrial or business environments, and Class B is equipment marketed for use in residential environment.

The Part 18 radiated and conducted emission limits are related to specific equipment types such as industrial heaters, rf stabilized arc welders, medical diathermy, ultrasonic equipment, induction cooking ranges, rf lighting devices and similar equipment.

FDA EMC GUIDELINES

The FDA has prepared a document entitled *Reviewer Guidance for Premarket Notification Submissions* which includes a series of EMC performance guidelines for medical electronic devices. These guidelines are part of a "510(k) premarket notification submission" process, an FDA product approval process. As the title indicates, the FDA provides guidelines, not requirements. If the same objective (i.e., the demonstration of the safety and effectiveness of the device in the intended environment) can be achieved by other means, or if certain recommendations are not applicable to the device, the manufacturer may present a rationale for taking such exceptions.

Table B-2 summarizes the FDA Guidelines. It can be seen that these are quite comprehensive and include requirements from international standards and U.S. Military standards.

EUROPEAN EMC DIRECTIVE

Products marketed in the EU must meet the EMC Directive 89/336/EEC as amended by Directive 92/31/EEC. The latter provided a transition period from January 1, 1992 to December 31, 1995. The Directive states that:

1. the electromagnetic disturbance that a device generates must not exceed a level allowing radio and telecommunications equipment and other apparatus to operate as intended, and
2. the device must have an adequate level of intrinsic immunity to electromagnetic disturbance to enable it to operate as intended.

Compliance is demonstrated by meeting the requirements of specific emission and immunity standards which are published periodically in the ***Official Journal of the European Union***. From this listing the manufacturer selects the standards which apply to his product. Where standards do not exist specific to a product, "generic" standards exist. Thus there are no exemptions.

While this may sound simple enough, understanding the EU standards process and finding the proper standard for ones application is a bit overwhelming to the newcomer. One of the reasons for this is the existence of many basically identical international standards with as many as three different document numbers. For example, EU standards must be approved by either CENELEC or ETSI (the European Telecommunications Standards Institute). CENELEC applies document numbers to released standards. Since they often adopt existing standards developed by other standards organizations like the IEC (International Electrotechnical Commission), the number used by CENELEC usually includes the document number of that organization. For example, CENELEC standard EN 60601-1-2 for medical devices is based upon IEC 601-1-2. In another case, the IEC 801 series of standards has recently been changed to the IEC 1000-4 series of standards, which are CENELEC EN 61000-4 series standards. So there exists, for example, three basically identical standards for electrostatic immunity with numbers IEC 801-2, IEC 1000-4-2 and EN 61000-4-2. To keep abreast of the dynamic European standards situation, it is necessary to obtain the *Official Journal of the European Union,* or subscribe to a service that provides periodic summaries of the EU activities. Also, companies that provide compliance testing can assist in determining the correct requirements for your product, as well as provide information on the approval process.

Obviously, before the EMC design of a product can commence, the requirements should be defined. The requirements for some of the more commonly used standards are presented below. You will find that most EMC standards follow similar formats.

Information Technology Equipment (for example, computer equipment)

The applicable emission standard is EN 55022, *Limits and methods of measurement of radio interference characteristics of information technology equipment.* An immunity standard, specifically applicable to computer equipment, is under development as of the date of this Design Guide. Therefore, the generic immunity standard currently applies. There are two generic immunity standards based upon the intended operating environment of the product. They are EN 50082-1, *Electromagnetic compatibility - Generic immunity standard; Part 1: Residential, commercial and light industry*, and EN 50082-2, *Electromagnetic compatibility - Generic immunity standard; Part 2: Industrial environment.*

EN 55022 emission limits are presented in Table B-3. Similar to the FCC limits, there are conducted and radiated emission limits for Class A (industrial) and Class B (residential) conducted and radiated emissions equipment.

EN 50082-1 and EN 50082-2 requirements are summarized in Tables B-4 and B-5 respectively. Note that most of the standards listed, as of the date of this Design Guide, are in the state of revision and the generic standards will be revised in the future to reflect this.

Medical Electronic Devices

The applicable standard is EN 60601-1-2, *Medical electrical equipment; Part 2: Particular requirements for safety, 2. Collateral Standard: Electromagnetic compatibility requirements and tests*, which includes emission and immunity requirements as shown on Table B-6.

Industrial Equipment

Requirements may vary depending on the particular device. For example, EN 55011 applies to ISM equipment which is defined as equipment designed to generate and/or use locally, radio frequency energy for industrial, scientific, medical, domestic or similar purposes, excluding applications in the field of telecommunications and information technology. Note that this definition of ISM equipment is broader than the FCC's definition.

Equipment is separated into Class A, non-domestic applications, and Class B, domestic applications. Furthermore, equipment is separated into Group 1 and Group 2 defined as follows:

Group 1 - equipment in which there is intentionally generated and/or used conductively coupled RF energy which is necessary for the internal functioning of the equipment itself.

Group 2 - equipment in which RF energy is intentionally generated and/or used in the form of electromagnetic radiation for the treatment of material, and spark erosion equipment.

The limits are summarized on Table B-7 for Group 1 equipment.

If this document fails to fit a particular industrial product, the generic emission standard would apply. That is EN 50081-1, *Electromagnetic compatibility - Generic emission standard; Part 1: Residential, commercial and light industry*. Table B-8 summarizes the limits.

Since, to date, there is no specific immunity standard for industrial equipment, the generic immunity standards EN 50082-1 and 50082-2, discussed above, would apply.

Section 6 - Special Applications

MILITARY EQUIPMENT EMC DESIGN

Since about 1990, there has been a trend in the military to accept commercial-off-the-shelf (COTS) equipment, especially in 'noncritical' equipment. In many military contracts, EMC requirements referencing FCC and IEC standards can be found. There are several reasons for this including cost reduction.

However, where more stringent requirements are deemed necessary the most commonly used military standards for both emissions and immunity (more commonly referred to as susceptibility in the military) are MIL-STD-461D, *Requirements for the Control of Electromagnetic Interference Emissions and Susceptibility* and MIL-STD-462D, *Measurement of Electromagnetic Interference Characteristics*. As the titles indicate, one document sets forth emission limits and susceptibility criteria while the other defines the test methodology.

As one might expect, the military emission limits are much lower and the susceptibility criteria more severe than those found in commercial standards. Also, the frequency ranges are broader as illustrated in Appendix B, Table B-9 which summarizes the MIL-STD-461D requirements.

The basic EMC design principles set forth in this Design Guide for commercial products applies as well to military products. The primary areas that differ are generally in the design of the enclosures and line filters. Also, especially in large complex systems, EMC design analyses are required in the schematic design phase to guide the electrical and mechanical engineers.

MODELING AND ANALYSIS

In many cases a circuit or module will emit or be susceptible to EMI only on certain frequencies. For example: a radio transmitter operating at 10 MHz might interfere with the normal operation of a digital electronic circuit located nearby, whereas, with a difference of as little as one percent in the transmission frequency, the problem might not exist. On the other hand, a particularly 'noisy' signal source might have several discrete emission frequencies, all within the response bandwidth of the susceptible circuit.

To comprehend the multifrequency problem associated with electromagnetic emissions, it is helpful to understand frequency relationships associated with fundamental waveforms, such as the square wave. An ideal square wave consists of a signal switching

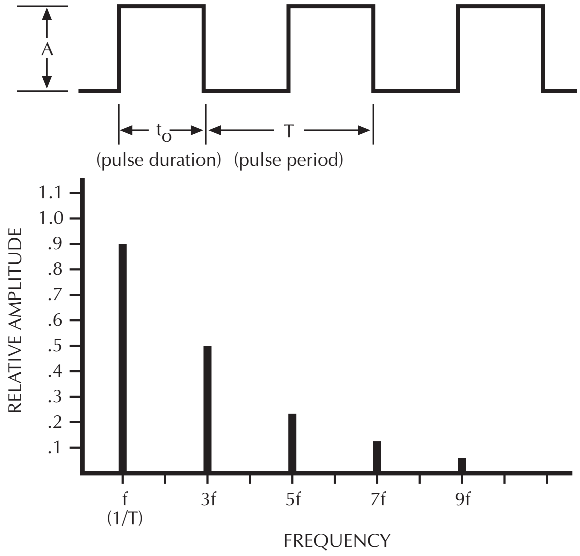


FIGURE 12
IDEALIZED SQUARE WAVE
WITH ITS FOURIER COMPONENTS

two distinct voltage levels with instantaneous transitions between levels. Figure 12 illustrates an ideal square wave along with its frequency spectrum. Fourier theory states that a square wave spectrum can be expressed as an infinite sum of simple sine waves of decreasing amplitude whose frequency decreases as the odd multiple of the basic frequency of the square wave itself. This figure illustrates that there is a significant amount of energy still contained in the higher order harmonics when compared to the energy contained in the fundamental frequency.

