EMC THROUGH PACKAGING

INTRODUCTION

Components, equipment, cables and systems can be electromagnetically compatible through EMI protected packaging. This packaging is known as shielding, screening, suppression, etc. all with the function of controlling the electromagnetic environment in which subject components, equipment or systems has to function, or is allowed to function. Incorporating "packaging" as an EMC design criteria in the conceptual design phase, will result in a much better cost effective design than utilizing protective packaging as a last resort to EMC design requirements.

ANATOMY OF AN ELECTROMAGNETIC FIELD

Electromagnetic energy radiates from a source containing both electric and magnetic field components. The field surrounding a highly electrically charged object is an electric field. Its presence can be demonstrated by such common experiences as oppositely charged objects clinging together or like-charged objects repelling each other. The field surrounding a permanent magnet is a magnetic field. Its presence can be demonstrated with a compass, iron filings, or attraction of other magnetic materials.

These examples are static fields; that is, their magnitude (or intensity) is constant and they have no motion - there is no change in either their strength or position. However, electromagnetic fields are not static; their intensity varies, both the electric and magnetic fields alternate polarities at the same frequency, and they are at right angles to each other. If the field is propagating to the right in Figure 1, each arrow would progressively acquire the magnitude and polarity of the arrow to its immediate left, making it appear as though the entire picture had shifted one arrow to the right. This "shifting-to-the-right" is at a velocity of $3 \times (10)^8$ m/sec (or 186,000 mi./sec.)

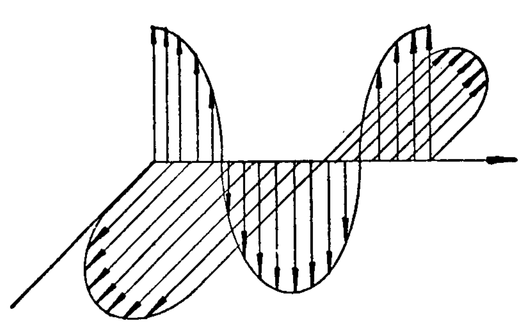


Figure 1 - Electromagnetic radiation is composed of an electric and a magnetic field oriented at right angles to each other.

Field strength or intensity describes the field's magnitude. Three units are used to measure this characteristic:

Watts/square meter defines field strength in terms of the power that impinges on a given area. When measured directly, calorimetric techniques are used.
Volts/meter defines the intensity of the electric-field portion only, and is measured with a rod antenna.
Amps/meter defines the intensity of the magnetic-field portion only, and is measured with a loop antenna.

Impedance **Z** of an electromagnetic field equals electric-field intensity **E** divided by the magnetic field intensity **H**. A field of normal characteristics has an impedance of 377 ohms. In other words, a wave propagating freely through space and far enough removed from its source and any other objects will always have a fixed ratio between the electric field intensity (**E** in V/m) and magnetic field intensity **H** in A/m) of 377 ohms.

If the **E** component is more intense than normal, then the field is called an electric or high-impedance field. A rod antenna connected to a high-voltage r-f generator would be such a source, Figure 2a. The heavy field lines indicate that the electric field is more intense than the magnetic field at the source. A field with a higher-than-normal **H** component is a magnetic or low-impedance field. A loop antenna connected to a generator with a high r-f current output would generate a low-impedance or magnetic field, Figure 2b.

There are three important basic electromagnetic field principles:

- All alternating electric fields gradually lose some of their intensity in generating a complementary magnetic field, Figure 2a.
- All alternating magnetic fields gradually lose some of their intensity in generating a complementary electric field, Figure 2b.
- All fields will have a normal impedance of 377 ohms beyond approximately one wavelength from the source.

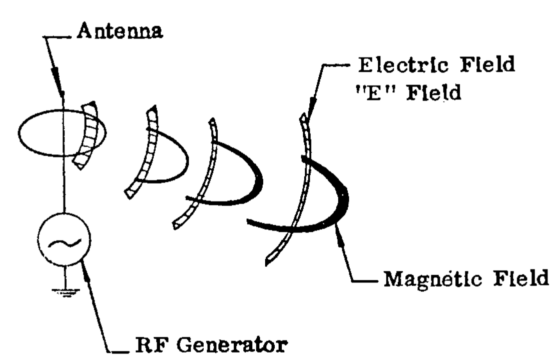
Stated mathematically:

$$Z_E = 60\frac{\lambda}{r} = \underline{18\ (10)^3} \left(\frac{r}{\lambda} < 0.1\right)$$

$$Z_H = 2360\frac{r}{\lambda} = 7.87\ \ Fr \left(\left(\frac{r}{\lambda} < 0.1\right)\right)$$

$$Z_P = 377 \left(\left(\frac{r}{\lambda} > 0.1\right)\right)$$

Where Z_E = impedance of an electric wave, Z_H = impedance of a magnetic wave, Z_P = impedance of a plane wave, *R = Distance in meters from the source, λ = wavelength in meters and F = frequency in MHz. For small values of R/λ (close to source), Z_E is very large compared to Z_H. For example, if $r/\lambda = 0.01$, and Z_E = 6,000 Ω and Z_H = 23.6 ohms. Figure 3 shows a graph to determine the type of field present if the distance to the source is known.



(a)

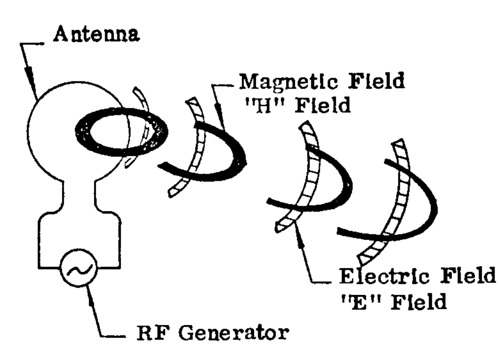


Figure 2 - High impedance fields contain a higher-than-normal electric content, (a). Low-impedance fields contain a higher-than-normal magnetic content, (b).

*Beyond one or two wavelengths, electromagnetic waves are usually called plane waves because the relatively small portion of a sperical wave fron that arrives at a shield will be flat.

HOW EMI SHIELDS WORK

An EMI shield contains (or excludes) electromagnetic energy by reflecting or absorbing the energy. Whenever EMI passes from one medium into another, a portion is reflected, just as light is at an air-to-water interface. Energy not reflected at the air-to-shield interface goes into the shield and is absorbed due to I^2R, losses from induced currents.

Evaluating a Shield: Shielding is measured and specified in terms of the reduction in field strength caused by the shield. Thus, to evaluate a shield, you must measure the EMI field strengths in the area to be protected under shielded and unshielded conditions. The shielding achieved is the change in field strength. The unit of shielding is the decibel (dB) which equals 20 log (E1/E2) when the change in V/m is measured; or 20 log (H1/H2) when the change in A/m is measured; or 10 log (P1/P2) when the change in W/m² is measured.

The total shielding, S, possible from a material is the amount the field stregth is reduced due to reflection R, plus absorption A; or, S = R + A. A more exact equation would include reflection at the exit interface by equating S = R + A + B. But if A = 10 dB (which is almost always the case), B can be neglected.

Absorption: The amount of energy absorbed by a shield depends on the impinging field's frequency, and the shielding material's thickness, conductivity and permeability. Absorption is computed from:

$$A = 3.34T \sqrt{FG}\,\mu$$

where A = absorption in dB, t = thickness of shield in 0.001 in., F = frequency in MHz, G = conductivity relative to copper, and μ = relative magnetic permeability.

The amount of shielding due to absorption only for .004 in. thick brass and nickel-iron alloy is shown in Figure 4.

Reflection: The amount of electromagnetic energy reflected from the surface of a shield depends on the impedance of the field as it arrives at the shield, and is determined by

$$R = 20 \log \frac{Z_W}{4Z_8} \qquad (Z_W > Z_8)$$

where R = reflection in dB, Z_W = impedance of the wave at the shield, and Z_8 = impedance of shield, which in all practical shielding problems is much less than Z_W. A high impedance field will be reflected more than a low impedance field. The effect of field impedance on reflection for brass and high permeable metal shields is shown in Figure 5. Shield thickness does not affect reflection provided the shield is at least a few mils thick. Note that the H field and E field lines converge on the plane wave line as distance approaches one wavelength.

Figure 5 also shows why low-frequency E field shielding is seldom a problem; the reflection is much greater than would ever be needed. Not so for the H field; its reflection decreases at lower frequencies.

Absorption Plus Reflection: Figure 6 shows total shielding (absorption plus reflection) or magnetic fields with a source to shield distance of 12" for brass and nickel-iron alloy .004 in. thick. Total shielding for all plane wave and electric fields is more than 120 dB for all metals.

