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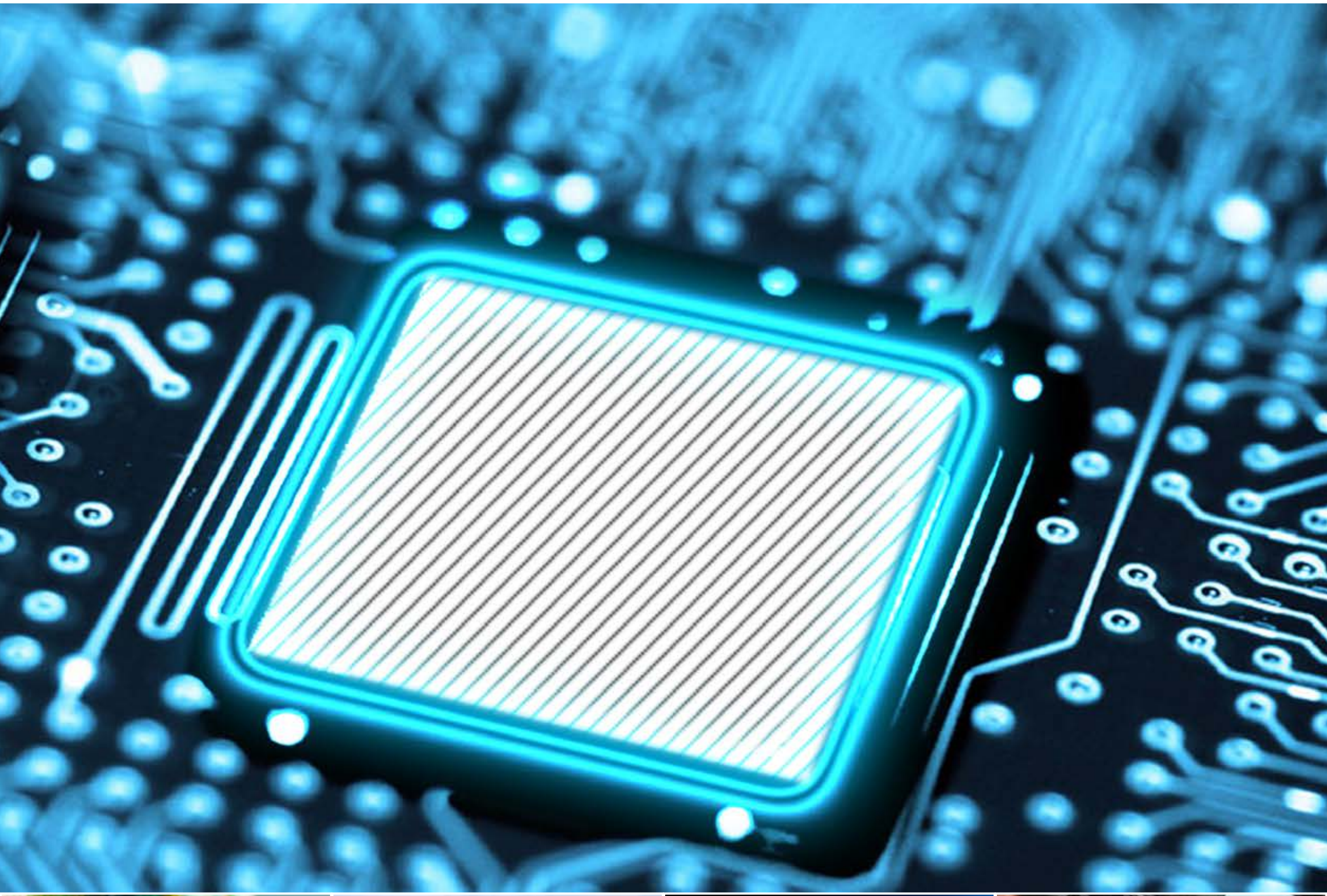
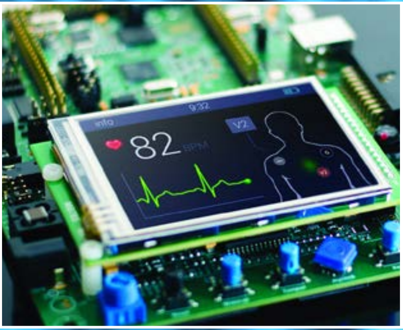
2016 EMI SHIELDING GUIDE





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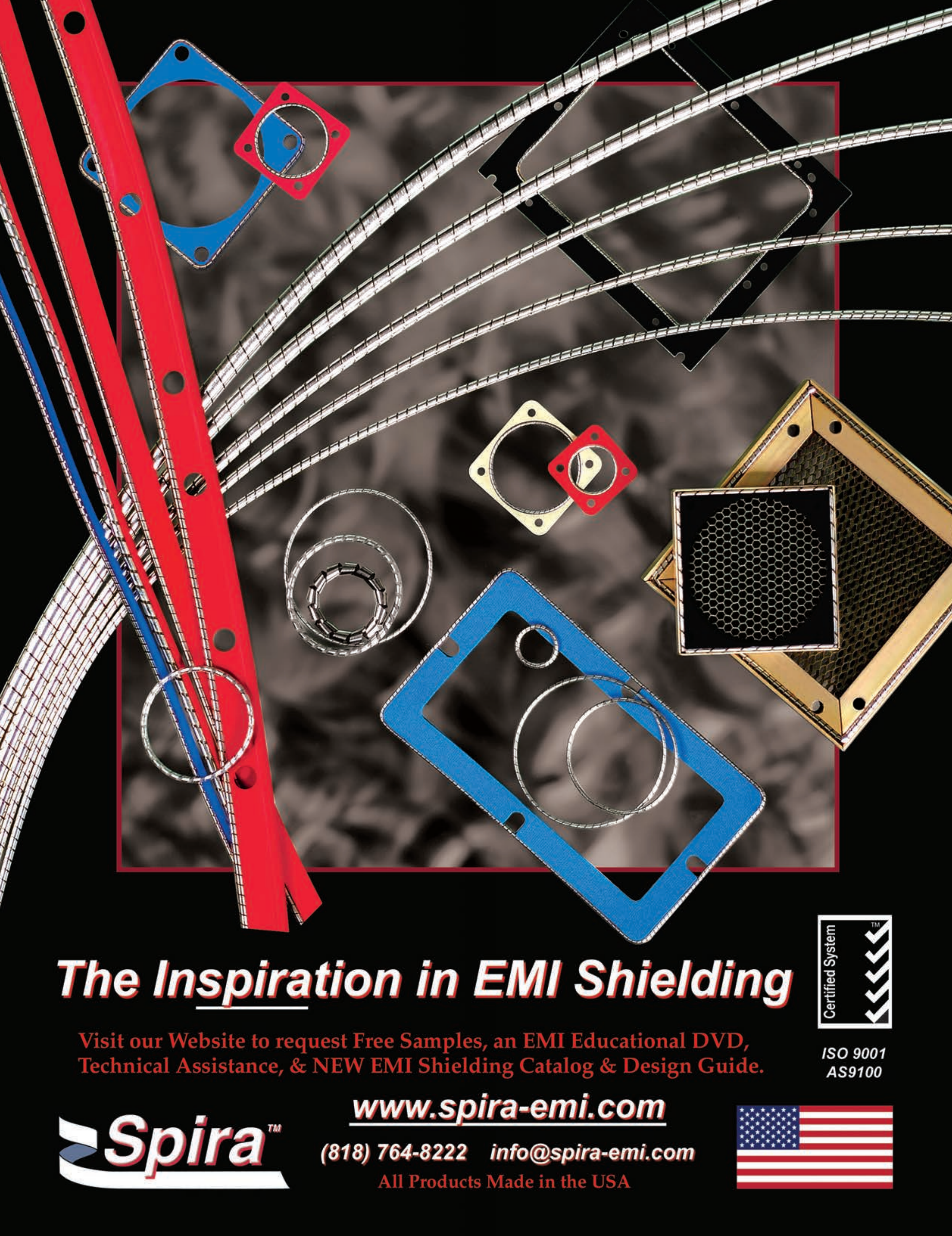
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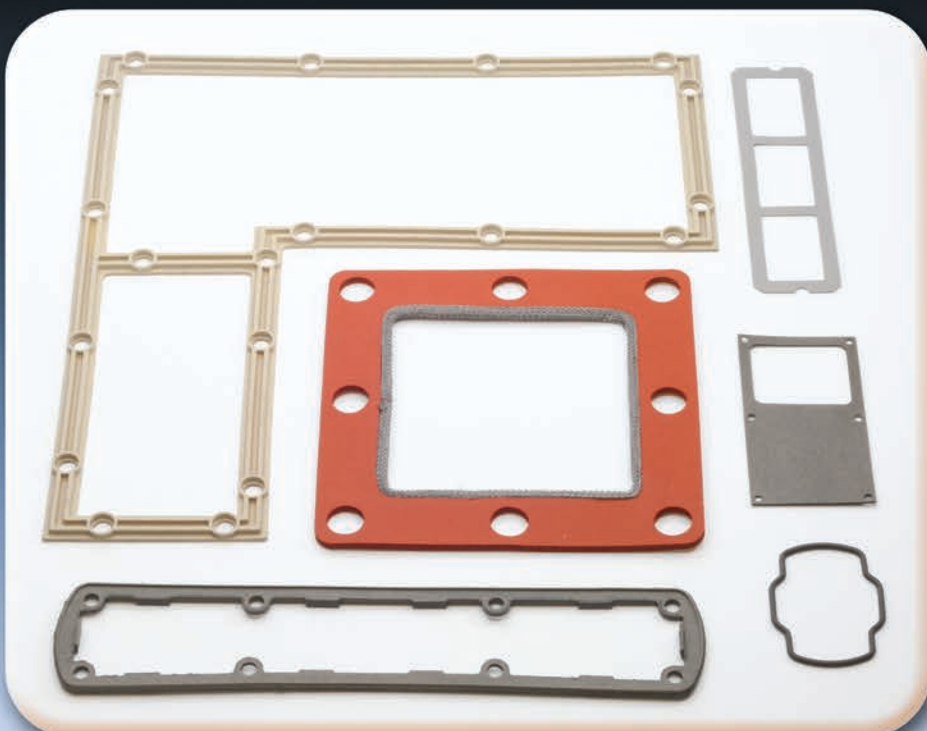
SHIELDING MANUFACTURERS GUIDE

Ed Nakauchi
EMC Consultant

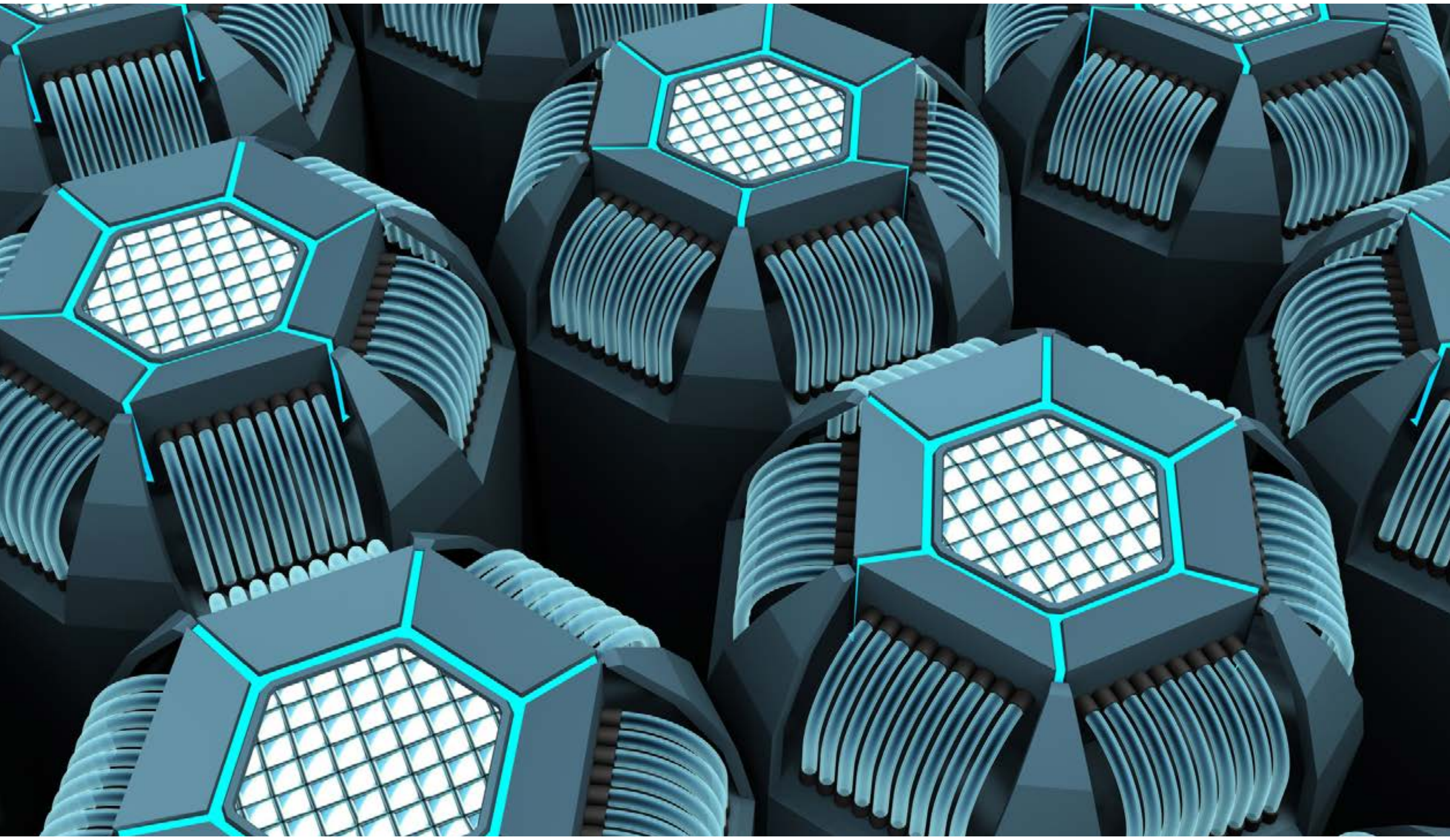
A Guide to Suppliers of EMI Shielding
Your quick reference guide by shielding type from Absorbers to Vent Panels, including various board level shielding types. With contact links for suppliers.

