COMMON MISCONCEPTIONS IN THE USE OF EMI GASKETS

Introduction

With natural and man-made sources of electromagnetic interference (EMI) ever increasing, and with tighter regulation of military and commercial electronic equipment, design engineers face a growing challenge, both in suppressing and containing electromagnetic emissions generated by equipment, and in shielding components and equipment susceptible to such emissions. The challenge is particularly difficult under extreme environmental conditions and where the equipment must maintain its operational integrity while subjected to radiation from a wide electromagnetic spectrum.

The ideal enclosure, of course, for protecting sensitive electronic equipment from electromagnetic interference would be a box containing the equipment and constructed of a perfectly conducting metal with no openings. Such a box, however, would be neither practical nor possible. In order to function, for instance, the equipment would need to have a source of power; it would most certainly need a device to control its operation, and, most probably, an output device to provide the user with necessary information, as well as an access panel. In other words, it is not feasible for the equipment to be self-contained and completely enclosed without openings. Where there must be an opening, there exists a potential EMI path either into or out of the box. Hence the challenge for the designer is to seal such openings in a manner which maintains the electrical continuity of the enclosure.

How can such continuity be maintained? There are a few options available. Of the several methods for electromagnetic sealing of openings (including direct metal-to-metal contact, soldering, and welding), the use or a conductive elastomer gasket provides an effective solution in terms of performance, cost and design flexibility.

Conductive elastomer gaskets are manufactured by filling a silicone or fluorosilicone binder with either silver or silver-plated particles. Widely used in applications requiring EMI and EMP shielding, elastomers provide for environmental sealing as well. In order to successfully protect sensitive electronic equipment from such hostile environments, however, proper material selection and gasket design are essential for the unique requirements of each particular application. Specific electrical and mechanical requirements, such as shielding effectiveness and compression deflection, will determine the configuration, cross section and type of binder and filler to be used.

Certain misconceptions, unfortunately, sometimes exist regarding the performance, reliability, and proper use of conductive elastomer materials. Such misconceptions, if allowed to continue, could lead to the selection of alternative materials and designs less suitable for an EMI application. It is with the intent of correcting these misconceptions that this presentation has been prepared.

Common Misconception #1: A conductive gasket acts as an EMI shield.

Conductive elastomer gaskets used in EMI shielding applications are often thought of as "shields" themselves. However, there is a subtle difference between a shield and a gasket: a shield is a barrier used to isolate one electromagnetic environment from the other, whereas a gasket is used to preserve the continuity of the shield.

How well an enclosure actually shields depends on a number of parameters, including the type and thickness of the material, its relative conductivity, and the frequency incident on the enclosure. Shielding can best be understood by considering what happens when an electromagnetic wave approaches a conducting surface. Consisting of both an electric field and a magnetic field, the wave impinging on the wall of the enclosure creates a current flow at the shield surface, which decays as it passes through the metal shield. The rate of decay is dependent on the conductivity and permeability of the metal wall. Any residual current appearing at the opposite side of the shield generates a radiating field at that point, and thereby provides electromagnetic "leakage" through the enclosure. This can be seen in Figure 1, where i_x is decaying current, and E_{xt} and H_{yt} represent the field generated by the leak.

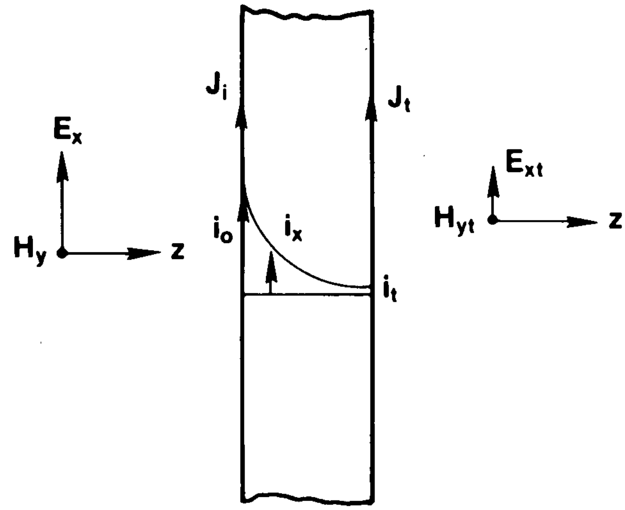

Figure 1
Current Decay Resulting From Impingement Of Electromagnetic Wave On Enclosure

There are two ways to reduce this RF leakage: a) increase the thickness of the shield, or b) use a material with higher conductivity for the shield. In either case, the current will be more thoroughly decayed by the time it has passed through the shield. By proper design and selection of shield material, then, residual current can be effectively reduced to acceptable levels.

In considering the use of conductive gaskets to seal openings in the shield, one may note that the properties that determine a good shield material are similar to those that make a good gasket. There are, however, other factors that must be considered to assure proper selection of an effective gasket. The most important criterion is to maintain a low contact resistance at the gasket/shield interface. For shielding design, the joint represents the greatest challenge, for continuity of current flow across the gasket/shield junction is necessary for an effective shield.

Lines of current flow in an effective gasketed joint are shown in Figure 2. It can be seen that the current lines tend to deflect along the interfaces due to the difference in conductivity between the gasket and shield materials. The example shown assumes that the gasket conductivity is somewhat lower than the shield. The primary reason for the effectiveness of this joint is that the continuity of the current flow is preserved across the gasket/shield junction.

Where such a joint is not achieved, shielding effectiveness is degraded, as depicted in Figure 3. Deflection of the current lines is sufficient to cause current flow on the inside, which, in turn, generates an unwanted radiating electromagnetic field.

