EMI gasket design theory and practice is a specific application of the principles and procedures that apply to the design of any gasketed joint. Therefore, a very generalized gasket design theory is presented first as the basis for the specific EMI gasket design procedures. The EMI gasket design theory and procedures follow and are presented as a specific application of general gasket design.

GASKET DESIGN–WHAT GASKETS DO

All gaskets whether they seal EMI, high pressure fluid, make a container dunk proof or simply keep forced ventilating air from escaping at a door-to-cabinet joint, do so by conforming to the unavoidable irregularities of the mating surfaces of a joint. Some examples are:

–The joint between a garden hose and water faucet.
–Housing for an emergency radio to be dropped into the sea.
–Joint between the cover and enclosure for a radar pulse modulator.

In each example the joint has two relatively rigid mating surfaces, and neither surface will be perfectly flat. When they are mated without a gasket, even very high closing forces will not cause the two surfaces to comply completely with each other, and the resultant gaps will allow leaks. A gasket resilient enough to comply to both surfaces under reasonable force will eliminate these leaks. The garden hose example makes this point very well; just try to prevent a leak by force alone without a gasket, but with a gasket in the hose fitting compressing against the faucet, even hand torque results in a watertight joint. To try to get the same watertightness by accurate machining of both surfaces would be prohibitively expensive. In most cases, the least expensive way to obtain a tight joint (watertight, oil-tight, or EMI tight) is to make the mating surfaces to normal tolerances on flatness, rigidity, and tolerance build-up and add a gasket to compensate for the resulting misfits between the two surfaces.

GASKET DESIGN THEORY

The degree of misfit needs to be defined so that design procedures can be clearly outlined. This misfit is commonly called "joint unevenness" and is designated as H and is defined in Figure 1. It is the maximum separation between the two surfaces when they are just touching. If the surfaces are not rigid, then the joint unevenness would also include any additional separation between the two surfaces due to the distortion of the joint when pressure is applied.

Figure 2 shows the same joint with a gasket installed. The dashed lines indicate the height of the gasket, H_g, before it was compressed. The minimum compressed gasket height, H_{min}, occurs at the point where the surfaces would touch without a gasket. Maximum compressed gasket height, H_{max}, is at the point of maximum joint unevenness. Note that the joint unevenness of the mating surfaces is equal to $H_{max}-H_{min}$. This concept must be kept in mind in all gasket design.

REQUIRED COMPRESSION PRESSURE

Three factors determine the required compression pressure on a gasket; its resiliency, the minimum pressure required for a seal, and the total joint unevenness.

Resiliency–This is the amount a gasket compresses per unit applied compression pressure. Resiliency is usually expressed in (% of original gasket height)/psi. A soft gasket would compress more than a hard gasket with the same applied pressure. Or stated the other way, a soft gasket would require less pressure than a hard gasket to compress the same % of gasket height. For instance a sponge neoprene gasket might compress 10% under an applied compression pressure of only 6 psi, but a solid neoprene gasket would require 50 psi for the same 10% deflection.

Minimum Pressure for Seal–As already stated, a gasket must at least make contact at the point of maximum separation between the mating surfaces (H_{max} H_g). Actually in most cases the pressure at this point must be a stated minimum in order to assure a seal. This would be rather easy to understand in the case of a high pressure hydraulic system. If there is not at least some required minimum pressure at the point of H_{max} the oil would blow by between the flange and the gasketing material. The pressure at H_{max} point must be high enough to prevent blow-by. For EMI gaskets this minimum pressure is determined by the pressure required to break through corrosion films and to make a suitable low resistance contact. For most EMI gaskets this is 20 psi, but can be as little as 5 psi.

Average Pressure–The average pressure applied to the gasket must also be large enough to compress the gasket so that the minimum gasket height subtracted from the maximum gasket height (which was determined by the minimum pressure required from the previous paragraph) is equal to the joint unevenness, that is $H_{max}-H_{min} = \Delta H$.