Figure 13 shows the same ideal square wave spectrum with amplitude converted to decibels and frequency on a logarithmic scale. This is commonly done to permit comparison with applicable limits which are formatted in this manner. The vertical lines represent the signal amplitude as a function of frequency and the curve drawn through the points of maximum amplitude represents the worst case limits. It is standard practice to ignore the discrete nature of emissions and deal exclusively with the curve shown connecting the points of maximum amplitude since it is difficult and time consuming to predict emissions one frequency at a time.

Figure 13 shows that the emissions profile of an ideal square wave decreases at the rate of 20 dB per frequency decade. Actual square waves do not have instantaneous transitions to perfectly flat voltage lev-

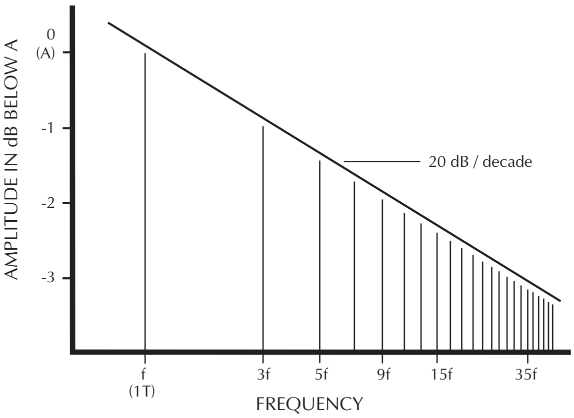


FIGURE 13
AMPLITUDE OF IDEALIZED SQUARE WAVE
IN dB REFERENCED TO A

els as shown in the idealized case. They are more accurately modeled by a trapezoidal waveform. Figure 14 shows a trapezoidal wave with a finite rise time together with a frequency versus amplitude plot. The slope of the emissions shifts from 20 dB per decade to 40 dB per decade as a function of the rise time/fall time of the waveform ($1/+t_r$). As the rise time (t_r) increases, the frequency at which the slope changes from 20 dB to 40 dB per decade decreases. In addition, the emissions profiles are functions of the duty cycle of the signal. If the signal is symmetrical (50% duty cycle) the worst case emissions profile results. As the duty cycle decreases, the amplitude of the low frequency emissions also decreases. the amplitude of the low frequency emissions also decreases. Figure 14 shows the amplitude verses frequency plot for 50% and 20% duty cycle trapezoidal waveforms.

After the major emission sources and the most susceptible devices in system have been identified and characterized, the entire EMC problem must be integrated into the total system EMC design plan. The noise acceptable from individual units or subsystems must be allocated on the basis of the total acceptable system noise. Each emitter circuit adds its noise to the system in a root mean square (rms) fashion. If all the noise emitters are of approximately equal strength, the total noise is equal to the average noise of the emitters times the square root of the number of emitters. If one emitter dominates the others, total noise would be approximately equal to the noise of the dominant emitter. Usually there are two or three dominant emitters of comparable magnitude.

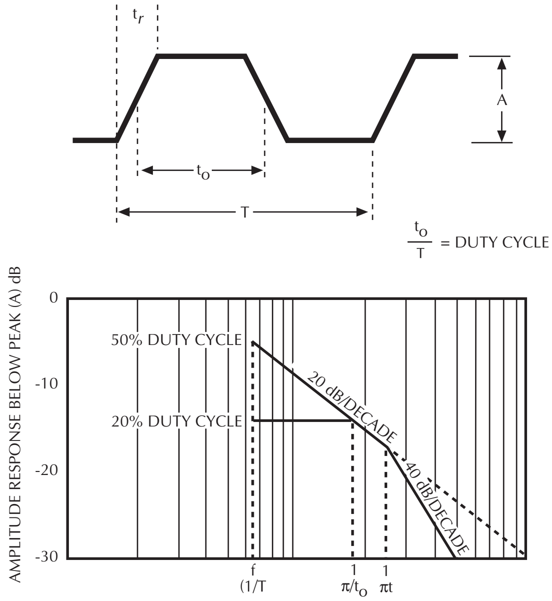


FIGURE 14
TRAPEZOIDAL WAVEFORM AMPLITUDE
VERSUS FREQUENCY

Both the emitter noise level as well as the susceptor's noise threshold must be considered. If the susceptor's lowest signal threshold level can be made greater by at least two times the highest emitter (noise) level (for a 6dB safety margin), then the emitter and susceptor are considered to be compatible with each other.

In addition to the interaction of the system with the external environment, interaction inside the system must also be considered, i.e., crosstalk must be controlled. In other cases, it may be necessary to characterize electromagnetic fields from high power antennas on ships and aircraft platforms, and how these fields affect on-board equipment. The more complex analytic problems require computer aided techniques. Many EMC analysis software packages are available for modeling these complex scenarios.

Whether simple manual models or the more complex computer aided models are used, the characteristics of any EMI control devices or techniques must be included in the final analysis. For example, shielding attenuation levels and filter insertion loss levels.

SPECIAL DESIGN CONSIDERATIONS

When military equipment must operate in severe electromagnetic environments or mission critical scenarios, the EMC design moves to a much higher level. As mentioned above, the basic EMC design principles and approach for non-military equipment and illustrated in Figure 5 still apply, however, the level of design changes significantly. Let's look at each design phase shown on Figure 5 and the briefly review the ways the design might change for a severe military environment or mission critical application.

Good Electrical and Mechanical Design

The major impact on the basic design of the equipment is generally due to reliability, maintainability, and atmospheric and mechanical environmental constraints. Thus, 'MIL' parts, those meeting military standards are used PCB Design.

Again PCB material, design and layout will be affected primarily by reliability, maintainability, and atmospheric and mechanical environmental constraints. However, when devices must operate in extremely high frequency regions, impedance discontinuities become particularly critical. For mission critical equipment, all aspects of good PCB EMC design become critical including the control of circuit emission, circuit susceptibility to external interference, coupling between circuits on the board, as well as circuits on the board and other nearby circuits.

Tecknit offers a variety of shielding components especially suited for PCB shielding applications. These are very effective in minimizing chip and circuit radiation. For example, Tecknit Shielding Laminates are available in a variety of foil and substrate combinations, from simple die cut shapes to formed complex assemblies with folds, scores, and cooling holes.

Internal Cable EMC Design

Internal cable design and layout is a real challenge in military equipment. For equipment designed to operate at millimeter wave and microwave frequencies, extremely high quality, rigid coaxial transmission lines must be used. In complex equipment in mission critical systems, containing large multi-wire cable harnesses, different circuit types (i.e., rf, data, DC power, AC power) must be separated and the cable routing controlled to prevent interference coupling. To prevent or minimize radiation from harnesses, shielding is often required, or as a minimum, the cables must be routed close to the metal enclosure surface. The latter enhances harness emission decoupling to ground.

Tecknit EMC Shielding Tape is specially designed for harness shielding providing 60 dB of shielding at 10 MHz and 30 dB of shielding at 10 GHz.

Enclosure Shielding Design

The area where EMC design criteria varies most between non-military and military equipment is in the enclosure shielding design. Therefore, this topic requires special attention. The reason for this is simply that the enclosure is the last line of defense for controlling radiated EMI, often the difference between meeting specification requirements and not meeting the requirements. Minor miscalculations in gasket pressure, aperture dimensions, and seam design, for example, may result in major EMC problems. Also, atmospheric and mechanical environmental factors must be integrated into the shielding design as discussed below.

a. Environmental Seals The EMI gasket is often called upon to function as an environmental seal to provide protection from dust, moisture and vapors. Therefore, selection of the sealing elastomer is as important as the EMI gasket. To seal against dust and moisture, flat or strip EMI gaskets joined to a sponge or solid elastomer are adequate. Sponge elastomers, characterized by compressibility, are ideally suited for use in sheet metal enclosures having uneven joints. Required closure pressures are generally low, between 5 and 15 psi. To avoid overcompressing sponge elastomers, compression stops are recommended. These stops can be designed into the enclosure or embedded in the elastomer. Both techniques are illustrated in Figure 15. Tecknit offers a wide variety of sponge elastomer gaskets, as well as other types of low closure force gaskets.

