Design Techniques for EMC
Part 4 — Shielding (Screening)
(This article has been split in three, this is the last part)

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This is the **fourth** in a series of six articles on basic good-practice electromagnetic compatibility (EMC) techniques in electronic design, to be published during 2006-7. It is intended for designers of electronic modules, products and equipment, but to avoid having to write modules/products/equipment throughout – everything that is sold as the result of a design process will be called a 'product' here.

This series is an update of the series first published in the UK EMC Journal in 1999 [1], and includes basic good EMC practices relevant for electronic, printed-circuit-board (PCB) and mechanical designers in all applications areas (household, commercial, entertainment, industrial, medical and healthcare, automotive, railway, marine, aerospace, military, etc.). Safety risks caused by electromagnetic interference (EMI) are not covered here; see [2] for more on this issue.

These articles deal with the practical issues of what EMC techniques should generally be used and how they should generally be applied. Why they are needed or why they work is not covered (or, at least, not covered in any theoretical depth) – but they are well understood academically and well proven over decades of practice. A good understanding of the basics of EMC is a great benefit in helping to prevent under- or over-engineering, but goes beyond the scope of these articles.

The techniques covered in these six articles will be:
1) Circuit design (digital, analogue, switch-mode, communications), and choosing components
2) Cables and connectors
3) Filtering and suppressing transients
4) **Shielding (screening)**
5) PCB layout (including transmission lines)
6) ESD, surge, electromechanical devices, power factor correction, voltage fluctuations, supply dips and dropouts

Many textbooks and articles have been written about all of the above topics, so this magazine article format can do no more than introduce the various issues and point to the most important of the basic good-practice EMC design techniques. References are provided for further study and more in-depth EMC design techniques.

Table of contents for this article

4. Part 4 – Shielding (screening)

4.6 EMC gaskets

EMC gaskets are conductive and compressible, and used to prevent apertures at joints, seams, doors and removable panels from compromising SE. They are also used for ensuring correct RF-bonding for connectors and filters. To function as intended they require a good electrical contact all along both sides of the seam, door, joint, etc., so metal contact surfaces usually need a conductive plating.

Gaskets must meet a number of often-conflicting mechanical and electrical requirements, not to mention chemical (e.g. to prevent corrosion). Shielding gaskets are sometimes required to be environmental seals too, adding to the compromise. Where a gasket does not return to its original shape when the pressure is removed, it is suffering from 'compression-set', so is not suitable for doors and removable panels. Considerations when designing or selecting gaskets include:

- Mechanical compliance
- Compression-set
- Impedance over a wide range of frequencies
- Resistance to corrosion (galvanic compatibility with its mating surfaces, appropriate for the intended environment, see 4.7.9)
- Ability to withstand the expected rigours of normal use
- Shape and preparation of mounting surface
- Ease of assembly and disassembly
- Environmental sealing, smoke and fire characteristics

There are many types of EMC gaskets, and the main types are discussed below.

4.6.1 Volume-conductive elastomers

These are elastomers with metal particles in them (usually tiny metal-plated glass spheres), available in tape (extruded) form or as cast or die-cut materials, in a very wide variety of shapes and sizes, see Figure 4BF. Solid elastomers can require quite large pressures to compress adequately, making them difficult to use in manually-opened doors without power assistance or levers. Extruded types are available with hollow cross-sections, making them much 'squashier'. If compressed overmuch they can also suffer from compression-set.

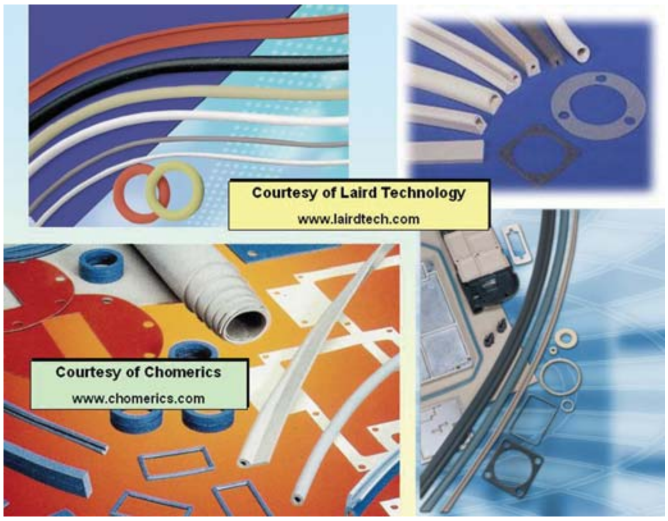

Figure 4BF Examples of some volume-conductive elastomeric EMC gaskets

They have environmental sealing properties, and can suffer from compression-set if over-compressed. Compression-set is generally prevented by designing a groove which helps to retain the gasket during assembly, and has mechanical features (like 'bump stops') which prevent over-compression. (See later for groove design).

The conductivity of these gaskets is not very high, even when they are compressed to their optimum, so the SE they can achieve is not as good as metal mesh or spring finger types. Hollow-core extruded elastomers are more suitable for gasketting plastic or sheet metal enclosures where high compressive forces might distort the mounting areas and degrade the SE of the enclosure, but they have even lower conductivity than solid types.

PTFE (Teflon) foam types filled with carbon particles are available (e.g. from W. L. Gore) and may be useful in combining EMC shielding with environmental sealing in especially aggressive environments.

A special type of volume-conductive gasket is supplied as a liquid and cured after being applied, often called 'form-in-place' gasketting. Application can be manual (e.g. with a glue gun) but in high-volume manufacture it is usually robotically applied, as shown in Figure 4BG.

Some of these liquid gaskets can also be used as adhesives, for applications such as that shown in Figure 4AH, and many of us are familiar with the use of 'conductive epoxy' to repair connections to the rear screen heaters in motorcars.

The elastomer is usually silicone, which is quite stiff – making it quite difficult to achieve adequate compression along its length, especially with plastic parts. Recently, types that foam-up after application have been developed, making much softer and more compliant gaskets that are easier to design with. These are the types of materials used in the 'mold-in-place' gaskets shown in Figure 4AY.