FIGURE 1

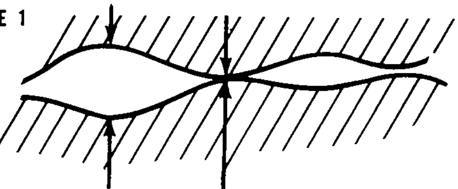
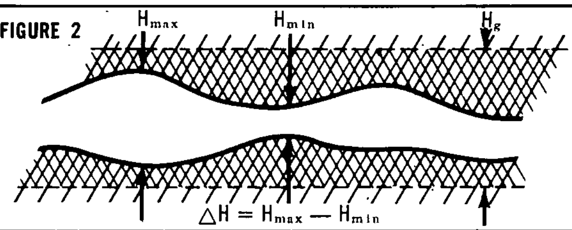


FIGURE 2

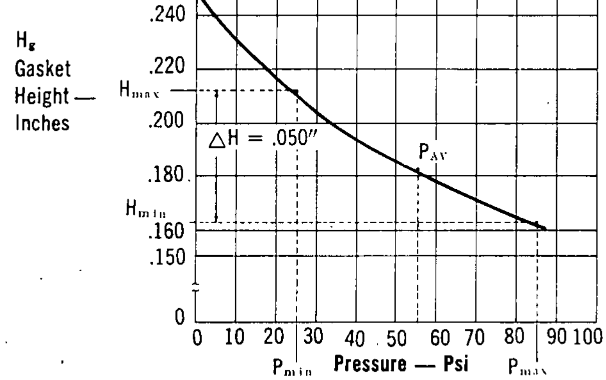


GASKET HEIGHT

To obtain the required seal from a gasketed joint, the gasket height must meet these criteria:

1. The pressure at point of maximum separation must be at least the minimum pressure to obtain the required seal.
2. The difference between maximum and minimum gasket compressed heights must be equal to the joint unevenness of the mating surfaces ($\Delta H = H_{max} - H_{min}$).

FIGURE 3

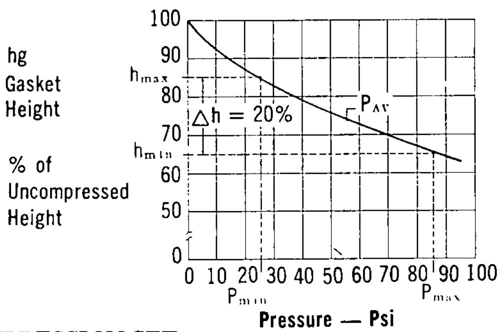


These principles are illustrated by reference to Figures 2 and 3. Figure 3 is the compression characteristic for the gasket material used in the joint illustrated in Figure 2. In this example the minimum pressure for a reliable seal is 20 psi. As shown, minimum pressure is actually 25 psi; the minimum pressure requirement has been met. Gasket height at this point is .212". Joint unevenness is .050" so the minimum gasket height is .212–.050 = .162. The second requirement has been met. From the curve, the pressure at this point is 85 psi. Average pressure is estimated by $\frac{P_{min} + P_{max}}{2}$, in this case $\frac{25 + 85}{2} = 55$ psi.

Average pressure is important in estimating total force required to compress the gasket.

Gasket compression characteristics are most frequently given in terms of percent of gasket height so that one curve can be used for many actual gasket heights. Figure 4 is a plot of the characteristics shown in Figure 3 except heights are given in percent of gasket height. To distinguish actual heights from heights expressed in percent of gasket height, the latter are designated by lower case h.

FIGURE 4



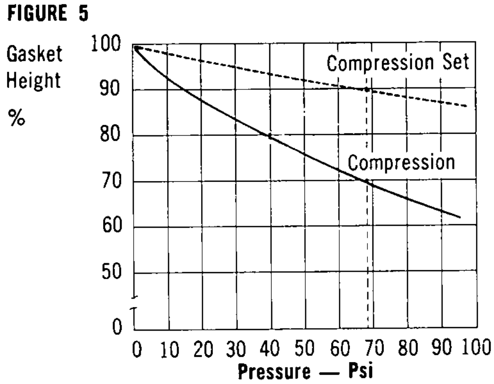
COMPRESSION SET

Some gasket materials take a compression set; that is, they do not return to original gasket height after compression. This is illustrated in Figure 5. The compressed height is indicated by the solid line. When compression pressure is removed, the gasket returns to the height indicated by the broken line. This is compression set. The importance of compression set depends on how the gasket is used.