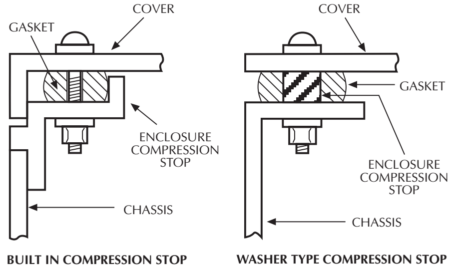


FIGURE 15
GASKET COMPRESSION STOPS

The listing below presents the most important characteristics of the more common elastomers.

Neoprene This elastomer is used commonly in EMI gaskets and will withstand temperatures ranging from -54°C to $+100^{\circ}$C for sponge (closed cell) elastomers. Neoprene is lightly resistant to normal environmental conditions, moisture and to some hydrocarbons. It is the least expensive of the synthetic rubber materials and is best suited from a cost standpoint for commercial applications.

Silicone This material has outstanding physical characteristics and will operate continuously at temperatures ranging from -62°C to $+260^{\circ}$C for solid and -75°C to $+205^{\circ}$C for closed cell sponge elastomers. Even under the severest temperature extremes these materials remain flexible and are highly resistant to water and to swelling in the presence of hydrocarbons.

Buna-n Butadiene-Acrylonitrile resists swelling in the presence of most oils, has moderate strength and heat resistance although it is not generally suited for low temperature applications.

Natural Rubber This material has good resistance to acids and alkalies (when specially treated) and can be used to 160°C, is resilient and impervious to water. Rubber will crack in a highly oxidizing (ozone) atmosphere and tends to swell in the presence of oils.

Fluorosilicone Has the same characteristics of silicone with improved resistance to petroleum oils, fuels and silicone oils.

Since most seals used with EMI gaskets have elastomeric properties of stretch and compressibility, some guidelines are needed when specifying the dimensional tolerance of these materials. Figure 16 shows some of the common errors encountered in gasket design.

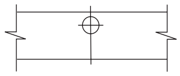
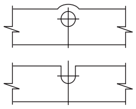
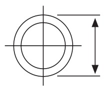
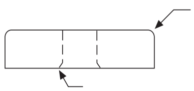
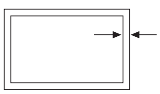
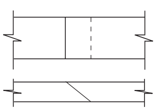
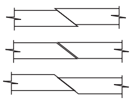
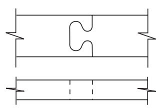
DETAIL	WHY FAULTY	SUGGESTED REMEDY
 Bolt holes close to edge	Causes breakage in stripping and assembling	 Projection or "ear" / Notch instead of hole.
 Metalworking tolerances applied to gasket thickness, diameters, length, width, etc.	Results in perfectly usable parts being rejected at incoming inspection. Requires time and correspondence to reach agreement on practical limits. Increases cost of parts and tooling. Delays deliveries.	Most gasket materials are compressible. Many are affected by humidity changes. Try standard or commercial tolerances before concluding that special accuracy is required.
 Transference of fillets, radii, etc., from mating metal parts to gasket.	Unless part is molded,such features mean extra operations and higher cost.	Most gasket stocks will conform to mating parts without preshaping. Be sure radii, chamfers, etc., are funtional, not merely copied from metal members.
 Thin walls, delicate cross section in relation to overall size.	High scrap loss; stretching or distortion in shipment or use. Restricts choice to high tensile strength materials.	Have the gasket in mind during early design stages.
 Large gaskets made in sections with beveled joints.	 Extra operations to skive. Extra operations glue. Difficult to obtain smooth, even joints without steps or traverse grooves.	 Die-cut dovetail joint.

FIGURE 16

GASKET DESIGN ERRORS

a.) Minimum gasket width should not be less than one half of the thickness (height).

b.) Minimum distance from bolt hole (or compression stop) to nearest edge of sealing gasket should not be less than the thickness of the gasket material. When bolt holes must be closer, use U-shaped slots.

c.) Minimum hole diameter not less than gasket thickness.

d.) Tolerances should be conservative whenever possible. Refer to Tecknit Shielding Products Catalog for tolerances on rule die-cut gaskets and elastomer strips.

Sealing against differential pressure between the enclosure interior and exterior is best accomplished using a gasket which is contained within a groove in the enclosure. This is also true for shielding extremely high frequencies. For these applications, the best known seal is the "O" ring. Tecknit offers seals of this type in either solid or hollow cross sections, and in various shapes.

Unlike sponge elastomers, solid elastomers do not compress, they deflect. Since solid elastomers do not change volume under pressure, groove design must take into consideration seal deflection. As a rule of thumb, the groove should have a minimum cross sectional area at least equal to 125% of that of the seal to accommodate deflection under worst case tolerance conditions of elastomer and groove.

Normal deflection for solid rectangular seals ranges from 5 to 15%. The pressure required to deflect solid elastomer seals is a function of the elastomer hardness and the cross section shape. Typical pressures are as low as 20 psi for low compression, low durometer material to 150 psi for high compression, high durometer material.

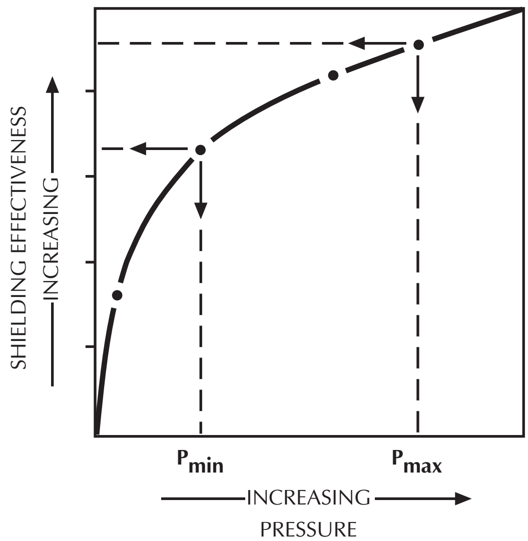


FIGURE 17
SHIELDING EFFECTIVENESS VERSES CLOSURE FORCE
(TYPICAL CHARACTERISTICS AT A GIVEN FREQUENCY)

b. Closure Pressure Shielding effectiveness and closure pressure have a general relationship as shown in Figure 17. The minimum closure force (P_{min}) is the recommended applied force to establish good shielding effectiveness and to minimize the effects of minor pressure difference. The maximum recommended closure force (P_{max}) is based on two criteria:

1. maximum compression set of 10% and/or
2. avoidance of possible irreversible damage to the gasket material when pressure exceeds the recommended maximum.

Higher closure pressures may be applied to most knitted wire mesh gaskets when used in Type 1 joints, but the gaskets should be replaced when cover plates are removed, i.e., whenever the seam is opened.

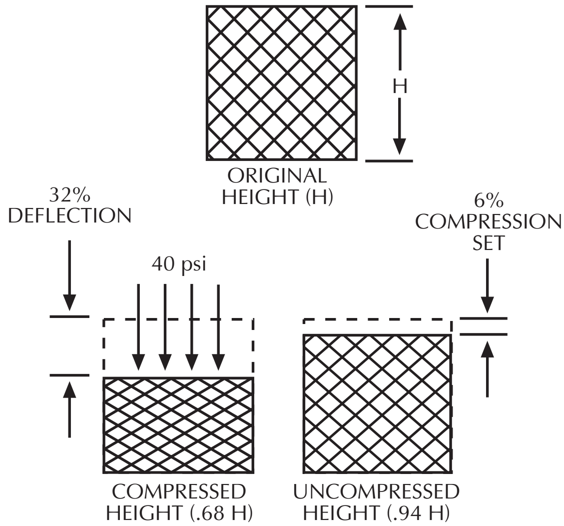


FIGURE 18
COMPRESSION SET

c. Compression Set Selection of a gasketing material for a seam which must be opened and closed is to a large extent determined by the compression set characteristics of the gasket material. Most resilient gasket materials will recover most of their original height after a sufficient length of time when subjected to moderate closing forces. The difference between the original height and the height after the compression force is removed is compression set. As the deflection pressure is increased, the compression set increases. See Figure 18.

Another consideration for pressure seals is the chemical permeability of the elastomer compound. This is defined as the volume (cm^3) of gas that will permeate in one second through a specimen of one cubic centimeter.