Shielding Manufacturers Guide		Type of Shielding Available																									
Manufacturer	Contact Information - URL	Absorbers	Adhesives	Board Level Shields	Cable Shielding	Conductive Coatings	Coil Springs	Elastomers	Electroless Plating	Fabric over Foam	Ferrites	Fingerstock	Foams	Form in Place	Gaskets	Grease	Grounding Components	Honeycomb Filters	Knitted Wire Mesh	Laminates	Metallized Fabric	High Mu Materials	Sealants	Silicone Elastomers	Tapes	Vent Panels	Windows
3M	www.3m.com	X																							X		
Alco Technologies	www.alcotech.com				X										X				X							X	
ARC Technologies	arc-tech.com	X																									
Bal Seal Engineering Inc.	www.balseal.com						X																				
Fotofab	www.fotofab.com			X					X																		
Ja-Bar Silicone Corp.	ja-bar.com							X																	X	X	
Kemet	www.kemet.com										X																
Kemtron	www.kemtron.co.uk	X		X				X		X	X	X		X						X					X	X	X
Kitagawa Industries America, Inc.	kgs-ind.com	X			X						X				X		X								X		
Laird Technologies	www.lairdtech.com	X	X	X				X		X	X	X		X	X				X	X					X	X	
Leader Tech	leadertechinc.com	X		X	X			X		X	X	X	X	X	X		X	X	X		X	X		X	X	X	
Magnetic Shield Corp.	www.magnetic-shield.com				X																	X					
MAJR Products	majr.com	X		X				X		X	X	X		X	X					X					X	X	X
MAST Technologies	www.masttechnologies.com	X																									
Metal Textile Corp.	www.metexcorp.com	X						X		X		X			X										X	X	X
Nolato Silikonteknik	www.nolato.com/page/770/html/nolato-emc.html&lang=en					X		X						X	X		X							X			
Orbel	www.orbel.com			X								X									X						
Parker/Chomerics	www.chomerics.com	X	X	X		X										X	X			X			X		X	X	X
Photofabrication Engineering Inc.	www.photofabrication.com			X																							
Rogers Corp.	www.rogerscorp.com							X							X									X			
Schlegel Electronic Materials	www.schlegelemi.com/en/index.php							X		X		X	X												X	X	X
Seleco	seleco.com					X																					
Shielding Source	shieldingsource.com	X						X		X		X	X														
Spira Manufacturing Corp.	www.spira-emi.com														X											X	
SSP Inc.	www.sspinc.com							X																			
Stockwell Elastomerics	www.stockwell.com/emi-gaskets.php							X							X			X					X				
Swift Textile Metalizing LLC	www.swift-textile.com																				X						
Tech Etch	www.tech-etch.com			X				X		X		X			X											X	
V Technical Textiles / Shieldex US	http://www.vtechtextiles.com																				X						
VTI Vacuum Technologies, Inc.	www.vactecinc.com								X					X													
W.L. Gore & Associates	www.gore.com/en_xx			X											X		X										
Wurth Elektronik	www.we-online.com/web/en/wuerth_elektronik/start.php										X																



THE FUTURE OF SHIELDING

Ed Nakauchi
EMC Consultant

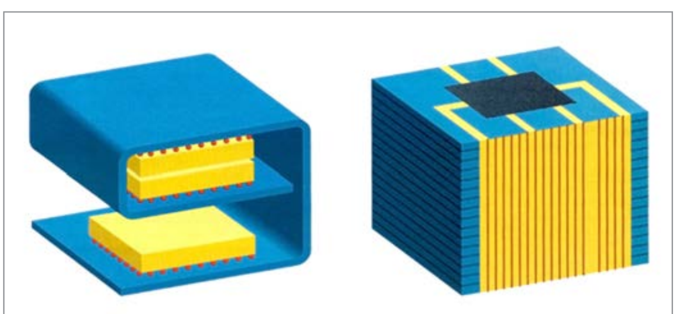


THE FUTURE OF SHIELDING

The future is not all that far off. With more electronic devices that are getting smaller, more portable and with continuing faster speeds, EMI or RF issues will continue to increase. There will be more integrated system-on-chips (SoCs) where several functions will all be in one device that will need to be electromagnetically isolated. As an example, a GPS receiver working at -100 to –120 dBm will have to co-exist with a transmitter working @ 0 to +40 dBm. Automotive collision avoidance systems work at about 75 GHz and "regular" gasketing begins to degrade above 18 GHz making them ineffective at these frequencies due to skin effects and electromigration.

Here are some excerpts of quotes from David Leinwand of Hamamatsu taken from **Tech Briefs**, "Visions of Tomorrow", December 2001 issue published by NASA as "food for thought".

"…a new wireless local-area network may have to operate at 60 GHz."; "…heterojunction bipolar transistors (HBTs), a technology that is now yielding large-scale integrated (LSI) circuits packing 1000 to 10,000 transistors on a chip and operating at over 65 GHz."; " …100 Gb/s links could be in production as soon as 2010". RSFQ (Rapid Single Flux Quantum) logic is real today with speeds of 10 GHz to 800 GHz! The future is not all that far away with the very next generation logic devices having edge rates of 10-25 picoseconds (f = 40 – 100 GHz). Carbon tubes and Nanotechnology is already here and available along with RSFQ logic. These are molecular size devices. A nanocomputer could fit in a box 1/100th of a cubic micron with gigabytes of storage in a box about a micron wide (the size of a bacterium!). "Integrated circuits will be designed in three dimensions. Data will be sent by photons…Quantum computing will replace conventional computers…"



Source: IEEE Spectrum Magazine

So, where does shielding go from here? At the higher frequencies, surface conductivity becomes a critical parameter. Skin effect basically means that currents will tend to crowd into the upper most layers of a conductor. So, as more current gets crowded into less thickness, the current density increases. This produces an increased voltage drop and hence, the potential for more radiation or leakage. The surface conductivity of the finishing layer or gasket material becomes critical. This is because some of the protective finishes such as zinc chromate are composed of conductive particles in a binder material. Of course, as frequencies go higher, wavelengths become shorter, openings become more significant leading to increase potential for leakage.

To demonstrate the magnitude of this EMI design criteria about keeping holes and slots small, let's go through a calculation. For a frequency of 100 GHz, the corresponding wavelength is 0.12 inches. Typically, holes should be no larger than 1/20th to 1/50th of a wavelength, and if anything, they may need to be smaller, so this calculates to 3 to 6 mil hole or aperture. So, at some point an alternative to enclosure shielding needs to be explored since it is impractical to completely enclose the source as any practical device will have holes and slots for antennas, cables, power cords, etc. It is becoming difficult to pursue the standard shielding approach of "containing" the noise.

Most of today's shielding theory is based upon far-field conditions and not near field conditions. This is especially critical in dealing with board level shields and the smaller size of today's devices, as different calculation methods need to be used for better results. The E or electric component and the H or magnetic field components must be analyzed separately. Current distribution and distributed parasitic impedances become involved. Also, skin depth effects can possibly be taken advantage of by having a two shielding layers separated by a low dielectric material and possibly obtain very high levels of shielding due to having "multiple layers."

With increasing use of "thin" shields like electrodeposition or vacuum metallization especially with plastic enclosures, the second boundary becomes important. When using thick metal shields/enclosures, re-reflection or multiple reflection effects could be ignored, but with thin shields, the absorption loss is negligible and hence passes through the thin shield with minimal loss. This effect is prevalent with magnetic fields. Electric fields are not affected that much since most of its losses comes from reflection at the first boundary.

Another issue with higher frequencies is resonance effect. Its coupling is a consequence of self-resonance of various structures such as reactively terminated transmission lines, slots in the PCB, slots between the PCB and metallic enclosure, etc. These structures behave as cavity resonators. A 2 inch by ½ inch enclosure resonates at a first order mode of around 12 GHz. Even weak coupling at these extremely high frequencies can induce strong oscillations than can then couple to any other point in the enclosure. To reduce this phenomenon, the "Q-factor" of the cavity must be lowered by introducing losses. So, in the future, shielding could become more of a multilevel concept. Board level shields will handle the "lower" frequencies as usual through it acting as a shielded enclosure, but then an inside layer of absorber coating will handle the much higher frequency components by reducing resonance conditions. Absorber materials are a viable option for handling these higher frequency issues. Absorbers work most efficiently at these higher frequencies (>1 GHz). Absorbers reduce radiation or "shield" by literally absorbing the energy and converting it to heat. This brings up another advantage in using absorber material in that since it converts the electromagnetic energy, it does not have to be "grounded." As long as the absorber material intercepts or is in the field path, then it will reduce the electromagnetic energy of the field.

Conductive plastics are re-emerging as a potential option to provide shielding. In the past, conductive particles (i.e. carbon, steel, etc.) were added to the plastic material to give it conductivity. However, this was without its own shortcomings in that it did not provide very effective shielding. Most conductive plastics only produced about 20-40 dB of shielding. Higher shielding levels were possible (i.e. 60-80 dB), but at the expense of harming the mechanical properties of the initial base plastic material since more conductive particles needed to be added. This also increased the weight and cost of the enclosure. Another equally important factor is that the surface of this conductive plastic was non-conductive since the conductive particles tended to settle away from the external surface. So, it is possible to have a plastic enclosure which has shielding qualities, but with major compromises in terms of processability, performance, and/or cost.

This finally leads us to today with the increasing exploration of intrinsic conductive polymers. This yields a true "conductive plastic". The main advantage in using inherently conductive polymers (ICPs) is that the user obtains the conductivity of metal such as copper, but at the fraction of the weight and with less sacrifice of losing the characteristic advantages of the main plastic material. Also, no additional processes or steps would be required to expose a conductive surface saving additional manufacturing process time and cost. Yet another advantage of conductive polymers is that they are more environmentally friendly which is especially important in today's trend.

Most shields are quantified with high levels of conductivity, but sometimes this kind of shield is not necessarily the ideal solution. It is also impossible with this kind of shield to perform frequency selective shielding. A shield where chirality, which means "handedness", has been added is called chirashield. The benefits are reduced weight for a given attenuation and, as mentioned earlier, frequency selectivity. Chirality is a geometrical concept. It is also described as handedness (i.e. left-handedness and right-handedness elements). Chirality is based upon molecules existing in two asymmetrical mirror image forms having a left-handed or right-handed structure. The structures resolve the electromagnetic field into two circularly polarized fields of opposite polarization directions and different phase velocities, so combining the structure or shield which have this relationship between their "handedness" yields an attenuation much like optical light passing (remember that light is an electromagnetic wave too!!) through polarized lenses.

Remember that Albert Einstein believed that imagination is limitless.

How about shielding "on demand" where the material can change depending on the applied stimuli (e.g. electric or magnetic). The future of shielding is not all that far off. In fact, it is here now!!

Please Feel Free to Contact the Author for Any Questions at: elnakauchi@aol.com

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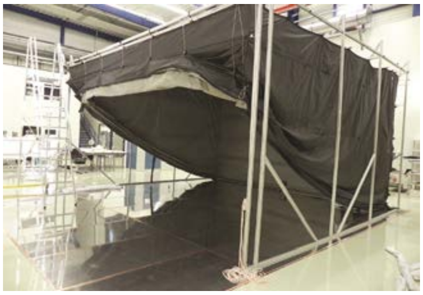
PORTABLE RF SHIELDED ENCLOSURES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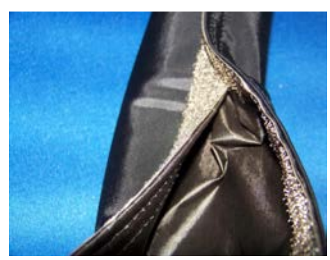
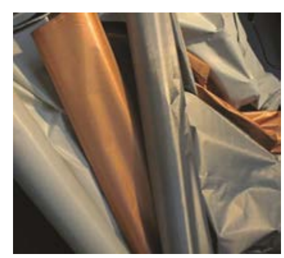

CABLE SHIELDING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HOW TO CHOOSE PARTICLE-FILLED SILICONES TO MEET MULTIPLE DESIGN REQUIREMENTS

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HOW TO CHOOSE PARTICLE-FILLED SILICONES TO MEET MULTIPLE DESIGN REQUIREMENTS

Many electronic designs need shielding materials that combine resistance to electromagnetic interference (EMI) with other application-specific requirements. For example, the EMI gaskets that are used in military touchscreens need to attenuate EMI emissions, provide electrical conductivity, and ensure environmental sealing. These shielding gaskets also must also cushion the unit from mechanical shock and be soft enough to avoid interfering with the display's touch function.