CLASS A, PERMANENTLY CLOSED—If the gasket is used under a component that will, in all probability never be removed, the compression set is unimportant. It would show up only on disassembly. This type of joint is called "permanently closed" and identified as Class A.

CLASS B, REPEATED IDENTICAL OPEN-CLOSE CYCLES—Many gaskets are used in joints that are frequently opened and closed but always in the same manner (hinged door or symmetrical cover, etc.). In this case minimum compressed gasket height will always occur at the same place. This will also be the point of maximum compression set. In effect, original gasket height has been reduced at this point, but the gasket is still being compressed. For instance, Figure 5 shows compression and compression set characteristics for a gasket material (set is more severe than normal for emphasis).

FIGURE 5



CLASS C, COMPLETELY INTERCHANGEABLE—The problem of compression set is much more severe when there is complete freedom of positioning on repeat closures. A specific example would be a round gasket in a waveguide that might be removed and reused in almost any position relative to points of minimum and maximum compression. The compression set height at point of maximum compression may actually be less than minimum compressed height! It would therefore be possible to not make contact at all between gasket and mating surfaces at this point.

USING STANDARD GASKETS

The designer should know or estimate:

1. Joint unevenness.
2. Available compression.
3. Shielding required.

The object of EMI gasket design procedure is to fit the application requirements (joint unevenness, available compression forces, and shielding requirement) to the gasket characteristics (compressibility and EMI shielding capability).

Average Shielding Problems—In general the same reasoning outlined for maximum shielding will apply; choice of gasket material and contact surface is most important, pressure is secondary. If low frequency magnetic shielding is not a severe problem, then a minimum pressure of 5 to 20 psi may well be adequate. This reduction of minimum pressure can be very important because it increases the Δh (gasket compression range) significantly for the same average applied compression pressure.

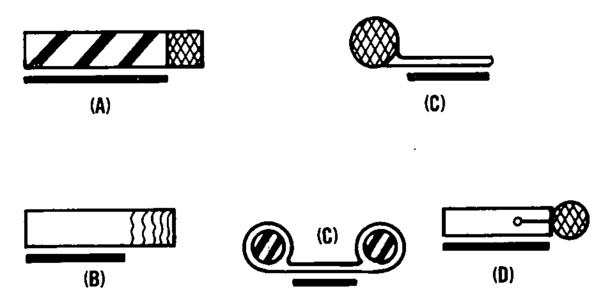
Minimum Shielding Problems—Especially when little or no low frequency magnetic shielding is required the minimum pressure could be as little as 1 to 5 psi.

Pressure Sensitive Adhesive—This is often the least expensive method for attaching EMI gasket materials; installation costs are often drastically reduced with only a slight increase in cost over a material without adhesive backing. As a matter of fact, most sales of sponge elastomer materials are for applications that do not require any pressure sealing; the adhesive backed rubber portion serves only as an inexpensive attachment method for the EMI portion!

In all cases the designer specifying non-conductive adhesive attachment must include adequate warnings in the applicable drawings and standard procedures for production personnel that the adhesive is to be applied only to the portion of the gasket material not involved with the EMI gasketing function. Experience teaches that installation workers will, either through carelessness or a misguided desire to do a better job ("This gasket would hold better if I glued all of it rather than half of it"), apply the non-conductive adhesive to the EMI gasket portion also. This will seriously degrade the EMI performance.

Bond Non-EMI Portion of Gasket—Since many very good non-conductive adhesives are now available, bonding a gasket product in position by applying the adhesive to the portion that is not the EMI gasket (which can be insulated from the mating surfaces by a non-conductive material) is often a very good way of mounting EMI gaskets.

FIGURE 6



Areas where non-conductive or dry-back adhesive can be used.

All aluminum EMI gasket products should be avoided since they make poor electrical contact. They should be used only when equipment specification explicitly require that only aluminum EMI gaskets be used against aluminum shields. Secondly, mating contact surfaces should be treated for best conductivity (tin coated, cadmium plated, conductive treatments of aluminum). Non-conductive protective coating such as paints and anodizing of aluminum are prohibited in all EMI gasket contact areas.