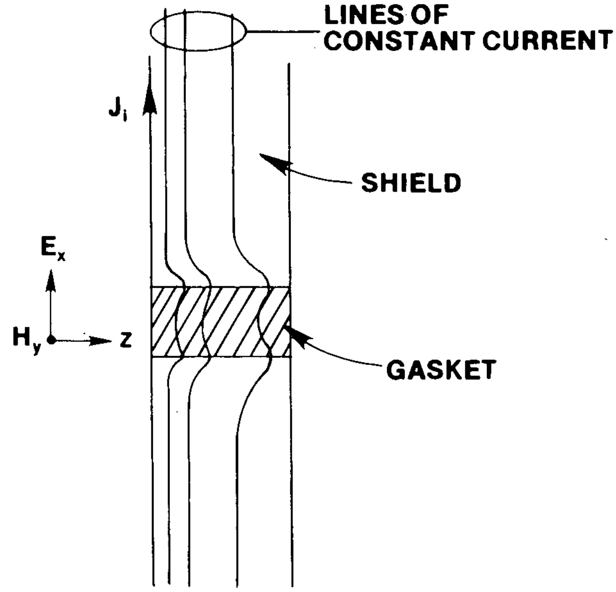

Figure 2
Current Paths Through An Effective Joint

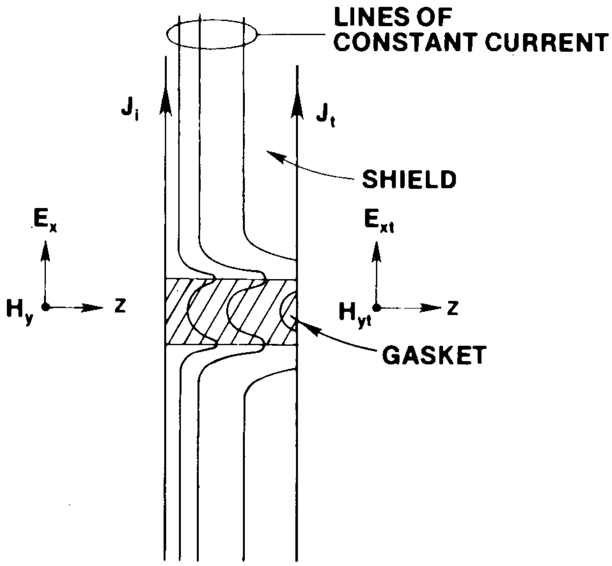

Figure 3
Current Paths Through An Ineffective Joint

When analyzing a leaking junction such as this, assuming the gasket itself is highly conductive, one is typically apt to find that the problem is caused by a) the poor condition of the flange surfaces (i.e., films, oxides), b) insufficient flatness of the flange, or c) gasket materials that will not conform to surface irregularities or abrade through flange surface films. High contact resistance is the primary cause of excessive current deflection that result in EMI problems. In fact, if the resistance at the interface is too high, the current will tend to flow along the boundaries of the junction and not across it.

In the case of a gap (non-contacting surfaces) at the gasket/shield interface, the current flow is entirely along the gap edge and into the interior of the shield, as depicted in Figure 4. Such an open gap may be the source of a serious EMI leakage problem. If any dimension associated with the gap is a quarter-wave multiple of the signal frequency, the gap may behave as a strong radiator.

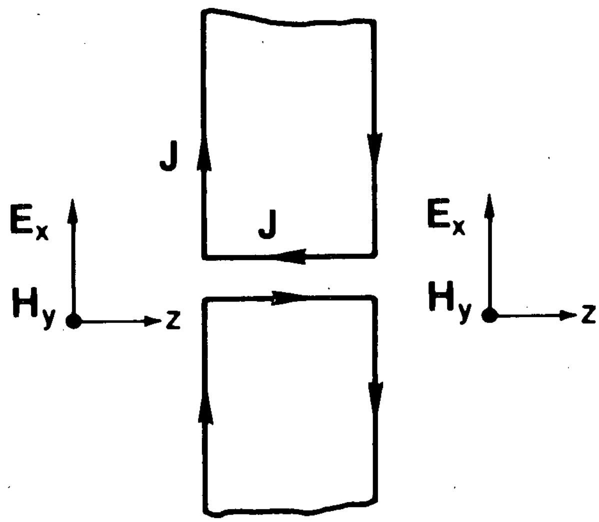

Figure 4
Current Flow In An Open Seam

To summarize, the properties that make a good shield or gasket are essentially the same, but, the primary function of an EMI gasket is to preserve the continuity of the shield.

Common Misconception #2: Testing of a gasket in terms of any single parameter, such as contact resistance, volume resistivity, electrical conductivity, or transfer impedance, will adequately determine EMI gasket effectiveness.

The use of only a single electrical property as a determining factor in the selection of a gasket material for a particular application can be misleading, inconclusive and inaccurate. As important as the electrical properties of a gasket may be individually, a number of these properties, as well as certain mechanical parameters, must be taken into account in designing a gasket for a specific application. In responding to this misconception, only electrical parameters are considered, the mechanical aspects of gasket design being discussed later in the text.

Volume resistivity measurements should be used as a quality control procedure. Through this type of testing, it is possible to determine whether a gasket material of a known formula and established properties has been properly manufactured. Transfer impedance is also measured to predict the shielding effectiveness of a gasket material. Such testing, however, can only provide an approximation, since transfer impedance measurements are dependent on a number of variables other than the material itself.

As mentioned, then, no one particular type of electrical test alone will provide a clear and concise evaluation of a gasket. In fact, considerations other than the electrical properties of the gasket alone must be taken into account in determining the parameters of the entire joint. For instance, in evaluating the total contact resistance of the joint, such factors must be considered as the surface preparation of the flanges, and whether or not there are any surface films (oxides, coatings, or adhesives, etc.) present, all of which would serve to increase the total contact resistance.

