A LOOK AT
METAL Barriers with discontinuities
for related TECKNIT PRODUCTS.

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INTRODUCTION

This report describes the effects of metal barriers with discontinuities, and how to maintain shielding with them.

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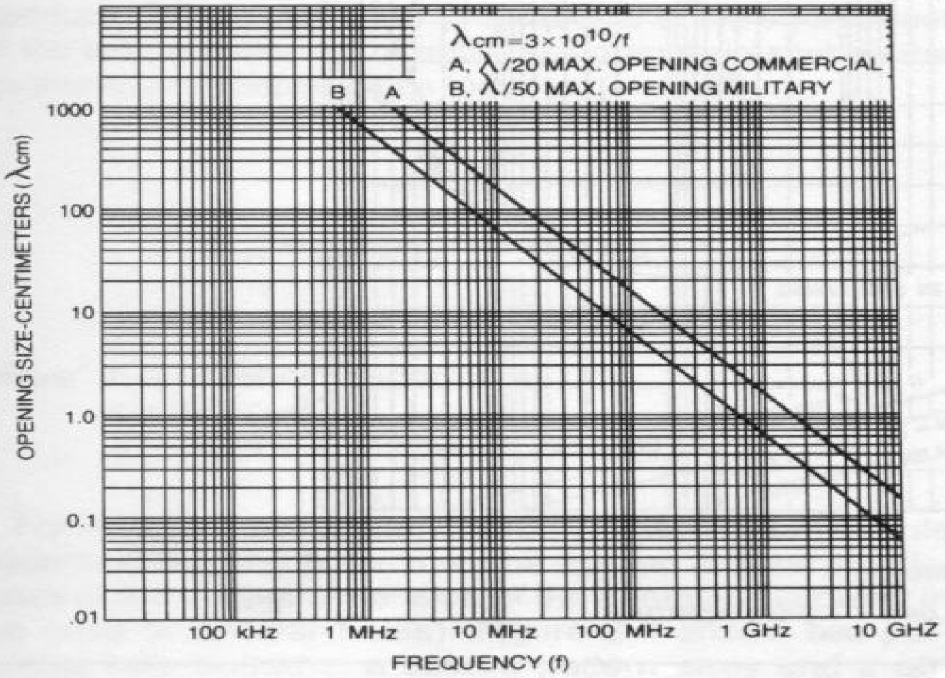


Figure 3-1, Maximum Size Opening Against Threat Frequency

The theoretical shielding analysis considers the barrier as an infinite plane of finite thickness. For practical purposes, barriers must be considered in terms of the need for normal enclosure discontinuities, such as seams and holes.

The ideal EMC enclosure would be fabricated from materials that possessed the desired physical and electrical characteristics, including resistance to adverse environmental conditions. Discontinuities degrade the shielding and moisture sealing integrity and their design is critical in maintaining the desired levels of shielding effectiveness. Access openings in the cabinet provide the possibility of electromagnetic coupling through the openings and seams created in normal construction techniques. The efficiency of the coupling depends upon the size of the hole or seam with relation to the wavelength of the interference. Any openings in an enclosure can provide a highly efficient coupling path at some frequency. As the aperture increases in size, its coupling efficiency also increases.

A good rule of thumb to follow in general design practice is to avoid openings larger than ë/20 for commercial systems and ë/50 for military systems (ë being the wave length of the threat frequency). Since most EMI coupling problems are broadband in nature, the frequency of concern must be the highest threat frequency within the bandwidth envelope. Figure 3-1 shows ë/20 and ë/50 aperture sizes over the frequency range of 100 kilohertz (kHz) to 10 gigahertz (GHz).

When it is necessary to specify an opening larger than ë/20 or ë/50, the designer must be aware that EMC protective measures are required to reduce the coupling threat which the aperture introduces. Any EMC protective measure will of necessity not be able to restore the shielding effectiveness of the original enclosure. The amount of degradation depends upon the shielding material used and the application of that material. The EMC restoration measures available are of two kinds: first, substitution of non solid barriers for metal removed from the enclosure to provide openings, and second, use of shielding gasket materials to fill interface seams.

Shielding materials tend to restore the shielding effectiveness of the barrier by absorbing and reflecting energy from an impinging electromagnetic wave and by providing conductive paths across discontinuities to permit uniform current flow reducing the threat of signal coupling through the aperture.

Holes in Thin Barriers (d > t)

Electromagnetic leakage through an aperture is dependent upon two factors: (a) the longest dimension, d, of the aperture and (b) the wavelength, ë, of the radiating field. For wavelengths less than two times the longest aperture dimension (ë < 2d), the electromagnetic energy will pass freely through the opening without being attenuated. For wavelengths equal to twice the opening (ë = 2d), the shielding is zero. The frequency at which this occurs is called the cut off frequency (fc.).

$$fc = \frac{C}{2d}$$

where C is propagation velocity of electromagnetic waves.