Finally, leakage can be reduced by using conductive grease. Compatibility of the grease with the seal elastomer and the application should be checked. Tecknit manufactures a wide variety of "O" ring gaskets and conductive grease for a broad range of applications.

d. Corrosion It is necessary to select shielding materials and finishes which inhibit corrosion, are compatible with the enclosure materials and are highly conductive. Corrosion occurs between dissimilar metals in the presence of an electrolyte. The rate of corrosion depends on the electrochemical potential between two metals and the conditions under which contact is made. Materials must be used which provide the least corrosion due to galvanic action when materials are in contact for an extended period of time with appropriate protective finish. Maximum galvanic activity occurs when dissimilar metals are exposed to salt atmosphere, fuels, chemicals and other liquids which may act as electrolytes. To minimize corrosion, all surfaces should be free of moisture.

Therefore, EMI gasket material making contact with the enclosure material in a corrosive atmosphere must be selected or treated to ensure that materials in contact are compatible. Table 1 separates metals by electrochemical compatibility. The design goal should be to use metals in the same group. When this is not feasible, a protective finish must be used to retard corrosion.

Table 1

GROUPING OF METALS BY ELECTROCHEMICAL COMPATIBILITY

GROUP I	GROUP II	GROUP III	GROUP IV
Magnesium	Aluminum	Cadmium Plating	Brass
Magnesium Alloys	Aluminum Alloys	Carbon Steel	Stainless Steel
Aluminum	Beryllium	Iron	Copper & Copper Alloys
Aluminum Alloys	Zinc & Zinc Plating	Nickel & Nickel Plating	Nickel/Copper Alloys
Beryllium	Chromium Plating	Tin & Tin Plating	Monel
Zinc & Zinc Plating	Cadmium Plating	Tin/Lead Solder	Silver
Chromium Plating	Carbon Steel	Lead	Graphite
	Iron	Brass	Rhodium
	Nickel & Nickel Plating	Stainless Steel	Palladium
	Tin & Tin Plating	Copper & Copper Alloys	Titanium
	Tin/Lead Solder	Nickel/Copper Alloys	Platinum
	Lead	Monel	Gold

When it is necessary for dissimilar metals to be used, the following practices should be applied to insure compatibility:

1. Use a tin or cadmium plated washer between a steel screw in contact with aluminum.
2. Use selective plating where it is essential to have reliable electrical contact.
3. Design to ensure that the area of the cathodic metal (lower position in a group) is smaller than the area of the anodic metal (higher position in a group).

e. Seam Design Generally, higher enclosure shielding effectiveness levels will be required for military equipment operating in severe electromagnetic environments or mission critical scenarios. Therefore, special attention must be given to seam design. A few special seam shielding features for achieving higher levels of shielding effectiveness are as follows:

Grooves For Retaining Gaskets: A groove for retaining a gasket assembly provides several advantages:

1. Can act as a compression stop.
2. Prevents overcompression.
3. Provides a fairly constant closure force under repeated opening and closing of the seam.
4. Provides a moisture and pressure seal when properly designed.
5. Cost effective in lowering assembly time and cost of gasketing material.
6. Best overall sealing performance.

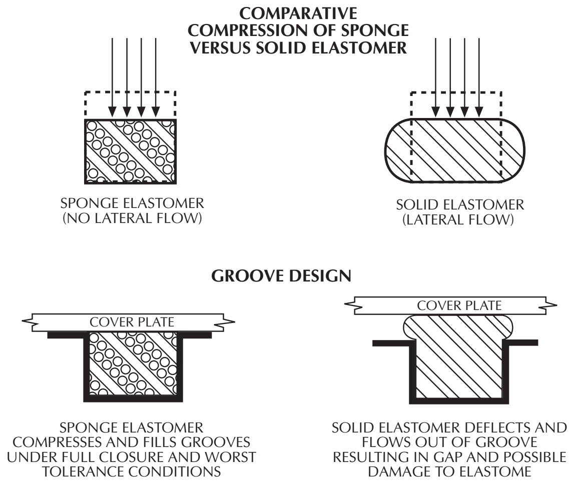


FIGURE 19
GROOVE DESIGN CONSIDERATIONS

Solid elastomers are not compressible. They are easily deformed but do not change in volume as do sponge elastomers. Therefore, allowance for material flow must be considered in the groove design. If the groove cross section (volume), when the cover flange is fully closed, is insufficient to contain the fully deflected material, proper closure of the flange may be difficult. In addition, overstressing of the material may degrade electrical and physical properties of the shielding material. Figure 19 depicts the various conditions of groove design.

Closely Spaced Fasteners: Fastener spacing design is a function of cover plate thickness, minimum-maximum pressures, gasket compressibility and material characteristics, and flange dimensions. This is reflected in the following equation for calculating fastener spacing (Refer to Figure 20):

$$C = [480\ (a/b)\ E\ t^3\ \Delta H\ /\ 13\ P_{min} + 2P_{max}\ ]1/4$$

where

- a = width of cover plate flange at seam
- b = width of gasket
- C = fastener spacing
- E = modulus of elasticity of cover plate
- $\Delta H = H1 - H2$
- $H1$ = minimum gasket deflection
- $H2$ = maximum gasket deflection
- H = gasket height
- P_{min} / P_{max} = minimum/maximum gasket pressure
- t = thickness of cover plate

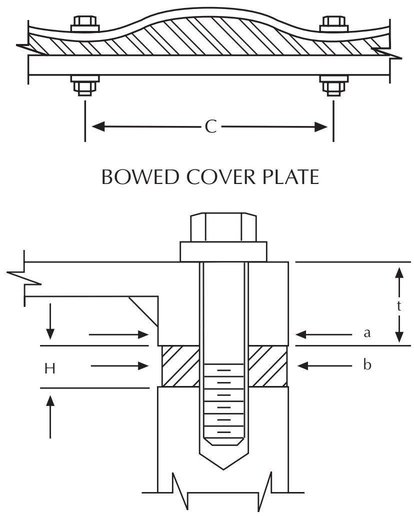


FIGURE 20
COVER PLATE AND GASKET DIMENSION

Input/Output Filters

Just as the enclosure shielding design is the last line of defense for radiated EMI control, I/O filtering is the last line of defense for controlling conducted EMI. Generally, higher filter insertion loss levels will be required for military equipment operating in severe electromagnetic environments or mission critical scenarios. This generally results in physically larger filters, which could conflict with size and weight constraints. To accommodate large filters it is often necessary to design the filter enclosure around other subassemblies within the equipment, resulting in filters with complex shapes. Interface connectors are often unique. Therefore, all things considered, filters for military equipment will most likely be a custom design.

To minimize cost and schedule impacts, the filter should be designed early in the equipment development cycle, as part of the EMC analysis and modeling effort.

ARCHITECTURAL SHIELDING DESIGN

Certain buildings, and large areas within buildings, must be designed to provide electromagnetic wave shielding. The purpose of this requirement is either:

1. to protect sensitive electronic equipment operating inside the building (generally computer based equipment) from high level rf or radar signals outside the building, or
2. to protect confidential or proprietary information being processed on computer equipment inside the building from interception by unauthorized persons outside the building through the detection and analysis of the electromagnetic waves emanating from the computer equipment.

A few examples of the first condition are as follows:

1. airline reservation centers located near airports,
2. computer facilities located near military installations, and
3. Magnetic Resonance Imaging (MRI) facilities located near a commercial radio broadcast station.

The second scenario is generally associated with the following:

1. government embassies,
2. secure government computer facilities,
3. stock and other financial organizations, and
4. industrial computer facilities involved in classified government contracts.

In both cases some level of electromagnetic shielding is required over a specified frequency spectrum. The owner, or user, of the building determines this shielding requirement based on an analysis of the potential problem. This analysis might include a site or computer equipment survey. When associated with a government installation, certain regulations and guidelines must also be followed to determine the shielding requirements.

Once these requirements have been established, they are passed on to the architects and engineers who generally work with an engineering firm that specializes in shielding design, so that the proper shielding design approach is employed in the building plans and specifications. Tecknit can direct you to the appropriate design firms.

Where unfinished material is appropriate, tin coated steel, galvanized steel, aluminum and copper are most frequently used. Basically, the entire building, or area in the building to be shielded, is "covered" with this metallic material; that is, the roof (or ceiling), walls and floor. In some cases, it is possible to make use of earth for completing a building shielding system. When shielding an entire building the shielding may be installed: a) outside the structural steel, b) as an integral part of the structure, or, c) inside, depending on the building design, materials selected, shielding requirements and cost. When shielding is required as part of the renovation of an existing building, shielding options are more limited. In the latter case, it is generally easier to apply to shielding on the exterior of the building.

In general, the shielding material is covered with standard exterior or interior building finishes such as architectural panels, sheet rock, brick, and so forth. Finished exterior metal architectural panels may be used to achieve shielding where low leve requirements exit (< 30 dB). The obvious advantage is economic where the finish and shield material are the same. This applies as well to metal roofing.