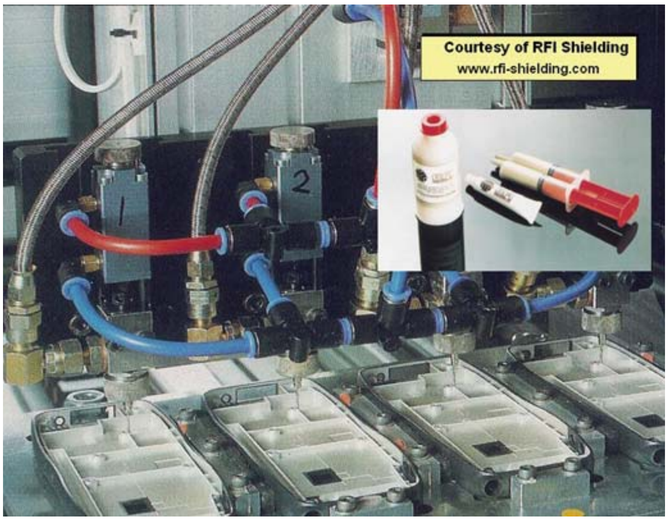

Figure 4BG Example of Form-In-Place (FIP) gaskets being robotically applied

4.6.2 Conductively coated or wrapped elastomers, see Figure 4BH

These are elastomer foams or tubes with conductive outer coatings or coverings of metallised fabric, with a low compression-set in general. The elastomer is not conductive, and merely provides a support function for its conductive covering. They can have hollow cross-sections or be foam, and can be very soft and flexible and only require low compressive forces. However, they do not – in general – make the best environmental seals, and their conductive layers may be vulnerable to wear.

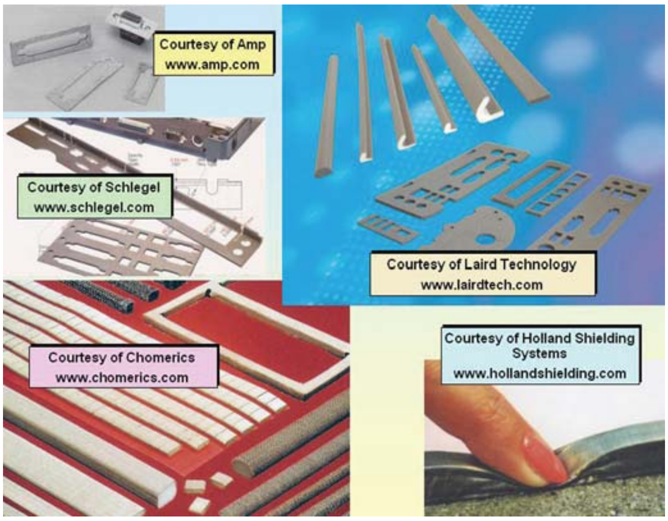

Figure 4BH Examples of some conductively-coated or wrapped polymer EMC gaskets

Coatings and wrappings for these gaskets include:

- metal films
- knitted wire mesh 'stockings'
- metallised fabrics
- metallised foils

4.6.3 Metal (wire) meshes, see Figure 4BJ

These can be random meshes or knitted types. They are generally very stiff but match the impedance of metal enclosures better and so provide better SEs than the above types. Some types of gaskets use a thin knitted mesh 'stocking' over a foam core (see later) to reduce the force required.

They have poor environmental sealing performance, but some types are available bonded to an environmental seal, so that two types of gasket may be applied in one operation. Also, some types are available filled with an uncured silicone, which provide good environmental sealing.

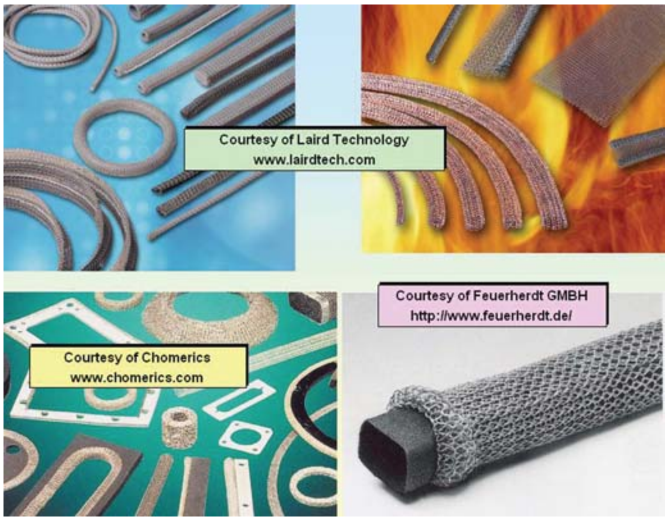

Figure 4BJ Examples of some metal mesh EMC gaskets

Commonly used mesh materials include:

- Phosphor Bronze
- Tin-coated Copper Clad Steel
- Silver plated Brass
- Monel

Wire mesh gaskets are available in tape, round or rectangular cross-section gaskets. Because they generally require high compressive forces they are best mounted in a slot or a flange of a stiff enclosure (see later). They tend to suffer from compression-set, so are not the best choice where a joint may be repeatedly opened and closed, but they are a good choice for sturdy metal parts that are permanently fastened, or where replacement of the gasket each time the joint is opened would not be a problem.

4.6.4 Spring fingers ('finger stock'), see Figure 4BK

These are traditionally made from beryllium-copper or stainless steel and can be very compliant. Because some people are becoming concerned about the possible health hazards of beryllium, other materials are being developed, such as Laird Technology's 'clean copper'.

Spring fingers have very low compressive forces and no compression-set, even if squashed flat for years, so are very suitable for modules, doors and panels, that must be easy to manually insert/extract and open, and which have a high level of use. Their wiping contact action helps to maintain a good RF bond by removing oxide and corrosion films and dirt, and they have a good impedance match with metal surfaces.

Spring fingers are quite vulnerable to accidental damage, such as snapping off by getting caught in a coat sleeve. The dimensions of spring fingers and the gaps between them causes inductance, so for high frequencies or critical use a double row may be required, such as is often seen on the doors of most EMC or RF test chambers.

For shielded rooms with spring-finger door gaskets, the usual instructions are to smear them with petroleum jelly once every year, but this is rarely a requirement in equipment user instructions.

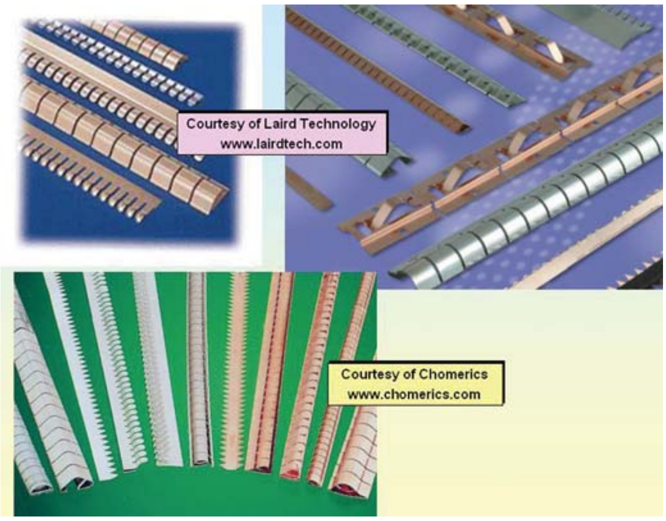

Figure 4BK Examples of some spring finger EMC gaskets

Spring fingers can be mounted by a variety of methods:

- gluing (often with a self-adhesive strip)
- riveting
- soldering
- welding
- clipping onto a mechanical feature like an edge or a flange-on, or into a slot in the metalwork.

