EMI Shielding Theory & Gasket Design Guide

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Theory of Shielding and Gasketing

Fundamental Concepts

A knowledge of the fundamental concepts of EMI shielding will aid the designer in selecting the gasket inherently best suited to a specific design.

All electromagnetic waves consist of two essential components, a magnetic field, and an electric field. These two fields are perpendicular to each other, and the direction of wave propagation is at right angles to the plane containing these two components. The relative magnitude between the magnetic (H) field and the electric (E) field depends upon how far away the wave is from its source, and on the nature of the generating source itself. The ratio of E to H is called the wave impedance, Z_W.

If the source contains a large current flow compared to its potential, such as may be generated by a loop, a transformer, or power lines, it is called a current, magnetic, or low impedance source. The latter definition is derived from the fact that the ratio of E to H has a small value. Conversely, if the source operates at high voltage, and only a small amount of current flows, the source impedance is said to be high, and the wave is commonly referred to as an electric field. At very large distances from the source, the ratio of E to H is equal for either wave regardless of its origination. When this occurs, the wave is said to be a plane wave, and the wave impedance is equal to 377 ohms, which is the intrinsic impedance of free space. Beyond this point all waves essentially lose their curvature, and the surface containing the two components becomes a plane instead of a section of a sphere in the case of a point source of radiation.

The importance of wave impedance can be illustrated by considering what happens when an electromagnetic wave encounters a discontinuity. If the magnitude of the wave impedance is greatly different from the intrinsic impedance of the discontinuity, most of the energy will be reflected, and very little will be transmitted across the boundary. Most metals have an intrinsic impedance of only milliohms. For low impedance fields (H dominant), less energy is reflected, and more is absorbed, because the metal is more closely matched to the impedance of the field. This is why it is so difficult to shield against magnetic fields. On the other hand, the wave impedance of electric fields is high, so most of the energy is reflected for this case.

Consider the theoretical case of an incident wave normal to the surface of a metallic structure as illustrated in Figure 1. If the conductivity of the metal wall is infinite, an electric field equal and opposite to that of the incident electric field components of the wave is generated in the shield. This satisfies the boundary condition that the total tangential electric field must vanish at the boundary. Under these ideal conditions, shielding should be perfect because the two fields exactly cancel one another. The fact that the magnetic fields are in phase means that the current flow in the shield is doubled.

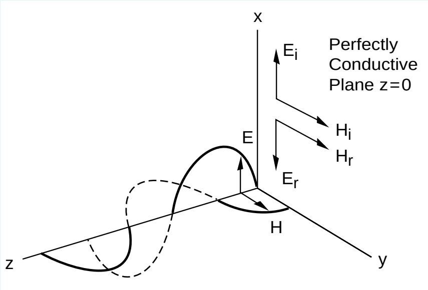

Figure 1 Standard Wave Pattern of a Perfect Conductor Illuminated by a Normally Incident, + X Polarized Plane Wave

Shielding effectiveness of metallic enclosures is not infinite, because the conductivity of all metals is finite. They can, however, approach very large values. Because metallic shields have less than infinite conductivity, part of the field is transmitted across the boundary and supports a current in the metal as illustrated in Figure 2. The amount of current flow at any depth in the shield, and the rate of decay is governed by the conductivity of the metal and its permeability. The residual current appearing on the opposite face is the one responsible for generating the field which exists on the other side.

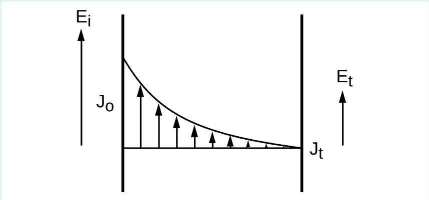

Figure 2 Variation of Current Density with Thickness for Electrically Thick Walls

Our conclusion from Figures 2 and 3 is that thickness plays an important role in shielding. When skin depth is considered, however, it turns out that thickness is only critical at low frequencies. At high frequencies, even metal foils are effective shields.

The current density for thin shields is shown in Figure 3. The current density in thick shields is the same as for thin shields. A secondary reflection occurs at the far side of the shield for all thicknesses. The only difference with thin shields is that a large part of the re-reflected wave may appear on the front surface. This wave can add to or subtract from the primary reflected wave depending upon the phase relationship between them. For this reason, a correction factor appears in the shielding calculations to account for reflections from the far surface of a thin shield.

A gap or slot in a shield will allow electromagnetic fields to radiate through the shield, unless the current continuity can be preserved across the gaps. The function of an EMI gasket is to preserve continuity of current flow in the shield. If the gasket is made of a material identical to the walls of the shielded

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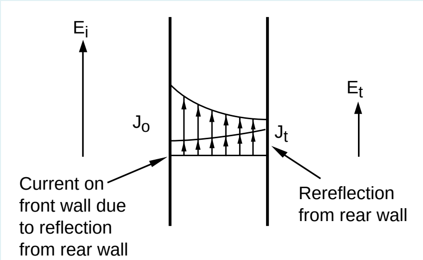

Figure 3 Variation of Current Density with Thickness for Electrically Thin Wall

enclosure, the current distribution in the gasket will also be the same assuming it could perfectly fill the slot. (This is not possible due to mechanical considerations.)

The flow of current through a shield including a gasket interface is illustrated in Figure 4. Electromagnetic leakage through the seam can occur in two ways. First, the energy can leak through the material directly. The gasket material shown in Figure 4 is assumed to have lower conductivity than the material in the shield. The rate of current decay, therefore, is also less in the gasket. It is apparent that more current will

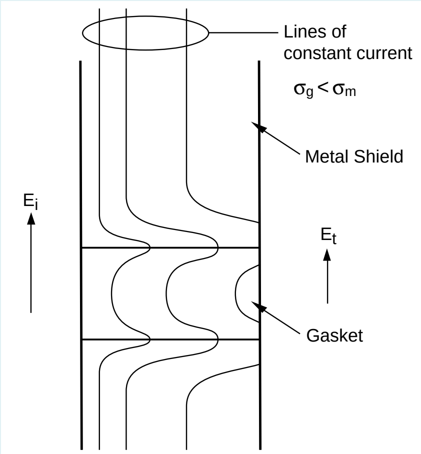

Figure 4 Lines of Constant Current Flow Through a Gasketed Seam

appear on the far side of the shield. This increased flow causes a larger leakage field to appear on the far side of the shield. Second, leakage can occur at the interface between the gasket and the shield. If an air gap exists in the seam, the flow of current will be diverted to those points or areas which are in contact. A change in the direction of the flow of current alters the current distribution in the shield as well as in the gasket. A high resistance joint does not behave much differently than open seams. It simply alters the distribution of current somewhat. A current distribution for a typical seam is shown in Figure 4. Lines of constant current flow spaced at larger intervals indicate less flow of current.

It is important in gasket design to make the electrical properties of the gasket as similar to the shield as possible, maintain a high degree of electrical conductivity at the interface, and avoid air, or high resistance gaps.

Shielding and Gasket Equations[1]

The previous section was devoted to a physical understanding of the fundamental concepts of shielding and gasketing. This section is devoted to mathematical expressions useful for general design purposes. It is helpful to understand the criteria for selecting the parameters of a shielded enclosure.

In the previous section, it was shown that electromagnetic waves incident upon a discontinuity will be partially reflected, and partly transmitted across the boundary and into the material. The effectiveness of the shield is the sum total of these two effects, plus a correction factor to account for reflections from the back surfaces of the shield. The overall expression for shielding effectiveness is written as:

$$S.E. = R + A + B \qquad (1)$$

where

S.E. is the shielding effectiveness[2] expressed in dB,

R is the reflection factor expressed in dB,

A is the absorption term expressed in dB, and

B is the correction factor due to reflections from the far boundary expressed in dB.

The reflection term is largely dependent upon the relative mismatch between the incoming wave and the surface impedance of the shield. Reflection terms for all wave types have been worked out by others.[3] The equations for the three principal fields are given by the expressions:

$$R_E = 353.6 + 10 \log_{10} \frac{G}{f^3 \mu r_1^2} \qquad (2)$$

$$R_H = 20 \log_{10}\left(\frac{0.462}{r_1} \sqrt{\frac{\mu}{Gf}} + 0.136 r_1 \sqrt{\frac{fG}{\mu}} + 0.354 \right) \qquad (3)$$

$$R_P = 108.2 + 10 \log_{10} \frac{G \times 10^6}{\mu f} \qquad (4)$$

where

R_E, R_H, and R_P are the reflection terms for the electric, magnetic, and plane wave fields expressed in dB.

G is the relative conductivity referred to copper,

f is the frequency in Hz,

μ is the relative permeability referred to free space,

r_1 is the distance from the source to the shield in inches.

The absorption term A is the same for all three waves and is given by the expression:

$$A = 3.338 \times 10^{-3} \times t \sqrt{\mu f G} \qquad (5)$$

where

A is the absorption or penetration loss expressed in dB, and t is the thickness of the shield in mils.

The factor B can be mathematically positive or negative (in practice it is always negative), and becomes insignificant when A>6 dB. It is usually only important when metals are thin, and at low frequencies (i.e., below approximately 20 kHz).

$$B \text{ (in dB)} = 20 \log_{10} \left| 1 - \left(\frac{(K-1)^2}{(K+1)^2} \right) \left(10^{-A/10} \right) \left(e^{-j.227A} \right) \right| \qquad (6)$$

where

A = absorption losses (dB)

$|K| = |Z_S/Z_H| = 1.3(\mu/fr^2G)^{1/2}$

Z_S = shield impedance

Z_H = impedance of the incident magnetic field

References

1. Much of the analysis discussed in this section was performed by Robert B. Cowdell, as published in *"Nomograms Simplify Calculations of Magnetic Shielding Effectiveness"* **EDN**, page 44, September 1, 1972.
2. Shielding Effectiveness is used in lieu of absorption because part of the shielding effect is caused by reflection from the shield, and as such is not an absorption type loss.
3. Vasaka, G.J., *Theory, Design and Engineering Evaluation of Radio-Frequency Shielded Rooms,* U.S. Naval Development Center, Johnsville, Pa., Report NADC-EL-54129, dated 13 August, 1956.

The preceding equation was solved in two parts. A digital computer was programmed to solve for B with a preselected value of A, while |K| varied between 10^{-4} and 10^{3}. The results are plotted in Figure 9.

The nomograph shown in Figure 8 was designed to solve for |K| in equation (6). Note that when Z_H becomes much smaller than Z_S (K>1), large positive values of B may result. These produce very large and unrealistic computed values of S.E., and imply a low frequency limitation on the B equation. In practical cases, absorption losses (A) must be calculated before B can be obtained.[1]

A plot of reflection and absorption loss for copper and steel is shown in Figure 5. This illustration gives a good physical representation of the behavior of the component parts of an electromagnetic wave. It also illustrates why it is so much more difficult to shield magnetic fields than electric fields or plane waves. Note: In Figure 5, copper offers more shielding effectiveness than steel in all cases except for absorption loss. This is due to the high permeability of iron. These shielding numbers are theoretical, hence they are very high (and unrealistic) practical values.

If magnetic shielding is required, particularly at frequencies below 14 kHz, it is customary to neglect all terms in equation (1) except the absorption term A. Measurements of numerous shielded enclosures bears this out. Conversely, if only electric field, or plane wave protection is required, reflection is the important factor to consider in the design.

The effects of junction geometry, contact resistance, applied force and other factors which affect gasket performance are discussed in the design section which follows.

Polarization Effects

Currents induced in a shield flow essentially in the same direction as the electric field component of the inducing wave. For example, if the electric component of a wave is vertical, it is known as a vertically polarized wave, and it will cause a current to flow in the shield in a vertical direction. A gasket placed transverse to the flow of current is less effective than one placed parallel to the flow of current.

A circularly polarized wave contains equal vertical and horizontal components, so gaskets must be equally effective in both directions. Where polarization is unknown, gasketed junctions must be designed and tested for the worse condition; that is, where the flow of current is parallel to the gasket seam.

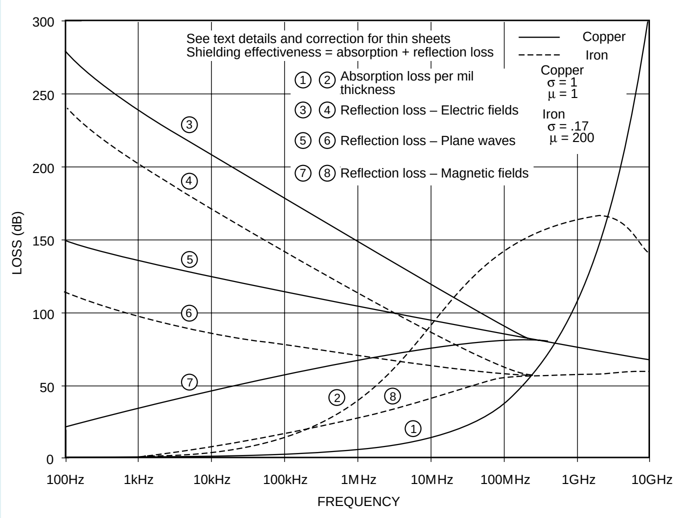

Figure 5 Shielding Effectiveness of Metal Barriers

Some care must be exercised in using these charts for ferrous materials because μ varies with magnetizing force.

Nomographs

The nomographs presented in Figures 6 through 9 will aid the designer in determining absorption and magnetic field reflection losses directly[1]. These nomographs are based on the equations described in the previous section.

Absorption Loss – Figure 6:

Given a desired amount of absorption loss at a known frequency, determine the required thickness for a known metal:

a. Locate the frequency on the f scale and the desired absorption loss on the A scale.

Place a straight-edge across these points and locate a point on the unmarked X scale *(Example: A = 10 dB, f =100 kHz).*

b. Pivot the straight-edge about the point on the unmarked X scale to various metals noted on the G x μ scale. A line connecting the G x μ scale and the point on the unmarked scale will give the required thickness on the t scale. *(Example: for copper t = 9.5 mils, cold rolled steel t = 2.1 mils).*

Magnetic Field Reflection – Figure 7: To determine magnetic field reflection loss R_H:

a. Locate a point on the G/μ scale for one of the metals listed. If the metal is not listed, compute G/μ and locate a point on the numerical scale.

b. Locate the distance between the energy source and the shield on the r scale.

c. Place a straight-edge between r and G/μ and locate a point on the unmarked X scale *(Example: r =10 inches for hot rolled steel).*

d. Place a straight-edge between the point on the X scale and the desired frequency on the f scale.

e. Read the reflection loss from the R_H scale. (For f = 10 kHz, R_H = 13 dB).

f. By sweeping the f scale while holding the point on the X scale, R_H versus frequency can be obtained. (For f = 1 kHz, R_H = 3.5 dB).

(Note that thickness is not a factor in calculating reflection losses.)

References

1. Robert B. Cowdell, *"Nomograms Simplify Calculations of Magnetic Shielding Effectiveness"* **EDN**, page 44, September 1, 1972.