For wavelengths greater than two times the maximum dimension (ë > 2d**),** the attenuation (Figure 3-2) is expressed as:

$$RdB = 20\log \frac{\text{ë}}{2d}$$

where ë / 2 > d> t (t=material thickness)

Apertures affect both the reflection and absorption terms. The reflection term is lowered as a result of an increase in the barrier impedance relative to the wave impedance. The increase in barrier impedance is caused by leakage inductance which is related to the dimensions of the aperture and the spacing of the radiating circuits from the aperture. A good approximation of the net shielding is to assume 0 dB shielding at the cut off frequency (fc.) and a linear increase of 20 dB per decade in shielding as the frequency decreases. The maximum possible shielding effectiveness, of course, is equal to that value calculated for a solid barrier without an aperture.

For example, consider an aluminum equipment enclosure with a barrier thickness of 1.5 mm (0.06 inch) and a single 7.5 cm (3 inch) fan hole. The E-Field shielding, where the distance between the source and barrier is 30 cm, is shown in Figure 3-3. The total shielding effectiveness for 1.5 mm thick aluminum is shown to be solely a function of the hole. The 7.5 cm hole becomes half-wave resonant at 2000 MHz and the shielding effectiveness at that frequency is zero. At frequencies below 2000 MHz, shielding increases 20 dB per decade. Thus at 200 MHz, the attenuation is 20 dB, at 20 MHz it is 40 dB and at 2 MHz it is 60 dB. As shown in Figure 3-3, the total shielding effectiveness has been significantly reduced by the presence of this one hole. However, below 20 MHz, the shielding is still significant for many applications. Some of the original shielding effectiveness can be restored with screens or honeycomb panels as discussed below.