They need a flat contact area on both sides, plated with a highly-conductive material that is galvanically compatible with the plating of the fingerstock to help prevent corrosion. Materials with tough oxide skins (like plain aluminium) or polymer passivation are unsuitable. Although the best RF-bonds require area contact rather than sharp points, there are types of spring fingers with sharp points that can give better results with less-than-perfect contact areas.

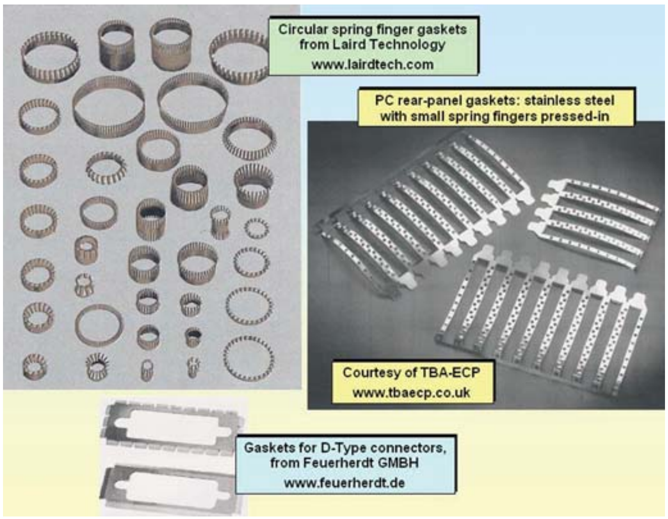

Figure 4BL Examples of some special types of spring finger EMC gaskets

Like some other types of gaskets, spring fingers can be made circular, for use in RF-bonding the mating halves of circular shielded connectors together (e.g. as in Figure 2T of [4]). Some examples are shown in Figure 4BL, which also shows some spring-finger gaskets for D-Type connectors, and for the expansion card slots of PCs.

It can be easy to design spring finger gaskets into the metalwork of a product, so that they do not require an additional assembly step. Figure 4BM shows the example of a Sun Microsystems server, where the attractive plastic cover was fitted with a plain springy-steel sheet underneath, with spring fingers around the edges to make connection with the metal box in which the server electronics was housed. Metal sheets like this can be cut and bent from plain sheet in one stamping operation, and are usually tinned to provide a lower resistance contact.

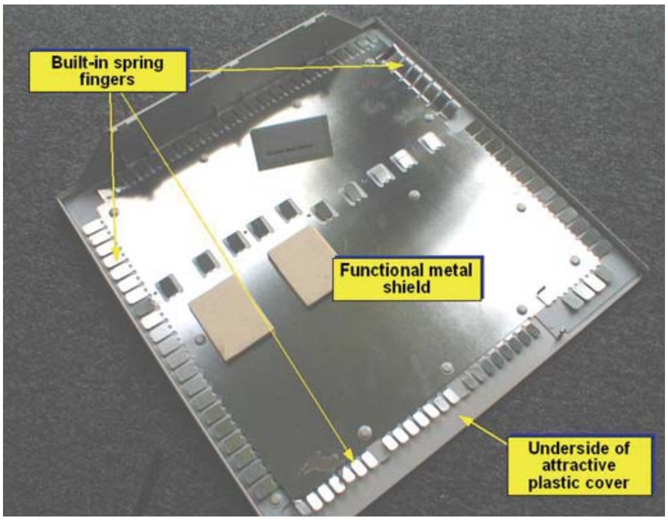

Figure 4BM Example of D-I-Y spring fingers

4.6.5 Some other types of gaskets

The four main types of gaskets have been described above, but there are many other types, some of which are shown in Figure 4BN, for example…

- Graphite (best used under very high compression, between machined surfaces)
- Oriented wires in silicone (good results with poor surfaces, but require high pressure)
- Spiral foil (can be combined with cured or uncured silicone to provide an environmental seal)
- Canted coil spring gaskets (often used in connectors and glands, see Figures 2T, 2V of [4])
- Metal fibre gaskets, using woven metal wire, sintered metal fibre or expanded metal (used on flanged mating surfaces where compressive forces are very high)
- Metal or metallised 'velcro' (mostly used for RF-bonding seams in metallised fabrics)

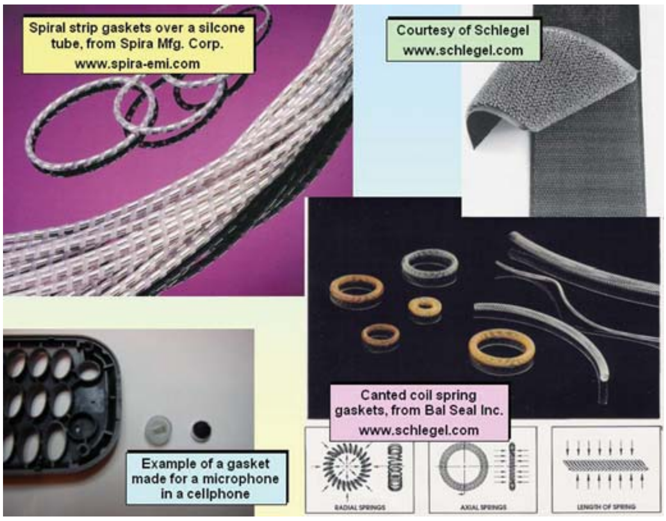

Figure 4BN Some examples of other types of conductive gasket

4.6.6 Mechanical design techniques for gaskets

Some gaskets require a low compression force, some a medium force and others a high force. But even very soft gaskets can require a surprising amount of pressure overall, sufficient to bend quite sturdy items of metalwork, so careful mechanical design is always required. The shielded enclosure must be capable of achieving sufficient pressure to achieve the required contact resistance, all along the length of the gasket. Some gaskets need up to 0.7MPa (100 psi) to achieve a low-enough contact resistance. Hollow elastomers generally need less than 180kg/metre (10 pounds/inch), whilst foam cored and spring finger types might only need 20kg/metre (1 pound/inch).

Designing lids, covers, doors, etc, so that they have sufficient stiffness and fixings to compress the chosen type of gasket is not easy (see 4.6.7) and is beyond the scope of this article. Some gasket manufacturers supply very useful application notes that provide a great deal of technical assistance with mechanical design, such as the advice on using gaskets in a sheet metal enclosure.

Figures 4BP and 4BQ show examples of the data and other design information provided by gasket manufacturers to help shielded enclosures be designed to compress their conductive gaskets correctly. For more information, see [11], [12], [39], [40], [41] and [42].