The EMI shielding that's used in automotive, aerospace, and medical electronics must also meet multiple requirements. For example, an EMI gasket that's used with commercial aircraft may need to resist the splash of jet fuel or cleaning agents. EMI gaskets that are used in medical devices must combine required levels of shielding with corrosion resistance. Shielding that's used with electric vehicle (EV) charging stations or robotics may require compliance with UL 94 standards for flammability.

For electronic designers, EMI shielding decisions can be complex. Particle-filled silicones are used in many demanding applications, but can they meet all of your application's requirements? Are EMI gaskets made of these materials cost-effective, and do particle-filled silicones support design for manufacturability?

Understanding Particle-Filled Silicones

Particle-filled silicones are elastomeric compounds that combine the advantages of silicone rubber with the electrical properties of metals. An inert, synthetic elastomer, silicone offers thermal stability over a wide temperature range along with resistance to ozone, water, and sunlight. When filled with tiny metal or metal-coated particles, silicone compounds combine EMI shielding and electrical conductivity with environmental sealing.

Table 1: Filler, Conductivity, and Volume Resistivity

Filler Type	Electrical Conductivity	Typical VR (ohms/cm)
Silver	Extremely Conductive	.0009
Silver-Aluminum	Super Conductive	.003
Silver-Copper	Super Conductive	.003
Silver-Glass	Very Conductive	.006
Nickel-Graphite	Conductive	.01
Carbon Black	Semi-Conductive	8.0

Table 1 shows the relationship between filler type, conductivity, and typical volume resistivity (VR) as measured in ohms per centimeter. Direct methods for measuring shielding effectiveness can be expensive and complex, so VR is a commonly used method for indicating EMI shielding effectiveness indirectly. Note the fill types for particle-filled silicones include pure silver, silver-plated materials, and nickel-coated fills.

Electrical Conductivity, Material Properties, and Cost

Silicones have many desirable properties, but loading them with a high percentage of metal particles to increase electrical conductivity can have negative tradeoffs. That's why historically; some designers have rejected particle-filled silicones as too hard or too brittle. Other designers have complained about part size limitations based on mold dimensions and long lead times for sheet materials. Some industry professionals also believe (incorrectly) that all particle-filled silicones are too thick to support thinner electronic designs.

The cost of older, particle-filled products also discouraged their use. For years, the filler of choice for shielding silicones was silver-aluminum. The U.S. military's development of the MIL-DTL-83528 specification played an important role in this particle's popularity. When silver began approaching $50 per Troy ounce in 2011, however, the fact that these elastomers were specified on thousands of gasket drawings and prints became problematic. EMI gaskets made of silicones filled were pure silver were even more expensive.

Table 2: Filler Type and Cost

Filler Type	Cost
Silver	$$$$$
Silver-Aluminum	$$$$
Silver-Copper	$$$$
Silver-Glass	$$$
Nickel-Graphite	$$
Carbon Black	$

Today's electronic designers can specify alternative particle fills. As *Table 2* shows, choices such as nickel-graphite cost significantly less. Note the difference in cost between silver, silver-aluminum, and nickel-graphite fills.

Table 3: Shielding Effectiveness Test Results

Frequency (MHz)	Reference Level (dB)	Dynamic Range (Analyzer Reading)	Test Sample (Analyzer Reading)	Dynamic Range (dB)	Nickel Graphite Gasket (Shielding Effectiveness) (dB)
20	95	-26.9	-25.1	121.9	120.1
30	100	-27.9	-24.5	129.9	124.5
40	100	-28	-24.3	128	124.3
60	100	-28.2	-25.1	128.2	125.1
80	100	-27.7	-25.5	127.7	125.5
100	100	-27.9	-25.2	127.9	125.2
200	100	-28.9	-27.7	128.9	127.2
400	100	-28.3	-26.3	128.3	126.3
601	100	-28.7	-26.1	128.7	126.1
800	100	-29.2	-27.1	129.2	127.1
1000	100	-17.8	-15.7	117.8	115.7
2000	100	-18.2	-15.5	118.2	115.5
4100	100	-17.9	-13.7	117.9	113.7
6000	100	-17.1	-13.1	117.1	113.1
8000	100	-17.2	-14.1	117.2	114.1
10000	100	-17.5	-15.7	117.5	115.7

Nickel-Graphite Silicones

Manufacturers, including Specialty Silicone Products (SSP), now supply cost-effective nickel-graphite silicones that perform at the shielding levels of silver-aluminum filled products. *Table 3* contains results from a third-party test report. It shows how SSP's nickel-graphite silicones meet the shielding effectiveness requirements of MIL-DTL-83528, which sets a minimum shielding effectiveness of 100 dB.

Table 4: Properties of Softer Silicones				
Durometer (Shore A)	Tensile Strength (psi)	Elongation (%)	Tear B (ppi)	Maximum VR (ohm/cm)
30	100	400	N/A	0.300
45	150	200	25	0.030
55	150	200	25	0.040
65	200	200	35	0.040
75	270	250	35	0.040

Particle-filled silicones also provide other desirable material properties. For example, as *Table 4* shows, SSP 502-series SpecShield™ silicones include lower-durometer (softer) materials with good tensile strength, elongation, and tear resistance along with maximum VR levels. Durometer, a measure of harness or softness, is an important engineering property because it affects the flexibility and compressibility of an EMI gasket. With particle-filled silicones, the Shore A scale for durometer is used.

Conductive silicone gaskets can also resist salt spray and corrosion according to ASTM B 117:2003 requirements. This is an important consideration for EMI gaskets that are used in marine environments.

Silver-Aluminum and Other Silver-Filled Silicones
If necessary, electronic designers can still choose silver and silver-filled elastomers in various durometers based on their application requirements. *Table 5* lists properties for silver and silver-filled elastomers, such as SpecShield™ materials that meet the requirements of MIL-DTL-83528. Included are two silver-aluminum products from SSP with a qualified product listing (QPL) from the Defense Logistics Agency (DLA), part of the U.S. Department of Defense.

Table 5: Some Properties of Silver-Filled Silicones				
Fill Material	Base Elastomer	Durometer	Maximum VR (ohm/cm)	QPL
Silver	Silicone	65	0.002	
Silver-Aluminum	Silicone	65	0.008	Yes (Type B)
Silver-Aluminum	Fluorosilicone	70	0.012	Yes (Type D)
Silver-Aluminum	Fluorosilicone	45	0.004	
Silver-Aluminum	Fluorosilicone	70	.012	
Silver-Copper	Silicone	65	0.004	
Silver-Copper	Silicone	80	0.005	
Silver-Glass	Silicone	65	0.006	
Silver-Nickel	Silicone	75	0.005	

Some silver-filled elastomers use fluorosilicone as the base material. Fluorosilicones such as the silver-aluminum products in *Table 5* have physical and mechanical properties that are very similar to standard silicones; however, fluorosilicones also provide improved resistance to fuels, oils, and solvents.

Overcoming Design and Manufacturing Challenges
Thanks to innovations in silicone compounding, particle-filled elastomers can meet demanding shielding requirements along with other project specifications. For example, because nickel-graphite silicones such as SpecShield™ elastomers are available in 30, 40, and 45 durometer (Shore A), they're soft enough for enclosure gaskets. Other, higher-durometer shielding elastomers that use fluorosilicone as the base elastomer can resist fuels and chemicals. These fluorosilicone compounds come in 50, 60, and 80 durometers (Shore A) for applications that require EMI gaskets made of harder materials.

Unlike older shielding elastomers, newer shielding materials such as SpecShield™ products contain enough metal filler to ensure effective EMI shielding and electrical conductivity. These material are also support the cost-effective fabrication of EMI gaskets. As the only supplier of shielding elastomers that offers solid, heat-cured EMI silicones in continuous rolls, SSP can supply nickel-graphite silicones in higher durometers for applications that require harder materials. Compared to molded sheets, continuous rolls promote optimum yields for cost-effective conversion. Continuous rolls also support the use of automated equipment instead of time-consuming manual operations.

Various higher-durometer, nickel-graphite silicones are available, but some EMI gasket applications require reinforcement for added strength. For example, SSP's ArmourRFI™ is a 65-durometer SpecShield™ elastomer that's reinforced with an internal nickel-coated mesh. Lower-durometer, nickel-graphite silicones can also be reinforced with an inner layer of conductive fabric for added conductivity and material strength, which helps to prevent brittleness and tearing during EMI gasket fabrication.

During gasket cutting, particle-filled silicones won't stretch or become deformed. Connector holes align properly, and the material's structural properties support greater tear resistance – an important consideration for thinner wall gaskets. Product designers can also specify the use of an adhesive backing for ease-of-installation. For shielding applications where Z-axis conductivity is required, particle-filled silicones can support the use of electrically conductive adhesives.

Conclusion
Particle-filled silicones are good choice for meeting EMI shielding and many other application requirements. Electronic designers can choose from various types of filled elastomers, but it's important to account for all of your project requirements – including cost and manufacturability. As silicone shielding elastomers are used in a growing number of military and commercial applications, designers can expect continued advancements in nickel-graphite and silver-aluminum materials.

SHIELDING DESIGN FLOW CHART

Michael Oliver
MAJR Corp.

SHIELDING DESIGN FLOW CHART

This flow chart in *Table 1* will assist the designer in selecting the appropriate shielding options necessary to meet their shielding and environmental requirements.

The shielding requirement flow chart begins by identifying the type of NEMA or IP enclosure based on the intended environment (indoor/outdoor, military/commercial, marine or land/desert). Then, using the resulting letter designation A-F and continuing on to the second shielding flow chart (*Table 2*), the engineer can then evaluate the available shielding product options for the particular NEMA/IP enclosure.

In addition, all shielding products shown in the table, depending on profile, configuration, compression, galvanic compatibility, required attenuation, etc., will enable an electronic product to meet MIL-STD-461 and other military or commercial specifications.

Table 1 – Flow Chart to Determine Shielding and Environmental Requirements

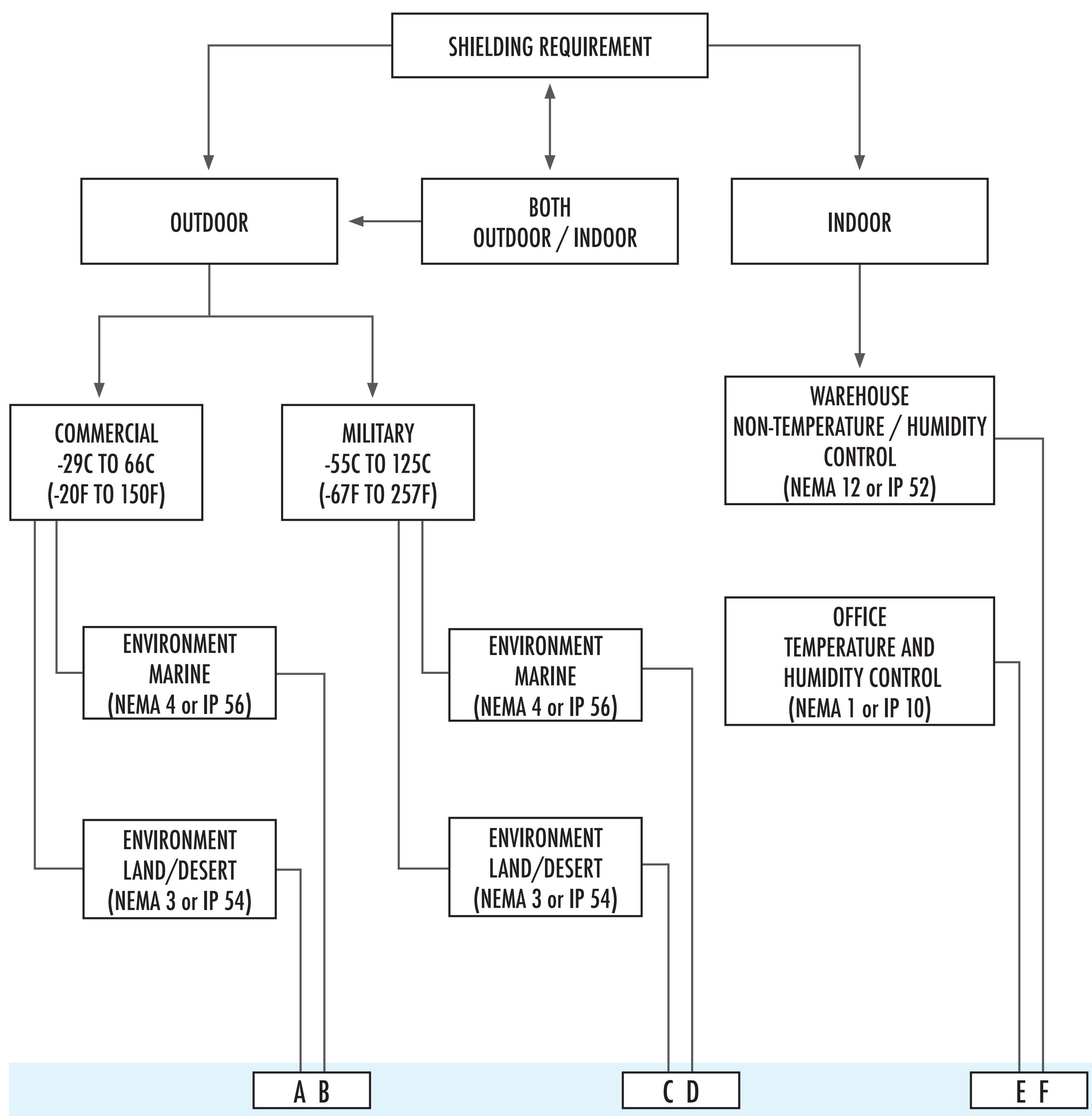
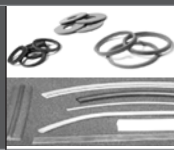
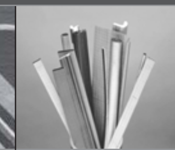
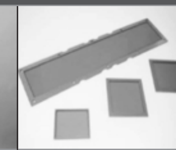
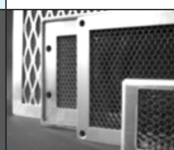
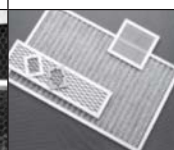
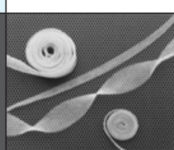
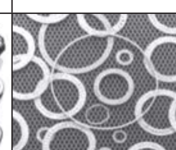
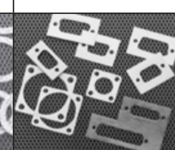