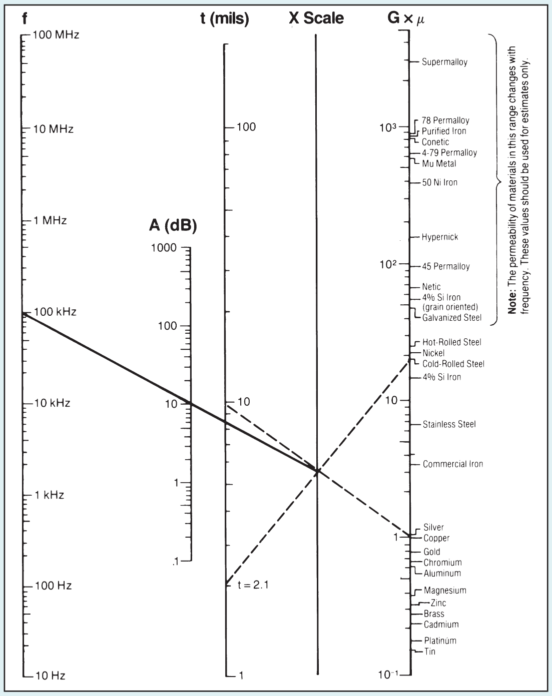

Figure 6 Absorption Loss Nomograph[1]

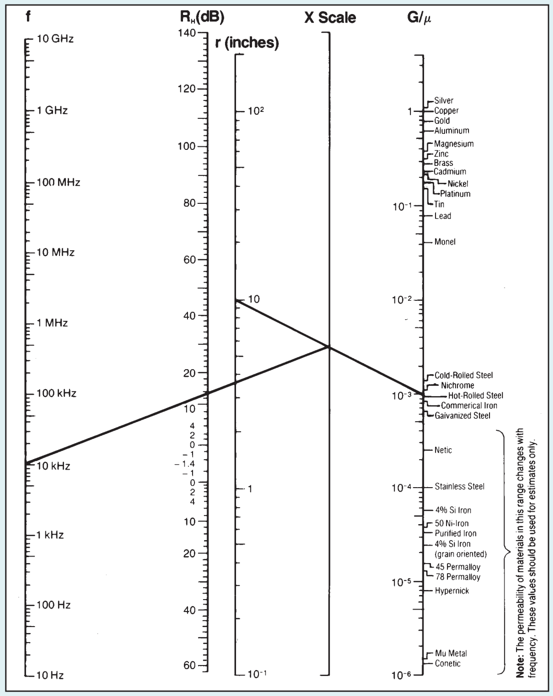

Figure 7 Magnetic Field Reflection Loss Nomograph, R_H[1]

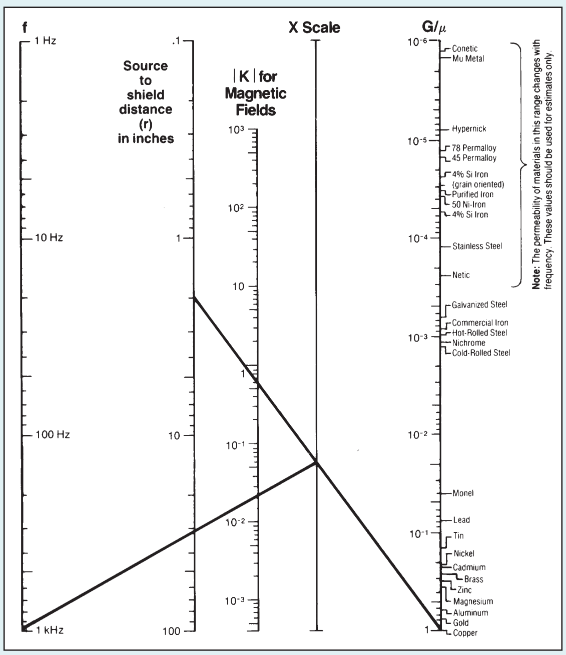

Figure 8 Magnetic Field Secondary Reflection Loss Factor Nomograph[1]

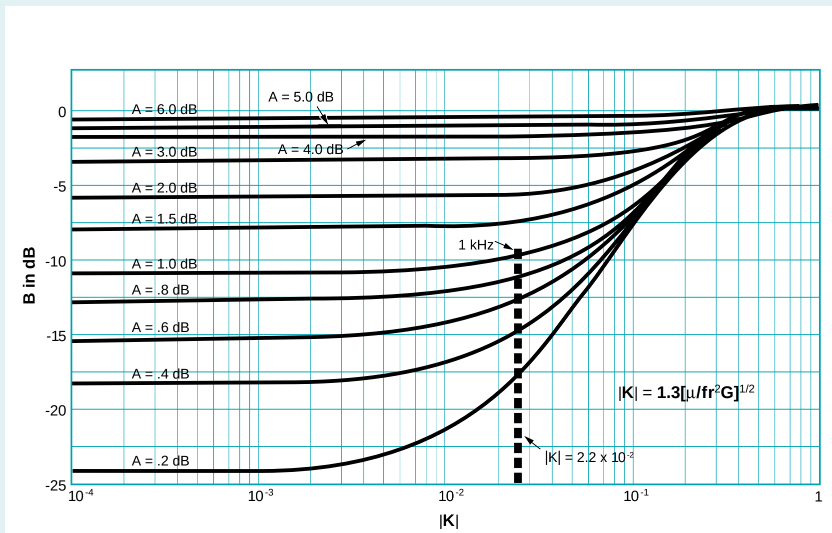

Figure 9 Solving for Secondary Reflection Loss (B)[1]

Magnetic Field Secondary Reflection Losses |K| Figures 8 and 9: To determine the magnetic field secondary reflection loss factor |K| to solve for B:

Given: r = 2 inches for 0.0162 in. thick copper and A = 1.3 dB.

Find B at 1 kHz.

a. Draw a line between copper on the G/µ scale and r = 2 inches on the "source to shield distance scale." Locate a point on the X scale.

b. Draw a line from the point on the X scale to 1 kHz on the f scale.

c. At its intersection with the |K| scale, read $|K| = 2.2 \times 10^{-2}$.

d. Proceed to Figure 9.

e. On Figure 9, locate $|K| = 2.2 \times 10^{-2}$ on the horizontal scale.

f. Move vertically to intersect the A = 1.3 curve (interpolate), and then horizontally to find B = –8.5 dB.

Conductive Elastomer Gasket Design*

Gasket Junction Design

The ideal gasketing surface is rigid and recessed to completely house the gasket. Moreover, it should be as conductive as possible. Metal surfaces mating with the gasket ideally should be non-corrosive. Where reaction with the environment is inevitable, the reaction products should be electrically conductive or easily penetrable by mechanical abrasion. It is here that many gasket designs fail. The designer could not, or did not treat the mating surface with the same care as that given to the selection of the gasketing material.

By definition, a gasket is necessary only where an imperfect surface exists. If the junction were perfect, which includes either a solidly welded closure, or one with mating surfaces infinitely stiff, perfectly flat, or with infinite conductivity across the junction, no gasket would be necessary. The more imperfect the mating surfaces, the more critical is the function of the gasket. Perfect surfaces are expensive. The final solution is generally a compromise between economics and performance, but it should not be at the expense of neglecting the design of the flange surfaces.

The important property that makes a *conductive elastomer* gasket a good EMI/EMP seal is its ability to provide good electrical conductivity across the gasket-flange interface. Generally, the better the conformability and conductivity, the higher the shielding effectiveness of the gasket. In practice, it has been found that surface conductivity of both the gasket and the mating surfaces is the single most important property that makes the gasketed seam effective; i.e., *the resistance between the flange and gasket should be as low as possible.*

At this stage of the design every effort should be given to choosing a flange that will be as stiff as possible consistent with the construction used and within the other design constraints.

1. Flange Materials

Flanges are generally made of the same material as the basic enclosure for reasons of economy, weldability, strength and resistance to corrosion. Wherever possible, the flanges should be made of materials with the highest possible conductivity. It is advisable to add caution notes on drawings not to paint the flange mating surfaces. If paint is to be applied to outside surfaces, be sure that the contact surfaces are well masked before paint is applied, and then cleaned after the masking tape is removed. If the assembled units are subject to painting or repainting in the field, add a cautionary note in a conspicuous location adjacent to the seal that the seal areas are to be masked before painting.

Ordinarily, the higher the conductivity of a material, the more readily it oxidizes – except for noble metals such as gold and silver. Gold is impervious to oxidation, and silver, although it oxidizes, forms oxides that are soft and relatively conductive.

Most oxides, however, are hard. Some of the oxide layers remain thin while others build up to substantial thickness in relatively short time. These oxides form insulating, or semi-conducting films at the boundary between the gasket and the flanges. This effect can be overcome to a degree by using materials that do not oxidize readily, or by coating the surface with a conductive material that is less subject to oxidation. Nickel plating is generally recommended for aluminum parts, although tin has become widely accepted. Zinc is primarily used with steel. Consult the applicable specifications before selecting a finish. A good guide to finishing EMI shielded flanges for aerospace applications has been published by SAE Committee AE-4 (Electromagnetic Compatibility) under the designation ARP 1481. A discussion of corrosion control follows later in this guide.

2. Advantages of Grooved Designs

All rubber materials are subject to "Compression Set," especially if over compressed. Because flange surfaces cannot be held uniformly flat when the bolts are tightened (unless the flanges are infinitely stiff), gaskets tend to overcompress in the areas of the bolts. Proper groove design is required to avoid this problem of over compression. A groove also provides metal-to-metal contact between the flange members, thereby reducing contact resistance across the junction.

A single groove will suffice for most designs. Adding a second groove parallel to the first adds approximately 6 dB to the overall performance of a single-groove design. Adding more grooves beyond the second does not increase the gasketing effectiveness significantly.

3. Flange Design Considerations

Most designers fight a space limitation, particularly in the vicinity of the gasketed seam. Complex fasteners are often required to make the junctions more compact.

The ideal flange includes a groove for limiting the deflection of a gasket. The screw or bolt fasteners are mounted outboard of the gasket to eliminate the need for providing gaskets under the fasteners. A machined flange and its recommended groove dimensions are shown in Figure 10. The gasket may

* Complete solid-O gasket design information starts on page 209.

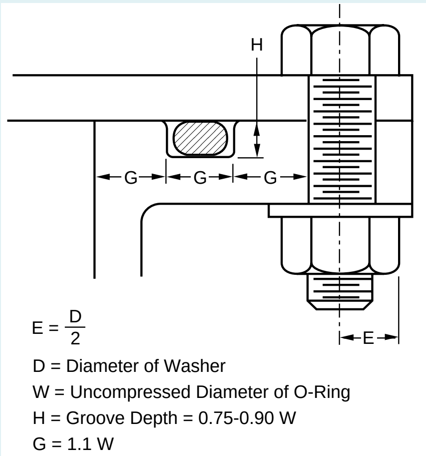

Figure 10 Machined Flange with Gasket Groove

be an "O" or "D"-shaped gasket, either solid or hollow.

Solid conductive O-rings are normally limited to a deflection of 25 percent. Therefore, the minimum compressed height of the O-ring (also the groove depth) is related to the uncompressed height (or diameter) by the expression H = 0.75 W, where W is the uncompressed diameter. The width of the groove, G, should be equal to 1.1 W. Allow sufficient void in the groove area to provide for a maximum gasket fill of 95 percent. Conductive elastomer gaskets may be thought of as "incompressible fluids." For this reason, sufficient groove cross sectional area must be allowed for the largest cross-sectional area of the gasket when tolerances are taken into account. Never allow groove and gasket tolerance accumulations to cause an "over-filled" groove (see gasket tolerances in section which follows).

When a seal is used to isolate pressure environments in addition to EMI, the bottom of the gasket groove should have a surface finish of 32-64 µin. (RMS) to minimize leakage along the grooves. Avoid machining methods that produce longitudinal (circumferential) scratches or chatter marks. Conversely, a surface that is too smooth will cause the gasket to "roll over" or twist in its groove.

The minimum distance from the edge of the groove to the nearest terminal edge, whether this terminal be the edge of a casting, a change in cross section, or a fastening device, should be equal to the groove width, G.

Bolts should be located a minimum distance, E (equal to one-half the diameter of the washer used under the head of the bolt) from the edge of the flange.

Square or rectangular cross section gaskets can be used in the same groove provided sufficient void is allowed for displacement of the rubber. A good design practice is not to allow the height of the gasket to exceed the base width. A better, or a more optimum ratio is a height-to-width ratio of one-half. Tall gaskets tend to roll over when loaded.

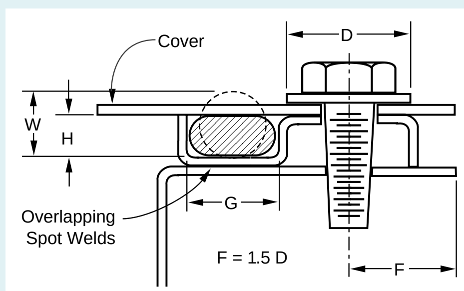

Figure 11a Shaped Sheet Metal Container

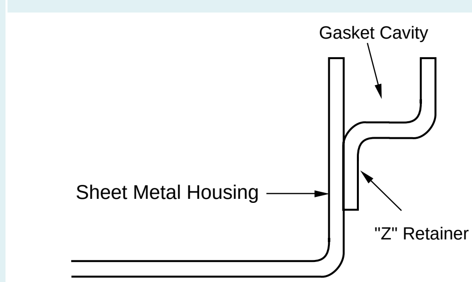

Figure 11b Z-Retainer Forms Gasket Cavity

The thickness of a flange is governed by the stiffness required to prevent excessive bowing between fastener points. Fewer, but larger bolts, require a thicker flange to prevent excessive deflections. For calculations of elastic deformation, refer to pages 206 and 207.

O-shaped and D-shaped gaskets may also be used in sheet metal flanges. The gaskets can be retained in a U-channel or Z-retainer, and are deflection-limited by adjusting the channel or retainer dimensions with respect to gasket height. Suggested retainer configurations are shown in Figures 11a and 11b.

A basic difference between flanges constructed from sheet metal and those which are machined from castings is that the bolts cannot be located as close to the edge of the part when the flange is made of sheet metal. Note, in Figure 11a, F is recommended to be 1.5 D, where D is the diameter of the washer.

Flat gaskets are ordinarily used with sheet metal or machined flanges as typically illustrated in Figure 12. Bolt holes in the flanges should be located at least 1.5 times the bolt diameter from the edge of the flange to prevent tearing when the metal is punched. If the holes are drilled, the position of the holes should be not less than the thickness of the gasket material from the edge of the flange. If holes must be placed closer to the edge than the recommended values, ears or

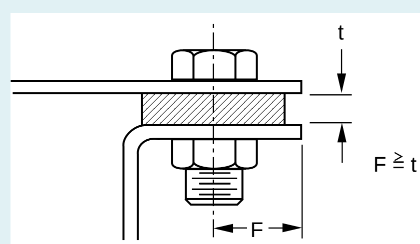

Figure 12 Flat Gasket on Sheet Metal Flange

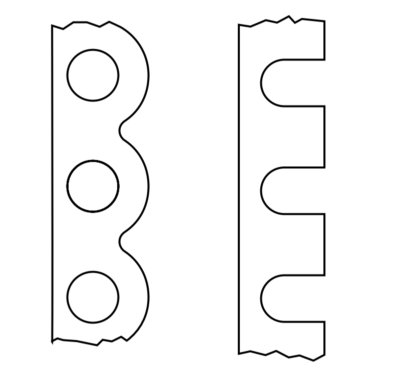

Figure 13 Ears or Slots in Sheet Metal Flanges or Flat Gaskets

slots should be considered as shown in Figure 13. Holes in flat gaskets should be treated in a similar manner.

4. Dimensional Tolerances

Grooves should be held to a machined tolerance of ±0.002 in. Holes drilled into machined parts should be held to within ±0.005 in. with respect to hole location. Location of punched holes should be within ±0.010 in. Sheet metal bends should be held to +0.030 and –0.000 in. Gasket tolerances are given in the "Selection of Seal Cross Section," later in this guide.

5. Waveguide Flanges

The three concerns for waveguide flanges are to ensure maximum transfer of electromagnetic energy across the flange interface to prevent RF leakage from the interface, and to maintain pressurization of the waveguide. Conductive elastomeric gaskets provide both an electrical and a seal function. For flat cover flanges, a die-cut sheet gasket (CHO-SEAL 1239 material), incorporating expanded metal reinforcement to control gasket creep into the waveguide opening, provides an excellent seal. Raised lips around the gasket cut-out improve the power handling and pressure sealing capability of the gasket. Choke flanges are best sealed with molded circular D-Section gaskets, and contact flanges with molded rectangular D-gaskets in a suitable groove (both in CHO-SEAL 1212 material).

The peak power handling capabilities of waveguide flanges are limited primarily by misalignment and sharp edges of flanges and/or gaskets. Average power handling is limited by the heating effects caused by contact resistance of the flange-gasket interface ("junction resistance").

Corrosion

All metals are subject to corrosion. That is, metal has an innate tendency to react either chemically or electrochemically with its environment to form a compound which is stable in the environment.

Most electronic packages must be designed for one of four general environments:

Class A. Controlled Environment Temperature and humidity are controlled. General indoor, habitable exposure.

Class B. Uncontrolled Environment Temperature and humidity are not controlled. Exposed to humidities of 100 percent with occasional wetting. Outdoor exposure or exposure in uncontrolled warehouses.

Class C. Marine Environment Shipboard exposure or land exposure within two miles of salt water where conditions of Class A are not met.

Class D. Space Environment Exposure to high vacuum and high radiation.