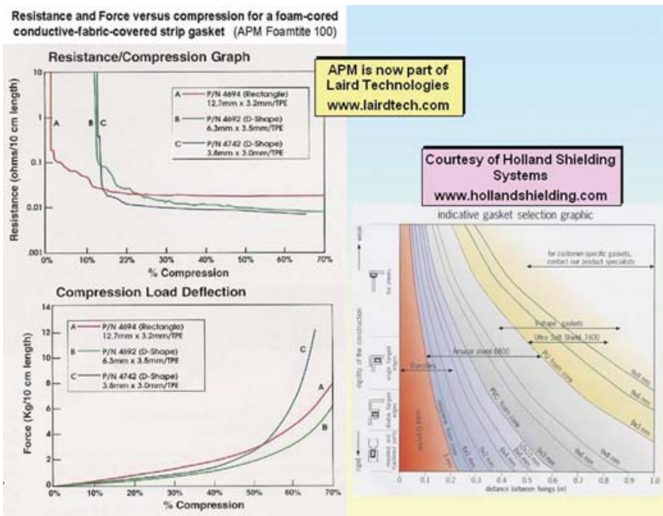

Figure 4BP Some examples of gasket mechanical design information

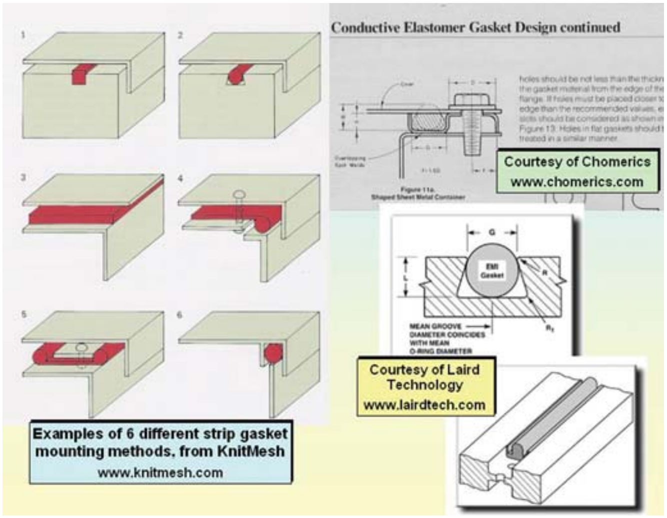

Figure 4BQ More examples of gasket mechanical design information

Softer gaskets ease mechanical design, but are less likely to break through films or oxide, corrosion or dirt to achieve good electrical contact over the life of the equipment, so they need high-quality corrosion-protected conductive surfaces for their contacts on both sides.

Figure 4BR shows a typical gasket design for the door of an industrial cabinet, using a conductive rubber or silicone compound to provide an environmental seal as well as an EMC shield. Spring fingers are also often used in such applications, but in this case are fixed to the side so that they wipe when being closed or opened, as the photograph of the stainless-steel cabinet in Figure 4BR shows.

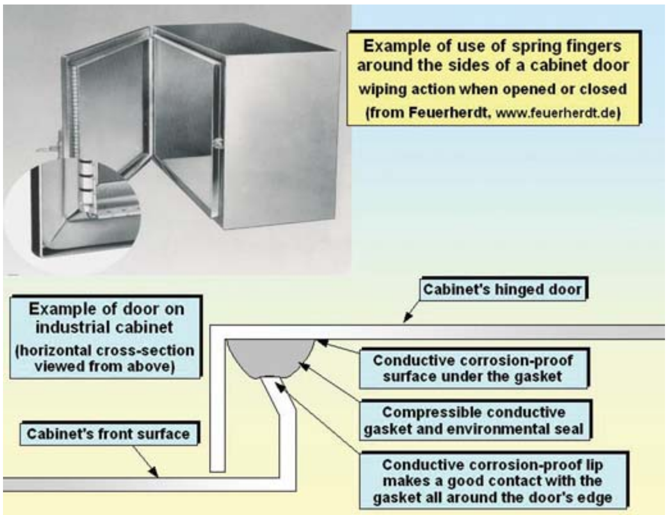

Figure 4BR Examples of gaskets on industrial cabinet doors

It is worth noting in passing that the green/yellow wire used for safety earthing of a door or panel has no benefits for EMC, above a few hundred kHz. This might be extended to a few MHz if a number of short wide earthing straps are used, spread along a hinge, instead of a single wire.

Gaskets need appropriate mechanical provisions to be easy to assemble whilst also effective at maintaining SE. If they are simply stuck on to a surface and squashed between mating parts they may not work as well as was hoped – the more the fixing screws are tightened in an effort to compress the gasket the more the gaps between the fixings can bow, opening up leaky gaps.

This is because of inadequate stiffness in the mating parts of the enclosure, but it is difficult to make the mating parts rigid enough without a groove for the gasket to be squashed into. This groove also helps correctly position and retain the gasket during assembly. The dimensions of the groove ensure that the gasket is compressed optimally to give a low contact resistance when the mating half is correctly fitted.

The groove should be designed so that so that if the fastenings are over-tightened, the gasket will not be compressed so much as to suffer compression-set or other damage, and the mating half will not become distorted. Where grooves are not used, bump-stops and similar mechanical features should be used. Figure 4BS sketches this type of design, and some partial examples of manufacturer's design information is shown in Figure 4BQ.

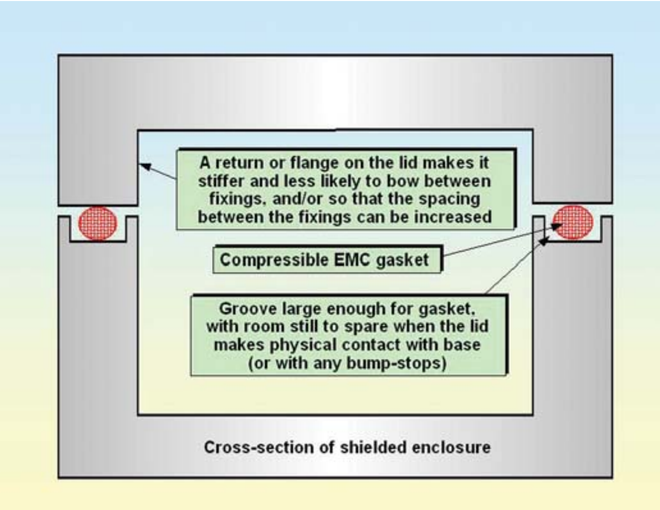

Figure 4BS Example of gasket groove design

Figure 4BS sketches an enclosure that is either die-cast or milled from solid, but gasket manufacturers' application notes describe how to design sheet-metal enclosures for gasket retention and optimal compression, as (partially) shown in Figure 4BR.

All gasket details and measures must be shown on manufacturing drawings, and all proposed changes to them assessed for their impact on shielding and EMC. It is not uncommon, when painting work is transferred to a different supplier, for gaskets to be made useless because masking information was not put on the drawings. Changes in the painting processes used can also have a deleterious effect (as can different painting operatives) due to varying degrees of overspray into gasket mounting areas which are not masked off. The use of special conductive tapes with a masking layer is discussed in 4.7.4.