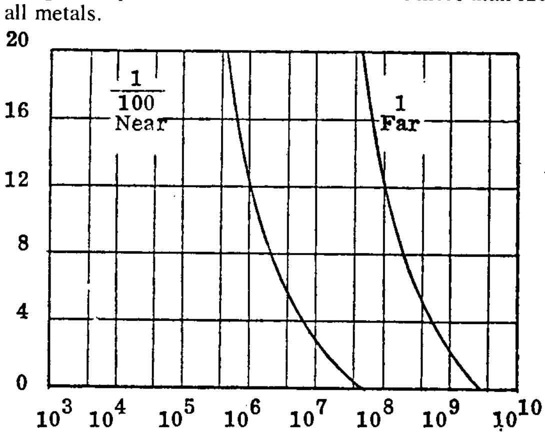


Figure 3 - Typical shielding problems involve wavelengths of 20 ft. and under.

See Singer Instrumentation on pages 2 thru 7.

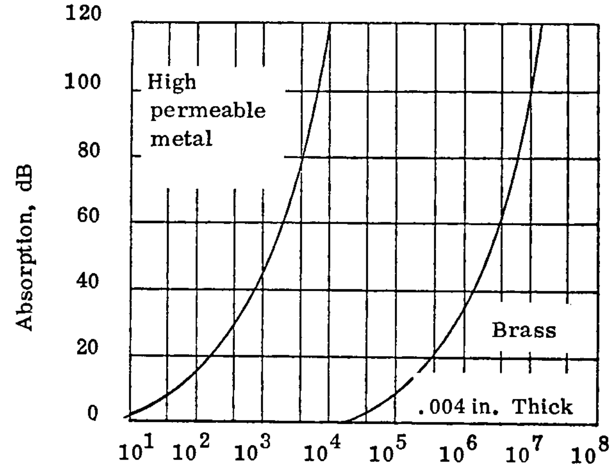


Figure 4 - High permeable metal is a good EMI absorber for frequencies up to several kilohertz. Above a few megahertz, any mechanically suitable metal will be a good EMI absorber.

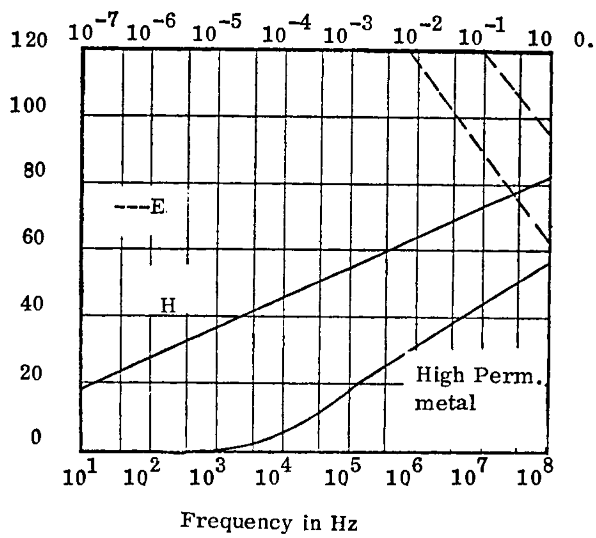


Figure 5 - Low-frequency E fields are reflected much more than H fields.

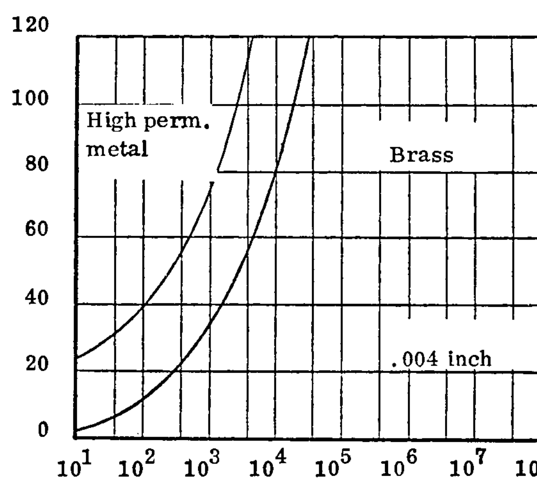
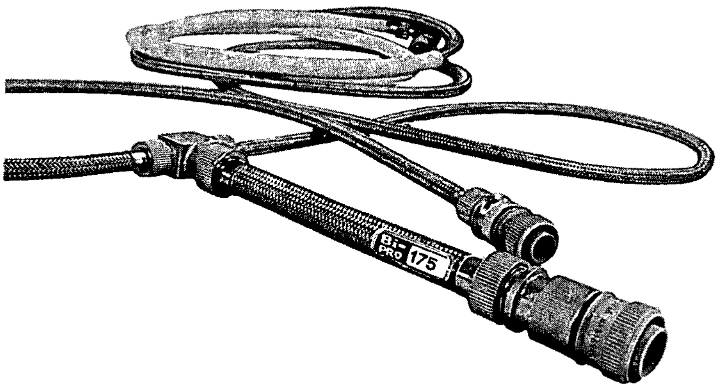
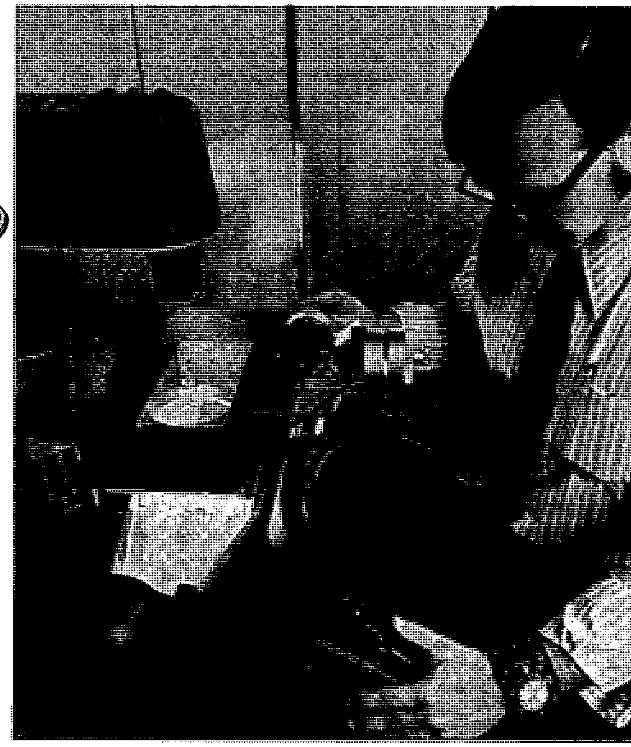


Figure 6 - Total shielding for plane-wave and electric fields is more than 120 dB for any metal.





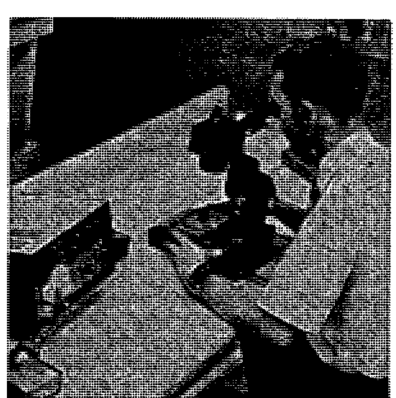
A complete manufacturing facility, Breeze-Illinois machines its own conduit, backshells and other hardware, special fittings, junction boxes and branches. We prepare our own dies and molds for molded assemblies and employ the latest materials, equipment and fabrication techniques such as Magna-Bonding™, the latest development in securing end fitting attachments. We are also leaders in the Fiber optic field, transmitting signals by light rather than electrical current.

Breeze-Illinois has developed a complete line of shielded interconnectors that assure wiring integrity in every situation. Trade marked **Bi-PRO** (for **B**reeze-**I**llinois **PRO**tected) our conduit is manufactured in accordance with all applicable Government, Military and NASA specifications. Some are super tough to withstand the punishment of continuous flexing and heavy work. Others are light weight to be compatible with aerospace requirements. High temperature Bi-Pro cable withstands hostile environments of over 1000°f. And, all Bi-Pro interconnectors feature superior shielding against the complete spectrum of electromagnetic interference, radiation and Tempest.

You should also know about our **Bi-SHIELD™** cable assemblies. Bi-SHIELD is our name for wiring assemblies that do not call for internal conduit, but instead receive their protection from jackets or combinations of jackets that are braided, molded or blown onto the wire assembly depending on the need.

Bi-SHELL™ is our trade name for backshell hardware specifically designed by Breeze to offer the interconnector designer the greatest flexibility possible for end fittings. Allowing more room for wire maintenance and cable assembly, these backshells come in any angle desired and can be specified for either permanent or repairable fittings.

Take a hard look at Breeze-Illinois. We may be able to save you money, space, weight—probably all three when you're talking interconnectors. Contact our home office today. We'll have a man in your area.



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FOR PROTECTED *INTERCONNECTOR ASSEMBLIES*

DISCONTINUITY LEAKS

Solid metal packaging which is mechanically suitable, provides more than adequate protection above 1 MHz, while most of the packaging design address requirement is well in excess of 1 MHz. Above 1 MHz, the level of protection, (shielding/screening) is controlled by the design of discontinuities which all practical design have. Enclosures heed excess panels, control shaft, cable and other entrees, ventilation panels, etc. Cables have discontinuities of the braid (if this is the protection media), backshell terminations, connector and connector interfaces.