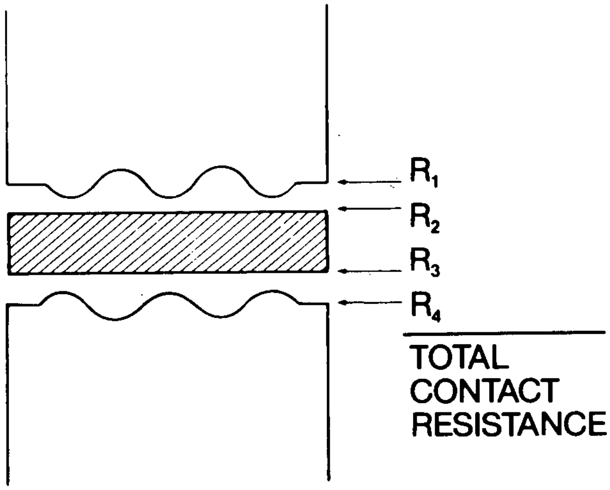

Figure 5
Surface Areas That Contribute To Contact Resistance

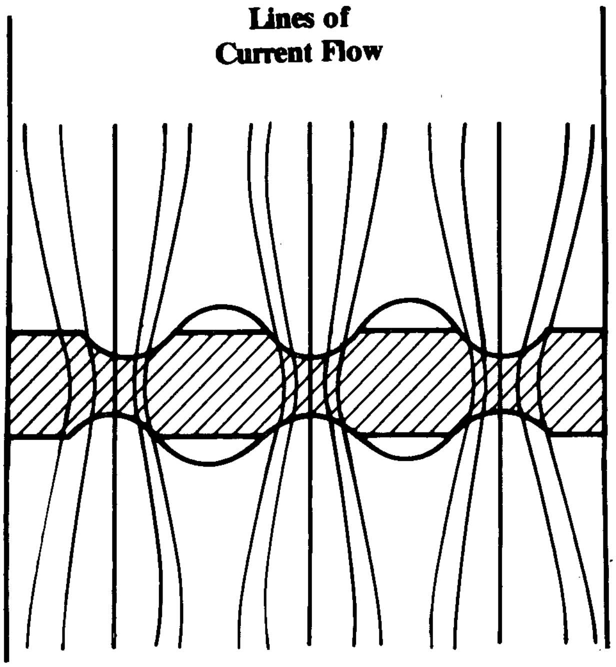

Figure 6
Current Flow Across A Poorly Mated Junction

Also important is total junction resistivity, which is a measure of the ability of the gasket and flange to form continuous electrical contact across the joint. Gaps, such as those shown in Figure 6, disturb the current flow across the junction, forcing the current flow to avoid the areas of high resistance and form as shown in the figure, with the possible consequence of a leak in the enclosure. It is essential, therefore, to prevent such gaps (and thereby minimize junction resistivity) by adequate stiffness and proper surface preparation of the flanges, and by selection of a gasket material and cross section such that the gasket fills the surface irregularities and forms with the flanges a continuous electrical bond as shown in Figure 7. In so doing, current flow across the junction is relatively uniform, with shielding effectiveness being maximized for that particular design. In addition, gaps at the gasket/flange interface can provide a path for direct electromagnetic leakage, and a gasket that can conform and provide this continuous contact will eliminate any "electronic holes" or discontinuities in the shield. Thus, the barrier resistance, or the ability of the gasket to act as a shield, at high frequencies is extremely important.

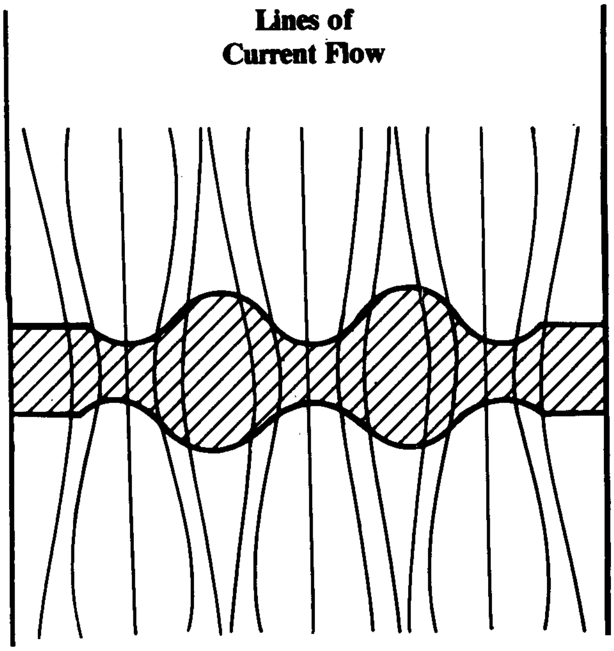

Figure 7
Current Flow Across An Adequately Mated Junction

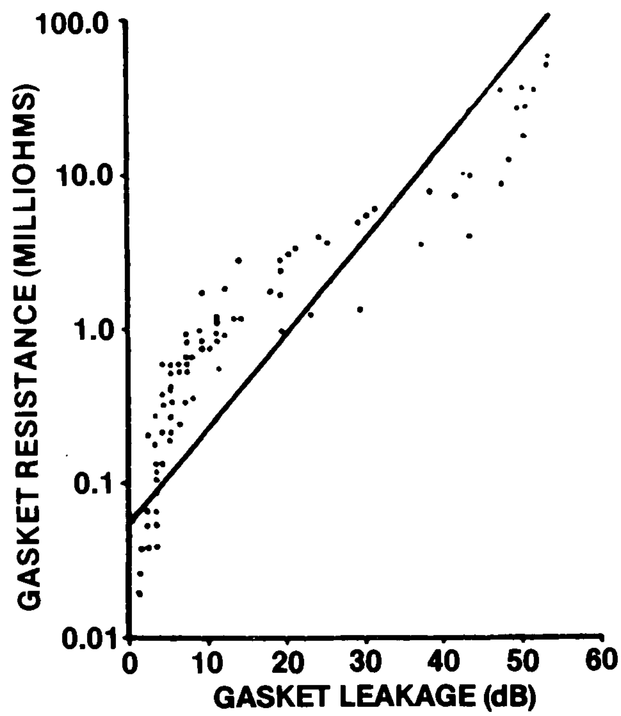

Figure 8
Gasket Leakage Versus Resistance

A note on conductivity is relevant at this point. It is generally believed that the more conductive a gasket is, the higher its shielding effectiveness. No conclusive data, however, has been offered as yet to support this view. In fact, data developed and published by Charles Kuist, Senior Vice President-Research and Engineering for Chomerics, suggests that such a hypothesis may not be true.[1] Mr. Kuist finds that once a certain band of threshold conductivity is reached, below that level any change in shielding effectiveness as a result of increased conductivity is negligible. As can be seen in Figure 8, where the gasket resistance across the joint is less than 0.1 milliohms, shielding effectiveness does not vary significantly with increasing conductivity.

In addressing the misconception being discussed, it is important to again stress that a number of electrical parameters must be taken into account. The significance of any one type of test might play may well depend on the frequency of the electromagnetic wave impinging on the enclosure. This is demonstrated in Figure 9, which indicates the general relationship between frequency and the key electrical parameters that contribute most to any determination of shielding effectiveness.