The shielding envelope must be continuous, free of openings which might allow a leak. This requirement poses some unique problems in the treatment of windows, doors, air vents, plumbing, electrical connections and other penetrations which are essential for the operation of the building.

An important consideration is the method used in joining the metallic shielding panels. The seams must be tight, metal-to-metal connections, free of paint, dirt, rust or any other insulating material. The various techniques used for joining shielding panels include welding, soldering, mechanical fasteners with pressure plates, and conductive tape. Tecknit has many products in its Shielding Products Catalog that can be used in these, architectural shielding applications, including gaskets, windows, vents, conductive coatings and tapes, etc..

Section 7 - Glossary

A

ABSORPTION Dissipation or loss of electromagnetic energy in the medium through which the energy passes. Measured is decibels (dB).

ABSORPTION LOSS A ratio of energy entering a substance to that absorbed by the substance. Measured in decibels (dB).

ADHESION The attraction of two dissimilar substances. Compare COHESION.

ADHESIVE-SEALANT A material which can perform as both an adhesive and environmental sealant.

AG/BR Silver plated brass.

AMPLITUDE The magnitude such as peak, rms, or average of a changing quality such as a voltage or current from its zero value.

ANALYSIS OR NUMERICAL ANALYSIS The study of methods of obtaining useful quantitative solutions to problems that have been expressed mathematically.

ANODE An electrode at which negative ions are discharged, or positive ions are formed, or at which other oxidizing reactions occur.

APERTURE A hole or seam in an electronic equipment enclosure through which internal or external electromagnetic fields may couple.

ARRESTANCE The capacity of an air filter to capture and hold particulate material or dust.

ATTENUATION A loss of energy. Generally expressed in decibels.

B

BARRIER A partition for the insulation or isolation of electric circuits.

BLEED To exude a liquid or gaseous material.

BOND, electrical A low impedance path between two metal surfaces.

BOND, mechanical Joining of objects by means of adhesion.

BUNA-N A synthetic rubber compound useful in applications involving exposure to jet fuels, e.g.. JP-1 through JP-6.

BUSS A metallic electrical conductor used to make a common electrical connection.

BUTYL A synthetic rubber made by polymerization of butylene and isoprene or butadiene. Useful in applications involving exposure to phosphate type hydraulic fluids.

C

CATHODE An electrode at which electrons or negative ions are formed or at which reduction reactions occur.

CHOKE FLANGE A waveguide flange having a mating surface designed with a slot to restrict leakage of electromagnetic energy.

CHROMATE CONVERSION COATING A surface protection treatment frequently used in shielding applications. Although non-conductive itself, the chromate conversion coating is easily penetrated by EMI gasket materials when pressure is applied. This low cost finish is usually applied in accordance with MIL-C-5541.

cm Centimeter.

COHESION The mutual attraction by which the elements of a material cling to each other. Compare ADHESION in which the elements of a material cling to the elements of a different material.

COLD FLOW See CREEP.

COMPATIBILITY The ability of two materials to form a chemically stable system. Two or more metals which display no appreciable corrosion when in contact with each other are said to display compatibility.

COMPRESSION The application of pressure to a material as opposed to the application of tension. In the case of cellular or sponge elastomers, compression will result in a decrease in cross-section area. Compression of solid elastomers produces a change in the shape of a cross-section with no change in its area (compare DEFLECTION).

COMPRESSION SET The percent of permanent height reduction in a material caused by compression under specific conditions of load, temperature, and time.

COMPRESSION STOP A material which acts to limit further compression of a gasket material. Used when a specified gap is required to avoid damage to gasket materials due to overcompression.

CONDUCTANCE A measure of the ability of a material to conduct electric current. The reciprocal of the resistance of the material expressed in ohms.

CONDUCTED SUSCEPTIBILITY The tendency of a piece of equipment to have its performance degraded in response to noise on its connecting wires.

CONDUCTIVITY Conductance of a unit cube of any material. Reciprocal of the volume resistivity, expressed in ohms per centimeter.

CONTACT RESISTANCE The resistance in ohms between two metal objects in contact with each other.

CORROSION A chemical action which causes gradual destruction of the surface of a metal by oxidation, electrolysis or chemical contamination.

COUPLING The association of two or more circuits or systems in such a way that power may be transferred from one to another.

CREEP The dimensional change in time of a material under pressure.

CROSSTALK Interference caused by stray electromagnetic or electrostatic coupling of energy from one circuit to another.

CURE To change the physical properties of a material by chemical reaction through the action of heat or catalysts or a combination of the two.

D

dB See DECIBEL.

DECIBEL (dB) A tenth of a bel. A dimensionless unit for expressing the ratio of two values of power. One bel is equivalent to the log of the ratio of two powers ($\log P_1/P_2$): one decibel is equivalent to 0.1 bel ($10 \log P_1/P_2$). Also used to express ratios of the magnitude of two voltages or two currents with common impedances voltage $10 \log (E_1/E_2)^2$ or $20 \log E_1/E_2$ and current $10 \log (I_1/I_2)^2$ or $20 \log (I_1/I_2)$.

DEFLECTION The amount of movement of a material as a result of stress. Deflection of elastomers occurs with the application of compression force.

DIELECTRIC STRENGTH The maximum potential gradient an insulating (dielectric) material can withstand before it breaks down, (volts per mil).

DRY BACK Solvent activated dry adhesive for permanent mounting of EMI gaskets which use solid or sponge neoprene rubber.

DYNAMIC RANGE The ratio of maximum level capability of a system to its least detectable or smallest level. (e.g., maximum signal level to system noise level). Usually expressed in decibels.

E

E-FIELD See ELECTRIC FIELD.

ELASTOMER Any of various polymers having elastic properties similar to natural rubber.

ELECTRIC FIELD OR E-FIELD The high impedance, or electric, component of an electromagnetic wave. An E-Field induces a charge on a shield and is measured in volts per meter. Compare MAGNETIC FIELD or H-FIELD.

ELECTRICAL NOISE Any unwanted disturbance within a dynamic electrical system (e.g., spurious signal or undesired electromagnetic radiation) which modifies the transmitting, receiving, indicating or recording of desired data.

ELECTROLYTIC CORROSION Corrosion which occurs when a DC current flows between two metals in the presence of a conducting fluid (electrolyte). The rate of corrosion depends upon the amount of current and the nature of the electrolyte. Compare GALVANIC CORROSION.

ELECTROMAGNETIC Having both magnetic and electric properties.

ELECTROMAGNETIC COMPATIBILITY (EMC) The ability of electronic equipment or systems to operate in their intended operational environments without causing or suffering unacceptable degradation because of unintentional electromagnetic radiation or response.

ELECTROMAGNETIC INTERFERENCE (EMI) Any electromagnetic interference, periodic or random, which may have a disturbing influence on devices exposed to it.

ELECTROMAGNETIC PULSE (EMP) Broadband, high-intensity, transient electromagnetic fields such as those produced by lightning and nuclear explosions.

ELECTROSTATIC CHARGE An electric charge accumulated on an object, usually by friction.

ELONGATION The fractional increase in length of a material stressed in tension.

EMCad Electromagnetic Compatibility Analysis and Design. A set of copyrighted and proprietary computer programs developed by Chris Kendall Consultants and Gisin Consultants Inc. which aids in understanding and predicting EMC phenomena.

EMC ISOLATION The technique for producing a high electrical resistance between an integrated-circuit component and the substrate in which it is formed.

EMISSION Electromagnetic energy propagated from a source by radiation or conduction.

EMULSION A suspension of one fluid in another.

ENCLOSURE Any electrical or electronic device housing.

ENVIRONMENTAL SEAL Sealing by gasket, potting, or other means to exclude contamination which might reduce performance.

EXPANDED METAL A technique whereby metal foil or sheet material is pierced with a pattern of small slits and stretched, or expanded, to yield a screen consisting of one unbroken piece of metal.

F

FIELD STRENGTH The strength of an electromagnetic field. The measurement may be of either the electric or the magnetic component of the field and may be expressed as V/m, A/m or W/m^2; any one of these may be converted to the others when the wave impedance is known.

FILLER Generally, material added to another material in order to improve its existing properties or add new ones. In the case of conductive elastomers (e.g., TECKNIT Consil materials) silver or carbon is introduced to add electrical conductivity.

FLASH The excess material on a rubber part resulting from rubber being forced out of the mold cavity during the molding operation.

FLUOROSILICONE A synthetic rubber useful in applications involving petroleum oils and fuels and silicone oils.