(The above material has been furnished courtesy of the Metex Corporation).

CORROSION AND THE SILVER-FILLED SILICONE RFI GASKET

Electrically conductive silicone elastomers have gained widespread use as EMI/RFI gaskets. The materials provide electrical continuity across mating surfaces without the necessity for extremely close tolerances, and at the same time seal the interface from its external environment (pressure or moisture).

The expanding use of these materials has been greeted by some materials and electrical/electronic packaging engineers amid some controversy. The controversy arises because conductive silicones contain silver, and silver, in metal form, can cause galvanic corrosion problems.

Experiments designed to measure the predicted galvanic activity when conductive elastomers are sandwiched between 2024-T6 aluminum panels have shown, instead, hardly any corrosion attributable to galvanic effects. The same experiments with silver foiled in the sandwich produce the predicted galvanic action.

In a conductive elastomer, the elastomer is generally silicone or fluorosilicone, because these polymers perform best across the broad temperature ranges required for most military/aerospace applications. The filler is generally silver, in the form of flake, powder or plated powder (plated substrate can be copper or glass). Selection of a suitable filler is based on the requirements of low resistivity, resistance to oxidation in the presence of uncured polymer (even at high curing temperatures), and the ability to be wetted by the polymer so that complete dispersion can be accomplished. Only noble metals, or powders plated with noble metals, exhibit all of these properties.

The conductive filler is incorporated into the raw rubber polymer prior to vulcanization in such a way that it is uniformly dispersed. By controlling the particle size and shape, loading ratio and filler/matrix structure, a wide range of physical properties can be produced.

The conductive elastomer in a free state (i.e., not sandwiched between flanges), will reflect the properties of the silicone polymer used. Its resistance to solvents, waters, acids, bases, temperature, fungus and radiation will have been compromised very little if at all. Its physical properties will have been decreased to some extent, and its resistance to flammability is increased.

Because the material is conductive, it is often subjected to corrosion tests designed for metals—generally with little regard to the actual use configuration or environment. If the material is considered to be a metal, its corrosion resistance in the free state is somewhat similar to that of silver. In a high sulfide atmosphere the typical black silver sulfide will be formed on the surface. Sulfide formation, however, is much less rapid than it is with silver metal, because of the influence of the encapsulating polymer. The reaction is fast enough, however, to negate any claim to sulfide resistance.

When subjected to MIL-STD-810 salt fog and cyclid temperature/humidity tests (method 507, procedure 1), the conductive elastomer, like silver metal, is unaffected except for a slight darkening. Its weight gain in the humidity tests is less than 2%. Weight loss in outgassing tests is less than 0.5%, and with special post-curing can be reduced to less than 0.05%.

Weather aging tests have been conducted continuously since 1967, with samples of various conductive elastomers exposed to the extremes of New England coastal weather. To date, these samples have been unaffected.

Other experiments comparing the behavior of conductive silicones to silver metal have shown that in a sodium chloride/hydrocholoric acid solution (pH 0.5), strips of conductive silicone connected to a 12 VDC source do not produce the same degree of anodic oxidation (and consequent resistance increase) as strips of silver foil.

The most common corrosion concern of conductive elastomer users is galvanic corrosion. For galvanic corrosion to occur, a unique set of conditions must exist: Two metals capable of generating a voltage between them (any two unlike metals will do), electrically joined by a current path, and immersed in a fluid capable of dissolving the less noble of the two. In short, the conditions of a battery must exist. When these conditions do exist, current will flow and the extent of corrosion which will occur will be directly related to the total amount of current the galvanic cell produces.

When a silver-containing conductive elastomer is used as a gasket between two metal flanges, the first condition is satisfied since the flanges will probably not be silver (although they are sometimes coated with silver-filled paint to create a more compatible couple). The second condition is satisfied by the inherent conductivity of the filled elastomer. The last condition could be realized when the electronic package is placed in service where atmospheric humidity, if allowed to collect at the flange/gasket interface, can provide the moisture for the solution of ions.