THE ELECTROMAGNETIC ENVIRONMENT

LOWER FREQUENCIES	HIGHER FREQUENCIES
Total Joint Contact Resistance	Barrier Resistance of the Joint
Bulk Conductivity	

Figure 9
Electrical Parameters Essential To Maximum Shielding Effectiveness

In any case, no evaluation of gasket performance can be accurate and complete without considering these parameters, as well as the mechanical constraints (size and configuration of the gasket, and enclosure, compression deflection, etc.) which are critical to the design.

Common Misconception #3: Metal-filled elastomers have too high a durometer and require a high compression force. Cold flow of the gasket can result.

Common Misconception #4: Silver-filled elastomers have poor contact resistance and require rigid flanges under high pressure.

These two misconceptions can be addressed at the same time, since they are somewhat related. The hardness of an elastomer gasket is commonly determined by means of durometer, a standard test that measures the resistance to the penetration of an indentor point into the surface of the rubber. The lower the penetration resistance, the "softer" the material. The hardness of elastomer gaskets depends on the silicone (or flurosilicone) binder and the amount of silver or silver-plated particles in the binder. The denser the loading, the harder the material. Typically, durometer values range from 45 to 85 Shore A for some conductive elastomers, compared with 30 to 90 Shore A for unfilled silicone rubber.

As can be seen from a comparison of these values, selecting a conductive elastomer with a durometer value similar to that of unfilled rubber would not seem to be a problem. In fact, poor interface conductivity can usually be attributed to mechanical factors resulting in the presence of gaps at the gasket/shield interface. The effect of such gaps has already been shown in Figure 6. Gaps may be due to improperly spaced or torqued fasteners; the presence of surface films, necessitating excessively high flange pressures (thereby resulting in buckling of the flanges, displacement of the gasket material, etc.); or gasket materials that do not conform and fill the flange irregularities.

When selecting a gasketing material and designing a gasket for a particular requirement, the durometer of the material itself is actually only one of several interrelated considerations. While the mechanical properties resulting from the inclusion of metal filler into the elastomer, for instance, have a marked effect on the deflection of the gasket under compression loads, deflection depends even more on the cross section of the gasket. This is demonstrated in Figure 10, with the flat gasket providing the least amount of deflection, and the hollow extrusions the most deflection for a given material. (With a hollow extrusion, deflection becomes a function not only of the particular cross section, but also the thickness of the extrusion wall.) A wide range of design latitude is thus available.

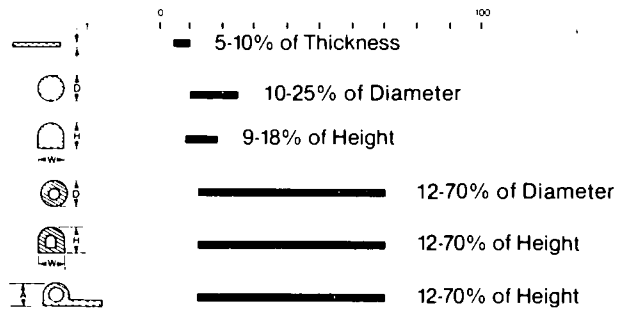

Figure 10
Deflection Capabilities Of Various Gasket Configurations

In addition to the cross section of the gasket, the microstructure of the material also has a bearing on its "softness" or "hardness". Two basic structures exist, homogeneous and reticulate, as shown in Figure 11. The homogeneous material is created by the mass loading of silver or silver-plated particles (somewhat like bunches of grapes) into a silicone or fluorosilicone binder; while the reticulate structure is analogous to a stone and mortar wall, where the "stones" are relatively large chunks of non-conductive silicone, and the "mortar" is a composite of silver and silicone. The reticulate structure is typically the "softer" of the two.[2]

The wide range of material and configuration possibilities available to the engineer in designing a gasket for a specific requirement is apparent from the deflection curves shown in Figures 12 and 13. Figure 12 compares various cross sections for a reticulate material. It can be seen that should the design engineer choose to apply a pressure of 5 lbs per linear inch to a flange, a 23% deflection would be obtained with an "O" strip, 16% with a "D" strip, and 39% with a hollow "O". In Figure 13, various cross sections of a homogeneous structure material are compared. For the same 5 lbs per linear inch pressure on the flange, a 16% deflection would be obtained with an "O" strip, 9% with a "D" strip, and 33% for a hollow "O". As one can see, then, the engineer is provided with more latitude in the design by using cross section rather than durometer.

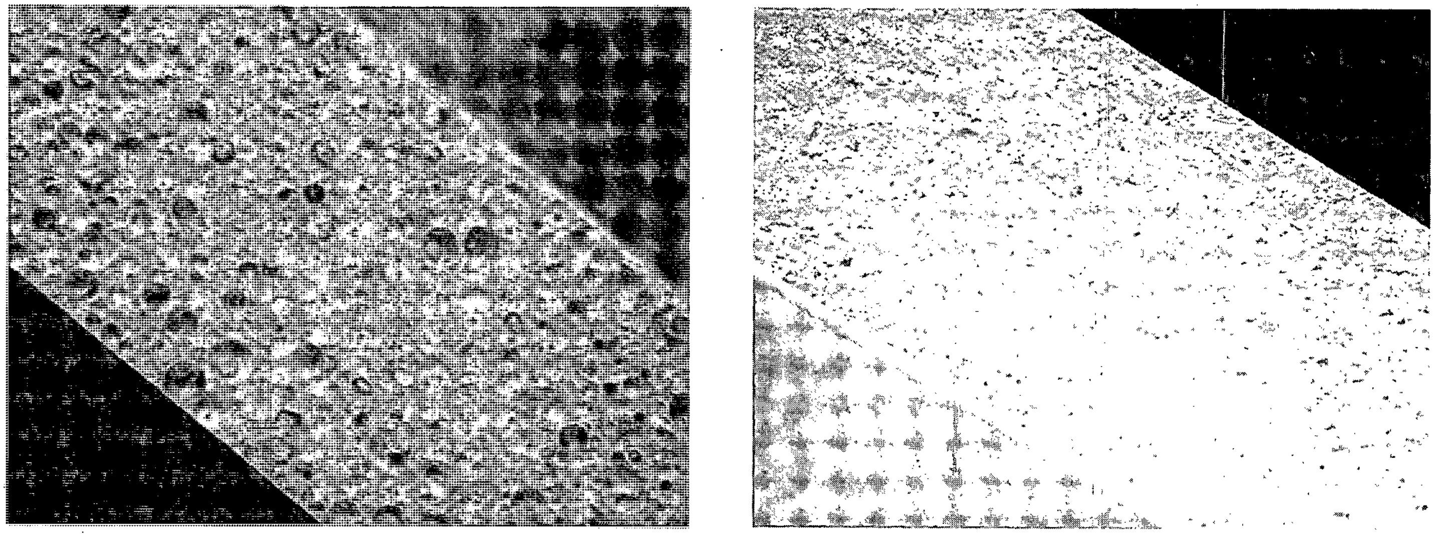

Figure 11
Comparison Of Homogeneous (left) And Reticulate Structures (right)