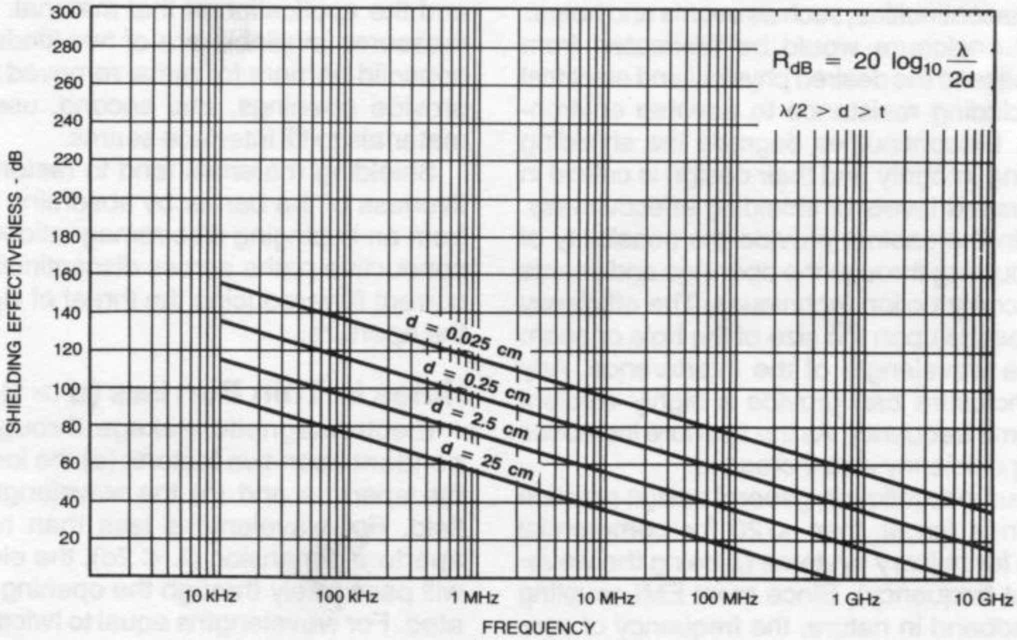


Figure 3-2, Aperture Attenuation

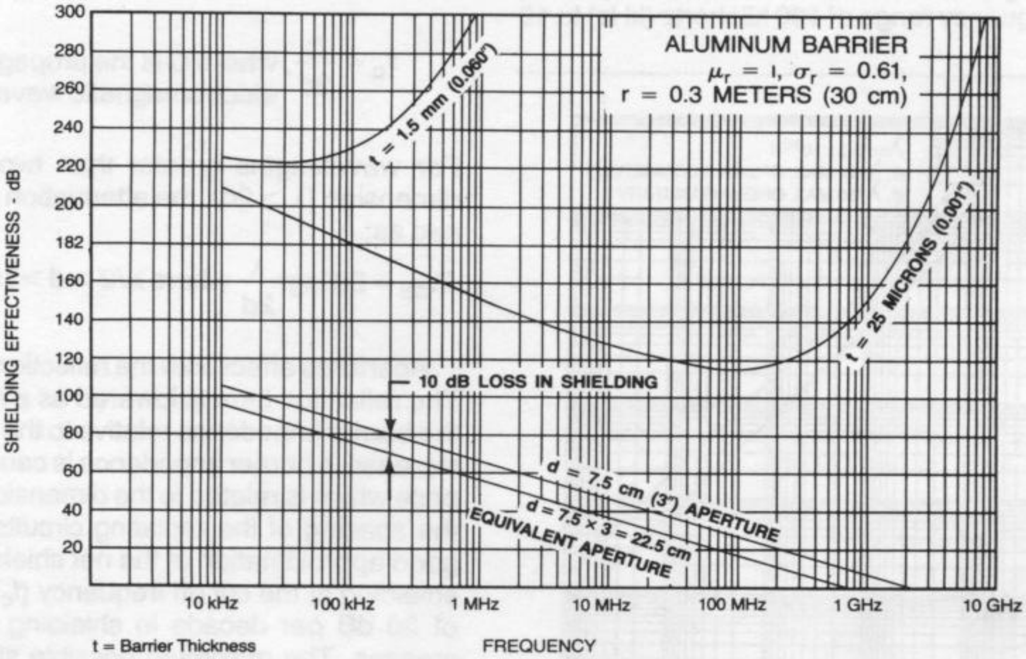


Figure 3-3, Shielding Loss – 7.5 cm Aperture

The above analysis has not assumed any factor for the effect of a noise source in close proximity to the aperture. As long as the potential EMI noise source is spaced at least as far away as the largest dimension of the aperture, the above analysis will be accurate. However, when the noise source is closer than the largest dimension of the aperture, then a reduction in shielding can be expected. Deriving the shielding requirement in this situation can be complicated. As an approximation, the effective cut off frequency is reduced proportionally to the ratio of the distance (r) from the aperture to the largest dimension of the aperture. For example, if a susceptor circuit were placed 2.5 cm from the 7.5 cm aperture, then the shielding effectiveness provided for that circuit would be 0 dB at 670 MHz (lowering the effective cut off frequency by one third 2.5 cm/7.5 cm). Below 670 MHz, the shielding for the circuit would vary inversely with frequency yielding 20 dB at 67 MHz and 40 dB at 6.7 MHz, as shown in Figure 3-3 (reference curve equivalent to 22.5 cm aperture).

$$Fc = \frac{C}{2d} \left(\frac{r}{d} \right)$$

and

$$R\ dB = 20 \log \frac{fc}{F} = 20 \log \frac{\text{ë}}{2d} \left(\frac{r}{d} \right) \quad \text{where ë}/2 > d$$

Multiple Apertures

The presence of more than one aperture of the same size in a solid metal barrier has the effect of reducing the total effective shielding. The amount of shielding reduction is dependent on the spacing(s) between any two adjacent apertures, the wavelength of the interference and the total number of apertures. If the two apertures have the same maximum dimension and are spaced at least a half-wave length apart (ë/2 > d) the shielding reduction is minimal and can be considered zero for practical purposes. However, as the apertures are brought closer together, they no longer behave independently as single apertures. The worst case condition occurs when no metal separates the apertures and the maximum dimension doubles. This condition halves the cut off frequency, reducing the total shielding by 6 dB (factor of two) at all frequencies below the cut off frequency. The reduction in shielding due to multiple apertures is approximately proportional to the square root of the total number (n) of equal sized apertures when the apertures are spaced close together (s < ë/2).

$$R\ dB = 20 \log \frac{\text{ë}}{2d} - 20 \log n\text{½}$$

where n = number of apertures

s **<** ë/2 >d >t

s = edge to edge hole spacing

For multiple hole patterns to be treated as single hole discontinuities, the holes must be spaced at least the distance of the largest dimension of the aperture (diameter in the case of circular holes). Figure 3-4 shows two perforated hole patterns, a square pattern array and a 60E staggered pattern. Hole spacing equal to the hole size occurs when the open area is 20% for the square pattern and 23% for the 60E staggered array. Open area values for several shapes and arrays are given in Table 3-1. As the hole size increases beyond that given in Table 3-1, the holes can no longer be treated as single hole discontinuities and must be considered as multiaperture discontinuities.