Table 2 on next page

Table 2 – Shield Selection Chart

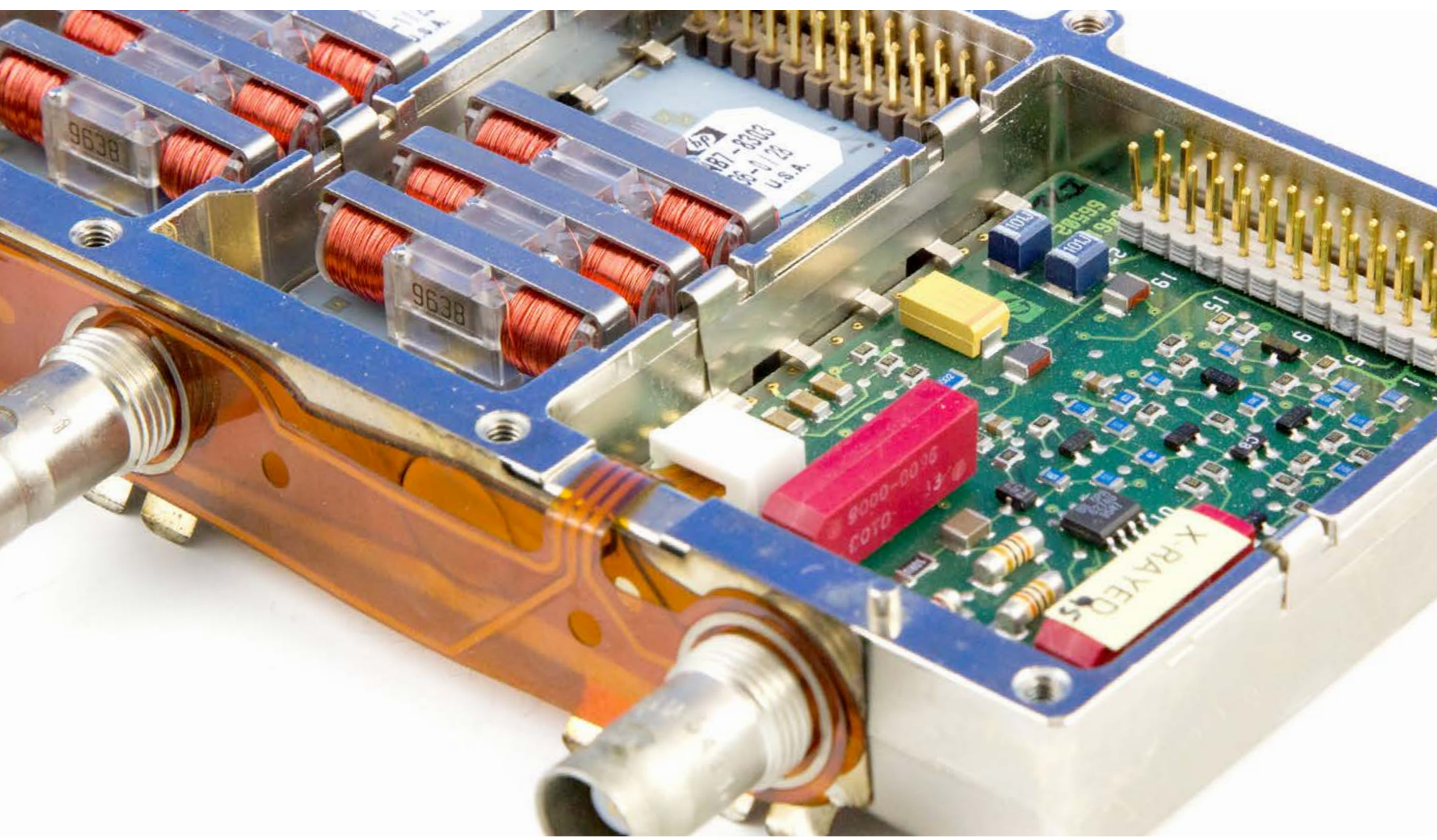
ENCLOSURE DOOR / COVER							
PRODUCT NAME	CONDUCTIVE ELASTOMER	FINGERSTOCK GASKET	SHIELD SEAL STRIP GASKET	MULTICON GASKET	KNITTED WIRE GASKET	CONDUCTIVE FABRIC	CONDUCTIVE WINDOW
NEMA / IP (DEPENDENT ON CONFIGURATION)	A, B, C, D, E, F	E, F	A, B, E, F	A, B, C, D, E, F	E, F	E, F	A, B, C, D, E, F
MIL-STD-461 (DEPENDENT ON CONFIGURATION)	YES	YES	YES	YES	YES	YES	YES
ENCLOSURE INTAKE / EXHAUST							
PRODUCT NAME	VENT PANEL	AIR FILTER	FRAME GASKET				
NEMA / IP (ANGLED HONEYCOMB)	E, F	E, F	E, F				
MIL-STD-461 (DEPENDENT ON CONFIGURATION)	YES	YES	YES				
ENCLOSURE CONNECTOR/CABLE							
PRODUCT NAME	WIRE MESH TAPE	METAL FOIL TAPE	FERRITE MATERIAL	WIRE MESH WASHER	CONNECTOR GASKET		
NEMA / IP (DEPENDENT ON CONFIGURATION)	N/A	N/A	N/A	E, F	A, B, C, D, E, F		
MIL-STD-461 (DEPENDENT ON CONFIGURATION)	YES	YES	YES	YES	YES		
ENCLOSURE ELECTRONICS							
PRODUCT NAME	BOARD LEVEL SHIELD	ABSORBER MATERIAL					
NEMA / IP (DEPENDENT ON CONFIGURATION)	N/A	N/A					
MIL-STD-461 (DEPENDENT ON CONFIGURATION)	YES	YES					

Please Contact the Author at: emi@majr.com
For Guidance on the Best Shielding Products to Meet or Exceed
Specific Shielding Requirements for Your Application

A CIRCUIT THEORY APPROACH TO CALCULATING THE ATTENUATION OF SHIELDING BARRIERS

George Kunkel, President/CEO
Spira Manufacturing Corp

EDITOR'S NOTE: *As a long time EMC engineer and working consultant, I've performed a lot of study and measurements on shielding effectiveness of real product shields. Invariably, I've noticed the measured results fail to compare with the classical Schelkunoff equations derived in the 1930s – that is, the Absorption, Reflection, and Multiple Reflection equations. It is my belief that real product shields are typically located in the near field and I suspect the Schelkunoff equations were far field derivations. George Kunkel has developed a shielding theory based on circuit theory that can accommodate "shielding quality" in both the near and far fields, for both electric and magnetic fields. I'd welcome any comments on this subject. Kenneth Wyatt, senior technical editor, Interference Technology.*



A CIRCUIT THEORY APPROACH TO CALCULATING THE ATTENUATION OF SHIELDING BARRIERS

Abstract

There are two commonly used methods for approximating the attenuation of shielding barriers. This approximation is defined as shielding effectiveness (SE) for shielding materials used in the design of shielded enclosures. Both methods use wave theory and quasi-stationary assumptions. One of the methods uses Maxwell's equations to estimate the shielding, and the other uses the correlation between transmission lines and radiated waves. This article proposes a third method based on circuit theory (Kirchhoff's Law) as an applicable method of approximation worthy of consideration.

Introduction

The two common methods of estimating the shielding effectiveness of material used in the design of shielded enclosures require the understanding and use of wave theory and Maxwell's equations. Very few working engineers understand, and therefore properly use wave theory and Maxwell's equations. Therefore they find it difficult to evaluate the materials used in the shielding of electromagnetic waves for compliance to the various commercial and DoD EMC requirements.

A method of estimating the shielding quality (SQ) of materials used in the design of shielded enclosures using circuit theory (Kirchhoff's Law) is included in this article. The advantages of using a circuit theory analogy are: (1) the ease by which the average design engineer can understand the variables and application of the theory; (2) these advantages will greatly assist the design engineer in selecting the proper material for meeting specific shielding requirements; and (3) the approximate magnitude of both the E and H fields emanating from a shielding barrier material can be easily obtained.

The paragraphs that follow will describe:

1. The generation and propagation of an electromagnetic wave.
2. The development of the attenuation factors associated with specific shielding materials.
3. Development of equations for estimating the shielding quality of specific barrier materials for both the E and H fields of an electromagnetic wave.
4. Boundary conditions and constraints associated with the theory.
5. Comparative analysis of shielding materials using wave theory and the circuit theory contained herein.

Generation and Propagation of EM Fields

The undergraduate courses on electromagnetic theory introduce the concept of an electromagnetic (EM) field by driving a pair of parallel plates with an AC voltage source as illustrated in *Figure 1*. The current that flows through the wire comes from the top plate and is stored in the bottom plate. The over presence of the electrons on the bottom plate is illustrated by plus symbols (+) and the absence of electrons on the top plate is illustrated by minus symbols (-). This creates an electromagnetic field which is illustrated in *Figure 2*. As is illustrated, a field exists between the plates. The magnitude of the E field is equal to the voltage differential between the plates divided by the distance between the plates in meters. The resultant E field is in volts/meter (e.g., we use a set of parallel plates for performing E field susceptibility testing to MIL-STD-461/462).

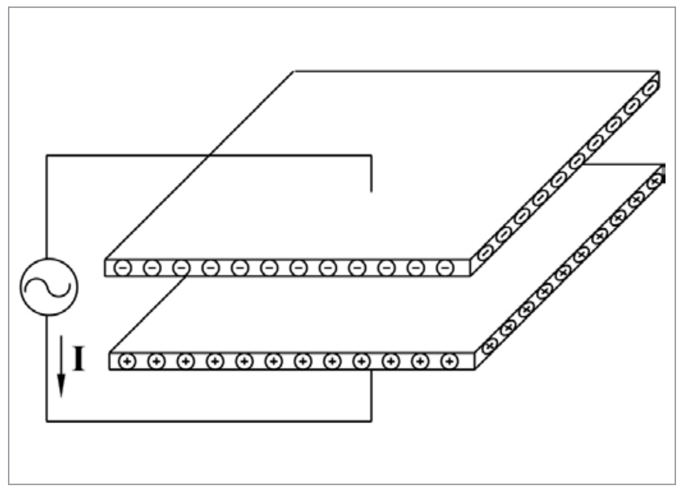


Figure 1 – Concept of an electromagnetic field resulting from an AC voltage source connected to two parallel plates.

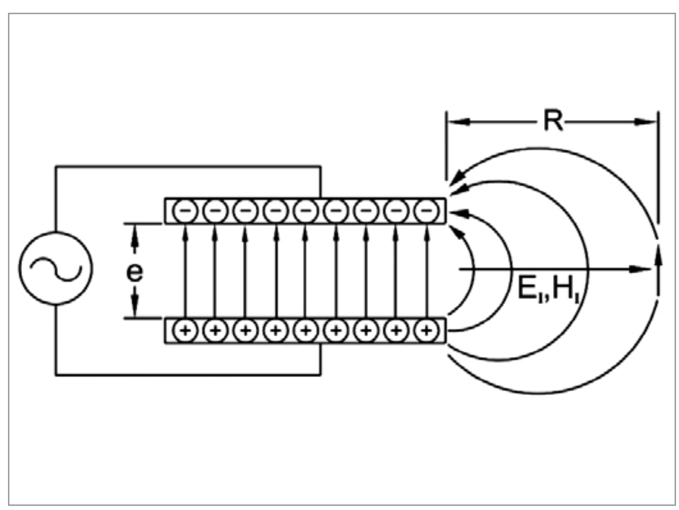


Figure 2 – The resulting electromagnetic field between two parallel plates.