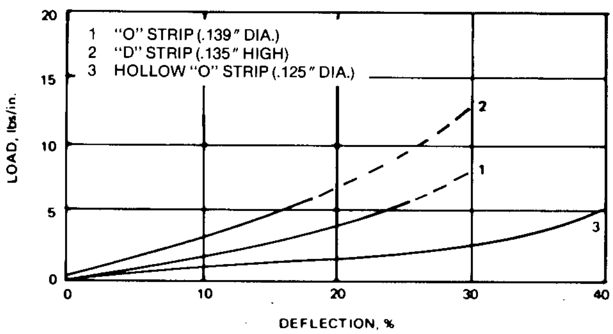

Figure 12
Compression Deflection Characteristics For Reticulate Material

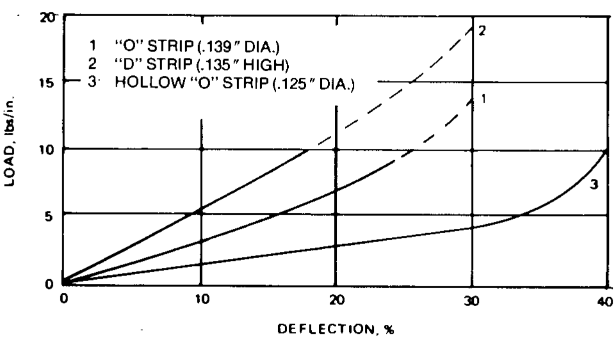

Figure 13
Compression Deflection Characteristics For Homogeneous Material

Having demonstrated the mechanical design flexibility available in terms of "softness" and deflection, it is appropriate to consider shielding effectiveness as a function of applied pressure. Figure 14 indicates the plane wave shielding effectiveness of a solid "D" gasket under various closure forces and over a frequency range of 1-40 GHz. As can be seen, 70dB or more is attained with a closure force of only 2 lbs per inch, increasing to greater than 105 dB with a closure force of 12 lbs per inch or more.

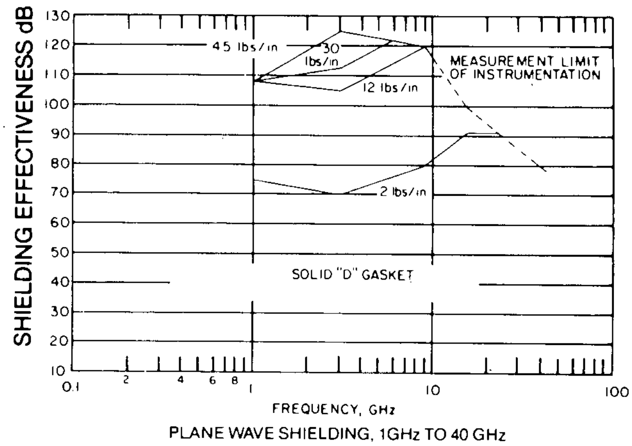

Figure 14
Closure Force Versus Shielding Effectiveness For A Solid "D" Gasket

In addressing the misconception which includes the comment regarding "cold flow", it is necessary to first discuss the phenomena of *stress relaxation.* When a cross-linked elastomer gasket, is placed under a constant load, it undergoes stress relaxation, as shown in Figure 15. After a period of time, the pressure across the flange reduces to approximately 75% of the initial stress. It is important to note, however, that the stress then stabilizes, and this can be easily predicted and accounted for in the design. During stress relaxation, while the pressure through the gasket is reduced, the material does not "flow" in any way.

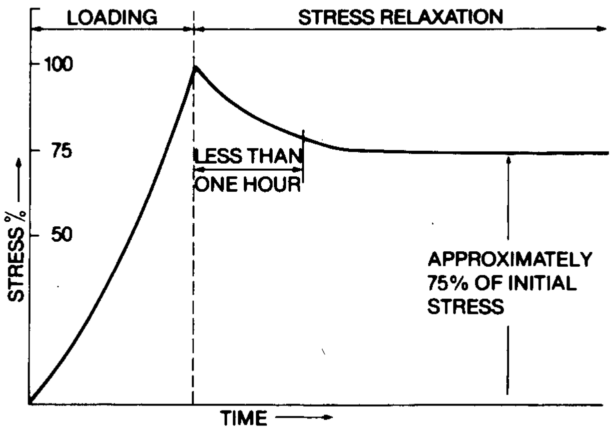

Figure 15
Stress Relaxation Of A Gasket Under A Load

Compression set in a thermoset elastomer gasket filled with metal particles is not a significant problem, providing the load conditions are within the design limit of the gasket materials. Typically, gasket height loss is less than 3-5%. Concern for Compression set undoubtedly is the result of prior experience with wire fillers or knitted wire mesh products, which tend to lose their "memory" once they are deflected.

In summary, conductive elastomers provide the necessary flexibility to meet the design requirements for a variety of flange designs and closure forces, while providing excellent mechanical and electrical integrity.

It should be noted at this point that for a particular EMI gasketing requirement, all electrical and mechanical design considerations must be carefully reviewed to determine the effect these various parameters will have on each other. To ensure an optimum joint design, each of the following factors must be taken into account:

Flanges:
- Type of materials
- Width and configuration
- Stiffness or deflection characteristics
- Tolerances
- Surface preparation

Gaskets:
- Type of material and cross section
- Conformability or deflection characteristics
- Compression limits
- Mechanical requirements
- Environmental factors
- Bulk conductivity or shielding effectiveness

Fasteners:
- Type of material
- Closure force required
- Size and spacing

In addition, radiated emission and susceptibility tests of a prototype enclosure (or fixture closely resembling the enclosure) early in the design phase will minimize the need for design "fixes" during the subsequent design stages.