4.6.7 Gasket clamping

For high values of SE when using a metal enclosure that has stiff flanges at its joints (e.g. cast metal box and lid, see Figure 4BS) – the fixing pitch should not generally exceed 50mm (2 inches). When using sheet metal enclosures, high values of SE will generally require a fixing pitch not more than 19mm (0.75 inch). Lower values of SE allow larger spacings between fixings.

The force required per fixing is determined by dividing the total compressive force required to compress the gasket optimally (see Figure 4BP), and of course the fixings chosen should be rated for at least their maximum tension. Where groove design is inadequate for gasket protection, and bump-stops are not used, assembly should be carried out with torque-controlled tools to ensure that gaskets are compressed correctly.

Thinner or more flexible materials will require the fixing pitch to be reduced to prevent distortion, which generally takes the form of bowing, creating apertures which can reduce SE as shown in Figure 4BT. This problem is not uncommon when trying to add gaskets to enclosures that were not designed to take them. Distortion becomes very obvious when, during emissions testing, fixings are tightened to try to improve SE – but beyond a certain torque the SE is worsened instead.

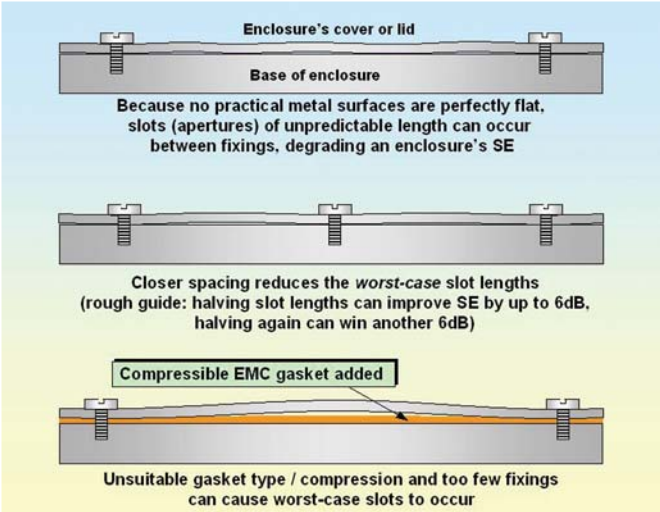

Figure 4BT Fixings, bowings, and SE

4.7 Materials useful for shielding

4.7.1 Metals and their surface finishes

Steel and aluminium are often used to construct enclosures, because they are relatively cheap and easy to cut, machine, bend and join. Aluminium has a high conductivity but is very reactive so its surfaces are always oxidised, and the oxide is a good insulator and very tough, making it difficult to RF-bond to. The thickness of the oxide grows with time, so the reflectivity of plain aluminium decreases and RF-bonding becomes more difficult.

Anodising is a very common surface treatment for aluminium, but works by increasing the thickness of the oxide layer, creating an insulating surface. It is not an appropriate surface treatment for a shielded enclosure, but I have seen products in which an anodised front panel was considered essential for its scratch resistance, so at all the shield bonding points it was removed by machining.

Alochrom, Alodine, Iridite, Oakite and tin plating are all names for commercial high-conductivity passivating finishes. These have good reflectivity, and help achieve good RF bonds, helping to achieve good SE. Some of these methods rely on hexavalent chromium, which is being outlawed in the European Union by the Restriction on Hazardous Substances directive (2002/95/EC) so alternatives based on trivalent chromium and other chemicals are being developed (see 4.7.8).

Aluminium can also be tin-plated, although this is not a simple process. Reasons for tin-plating are to make it solderable, or to reduce galvanic potentials at metal contacts (e.g. with tin-plated steel or copper) and so reduce corrosion (see 4.7.9).

Mild steel has a reasonable conductivity and also has significant relative permeability that helps shield low-frequency magnetic fields (see 4.3.4 and Figure 4G of [20]). Steel surfaces also oxidise (rust) so for good RF bonds in shielded enclosures steel is usually plated with zinc or tin. Zinc can be plated as a metal, or as 'galvanising', and the metal is better for EMC purposes. Tin can also be plated in two forms, dull (matt) or bright – and the dull finish is better for EMC as it is easier to make RF bonds and solder to. Zinc and tin have higher conductivity than steel, so plating with them improves reflectivity.

Sheet steel that is galvanised or already zinc plated (e.g. 'Zintec') helps prevent rusting, but it will still rust at its cut edges. Another problem with plated sheet metals such as Zintec is that they are often supplied already passivated with a polymer coating, which is an insulator, making it impossible to create the RF-bonds required for good SE without using high-compressive-force conductive gaskets with all their mechanical design difficulties. So it is best to fabricate the metal parts from plain metals, and only then plate them with zinc or tin.

Stainless steel has lower conductivity and permeability than mild steel, is harder to work and more expensive, so is generally only used in specialised areas such as in food preparation and other areas which are subject to regular wetting. But stainless steel cabinets are usually made of metal that is quite thick, and seam welded to a high quality (for hygiene purposes), so they often make excellent shielded enclosures (see the one photographed in Figure 4BR).

Copper, brass, tin and similar metals have a high conductivity and are easily worked but their high cost means they are generally only used for small enclosures, such as PCB shielding-cans, and even then tin-plated steel is more common.

Zinc metal plating can suffer from a heavy white 'bloom' in high humidity. A chromate conversion process can passivate the zinc surface to prevent this, leaving a conductive surface (unlike polymer passivation). As discussed above, chromate passivation processes are currently being modified to replace hexavalent chromium with its trivalent form, but not all metals can be passivated as successfully so some further development is required.

Where metal or metal parts are for use in constructing a shielded enclosure, it is very important to specify 'no passivation' or 'chromate passivation only' on metal drawings. And even so, a surface resistance test (using very smooth probes and low pressure) is always recommended before accepting *any* batches of sheet metal or metal parts into a manufacturer's stores.

Enclosures made from cast or 'machined-from-solid' metal have some advantages over those made from folded sheet metal, including...

- fewer joints and seams (apertures) to degrade SE
- easier to include grooves for EMC gaskets
- stiffer, making it easier to compress lengths of gasket

Castings often use aluminium/zinc alloys, but magnesium alloys are increasingly popular. Aluminium/zinc casting alloys can often be polished to a high gloss, and if their zinc content is high they can retain a good surface conductivity for many years – but they do scratch easily. Chromate (trivalent) passivation or similar is generally required, and always required for magnesium alloys.

Apart from the EMC benefits (which make cast or machined enclosures almost mandatory in some high-performance applications), suitable design of cast or machined enclosures can make them quicker and easier to assemble than sheet metal, helping offset their generally higher material and tooling costs.

4.7.2 The problems of polymer passivation

Beware of 'automatic' passivation with polymers. Many buyers, suppliers and metal platers assume that polymer passivation is always required – even when not specified on the drawing – and it is no good specifying the surface conductivity to be achieved as some metal platers do not seem to understand the concept and apply polymer passivation regardless.