As is illustrated in *Figure 2*, the lines of flux in the center of the plates are straight and flow from the bottom to the top plate. At the edges they bow out, where the fields or lines of flux repel each other, forcing the bowing. The field that bows out is an EM field where the E vector quantity is equal to the voltage divided by the length of the force line in meters (i.e., if the point of concern is one meter from the set of plates, the E field would be the voltage across the set of plates divided by the circumference of the circle or approximately E/3.1). The magnetic or H field is approximated by the following equation:

$$H_I = 2\pi R E_I/377\lambda \quad R \le \lambda/2\pi$$
$$= E_I/377 \quad R \ge \lambda/2\pi \qquad (1)$$

Where R = Distance from dipole antenna to barrier (m)
λ = Wave length = c/f
c = 3 x 10^8 m/sec
f = Frequency (Hz)

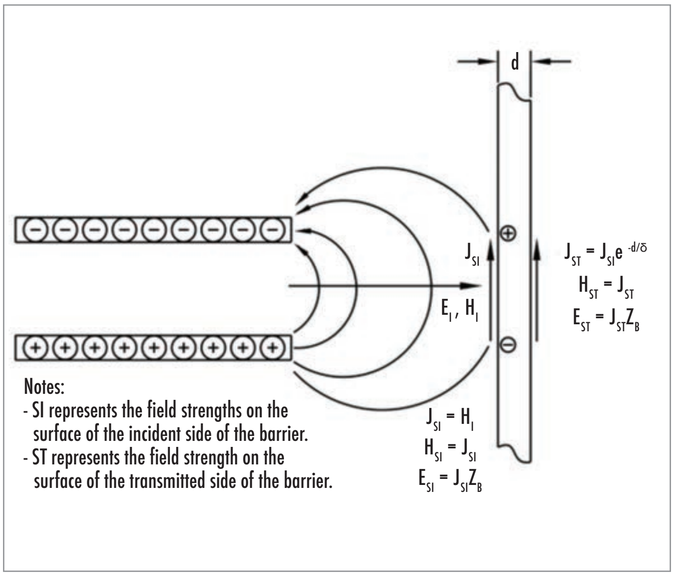


Figure 3 – Current flow in a shielding barrier in close proximity to an EM field.

Suppression (Shielding) of EM Waves
When we place a shielding barrier in the path of the EM field, the force of the field causes current to flow in the barrier. As is illustrated in *Figure 3,* the excess electrons in the bottom plate create a force on the electrons in the barrier. This force causes the electrons to flow away from the point of contact. In a similar manner, the lack of electrons on the upper plate will create an excess of electrons on the barrier at the upper point of contact. This current flow in the barrier is called the "surface current density" (Js) in amperes/meter, and is equal to the H field incident on the barrier when the field is perpendicular to the barrier. The current flowing in the barrier is attenuated by the skin effect.

The current on the transmitted side is equal to $J_{SI} e^{-d/\delta}$ (i.e., the current on the incident side attenuated by skin effect). The impedance of the field emanating from the barrier is equal to the impedance of the barrier. The values of E_T and H_T are as illustrated in *Figure 3* and are as follows:

$$H_T = J_{SI} e^{-d/\delta} \qquad (2)$$

$$E_T = H_T Z_B \qquad (3)$$

Where E_T = Transmitted E field (V/m)
H_T = Transmitted H field (A/m)
d = Thickness of barrier (m)
δ = Skin depth (m)
Z_B = Impedance of barrier (ohms)

$$Z_B = \frac{1+j}{\sigma\delta(1-e^{-d/\delta})}$$

Shielding Quality of Shielding Materials
The definition of shielding quality as used herein is the difference in dB between the E field and H field of the wave incident on the barrier and the wave emanating from the barrier on the opposite side, i.e.,

$$SQ_E = 20\ 1og E_I/E_T \qquad (4)$$

$$SQ_H = 20\ 1og H_I/H_T \qquad (5)$$

From *Figure 3* we know that the E field in the barrier on the incident side is equal to the H field (i.e., Js) times the impedance of the barrier. Therefore, we can conclude that the ratio of the E field of the incident wave to the E field in the barrier on the incident side is:

$$E_I/Z_B H_I \qquad (6)$$

We also know that the impedance of the incident wave is equal to:

$$Z_W = E_I/H_I \qquad (7)$$
and therefore $H_I = E_I/Z_W$

Substituting E_I/Z_W for H_I in *Equation 6* we can conclude that the ratio of the E fields in the incident wave and the E field in the barrier on the incident side equals:

$$Z_W/Z_B \qquad (8)$$

From *Figure 3* we also note that the E field in the barrier is attenuated by the skin effect, i.e.,

$$E_T = E_O e^{-d/\delta} \qquad (9)$$

Where E_T = Transmitted E field
E_O = E field in barrier on incident side
d = Thickness of barrier (m)
δ = Skin depth (m)

From *Equations 4, 8* and *9* we can conclude that the shielding quality of material used in a shielding barrier for the E field is:

$$SQ_E = 20 \log ZW \qquad (10)$$

Where $Z_w = \frac{E_I}{H_I}$
= $-j377\lambda/2\pi r$ ($r < \lambda/2\pi$) Elec. dipole source
= $j377\ (2\pi r/\lambda)$ ($r < \lambda/2\pi$) Mag. dipole source
= 377 ($r \ge \lambda/2\pi$) Both sources

$$Z_B = \frac{1+j}{\sigma\delta(1-e^{-d/\delta})}$$

$\delta = (2/\mu\sigma\delta)^{1/2}$ skin depth (m)
σ = Volume conductivity of mat'l (mohs/m)
μ = Absolute permeability of mat'l (Henrys/m)
$\lambda = c/f = 3\times10^8$/frequency (m)
r = Distance from source to barrier (m)
d = Thickness of material (m)

Using the same logic and the information of *Figure 3* we can conclude that the shielding quality of a material for the H field is:

$$SQ_H = 20 \text{ 1og } e^{-d/\delta} \qquad (11)$$

Comparative Analysis
A comparative analysis at 1 MHz has been performed comparing the results of the shielding effectiveness of an aluminum shield using the accepted SE = R + A + B formula derived from wave theory and the shielding quality equations derived from circuit theory (see *Appendix A* for analysis).

The conditions used for the comparative analysis are consistent with the test conditions of an earlier paper entitled "Shielding Effectiveness Test Results of Aluminized Mylar." These conditions are as follows:

1. The aluminum shield is aluminized Mylar having a dc resistance of 1.4 ohms/square. The thickness of the aluminum (based on the resistance) is 2×10^{-8} meters and has a theoretical impedance of 2.0 ohms.

2. The impedance of the wave at the shield radiating from the loop antenna is 4.0 ohms.

3. The impedance of the wave at the shield radiating from the electric dipole antenna is 3500 ohms.

The results of this analysis along with the results of the test contained in the earlier paper are illustrated in *Table 1.* These results are as follows:

1. Attenuation to E field. The analysis using equations derived from wave theory and circuit theory yielded a close approximation to the E field from both the electric and magnetic dipole antennas.

2. Attenuation to H field. The analysis using the equations derived from circuit theory gave a very close approximation. However, the analysis using the equations derived from wave theory resulted in an error of more than three orders of magnitude using the electric dipole antenna as the radiating source.

We can conclude from the results of the "SE=R+A+B" equations derived from wave theory that the equations were intended to predict the attenuation of only the E field through a shielding barrier.

Table 1: Results of comparative analysis as compared to test results at 1 MHz with two ohm aluminized Mylar shield.

SE/SQ at 1 MHz	Radiating Source	
	Electric Dipole Antenna	Magnetic Dipole Antenna
E Field		
Test Results	66	7
Wave Theory	62	3
Circuit Theory	65	6
H Field		
Test Results	0	0
Wave Theory	62	3
Circuit Theory	0	0

The comparative analysis contained in the appendix contains a significant amount of information. Of particular concern are the results of the analysis contained in *Table A-I* (of the Appendix) using the wave impedance consistent with the magnetic dipole (loop) radiation source (4 ohms) and the thickness of the shield of 2×10^{-8} meters. From the explanation contained in the books and papers on shielding theory using R + A + B we learn that the reflection coefficient "R" represents a ratio of power reflected from the shield material to that which penetrates into the shield material. The 66.5 dB means that if 1 watt of power is incident on the shield, 2113 units are reflected for each unit that penetrates into the barrier (99.95% is reflected and .05% or .5 milliwatts penetrate the barrier). The shielding effectiveness level of 3.1 dB implies that 20% of the 1 watt (or 700 milliwatts) is observed on the secondary side of the shield material. This means that the re-reflection coefficient amplifies the energy which penetrates the shield by 140,000%. This amplification is obviously not possible and means that the explanation is faulty. It can also be noted using the equations of SE = R + A + B derived from wave theory that the impedance of the barrier Z_B is calculated to be 4 orders of magnitude less than the actual impedance using a resistance bridge when the barrier was 2×10^{-8} meters thick (i.e., the impedance of the barrier is the same regardless of the thickness of the barrier).

Conclusion
The shielding quality equations which have been derived from circuit theory provide a close approximation of the attenuation of a wave through a barrier and are far easier to understand by the average design engineer than the presently used shielding effectiveness equations. The equations also provide information that is more appropriate to the design engineering community, i.e.,

> The voltage induced into a circuit is a function of the wave impedance and the impedance of the circuit. If a design engineer uses 377 ohms instead of the 2 ohms emanating from the aluminized Mylar shield in

performing a susceptibility analysis of a piece of electronic equipment, the calculated induced voltage can be off by more than two orders of magnitude.

Shielding quality as a measure of the attenuation characteristics of a shield is considered a more appropriate term. Shielding effectiveness is a well-defined term and possesses a specific connotation within the engineering community. However, the definition is not well understood. For example, suppose an engineer performs a susceptibility test on equipment circuits and discovers that he needs 40 dB of shielding to comply with his requirements. He selects a shield that renders 60 dB of shielding effectiveness using the shielding effectiveness equations. Upon retest after manufacturing his shield, he finds he still need 20 dB of shielding.

The term shielding effectiveness implies a level of shielding the engineer is going to obtain. In the above case the results are a level 40 dB less than is expected. There is nothing associated with the equations that can explain the results to him where the problem could easily be the distance from the shield material to the circuits being affected by the radiated field. The term of shielding quality defines the attenuation of a field by the shield material, and that definite information with regard to the field of the incident wave as well as information associated with the susceptibility of the circuits is required. Once the required information is available, a ready solution can be obtained.

The use of the shielding quality equations derived from circuit theory are more consistent with the principles associated with the engineering discipline than are the shielding effectiveness equations, especially when the shielding barrier is in close proximity to the EM source (near field).

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Appendix A
Shielding Effectiveness Versus
Shielding Quality Analysis

Included is an analysis for estimating the shielding effectiveness of aluminum shielded barriers using the equations consistent with wave theory and R + A + B technology and estimating the shielding quality of the same barriers under the same conditions using the equations contained in the body of this article.

The shielding effectiveness equations of concern associated with wave theory are:

$$SE = R + A + B$$

$$R = 20 log \frac{(K+1)^2}{4|K|} \quad \text{where } K = Z_{Wave}/Z_{Barrier}$$

$$Z_{Barrier} = \frac{1+j}{\delta\sigma}$$

$$A = 201og\ e^{-d/\delta}$$

$$B = 20\log\left(1 - \left[\frac{K-1}{K+1}\right]^2 e^{-2d/\delta}\right)$$

$\delta = \left[\frac{2}{\mu\sigma\omega}\right]^{1/2}$ skin depth (m)
d = Thickness of barrier (m)
σ = Volume conductivity of material (mohs/m)
μ = Absolute permeability of material (Henrys/m)
ω = 2πf

Table A-1: Results of Shielding Effectiveness Analysis Using Wave Theory and SE = R + A + B

Frequency (Hz)	d (meters)	Zw (ohms)	Zb** (ohms)	R (dB)	A (dB)	B (dB)	SE* (dB)
10^6	$2x10^8$	4.0	$4.72x10^4$	66.5	0.0	63.4	3.1
10^6	$2x10^8$	3500	$4.72x10^4$	125.4	0.0	63.4	62.0

The results of the analysis are shown in *Table A-l*.
The equations used for calculating the shielding quality of the shielding material using circuit theory and contained in the body of this article are:

$$SQ_E = 20\log\frac{Z_W}{Z_B}\ e^{-d/\delta}$$

$$SQ_H = 20 \text{ 1og } e^{-d/\delta}$$

$$Z_B = \frac{1+j}{\sigma\delta(1-e^{-d/\delta})}$$ with d and σ as defined above.

The results of the analysis are shown in *Table A-2*.

Table A-2: Results of Shielding Quality Analysis Using Circuit Theory

Frequency (Hz)	d (meters)	Zw (ohms)	Zb** (ohms)	SQ_E (dB)	SQ_H (dB)
10^6	$2x10^{-8}$	4.0	2.0	6.0	0.0
10^6	$2x10^{-8}$	3500	2.0	65	0.0

* This shielding effectiveness estimate is for both E and H fields (i.e., the shielding effectiveness for both fields is stated to be the same).