■ Finishes

Table I shows the minimum finish necessary to arrest chemical corrosion and provide an electrically conductive surface for the common metals of construction. Only the Class A, B, and C environments are shown in the table because the space environment is not a corrosive one (i.e., metals are not generally affected by the space environment).

Some metals require finishing because they chemically corrode. These are listed in Table I, and should be finished in accordance with the table. To select a proper finish for metals not given in Table I, refer to the material groupings of Table II. Adjacent groups in Table II are compatible. Another excellent source of information on corrosion-compatible finishes for EMI shielded

Table I

MINIMUM FINISH REQUIREMENTS FOR STRUCTURAL METALS

	ENVIRONMENT		
Metal	**Class A**	**Class B**	**Class C**
Carbon and Alloy Steel	0.0003 in. cadmium plate 0.0005 in. zinc plate 0.0003 in. tin	0.0005 in. cadmium 0.001 in. zinc 0.0005 in. tin	0.003 in. nickel 0.001 in. tin
Corrosion-Resistant Steels	No finish required	No finish required; 0.0005 in. nickel to prevent tarnish	No finish required; 0.001 in. nickel to prevent tarnish
Aluminum 2000 & 7000 series	Chromate conversion coat (MIL-C-5541, Class 3)	Chromate conversion coat (MIL-C-5541) plus conductive epoxy or urethane	0.001 in. tin
Aluminum 3000, 5000, 6000 series and clad	No finish required, unless shielding requirements are high (see above)	Chromate conversion coat	Chromate conversion coat plus conductive epoxy or urethane
Copper and Copper Alloys	0.0003 in. tin	0.0005 in. tin	0.003 in. nickel 0.001 in. tin
Magnesium	0.0003 in. tin	0.0005 in. tin	0.001 in. tin
Zinc Base Castings	No finish required	0.0003 in. tin	0.0005 in. tin

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Parker Seals

Table II

Group	Material Groupings*
	METALS COMPATIBILITY
1	Gold – Platinum – Gold/Platinum Alloys – Rhodium – Graphite – Palladium – 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 – Certain Silver Filled Elastomers
4	Leaded Brass and Bronze – Naval Brass – Steels AISI 431, 440, 410, 416, 420, AM 355 and PH hardened – Chromium Plate – Tungsten – Molybdenum – Tin-Indium – Tin Lead Solder – Lead – Lead Tin Solder – Aluminum 2000 and 7000 Series – Alloy and Carbon Steel – Certain Silver Filled Elastomers – CHO-SHIELD 2000 Series Coatings
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.

flanges is ARP 1481, developed and published by SAE's Committee AE-4 (Electromagnetic Compatibility).

When a finish is required to make two mating metals compatible, finish the metal which is found in the lower numbered grouping of Table II. Metals given in Table II will, because of their inherent corrodibility, already be finished and the finish metal will be subject to the same rule. For example, to couple metals separated by two or more groups (e.g., 4 to 2), find a finish which appears in Group 3 and 4. The Group 3 metal should be plated onto the Group 2 metal to make metals 2 and 4 compatible. The reason for this is, if the finish metal breaks down, or is porous, its area will be large in comparison to the exposed area of the Group 2 metal, and the galvanic corrosion will be less.

On aluminum, chromate conversion coatings (such as Iridite) can be considered as conductive finishes. MIL-C-5541 Class 3 conversion coatings are required to have less than 200 milliohms resistance when measured at 200 psi contact pressure after 168 hours of exposure to a 5 percent salt spray. Recommended MIL-C-5541 Class 3 coatings are Alodine 600, or Alodine 1200 and 1200S dipped.

Organic Finishes

Organic finishes have been used with a great deal of success to prevent corrosion. Many organic finishes can be used, but none will be effective unless properly applied. The following procedure has been used with no traces of corrosion after 240 hours of MIL-STD-810B salt fog testing.

Aluminum panels are cleaned with a 20% solution of sodium hydroxide and then chromate conversion coated per MIL-C-5541 Class 3 (immersion process). The conversion coated panels are then coated with MIL-C-46168 Type 2 urethane coating, except in the areas where contact is required. For maximum protection of aluminum flanges, a CHO-SHIELD 2000 series conductive coating and CHO-SEAL 1298 conductive elastomer gasket material are recommended. For additional information, refer to Design Guides for Corrosion Control on page 201.

The finish coat can be any suitable urethane coating that is compatible with the MIL-C-46168 coating. It is important to note that test specimens without the MIL-C-46168 coating will show some signs of corrosion, while coated test specimens will show no traces of corrosion.

CHO-SHIELD® 2000 Series Coatings

When using CHO-SHIELD 2000 series conductive urethane coatings, not enough can be said about surface preparation to attain maximum adhesion. The easily mixed three-component system allows minimum waste with no weighing of components, thus eliminating weighing errors. Because of the filler loading of the 2000 series coatings, it is recommended that an air agitator cup be incorporated into the spray system to keep the conductive particles in suspension during the spraying sequence. It is recommended that approximately 7 mils of wet coating be applied. This thickness can be achieved by spraying multiple passes, with a ten minute wait between passes.

A 7-mil wet film coating will yield a dry film thickness of 4 mils, which is the minimum thickness required to attain the necessary corrosion and electrical values referenced in Chomerics' Technical Bulletin **30**. The coating thickness plays an important role in the electrical and corrosion properties. Thinner coatings of 1-3 mils do not exhibit the corrosion resistance of 4-5 mil coatings.

The coating will be smooth to the touch when cured. It is recommended that the coating be cured at room temperature for 2 hours followed by 250°F +/-10°F for one-half hour whenever possible. Alternate cure cycles are available, but with significant differences in corrosion and electrical properties. Two alternate cure schedules are two hours at room temperature followed by 150°F for two hours, or 7 days at room temperature.

Full electrical properties are achieved at room temperature after 7 days. It should be noted that the 250°F cure cycle reflects the ultimate in corrosion resistance properties. The 150°F/2 hour and room temperature/7 day cures will provide less corrosion resistance than the 250°F cure, but are well within the specification noted in Technical Bulletin **30**.

1091 Primer

Because of the sensitivity of surface preparation on certain substrates and the availability of equipment to perform the etching of aluminum prior to the conversion coating, Chomerics has introduced 1091 primer, which is an adhesion promoter for CHO-SHIELD 2000 series coatings. When used in conjunction with an alkaline etch or chemical conversion coating per MIL-C-5541 Class 3, the 1091 primer will provide maximum adhesion when correctly applied. (See Technical Bulletin **31**.) This primer is recommended only for the 2000 series coatings on properly treated aluminum and is not recommended for composites.

For further assistance on the application of CHO-SHIELD 2000 series coatings on other metallic and non-metallic substrates, contact Chomerics' Applications Engineering Department.

■ Galvanic Corrosion

The most common corrosion concern related to EMI gaskets 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 (an electrolyte). 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 an EMI gasket is placed between two metal flanges, the first condition is generally satisfied because the flanges will probably not be made of the same metal as the gasket (most flanges are aluminum or steel, and most EMI gaskets contain Monel, silver, tin, etc.). The second condition is satisfied by the inherent conductivity of the EMI gasket. The last condition could be realized when the electronic package is placed in service, where salt spray or atmospheric humidity, if allowed to collect at the flange/gasket interface, can provide the electrolyte for the solution of ions.

Many users of EMI gaskets select Monel mesh or Monel wire-filled materials because they are often described as "corrosion-resistant." Actually, they are only corrosion-resistant in the sense that they do not readily oxidize over time, even in the presence of moisture. However, in terms of electrochemical compatibility with aluminum flanges, Monel is extremely active and its use requires extensive edge sealing and flange finish treatment to prevent galvanic corrosion. Most galvanic tables do not include Monel, because it is not a commonly used structural metal. The galvanic table given in MIL-STD-1250 does include Monel, and shows it to have a 0.6 volt potential difference with respect to aluminum – or almost the same as silver.

A common misconception is that all silver-bearing conductive elastomers behave galvanically as silver. Experiments designed to show the galvanic effects of silver-filled elastomer gaskets in aluminum flanges have shown less corrosion than predicted. Silver-plated-aluminum filled elastomers exhibit the least traces of galvanic corrosion and silver-plated-copper filled elastomers exhibit more. (See Table III).

Tables of galvanic potential do not accurately predict the corrosivity of metal-filled conductive elastomers because of the composite nature of these materials. Also, these tables do not measure directly two important aspects of conductive elastomer "corrosion resistance": 1) the corrosion of the mating metal flange and 2) the retention of conductivity by the elastomer after exposure to a corrosive environment.

Table III

CORROSION POTENTIALS OF VARIOUS METALS AND EMI GASKET MATERIALS *(in 5% NaCl at 21°C after 15 minutes of immersion)*

Material	E_{corr} vs. SCE* (Millivolts)
Pure Silver	–25
Silver-filled elastomer	–50
Monel mesh	–125
Silver-plated-copper filled elastomer	–190
Silver-plated-aluminum filled elastomer	–200
Copper	–244
Nickel	–250
Tin-plated Beryllium-copper	–440
Tin-plated copper-clad steel mesh	–440
Aluminum* (1100)	–730
Silver-plated-aluminum filled elastomer (die-cut edge)	–740

*Standard Calamel Electrode. Aluminum Alloys approximately –700 to –840 mV vs. SCE in 3% NaCl. Mansfield, F. and Kenkel, J.V., *"Laboratory Studies of Galvanic Corrosion of Aluminum Alloys,"* **Galvanic and Pitting Corrosion – Field and Lab Studies**, ASTM STP 576, 1976, pp. 20-47.

Instead of using a table of galvanic potentials, the corrosion caused by different conductive elastomers was determined directly by measuring the weight loss of an aluminum coupon in contact with the conductive elastomer (after exposure to a salt fog environment). The electrical stability of the elastomer was determined by measuring its resistance before and after exposure. Figure 14a describes the test fixture that was used. Figure 14b shows the aluminum weight loss results for several different silver-filled conductive elastomers. The aluminum weight loss shows a two order of magnitude difference between the least corrosive (1298 silver-plated-aluminum) and most corrosive (1215 silver-plated-copper) filled elastomers. For silver-containing elastomers, the filler

Figure 14a Test Fixture

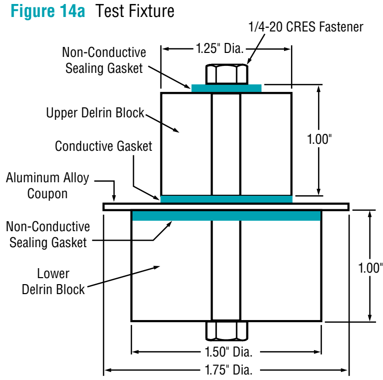


Figure 14b Average Weight Loss of CHO-SEAL Elastomers

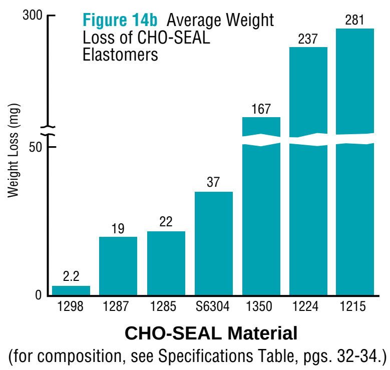


Figure 14c Weight Loss of 6061-T6 Aluminum Coupons in Contact with Conductive Elastomers During 168 hr. Salt Fog

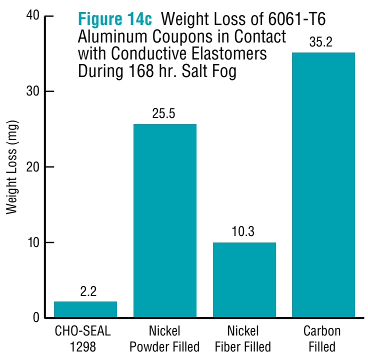
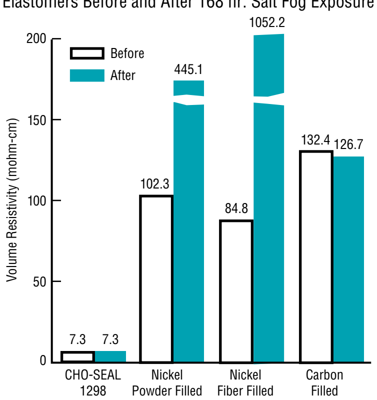


Figure 14d Volume Resistivity (mohm-cm) of Conductive Elastomers Before and After 168 hr. Salt Fog Exposure



substrate that the silver is plated on is the single most important factor in determining the corrosion caused by the conductive elastomer.

Figure 14c shows the weight loss results for nickel and carbon-filled elastomers compared to 1298. The nickel-filled materials are actually *more* corrosive than the silver-plated-aluminum filled elastomers. The carbon-filled materials are extremely corrosive.

Figure 14d compares the electrical stability of several conductive elastomers before and after salt fog exposure. In general, silver-containing elastomers are more electrically stable in a salt fog environment than nickel-containing elastomers.

Design Guides for Corrosion Control

The foregoing discussion is not intended to suggest that corrosion should be of no concern when flanges are sealed with silver-bearing conductive elastomers. Rather, corrosion control by and large presents the same problem whether the gasket is silver-filled, Monel wire-filled, or tin-plated. 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 may be generally tolerable) at the outer (unsealed) edges of a flange after long-term exposure to salt-fog 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.

The key to corrosion control in flanges sealed with EMI gaskets is proper design of the flange and gasket (and, of course, proper selection of the gasket material). A properly designed interface requires a moisture-sealing 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. It is important to note that magnesium is the least noble structural metal commonly used, and a silver-filled elastomer in contact with magnesium would theoretically produce an unacceptable couple.

Some specific design suggestions for proper corrosion control at EMI flanges are:

1. Select silver-plated-aluminum filled elastomers for best overall sealing and corrosion protection. CHO-SEAL 1298 material offers more corrosion resistance than any other silver-filled elastomer (see Figure 15, next page).

2. For aircraft applications, consider "seal-to-seal" designs, with same gasket material applied to both flange surfaces (see Figure 16).

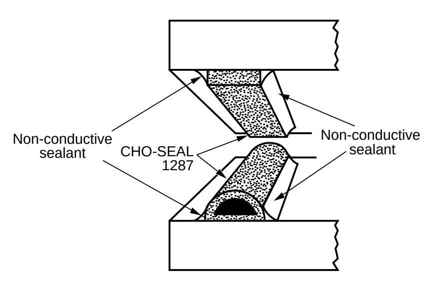


Figure 16 "Seal-to-seal" design incorporating CHO-SEAL® 1287 conductive silver-aluminum fluorosilicone gaskets on both mating flange surfaces. Gaskets are bonded and edge sealed to prevent moisture from entering the gasket/flange area.

3. To prevent corrosion on outside edges exposed to severe corrosive environments, use dual conductive/non-conductive gaskets (see page 55) or allow the non-conductive protective paint (normally applied to outside surfaces) to intrude slightly under the gasket (see Figure 17).

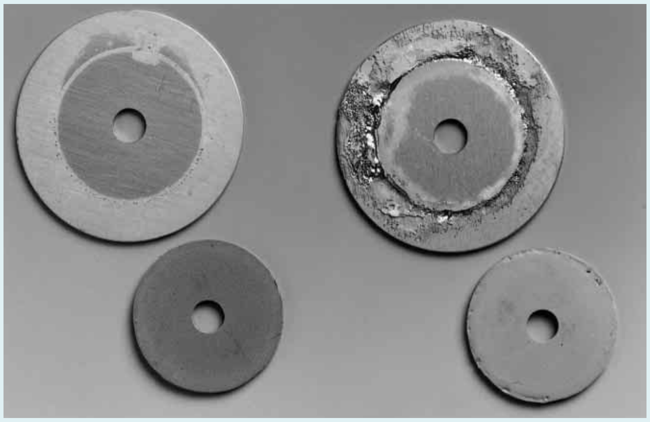


Figure 15 Comparison of corrosion results obtained from CHO-SEAL® 1298 conductive elastomer (left) and pure silver-filled elastomer (right) mated with aluminum after 168 hours of salt fog exposure.