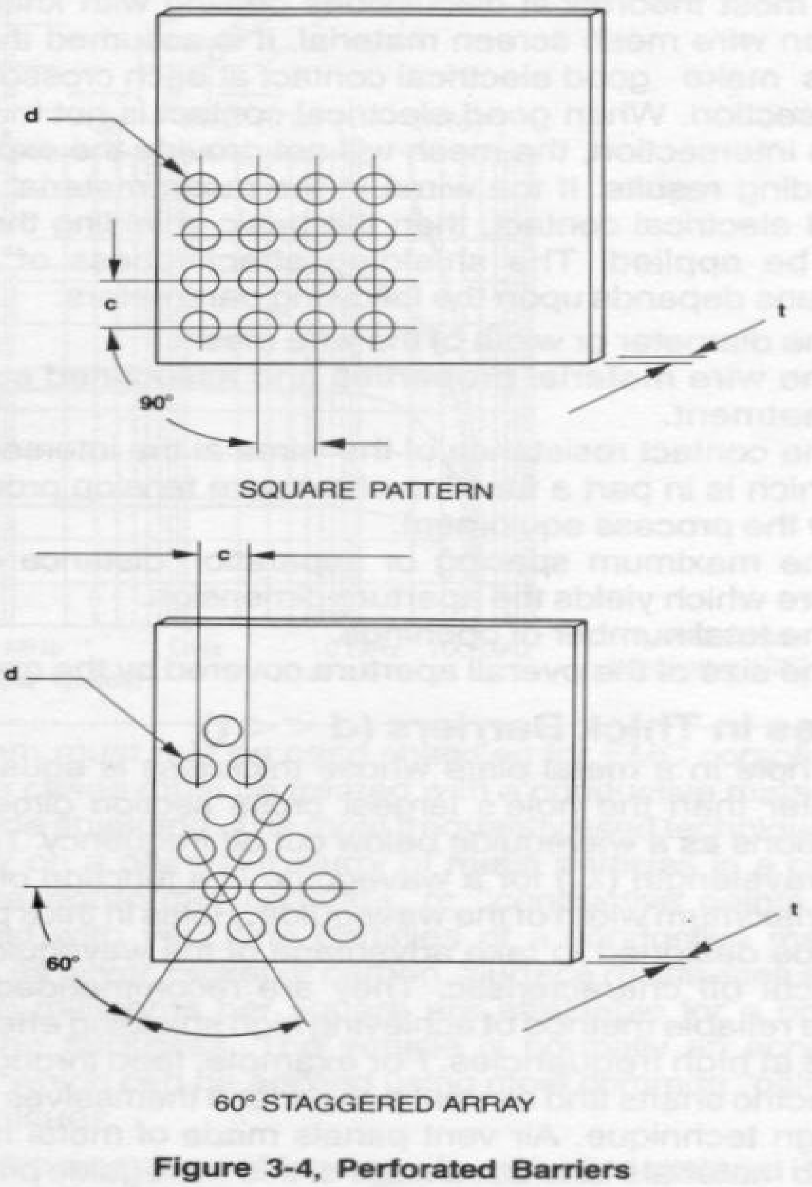


Figure 3-4, Perforated Barriers

Perforated hole pattern data:

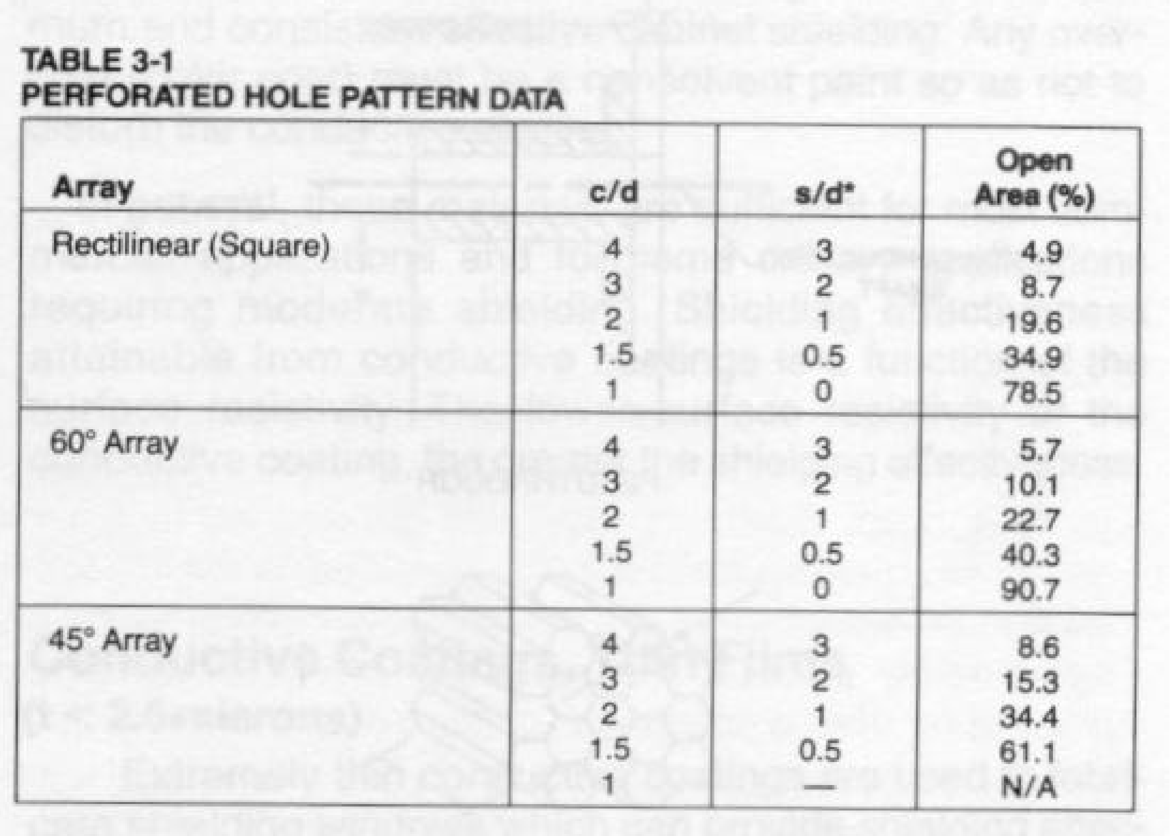


TABLE 3-1
PERFORATED HOLE PATTERN DATA

Array	c/d	s/d*	Open Area (%)
Rectilinear (Square)	4	3	4.9
	3	2	8.7
	2	1	19.6
	1.5	0.5	34.9
	1	0	78.5
60° Array	4	3	5.7
	3	2	10.1
	2	1	22.7
	1.5	0.5	40.3
	1	0	90.7
45° Array	4	3	8.6
	3	2	15.3
	2	1	34.4
	1.5	0.5	61.1
	1	—	N/A

s = Spacing between holes of diameter (d)
c = Center to center hole spacing
*s/d < 1, multiple aperture condition
N/A = not applicable for 45E array

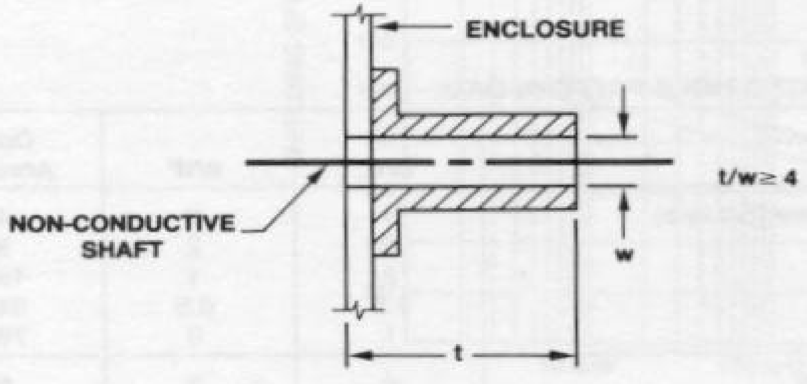
Knitted and Woven Mesh Screens

In most theoretical discussions dealing with knitted or woven wire mesh screen material, it is assumed that the wires make good electrical contact at each crossover or intersection. When good electrical contact is not made at each intersection, the mesh will not provide the expected shielding results. If the wires in the mesh material make good electrical contact, then the basic shielding theories can be applied. The shielding effectiveness of mesh screens depends upon the following parameters:

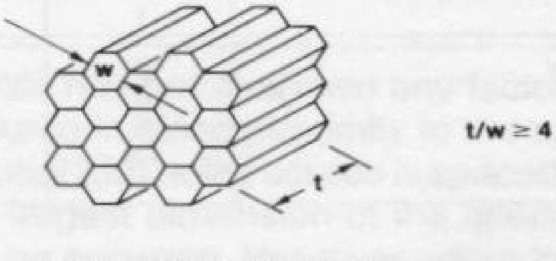
1. The diameter or width of the wire mesh.
2. The wire material properties and associated surface treatment.
3. The contact resistance of the wires at the intersections which is in part a function of the wire tension produced by the process equipment.
4. The maximum spacing or separation distance of the wire which yields the aperture dimension.
5. The total number of openings.
6. The size of the overall aperture covered by the mesh.