FULL INTEGRITY Said of an enclosure when all seams, joints, and apertures are completely sealed or covered so as to provide no degradation in electromagnetic shielding performance.

FUNGUS Mold, yeast, mildew, and other microorganisms.

FUNGUS INERT Neither destroying nor supporting fungi.

FUNGUS RESISTANT Unaffected by fungi when tested in accordance with MIL-STD-810, Method 508.

G

G Giga (a multiplier, 10^9).

g Gram (metric unit of mass).

g/cm^3 Gram per cubic centimeter. Metric expression for density (mass per unit volume).

GALVANIC CORROSION Corrosion which occurs between two dissimilar metals in the presence of moisture or some other electrolyte. Under these conditions an electrochemical cell is formed and current will flow from one metal to the other carrying ions of the metal with it (See TECKNIT Report PN 555). Compare ELECTROLYTIC CORROSION.

GASKET, EMI A material, or combination of materials, which conducts electricity and which is used to ensure a continuous low-impedance contact between two surfaces which conduct electromagnetic energy.

GO/NO-GO A test technique in which the object tested is required to perform in a specified manner. If it performs, it passes (GO); if it does not perform, it fails (NO-GO). (e.g., a tapped hole which will (GO) or will not (NO-GO) accept a particular screw-thread gauge).

GROUND A reference potential to which all signal and power voltages are established.

GROUNDING The establishment of an electrically conductive path between two points, with one point generally being a reference point.

GROUNDPLANE A conductive surface or plate used as a common reference point for circuit returns and electrical or signal potentials.

H

HANDLING TIME The time required for curing, drying or setting of a material prior to handling without damage.

HARDNESS Resistance of material to plastic deformation usually by indentation.

HERTZ (Hz) A unit of frequency which is equivalent to one cycle per second (1/s).

H-FIELD See MAGNETIC FIELD.

HONEYCOMB A low air resistance core material used in EMI shielding air vent panels. Generally made of aluminum, brass, or steel, the material consists of multiple hexagonal cells operating as wave guides below cut-off. The material offers extremely low resistance to air flow and high shielding effectiveness.

HYDROSCOPIC Tending to absorb moisture.

Hz See HERTZ (Hz).

I

IMPEDANCE (Z) The total opposition offered by a component or circuit to the flow of an alternating or varying current. Impedance Z is expressed in ohms and is a combination of resistance R and reactance X, computed as $Z = \sqrt{R^2 + X^2}$. Impedance is also computed as Z = E/I, where E is applied a-c voltage and I is the resulting current. In computations, impedance is handled as a complex ratio of voltage to current.

IMPEDANCE CONTROL The design technique of suppressing unintentional radiation by providing matched impedance conduction paths for electronic signals.

IMPINGEMENT FILTER An air filter coated with a viscous fluid to improve its dust arrestance and holding capacity.

INCIDENTAL RADIATOR Radiation in the ratio-frequency spectrum from a device not specifically designed as a transmitter or electromagnetic energy.

INCIDENTAL RECEIVER A device which displays an unintended capacity to respond to electromagnetic energy.

INSERTION LOSS The loss in power due to the insertion of a gasket, window, or vent panel in a seam, joint, or aperture. Generally expressed as the ratio in decibels of the power received before insertion to the power received after insertion.

IRIDITE See CHROMATE CONVERSION COATING.

K

k Kilo (multiplier, 10^3).

K Kelvin, a metric unit of temperature wherein the absolute zero degrees Kelvin is equivalent to -273.16°C (Celsius).

M

m Milli (a multiplier, 10^{-3}) and meter.

M Mega (a multiplier, 10^6).

MAGNETIC FIELD or H-FIELD The low impedance, or magnetic component of an electromagnetic wave. A magnetic field induces current in a shield. Compare ELECTRIC or E-FIELD.

MIL 0.001 inch.

MONEL An alloy of 67% nickel and 30% copper.

N

NECKING The localized reduction in cross-section that may occur in a material under tensile stress.

NEOPRENE A synthetic rubber made by the polymerization of chloroprene. A general purpose polymer with many desirable characteristics, including high resilience with low compression set and flame resistance. Attacked by ozone and various hydrocarbon fluids including jet fuels.

NEWTON A metric unit of force equal to 0.2248 pounds.

NOISE BUDGET An EMC design tool specifying the portion of allowed system noise emission to be allotted to each noise source.

NOMINAL A stated value as opposed to an actual one. Values expressed as nominals may actually express a mid point between two limits, or an average, normal, or typical value.

NONSETTING Nonhardening.

O

OHM (Ω) A unit of electrical resistance.

OHM-cm A unit of material volume resistivity.

OHM/SQUARE A unit of material surface resistivity.

OVERCOMPRESSION Compression which causes irreparable damage to a material or component.

P

PARAMETER A quantity to which arbitrary values may be assigned.

PASCAL (pa) The metric unit of pressure or stress equal to one n/m^2, or 0.000145 psi.

PASSIVATION The growth of an oxide layer on the surface of a metal to provide corrosion resistance by isolating the surface from electrical and chemical conditions in the environment.

PERMEABILITY, CHEMICAL The tendency of a compound to admit or pass molecules of a different compound, usually gas or vapor.

PERMEABILITY, MAGNETIC (μ) A relative measure of the ability of a material to serve as a path for magnetic lines of force based on air = 1. Permeability is the magnetic induction B in gauss divided by the magnetizing force H in oersteds.

PLANE WAVE A electromagnetic wave in which all points normal to the direction of propagation are in phase.

PRESSURE-SENSITIVE ADHESIVE An adhesive which, under normal conditions of temperature and humidity, remains tacky. Used on gasket materials as a positioning aid during equipment assembly. It is not intended to be used for permanent mounting. See DRY BACK.

POT LIFE The period of time during which a reacting plastic or rubber compound remains suitable for application after a reaction with an initiating agent or hardener.

R

RADIATED EMISSION Radiation of electromagnetic fields into space.

RADIATED SUSCEPTIBILITY Tendency of an electronic device to respond with degraded performance to radiated noise.

RADIATION Electromagnetic energy, such as light waves, sound waves, radio waves, x-rays, infra-red and thermal waves traveling through a medium or through space.

RADIO WAVES (or Hertzian Waves) Electromagnetic waves in the frequency range of 10 kHz to 100 GHz propagated in space without artificial guide.

REF. Reference information. Not a requirement.

REFLECTION The redirection of electromagnetic energy due to reflection at the air-metal boundary of a shield. Thr efficiency of the reflecting shield is a complex function of the wave and shield impedance. Compare ABSORPTION.

REFLECTION LOSS A ratio of energy incident at an air-metal boundary of a shield to that reflected. Measured in decibels (dB).

RELATIVE CONDUCTIVITY (σ_r) A comparative measure of electrical conductivity based on copper = 1.

RE-REFLECTION LOSS A ratio of energy incident within a metal barrier at the metal-air boundary to that reflected internally. Measured in decibels (dB).

RESILIENCY The capability of a compressed gasket to quickly recover its size and shape after deformation within its elastic limits.

RESONANT CAVITY A form of resonant circuit in which the current is distributed on the inner surface of an enclosed chamber.

RFI Radio Frequency Interference. Electromagnetic interference (EMI) within the frequency range 3 kHz to 300 GHz.

RH Relative humidity.

RTV (Room Temperature Vulcanizing) An elastomeric adhesive which cures at room temperature, about 23˚C.

"RULE OF THUMB" Empirical design practices or guidelines employed to simplify a design problem. May or may not have a theoretical justification.

S

SHELF LIFE Length of time under specified conditions that a material retains its usability and specified properties.

SHIELD Electrically conductive materials placed around a circuit, component, or cable to suppress the effect of an electromagnetic field within or beyond definite regions.

SHIELDING EFFECTIVENESS The effectiveness of a given material as a shield under a specific set of conditions, measured in decibels (dB).

SHIELD-SEAL A material which provides both EMI and environmental sealing.

SHORE A A scale used for the measurement of hardness with a durometer.

SILICONES Polymeric materials in which the recurring chemical group contains silicon and oxygen atoms as links in the main chain.

SI METRIC International System of metric units as described and defined in American National Standards Institute document ANSI Z210.1, Metric Practice.

SINTERED Metal particles fused together under pressure at a temperature below their melting points.

SKIN DEPTH (δ) The depth below the surface of a current carrying conductor at which the current density has decreased one neper (i.e., 1/e or 36.8%) below the current density at the surface.

Sn/Cu/Fe Tecknit designation for a tin coated, copper-clad steel wire used to make EMI gasket materials.