** The Z_B equation and value in the shielding effectiveness equations assumes the barrier is infinitely thick.

$$\text{i.e., } Z_{Barrier} = \frac{1+j}{\delta\sigma}$$

where δ thickness in meters is applicable for an infinitely thick barrier.
The equation for a barrier of any thickness is:

$$Z_B = \frac{1+j}{\sigma\delta(1-e^{-d/\delta})}$$

where $(1-e^{-d/\delta})$ is a correction factor when the thickness is finite.

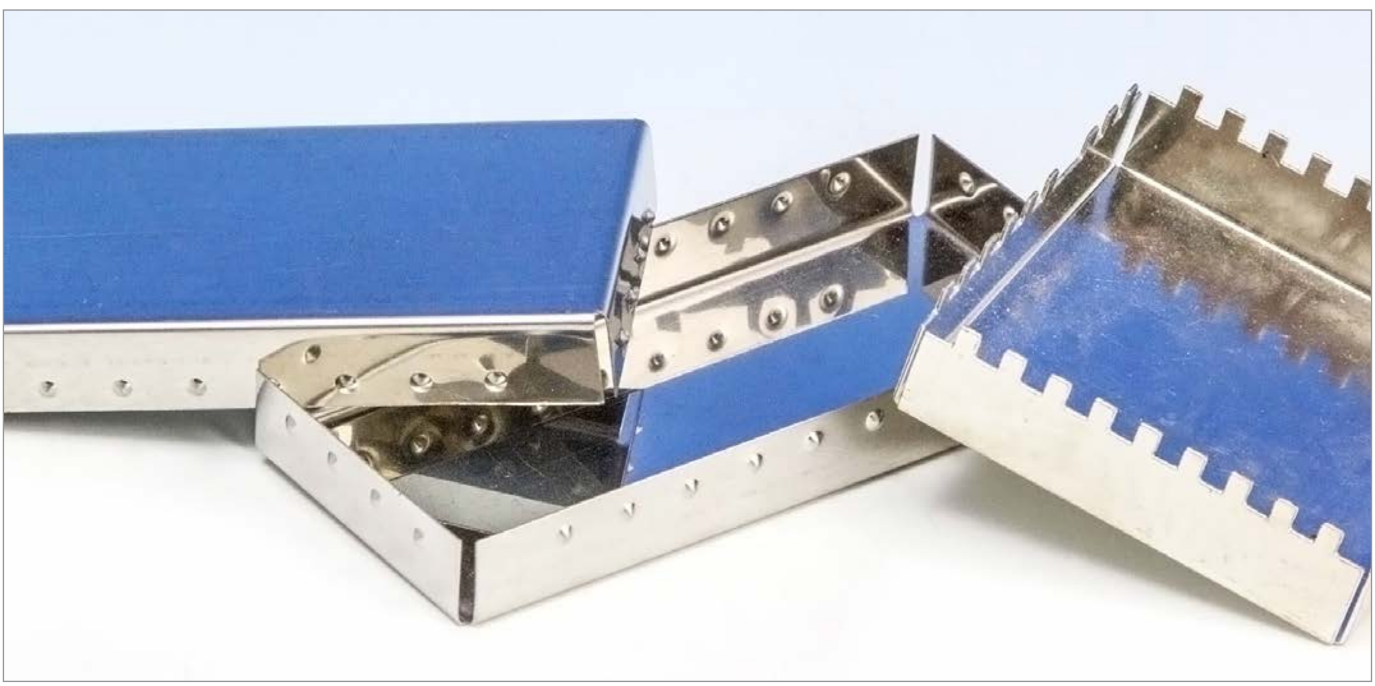
Appendix B
Shielding Effectiveness Approach to Shielding Theory

The use of Maxwell's equation to obtain the Shielding Effectiveness (SE) of a shielding material requires compliance to "Stokes Function" (the sum total of all power entering or leaving a given area must equal zero unless there is a sink or source of power). This method if properly applied will provide the engineering community with values of "SE" and the attenuation for the E and H field that are useful to the design engineer.

The wave theory approach (as presently interpreted) does not meet the requirements of "Stokes Function". The present interpretation stipulates that the power loss to an H field inside the barrier is equal to the power loss associated with an E field being reflected at the incident side of the barrier. This does not occur for the following reasons:

1. Broaddus and Kunkel did not detect an H field loss.

2. When the barrier is thick, skin effect prevents the EM wave from reaching the back side of the barrier. This fact eliminates the possibility of an H field reflection.



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USE OF ABSORBERS FOR SHIELDING

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USE OF ABSORBERS FOR SHIELDING

Background
With the trending small size of electronic devices coupled with higher data speeds, there is a merging of the increasing physical closeness among components and the shrinking wavelengths associated with higher speeds. As wavelengths shrink, they approach the physical dimensions of components and devices, which result in increased “antenna effect” of noise. Therefore, it is becoming increasingly critical to prevent coupling of noise to these “antenna” structures that can radiate or to reduce the coupled field levels since it is becoming more difficult to shield products in a cost efficient manner at higher frequencies.

Also, smaller wavelengths can approach the physical dimensions of many EUTs, which lead to possible cavity resonance effects. The resonant frequency is the frequency where integer half-wavelengths corresponds to the dimension of the enclosure. A wave is set up inside the enclosure whose nodes (i.e. zero amplitude) lie on the conductive walls of the enclosure. These structures behave as cavity resonators. For example, a 2-inch square by ½-inch metallic enclosure resonates at a first order mode of around 12 GHz. Even weak coupling at these extremely high frequencies can induce strong oscillations than can then couple to any other points in the enclosure or can radiate. The danger of a cavity resonance is that if a noise source has a frequency component that corresponds to a resonant point, then a large field can be generated at this frequency due to the multiplication or amplification effect by the “Q-factor” of the cavity. One approach to reduce this phenomenon is to lower the “Q-factor” of the cavity by introducing losses (Q-dampening). We commonly do that by installing absorber material inside the cavity.

Reduce PCB Edge Fringing on PCB
When proper PCB layout design techniques such as trace routing, stack-up assignment, decoupling, and termination, are implemented, the radiation from the printed circuit board itself can be minimized. However, there are several other mechanisms of the printed circuit board assembly remaining that can still be radiation sources. These are the components themselves, cavity resonance effects of the power/signal return layers, and the edges of the printed circuit board. Edge effects can be particularly burdensome since it is the board edges that are in such close proximity to the chassis and hence these radiation fields can induce currents into the chassis frame.

There are numerous studies that discuss various approaches or techniques pertaining to reducing radiation edge effects from the printed circuit board such as proper termination. One problem with these techniques is that they can require the use of additional components and valuable PCB real estate, and often do not actually reduce the energy. Rather these common approaches allow the energy to be reflected, potentially creating additional internal resonant effects and coupling to internal vias, which can result in increased radiation.

The use of microwave absorbing material applied along the edge of the printed circuit board reduces the edge radiation from the board without using additional board real estate. The absorber also reduces the possibility of board resonance problems by dissipating the energy and not reflecting the energy back into the interior of the board. This can be attached to the edge of the board using a U-channel.

Reduce PCB Trace Radiation
Placing absorber material directly on top of microstrip traces reduces the fields emanating from the top side of the traces. This can be a particularly troublesome coupling mechanism if the traces are located on the bottom side of the board laying adjacent to the bottom of the enclosure. The coupling of the field to the chassis will cause currents to flow into the chassis and set up circulating currents within it. These circulating currents can then cause radiation from any slots, seams or apertures in their path. Placing absorber with pressure sensitive adhesive, PSA, on the traces reduces the field coupling to the chassis. The effect on the trace impedance is minimal since the absorber material is high impedance (> 10 kOhm). It can also be conveniently placed directly on top of the trace without any additional mounting or mechanical fastening mechanisms. This approach was used on a switch box and produced about 4-6 dB reduction in radiated emissions at 6 GHz.

Reducing Cavity Resonance Effects
As mentioned earlier, a six-sided conductive enclosure or cavity can support electromagnetic resonance. Its coupling is a consequence of self-resonance of various structures such as slots in the PCB, metallic enclosures, slots between the PCB and the metallic enclosure. However, small size enclosures such as a GBIC (GigaBit Interface Converter) module or a board shields with a single PCB and/or containing only a few components will appear as more of a true resonant cavity since most of the volume will be empty space (i.e. air). The danger of a resonance is that if a noise source has a frequency component that corresponds to a resonant point, then a large field can be generated at this frequency due to the multiplication or amplification effect by the “Q-factor”. One approach to reduce this phenomenon is that the “Q-factor” of the cavity must be lowered by introducing losses (Q-dampening). The absorber material acts as a resistive load in the cavity. Today we see shielding more and more as a multilevel concept. Board shields will handle the lower frequencies, and an internal layer of microwave absorbing material will handle the higher frequency components. Absorbers are a viable option for handling these higher frequency res-

onant frequency issues. Absorbers work most efficiently at higher frequencies (i.e.>1 GHz) although work is continuing to keep reducing the low frequency end of these types of materials.

Absorbers reduce radiation or "shield" by literally absorbing the energy and converting it to heat while reducing the Q factor in a cavity. Using absorber material is convenient because it converts the electromagnetic energy to heat, and does not have to be "grounded." As long as the absorber material intercepts the field or is in the field path, then it will reduce the electromagnetic energy of the field. A secondary effect of adding absorbing material inside the cavity is that it will change the effective permittivity of the cavity depending upon the amount of material added. As the volume of material becomes a more significant percentage of the interior volume, the more effect on the combined permittivity. By changing the effective permittivity, one can cause a shift in the location of the resonant frequency. This technique was used in a switch box design and resulted in about a 6 dB reduction at 8.5 GHz.

Heat Sink Radiation

Generally, a heatsink is physically and electrically larger than the high frequency chip device to which it's attached and so it is an efficient radiator. No matter how well the signals are routed on the printed circuit board, if the chip's currents are parasitically coupled onto the heatsink, radiated emission will occur. Each fin of the heatsink acts as a monopole antenna structure with the total fins act as an antenna array. Depending on overall shielding enclosure effect or heatsink resonance effect, these emissions may or may not exceed regulatory limits. The most common practice for controlling this heat sink-produced radiated emission is to "ground" the heatsink to the PCBs reference ground.

As frequencies rise, the size of the heatsink becomes electrically larger and even of a more efficient radiator. Therefore, any grounding scheme for the heatsink must therefore also be designed to be effective at these higher frequencies. The contact between the heatsink and the reference ground of the printed circuit will have inductance and it must be low impedance. The greater the number of contacts used, the lower the impedance, and the more effective in reducing the radiated emissions. In general, grounding of the heatsink does not reduce the radiated emissions effectively at frequencies above 1 GHz. Therefore, other approaches must be considered. To improve the grounding at higher frequencies, we must have contact points closer than λ/20 of a wavelength to be effective. An example would be a continuous grounding of the heatsink through an elastomeric conductive gasket to a continuous reference ground trace surrounding the heatsink. However, not only does this still require quite a bit of board real estate, but it has been shown to not reduce radiated emissions all that effectively above 10 GHz. The use of absorber material to reduce the surface currents flowing on the heatsink and hence reduce the radiating effect of the heat sink has been shown to be effective. So, using absorber reduces the potential radiated emissions by reducing the surface currents that flow on the fins of the heatsink. Studies indicate that the absorber will also reduce radiated emissions by being placed directly underneath the heatsink, between it and the printed circuit board.

RF absorbing materials and microwave absorbing materials can take on many different names. Some of the more common names include: RF absorber, microwave absorber, EMI absorber, Radar Absorbing Material or RAM, magnetically radar absorbing material or mag-RAM, EMI suppression material, or surface wave absorber. All of these different nomenclatures point to a material who's magnetic and/or electric properties have been altered, such that they absorb or attenuate energy.

Historically, worldwide military forces used microwave-absorbing materials to reduce reflections of high-frequency radar. However, with the increase in clock speeds, there has been a trend toward the use of microwave absorbing materials in commercial applications. Consumer electronics, notebook computers, wireless LAN devices, network servers and switches, wireless antenna systems, cellular phone base stations are just a few of the high-frequency device applications that have adopted this technology.

Material Types

Flexible and thin magnetically loaded rubber absorbers:

Tuned Frequency Absorbers

Tuned Frequency Absorbers, or resonant frequency absorbers, provide great reflection loss at a discrete frequency, typically offering 20dB of attenuation. Tuned frequency absorbers offer narrowband absorption from 1 to 40 GHz.MR2 Cavity Resonance Absorbers.

Cavity Resonance Absorbers are designed to exhibit high loss within a microwave cavity. The absorber will in effect lower the Q factor of the cavity by attenuating cavity oscillations, resonant frequencies, or harmonics. Cavity Resonant Absorbers attenuate energy at normal and high angles of incidence at frequencies from 1 to 20 GHz.

RF Absorbing Foam by Mast Tech

Surface Wave Absorbers

Surface Wave Absorbers are the most heavily magnetically loaded elastomeric absorber. Surface Wave absorbers are designed to exhibit the highest loss and are intended to be applied to a conductive or metal surface for traveling or surface wave attenuation. Surface Wave Absorbers attenuate traveling or surface wave energy from 1 to 20 GHz.