Holes in Thick Barriers (d << t)

A hole in a metal plate whose thickness is equal to or greater than the hole's largest cross section dimension functions as a waveguide below cut off frequency. The cut off wavelength (ëc.) for a waveguide is a function of twice the maximum width of the waveguide. Holes in thick panels can be designed to take advantage of the waveguide below cut off characteristic. They are recommended as a more reliable method of achieving high shielding effectiveness at high frequencies. For example, feed throughs for dielectric shafts and air vent panels lend themselves to this design technique. Air vent panels made of metal honey- comb materials take advantage of this waveguide principle as it applies to the individual honeycomb cells. Such a panel is functionally a cluster of waveguides (see Figure -3-5). -



FEEDTHROUGH



HONEYCOMB PATTERN

Figure 3-5, Waveguides Beyond Cutoff

The barrier characteristics of an individual waveguide below cut off is a function of the thickness (depth) to width ratio (t/w). As the thickness to width ratio increases, so does the shielding effectiveness of the material.

The absorption factor (ë) for a waveguide below cut off frequency is give by:

á = (2ð / ëc) **/** (1 - (f/fc)²

where ëc = cut off frequency wavelength

The cut off frequency is a function of the cross sectional geometry of the waveguide. For rectangular waveguides, the cut off frequency is:

fc = 1.5 x 10exp10 /wcm = 5.9 x 10exp9/win

wcm in centimeters, win in inches

where w is the largest dimension of the waveguide cross section. For frequencies much below the cut off frequency $(f / fc)^2 < < 1$) the absorption factor approaches:

á = (2ð / ëc)= ð / w, where ëc = 2w

and the absorption loss A dB**,** becomes:

AdB = 8.686 át = 27.3 t/w,

where t = depth of the waveguide.

For circular waveguides, the cut off frequency is:

fc **=** 1.76 x 10exp10 /wcm = 6.92 x 10exp9 / win,

and A dB = 32 t / w

Figure 3-6 shows that with only moderate values for t/w (e.g. 4), the shielding levels of a single honeycomb cell are high enough that the overall shielding effectiveness of a honeycomb panel may be determined by how well the seam is gasketed. In the construction of honeycomb panels, the foil strips making up the cells are treated so that the individual cells make good electrical contact with each other in all directions. Electrical continuity is important in the construction of vent panels. Shielding effectiveness of honeycomb material can be significantly improved when the complete panel is plated with a conductive material, such as tin. Plating improves the conductivity between adjacent cells of the honeycomb and between the honey- comb and the mounting frame. The above theory on waveguide beyond cut off shielding pertains to "honeycomb" type materials commonly used to make air vent panels for electronic enclosures. Common honeycomb material which has a depth-to-width (t/w) ratio of approximately 4:1, is capable of substantial attenuation (over 100 dB). For honeycomb panels, the absorption loss for a single waveguide is reduced by a factor related to the total number of openings in the panel. The total shielding effectiveness including the first reflection term (RdB) is:

$$SE\ db = 20 \log \frac{fc}{f} + 27.3 \frac{t}{w} - 10 \log n$$

where n= total number of cells, and f<= fc/10

For a vent panel containing as many as 10,000 honeycomb cells, the total shielding degradation is 40 dB. Nevertheless, given a t/w ratio of 4:1 and a threat frequency (f) equal to one tenth cut off frequency (f,), the shielding afforded by a panel with an eighth inch cell cross section and 10,000 openings is still in excess of 90 dB at 4.7 GHz.

Table 3-2 lists the cut off frequencies for standard cell sizes of commonly available honeycomb materials:

Cell Size (W)	Cell depth (t)	t/w	cut - off Frequency (fc)	Absorption (A dB)
1/8 inch	½ inch	4	47 GHz	109 dB
1/8 inch	3/4 inch	6	47 GHz	164 dB
3/16 inch	3/4 inch	4	31 GHz	109 dB
3/16 inch	1 inch	5+	31 GHz	146 dB
1/4 inch	1 inch	4	24 GHz	109 dB