SPECTRUM 1. All the frequencies used for a specific purpose. 2. The frequency components, band or range that make up a complex waveform or transmission of a given type of intelligence.

SQUARE WAVE A square or rectangular shaped periodic wave which alternately assumes two fixed values of near equal time duration in which the transition time is negligible in comparison with the duration time.

STRESS RELAXATION The decrease in stress after a given time at constant strain.

SURFACE RESISTIVITY The resistance of a material between two opposite sides of a unit square of its surface.

SUSCEPTIBILITY The undesired response of electronic equipment to emission, interference, or transients, or to signals other than those to which the equipment is intended to be responsive.

T

TACK-FREE TIME The time required for a coating or adhesive surface to be free of tack or stickiness.

TEAR STRENGTH The maximum force required to tear a specified specimen the force acting substantially parallel to the major axis of the test specimen.

TENSILE STRENGTH The maximum tensile stress applied during stretching a specimen to rupture.

THERMOPLASTIC A term used to describe those materials which can be repeatedly made to flow under the application of heat.

THERMOSETTING A term used to describe plastic materials that are capable of being changed into substantially infusible or insoluble products when cured by application of heat or by chemical means. Once cured, the plastic cannot be made to flow.

THIXOTROPIC Describes materials that are gel-like at rest but fluid when agitated.

TOGGLE BOOT A component designed to provide EMI shielding and moisture sealing for toggle switches.

TRANSMISSION LINE A path from one place to another, used for directing the transmission of electromagnetic energy.

TRAPEZOIDAL WAVE A square-like wave having rise and fall times which are significant portions of the period of the signal.

V

VISCOSITY The resistance of a material to flow under stress.

VOLUME RESISTIVITY The electrical resistance between opposite faces of a 1 centimeter cube of material, commonly expressed in ohm-centimeters (ohm-cm or Ω-cm).

W

WAVEGUIDE A system of material boundaries capable of guiding electromagnetic waves. A transmission line comprising a hollow conducting tube within which electromagnetic waves are propagated on a solid dielectric or dielectric-filled conductor.

WAVE IMPEDANCE The complex ratio between the transverse components of the electric and magnetic fields.

WAVELENGTH In a periodic wave, the distance between points of corresponding phase of two consecutive cycles. The wavelength (λ) is related to the propagation velocity (c) and the frequency (f) by the formula $\lambda = c/f$.

W.G. Water gauge.

WICKING Capillary absorption of liquid (including water) along fibers or holes in a base material.

W/m-K Watt per meter-kelvin (metric unit of thermal conductivity).

Section 8 - Appendix A

Materials normally encountered in enclosure and shielding design are presented in Table A-1. The materials are listed in two groups. The first grouping ranks the relative conductivity of nonmagnetic materials from silver (most conductive) through titanium (least conductive). The second group ranks the materials by relative permeability for steel (lowest permeability) through supermalloy (highest permeability). Relative permeability for the first group is effectively independent of frequency, whereas the materials in the second group are highly dependent upon frequency and magnetic induction or flux density (gauss).

The relative permeability values for the magnetic materials (relative permeability greater than 1, $\mu_r > 1$) are provided for frequencies of 1 kHz, 10 kHz and 100 kHz. Above 1 megahertz, the relative permeability approaches 1 and approximates the permeability of the nonmagnetic material of the first group.

The effect of frequency dependent permeability on the absorption loss term (A_{dB}) is shown for the magnetic materials at the discrete frequencies from 1kHz to 1 MHz. For example, the absorption loss for Mu-Metal peaks at about 9 kHz whereas supermalloy peaks at about 20 kHz with a constant magnetic induction (B) of 20 gauss.

The last columns, relative reflection loss, depict the effects of loss in the reflection term (R_{dB}) due to the high values of permeability at low frequencies.

Table A-1

SHIELDING MATERIAL CHARACTERISTICS

	Relative Conductivity	Relative Permeability μ_r B (Magnetic Ind) = 20 Gauss			Absorption Loss (dB) Per MIL Barrier Thickness $A_{dB} = 3.334\ (t_{in})\ (\mu_r\sigma_r f)^{1/2}=$				Relative Reflection Loss (dB) $\Delta R_{dB} = 10 \log_{10} (\sigma_r/\mu_r)$		
Material	σ_r (Cu=1)	f= 1 kHz	f= 10 kHz	*f= 100 kHz	f= 1 kHz	f= 10 kHz	f= 100 kHz	f= 1 MHz	f= 10 kHz	f= 100 kHz	f= 1 MHz
Group 1											
Silver (Pure)	1.08	1	1	1	0.11	0.35	1.10	3.46	+ 0.3	+ 0.3	+ 0.3
Copper (Annealed)	1.00	1	1	1	0.11	0.33	1.05	3.33	0.0	0.0	0.0
Gold	0.70	1	1	1	0.09	0.28	0.88	2.79	- 1.6	- 1.6	- 1.6
Chromium	0.66	1	1	1	0.09	0.27	0.86	2.71	- 1.8	- 1.8	- 1.8
Aluminum	0.61	1	1	1	0.08	0.26	0.82	2.60	- 2.2	- 2.2	- 2.2
Brass (91% Cu 9% Zn)	0.47	1	1	1	0.07	0.23	0.72	2.29	- 3.3	- 3.3	- 3.3
Magnesium	0.37	1	1	1	0.06	0.20	0.64	2.03	- 4.3	- 4.3	- 4.3
Tungsten	0.31	1	1	1	0.06	0.19	0.59	1.86	- 5.1	- 5.1	- 5.1
Zinc	0.30	1	1	1	0.06	0.18	0.58	1.83	- 5.2	- 5.2	- 5.2
Cadmium	0.23	1	1	1	0.05	0.16	0.51	1.60	- 6.4	- 6.4	- 6.4
Nickel	0.22	1	1	1	0.05	0.16	0.49	1.56	- 6.6	- 6.6	- 6.6
Phosphor-Bronze	0.22	1	1	1	0.05	0.16	0.49	1.56	- 6.6	- 6.6	- 6.6
Tin	0.15	1	1	1	0.04	0.13	0.41	1.29	- 8.2	- 8.2	- 8.2
Beryllium	0.10	1	1	1	0.03	0.11	0.33	1.05	- 10.0	- 10.0	- 10.0
Lead	0.08	1	1	1	0.03	0.09	0.30	0.94	- 11.0	- 11.0	- 11.0
Monel	0.041	1	1	1	0.02	0.07	0.21	0.68	- 13.9	- 13.9	- 13.9
Manganese	0.040	1	1	1	0.02	0.07	0.21	0.67	- 14.0	- 14.0	- 14.0
Titanium	0.039	1	1	1	0.02	0.07	0.21	0.66	- 14.1	- 14.1	- 14.1
Group II											
Steel	0.10	180	60	5	0.45	0.82	0.75	1.05	-27.8	- 17.0	- 10.0
Iron	0.17	200	100	10	0.61	1.37	1.37	1.37	-27.7	-17.7	- 7.7
4% Silicon Iron	0.23	500	150	10	1.13	1.96	1.60	1.60	-28.1	-16.4	- 6.4
Permalloy	0.21	2,500	800	50	2.42	4.32	3.42	1.53	-35.8	-23.8	- 6.8
Hypernik	0.21	4,500	1,400	95	3.24	5.72	4.71	1.53	-38.2	-26.6	- 6.8
Iron (Purified)	0.17	5,000	1,500	100	3.07	5.32	4.35	1.37	-39.5	-27.7	- 7.7
Mu-Metal	0.20	20,000	6,000	400	6.67	11.55	9.43	1.49	-44.8	-33.0	- 7.0
Supermalloy	0.20	100,000	30,000	2,000	14.91	25.83	21.09	1.49	-51.8	-40.0	- 7.0

* Permeability above 1 MHz for most materials approaches unity ($\mu_r \rightarrow 1$)

Appendix B

Table B-1

FCC PART 15 LIMITS FOR DIGITAL DEVICES

CONDUCTED EMISSION

	Frequency of Emission (MHz)	Conducted Limit (microvolts)
CLASS A	0.45 - 1.705 1.705 - 30.0	1000 3000
CLASS B	0.45 - 30.0	250

RADIATED EMISSION

	Frequency of Emission (MHz)	Field Strength (microvolts/meter)
CLASS A (10 meters)	30 - 88 88 - 216 216 - 960 above 960	90 150 210 300
CLASS B (3 meters)	30 - 88 88 - 216 216 - 960 above 960	100 150 200 500