Low Frequency Absorbers

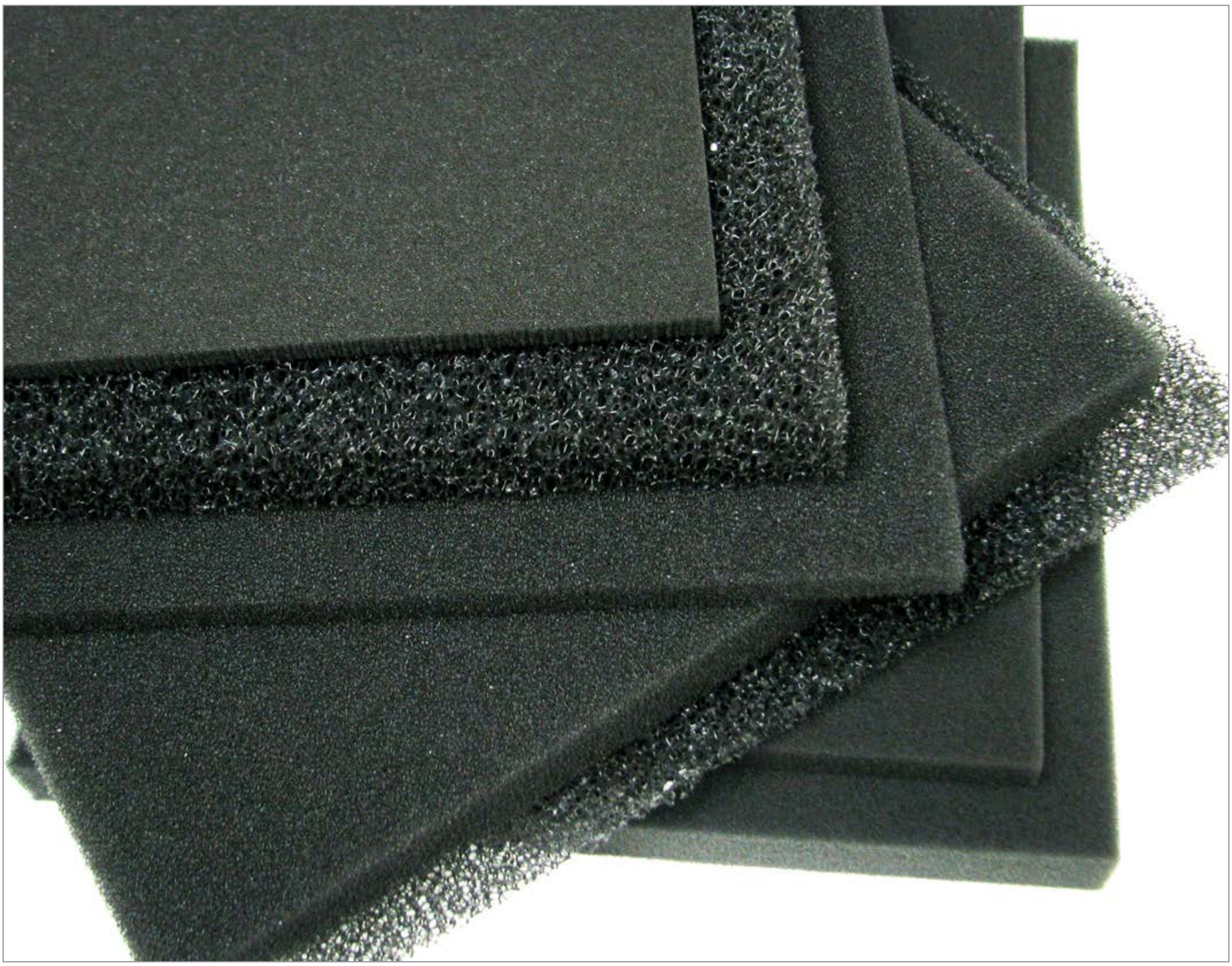
Low Frequency Absorbers provide high loss at sub-microwave frequencies. Low Frequency Absorbers are designed with shaped magnetic particles, which exhibit high permeability at frequencies from 1 MHz to 3 GHz.

Flexible dielectric foam absorbers:
Reticulated Foam Absorbers
Reticulated Foam Absorbers are very lightweight conductive carbon loaded sheet absorbers, which provide high levels of loss at normal and off normal angles of incidence. Reticulated Foam Absorbers are manufactured with a continuous gradient coating, which produces broadband reflection loss performance from 1 to 20 GHz. MF2 Lossy Foam Absorbers.

Lossy Foam Absorbers are a lightweight, low cost carbon loaded sheet stock. Lossy Foam Absorbers are manufactured with a constant coating to exhibit high insertion loss from 1 to 20 GHz.

RF Absorbing Materials by Mast Tech
Convoluted Foam Absorbers
Convoluted Foam Absorbers are lightweight carbon loaded sheet, which have the geometric shape similar to an "egg crate". The cones produce high levels of reflection loss from 1 to 20 GHz.

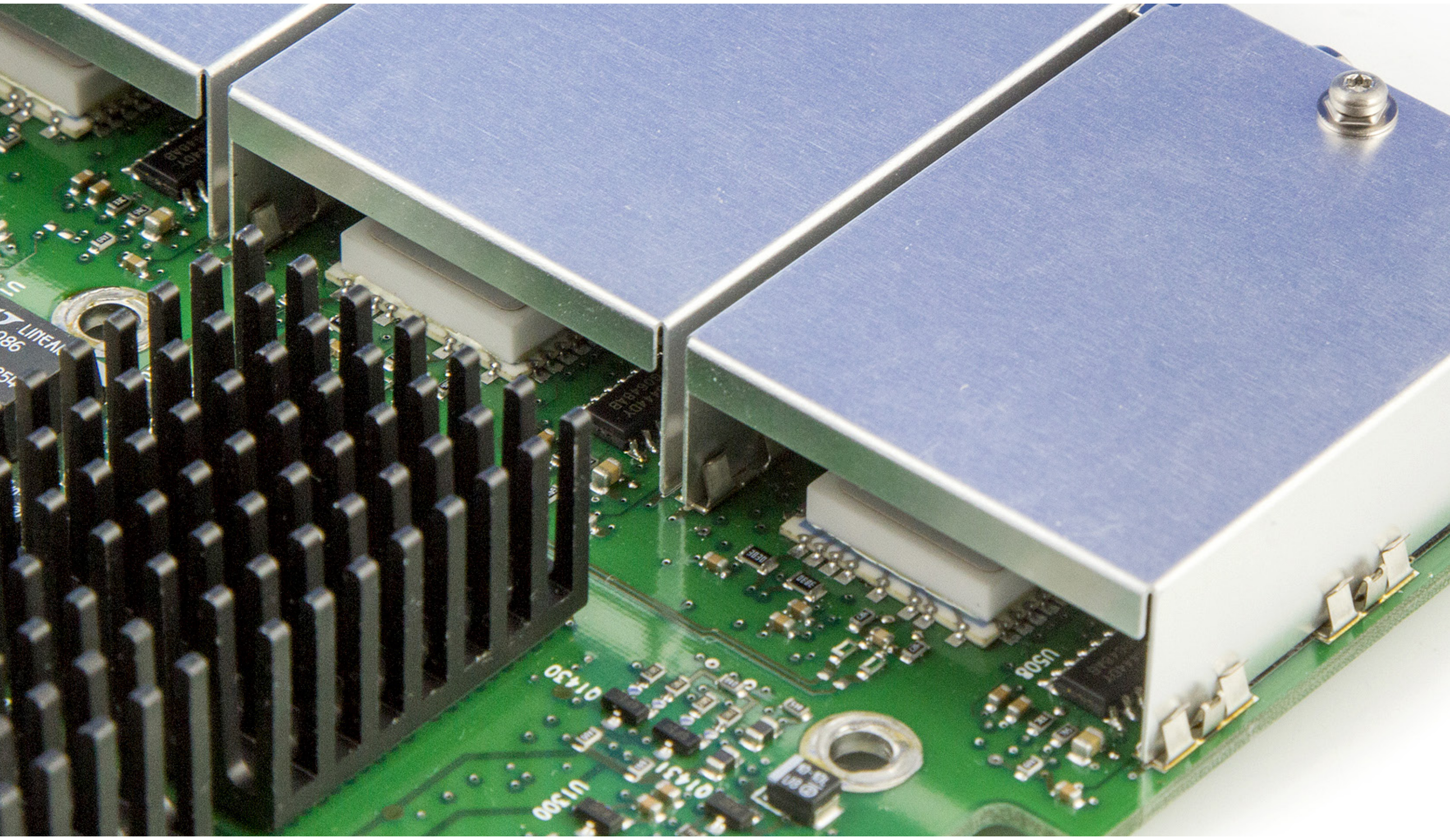
Sprayable and Cast Absorbers:
Absorber Caulks, Inks, & Coatings
Absorber coatings can be manufactured for a variety of application techniques from spray, injection, or dip coating. The materials can be manufactured using one or two part systems in a variety of viscosities.



Please Contact the Author at: a.sundsmo@masttechnologies.com
For More information Surrounding Specific Applications, Please Visit the Applications Pages of Our Website (http://www.masttechnologies.com).

HOW TO SPECIFY BOARD LEVEL SHIELDING

Ken Marino, President
Orbel Engineered Solutions



HOW TO SPECIFY BOARD LEVEL SHIELDING

The Purpose of Board Level Shields
Board level shields (BLS) are generally small metallic shielded boxes mounted directly to PC board ground return layers. There are three primary purposes of board level shields:

- Isolation of sensitive circuitry from other noisy circuits on the board
- Trapping the emissions from noisy circuits on a board from propagating to the outside environment
- Keeping RF sources from the external environment from disrupting sensitive circuitry on the board.

Note that, depending on the wavelengths of the RF sources or noise, the connecting pin spacing for the attachment to ground return layer may need to be fairly close together. A good rule of thumb is no farther apart than 1/20th of a wavelength at the highest expected frequency. For critical applications, some board level shields are soldered with a continuous seam along the attachment point to the PC board.

Selecting a Shielding Manufacturer
The first step in specifying board level shielding is selecting a shielding manufacturer who can design and produce both standard and custom BLS while offering design flexibility for surface-mount and through-hole configurations. Ideally, this manufacturer will offer an array of standard shields that can be customized to any performance or application requirement, meeting today's challenging EMI/RFI shielding applications.

An extensive selection of standard BLS features (pin options, corner options, etc.) and material/design options will make it easy for you to specify board level shields that meet your product requirements. Look for the following:

- Unlimited shield sizes
- Variety of material options
- Multiple fence/cover retention methods
- Variety of pin and surface-mount styles
- Custom trace notches at no extra cost
- Standard ventilation holes
- Part number and logo identification
- Standard pick target for pick and place
- Tape-and-reel and/or tray packaging
- RoHS compliance

**Choosing Your
Features & Performance Specs**
Whether you're in need of one-piece, two-piece, multi-cavity, or custom-configured shielding, your next step is choosing the features and performance specs that will transform your shielding concept into a high-performance reality:

Pin Options
- Alignment Pins
- Through-Hole Pins
- Through-Hole Pins with Standoffs
- Castellation Edges
- Straight Edges with No Pins

Corner Options
- Tight Corners
- Louvered Corners
- Welded Corners

Additional Options
- Trace Notches
- Pick Targets
- Ventilation Holes
- Logo or Part Number Markings

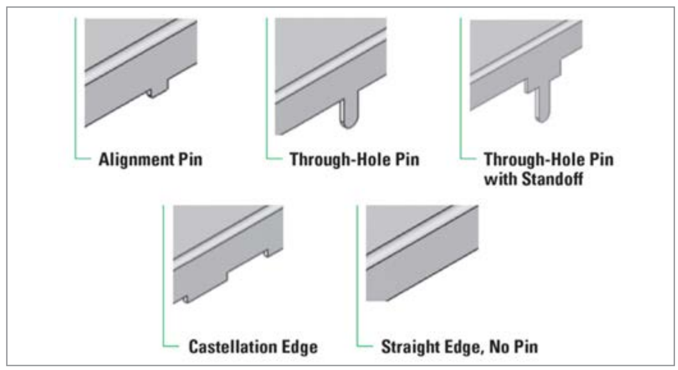


Figure 1 - Typical pin option attachments for board level shields. Figure, courtesy Orbel.

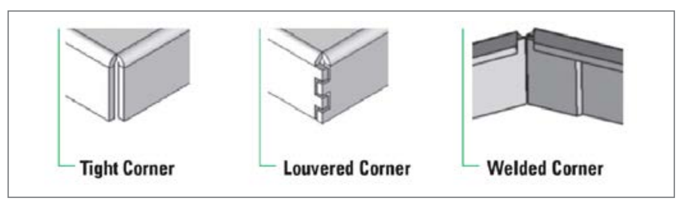


Figure 2 - Typical corner options for board level shields. Figure, courtesy Orbel.

