# Design considerations for minimizing large aperture effects in shielding

## Large aperture arrays can present special shielding challenges.

**Ron Brewer**
Laird Technologies
Delaware Water Gap, PA

Shielding can be used at the systems or PC board level to protect sensitive equipment or circuits from both internal and external RF sources. Large systems can be placed in shielded rooms or even shielded buildings. However, regardless of the size of the enclosure, the shielding works the same way and suffers from the same problems. Briefly, shields work because the difference in the radiated field and shield impedance results in some of the RF energy targeting the enclosure being reflected (R) from the surface and in some of the energy being absorbed (A) as it travels through the shield material. The remainder of the energy exits the other side of the enclosure.

The ratio of the incident field intensity entering the shield to the field intensity exiting on the other side is the shielding effectiveness. At the higher frequencies, an enclosure's shielding effectiveness is dominated by absorption:

$$A(dB) = Ka\ t\ \sqrt{(\mu\sigma\ F)}$$

where
$A(dB)$ = absorption loss,
$Ka$ = 3.338 (t in mils) or 131.4 (t in mm),
$t$ = thickness (mils or mm),
$\mu$ = relative permeability,
$\sigma$ = relative conductivity, and
$F$ = frequency in MHz.

Absorption is significant and continues to increase with frequency. In fact, the attenuation becomes so large that high frequency shielding is not normally determined by the shield material. For example, a small electronic enclosure made from aluminum ($\mu = 1$, $\sigma = 0.64$) would have an approximate thickness of 40 mils. At a frequency of 100 MHz, the absorption loss is 26.7 dB per mil of thickness, and the enclosure attenuation would be 1068 dB. At 1000 MHz, its absorption loss would be 3378 dB!

Of course, we aren't able to measure attenuation that large. Measurements are limited to about 140 dB. Nevertheless, shielding affords suppression that does not attach to the circuit, that is capable of providing attenuation levels exceeding 3000 dB, and that provides attenuation levels that increase with frequency.

Seemingly, shielding could be the almost-perfect suppression component. Unfortunately, the circuits requiring shielding are not so perfect! As circuits generate heat because of their inefficiencies, the temperature internal to the shield rises; and the resultant heat must be removed. There are three ways of eliminating this heat: thermal radiation, conduction, and convection. The most effective is convection, which can be either natural or forced air using internal exhaust fans. The mechanical, fan-based approach to heat exhaustion is highly effective and thus allows greater circuit density, but it requires holes in the shield. Further, to provide the necessary airflow, one hole is generally not enough. An array of holes (apertures) is needed. These large aperture arrays degrade the shielding and present special design difficulties because of mechanical variations. The bigger the aperture, the poorer the shielding; and in many cases, in spite of the material being used for the enclosure, shielding effectiveness (SE) does not exceed 30 to 40 dB!

A simple expression for the worst-case attenuation of a single hole or slot aperture (that is not penetrated by a conductor) in a thin conducting sheet is:

$$S(dB) = k \log (\lambda/2\ L)$$

where
$S(dB)$ = slot attenuation
$k$ is determined by the shape of the hole and ranges between 20 and 40,[1, 2, 3]
$\lambda$ = incident wavelength, and
$L$ = slot length (which is $< \lambda/2$).

At or above the cutoff frequency for the hole (when $L = \lambda/2$), the shielding effectiveness is assumed to be zero (0). Even though this assumption simplifies the equation, it is inaccurate because the actual behavior of the slot aperture is equivalent to that of a complementary dipole. Note that the electromagnetic field patterns for the dipole and the slot are the same, but their electric and magnetic fields are transposed.

The above equation can be solved in terms of the slot length (L) to determine the aperture size that results in a given attenuation. In general, however, apertures should be smaller than λ/50 and should never be larger than λ/20. To achieve acceptable attenuation values at 100 MHz, for example, apertures should be smaller than 10 mm. In general, seams tend to be the largest, and consequently, the "worst-case apertures." Obviously, since seams cannot be any larger than the enclosure itself, the smaller the enclosure, the better. Also, smaller enclosures have fewer penetrations; and these penetrations are, in turn, smaller.