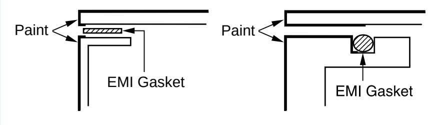


Figure 17 Non-Conductive Paint Intrudes Slightly Under Gasket to Provide Edge Protection

4. If moisture is expected to reach the flange interfaces in Class C (marine) environments, flange surfaces should be coated or plated to make them more compatible with the EMI gasket material. Chomerics' CHO-SHIELD 2000 series coatings are recommended for silver-filled elastomer or Monel wire gaskets, and tin plating for tin-plated gaskets.

5. Avoid designs which create sump areas.

6. Provide drainage and/or drain holes for all parts which would become natural sumps.

7. Provide dessicants for parts which will include sumps but cannot be provided with drain holes. Dessicant filters can also be provided for air intake.

8. Avoid sharp edges or protrusions.

9. Select proper protective finishes.

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 (e.g., airframe applications) 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 EMI-gasketed flanges might also require peripheral sealing as defined in MIL-STD-1250, MIL-STD-889 or MIL-STD-454. MIL-STD-1250 deserves special mention. Although it was developed many years prior to the availability of CHO-SEAL 1298 conductive elastomer and CHO-SHIELD 2000 series conductive coatings, it offers the following useful corrosion control methods applicable to electronic enclosures:

1. Bonds made by conductive gaskets or adhesives, and involving dissimilar contact, shall be sealed with organic sealant.

2. When conductive gaskets are used, provision shall be made in design for environmental and electromagnetic seal. Where practical, a combination gasket with conductive metal encased in resin or elastomer shall be preferred.

3. Attention is drawn to possible moisture retention when sponge elastomers are used.

4. Because of the serious loss in conductivity caused by corrosion, special precautions such as environmental seals or external sealant bead shall be taken when wire mesh gaskets of Monel or silver are used in conjunction with aluminum or magnesium.

5. Cut or machined edges of laminated, molded, or filled plastics shall be sealed with impervious materials.

6. Materials that "wick" or are hygroscopic (like sponge core mesh gaskets) shall not be used.

7. In addition to suitability for the intended application, nonmetallic materials shall be selected which have the following characteristics:

a. Low moisture absorption;

b. Resistance to fungi and microbial attack;

c. Stability throughout the temperature range;

d. Freedom from outgassing;

e. Compatibility with other materials in the assembly;

f. Resistance to flame and arc;

g. For outdoor applications, ability to withstand weathering.

Selection of Seal Cross Section

Selection of the proper conductive elastomer gasket cross section is largely one of application, compromise, and experience with similar designs used in the past. Some general rules, however, can be established as initial design guidelines in selecting the class of gasket to be used.

1. Flat Gaskets

When using flat gaskets, care must be taken not to locate holes closer to the edge than the thickness of the gasket, or to cut a web narrower than the gasket thickness. This is not to be confused with the criteria for punching holes in sheet metal parts discussed earlier.

Keep in mind also that flat gaskets should not be deflected more than about 10 percent, compared with 15 to 30 percent for molded and solid extruded gaskets and 50% for hollow gaskets. Standard thicknesses for flat gaskets are 0.020, 0.032, 0.062, 0.093 and 0.125 in. (see General Tolerances on page 204.)

Where possible, the flange should be bent outward so that the screws or bolts do not penetrate the shielded compartment (see Figure 18a). If the flange must be bent inward to save space, the holes in the gasket must fit snugly around the threads of the bolts to prevent leakage along the threads and directly into the compartment. This calls for closely toleranced holes and accurate registration between the holes in the flange and the holes in the gasket, and would require machined dies (rather than rule dies) to produce the gasket. An alternate solution can be achieved by adding an EMI seal under the heads of bolts penetrating the enclosure, or by using an insert similar to an acorn nut that has been inserted in the flange and flared to make the joint RF-tight. "Blind nuts" can also be welded or attached with a conductive epoxy adhesive (see Figure 18b).

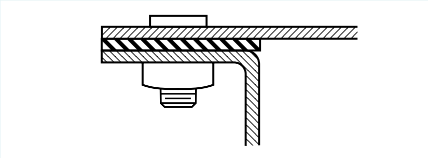


Figure 18a External Bolting Prevents EMI Leakage

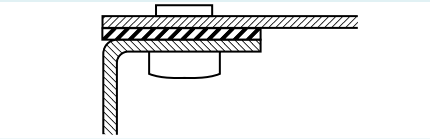


Figure 18b Insert Pressed-In and Flared Makes EMI Tight Joint (Alternate: Weld or Cement with Conductive Epoxy)

2. Shaped or Molded Gaskets

Groove designs for O- or D-shaped configurations are effective because gasket deflection can be controlled and larger deflections can be accommodated. O-ring cross sections are preferred because they can be deflected more easily under a given load. D-shapes or rectangular cross sections are excellent for retrofit applications because they can be made to accommodate almost any groove cross section. Groove designs also provide metal-to-metal flange contact, and require fewer fasteners, thereby minimizing the number of paths where direct leakage can occur.

Fasteners should be located such that pressure distribution is uniform at the corners (see Figure 19).

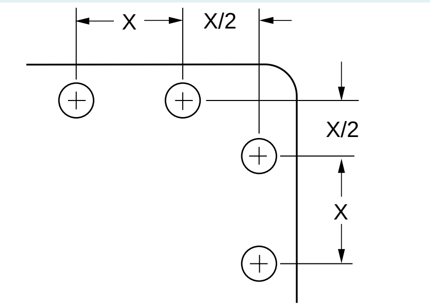
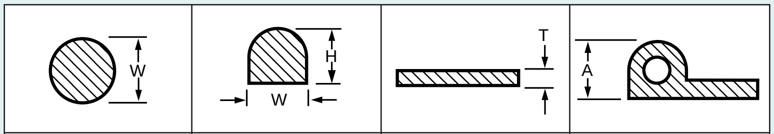


Figure 19 Fastener Location Near Corners



Deflection Range	W Dia.	Deflection Range	H	Deflection Range	T	Deflection Range	A
0.007-0.018 (0.178-0.457)	0.070 (1.778)	0.006-0.012 (0.152-0.305)	0.068 (1.727)	0.001-0.002 (0.025-0.051)	0.020 (0.508)	0.025-0.080 (0.635-2.032)	0.200 (5.08)
0.010-0.026 (0.254-0.660)	0.103 (2.616)	0.008-0.016 (0.203-0.406)	0.089 (2.261)	0.001-0.003 (0.025-0.076)	0.032 (0.813)	0.030-0.125 (0.762-3.175)	0.250 (6.35)
0.013-0.031 (0.330-0.787)	0.125 (3.175)	0.012-0.024 (0.305-0.610)	0.131 (3.327)	0.003-0.006 0.076-0.152)	0.062 (1.575)	0.075-0.250 (1.905-6.35)	0.360 (9.144)
0.014-0.035 (0.356-0.889)	0.139 (3.531)	0.014-0.029 (0.356-0.737)	0.156 (3.962)	0.003-0.009 (0.076-0.229)	0.093 (2.362)		
		0.016-0.032 (0.406-0.813)	0.175 (4.445)				

Figure 20 Gasket Deflection Ranges (mm dimensions in parentheses)

3. Hollow Gaskets

Hollow gasket configurations are very useful when large gaps are encountered, or where low closure forces are required. Hollow gaskets are often less expensive, and they can be obtained with or without attachment tabs. Hollow gaskets with tabs are referred to in the text and in the tables as "P-gaskets". The minimum wall thickness of hollow gaskets is 0.020 in. depending on material. Contact Chomerics' Applications Department for details. Hollow gaskets will compensate for a large lack of uniformity between mating surfaces because they can be compressed to the point of eliminating the hollow area.

4. Compression Limits

When compression cannot be controlled, compression stops should be provided to prevent gasket rupture caused by over-compression. Grooves provide built-in compression stops. Figure 20 gives nominal recommended compression ranges for CHO-SEAL and CHO-SIL materials, assuming standard tolerances.

5. Elongation

The tensile strength of conductive elastomer gaskets is not high. It is good practice to limit elongation to less than 10 percent.

6. Splicing

When grooves are provided for gasket containment, two approaches are possible. A custom gasket can be molded in one piece and placed into the desired groove, or a strip gasket can be spliced to length and fitted to the groove. To properly seat a spliced solid "O" cross section gasket, the inner radius of the groove at the corners must be equal to or greater than the gasket cross section width. Other cross sections need greater inner radius and may not be practical due to twisting when bent around corners. Splices can be simply butted (with no adhesive) or bonded with a conductive or non-conductive compound. If it has been decided that a spliced gasket will provide a satisfactory seal, the decision between splicing and molding should be based on cost. When a standard extrusion is available, splicing is generally recommended. For custom extrusions, splicing is generally more cost effective in quantities over 500 feet.

7. Gasket Limitations Imposed by Manufacturing Methods

Current manufacturing technology limits conductive elastomer gasket configurations to the following dimensions and shapes :

- ***Die-cut Parts***

  Maximum Overall Size: 32 in. long x 32 in. wide x 0.125 in. thick (81 cm x 81 cm x 3.18 mm)

  Minimum Cross Section: Width-to-thickness ratio 1:1 (width is not to be less than the thickness of the gasket).

- ***Molded Parts***
  Currently available in any solid cross section, but not less than 0.040 in. in diameter. The outer dimensions of the gasket are limited to 34 inches in any direction. Larger parts can be made by splicing. Molded parts will include a small amount of flash (0.008 in. width and 0.005 in. thickness, maximum).
- ***Extruded Parts***
  No limitation on length. Minimum solid cross-section is limited to 0.028 in. extrusions. Wall thickness of hollow extrusions varies with material but 0.020 in. can be achieved with most materials.

8. General Tolerances

The following tables provide general tolerances for conductive elastomer gaskets. It is important to note that all flat die-cut, molded, and extruded gaskets are subject to free-state variation in the unrestrained condition. The use of inspection fixtures to verify conformance of finished parts is common and recommended where appropriate.

Also note that "Over-all Dimensions" for flat die-cut gaskets and molded gaskets includes any feature-to-feature dimensions (e.g., edge-to-edge, edge-to-hole, hole-to-hole).

FLAT DIE-CUT GASKETS *inch (mm)*	TOLERANCE
Overall Dimensions	
≤10 (254)	±0.010 (0.25)
>10 to ≤15 (254 to 381)	±0.020 (0.51)
>15 (>381)	±0.20% Nom. Dim.
Thickness	
0.020 (0.51)	±0.004 (0.10)
0.032 (0.81)	±0.005 (0.13)
0.045 (1.14)	±0.006 (0.15)
0.062 (1.57)	±0.007 (0.18)
0.093 (2.36)	±0.010 (0.25)
0.125 (3.18)	±0.010 (0.25)
>0.125 (>3.18)	Contact a Chomerics Applications or Sales Engineer
Hole Diameters	
>0.060 (1.52) dia. if sheet thickness is...	
≤0.062 (1.57)	±0.005 (0.13)
>0.062 (1.57)	±0.008 (0.20)

MOLDED GASKETS *inch (mm)*	TOLERANCE
Overall Dimensions	
0.100 to 1.500 (2.54 to 38.10)	±0.010 (0.25)
1.501 to 2.500 (38.13 to 63.50)	±0.015 (0.38)
2.501 to 4.500 (63.53 to 114.30)	±0.020 (0.51)
4.501 to 7.000 (114.33 to 177.80)	±0.025 (0.64)
>7.000 (>177.80)	±0.35% Nom. Dim.
Cross Section	
0.040 to 0.069 (1.02 to 1.75)	±0.003 (0.08)
0.070 to 0.100 (1.78 to 2.54)	±0.004 (0.11)
0.101 to 0.200 (2.57 to 5.08)	±0.005 (0.13)
0.201 to 0.350 (5.11 to 8.89)	±0.008 (0.20)
Flash Tolerance	0.005 (0.13) Max.Thickness 0.008 (0.20) Max. Extension

EXTRUDED STRIP GASKETS *inch (mm)*	TOLERANCE
Cut Length	
<1.000 (25.40)	±0.010 (0.25)
1.0 to 30.000 (25.40 to 762)	±0.062 (1.58)
> 30.000 (762)	±0.2% Nom. Dim.
Cross Section	
< 0.200 (5.08)	±0.005 (0.13)
0.200-0.349 (5.08-8.86)	±0.008 (0.20)
0.350-0.500 (8.89-12.70)	±0.010 (0.25)
> 0.500 (12.70)	±3% Nom. Dim.

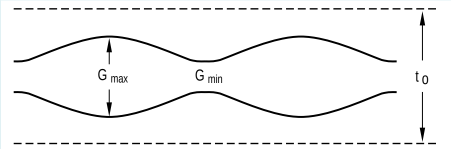
9. Gasket Cross Section Based on Junction Gaps

Gasket geometry is largely determined by the largest gap allowed to exist in the junction. Sheet metal enclosures will have larger variations than machined or die castings. The ultimate choice in allowable gap tolerance is a compromise between cost, performance and the reliability required during the life of the device. When a value analysis is conducted, it should be made of the entire junction, including the machining required, special handling, treatment of the surfaces and other factors required to make the junction functional. Often, the gasket is the least expensive item, and contributes to cost-effectiveness by allowing loosely-toleranced flanges to be made EMI-tight.

The maximum gap allowed to exist in a junction is generally determined by the minimum electrical performance expected of the seal. A secondary consideration must be given to the barrier as a pressure seal if gas pressures of significant magnitude are expected. The gasket will blow out if the pressure is too high for the gap.

The minimum gap allowed in the junction is determined by the allowable squeeze that can be tolerated by the gasket material. Deflection of conductive elastomer gaskets was given in Figure 20. Flat gaskets may be deflected as much as 6-10 percent (nominal), depending on initial thickness and applied force. O-shaped and D-shaped gaskets are normally deflected 10 to 25 percent; however, greater deflections can be achieved by manipulating cross section configuration.

Determination of the exact gasket thickness is a complex problem involving electrical performance, flange characteristics, fastener spacing and the properties of the gasket material. However, an initial estimate of the necessary thickness of a noncontained gasket can be determined by multiplying the difference in the expected minimum and maximum flange gaps by a factor of 4, as illustrated in Figure 21. A more detailed discussion, and a more accurate determination of gasket performance under loaded flange conditions, can be found in the Fastener Requirements section, page 206.

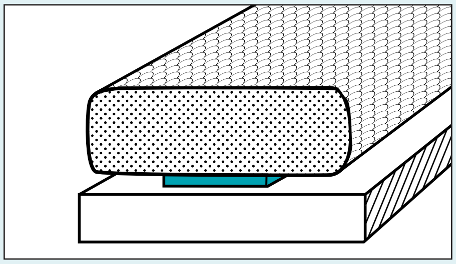


$t_O = 4\,(G_{max} - G_{min})$
(t_O = Original thickness of gasket)

Figure 21 Gasket Deflection Along a Flange

Gasket Mounting Choices

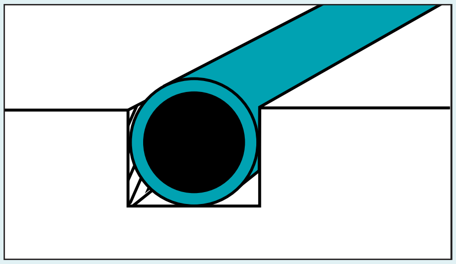
Our various EMI gasket mounting techniques offer designers cost-effective choices in both materials and assembly. These options offer aesthetic choices and accommodate packaging requirements such as tight spaces, weight limits, housing materials and assembly costs. Most Chomerics gaskets attach using easily repairable systems. Our Applications Engineering Department or your local Chomerics representative can provide full details on EMI gasket mounting. The most common systems are shown here with the available shielding products.