Experiments designed to show the galvanic effects of such a sandwich have shown very little corrosion of this type. Replacing the conductive elastomer with silver foil resulted in the predicted galvanic action. A number of factors are thought to explain these results. The volume resistivity of pure silver is 1.6×10^{-6} ohm-cm and the volume resistivity of a typical conductive elastomer is 9×10^{-3} ohm-cm. Clearly then, the ability of the cell containing a typical conductive elastomer to conduct current is several orders of magnitude less than one with pure silver. This restriction in current-carrying ability greatly reduces the cell's corrosion-promoting capability.

When the elastomer is designed properly into a flanged joint, moisture is excluded from the joint because of the sealing properties of the gasket material; therefore, another necessary element of the galvanic cell is eliminated or minimized. A third favorable factor results from the general area relationship between the silver-filled elastomer (the noble member of the couple) and the flange metal (the corrodible member of the couple). When the area of the less noble material is large in relation to the more noble material, as it is in the case of the flange, the large area over which the corrosion current can be collected results in low current densities and consequently less corrosion.

The foregoing discussion is not intended to suggest that corrosion should be of no concern when flanges are sealed with conductive elastomers. Rather, corrosion control by and large presents the same problems whether the gasket is silver filled or unfilled. Furthermore, the designer must understand the factors which promote galvanic activity and strive to keep them at safe levels. By "safe," it should be recognized that some corrosion is likely to occur (and is generally tolerable) at the outer (unsealed) edges of a flange after long-term exposure to high-humidity environments. This is especially true if proper attention has not been given to flange materials and finishes. The objective should be control of corrosion within acceptable limits—not prevention of corrosion per se. The latter objective usually represents wasted dollars.

In aerospace applications, attention is often given to the strength-to-weight ratio of metals; therefore, aluminum and magnesium are commonly used in electronic structures. Without proper finishing, these materials by themselves will severely corrode in high-humidity environments (i.e., without even the presence of a galvanic cell). In commercial applications, zinc- or cadmium-coated steel, zinc-base castings, etc., are commonly used for economic reasons. Zinc and cadmium will prevent steel from rusting, but they are quite corrodible in humid environments.

When these basically corrosive materials are tested in contact with a conductive elastomer, some corrosion is noticed. Important to note, however, is that when they are tested by themselves, or in contact with an unfilled elastomer, a similar degree and type of corrosion is noticed. Using such inherently corrodible materials often leads to the false conclusion that the observed corrosion is caused by, or at least increased by, the conductive elastomer.

The key to corrosion control in flanges sealed with conductive elastomers is proper design of the flange and gasket (and, of course, proper selection of the gasket material). A properly designed interface requires a gasket whose thickness, shape and compression-deflection characteristics allow it to fill all gaps caused by uneven or unflat flanges, surface irregularities, bowing between fasteners and tolerance buildups. If the gasket is designed and applied correctly, it will exclude moisture and inhibit corrosion on the flange faces and inside the package.

Bare aluminum and magnesium, as well as iridited aluminum and magnesium, can be protected by properly designed conductive elastomer gaskets. The unfilled silicone gasket with oriented wires (which is not a "conductive elastomer," but is treated here because its intended function is the same—i.e., EMI and environmental sealing) often cannot protect the surfaces because the wires exhibit a "wicking" tendency, allowing moisture to be drawn onto the metal surfaces. In addition, these wires restrict the ability of the rubber to flow and seal.

The definition of a "safe" level of galvanic activity must clearly be expanded to include the requirements of the design. If all traces of corrosion must be prevented—inside and outside—the structure must be properly finished or must be made of materials which will not corrode in the use environment. In these cases, the outside edges of flanges sealed with conductive elastomers might also require peripheral sealing as defined in MIL-STD-1250, MIL-STD-889 or MIL-STD-454. MIL-STD-1250 deserves special mention, as it is very specific in relation to corrosion control methods applicable to enclosures.

If, on the other hand, the requirement is to design a structure which will function reliably, at the most reasonable cost, and with proper regard to maintainability and service life, the common materials of construction with their usual finishes can be used with silver-filled elastomers. The primary function of the gasketed joint, which is to maintain electrical continuity and provide moisture sealing, will be maintained.