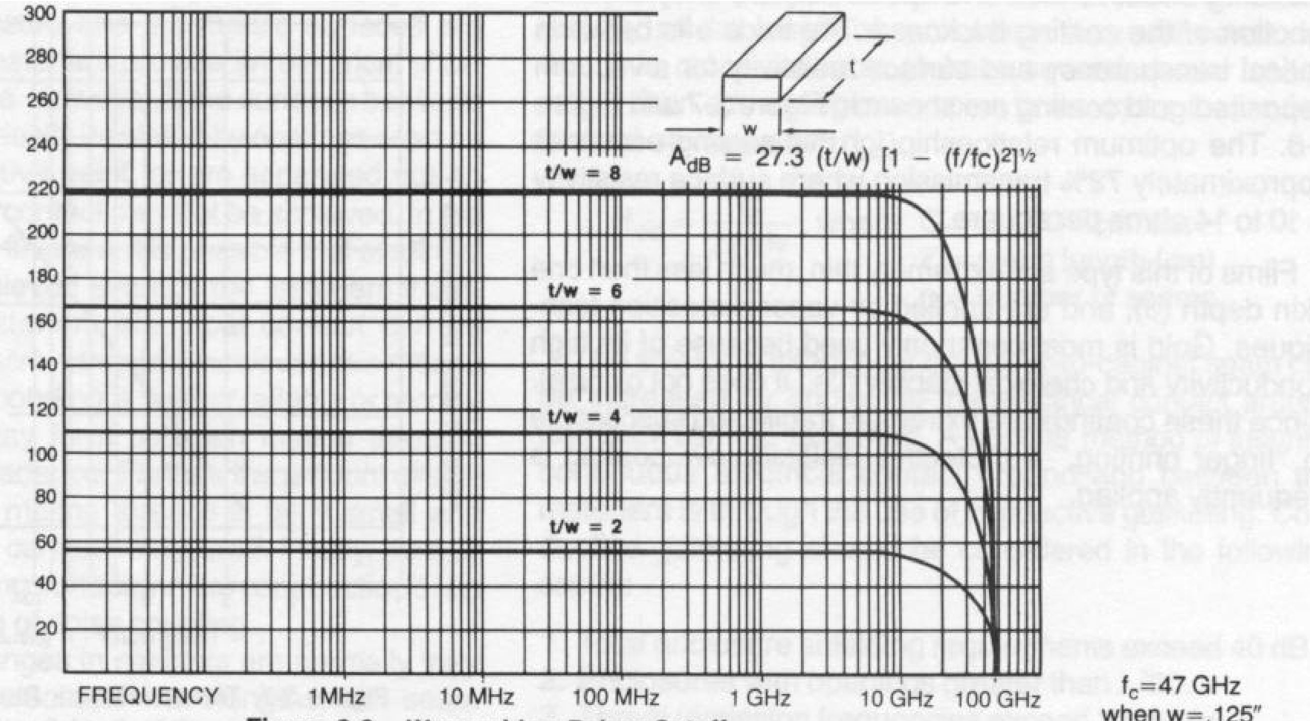


Figure 3-6, Waveguides Below Cutoff

Conductive Coatings, Thick Films (t > 2.5 microns)

Many commercial electronic systems are packaged in cabinets of plastic or other nonconductive material. If the system must rely on case shielding for EMC compliance, these cases must be treated with a conductive material to provide shielding. The most frequently used technique is to spray on a paint-like slurry of metal particles in a carrier. These conformal coatings, or "conductive paints," are loaded with very fine particles of a conductive material such as silver, nickel or carbon. Surface resistance as low as 50 milli-ohms per square are attainable for a one mil coating thickness. The vehicle is normally an acrylic or latex which can be applied using most common "painting" techniques.

The percentage of loading of conductive material is from 20% to 80% by weight to provide moderate to very high conductivity. Shielding effectiveness of a uniform coating is excellent. Care must be excercised in the preparation and mixing of these conductive coatings to ensure maximum and consistent effective cabinet shielding. Any overcoat (color coat) must be a non solvent paint so as not to disturb the conductive coating.

In general, these materials are sufficient for most commercial applications and for some military applications requiring moderate shielding. Shielding effectiveness attainable from conductive coatings is a function of the surface resistivity. The lower surface resistivity of the conductive coating, the greater the shielding effectiveness.

Conductive Coatings, Thin Films (t < 2.5 microns)

Extremely thin conductive coatings are used to fabricate shielding windows which can provide shielding effectiveness of better than 60 dB up to 100 MHz and beyond. These coatings are generally applied to clear materials, such as plastics and glass.

In this case, surface resistivity, shielding effectiveness and optical transparency are all a function of the coating thickness. The trade-offs between optical transparency and surface resistivity for a vacuum deposited gold coating are shown in Figure 3-7 and Figure 3-8. The optimum relationship for this coating occurs at approximately 72% transmission where surface resistivity is 10 to 14 ohms per square.

Films of this type are extremely thin, much less than one skin depth, and are applied by vapor deposition techniques. Gold is most commonly used because of its high conductivity and chemical stability (i.e., it does not oxidize). Since these coatings are extremely fragile and susceptible to "finger printing," a protective dielectric overcoating is frequently applied.