Pressure-Sensitive Adhesive

Quick, efficient attachment strip

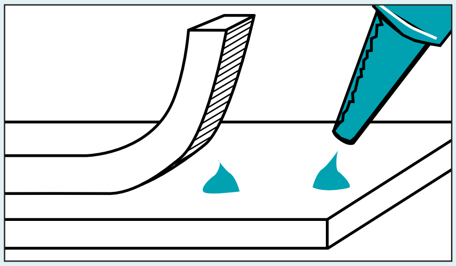
- Conductive Elastomers
- SOFT-SHIELD
- SPRING-LINE
- POLASHEET
- POLASTRIP



Friction Fit in a Groove

Prevents over-deflection of gasket
Retaining groove required

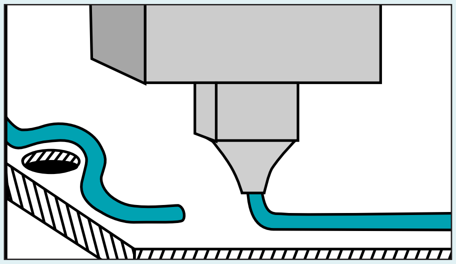
- Conductive Elastomers
- SOFT-SHIELD
- MESH STRIP
- POLASTRIP
- SPRINGMESH



Adhesive Compounds

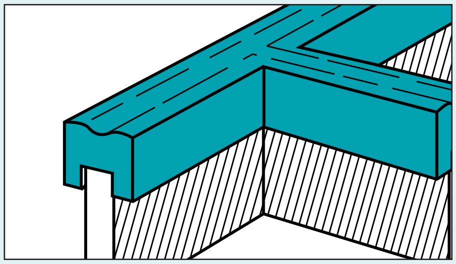
Conductive or non-conductive spot bonding

- Conductive Elastomers
- MESH STRIP



Robotically Dispensed Form-in-Place Conductive Elastomer

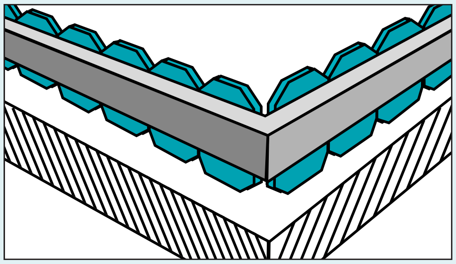
Chomerics' Cho-Form® automated technology applies high quality conductive elastomer gaskets to metal or plastic housings. Manufacturing options include Chomerics facilities, authorized Application Partners, and turnkey systems.



Friction Fit on Tangs

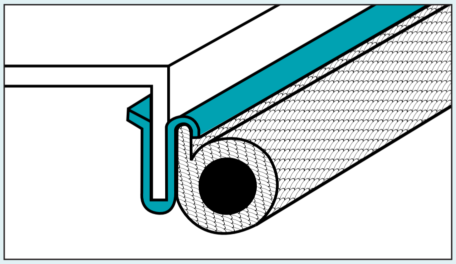
Accommodates thin walls, intricate shapes

- Conductive Elastomers



Spacer Gaskets

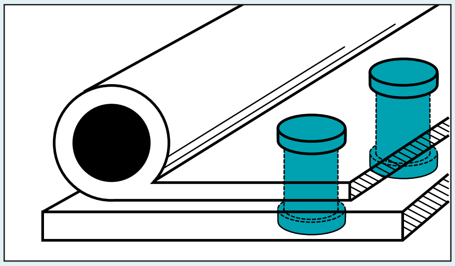
Fully customized, integral conductive elastomer and plastic spacer provide economical EMI shielding and grounding in small enclosures. Locator pins ensure accurate and easy installation, manually or robotically.



Metal Clips

Teeth bite through painted panels
Require knife edge mounting flange

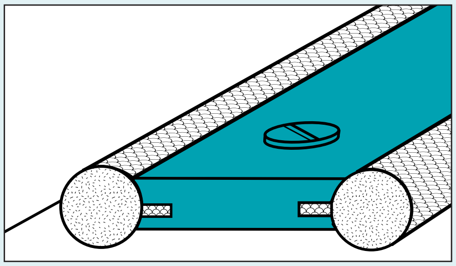
- Conductive Elastomers
- METALKLIP
- SPRING-LINE



Rivets/Screws

Require integral compression stops
Require mounting holes on flange

- Conductive Elastomers
- SPRING-LINE
- SHIELDMESH
- COMBO STRIP



Frames

Extruded aluminum frames and strips add rigidity. Built-in compression stops for rivets and screws.

- Conductive Elastomers
- MESH STRIP

Fastener Requirements

1. Applied Force

Most applications do not require more than 100 psi (0.69 MPa) to achieve an effective EMI seal. Waveguide flanges often provide ten times this amount. Hollow strips require less than 10 pounds per in. Compression deflection data for many shapes, sizes and materials is included in the Performance Data section of this handbook.

The force required at the point of least pressure, generally midway between fasteners, can be obtained by using a large number of small fasteners spaced closely together. Alternatively, fasteners can be spaced further apart by using stiffer flanges and larger diameter bolts. Sheet metal parts require more fasteners per unit length than castings because they lack stiffness.

To calculate average applied force required, refer to load-deflection curves for specific gasket materials and cross sections (see Performance Data, page 80).

2. Fastener Sizes and Spacing

Fastener spacing should be determined first. As a general rule, fasteners should not be spaced more than 2.0 inches (50 mm) apart for stiff flanges, and 0.75 inch (19 mm) apart for sheet metal if high levels of shielding are required. An exception to the rule is the spacing between fasteners found in large cabinet doors, which may vary from 3 inches (76.02 mm) between centers to single fasteners (i.e., door latches). The larger spacings are compensated for by stiffer flange sections, very large gaskets, and/or some reduction in electrical performance requirements.

The force per bolt is determined by dividing the total closure force by the number of bolts. Select a fastener with a stress value safely below the allowable stress of the fastener.

3. Flange Deflection

The flange deflection between fasteners is a complex problem involving the geometry of the flange and the asymmetrical application of forces in two directions. The one-dimensional solution, which treats the flange as a simple beam on an elastic foundation, is much easier to analyze[1] and gives a good first order approximation of the spacings required between fasteners, because most EMI gaskets are sandwiched between compliant flanges.

Variation in applied forces between fasteners can be limited to ±10 percent by adjusting the constants of the flange such that

$$\beta d = 2,$$

where

$$\beta = \sqrt[4]{\frac{k}{4 E_f I_f}}$$

where

k = foundation modulus of the seal

E_f = the modulus of elasticity of the flange

I_f = the moment of inertia of the flange and seal

d = spacing between fasteners

The modulus of elasticity (E_f) for steel is typically 3 x 10^7. The modulus for aluminum is typically 1 x 10^7, and for brass it is about 1.4 x 10^7.

The foundation modulus (k) of seals is typically 10,000 to 15,000 psi.

The moment of inertia (I_f) of rectangular sections, for example, may be obtained from the following expression[2]:

$$I_f = \frac{bh^3}{12}$$

where

b is the width of the flange in contact with the gasket (inches) and

h is the thickness of the flange (inches).

Example

Calculate the bolt spacings for flanges with a rectangular cross-section, such as shown in Figure 22,

where

h is the thickness of the flange.

b is the width of the flange.

d is the spacing between fasteners.

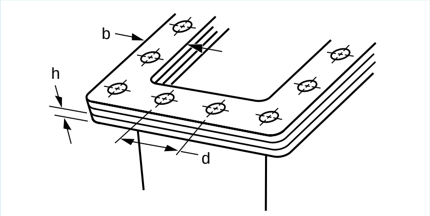


Figure 22 Bolt Spacings for Flanges

Assume the flange is to be made of aluminum.

To maintain a pressure distribution between bolts of less than ±10 percent, ßd must be equal to 2 (see Figure 23 and discussion).

Assume an average foundation modulus (k) of 12,500 psi for the seal. If the actual modulus is known (stress divided by strain), substitute that value instead.

The bolt spacings for aluminum flanges for various thicknesses and widths have been calculated for the previous example and are shown in Figure 24.

The previous example does not take into account the additional stiffness contributed by the box to which the flange is attached, so the results are somewhat conservative.

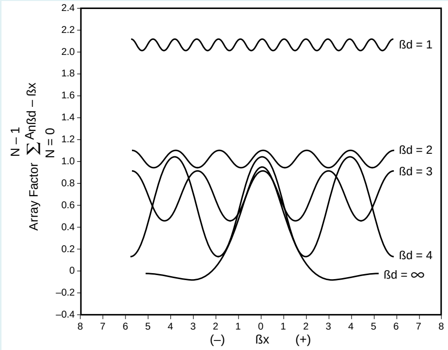


Figure 23 Array Factor vs. Spacing

References

1. Galagan, Steven, *Designing Flanges and Seals for Low EMI*, **MICROWAVES**, December 1966.

2. Roark, R.J., *Formulas for Stress and Strain,* McGraw-Hill, 4th Ed., p. 74.

Actual deflection vs. distance between fasteners may be computed from the following expression:

$$y = \frac{\beta p}{2k} \sum_{n=0}^{N-1} A_{n\beta d - \beta x}$$

where p is the force applied by the fastener, and β and k are the constants of the flange as determined previously. N represents the number of bolts in the array.

The array factor denoted by the summation sign adds the contribution of each fastener in the array. The array factor for various bolt spacings (βd) is shown in Figure 23. Although any value can be selected for βd, a practical compromise between deflection, bolt spacing and electrical performance is to select a bolt spacing which yields a value βd equal to 2.

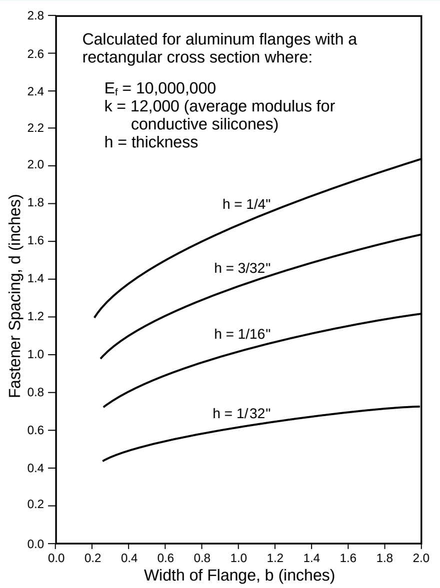


Figure 24 Fastener Spacing

For βd = 2, the flange deflection fluctuates by ±10 percent. Minimum deflection occurs midway between fasteners and is 20 percent less than the deflection directly under the fasteners. The variation in deflection is approximately sinusoidal.

Table IV lists a few recommendations for bolts and bolt spacings in various thin cross section aluminum flanges.

Bolt spacings for waveguide flanges are fixed by Military and EIA Standards. Waveguide flanges normally have bolts located in the middle of the long dimension of the flange because the flow of current is most intense at this point.

Table IV

SCREW SIZE	℄-TO-℄ (in.)	THICKNESS (in.)	MAX. TORQUE TO PREVENT STRIPPING FOR UNC-2A THREAD (in.-lbs.)
#2	⅜	0.062	4.5
#4	¾	0.125	10.0
#6	1	0.125	21.0
#8	1¼	0.156	37.5
#10	1⅜	0.156	42.5

4. Common Fasteners

Many different types of fasteners are available, but bolts are the most widely used fastening devices. The approximate torque required to apply adequate force for mild steel bolts is shown in Table V.

These values are approximate and will be affected by the type of lubricants used (if any), plating, the type of washers used, the class and finish of the threads, and numerous other factors.

The final torque applied to the fasteners during assembly should be 133 percent of the design value to overcome the effect of stress-relaxation. When torqued to this value, the gasket will relax over a period of time and then settle to the design value.

Torque may be converted to tension in the bolts by applying the formula

$$\text{Tension} = \frac{\text{Torque}}{0.2 \times \text{Bolt Dia.}}$$

Frequently the rule of thumb value of 0.2 for the coefficient of friction can result in torque and bolt estimates which may be seriously in error. Excessive bolt preload may lead to RF leakage. Therefore, if lubricants are used for any reason, refer to the literature[3] for the proper coefficient values to be applied.

In soft materials, such as aluminum, magnesium and insulating materials, inserts should be provided if the threads are "working threads." A thread is considered a "working thread" if it will be assembled and disassembled ten or more times.

Torque loss caused by elongation of stainless steel fasteners should also be considered. High tensile strength hardware is advised when this becomes a problem, but care must be taken of the finish specified to minimize galvanic corrosion.

Thermal conductivity of high tensile strength hardware is lower than most materials used in electro-mechanical packaging today, so

Table V

RECOMMENDED TORQUE VALUES FOR MILD STEEL BOLTS

Size	Threads per in.	Max. Recommended Torque (in.-lbs.)	Max. Recommended Tension* (lbs.)	Basic Pitch Dia.(inches)
#4	40	4 3/4		0.0958
	48	6		0.0985
#5	40	7		0.1088
	44	8 1/2		0.1102
#6	32	8 3/4		0.1177
	40	11		0.1218
#8	32	18		0.1437
	36	20		0.1460
#10	24	23		0.1629
	32	32		0.1697
1/4"	20	80	1840	0.2175
	28	100	2200	0.2268
5/16"	18	140	2530	0.2764
	24	150	2630	0.2854
3/8"	16	250	3740	0.3344
	24	275	3950	0.3479
7/16"	14	400	5110	0.3911
	20	425	5250	0.4050
1/2"	13	550	6110	0.4500
	20	575	6150	0.4675
9/16"	12	725	7130	0.5084
	18	800	7600	0.5264
5/8"	11	1250	11,040	0.5660
	18	1400	11,880	0.5889

$$^{*}\ \text{Tension} = \frac{\text{Torque}}{0.2 \times \text{Diameter of Bolt}^{\dagger}}$$

† Basic Pitch Diameter

3. Roehrich, R.L., *Torquing Stresses in Lubricated Bolts*, **Machine Design**, June 8, 1967, pp. 171-175.

that the enclosure expands faster than the hardware and usually helps to tighten the seal. Should the equipment be subjected to low temperatures for long periods of time, the bolts may require tightening in the field, or can be pretightened in the factory under similar conditions.

Under shock and vibration, a stack up of a flat washer, split helical lockwasher and nut are the least reliable, partly because of elongation of the stainless steel fasteners, which causes the initial loosening. The process is continued under shock and vibration conditions. Elastic stop nuts and locking inserts installed in tapped holes have proven to be more reliable under shock and vibration conditions, but they cost more and are more expensive to assemble.

5. Electrical Performance as a Function of Fastener Spacing

The electrical performance (shielding effectiveness) provided by a gasket sandwiched between two flanges and fastened by bolts spaced d distance apart is equivalent to the shielding effectiveness obtained by applying a pressure which is the arithmetic mean of the maximum and minimum pressure applied to the gasket under the condition that the spacing between fasteners is considerably less than a half wavelength. For bolt spacings equal to or approaching one-half wavelength at the highest operating frequency being considered, the shielding effectiveness at the point of least pressure is the governing value.

For example, assume that a gasket is sandwiched between two flanges which, when fastened together with bolts, have a value of βd equal to 2. Figure 23 shows that a value of $\beta d = 2$ represents a deflection change of ±10 percent about the mean deflection point. Because applied pressure is directly proportional to deflection, the applied pressure also varies by ±10 percent.

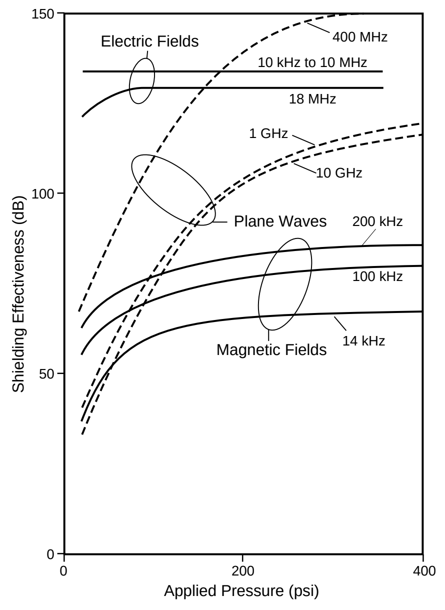


Figure 25 Shielding Effectiveness vs. Applied Pressure

Shielding effectiveness values for typical silver-plated-copper filled, die-cut gaskets as a function of applied pressure are shown in Figure 25. The curves show that the shielding effectiveness varies appreciably with applied pressure, and changes as a function of the type of field considered. Plane wave attenuation, for example, is more sensitive to applied pressure than electric or magnetic fields.

Thus, in determining the performance to be expected from a junction, find the value for an applied pressure which is 10 percent less (for $\beta d = 2$) than the value exerted by the bolts directly adjacent to the gasket. For example, examine a portion of a typical gasket performance curve as shown in Figure 26.

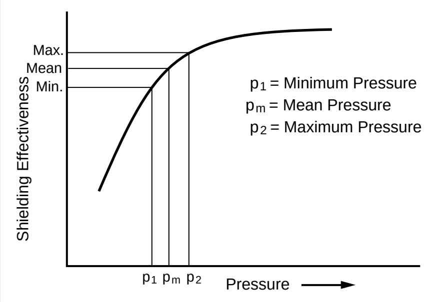


Figure 26 Typical Gasket Performance Curve

The average shielding effectiveness of the gasketed seam is a function of the mean applied pressure, p_m.