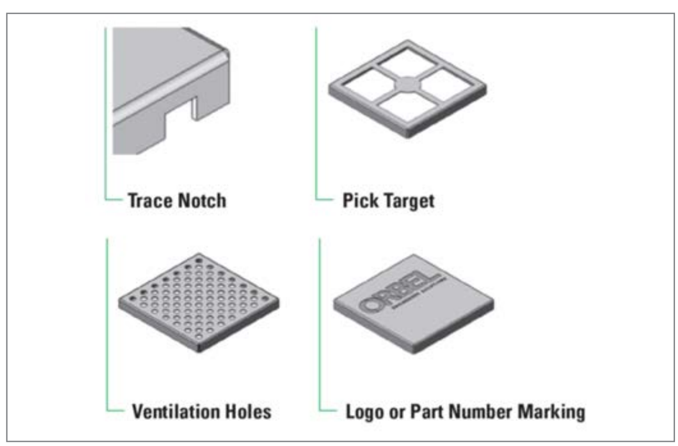


Figure 3 - Typical attachment and style options. Figure, courtesy Orbel.

When choosing performance specs, it is also important to consider your material options (nickel silver, beryllium copper, phosphorus bronze, stainless steel, etc.), co-planarity, material thickness, RoHS compliance, and shielding effectiveness.

Configuring & Ordering Your Shielding

Most BLS manufacturers utilize a part number system that both serves as a product reference guide and identifies the way a shield has been configured. In the case of Orbel Corporation, the part number codes are as follows and are described in the example shown.

For example, let's evaluate a sample Orbel part number, **B-0750 TB 1125-0250 X F-TPS**, piece by piece. Other manufacturers may have a similar part numbering system.

"B" represents the "B" in "Snap-Shield Bullzeye™," a popular board shield style. Other board shield styles include:

G = EZ-Shield **Guardian™**
M = Snap-Shield **Micro™**
L = Snap-Shield **LaZerLock™**
S = Snap-Shield **SmartFORM™**
T = Snap-Shield **TRU-View™**
V = **Vault**-Shield™
H = Snap=Shield **HEMI™**

"0750" represents the shield's frame width.

"TB" represents "Through-Hole (0.500" spacing)," the shield's mounting style. Other standard mounting styles include:

TA = Through-Hole (0.250" spacing)
TC = Through-Hole (1.000" spacing)
SA = Surface-Mount with Alignment Pins
SB = Surface-Mount with Castellations
SC = Surface-Mount with No Pins

"1125" represents the shield's frame length.
"0250" represents the shield's frame height.

"X" represents a material thickness of 0.010", which is a standard size for Orbel. Other standard material thicknesses include:

Y = 0.015"
Z = 0.008"

"F" is the shield code for "Shield Frame." Other standard shield codes include:

C = Shield Cover
A = Assembled
P = Unassembled Pair

"TPS" represents "Tin-Plated Steel." Other standard material options include:

No Code = Nickel Silver (standard)
TPB = Tin-Plated Brass
TPC = Tin-Plated Copper

Other manufacturers will offer similar coding.

Figure 4 - Designed around today's most challenging EMI shielding applications, board level shielding (BLS) from Orbel, and other manufacturers, is available in one-piece, two-piece, multi-cavity, and custom configurations.

Specifying Custom Board Level Shielding

If you are in need of a custom BLS solution, make sure you are working with a shielding manufacturer with proven engineering expertise and the advanced production techniques needed to deliver unlimited design flexibility. If your manufacturer offers custom features for both surface-mount and through-hole shield configurations, they will be able to transform your shield concept into an innovative, cost-effective solution. Look for the following custom capabilities:

- One-piece, two-piece, and multi-cavity
- Unlimited design flexibility
- Any shape or size
- Wide selection of materials
- Variety of plating finishes
- Consultative engineering services

With the right shielding manufacturer on your side, any shielding concept can be turned into a practical BLS solution. Simply convey the features you need to incorporate into your shield design, and your manufacturer can help you create a custom-configured shield that meets your needs.

Please Feel Free to Contact the Author for Any Questions at: kmarino@orbel.com

AN EASY WAY TO CALCULATE A MICROWAVE WAVELENGTH IN INCHES

Mike Oliver, VP Electrical Engineering
MAJR Products Corp.

MICROWAVE WAVELENGTH IN INCHES

A colleague, Mike Stasiowski, and I came up with this quick GHz wavelength formula while designing quad ridge circular polarized jamming antennas for the military when working at Nurad. The textbook formula (wavelength = c/f) where: c = the speed of light 3.00×10^8 m/s, and f = frequency in Hz, was cumbersome at times to calculate, then convert, to inches for practical hardware design purposes; especially since we utilized the formula in the GHz ranges 90% of the time. Therefore, to calculate a microwave wavelength in inches, a useful approximate formula is as follows:

11.8028 / GHz = Wavelength (λ) in inches. For MHz use the decimal equivalent to GHz, for example 250 MHz, use 0.250.

Examples:

Fixed Satellite Service:

Space to Earth = 19.790 GHz; the wavelength in inches is: **11.8028 / 19.790 = 0.596 in.**
Earth to Space = 28.570 GHz; the wavelength in inches is: **11.8028 / 28.570 = 0.413 in.**

Weather Radar:

5.475 GHz; 11.8028 / **5.475 = 2.156 in.**

Microwave Oven:

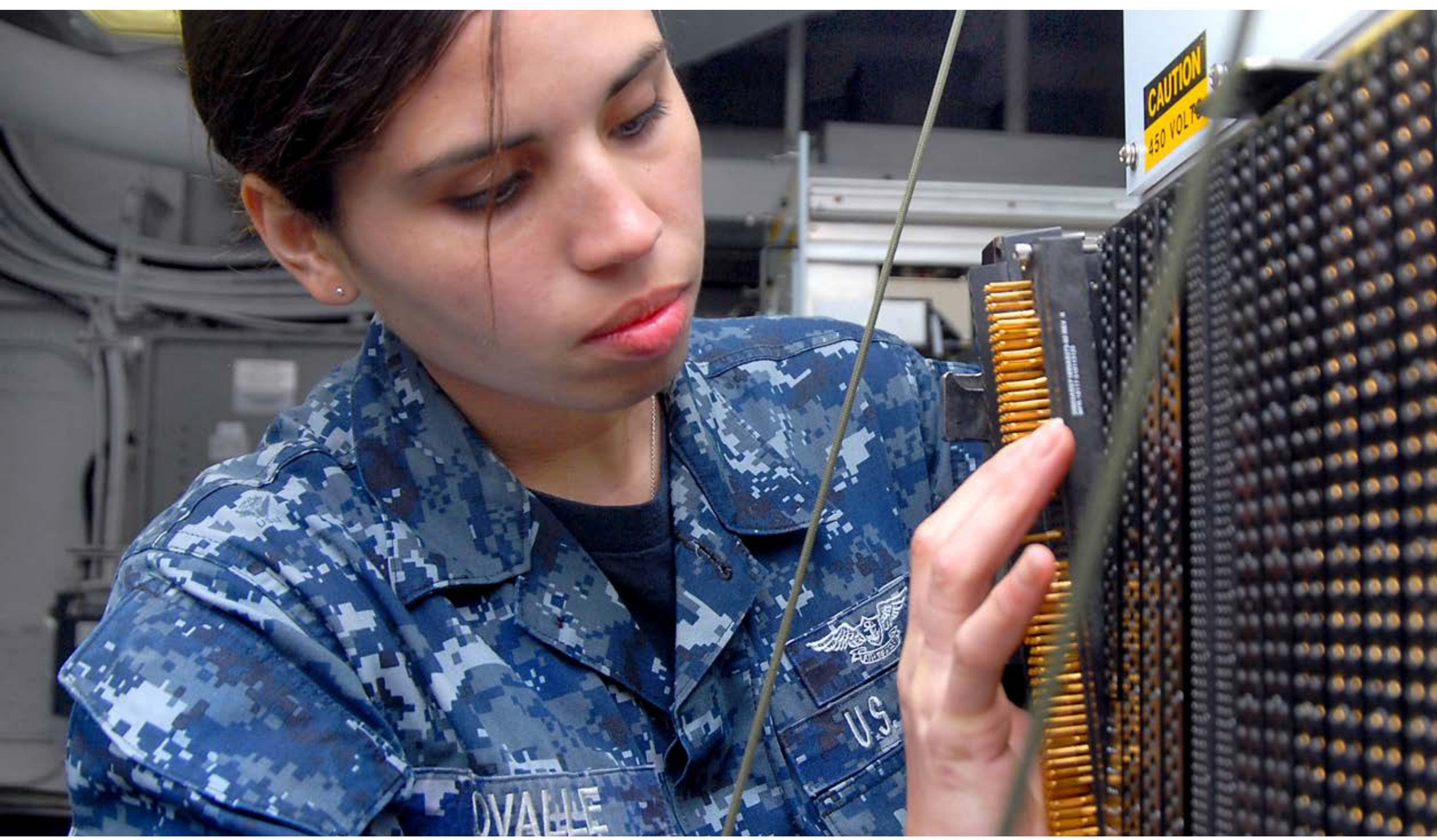
2.450 GHz: **11.8028 / 2.450 = 4.818 in.** (divide by 2 and you have the half wavelength of 2.409 in., multiply by 0.02 and you have 0.048 in. which is the size of an aperture that will attenuate microwave oven emissions by approximately 40dB; the apertures in the window of microwave ovens are approximately 0.048 in. in diameter.)

A favorite – police radar:

10.550 GHz; **11.8028 / 10.550 = 1.119 in.**

GALVANIC CHART

Mike Oliver, VP Electrical Engineering
MAJR Products Corp.



Galvanic Chart

MIL-STD 1250A (Reference)		Gold	Graphite, Rhodium	Silver	Nickel, Monel	Copper, Bronze	Nickel silver	Stainless Steel	Brass	Chromium	Tin	Tin-lead solder	Lead	Iron, Steel	Aluminum	Cadmium	Galvanized steel	Hot-dip-zinc plate	Zinc	Magnesium
	Volt	0.15	0.05	0.00	-0.15	-0.20	-0.20	-0.20	-0.30	-0.45	-0.50	-0.50	-0.55	-0.70	-0.75	-0.80	-1.05	-1.05	-1.10	-1.60
Gold	0.15																			
Graphite, Rhodium	0.05	-0.10																		
Silver	0.00	-0.15	-0.05																	
Nickel, Monel	-0.15	-0.30	-0.20	-0.15																
Copper, Bronze	-0.20	-0.35	-0.25	-0.20	-0.05															
Nickel silver	-0.20	-0.35	-0.25	-0.20	-0.05	0.00														
Stainless Steel	-0.20	-0.35	-0.25	-0.20	-0.05	0.00	0.00													
Brass	-0.30	-0.45	-0.35	-0.30	-0.15	-0.10	-0.10	-0.10												
Chromium	-0.45	-0.60	-0.50	-0.45	-0.30	-0.25	-0.25	-0.25	-0.15											
Tin	-0.50	-0.65	-0.55	-0.50	-0.35	-0.30	-0.30	-0.30	-0.20	-0.05										
Tin-lead solder	-0.50	-0.65	-0.55	-0.50	-0.35	-0.30	-0.30	-0.30	-0.20	-0.05	0.00									
Lead	-0.55	-0.70	-0.60	-0.55	-0.40	-0.35	-0.35	-0.35	-0.25	-0.10	-0.05	-0.05								
Iron, Steel	-0.70	-0.85	-0.75	-0.70	-0.55	-0.50	-0.50	-0.50	-0.40	-0.25	-0.20	-0.20	-0.15							
Aluminum	-0.75	-0.90	-0.80	-0.75	-0.60	-0.55	-0.55	-0.55	-0.45	-0.30	-0.25	-0.25	-0.20	-0.05						
Cadmium	-0.80	-0.95	-0.85	-0.80	-0.65	-0.60	-0.60	-0.60	-0.50	-0.35	-0.30	-0.30	-0.25	-0.10	-0.05					
Galvanized steel	-1.05	-1.20	-1.10	-1.05	-0.90	-0.85	-0.85	-0.85	-0.75	-0.60	-0.55	-0.55	-0.50	-0.35	-0.30	-0.25				
Hot-dip-zinc plate	-1.05	-1.20	-1.10	-1.05	-0.90	-0.85	-0.85	-0.85	-0.75	-0.60	-0.55	-0.55	-0.50	-0.35	-0.30	-0.25	0.00			
Zinc	-1.10	-1.25	-1.15	-1.10	-0.95	-0.90	-0.90	-0.90	-0.80	-0.65	-0.60	-0.60	-0.55	-0.40	-0.35	-0.30	-0.05	-0.05		
Magnesium	-1.60	-1.75	-1.65	-1.60	-1.45	-1.40	-1.40	-1.40	-1.30	-1.15	-1.10	-1.10	-1.05	-0.90	-0.85	-0.80	-0.55	-0.55	-0.50	

Cathotic metals - least suseptable to corrosion (noble to less noble - vertical to horizontal)
Anodic metals - most suseptable to corrosion (less noble to noble - horizontal to vertical)

Green - Metals in harsh or marine environments such as salt spray or salt water. Volt potential difference equal or less than 0.15V
Blue - Metals in normal environments without temperature or humidity control, warehouse storage. Volt potential difference equal or less than 0.45V
Yellow - Metals in controlled environments with temperature and humidity control. Volt potential difference equal or less than 0.95V
Red - Not recommended

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