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FINGER STOCK

Another form of EMI/RFI gasket used in many applications is contact fingers, often referred to as finger stock. They are available in various configurations including straight strips, corner strips and circular rings with inside or outside contact tips.

APPLICATIONS:

The fingers are most often used as a RF gasket where frequent access through the opening is required. They can be found around the periphery of most shielded room doors in parallel rows—two and three deep. Here, their wiping action as it is compressed, is a most desirable feature since it cuts through film and dirt which can build up along the mating surfaces. Figure 7 illustrates the wiping action of finger stock.

The fingers can also be used behind panels and drawers where it not only provides RF shielding, but also assures a good ground contact across the mating surfaces. Circular finger rings can be used to ground metal shafts where they penetrate a panel and protect against RF leakage. Their wiping action allows the shaft to rotate without appreciable drag.

CHARACTERISTICS:

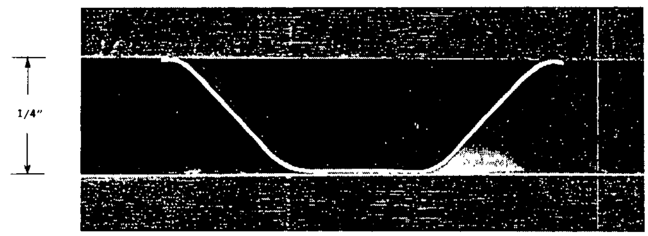
Finger stock is made of high-performance beryllium copper which has a relative electrical conductivity of 22 to 28. It can be purchased in many standard finishes including gold flashed, gold plated, silver plated, bright finish or as heat-treated ready for the user to apply the finish. The ring fingers are also available with localized deposits of silver or gold on the contact tips.

The finger strips feature a mechanically balanced design to provide high dynamic range, long endurance life and multiple lines of contact under relatively light pressure. Attenuation against electric fields of more than 100dB at 200kHz, 400kHz, 400MHz and 10GHz has been measured for a single rectangular enclosure.

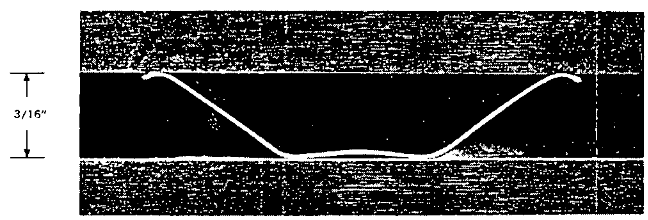
Finger stock can be fastened in place with rivets, clips, and epoxy or can be soldered. The newest technique is finger strips with a self-adhesive backing. Referred to as "Sticky Fingers" by Instrument Specialties, the pressure-sensitive adhesive was developed to provide an extremely tight permanent bond. The adhesive strengthens as it cures with age. Sticky fingers are unaffected in temperature ranges from -65°F. to 160°F. The adhesive also meets most salt spray, shock and humidity cycle tests.

To provide for an increase in the shielding effectiveness against magnetic fields, the sticky fingers can be furnished with a magnetic core insert. As an example, tests have shown that magnetic field shielding effectiveness has been increased from 14 to 18dB at 400Hz and from 46 to 59dB at 14kHz using the magnetic insert.

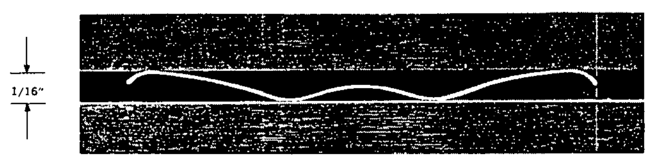
end views of linear gasket 97-436 compressed between flat surfaces



Three lines of contact occur when gap is 1/4". (Note: This photo was made after the gasket had been compressed to 1/64", and released.)



At 3/16" gap there are four lines of contact due to arching of center.



Note increased arching of center at 1/16" gap. This produces wiping contact with the mounting surface.

At 1/32" gap the tips of the fingers are in contact with the mounting surface, and the center arch is in contact with the closing surface, making a total of seven lines of contact.

At least nine lines of contact occur when the gasket is compressed to 1/64". (Note: Recovery from this deflection is excellent. See top illustration.)