For spacings which approach or are equal to one-half wavelength, the shielding effectiveness is a function of the minimum pressure, p_1. Therefore, the applied pressure must be 20 percent higher to achieve the required performance. For this condition, the space between the fasteners can be considered to be a slot antenna loaded with a lossy dielectric. If the slot is completely filled, then the applied pressure must be 20 percent higher as cited. Conversely, if the slot is not completely filled (as shown in Figure 27), the open area will be free to radiate energy through the slot.

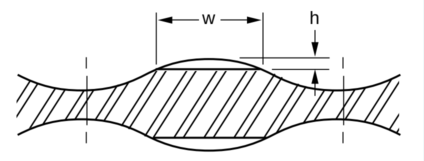


Figure 27 Unfilled Slot is Free to Radiate When Spacing is Equal to 1/2 Wavelength

The cut-off frequency for polarizations parallel to the long dimension of the slot will be determined by the gap height, h. The cut-off frequency for the polarization vector perpendicular to the slot will be determined by the width of the slot, w. The attenuation through the slot is determined by the approximate formula

$$A(dB) = 54.5\ d/\lambda_c$$

where

d = the depth of the slot,

and

λ_c is equal to 2w or 2h, depending upon the polarization being considered.

This example also illustrates why leakage is apt to be more for polarizations which are perpendicular to the seam.

For large values of βd, the percentage adjustments must be even greater. For example, the percentage increase required to satisfy βd = 3 is 64 percent. It is desirable, therefore, that βd should be kept as small as possible. This can be achieved by using stiff flanges or spacing bolts closer together.

Designing a Solid-O Conductive Elastomer Gasket-in-a-Groove

The *solid-O profile* is the most often specified conductive elastomer EMI gasket for several key reasons. Compared to other solid cross sections, it offers the widest deflection range to compensate for poorly toleranced mating surfaces and to provide reliable EMI shielding and pressure sealing. It can be installed in a relatively small space, and is the most easily installed and manufactured. It also tends to be less prone to damage, due to the absence of angles, corners or other cross section appendages.

The *"gasket-in-a-groove"* design offers five significant advantages over surface-mounted EMI gaskets:

1. Superior shielding, due to substantial metal-to-metal contact achieved when the mating surfaces are bolted together and "bottom out". (Flat die-cut gaskets prevent metal-to-metal contact between mating flange members, which reduces EMI shielding performance – especially in low frequency magnetic fields.)

2. Positive control over sealing performance. Controlling the size of the gasket and groove can ensure that required shielding and sealing are achieved with less careful assembly than is required for flat gaskets. In other words, the gasket-in-a-groove is more foolproof.

3. Built-in compression stop provided by the groove eliminates the risk of gasket damage due to excessive compression.

4. A gasket retention mechanism can be provided by the groove, eliminating the need for adhesives or mounting frames.

5. High current-handling characteristics of the metal-to-metal flange design improves the EMP and lightning protection offered by an enclosure.

This section presents the method for calculating groove and gasket dimensions which will permit the shielding system to function under worst-case tolerance conditions. Adherence to these general guidelines will result in optimum shielding and sealing for typical electronics "boxes". It should be understood that they may not be suitable for designing shielding for sheet metal cabinets, doors, rooms or other large, unconventional enclosures.

Important Notes: The guidelines presented here are intended to consider only "solid O" gasket cross sections. The calculations for hollow O, solid and hollow D, and custom gasket cross sections differ from these guidelines in several key areas.

Chomerics generally does not recommend bonding solid O gaskets in grooves. If for some reason your design requires gasket retention, contact Chomerics' Applications Engineering Department for specific recommendations, since the use of adhesives, dove-tailed grooves or "friction-fit" techniques require special design considerations not covered here.

Extreme design requirements or unusually demanding specifications are also beyond the scope of the guidelines presented here. Examples would include critical specifications for pressure sealing, exceptionally high levels of EMI shielding, exceptional resistance to corrosion, harsh chemicals, high temperatures, heavy vibration, or unusual mounting and assembly considerations.

Mechanical Considerations

Causes of Seal Failure

In order to produce a gasket-in-a-groove system which will not fail, the designer must consider three mechanical causes of seal failure:

- *gasket over-deflection* and associated damage (see Figure 28d)
- *gasket under-deflection* and loss of seal (see Figure 28f)
- *groove over-fill*, which can destroy the gasket (see Figure 28e).

Designing to avoid these problems is made more complicated by the effects of:

- *worst-case tolerance conditions*
- *deformation of the cover* (cover bowing)
- *poor fit of mating surfaces*.

The key to success involves selection of the appropriate gasket size and material, and careful design of the corresponding groove.

Deflection Limits

In nearly every solid-O application, Chomerics recommends a *minimum deflection of 10% of gasket diameter.* This includes adjustments for all worst-case tolerances of both the gasket and groove, cover bowing, and lack of conformity between mating surfaces. We recommend a *maximum gasket deflection of 25% of gasket diameter*, considering all gasket and groove tolerances.

Although sometimes modified to accommodate application peculiarities, these limits have been established to allow for stress relaxation, aging, compression set, elastic limits, thermal expansion, etc.

Maximum Groove Fill

Solid elastomer gaskets (as opposed to foam rubber gaskets) seal by changing shape to conform to mating surfaces. They *cannot* change volume. The recommended limit is *100% groove fill under worst-case tolerances of both gasket and groove.* The *largest* gasket cross sectional area must fit into the *smallest* cross sectional groove area.

Analyzing Worst-Case Tolerances

Figures 28a-c illustrate the issues of concern, and identify the parameters which should be considered in developing an effective design.

Figures 28d and e illustrate two different cases which can result in gasket damage in the area of torqued bolts. In Figure 28d, the relationship between groove depth and gasket diameter is critical in avoiding over-deflection. In Figure 28e, sufficient groove volume must be provided for a given gasket volume to permit the gasket to deflect without over-filling the groove.

As shown in *Figure 28f*, cover deformation and groove sizing must be controlled to make sure the gasket is sufficiently deflected to seal the system.

Since a single gasket and groove are employed for the entire perimeter, the design must be optimized for each of the worst-case examples illustrated in Figures 28d-f.

Figure 28a
Exploded View of Electronic Enclosure

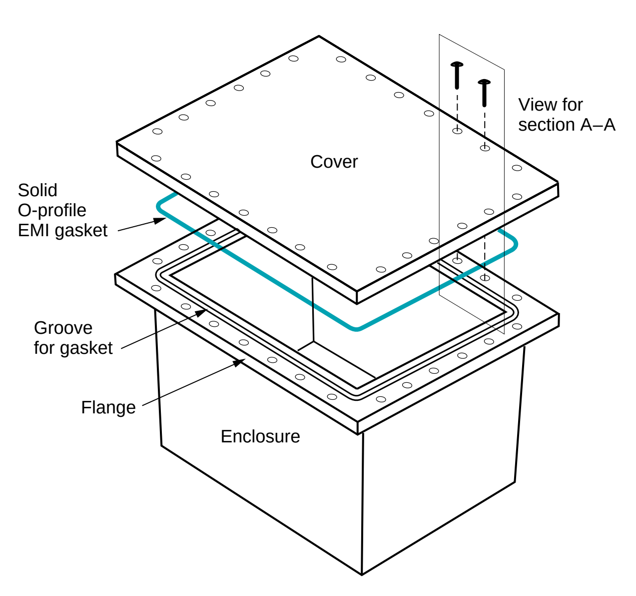


Figure 28b
Cut-away View of Assembly

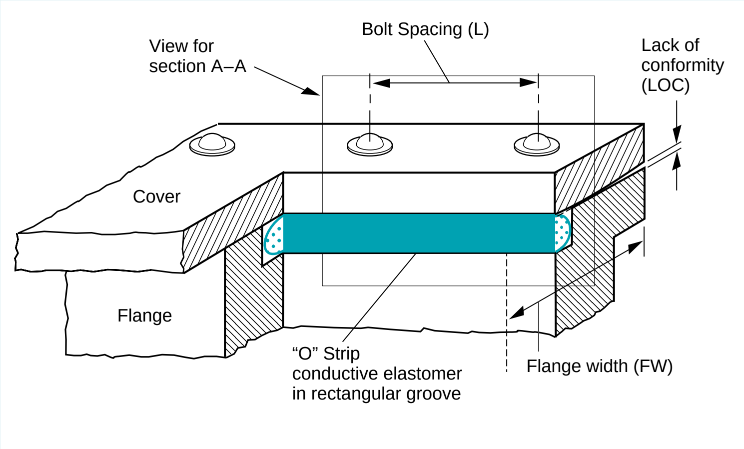


Figure 28c
Section A-A of Assembled Enclosure Flange and Gasket
(Sectioned midway through gasket and groove)

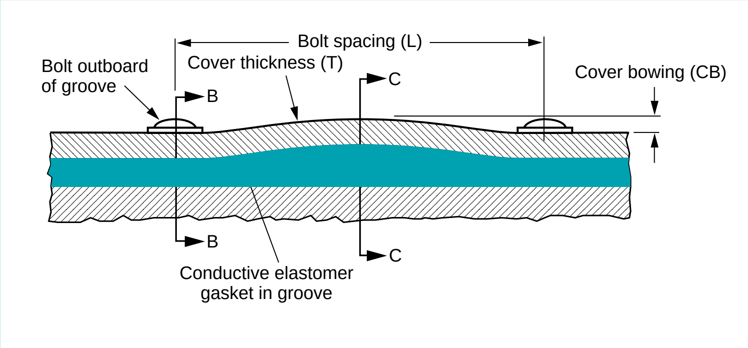


Figure 28d Section B-B from Figure 28c – Worst Case Maximum Deflection *(Maximum gasket diameter, minimum groove depth)*

Problem: Gasket too tall for minimum groove depth (deflection beyond elastic limit). Results in gasket damage or fracture.

Solution: Over-deflection avoided with smaller maximum gasket diameter and/or deeper minimum groove depth.

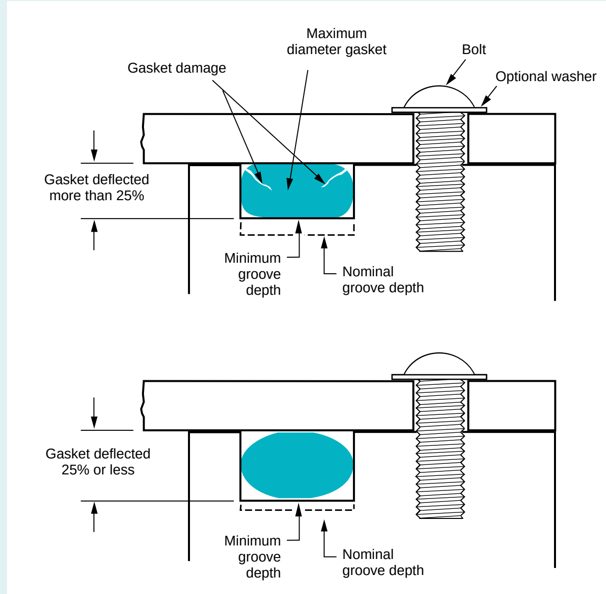


Figure 28e Section B-B from Figure 28c – Worst Case Maximum Groove Fill *(Maximum gasket diameter in minimum groove depth and width)*

Problem: Minimum groove dimension cannot accommodate maximum gasket diameter, resulting in gasket damage.

Solution: Groove over-fill avoided with smaller maximum gasket diameter and/or greater minimum groove depth and/or width.

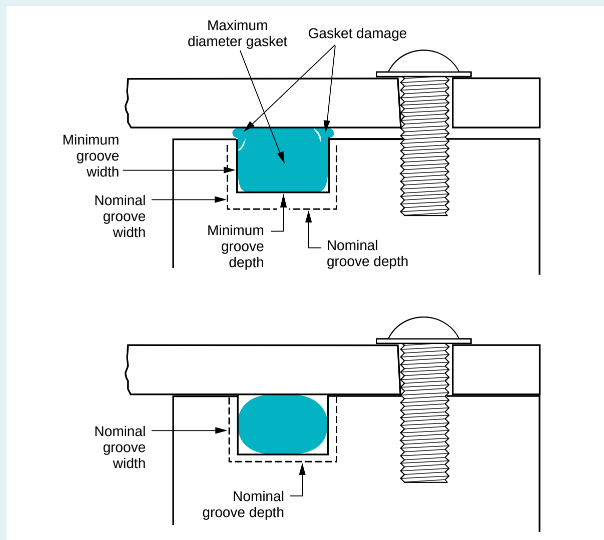
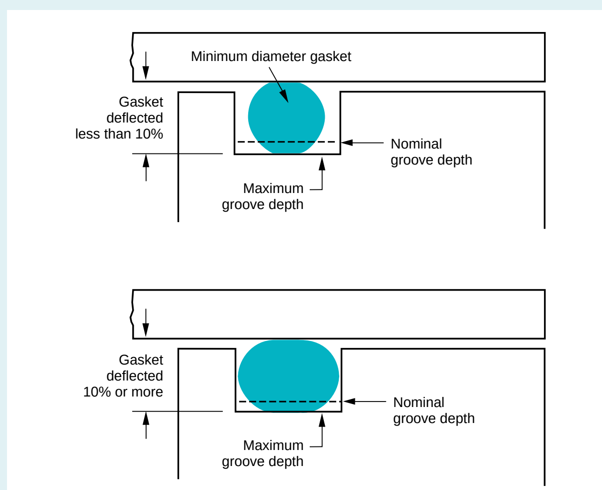


Figure 28f Section C-C from Figure 28c – Worst Case Minimum Deflection *(Minimum gasket diameter in maximum depth groove, aggravated by cover bowing and lack of conformity between mating surfaces)*

Problem: Gasket will not be deflected the recommended 10% minimum. Combined effects of tolerances, cover bowing, and lack of conformity can result in complete loss of cover-to-gasket contact over time, and consequent seal failure.

Solution: Under-deflection avoided with larger minimum gasket diameter and/or shallower maximum groove depth.



Calculating the Dimensions and Tolerances for the Groove and EMI Gasket

Figure 29 diagrams the calculation and decision sequence required to determine the dimensions for a properly designed solid-O gasket/groove system. Because the relationship between groove depth and gasket diameter is central to seal performance, *groove depth is selected as the key variable to determine first.*

Start by making an educated guess as to reasonable values for groove and gasket sizes and tolerances, based on desired nominal gasket deflection of 18%. For example, if 0.025 in. of gasket deflection is desired, start with a nominal gasket diameter of 0.139 in. This is calculated by dividing the desired total gasket deflection by 0.18 to estimate the required gasket size. (Total Gasket Deflection ÷ 0.18 = Approx. Nominal Gasket Size.) This relationship is an alternate form of Formula 1. Final groove dimensions can only be determined after completing all of the calculations called for in Figure 29, and arriving at values which remain within the recommended limits for gasket deflection and groove fill.