Figure 3-7

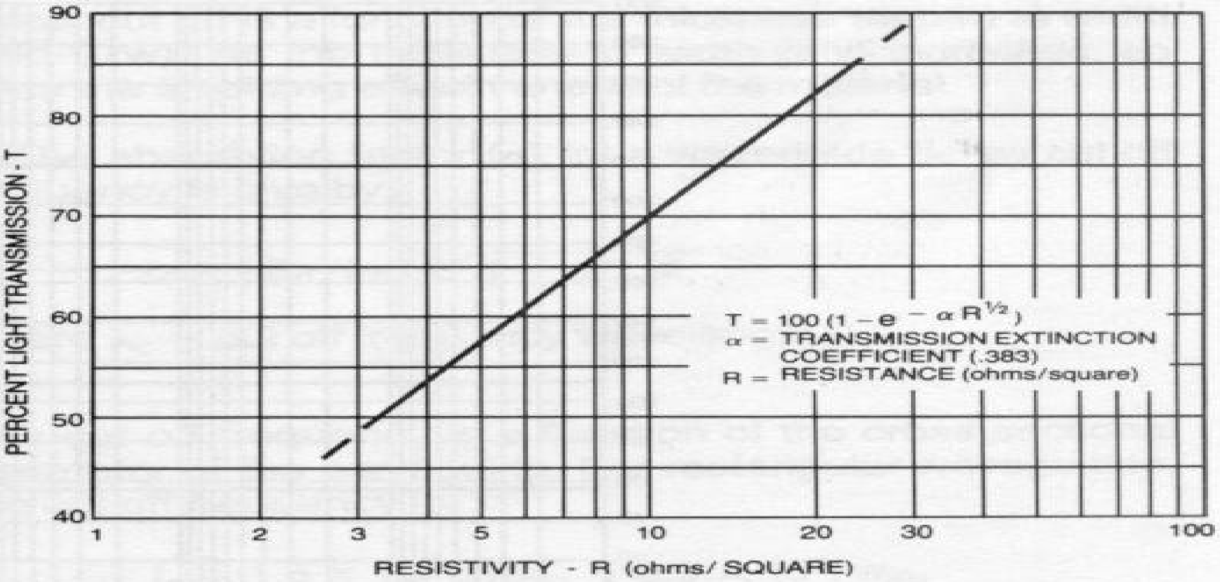


Figure 3-7, Transmission - Resistivity Relationship - Thin Gold Coatings

Figure 3-8

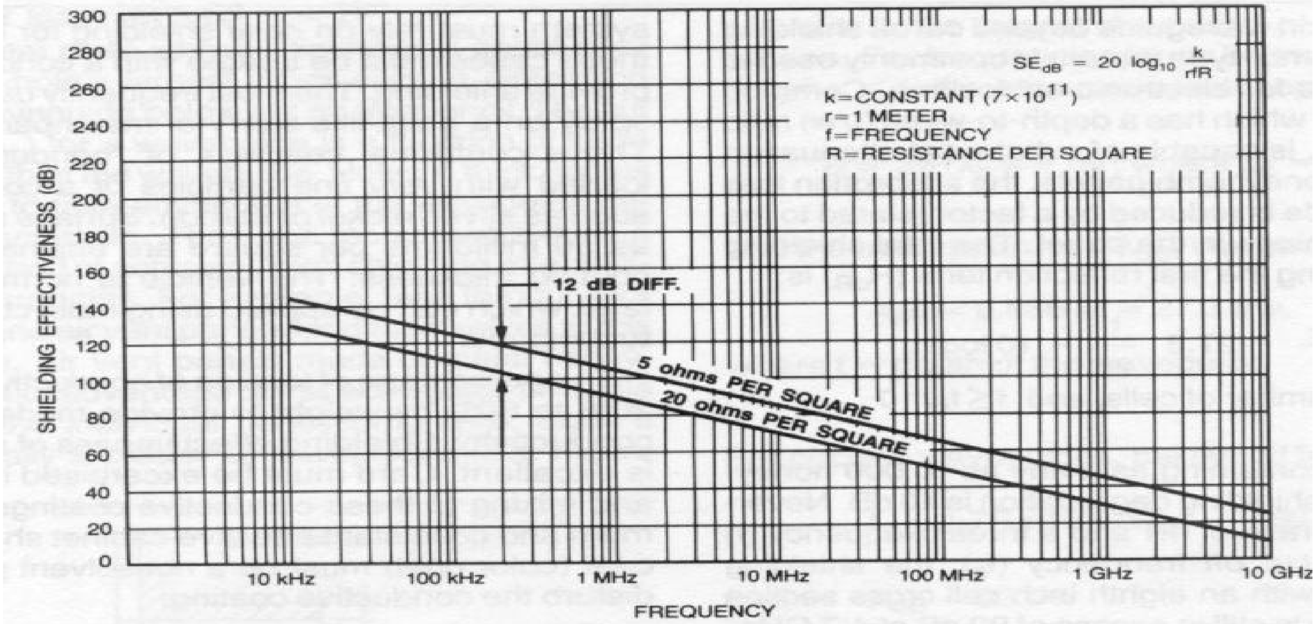


Figure 3-8, Shielding Effectiveness, Thin Coatings (t << 2.5 MICRONS)