Table B-2

FDA EMC GUIDELINES SUMMARY

	TEST REQUIREMENTS	STANDARD
Radiated and Conducted Emission: **Magnetic Field Emission:** **Electrostatic Discharge Immunity:**	CISPR 11 CISPR 11 Army 7 cm. limit 2, 4, 6 and 8 kV Air Discharges 2, 4, and 6 kV Contact Discharges	 MIL-STD-462D, Method RE101 IEC 801-2
Radiated Field Immunity :	3 V/m, 26 MHz to 1 GHz 100% square wave modulation	
Steady State Voltage Fluctuations: **Line Voltage Dropouts:** **Slow Line Voltage Sags and Surges:**	132 Vrms to 95 Vrms 10 milliseconds 150 Vrms for 500 milliseconds 90 Vrms for 500 milliseconds	
Fast Transient Bursts:	Power Lines - 0.5, 1 and 2 kV Signal Leads - 0.25, 0.5 and 1 kV	IEC 801-4
Fast Line Voltage Surges:	1.2 x 50 microsecond voltage 8 x 20 microsecond current surge 100 ohm impedance 1 kV differential mode 2 kV common mode	
Conducted Energy Immunity:	Curve #3	MIL-STD-462D, Method CS114
Magnetic Field Immunity:	MIL-STD-462D	MIL-STD-462D, Method RE101
Quasi-static Electric Field Immunity:	0.5 Hz, 2000 V/m	

Table B-3

EN 55022 LIMITS FOR INFORMATION TECHNOLOGY EQUIPMENT

CONDUCTED EMISSION

	Frequency of Emission (MHz)	Conducted Limit (dB/microvolts) Quasi-peak	Average
CLASS A	0.15 - 0.50 0.50 - 30.0	79 73	66 60
CLASS B	0.15 - 0.50 0.50 - 5 5 to 30	66 to 56 56 60	56 to 46 46 50

RADIATED EMISSION

	Frequency of Emission (MHz)	Field Strength (QP) (dB/microvolts/meter)
CLASS A (10 meters)	30 - 230 230 - 1000	40 47
CLASS B (10 meters)	30 - 230 230 - 1000	30 37

Table B-4

EN 50082-1:1992 IMMUNITY REQUIREMENTS SUMMARY

	TEST REQUIREMENTS	STANDARD
Enclosure:	RF Electromagnetic Field 27 to 500 MHz, 3 V/m Performance Criteria A	IEC 801-3:1984
	Electrostatic Discharge 8 kV Air Discharge Performance Criteria B	IEC 801-2:1984
Ports for signal lines, control lines, and input and output DC power lines:	Fast Transients .5 kV (pk), 5/50 ns, 5 kHz Performance Criteria B	IEC 801-4:1988
Ports for input and output AC power ports:	Fast Transients 1 kV (pk), 5/50 ns, 5 kHz Performance Criteria B	IEC 801-4-1988

Table B-5

EN 50082-2:1995 IMMUNITY REQUIREMENTS SUMMARY

	TEST REQUIREMENTS	STANDARD
Enclosure:	RF Electromagnetic Field 80-1000 MHz, 10 V/m, 80% AM (I kHz) Performance Criteria A	ENV 50140
	RF Electromagnetic Field 900 MHz +/- 5, 10 V/m, 50% PM (200Hz) Performance Criteria A	ENV 50140
	Power Frequency Magnetic Field 50 Hz, 30 A (rms)/m	EN 61000-4-8
	Electrostatic Discharge 4 kV Contact 8 kV Air Discharge Performance Criteria B	EN 61000-4-2
Ports for signal lines and data busses, and AC and DC input and output power ports:	Radio frequency - common mode 0.15 - 80 MHz, 10 V (rms) 80% AM (1 kHz), 150 ohms Performance Criteria A	ENV 50141
Ports for signal lines and data busses not involved in process control	Fast TransientsEN 61000-4-4 1 kV (pk), 5/50 ns, 5 kHz Performance Criteria B	
Ports for process, measurement and control lines, and long bus and control lines; AC and DC input and output ports:	Fast TransientsEN 61000-4-4 2 kV (pk), 5/50 ns, 5 kHz Performance Criteria B	

Table B-6

EN 60601-1-2 REQUIREMENTS SUMMARY

	TEST REQUIREMENTS	STANDARD
Radiated and Conducted Emission:	CISPR 11	CISPR 11
Electrostatic Discharge Immunity:	8 kV Air Discharges 3 kV Contact Discharges	IEC 801-2
Radiated Field Immunity :	1 or 3 V/m, 26 MHz to 1 GHz	IEC 801-3
Fast Transient Bursts:	Power Lines - 1 kV plug connected 2 kV permanently connected Signal Leads - 0.5 kV	IEC 801-4
Fast Line Voltage Surges:	1.2 x 50 microsecond voltage 8 x 20 microsecond current surge 2 ohm impedance 1 kV differential mode 2 kV common mode	IEC 801-5

Table B-7

EN 55011 LIMITS FOR INDUSTRIAL, SCIENTIFIC AND MEDICAL EQUIPMENT (Group 1)

CONDUCTED EMISSION

	Frequency of Emission (MHz)	Conducted Limit (dB/microvolts) Quasi-peak	 Average
CLASS A	0.15 - 0.50 0.50 - 30.0	79 73	66 60
CLASS B	0.15 - 0.50 0.50 - 5 5 to 30	66 to 56 56 60	56 to 46 46 50

RADIATED EMISSION

	Frequency of Emission (MHz)	Field Strength (QP) (dB/microvolts/meter)
CLASS A (30 meters)	30 - 230 230 - 1000	30 37
CLASS B (10 meters)	30 - 230 230 - 1000	30 37

Table B-8

EN 50081-1:1992 EMISSION REQUIREMENTS SUMMARY

EMISSION					
Port	**Frequency range**	**Limits**	**Basic Standard**	**Applicability Note**	**Remarks**
Enclosure	30 - 230 MHz 230 - 1000 MHz	30 dB (mV/m) at 10 m 37 dB (mV/m) at 10 m	EN 55022 Class B	See Note 1	The statistical evaluation in the basic standard applies
AC Mains	0 - 2 kHz	EN 60555-2 EN 6O555-3		See Note 2	
	0,15-0,5 MHz limits decrease linearly with log. frequency	66-56 dB (mV) quasi peak 56-46 dB (mV) average	EN 55022 Class B		The statistical evaluation in the basic standard applies
	0,5-5 MHz 46 dB (i~V) average	56 dB (mV) quasi peak			
	5-30 MHz 50 dB (IzV) average	60 dB (mV) quasi peak			
	0,15-30 MHz	See basic standard Clause: discontinuous interference	EN 55014		

NOTE 1: Applicable only for apparatus containing processing devices, e.g. microprocessors, operating at frequencies greater than 9 kHz.

NOTE 2: Applicable to apparatus covered within the scope of EN 60555-2 and EN 60555-3. Limits for apparatus not currently covered by EN 60555-2 and EN 60555-3 are under consideration.

Table B-9

MIL-STD-461D REQUIREMENTS SUMMARY

I.D.	DESCRIPTION
CE101	Conducted Emissions, Power Leads, 30 Hz to 10 kHz
CE102	Conducted Emissions, Power Leads, 10 kHz to 10 MHz
CE106	Conducted Emissions, Antenna Terminal, 10 kHz to 40 Ghz
CS101	Conducted Susceptibility, Power Leads, 30 Hz to 50 kHz
CS103	Conducted Susceptibility, Antenna Port, Intermodulation, 15 kHz to 10 GHz
CS104	Conducted Susceptibility, Antenna Port, Rejection of Undesired Signals, 30 Hz to 20 GHz
CS105	Conducted Susceptibility, Antenna Port, Cross Modulation, 30 Hz to 20 GHz
CS109	Conducted Susceptibility, Structure Current, 60 Hz to 100 kHz
CS114	Conducted Susceptibility, Bulk Cable Injection, 10 kHz to 400 MHz
CS115	Conducted Susceptibility, Bulk Cable Injection, Impulse Excitation
RE101	Radiated Emissions, Magnetic Field, 30 Hz to 100 kHz
RE102	Radiated Emissions, Electric Field, 10 kHz to 18 GHz
RE103	Radiated Emissions, Antenna Spurious and Harmonic Outputs,10 kHz to 40 GHz
RS101	Radiated Susceptibility, Magnetic Field, 30 Hz to 100 kHz
RS102	Radiated Susceptibility, Electric Field, 10 kHz to 40 GHz
RS105	Radiated Susceptibility, Transient Electromagnetic Field