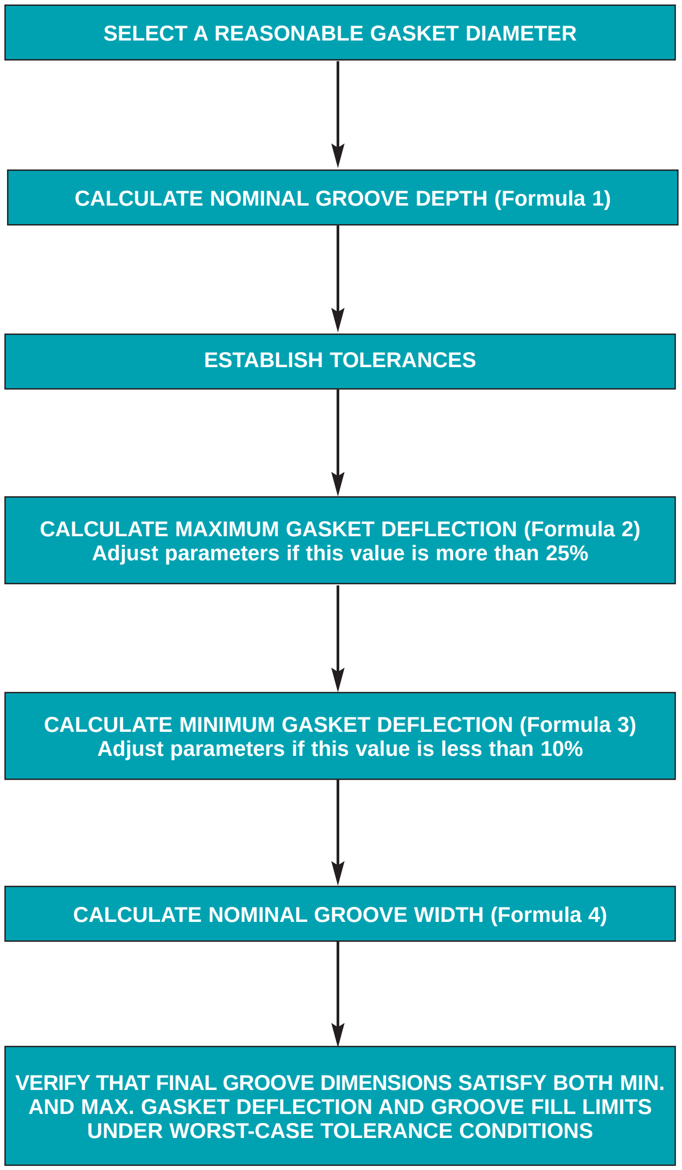


Figure 29 Procedure for Calculating Gasket and Groove Dimensions

Formulas *(see definition of terms at right)*

1. Nominal Groove Depth

$GrD_{nom} = 0.82\ GaD_{nom}$

2. Maximum Gasket Deflection

(Worst Case, expressed as a % of gasket diameter)

$$GaDf_{max} = 100\left[\frac{(GaD_{nom} + GaT) - (GrD_{nom} - GrDT)}{(GaD_{nom} + GaT)}\right]$$

3. Minimum Gasket Deflection

(Worst Case, expressed as a % of gasket diameter)

a. $$GaDf_{min} = 100\left[\frac{(GaD_{nom} - GaT) - (GrD_{nom} + GrDT) - CB - LOC}{(GaD_{nom} - GaT)}\right]$$

where

b. $$CB = \frac{GDF \times L^4_{max}}{FW_{min} \times T^3_{min} \times E \times 32}$$

(***Note:*** Formula must be adjusted when using metric units)

and

c. LOC = 0.001 in. for machined surfaces with surface roughness of 32-64 µin. RMS.

(For discussion, see Terms.)

4. Nominal Groove Width

a. $GaA_{max} = 0.7854^* (GaD_{nom} + GaT)^2$

b. $$GrW_{min} = \frac{GaA_{max}}{GrD_{min}}$$

c. $GrW_{nom} = GrW_{min} + GrWT$

*****Note:*** $0.7854 = \frac{\pi}{4}$

Terms

All values may be calculated in inches or mm unless otherwise indicated.

GaA_{max} – Maximum gasket cross section area (in^2 or mm^2)

GaD_{nom} – Nominal gasket diameter

GaT – Gasket tolerance (difference between max. and nom. or min. and nom.)

GrW_{min} – Minimum groove width

GrWT – Groove width tolerance

GrW_{nom} – Nominal groove width

GrD_{min} – Minimum groove depth

GrD_{nom} – Nominal groove depth

GrDT – Groove depth tolerance (difference between max. and nom. or min. and nom.)

$GaDf_{max}$ – Maximum gasket deflection (%)

$GaDf_{min}$ – Minimum gasket deflection (%)

L_{max} – Maximum bolt spacing

FW_{min} – Minimum flange width

T_{min} – Minimum cover thickness

GDF – Gasket deflection force (ppi or Newtons per meter).

Note: For the purpose of this guide, the GDF value should represent the worst-case minimum gasket deflection arising from cover bowing. For example, the GDF is taken at 10% deflection for the calculation in Formula 3b.

E – Young's modulus. (For aluminum, use 1×10^7 psi, or 7×10^5 kg/cm^2.)

CB – Cover bowing, generally calculated by modeling the elastic deformation of the cover as a uniformly loaded beam with two fixed supports. (The moment of inertia of the cover is modeled as a rectangular beam, the "height" of which is taken to be equal to the cover thickness, while "width" is considered equal to flange width. The moment of inertia can be adjusted for cover configurations other than flat. Refer to an engineering handbook for the necessary revisions to Formula 3b.) An assumption is made that one side of a cover/flange interface is infinitely stiff, typically the flange. If this is not essentially true, elastic deformation of each is computed as though the other were infinitely stiff, and the two values combined.

LOC – Lack of conformity, the measure of the mismatch between two mating surfaces when bolted together, expressed in inches. Experience has shown that machined surfaces with a surface roughness of 32-64 µin. RMS exhibit an LOC of 0.001 in. It is left to the engineer's judgment to determine LOC for other surfaces. LOC can be determined empirically from measurements made of actual hardware. In this guide, LOC applies only to the surfaces which form the EMI shielding interface.

EMI Shielding Plus Environmental/ Pressure Sealing

Some gasket applications require only restoration of the shielding integrity of an enclosure, and can be satisfied with Chomerics' simple MESH STRIP gasketing. In these cases, the use of MESH STRIP with Elastomer Core provides additional resiliency. Elastomer cored strips offer limited environmental sealing by positive blocking of dust and rain.

Additional environmental sealing or exclusion of ventilating air or vapor requires a gasket such as COMBO STRIP, which incorporates a smooth, easily compressed, elastomer sealing strip in parallel with the EMI shielding strip. When an appreciable pressure differential must be maintained between the interior and exterior of an enclosure, in addition to EMI protection, materials such as CHO-SEAL conductive elastomers or POLA gaskets should be used.

Gasket Attachment and Positioning

Substantial cost savings can result from the careful choice of gasket attachment or positioning method, which often determines the final choice of material.

A. Groove Capture This method is strongly recommended if a groove can be provided at relatively low cost, such as die-casting. (*Caution:* POLA-STRIP gaskets are essentially incompressible, although they seem to compress because the material flows while maintaining the same volume. Extra space must be allowed to permit the solid elastomer material to flow (see Figure 30).

B. Pressure-Sensitive Adhesive This is often the least expensive attachment method for mesh EMI gasket materials. Installation costs are dramatically reduced with only a slight increase in cost over gasketing

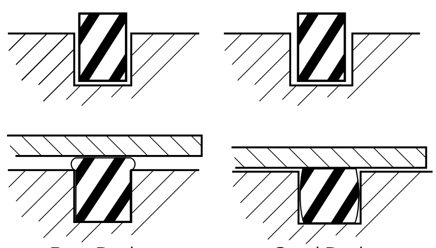


Figure 30 Allowing for Solid Elastomer Flow in Groove Capture Attachment Method

without adhesive backing. In many cases customers purchase COMBO STRIP or COMBO Gasket materials for applications which don't require environmental sealing, but utilize the adhesive-backed rubber portion as an inexpensive, temporary attachment method ("third hand") during installation.

C. Bond Non-EMI Portion of Gasket Non-conductive adhesives may be employed to bond an EMI gasket in position by applying adhesive to the portion that is *not the EMI gasket* (and which can be insulated from the mating surfaces by a non-conductive material).

Note: When specifying non-conductive adhesive attachment, applicable drawings and standard procedures for production personnel should emphasize that the adhesive is to be applied only to the portion of the gasket which is not involved with the EMI shielding function. The assumption that the gasket "will hold better if all of it is bonded rather than half of it" will result in serious degradation of EMI shielding effectiveness.

1. Figure 31a illustrates this method used for *COMBO STRIP* and *COMBO Gaskets*, in which only the elastomer portion is bonded to one of the mating surfaces.
2. *"Combo" forms of POLASTRIP* may be bonded if, as in Figure 31b, the adhesive is restricted to the non-conductive portion. Spot applications to the conductive area are permissible.
3. *MESH STRIP* – The all metal and elastomer core versions of these with attachment fins can be held in position with non-conductive adhesive or epoxy if it is restricted to the mounting fins (see Figure 31c).
4. *Frame Gasketing* can be attached with a non-conductive adhesive or epoxy restricted to the aluminum extrusion (see Figure 31d). However, most Frame Gaskets are attached mechanically with fasteners.
5. *Dry Back Adhesive for Neoprene Sponge COMBO Gaskets* – Factory-applied solvent-activated adhesive is recommended for several reasons: a) controlled application guarantees restriction of the adhesive to the non-conductive portion; b) controlled adhesive thickness assures reliable bonding without reducing compressibility; and c) the adhesive provides a permanent bond.

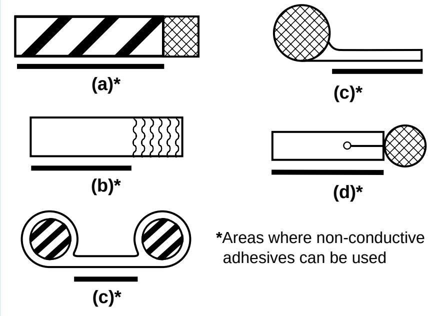


Figure 31 a-d Application of Non-Conductive Adhesive

D. Bolt-Through Holes This is a common, inexpensive means to hold gaskets in position (see Figure 32). For most Chomerics metal shielding products, providing bolt holes involves only a small tooling charge, with no additional cost for the holes

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Asia Pacific TEL +(852) 2 428 8008 FAX +(852) 2 423 8253
South America TEL +(55) 11 3917 1099 FAX +(55) 11 3917 0817
Parker Seals

in the unit price of the gasket. Bolt-holes can be provided in the fin portion of MESH STRIP, or in rectangular cross section MESH STRIP if these are wide enough, (minimum width 3/8 in. (9.52 mm).

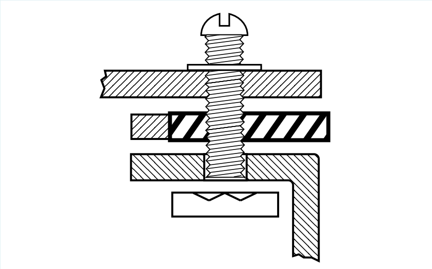

Figure 32 Bolt-Through Gasket Mounting

E. Special Attachment Means

Knitted mesh fins provided on some versions of MESH STRIP, and extruded aluminum strips on Frame Gasketing are designed for attachment (see Figure 33). Attachment fins can be clamped under a metal strip held down by riveting or spot welding, or can be bonded with a structural adhesive or epoxy. The aluminum extrusions in Frame Gaskets can also be fastened by riveting or bolting.

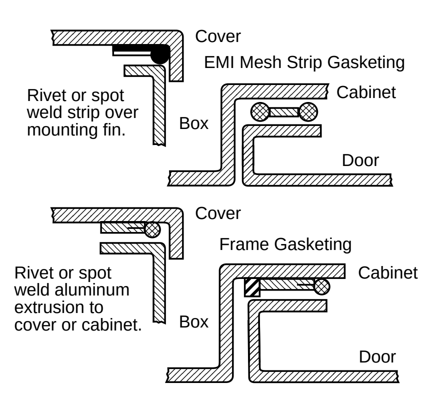

Figure 33 Rivet or Spot Welding

Friction, Abrasion and Impact Considerations

EMI gaskets should be positioned so that little or no sliding or shear occurs when compressed. In Figure 34a, the EMI gasket is subject to sliding as the door is closed, which may lead to tearing, wearing out, or detachment. Figure 34b illustrates the preferred position, in which the EMI gasket is subjected almost entirely to compression forces.

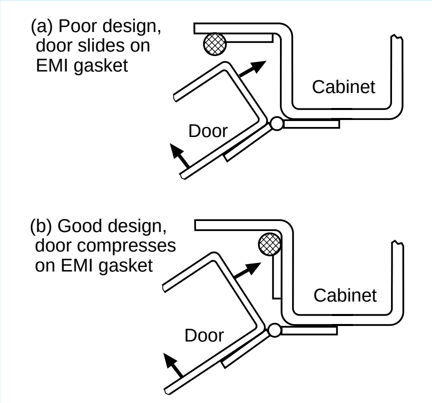

Figure 34 a-b Sliding Motion vs. Straight Compression

Mesh Gasketing Materials

A. Knitted Wire Mesh

Knitted wire mesh can be produced from any metal which can be drawn into wire form. However, the great majority of shielding requirements are readily satisfied with a choice of two materials – monel or Ferrex – both of which are standard production materials for Chomerics' mesh gaskets.

Two design considerations should influence the choice of EMI gaskets:

- required shielding performance in E-, H- and Plane Wave fields,
- required corrosion resistance of the gasket.

Additional considerations include the mechanical strength, durability, resiliency and compression set of the gasket material.

Monel

This good all-purpose nickel-copper alloy resists oxidation (thereby maintaining its conductivity), has good EMI qualities, and very good mechanical strength and resiliency. In controlled or protected atmospheres, it may be used in contact with aluminum; but where salt spray environments are encountered, galvanic corrosion is a problem.

Note: In salt spray environments, monel is corrosion-resistant, but when in contact with aluminum flanges, electrolytic currents will cause corrosion of the aluminum flange.

Ferrex®

Chomerics' Ferrex tin-plated copper-clad steel wire offers the best EMI/EMP performance of the standard mesh materials, especially for H-field shielding. Its mechanical properties are very close to monel, and it is more compatible with aluminum, but it has poorer intrinsic corrosion resistance than monel.

With this understanding of material characteristics, gasket metal is usually chosen using the following guidelines:

For low frequency magnetic field shielding: recommended gaskets are Ferrex versions of knitted mesh gasketing (provided corrosion resistance requirements are not severe).

For high frequency electric field shielding: recommended gaskets are monel or Ferrex.

For best corrosion resistance (except in contact with aluminum in salt spray environments where corrosion will occur): monel is recommended, preferably embedded in elastomer (e.g., POLA). Aluminum mesh is sometimes selected when equipment specifications permit no other metal to be used against aluminum mating surfaces, for galvanic corrosion compatibility. However, it must be understood that aluminum mesh oxidizes readily, and shielding effectiveness therefore degrades.

Chomerics Knitted Wire Mesh Products

MESH STRIP is available as resilient, single and dual all-metal strips or compressed shapes, with optional mounting fins. Both rectangular and round profiles are offered in a large range of standard dimensions for use as EMI gaskets where no environmental sealing is required (see Figure 35). *Note:* See also *SPRINGMESH* highly resilient wire mesh gaskets made from tin-plated steel wire, page 111.

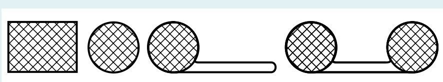

Figure 35 MESH STRIP Gasketing Profiles

Wire Mesh Frame Gaskets offer combinations of one or two round-profile mesh strips, or one mesh/one pressure-seal strip (round or rectangular) with a metal mounting frame (see Figure 36). *METALKLIP* clip-on strips consist of wire mesh over elastomer core gaskets attached to metal mounting clips.

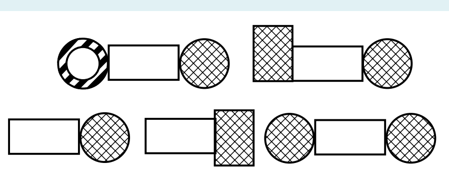

Figure 36 Frame Gasketing Profiles

COMBO and COMBO STRIP Gaskets combine a low-profile, solid or sponge elastomer strip in parallel with one or two rectangular mesh strips (see Figure 37). With solid elastomers, the mesh strip has a higher profile than the elastomer, to allow for compression of the mesh.

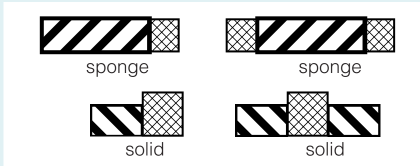

Figure 37 Normal and High Pressure COMBO STRIP Gaskets

MESH STRIP with Elastomer Core is available in round or rectangular profiles, with solid or hollow elastomer, with an optional mesh mounting fin (see Figure 38).

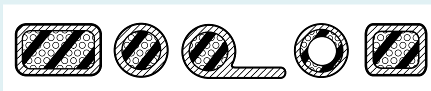

Figure 38 MESH STRIP with Elastomer Core Profiles

Compressed Mesh Gaskets are jointless units made by die-compressing knitted metal mesh, usually in round or rectangular forms, with a constant rectangular cross section. Standard waveguide types are available, and Chomerics maintains a large selection of existing tooling for other annular types.