Maximum length of the opening is important because the voltage will be highest wherever the detour for the currents is longest. This location is at the center of the slot, and voltage increases as the length of the slot increases. Slot width has almost no effect on detour length and thus, has little effect on the voltage.

Wave impedance is also important because a low-impedance wave induces high current, resulting in higher voltages. A high impedance induces only weak current. Wavelength controls how much the slow antenna radiates. If the slow length is 1/4 wavelength or longer, it will be a very efficient radiator; if it is less than 1/100 wavelength, it will be a rather inefficient radiator.

Therefore, slots only 0.001 to 0.005 in. wide but 1/100 wavelength or more long can be responsible for large leaks. Figure 9 shows wavelength and 1/100 wavelength or more long can be responsible for large leaks. Figure 7 shows wavelength and 1/100 wavelengths vs. frequency for 0-6 in. slot lengths that can typically occur in normal metal enclosures. Combinations of frequency and slot lengths to the right of the 0.001 - line would tend to be leaky; to the right of the 1 - line they could be very leaky. Thus, discontinuities in shields, even if very narrow but long, severely reduce the shielding capability of cable shielding.

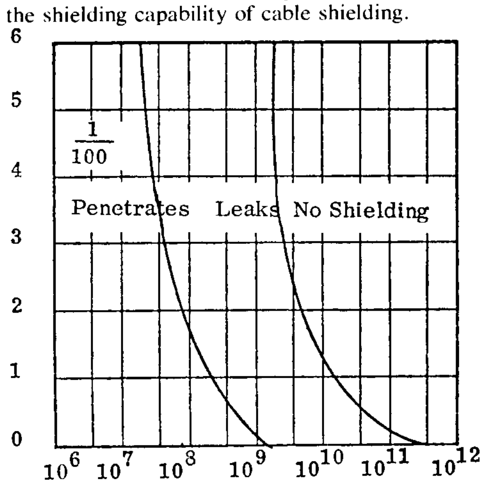


Figure 7

SEAMS AND JOINTS

Clean, conductive surfaces under contact pressure should provide shielding continuity. While surfaces may be designed to be in contact, the stresses created by fasteners may produce gaps in the joint. Spot-welded, screw-fastened, and riveted joints are common examples. Hole misalignment is another cause for bowing.

Bowing effects may be reduced by closer spacing of fasteners. The effects of screw spacing on total enclosure shielding effectiveness at 200 MHz is illustrated in Figure 8. At frequencies above 200 MHz, the effects would be greatly increased as the electrical length of the slots approach the wavelength of the higher frequencies.

For infrequently opened doors, lids, and panels, one of the many types of rf gaskets may be used. They are available in continuous strip, sheets, and pre-formed to almost any shape. Where environmental sealing is also required, combination gaskets are available. An rf gasket performs by providing a very large number of closely spaced electrical shorts between the surfaces in contact.

This may be accomplished if the contacting surfaces are conductive and remain so. The gasket must be compressed to the psi recommended by the manufacturer. If this is exceeded, the gasket will be crushed with a loss of resiliency. If compression is insufficient, the gasket will not fill irregularities in the mating surfaces.

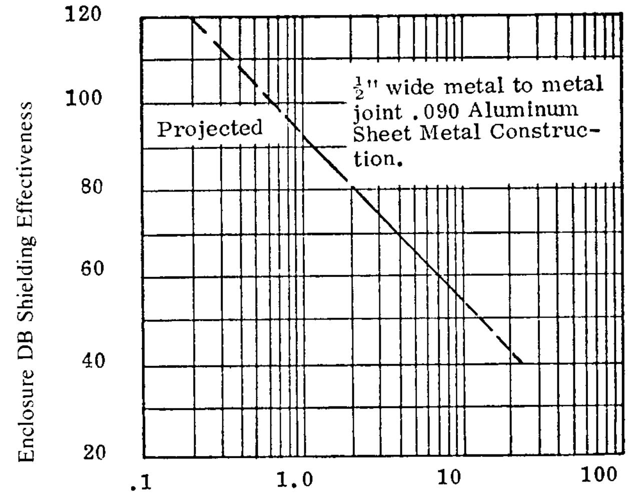


Figure 8

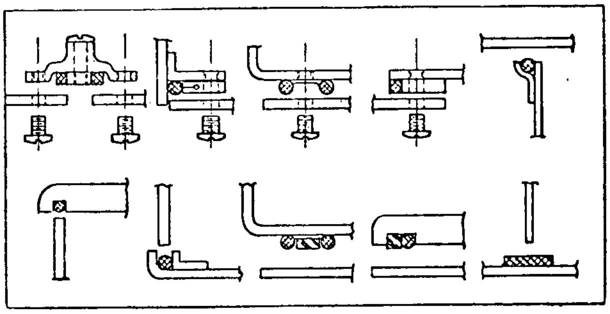
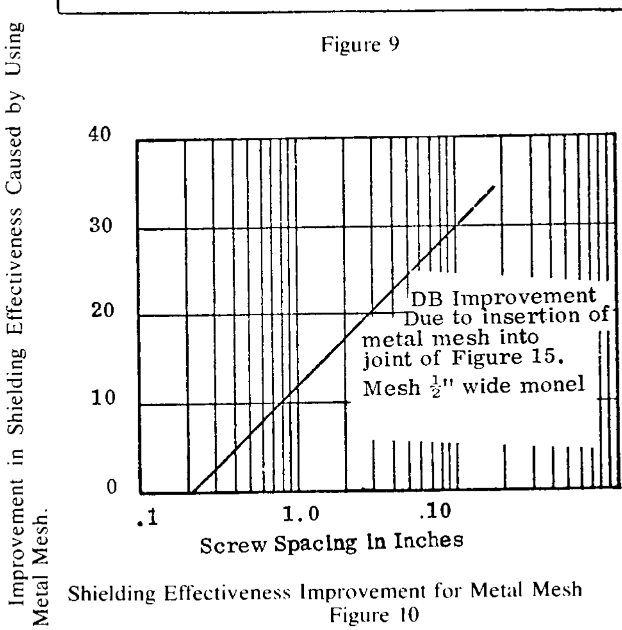


Figure 9



Shielding Effectiveness Improvement for Metal Mesh
Figure 10

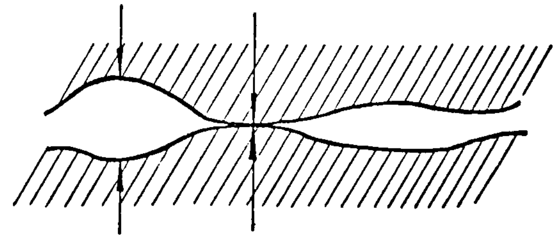


Figure 11

GETTING A FEEL FOR THE DECIBEL

For evaluating the effectiveness of protection, the decibel is a measure of the change in field strength due to the shield. The following descriptions are an attempt to correlate protection effectiveness to field strength attenuation readings in decibels. These descriptions are not precise or all-inclusive, but merely guides for better understanding the practical implication of the dB.

0-19 dB	Very little shielding. The effects may be noticeable but EMI, generally speaking, would not be eliminated.
10-30 dB	Minimum range for meaningful shielding. In mild cases, EMI would be eliminated. Shield design is very simple.
30-60 dB	Average shielding that solves all mild and some moderate EMI problems. Attenuation should be paid to good shield design. Measurement of shielding easy, even possible with ordinary equipment.
60-90 dB	Above average shielding; it is required to solve moderate to severe EMI problems. Shield design is of primary importance; other considerations become secondary. Measurement of shielding requires special instrumentation.
90-120 dB	Generally, the maximum possible with the best shielding design. Measurements require instrumentation specifically designed for these measurements.
Over 120 dB	Limit of the state-of-the-art (with some specific exceptions) dependent on frequency, field intensity, etc.

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CONDUCTIVE PAINTS AND COATINGS

Spray paints have offered a quick and inexpensive method of obtaining conductive coatings. They can be applied with conventional painting equipment and do not require special engineering know-how or extensive capital investment for facilities. Spray paints can be applied to complex and shaped surfaces and can be controlled as to how much electrical conductivity is functional or necessary. They offer good adhesion to most structural foam plastics, a durable film finish, and can be utilized as an undercoat for conventional esthetic finishes.

Prior to the introduction of structural foam plastics for the replacement of metal enclosures, extensive research was conducted to establish a conductive paint that would be compatible with the plastic materials. The requirements were relatively simple: compatibility with all structural foam materials; good adhesion to plastics; durable finish; good wetting characteristics for metallic fillers; easy sprayability using conventional equipment; and quick air-dry time. Controlled surface resistivity and long-term stability at operating temperatures equal to those of the carrier paint were requirements of metallic fillers.