Common Misconception #5: Silver-filled elastomers are all alike. With the variety of silver and silver-plated or coated fillers used in conductive elastomers and the wide choice in cost, there is a tendency toward substitution of low cost fillers which "essentially" meet the same shielding requirements. For an engineer involved in the design of military/aerospace or other high reliability equipment, such an approach could cause severe problems during the lifetime of the equipment. As depicted in Figure 16, the effectiveness of a gasket very much depends on the total environment in which it must perform.

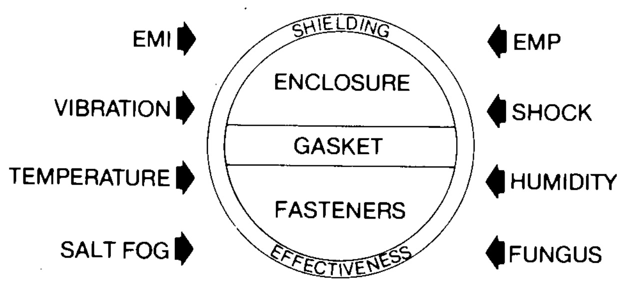

Figure 16
Environmental Factors Requiring Design Consideration

On the surface, the different types of silver-filled elastomers may appear somewhat the same. For instance, as shown in Figure 17, the shielding effectiveness of the three basic filler types appears to be similar. These figures are representative of the various fillers as tested per MIL-STD 285. An examination of the specifications for the physical properties of these materials would also seem to substantiate the similiarity (even though material selection based on these parameters could be misleading).

FILLERS	MAGNETIC (10kHz)	ELECTRIC (1MHz)	PLANE (10GHz)
Pure silver	68-70	>140	100-120
Silver plated copper	70-80	>140	110-120
Silver plated glass	70-78	>140	84-110

Figure 17
Shielding Effectiveness (dB) For Gaskets With Various Silver Fillers

During typical qualification testing of a product, many of the environmental tests indicated in Figure 16 are conducted independently of one another. However, such an approach to testing often overlooks the insidious effects one environmental factor may have on another, with a problem or malfunction surfacing when the product is in the field, often with disastrous results.

One of the most critical environments occurs when the gasket must perform under vibration. Under such conditions, a defective gasket might appear as a malfunction in a microprocessor, avionics equipment, or any electronic equipment during operation, with the problem no longer being apparent once the vibration stops.

The differences in shielding effectiveness between silver-plated copper and silver-coated glass under vibration have been reported.[3] Figure 18, indicates the high levels of electromagnetic leakage that will occur with a silver-coated glass filler. Significant to note is the fact that even at a relatively low level of 2 g's, up to 25-30 dB difference in leakage is possible.

By taking a close look at the microstructure of the materials the causes of this phenomena become clear. Silver-plated copper particles are somewhat irregular in shape, providing many points of electrical contact and a strong bond within the silicone. Silver-coated glass particles, however, are non-conductive glass beads with a thin silver coating through which current flow takes place. The beads are spherical in shape, thereby limiting the direct points of contact and, hence, paths of electrical continuity through the gasket. Under conditions of vibration, the glass spheres tend to separate, the paths of conductivity break down, and the resistance of the gasket material increases.

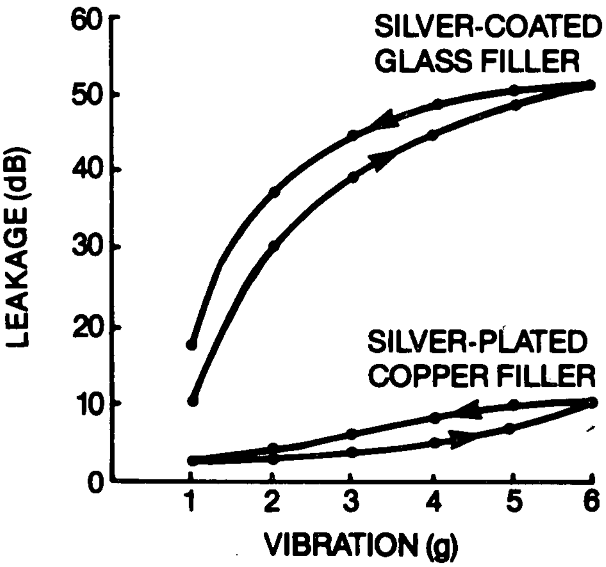

Figure 18
Shielding Effectiveness Of Silver-Plated Copper Versus Silver-Coated Glass Under Vibration

Another environmental factor that has an effect on shielded enclosures is that of a high current, short pulse phenomena such as lightning, or electromagnetic pulse (EMP). Figure 19 indicates the effect of a simulated electromagnetic pulse on conductive elastomer gaskets with various fillers, the testing being performed and reported on by Spire Corporation.[4] In addition to operating in a lightning environment, and with the ever-increasing requirement for military avionics and electronics equipment to be resistant to EMP, gasket performance in such an environment is an important design parameter. Figure 19 shows that silver-plated glass is particularly susceptible to EMP; pure silver performs somewhat better; and silver-plated copper is essentially unaffected.

In summary, the performance of silver-filled elastomers, as well as other conductive elastomers, can vary significantly, depending on the type of filler, its shape, its concentration, and the type of elastomer binder used. The selection of a specific filler should be based on the total requirement, including all aspects of the environment in which the gasket is intended to function.

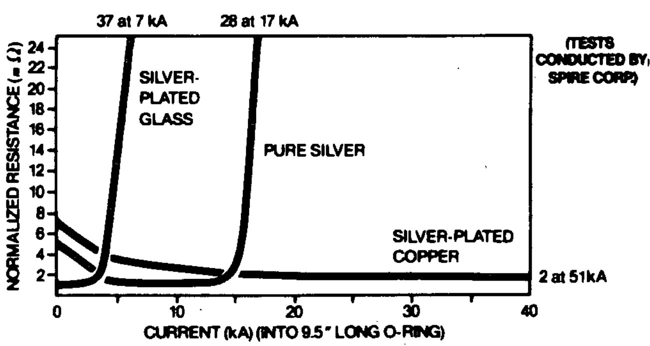

Figure 19
Effect Of Electromagnetic Pulse On Conductive Elastomer Gaskets

Common Misconception #6: Metal-filled elastomers exhibit poor tensile strength and abrasion resistance.