B. Oriented Wire in Silicone

POLASTRIP/POLASHEET are composite mesh and elastomer materials in which wire is embedded in part or all of the silicone elastomer. The mesh is in the form of individual wires oriented perpendicular to the joint mating surfaces, for maximum EMI shielding (see Figure 39).

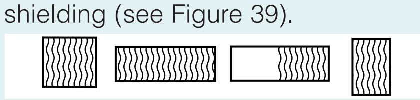

Figure 39 POLA Materials Profiles

C. Woven Metal Mesh

METALASTIC Gasketing is formed of woven aluminum mesh, filled with silicone or neoprene for pressure sealing. It is produced in 8 in. (20.3 cm) wide sheets in random lengths, in thicknesses of 0.016 in. (0.40 mm) and 0.020 in. (0.51 mm). The 0.016 in. (0.40 mm) material is the thinnest available for *EMI plus pressure seal* gasketing. It can be obtained in sheets, standard connector gaskets, or custom die-cut configurations. It should only be used where joint unevenness is less than 0.002 in. (0.05 mm).

D. Expanded Metal Mesh

PORCUPINE METALASTIC gasketing is a material composed of expanded Monel metal mesh, and is available with optional silicone filling. It is produced in sheets of continuous length, 12 in. (30.4 cm) by 0.020 in. or 0.030 in. (0.51 mm or 0.76 mm) thick. *PORCUPINE METALASTIC* gasketing is easily cut into intricate shapes with inexpensive rule dies, has high uniformity in thickness, ±0.004 in. (0.010 mm), and withstands high compression forces without damage. Available as sheets and standard connector gaskets, it can also be supplied in custom die-cut configurations. It should only be used where joint unevenness is less than 0.003 in. (0.08 mm) (see Figure 40).

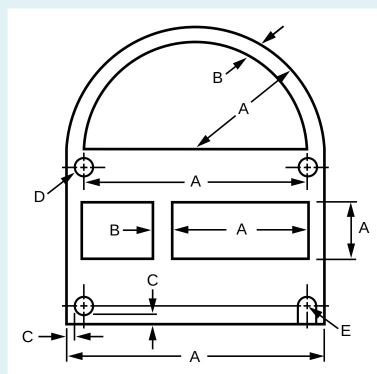

Figure 40 PORCUPINE METALASTIC Die-Cut Gaskets (fully dimensioned drawings required)

Wire Mesh EMI Gasket Selection Guide

PRODUCT TRADE NAME		MESH STRIP™ (ALL-METAL)	SHIELDMESH™ COMPRESSED MESH GASKETS	MESH STRIP™ (ELASTOMER CORE) AND METALKLIP® GASKETING	COMBO® AND COMBO® STRIP GASKETING	COMBO® GASKETS	FRAME GASKETING	PORCUPINE (5) METALASTIC® GASKETING	METALASTIC® GASKETING	POLASTRIP® GASKETING	POLASHEET®
Schematic Cross Section											
Construction		Formed or Compressed Knitted Wire Mesh		Knitted Wire Mesh Over Elastomer Strips	Formed Knitted Wire Strips in Parallel with Elastomer Strips; or Die-Cut Gaskets		Formed Knitted Wire Strips Clamped in Aluminum Extrusions	Expanded Metal in Elastomer	Woven Wire in Elastomer	Oriented Wire in Matrix of Silicone Elastomer (available with pressure sensitive adhesive)	
Available Forms		Strips, Gaskets Made by Joining Strips	Jointless Rings or Rectangular Gaskets	Strips, Gaskets Made by Joining Strips, Clip-On Strips	Strips, Gaskets Made by Joining Strips	Die-Cut Elastomer with Joined EMI Strips	Strips, Fab. Lengths, Frames with Joined EMI Strips	Sheets, Die-Cut Gaskets	Sheets, Die-Cut Gaskets	Strips, Gaskets Made by Joining Strips	Sheets, Die-Cut Gaskets
EMI Rating(6)	14 kHz (H)	>20- >30 dB	>25- >30 dB	>25- >35 dB	>20- >30 dB		>20- >30 dB	>35 dB	>35 dB	>46 dB	>35 dB
	18 MHz (E)	>102 dB	>102 dB	>102 dB	>102 dB		>102 dB	>102 dB	>102 dB	>102 dB	>102 dB
	1.0 GHz (P)	>83- >93 dB	>93 dB	>93 dB	>83- >93 dB		>93 dB	>85 dB	>40 dB	>93 dB	>93 dB
Maximum Joint Unevenness, % of Gasket Height	Class A – Permanently Closed	30-40%	30%	30-50%	30%		30%	15%	10%`	20%	20%
	Class B – Open-Close in Same Position	25-30%	25%	25-40%	30%		25%	10%	7%	17%	17%
	Class C – Completely Interchangeable	20-25%	20%	20-30%	25%		25%	10%	7%	17%	17%
Minimum/Maximum Height	Inches (mm)	0.062/0.500 (1.57/12.70)	0.040/0.375 (1.02/9.53)	0.125/0.750 (3.18/19.05)	0.062/0.375 (1.57/9.53)		0.093/0.250 (2.36/6.35)	0.020/0.030 (0.51/0.76)	0.016/0.020 (0.41/0.51)	0.062/0.312 (1.57/7.92)	0.030/0.250 (0.76/6.35)
Min. Width (Greater of Actual Dim. or Portion of Height)	Inches (mm)	0.062/½H (1.57/½H)	0.062/½H (1.57/½H)	0.62/½H (1.57/½H)	0.125/1½H (3.18/1½H)		0.437 (11.0)	0.140 (3.56)	0.125 (3.18)	0.093/½H (2.36/½H)	0.125 (3.18)
Recommended Compression Pressure	psi (kg/cm)	5-100 (0.35-7.03)	5-100 (0.35-7.03)	5-100 (0.35-7.03)	20-100 (1.41-7.03)		5-100 (0.35-7.03)	20-100 (1.41-7.03)	20-100 (1.41-7.03)	20-100 (1.41-7.03)	20-100 (1.41-7.03)
Attachment or Positioning	In Slot	Excellent	Excellent	Excellent	Excellent		No	No	No	Good	Possible
	Pressure Sensitive Adhesive	N/A	N/A	N/A	Excellent		N/A	N/A	N/A	Special	Excellent
	Bond Non-EMI Gasket Portion(4)	Versions with Fins Only(2)	*	Versions with Fins Only(2)	Good-Excellent		Poor(3)	Special	Special	Combo Version Only	N/A
	Conductive Adhesive	Poor to Good	Poor to Good	Poor to Good	N/A		N/A	No	No	Use Silicone Base Adhesive See Note 7.	
	Bolt thru Bolt Holes	Possible with Fin Versions(2)	N/A	Possible with Fin Versions(2)	Excellent		Excellent(3)	Excellent	Excellent	Excellent	Excellent
Elastomer Temperature Range	Neoprene Version	N/A	N/A	–30°F to 150°F –34°C to 66°C	–30°F to 150°F –34°C to 66°C		–30°F to 150°F –34°C to 66°C	N/A	–40°F to 225°F –40°C to 107°C	Special	Special
	Silicone Version	N/A	N/A	–80°F to 400°F –62°C to 204°C	–80°F to 400°F –62°C to 204°C		–80°F to 400°F –62°C to 204°C	–80°F to 400°F –62°C to 204°C	–65°F to 500°F –53°C to 260°C	–70°F to 500°F –57°C to 260°C	–80°F to 400°F –62°C to 204°C
Standard Metals Available in EMI Portion (others also available)		Monel Ferrex(1), Aluminum	Monel Ferrex(1), Aluminum	Monel Ferrex(1), Aluminum	Monel, Ferrex(1), Aluminum		Monel, Ferrex(1)	Monel, Aluminum	Aluminum Only	Monel, Aluminum	Monel, Aluminum

(1) Ferrex® is Chomerics' tradename for tin-plated, copper-clad steel EMI gasketing.

(2) Two versions, and have fins especially designed for easy attachment.

(3) The aluminum extrusion is intended as a convenient means of attachment.

(4) Most products for which this method is suitable are available with "dry back" (solvent-activated) adhesives already applied.

(5) Available without elastomer in metal form only.

(6) These EMI ratings are based on MIL-STD-285 test methods and are useful for making meaningful qualitative comparisons between products in this table since all tests were conducted under similar conditions. They cannot be used to compare to other EMI gasket data unless those data were obtained by the same methods.

(7) Non-conductive RTV yields excellent results, but use sparingly. If more adhesive surface is needed, use conductive adhesive.

*Pressure sensitive adhesive is available for certain mesh over core gaskets. Contact Chomerics for details.

Glossary of Terms

Electrical

Absorption Loss: Attenuation of an electromagnetic wave or energy encountered in penetrating a shield caused by the induction of current flow in the barrier and the resulting I^2R loss. Usually stated in dB (decibels).

Ambient Electromagnetic Environment: That electromagnetic field level existing in an area and emanating from sources other than the system under test.

Attenuation: A reduction in energy. Attenuation occurs naturally during wave travel through transmission lines, waveguides, space or a medium such as water, or may be produced intentionally by inserting an attenuator in a circuit or a shielding absorbing device in the path of radiation. The degree of attenuation is expressed in decibels or decibels per unit length.

Attenuator: An arrangement of fixed and/or variable resistive elements used to attenuate a signal by a desired amount.

Cross Coupling: Coupling of the signal from one channel to another where it becomes an undesired signal.

Conductivity: Capability of a material to conduct electrical currents.

Decibel (dB): A convenient method for expressing voltage or power ratios in logarithmic terms. The number of such units of attenuation, N is

$$N\ (dB) = 10 \log \frac{P_1}{P_2}$$

where

P_1/P_2 is a unitless power ratio. N can also be expressed in terms of a voltage ratio E_1/E_2 as follows:

$$N\ (dB) = 20 \log \frac{E_1}{E_2}$$

Degradation: An undesired change in the operational performance of a test specimen. Degradation of the operation of a test specimen does not necessarily mean malfunction.

Depth of Penetration: Distance which a plane wave must travel through a shield to be attenuated 1/e, or approximately 37 percent of its original value. (Also called “skin depth”). It is a function of the shield’s conductivity and permeability and the wave’s frequency.

Electrical or E-Field: A field induced by a high impedance source, such as a short dipole.

Electromagnetic Compatibility (EMC): A measure of an equipment’s ability to neither radiate nor conduct electromagnetic energy, or to be susceptible to such energy from other equipment or an external electromagnetic environment.

Electromagnetic Interference (EMI): Undesired conducted or radiated electrical disturbances, including transients, which can interfere with the operation of electrical or electronic equipment. These disturbances can occur anywhere in the electromagnetic spectrum.

Emanation: Undesired electromagnetic energy radiated or conducted from a system.

Gasket-EMI: A material that is inserted between mating surfaces of an electronic enclosure to provide low resistance across the seam and thereby preserve current continuity of the enclosure.

Ground: A reference plane common to all electronic, electrical,electro-mechanical systems and connected to earth by means of a ground rod, ground grid, or other similar means.

Hertz: An international designation for cycles per second (cps).

Insertion Loss: Measure of improvement in a seam, joint or shield by the addition of a conductive gasket. Usually stated in dB.

Interference: Any electromagnetic phenomenon, signal or emission, man-made or natural, which causes or can cause an undesired response, malfunctioning or degradation of performance of electrical or electronic equipment.

Internal Loss: Attenuation of electromagnetic energy by the reflection and re-reflection of electromagnetic waves within a shield or a barrier. Usually stated in dB.

Magnetic or H-Field: An induction field caused predominantly by a current source. Also called a low impedance source, such as may be generated by a loop antenna.

Malfunction: A change in the equipment’s normal characteristics which effectively destroys proper operation.

Permeability: The capability of a material to be magnetized at a given rate. It is a non-linear property of both the magnetic flux density and the frequency of wave propagation.

Plane Wave: An electromagnetic wave which exists at a distance greater than a wavelength from the source, where the impedance of the wave is nearly equal to the impedance of free space – 377 ohms.

Radio Frequency (RF): Any frequency at which coherent electromagnetic radiation of energy is possible. Generally considered to be any frequency above 10 kHz.

Radio Frequency Interference (RFI): Used interchangeably with EMI. EMI is a later definition which includes the entire electromagnetic spectrum, whereas RFI is more restricted to the radio frequency band, generally considered to be between the limits 10 kHz to 10 GHz.

Reflection Loss: Attenuation of the electromagnetic wave or energy caused by impedance mismatch between the wave in air and the wave in metal.

Relative Conductivity: Conductivity of the shield material relative to the conductivity of copper.

Relative Permeability: Magnetic permeability of the shield material relative to the permeability of free space.

Shield: A metallic configuration inserted between a source and the desired area of protection which has the capability to reduce the energy level of a radiating electromagnetic field by reflecting and absorbing the energy contained in the field.

Shielding Effectiveness: A measure of the reduction or attenuation in electromagnetic field strength at a point in space caused by the insertion of a shield between the source and that point. Usually stated in dB.

Shielding Increase: The difference of an electromagnetic field amplitude emanating through a seam (measured under fixed test conditions) with and without the gasket in the seam, with the force joining the seam remaining constant. The difference is expressed in dB based on voltage measurements.

Skin Effect: Increase in shield resistance with frequency because of crowding of current near the shield surface because of rapid attenuation of current as a function of depth from the shield surface.

Surface Treatment: Coating or plating of mating surfaces of a junction.

Susceptibility: Measure of the degradation of performance of a system when exposed to an electromagnetic environment.

Total Shielding Effectiveness: The difference of an electromagnetic amplitude emanating from a source within an enclosure, and that from a source in free space. The difference is expressed in dB based on voltage measurements.

Wave Impedance: The ratio of electric field intensity to magnetic field intensity at a given frequency expressed in ohms.

Mechanical

Abrasion Resistance: The resistance of a material to wearing away by contact with a moving abrasive surface. Usefulness of standard tests very limited. Abrasion resistance is a complex of properties: resilience, stiffness, thermal stability, resistance to cutting and tearing.

Cold Flow: Continued deformation under stress.

Compression Set: The decrease in height of a specimen which has been deformed under specific conditions of load, time, and temperature. Normally expressed as a percentage of the initial deflection (rather than as a percentage of the initial height).

Durometer: An instrument for measuring the hardness of rubber. Measures the resistance to the penetration of an indentor point into the surface of the rubber.

Elasticity: The property of an article which tends to return to its original shape after deformation.

Elastic Limit: The greatest stress which a material is capable of developing without a permanent deformation remaining after complete release of the stress. Usually this term is replaced by various load limits for specific cases in which the resulting permanent deformations are not zero but are negligible.

Elastomer: A general term for elastic, rubber-like substances.

Elongation: Increase in length expressed numerically as a fraction or percentage of initial length.

Hardness: Relative resistance of rubber surface to indentation by an indentor of specific dimensions under a specified load. (See Durometer). Numerical hardness values represent either depth of penetration or convenient arbitrary units derived from depth of penetration. Devices for measuring rubber hardness are known as durometers and plastometers. Durometers are used most commonly. The higher the durometer number, the harder the rubber, and vice versa.

Hardness Shore A: Durometer reading in degrees of hardness using a Type A Shore durometer. (Shore A hardness of 35 is soft; 90 is hard).

Permeability: A measure of the ease with which a liquid or gas can pass through a material.

Permanent Set, Stress and Strain Relaxation: Permanent Set is defined as the amount of residual displacement in a rubber part after the distorting load has been removed. Stress Relaxation, or Creep, is a gradual increase in deformation of an elastomer under constant load with the passage of time, accompanied by a corresponding reduction in stress level.

Resilience: The ratio of energy given up on recovery from deformation to the energy required to produce the deformation – usually expressed in percent.

Tear Strength: The force per unit of thickness required to initiate tearing in a direction normal to the direction of the stress.

Tensile Strength and Elongation: Tensile Strength is the force per unit of the original cross sectional area which is applied at the time of the rupture of the specimen during tensile stress. Elongation is defined as the extension between benchmarks produced by a tensile force applied to a specimen, and is expressed as a percentage of the original distance between the marks. Ultimate elongation is the elongation at the moment of rupture. Tensile Stress, more commonly called "modulus," is the stress required to produce a certain elongation.

Chomerics Part Number Cross Reference Index

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