Acrylic carriers have been found to offer the best balance of these requirements, and silver metallic fillers are best suited to meet the overall requirements of electrical conductivity. Testing found that for electrostatic neutralization or dissipation a surface resistivity of 50 ohms-square or more is needed and a coating thickness of 0.5 to 4 mils is required to provide this level of resistivity. For grounding requirements, a surface resistivity of 10 ohms-square is needed, and a coating thickness of 1 to 3 mils. In cases involving electromagnetic shielding, 1 ohm-square of surface resistivity is required; this can be satisfied by a coating thickness of 1 to 3 mils.

Acrylic-silver paints have now been in the field for over 5 years and are approved by leading companies in the electronic business-machine industry for use on structural foam or other plastic machine components.

ELECTROMAGNETIC SHIELDING EFFECTIVENESS

The acrylic-silver paints have been in the field for over five years, tested on radar tow targets, and approved by leaders in the electronic business machine industry. Extensive EMI/RFI shielding tests have been conducted, first comparing various processes or methods available to the plastics industry. These tests were conducted using Lexan® Structural Foam FL-900 boxes 10" x 10" x 10" (P. J. LeBlanc, Plastics Department, General Electric Company, Pittsfield, Ma.). Although there must have been a "box resonance" at the 50 MHz frequency, it does show the comparison of shielding increase of a steel enclosure with carbon coated, flame sprayed, silver painted, and vacuum metallized enclosures. Surface resistivities were not measured, although no added shielding increase was noted when both the inside and outside of the enclosure were coated with conductive (silver) paint.

Another EMI/RFI test was conducted using three basic surface resistivity values:

Acrylic 1 ... less	1 ohm-square
Acrylic 10 ... less	10 ohms-square
Acrylic 100 ... less	100 ohms-square

The testing was conducted by Honeywell, Inc., and the procedure was designed to meet MIL-Standard 285. These tests of silver and non-metallic paints were compared to the results of the enclosures with full integrity and degraded integrity with an opening of 8" x 8". Once again, it is apparent that conductive paints with surface resistivity of less than 1 ohm-square up to 10 ohms-square are similar at all frequencies tested. It should be noted that no conductive paint or any other type of conductive finish offers shielding effectiveness within the magnetic field of any appreciable nature (dB). The shielding effectiveness of the conductive (non-metallic) paint was very little from 5 MHz up to and including 10 GHz (electric and plane wave fields). This conclusion agrees with the results of the shielding increase (dB) previously reported by General Electric.

Instrument Specialties now offers STICKY FINGERS, a high performance beryllium copper finger contact strip with its own self-adhesive that provides an extremely tight, instant bond. Completely eliminates old-fashioned mechanical fasteners, clips, or solder, formerly used to attach RFI/EMI gaskets. To install, simply peel off the protective paper backing . . . place strip into position . . . and press down firmly. You get a perfect seal instantly to shield against RFI/EMI interference in all types of metal cabinets and electronic enclosures.

The principle of STICKY FINGERS and how it functions:

STICKY FINGERS combine the use of beryllium copper in a well-balanced design contact strip with a unique, fast-acting adhesive. When compressed, these strips provide multiple lines of contact using light pressure. Thus, they permit high conductivity characteristics and high attenuation. Moreover, repeatability of the shielding effect is assured as a result of the superior spring properties inherent in beryllium copper.

New formula adhesive makes STICKY FINGERS grip tight!

The pressure-sensitive adhesive used to install STICKY FINGERS was developed to provide an extremely tight permanent bond. The adhesive strengthens as it cures with age. The geometry of the strip design, continually compressed, further assists in strengthening the bond.

Many different types available

A number of different styles, shapes and widths of STICKY FINGERS are available, to suit virtually every need.

tions that require high shielding effectiveness despite frequent opening and closing of the cabinet.

Series 97-520 when tested per Military Standard MIL-STD-285 for electromagnetic shielding, showed superior performance under increased compression. It is supplied in standard 16" lengths, and in a variety of surface finishes.

*Patented

Typical Performance Capabilities*

*An independent testing laboratory has indicated the following performance:

Frequency	Field	Shielding Effectiveness (Fully Deflected) 97-520 at .045" Gap	97-520 at .090" Gap
14 kHz	Magnetic	63dB	38dB
200 kHz		81	57
1 MHz		>92	>92
1 MHz	Electric	>126	>126
18 MHz		>120	>120
400 MHz	Plane Wave	118	111
1 GHz		78	100
10 GHz		92	82

Approx. Pressure Required in Pounds/Linear Foot

	97-520
Deflected to .090" height	26 lbs./ft.
.060" height	37 lbs./ft.

Standard finishes available

Add proper suffix to catalog number

-A	-Bright (stock)	-G	-Gold
-SnPb	-Tin Lead	-S	-Silver
-CdC	-Cadmium Plate plus Chromate		

Other finishes available on special order.

geometry of the strip design, continually compressed, further assists in strengthening the bond. Soldering or mechanical fastenings are completely eliminated. Shielding effectiveness of 97-500 has been proved greater than 46 dB at 14 kHz magnetic and 108 dB at 10 GHz plane wave.

STICKY FINGERS are unaffected in temperature ranges from −65 F. to 225 F. The adhesive meets salt spray, shock and humidity cycle tests, and complies with MIL-D-8634, MIL-N-25076 and MIL-P-19834A.

Furnished in approximately 24" lengths, cut to the center of nearest slot.

Typical Performance Capabilities

Frequency	Field	Shielding Effectiveness At 1/16" Gap 97-500	At 1/8" Gap 97-500
60 Hz	Magnetic	12dB	–
400 Hz		14	–
14 kHz		46	38dB
200 kHz		70	63
1 MHz		≥90	≥90
1 MHz	Electric	≥120dB	≥120dB
18 MHz		≥145	≥145
400 MHz	Plane Wave	117	109
1 GHz		104	100
10 GHz		≥108	100

Approx. Pressure Required in Pounds/Linear Foot

At 1/16" Gap: 36 lb/ft
At 1/8" Gap: 16 lb/ft

Sticky Fingers
Twist Series

Self-adhesive beryllium copper contact strips with scientific twist design offer narrower-than-ever electronic gaskets for general shielding applications where space is at a premium.

Series 97-555 single edge contact strip measures only 3/8" wide, yet shielding effectiveness is 71 dB at 14 kHz magnetic and 102 dB at 10 GHz plane wave. Ideal for all types of panels or electronic enclosures.

Series 97-560 strips for cabinets with panel-divider bars. Unique double edge design, ½" wide, permits panels to be easily removed and replaced without damage to the installed strip.

Typical Performance Capabilities

Frequency	Field	Shielding Effectiveness (Fully Deflected) 97-555	97-560
14 kHz	Magnetic	71dB	≥75dB
200 kHz		96	≥97
1 MHz	Electric	≥120	≥120
18 MHz		≥120	≥120
400 MHz	Plane Wave	≥115	≥115
1 GHz		≥106	≥106
10 GHz		102	≥126

Approx. Pressure Required in Pounds/Linear Foot

	97-555	97-560
Deflected to .030" height	30 lbs./ft.	48 lbs./ft.
.015" height	67 lbs./ft.	72 lbs./ft.

INSTRUMENT SPECIALTIES COMPANY

Little Falls, N.J. 07424
Phone—201-256-3500 • TWX—710-988-5732

Specialists in beryllium copper springs since 1938

The degree of misfit needs to be defined so that design procedures can be clearly outlined. This misfit is commonly called "joint unevenness" and is designated as ΔH and is defined in Figure II. It is the maximum separation between the two surfaces when they are just touching. If the surfaces are not rigid, then the joint unevenness would also include any additional separation between the two surfaces due to the distortion of the joint when pressure is applied.

Figure 12 shows the same joint with a gasket installed. The small lines indicate the height of the gasket, H_{min}, occurs at the point where the surfaces would touch without a gasket. Maximum compressed gasket height H_{max}, is at the point of maximum joint unevenness. IMPORTANT: Note that the joint unevenness of the mating surfaces is equal to H_{max} - H_{min}. This concept must be kept in mind in all gasket design.

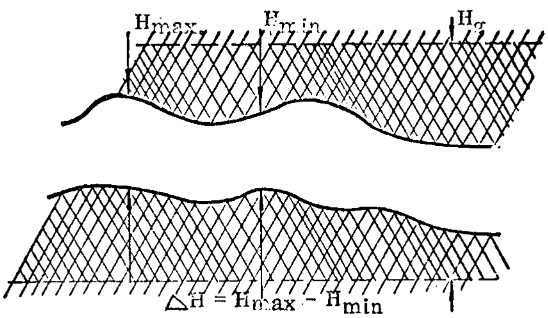
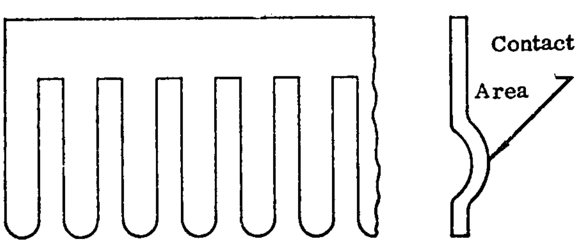


Figure 12

Doors and lids which are frequently opened are usually sealed with spring finger stock (Figure 13). This should be welded, brazed, or soldered in place. Where a high degree of attenuation is required, a double row arranged to provide both wiping and pressure contact is recommended. This material is ideally suited for rf sealing of sliding joints. Where corrosion is a consideration, the basis metal of the stock should be plated with a metal which is compatible with the surfaces in contact. Avoid fabrication techniques which might anneal the material as contact is dependent on springing action of the fingers.