Tensile strength and abrasion resistance need not be important parameters in judging the suitability of a gasket for an EMI application. There are two reasons for making this statement: 1) in most cases, the gasket is required to function in a fixed joint, where neither parameter is a factor; and 2) in movable joint, proper design can preclude the need for a gasket with high tensile strength and/or abrasion resistance. The latter claim is demonstrated in Figure 20, where "good" design techniques, such as proper positioning and selection of cross section, as well as stand-off hinges, provide a more durable and effective EMI shield. In such an application, conductive elastomer gaskets are decidedly superior because of their resiliency; whereas mesh gaskets, in comparison, will take a moderate set.

With proper design considerations, then, mechanical wear and tear of conductive gaskets can be virtually eliminated.

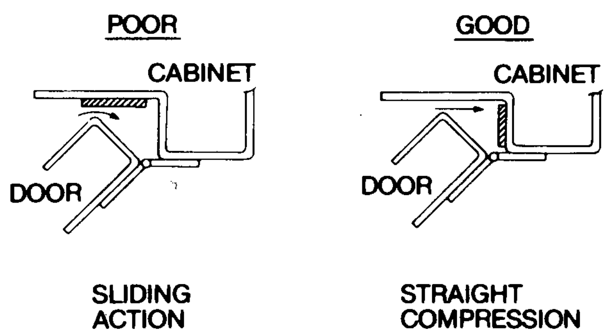

Figure 20
Gasketing Design In A Movable Joint

Common Misconception #7: Conductive Elastomers Outgas.

Shown in Table 1 is an excerpt from a NASA-Goddard Technical Note[5] on outgassing characteristics, which indicates that some elastomer materials outgas very little. All elastomers will typically outgas to some extent. Some gasket materials, as normally provided, will have a weight loss of about 1%, with about 0.5% present as condensible volatiles. The reason these values are low is that some silicone elastomers are chemically reacted through the use of a catalyst. *No plasticizers are used,* which means that no residues remain in the elastomer.

MATERIAL	TOTAL WEIGHT LOSS (%)	VOLATILE CONDENSIBLE MATERIALS (%)
1212	0.082	0.020
1214	0.048	0.023
1215	0.062	0.026
1217	0.037	0.006
1220	0.051	0.028
1221	0.050	0.005
1224	0.046	0.022
1250	0.710	0.160
1401	0.058	0.026
1405	1.037	0.270

Table 1
Outgassing Characteristics

Of course, these outgassing levels may not be good enough for some applications. Where this is the case, special post curing techniques can be employed, the result being the irreversible removal of outgassed materials. Conductive elastomers have been used successfully on space programs such as Mercury, Gemini, Apollo, LEM, Mariner, and others.

Common Misconception #8: Silver-filled elastomers lose shielding effectiveness with time.

Aging is an oxidation process occurring over a period of time that results in a degradation of electrical and mechanical properties. There are two ways a silver-filled elastomer can possibly age: 1) by oxidation of the conductive metal filler, and 2) by aging of the elastomer binder itself.

Oxidation of the filler can occur only if the air permeates the gasket, which is highly unlikely if the permeability of materials is 1¼ cc per hour (helium leak test with 1 atmosphere differential) as compared with that of the best rubber compounds of 1 cc per hour. In addition, while the oxides of most metals are hard and nonconductive, silver oxides (if oxidation does occur) are soft and electrically conductive.

As far as the binder is concerned, the silicone, or fluorosilicone rubber used in gaskets should be highly resistant to deterioration as a function of age. These elastomers are stable to the degree that they are exempt from the aging limits specified for elastomers in MIL-HANDBOOK 695.

High temperature aging data on gasket materials is shown in Figure 21. It can be seen that under test, the volume resistivities of some elastomers, both with pure silver and with silver-plated copper fillers, level out below the threshold conductivity limit for a continuous-use temperature of + 125°C. (These materials were exposed to a worse case—oxygen atmosphere in an unflanged condition; in a flanged condition increases in volume resistivity would be significantly less.) It should be noted that similar tests of other fillers not using other fillers not using silver plating or coatings show unsatisfactory volume resistivity increases (many with a growth that is exponential) within the first 3 to 10 days. In fact, over the past 19 years, engineers have evaluated virtually every feasible filler material and found that only pure silver or silver-plated particles have the long term stability that has been successfully used in high reliability military/aerospace programs during this time.

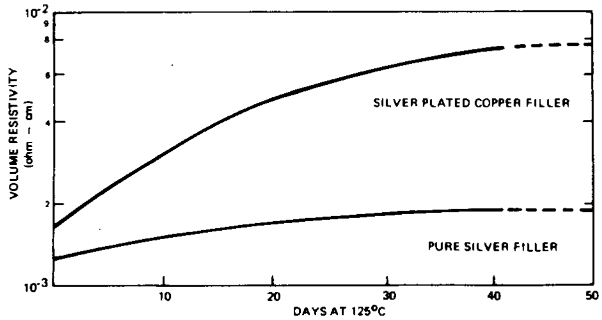

Figure 21
Accelerated Aging Tests Of Some Elastomer Gaskets

Common Misconception #9: Silver-filled elastomers cause galvanic corrosion in gasketed joints.

Corrosion is of concern in any gasketed joint where dissimilar metals exist. This is true whether the gasket has a silver filler or is made of wire mesh. Although of "concern", corrosion need not be a problem. In order for galvanic corrosion to occur, two dissimilar metals must be in electrical contact with one another in the presence of an electrolyte. Eliminate any one of these conditions, and galvanic corrosion will not occur.

It should be noted that some corrosion control guidelines make no distinction between the galvanic potential of pure silver and that of a silver-filled elastomer. The distinction, however, is important. For example, the volume resistivity of pure silver is 10^{-6} ohm-cm, while the values for silver-filled elastomers range from 10^{-3} to 10^{-2} ohm-cm. The current carrying capacity of silver-filled elastomers is thus at least 1,000 times less than that of pure silver. Since galvanic corrosion is directly related to the total amount of current that flows across the junction, the tendency of silver-filled elastomers to support galvanic corrosion is markedly less and they are compatible with materials not normally considered to be compatible with silver.