If the traditional 'yellow passivation' is applied it is obvious that the plater has done something to the metal parts – but if they use a clear polymer it is impossible to tell it from bare metal by eye or touch.

Many product manufacturers suffer shielding problems until they discover that their shiny metal parts actually have an invisible insulating passivation layer. Sometimes, although metal parts have been supplied with a perfectly good surface-conductive finish for years, they can suddenly and without any warning start to arrive with polymer passivation layer – this may be because the company buyer has changed suppliers, or the supplier has unilaterally decided to make the change.

Based on the costly experiences of numerous manufacturers, I now always recommend employing a surface conductivity test at goods-in, and including this test and its specifications in the manufacturing drawings and purchasing order. It is best to have an agreement with the supplier that any deliveries that do not pass this test will be rejected back to the supplier at his own cost, who must then replace them within a specified time with parts that pass the test.

It is easy to make a suitable test device with a low-voltage electronic buzzer mounted in a hand-held device fitted with two spring-loaded contacts that press smooth conductive pads onto the metal surface to be tested. For the best sensitivity to surface conductivity, the conductive pads can be made of tin-plated copper onto which are stuck some soft conductive gaskets, such as the conductive-fabric-over-foam types (see below). The soft gaskets press against the sample, and apply a uniform low pressure – helping to avoid the possibility that any sharp edges, grit or swarf would cause an erroneously low reading.

Because an alochromed aluminium surface looks much like an anodised one, and because anodising is the more common treatment, it is easy for errors to be made in the design and purchasing process. A product that had good SE when made with alochromed aluminium can suddenly become non-compliant when constructed with anodised aluminium that looks just the same. The solution is to check all parts that are supposed to be conductive, before they are accepted into a manufacturer's stores, as discussed for polymer passivation above.

4.7.3 Metallised papers and fabrics

Short fibres of polyester and similar materials can be metallised and bonded into a paper-like material with a random alignment of fibres. The coating on the individual fibres is very thin but the paper can be made to various thicknesses to improve its absorption. It is a low-cost material that makes good RF-bonds, and is easy to cut and glue. It can even be pasted onto walls to construct a shielded room, when it is often called 'EMC wallpaper'. Figure 4BU shows some examples of metallised paper materials being used to shield a product.

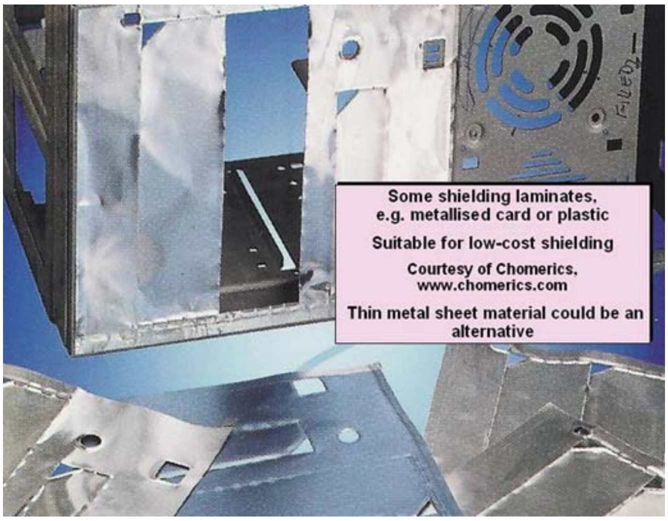

Figure 4BU Example of the use of metallised paper

Conductive fabrics are made in a similar way, except that the metallised fibres are longer and are twisted into threads and then woven to create a fabric. Conductive fabrics are often used to make shielded tents, as shown in Figure 4BV, which have the advantage of light weight and portability because they can be folded for transport. Where a product needs to be shielded and the appearance of the shielding does not matter, for example a missile during transport, or a mobile phone that has been seized by police or security forces, metallised fabrics are often very appropriate materials.

Figure 4BV Example of a shielded tent made from metallised fabrics

Compared with metal, metallised papers and fabrics have lower conductivity, and so have lower values of reflectivity and absorption.

4.7.4 Paints and lacquers

Non-conductive paints and lacquers do not reduce the reflectivity of a metal surface. But they can create SE problems by overspraying onto areas where they increase the impedance of RF-bonds. Painting is often a manual process, so overspray can vary as can the degree of skill used to mask off critical areas. Changes in painting methods or technology can affect overspray, so where masking was not previously required, new painting techniques might make it essential, to maintain the desired SE.

One solution that avoids having to control the painting process is to use special metal tapes with a masking tape layer on top, that affix to the metal surface with a conductive pressure-sensitive adhesive, available from 3M and others. Before the metal is painted, the tape is stuck onto the areas where the gaskets must make contact. After painting, the masking tape layer is peeled off to reveal the bright shiny metal tape. The metal under the tape is protected from oxidation and corrosion by the conductive glue.

Conductive paints and epoxies consist of a binding agent and conductive filler. They have a lower conductivity than metal, so have lower reflectivity. Silver-loaded epoxy is sometimes used to reduce corrosion, and although its reflectivity is not as good as the metal when it is new, it will probably be better than if it was allowed to corrode.

4.7.5 Painted or plated plastics

Plastics can be conductively coated by painting with conductive paints (see 4.7.4); flame spraying; thermo spraying; plasma flame spraying; or electroless plating (a chemical deposition process). Suitable materials include graphite; silver; copper; and nickel, but they do not usually achieve the same conductivity as their bulk materials. Conductive paints require much thicker layers for their SE to compare with metallised finishes, because they are mostly binding agent so have low conductivity.

The most important issue with conductively-coating plastics is to ensure that the coating remains firmly stuck to the plastic over at least the intended operational lifetime. Different types of plastics require different coating materials and coating processes, and flaking or peeling conductive films can compromise reliability, and even increase safety risks. Accelerated lifecycle tests are strongly recommended to ensure that the conductive coatings don't crack or flake off over the anticipated life of the product despite its environmental exposure (temperature, condensation, salt spray, etc.).

A problem with some conductive coatings, especially paints, is that they can flake off if sufficient mechanical pressure is applied, or rub off due to friction.

Metallised coatings are very thin, so have poor absorption at frequencies below a few hundred MHz, Nickel is often used to improve absorption at low frequencies, because it is ferromagnetic. But despite the shortcomings of painting or plating plastics, the SE of an enclosure made from such materials is usually limited by apertures and conductor penetrations, just as for enclosure made of solid metals.

See 4.3 in [20] for the basic issues of shielding, which apply equally to the conductive coatings on shielded plastic enclosures.

It can be difficult to get good RF bonds between the conductive surfaces of a plated or conductively-painted plastic enclosure – especially if the coating was a retro-fit to an existing enclosure that was not originally designed to be shielded. Figure 4BW shows the typical problem. The parts to be RF-bonded have been conductively coated on their inside surfaces, but these do not come into contact when assembled – creating an aperture in the shield.