Spring Finger Stock

Figure 13

EMI GASKET DESIGN

EMI gasket design involves making suitable matches and trade-offs between the available EMI gasket materials and their characteristics on the one hand, and the performance requirements of the equipment and the design constraints of the mating surfaces on the other:

GASKET CHARACTERISTICS - Thickness, size, shape, compressibility, corrosion resistance, EMI rating, pressure sealing capability, compatibility with mating materials, temperature range, etc.

APPLICATION REQUIREMENTS - (usually equipment performance specifications). Amount of shielding, amount of pressure sealing, environmental exposure (temperature, salt spray, ambient pressure, corrosive material, etc.).

APPLICATION CONSTRAINTS - (usually imposed by equipment housing design). Space available, compression force, joint unevenness, contact surface characteristics, attachment possibilities, etc.

The important matches and trade-offs are:

- *Gasket height and compressibility must be large enough to compensate for joint unevenness under the force available.*
- *The gasket must be sufficient space for the gasket within the design limitations of the application.*
- *The gasket must be attached or positioned by a means that fits in with the joint design.*
- *The metal portion of the EMI gasket must be sufficiently corrosion resistant and compatible with the mating surface.*
- *The EMI gasket must meet the temperature needs of the equipment specification.*

OPENINGS

Analysis of single round hole leakage for large holes indicates that leakage at a given distance from the hole is proportional to the cube of hole diameter. For example, doubling the diameter of a round hole will increase leakage by a factor of eight. Jarva developed equation for calculations of shielding effectiveness of round and square apertures. When large holes cannot be reduced in size, a conductive screen or a panel of parallel waveguides below cut-off may be useful. Metallic screen is an effective shielding material and provides limited air flow and visual access. Measurement of the attenuation of 22-mesh, 15-mil copper screen compares reasonably well with values as calculated by Jarva's method (see table.).

Measured vs. Calculated Copper Screen Attenuation

Copper Screen	Field	Freq(MH_z)	measured	calculated
22 mesh, 15 mil	mag.	.085	31	28
		1.0	43	45
		10.0	43	49
22 mesh, 15 mil	plane wave	0.2	118	124
		1.0	106	100
		5.0	100	93
		100.0	80	70
22 mesh 15 mil	electric	.014 to 60	65	65
22 mesh, 15 mil	electric	.014 to 60	50	53

Waveguides will propagate rf fields if the relationship of wavelength to waveguide dimensions is correct. Depending on the mode of propagation and the dimensions of the guide, there is a cut-off frequency below which the waveguide behaves like a high-pass filter. Below cut-off, attenuation of fields is exponential with length of the waveguide. This characteristic may be used to provide holes for ventilation, fluid flow, etc.

Panels of parallel waveguides may be used where a large open area is required. Circular or rectangular cross sections may be used. A light, rugged panel may be constructed of hexagonal cross sections. Figure 14 shows attenuation and cut-off frequency for a commercially available honeycomb material.

Protected Interconnect Design

When electrical connections are required from one shielded enclosure to another, the protection of these circuits should be as good as that of the enclosures. The exception to this would be where filters provide isolation at the entrance to the enclosure. This applies to circuit shields, electrical connectors, and the method of terminating the shielded cable at each end. The ideal interconnecting system would be a solid conductive conduit, welded to the enclosure at each end so that electrically one enclosure exists. The opposite would be a single conductor routed at random spacing from ground planes, objects and over a longer than necessary distance. Between these two extremes, the number of varations is limitless. Reducing our scope, we will examine only those designs which provide extra protection over and above such interference reduction techniques as twisting, coaxial wire, balanced impedance transmission controlled bundling, etc.

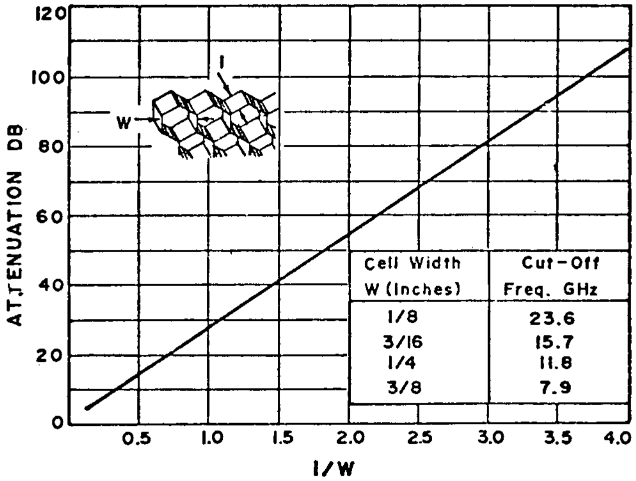


Figure 14

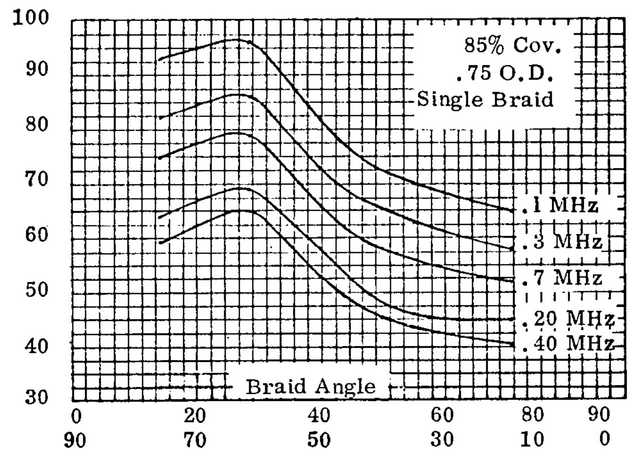


Figure 15

We will divide this in two sections - cable sheath design and the termination of sheath to connectors and enclosures by means of backshells/adapters. The most common EMI protective sheath is metallic braid - it provides a controlled amount of coverages (%) and can be applied in multiple layers. These layers can be separated by an insulator for reduction in conductive and inductive coupling or be applied over each other to increase the percentage coverage and reduce the capacitive coupling. It is important to note that addition to percentage of coverage the braiding angle (conductive path direction) has an influence on the amount of protection the sheath will yield. (See figure 15). Tin or silver plated copper is the most common. However, other metals particularly metals with permeability can provide that extra level of performance desired. But it is important to note that whatever material is selected - a good surface/contact conductivity is needed either through plating or intrinsic.

Metallic mylar with drain wires under but in contact with the shield is a very effective protection against capacitive coupling. The overlap, number of layers determine the level of shielding/screening obtained. Conductive elastomers or elastomeric conductive coating on shrink tubing is another type of reduction. The conductivity and the uniformity are the most important parameters in providing the level of shielding/screening needed. Due to the construction of the conductive path (thin - mostly silver or carbon filled elastomer) it is desirous to include drain conductor(s) under the sheath. (Figures 16 & 17).

A helically convoluted thin metal tubing with the seam soldered or brazed is commonly used as the protective sheath when shielding/screening over a wide portion of the spectrum and/or very high level of attenuation is desired. (Figure 18).

This sheath construction also allows the use of very high permeable (100,000) metals such as 80/20 nickel iron alloys providing as much as 40 dB of protection against magnetic field at 60 Hz. Usually, an additional braid cover is provided to protect the thin metal convoluted tubing from mechanical damage. The additional shielding/screening is negligible. This protection media is also many times used where extensive flexing is required as long as the mechanical stress remains within the elastic limits of the metal - there will be no degradation. This method of protection also lends itself to being solder/brazed to terminating hardware (backshell/adapters) reducing troublesome terminations on high level protected interconnections.

Sheath Terminations (Backshell Adapters)

A very significant amount of the cost and reliability of the protective system is in the selection/design of the method of termination. For EMI protection, a 360 degree extreme low impedance joint will yield an uncomprised level of shielding/screening. Some of the better known designs are:

Tapered Cone

Most often used with braided sheath. The braid is stretched over a tapered section which is forced into the tapered opening of the backshell/adapter, (Figure 19).

Magna-forming is a metal forming process that utilizes an electromagnetic pulse to create two opposing fields. One on the surface of the to be formed part, the other on a metallic field shaper, resulting in the movement of metal without physically touching the material. This technique results into being able to bond (electrical) metallic components in an absolute continuous peripheral continuous manner. The continuity of a peripheral bond being one of the key termination criteria, this technique is rapidly becoming a preferred technique, (Figure 20).