A silver-filled elastomer will provide a highly conductive joint with the filler particles abrading through the surface films, and will not corrode since the silicone rubber adheres on a molecular basis to most surfaces, thus excluding any foreign environment from the

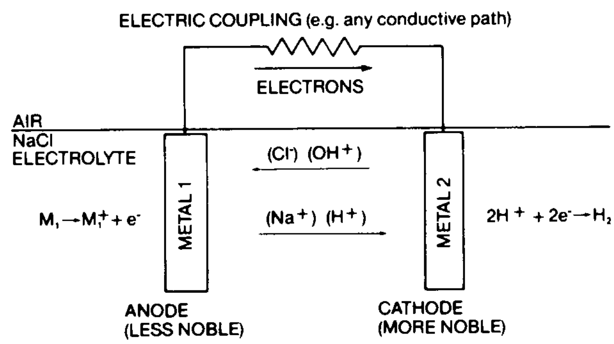

Figure 22
Typical Galvanic Coupling

Group	Material Groupings*
1	Gold – Platinum – Gold/Platinum Alloys – Rhodium – Graphite – Paladium – Silver – Silver Alloys – Titanium – **Silver Filled Elastomers — Silver Filled Coatings**
2	Rhodium – Graphite – Palladium – Silver – Silver Alloys – Titanium – Nickel – Monel – Cobalt – Nickel and Cobalt Alloys – Nickel Copper Alloys – AISI 300 Series Steels – A286 Steel – **Silver Filled Elastomers — Silver Filled Coatings**
3	Titanium – Nickel – Monel – Cobalt – Nickel and Cobalt Alloys – Nickel Copper Alloys – Copper – Bronze – Brass – Copper Alloys – Silver Solder – Commercial Yellow Brass and Bronze – Leaded Brass and Bronze – Naval Brass – Steels AISI 300 Series, 451, 440, AM 355 and PH hardened – Chromium Plate – Tungsten – Molybdenum – **Silver Filled Elastomers**
4	Leaded Brass and Bronze – Naval Brass – Steels AISI 431, 440, 410, 416, 420, AM 355, PH hardened – Chromium Plate – Tungsten – Molybdenum – Tin-Indium – Tin Lead Solder – Lead – Lead Tin Solder – Aluminum 2000 and 7000 Series – Alloy and Carbon Steel – **Silver and Silver Plated Copper Filled Elastomers**
5	Chromium Plate – Tungsten – Molybdenum – Steel AISI 410, 416, 420, Alloy and Carbon – Tin – Indium – Tin Lead Solder – Lead – Lead Tin Solder – Aluminum – All Aluminum Alloys – Cadmium – Zinc – Galvanized Steel – Beryllium – Zinc Base Castings
6	Magnesium – Tin

*Each of these groups overlaps, making it possible to safely use materials from adjacent groups.

Table 2
Metals Compatibility

conductive interfaces. For these reasons Table 2 was prepared with data from the "Corrosion Control in EMI Design" paper published by Earl Groshart of Boeing, presented at the 1977 IEEE EMC Symposium, and with the guidance of members of the Society of Automotive Engineers AE-4 Committee. As mentioned previously, silver-filled elastomers are compatible with, and have been successfully used, with a wide variety of structural metals.

Figure 22 illustrates a typical galvanic coupling. As can be seen in the figure, the electrons, in the presence of an electrolyte, flow from the less noble metal (anode) to the more noble metal (cathode). In terms of the gasketed joint, the silver-filled elastomer would act as the cathode, while an aluminum flange for instance would act as the anode. In order to prevent such action, two possibilities are obvious; one is to remove the marine environment, and the other is to use the same metal for both the flanges and the gasket, however, neither is realistic nor practical in most cases. A more realistic approach, however, is to eliminate the conductive path between the metals exposed to the environment so that the galvanic cell no longer exists. Figure 23 shows some of the commonly used painting techniques used to encapsulate one exposed dissimilar metal from the other. A Class III chromate conversion coat is normally applied first if the metal is aluminum, as it provides a low resistance path across the flanges, and inhibits oxidation.

Following chromate conversion coatings, organic finishes such as epoxy primers and paints are used as shown. Where a panel frequently opened in a marine environment, a conductive coating such as a silver epoxy paint may be applied to the flange surfaces to provide additional protection. Thus, in both cases the marine environment sees only the conductive gasket interfacing with a non-conductive paint. These encapsulating techniques are not only used with silver-filled elastomers, but other dissimilar conductive gaskets as well.

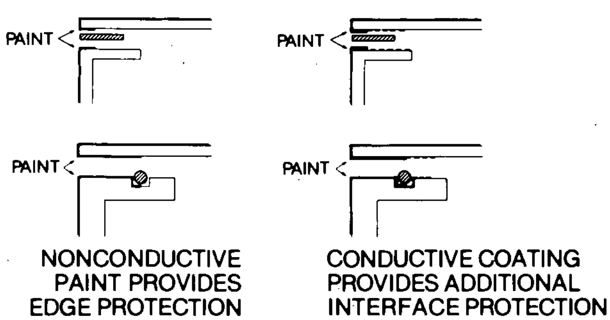

Figure 23
Typical Surface Areas Of An Enclosure Which Are Painted To Prevent Corrosion

1. "EMR Shielding of Conductive Gaskets Under Vibration", IEEE EMC Symposium, 1976. Copies available on request from Chomerics.

2. A chemical alternative to the reticulate structure as a means of "softening" elastomer gasket materials is the use of additional plasticizers. This chemical approach to offset an inherent material deficiency has its problems, with the plasticizer even leaking out of the binder under certain conditions of heat and pressure.

3. "EMR Shielding of Conductive Gaskets Under Vibration", IEEE EMC Symposium, 1976.

4. Prepared by W.R. Neal, F.C. DeCicco, Spire Corporation, Bedford, *Mass.*

5. NASA Technical Note D-7362, W.A. Campbell, R.S. Marriot, J.J. Park, NASA Goddard, Sept. 1973.

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