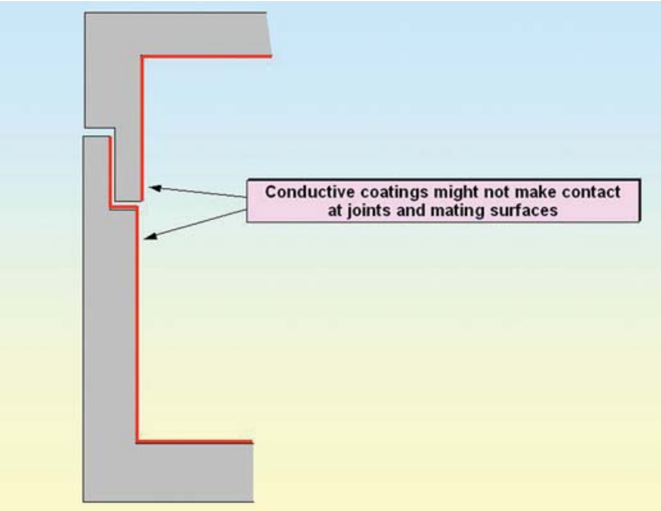

Figure 4BW A typical problem with RF-bonding coated plastic enclosures

Even where the conductive coatings wrap around the joints, contact never occurs along the full length of the seam – just as with metal parts, contact only occurs at a few 'high spots'. Temperature variations could even cause the contact points to move, changing the size of the shield apertures and making enclosure SE unpredictable.

One way of dealing with this problem is to design shielded plastic enclosures with 'built-in' plastic spring fingers. When conductively-coated, these can make good RF-bonds to their mating part's shielding surface.

Conductive gaskets can be used at seams and joints, as described for metal enclosures above – but the lower Young's modulus of plastics means that achieving the compressive forces they require, without causing mechanical distortion, is more difficult. However, it is possible to design so that gaskets can be used successfully – although it may be very costly to retrofit such design characteristics. So – where it is possible that a plastic enclosure might need to be shielded using a conductive coating – it is strongly recommended to design it from the first with the necessary 'built-in' spring fingers or fixings suitable for conductive gaskets.

Prototypes usually use conductive coatings that are hand-applied, and their quality and thickness will vary depending on the skill of the operator. Where manual application is used in serial manufacture, less care might be used, and the SE suffer. Automatic coating processes should give better repeatability, but where it is used the final EMC testing should be done on products that have used the automatic process, because the results can be very different from the hand-applied coatings on prototypes.

As well as an internal conductive coating, an additional external conductive coating can improve the SE of a plastic enclosure. Conductively coating all sides of plastic parts can also help overcome the problems with RF-bonding sketched in Figure 4BW. The external coating could be overpainted with something more aesthetically pleasing, as long as overspray did not compromise any RF bonds.

Care should be taken, when retrofitting shielding to a plastic enclosure by adding conductive coatings, not to increase safety risks by decreasing creepage distances and clearances. It often happens that immunity to electrostatic discharge (ESD) is compromised, because air-discharge can be more likely to occur due to the conductive coatings.

4.7.6 Shielding with volume-conductive plastics

Volume-conductive plastics or resins generally use distributed conductive particles or threads in an insulating binder that provides the mechanical strength. Typical conductive fillers include: carbon fibres; carbon black; metal-coated glass beads; nickel coated carbon fibres; and stainless steel fibres.

They often suffer from a 'skin' of the basic plastic or resin that forms over the surfaces, making it difficult to achieve good RF bonds without machining the surface, using helicoil inserts or similar methods. This insulating skin makes it difficult to prevent long apertures being created at joints, and also makes it difficult to provide good bonds to the bodies of connectors, glands, and filters.

Other problems include the consistency of mixing the conductive particles in the polymer or resin, which can make enclosures weak in some areas (too much conductive filler), and lacking in shielding in others (too little conductive filler). This is especially a problem at corners, which tend to suffer form too little filler.

Materials based on carbon fibres (which are themselves conductive) and self-conductive polymers are starting to become available, but they do not have the high conductivity of metal and so do not give as good an SE for a given thickness.

The conductivity of conductive plastics is generally much lower than that of bulk material of the filler, so reflectivity and absorption are both reduced.

The low conductivity of many conductive plastic coatings, and volume-conductive plastics, prevents them from being able to handle high fault currents or high levels of surge currents from lightning. These high current events generate significant heat, which damages the materials.

4.7.7 Alternatives to shielding plastic enclosures

Because of the Waste Electrical and Electronic Equipment in the Environment directive (2002/96/EC) conductively-coated or volume-conductive plastic parts are falling out of favour, because they are so difficult to recycle. Instead, products are increasingly being designed using PCB-level shielding (see 4.4).

Another alterative technique that is often employed is to fit a thin metal (or metallised card or plastic) shielding box within the plastic box, but around all the electronics. This metal box does not have to look nice, or provide any mechanical support – so it can be low-cost. Retrofitting such a box to an existing design is often very difficult indeed, if it is even possible. If such an internal shielding box might possibly be required – it is strongly recommended to design the product so that the box can be fitted later in the project, if found to be necessary.

Magnesium (or zinc) alloy castings can be used instead of plastic mouldings, and of course are much easier to use as shields and more easily recycled. Magnesium alloys can be as light as plastic for greater strength, or thinner and lighter for the same strength, but they cost more – so tend to be used for improving ruggedness, reducing size and weight, or for fashionable items.

4.7.8 Environmental considerations

Two European Directives concerning the protection of the environment (known as WEEE and RoHS) are now in force in the European Union. These directives will influence the type of shielding used, and the materials used in their construction, as has already been mentioned in 4.7.7 and other sections above. The volatile chemicals used in some conductive coating and electro-plating processes have a negative environmental impact, and these processes tend to make the coated materials difficult to recycle [38].

Chromate passivation using hexavalent chromium ('Chrome 6' or 'Hex-Cr') has been a marvellous technique for decades, but when Hex-Cr gets into water supplies very serious cancer outbreaks can occur. There are no direct replacements for surface treatment with Hex-Cr that provide all of its good properties on all metals (but without the cancer risks), but for specific applications/metals there are replacement coatings that can be as good, maybe even better on some tests [43]. The US Military has developed a trivalent chromium coating called TCP for aluminium, which is also effective on some other metals, and is available commercially. TCP applied to zinc-plated steel also looks promising.

Vacuum metallisation is 'eco-friendly', and tin and aluminium are non-toxic and easy to recycle - so vacuum-metallised plastic shielding-cans that are pressed, clipped or soldered into place may have fewer environmental disadvantages than conductively-coating the plastic enclosures themselves, or using volume-conductive plastics. [25] describes how thermo-formed shielding inserts can aid the recycling of plastic enclosures, and [29] describes how surface-mounted metal cans are easy to remove and recycle.