Direct Bond or Ring Termination

With this design, the sheath is applied over a supporting ring or directly onto an extended section of the backshell/adapter. The shield/screening is then secured to the backshell/adapter through one of the following; soldering, brazing, swaging/crimping, magna-forming, (Figure 21).

Compression Media Terminations

This technique employs the principal of wedging a compressible element such as a metal coil spring, conductive elastomer, or other compressive and conductive media in contact with the sheath, while maintaining in contact with the backshell/adapter. The chief benefit is terminating the protective sheath without disturbing it and having effective control over how many contacts there will be around the periphery, (Figure 22).

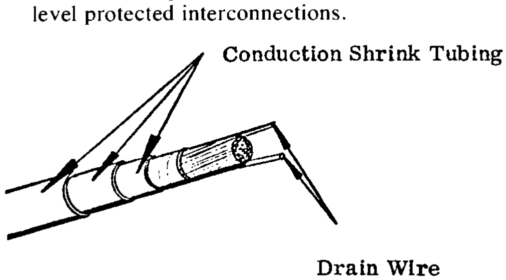


Figure 16

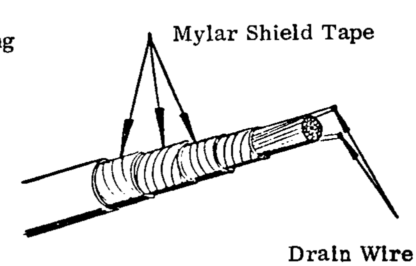


Figure 17

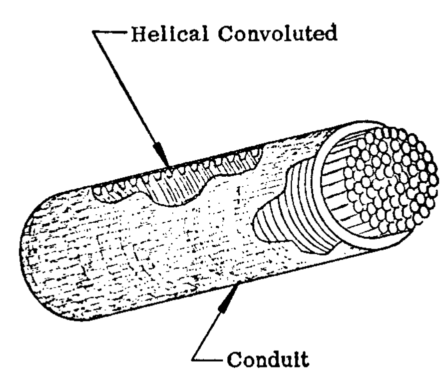


Figure 18

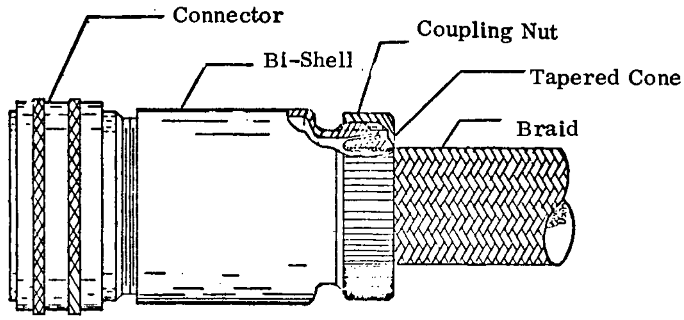


Figure 19

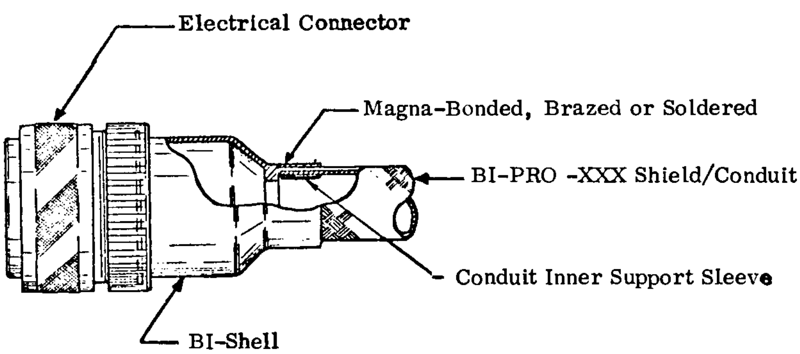


Figure 20

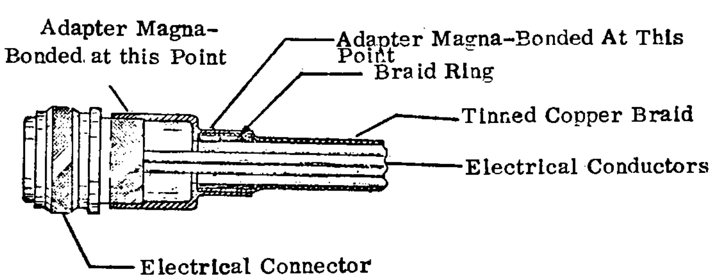


Figure 21

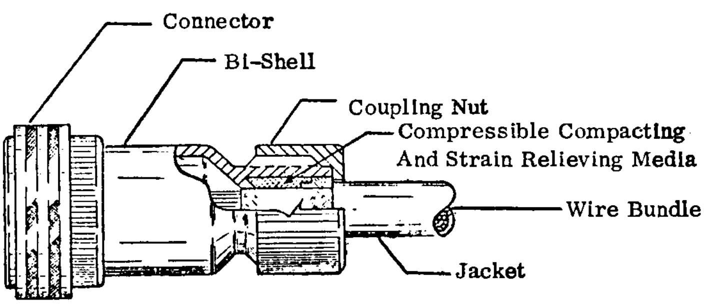


Figure 22

EVALUATION

Gasketing for seams and joints is presently evaluated in two different methods. Both are based on substitution (measuring electromagnetic field intensity with and without the gasketing in place). This requires the use of a high performance shielded room of which one of the walls is provided with an opening. Then this opening is closed with a cover and subject gasketing in place. The shielding effectiveness measured per standard enclosure measurement techniques is the performance level of the gasket evaluated. (See figure 23.)

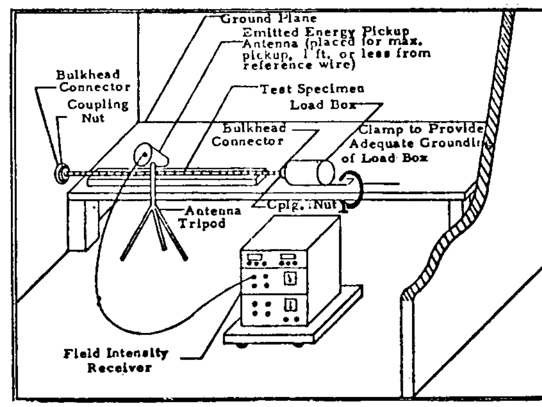
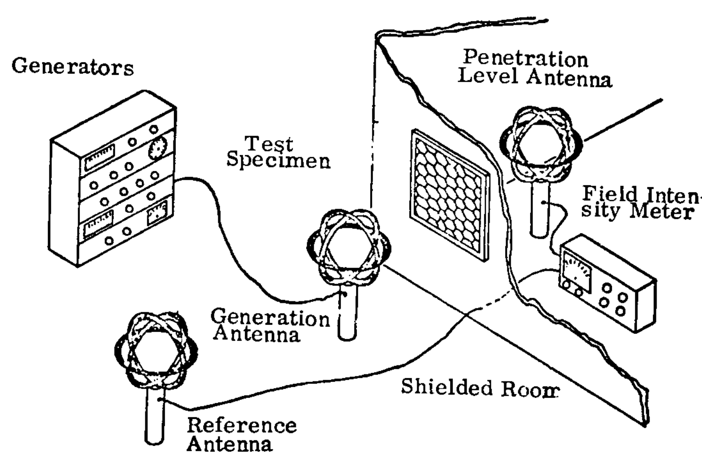


Figure 23

The other is the method generated by a sub-committee of SAE AE-4. It evolves around the use of a standardized enclosure from which or into which the penetration of electromagnetic energy is measured both with and without the to be evaluated gasket between the cover and enclosure. (See figure 24.)



Magnetic Field Test Set-Up

Figure 24

The evaluation of opening shields/screens such as honeycomb panels, use the same two techniuqes as gasketing material, only the cover is replaced with a panel made of the material to be evaluated.

It is essential to control the parameters effecting the performance. Some of which are; pressure, surface finish (contact conductive) and overall physical dimensions.