4.7.9 Preventing corrosion

Corrosion replaces metals with oxides, sulphides, chlorides, etc., increasing the resistance at RF bonds and reducing SE. Corrosion products are bulkier than their original metal, so tend to force joints apart, opening up apertures and reducing SE.

Some corrosion products behave as semi-conductors (non-linear resistance), which can generate harmonics of any AC flowing through them. They can also demodulate RF waveforms, and can intermodulate two or more AC signals creating new frequencies at their sum and difference frequencies. These can add to emissions, or cause immunity problems. Corrosion in connectors, antennas and grounding structures is especially a problem for RF transmitters, which have tight specifications on their harmonic and spurious emissions so as not to interfere with other radio frequencies.

Gases such as oxygen, sulphur dioxide or similar pollutants are usually dealt with by plating with a less reactive metal (e.g. zinc plating on steel) or a number of other surface treatments, discussed earlier. Multipoint RF-bonding using small, hard, contact points can generate pressures that are so high that cold-welding occurs, creating a small but gas-tight bond that is less susceptible to corrosion from gasses. Star washers are often used for this purpose, but – as mentioned in the section on spring fingers - RF bonds at higher frequencies benefit from area contacts instead of points.

Liquids that bridge joints between dissimilar metals can cause very rapid corrosion due to the galvanic effect. Environmental sealing gaskets can help keep certain gases and liquids away from a joint, but it is also good practice to use similar metals in contact, because condensation can occur inside an equipment (unless anti-condensation heaters are used).

Corrosion is most likely when dissimilar metals are in close proximity, or in contact, in the presence of electrolytes such as water (e.g. condensation), beer, food and drink, jet fuel, blood or tissue fluids, or a variety of other liquids. Two different metals plus an electrolyte creates an 'accidental battery', and current will flow from the cathode to the anode all the time the liquid bridges between the two metals. The anodic end of the accidental battery (the most positive in galvanic potential) has its metal turned into corrosion products, whereas the cathodic end (the most negative) is hardly affected at all.

Metals can be divided into a number of groups according to their galvanic potential, and five typical groups, with approximately 0.3V range within each group, are shown below….

Group 1	*(Most anodic)* magnesium, and magnesium alloys
Group 2	Aluminium and its alloys, cadmium, galvanised steel, and zinc
Group 3	Tin, tin-lead solder, lead, duralumin alloys, iron, and low alloy steels
Group 4	Nickel, monel, copper, brass, bronze, stainless steels, chromium, chrome steels
Group 5	*(Most cathodic)* silver, gold, platinum, graphite, and titanium

Monel (in Group 4) is often claimed to be a metal that does not corrode, and is often used in conductive gaskets. It does not oxidise readily in the air, but has no special resistance to galvanic corrosion.

Figure 4BX shows the recommended relationships in [41] between the groups the joint metals come from, the environment the joint is in, and the additional protective measures (like grease or painting). 'Protected' means indoors, inside a housing, not exposed to liquids and free from condensation almost all of the time.

Exposure situation	Anodic end (most heavily corroded)				Cathodic end
	Group 1	Group 2	Group 3	Group 4	
Exposed	B	A	n/a	n/a	Group 2
Sheltered	A	A	n/a	n/a	Group 2
Protected	A	A	n/a	n/a	Group 2
Exposed	C	B	A	n/a	Group 3
Sheltered	C	A	A	n/a	Group 3
Protected	B	A	A	n/a	Group 3
Exposed	No	C	B	A	Group 4
Sheltered	C	B	A	A	Group 4
Protected	C	A	A	A	Group 4
Exposed	No	No	C	B	Group 5
Sheltered	No	B	B	A	Group 5
Protected	C	B	A	A	Group 5

KEY: No = Do not use this combination
A = Metal may be exposed at junction surfaces
B = Coating *must* prevent any possibility of liquid bridging the join
C = Protective coatings mandatory, but joint may still have a short life

Figure 4BX Corrosion prevention guidance from NAVAIR AD 115 [44]

Dissimilar metals can be plated to reduce their galvanic effect, for example tin-plated copper is a better partner for aluminium than copper would be. When plated, the dissimilar metal joint is protected from any liquids, so will not experience galvanic corrosion. However, scratches or pinholes in the plating can expose the underlying metal so the plating must be thick enough for the expected mechanical stresses, and also of sufficient quality.

AC or DC current through a dissimilar metal joint hastens galvanic corrosion, even when a liquid is not present to act as an electrolyte (this is why car battery terminals are always kept very heavily greased). So it is best to use metals that are in the same group, or the same metal, where currents could be significant. Plating dissimilar metals with the same metal is a good way to prevent galvanic corrosion, for example tin-plated aluminium with tin-plated copper, as long as the plated surfaces are robust enough and don't have pinholes.

Appendix E of [45] has a great deal of useful information and design guides on preventing corrosion, and a wealth of references for further study.

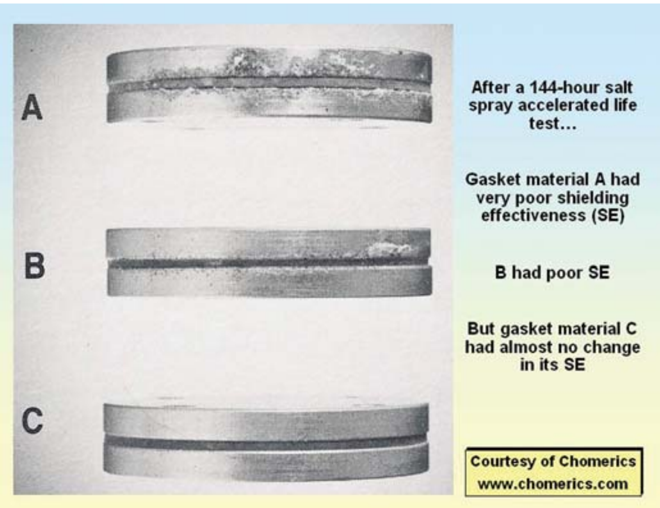

Figure 4BY Example of a corrosion test on three different gaskets

As mentioned in 4.6, conductive gaskets must also be galvanically compatible with the material they are in contact with, for enclosure SE to be maintained reasonably well over the life of the equipment. Figure 4BY shows the effect of a standard 144 hour salt spray test on two aluminium discs separated by three different kinds of gasket. The least suitable gasket was sample A, whilst the best was sample C. Even though a joint might not have to weather salt spray, 144 hours is not a long time, so this test is an indication of how well a joint might last in more normal environments over a period of years.

Good gasket manufacturers should be able to supply a wealth of test data on the compatibility of their products with different metals.

There are modern corrosion protection materials that might prove useful, such as 'vapour-phase corrosion inhibition' (visit www.cortecVpCI.com). I have no experience of this technique, but understand that this is based on pellets of a solid material that slowly sublime, coating everything nearby with a molecular layer that is a barrier to gasses and liquids, but is easily displaced by mechanical pressure, for example at an RF bond.

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