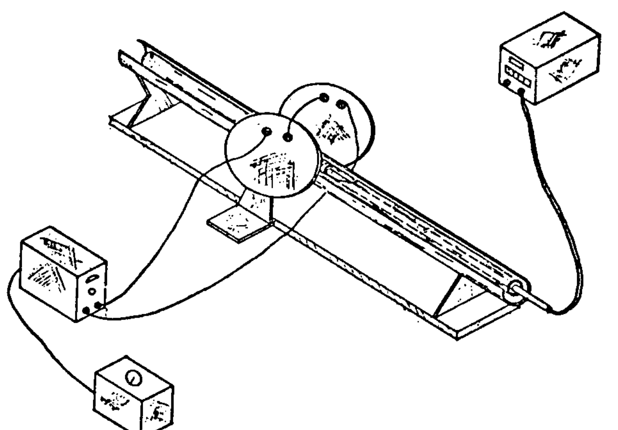


Figure 25

The evaluation of interconnection systems is principally divided into two schools' of thought that of emission substitution and Transfer Impedance (current attenuation). The Emission Substitution is very similar to that used for gasketing and ventilation panels. It usually is set up to simulate the operational condition of the interconnectors and the Emission from "it" or the voltage generated into "it" is measured (with the same instrumentation/configuration as to which the system is subject) with and without the EMI protection in place. See Figure 25. The difference between the two measurements represents the performance of the protective shield/screen under evaluation.

$$SE = 20 \log \frac{E \text{ without protection}}{E \text{ with protection}}$$

The transfer impedance criteria as a level of protection has to be used for a long period of time and numbers analysis have been performed. But over the last few years, a transmission line type of evaluation has been developed, overcoming many of the prior testing techniques shortcomings. A brief analysis of the theoretical criteria will be helpful in understanding the described techniques.

Energy can leak into a shield by Diffusion, Electric field coupling through a penetration, or Magnetic field coupling through a penetration.

- *Diffusion parameters are thickness (t), conductivity ( ) and permeability ( )*
- *Electric field coupling parameter is mutual capacitance*
- *Magnetic field coupling parameters are ohmic resistance (dR) longitudinally at the penetration and mutual inductance (dM) between the exterior and interior at the penetration both for a short distance d in the vicinity of the penetration or joint.*

Leakage Models

Figure 26 shows a thin sheath joined to a backshell which is in partial contact with a connector shell. Figure 27 uses the approach of Taylor and Harrison to model the resulting leakages with lumped voltage and current generators for the thin sheath and separately for the shell joint. For well-shielded connectors, the electric field coupling is always uimportant and is hereafter ignored. The Transfer Impedance A_{tr} is defined as:

$$Z_{tr} = V_c/Is$$

Where I_s is the external shield current; V_c is the voltage induced in series with the center conductors by diffusion or magnetically coupled leakage energy.

Method

There are many possible configurations in which a shield current I_s can be made to flow over the exterior of a sheath while the integral of the leakage signals induced in a conductor located concentrically inside the shield is monitored.

Open Wire Configuration

Figure 28 shows a configuration in which the requirement that:

$$R_{exterior} = R_{interior} = Z_{exterior} = Z_{interior}$$

Can only be met at low frequencies. The "matching resistor" $R_{external}$ is connected in series with inductance $L_{external}$ and consequently the total source impedance, can only be matched at low frequencies when the impedance $L_{external}$ is vanishingly small.

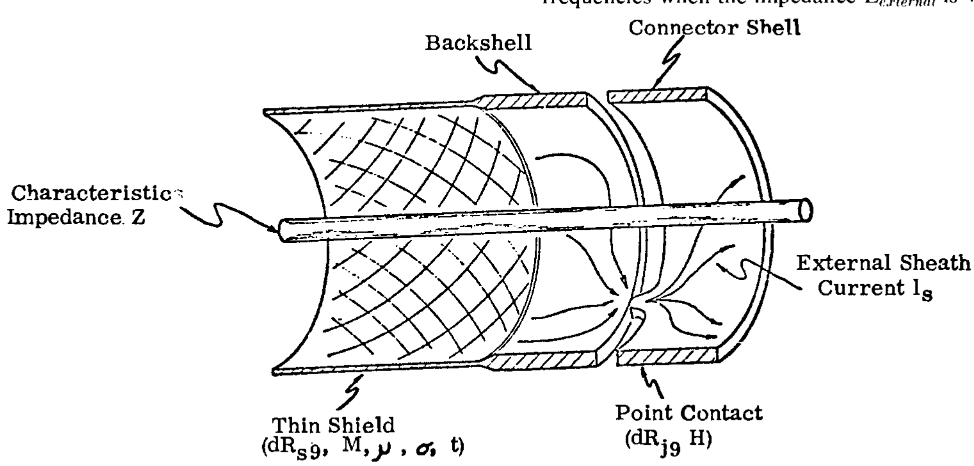


Figure 26

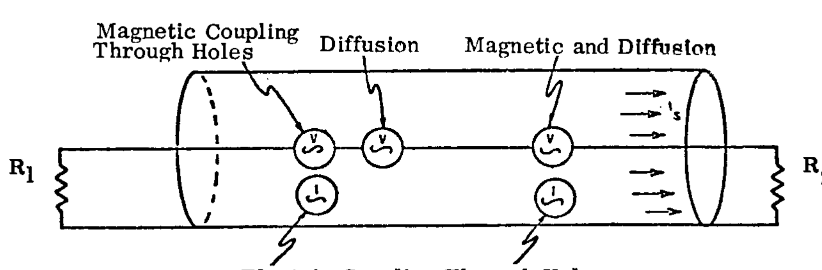


Figure 27

The inverted Triaxial Configuration shown in Figure 28 makes use of an adjustable "Outer Tube" length. At high frequencies the total load imposed on the signal generator can be made to be $R_{external}$ by adjusting the position of the shorting ring such that $Z_{exterior}$ is a quarter-wave tuned stub. Under these conditions, however, the current along the interconnect assembly under test will vary coinusoidally with length reaching a maximum at the position of the shorting ring. The magnitude of this current will always be greater than the current flowing through $R_{external}$, thus assuming this be used as a reference, the measured shielding value will be in error by an amount dependent upon the Q of the resonant stub and the position along the interconnection of the dominant leakage sources.

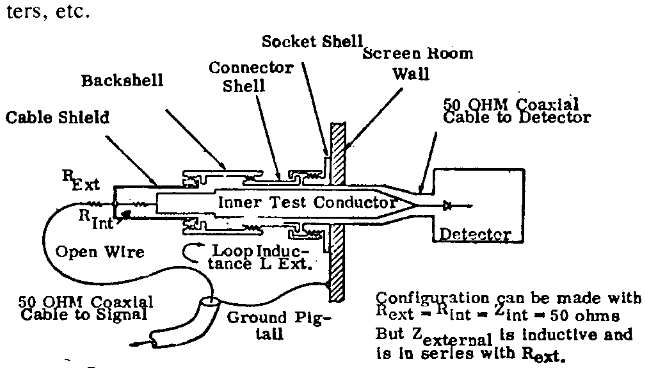
Triaxial Configuration

The familiar Triaxial configuration, used by many organizations and required by U.S. Military specifications, is obtained by interchanging the signal generator and the detector and by omitting the resistor $R_{external}$ shown in Figure 29. In this Triaxial configuration the load imposed on the signal generator can be constant and matched over a wide band of frequencies, thus allowing a uniform current to flow through or past all leakage sources. However, the coaxial path which integrates the leakage energy and feeds the detector cannot be matched. This path includes the "sliding shorting ring" which is positioned for maximum detector signal for each test frequency. The signal reaching the detector is then the sum of the energy leaking through the assembly under test, and propagating in the direction of the detector with the energy leaking through the interconnection and propagating in the opposite direction towards the source. This latter energy being reflected by the shorting ring and adding, in-phase, with the former. The lowest useful frequency is limited by the length of the sliding path provided for the shorting ring. The Triaxial configuration can be used at high frequencies subject to the limitations concerning TEM modes stated in page 25 of the appendix to MIL-C-39012B.

Quadraxial Configuration

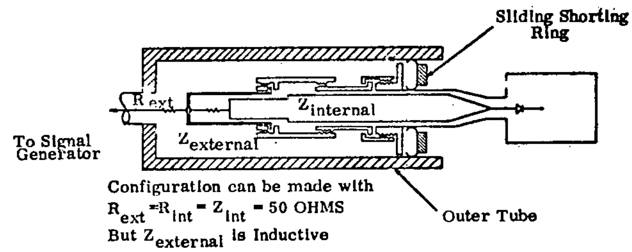
Figures 30 & 31 shows a Quadraxial configuration which allows both the signal generator, or driven path, and the leakage integrating, or detector path, to be matched at all frequencies for which TEM modes predominate thus eliminating the need for an adjustable shorting ring. The usable frequency range extends from zero frequency to the limit at which TEM modes no longer predominates. Since this frequency range can be achieved without mechanical adjustment, a swept frequency source and an automatically tracked or self-tuned detector can be used resulting in a considerable reduction in test time and eliminating the possibility of a frequency dependent leak escaping notice between the chosen or specified discrete measurement frequencies.

The Quadraxial test method in addition lends itself to measuring complex interconnection cable assemblies through the design of a 3 sided (trough) transmission line into the assembly under test is placed. A current probe is used to measure the level of current induced in the sheath under evaluation. The SAE-AE4 subcommittee on EMT connector evaluation is preparing an ARP using a modified quadraxial test fixture to evaluate connectors and other interconnection systems components such as backshells, adapters, etc.



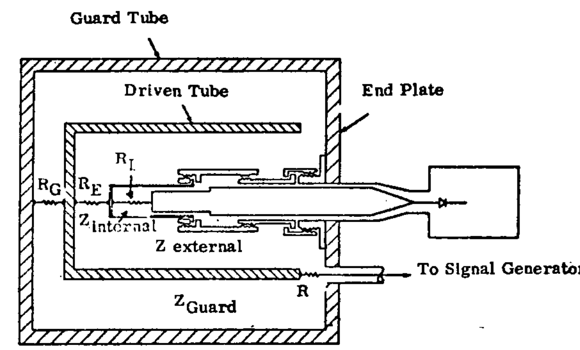
Open Wire Configuration

Figure 28



Inverted Triaxial Configuration

Figure 29



Quadraxial Configuration

Figure 30

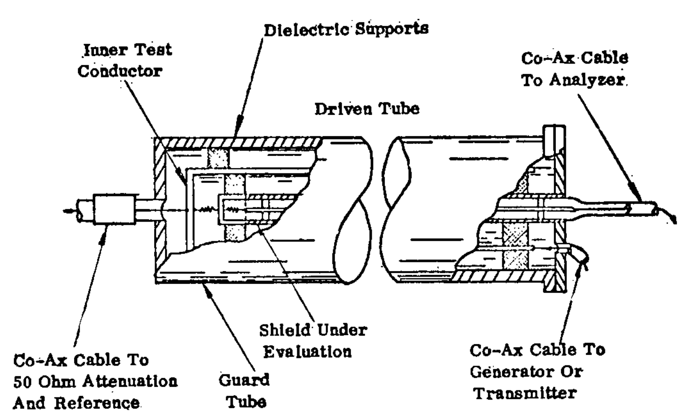


Figure 31

SUMMARIZING THE OPTIONS FOR TEST CONFIGURATIONS

Options	Frequency Range	Data Format	Relative Complexity
Open Wire	DC to Very Low	X-Y Plotter	Simple
Coaxial	DC to Low	X-Y Plotter	Simple
Inverted Triaxial	100 MHz to High	Discrete, tabular	Not Simple
Triaxial	100 MHz to Very High	Discrete, tabular	Complex
Quadraxial	DC to Very High	X-Y Plotter	Complex

Generally, it should be noted that any conductive coating that has a surface resistivity of less than 10 ohms-square will adequately offer a shielding increase within the electric field (200 KHz through and up to 500 MHz). Although these design guidelines are adequate for most electromagnetic shielding functions, it is important to know that the system testing should be conducted by the designer if shielding is a critical design criteria. All results have been graphically plotted in Figures 1 and 2.

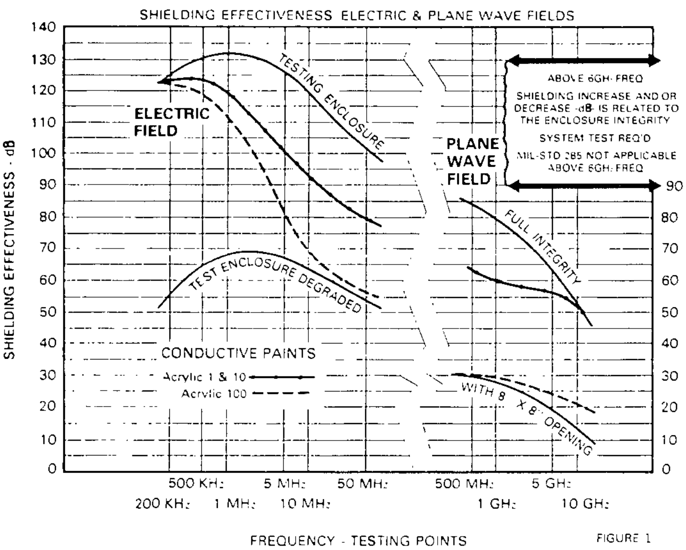


FIGURE 1

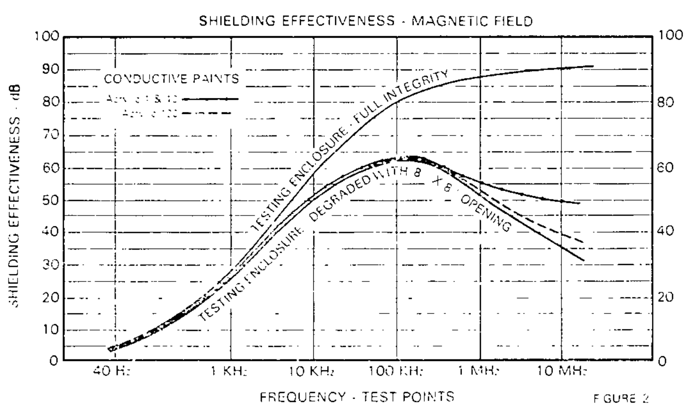
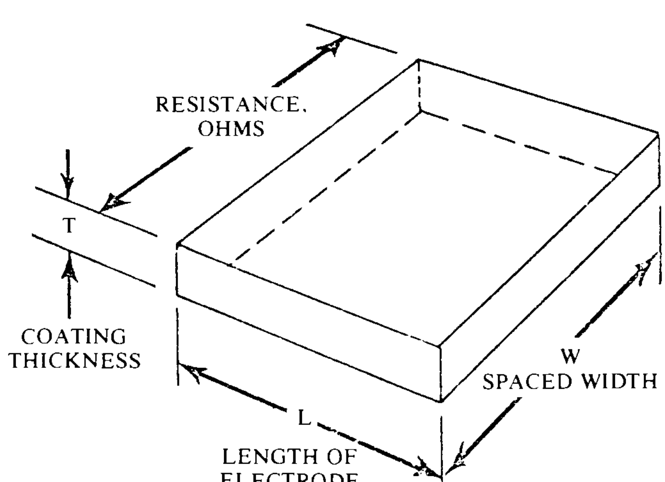


FIGURE 2

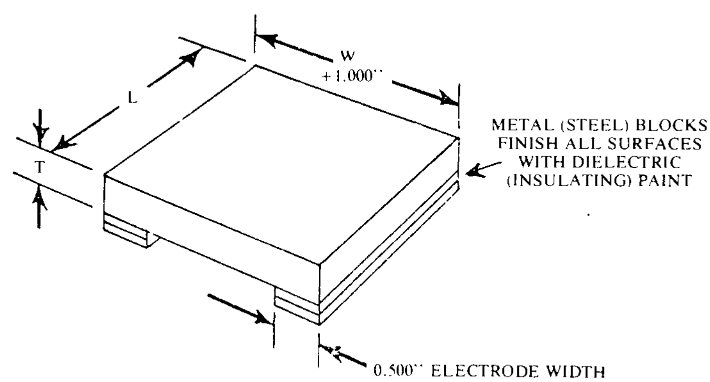


Testing for Surface Resistivity

This test will determine the resistivity of the conductive paint expressed in ohms-square. Ohms per square is a non-dimensional measurement and does not refer to square inches or square feet. Therefore, all surface resistivity is measured with two electrodes (L = length) that are spaced (W = width spaced) apart from each other. Thus, as long as L = W (as in a square) and thickness (T = thickness) of coating is constant, the resistance is the same for any square.

Standard test procedures are outlined and can be referred to ASTMD-257. Testing for surface resistivity is most important for it controls the conductive finish functions, your coating costs, and is subject to many factors that are not known to conventional practices. Of all the tests discussed herein, this test must be maintained throughout your production cycles, production practices, and production methods.

A sample surface resistivity device can be fabricated to assure meeting engineering design criteria and functional finish requirements involvingconductivity (or inversely proportional to surface resistivity.) Two sizes of surface resistivity testing devices are suggested, one for small areas of approximately 1 centimeter square (0.394") and one for larger areas of approximately 10 centimeters square (3.94"). The design is simple and relatively low in cost.



Testing Device	L & W	T	Pressure psi Weight per Square Inch
1 cm. square	0.394"	2.000"	13.8 ounces
10 cm. square	3.937"	0.564"	13.8 ounces
20 cm. square	7.874"	0.354"	13.8 ounces

Please notice that equal pressure (force per square inch of electrode) was designed for each device, assuring equal conditions of measurement. The electrode device should be designed with brass shin stock 0.010" or thinner and 0.500" wide, and attached to the steel block with double faced adhesive foam approximately 0.0625" thick. Extend the length of the electrode (shin stock) approximately 0.5" to 1.0" thereby allowing attachment of VOM (ohm meter leads).

It is important that the adhesive tape be of a foam type, allowing variance in surface flatness and other irregularities. Care should be taken to check instrumentation for correct and accurate readings (zero test is adequate), and electrodes should be cleaned prior to use by wiping with Scotch-Brite lightly on the contacting surfaces.

The above material was excerpted with permission from Report No. IR-728, "Conductive Paints for the Plastics Industry" prepared by Richard W. Lamp, Senior Vice President, Technical Wire Products, Inc., Cranford, NJ. Copies of the complete report are available upon request.