Still, there is a problem with this simplified approach because holes of equal area can have significantly different shapes. A slot is a good example. Slots have long opening lengths combined with small opening widths. Obviously, a narrow-width slot must be quite long to equal the area of a square. Since the cutoff frequency for RF energy polarized with the slot length is determined only by the length and not by the opening width, the degradation in shielding is proportional to the combined length of the slots and not their area. For this polarization, the width of the slot principally determines the slot bandwidth (Figures 1 and 2).

Considerable improvement in aperture shielding effectiveness can be obtained (as λ/2 approaches the value L) by increasing the thickness of the material so that it is equal to, or greater than L—*i.e.*, (t ≥ L).

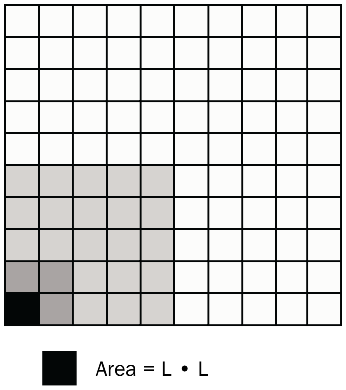
At this point, the opening begins to act as a waveguide being operated below its cutoff frequency. Although it will depend on the propagation mode, for frequencies that are less than $F_{co}/3$, waveguide attenuation is independent of frequency and is given thusly

$$A(dB) \cong 30\ t/L$$

where

A(dB) = attenuation,
t = thickness, and
L = length or diameter of the opening.

This equation is for one waveguide, and the constant, 30, is an approximation. The actual value is determined by hole shape, and ranges from about 28 to 32. For a t/L ratio of 4, typical of high performance honeycomb shields, the calculated attenuation of one cell is 120 dB. In the frequency range between $F_{co}/3$ and $F_{co}$, the attenuation decreases, reaching 0 dB at $F_{co}$. Even so, the waveguide has significantly greater attenuation in this frequency range than the same size hole in a thin sheet would exhibit. Although there may be considerable variation in the attenuation resulting from manufacturing differences, this characteristic is fundamental to the superiority of honeycomb, which is constructed to create small waveguides assembled in parallel. The shielding relationship (attenuation in dB/in. for a single aperture) between frequency, hole size, and thickness is shown in Figure 3.



For a multiple array of N equal size holes (approximately square, *i.e.*, the length-to-width is ratio less than about 3:1), the degradation is proportional to the combined areas of the holes, and the shielding is calculated from:

$$\begin{aligned} SE\ (dB) &= k \log (\lambda/2L) - 20 \log \sqrt{N} \\ &= k \log (\lambda/2L) - 10 \log N \end{aligned}$$

*Figure 1. Shielding degradation is proportional to the combined area of the holes.*

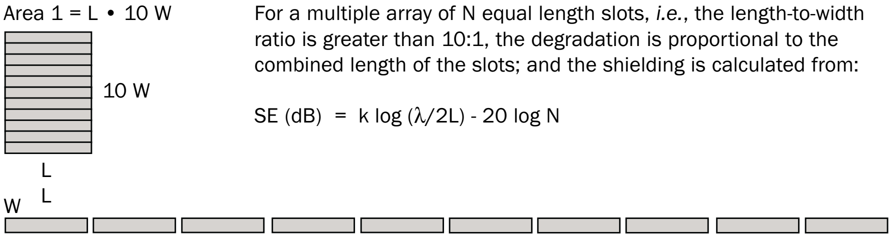
As more apertures are added, the enclosure attenuation degrades. A simplified way of calculating the effects of multiple holes is to reduce the attenuation estimate by 20 log *n*, where *n* is the number of holes. Two holes would be -6 dB; ten holes would be -20 dB; and so on. Simplistically, it would seem that a large aperture array with many holes would have no attenuation at all.

Fortunately, in the near field, the number of holes that can contribute to the reduction in shielding is limited. This limiting effect is determined by the separation between the holes. As the spacing between the holes increases, coherent recombination of the RF energy from the widely spaced holes becomes impossible; and consequently, the holes act independently. Thus the maximum number of holes that determine the attenuation of the array can be approximated by those contained in a circular area ($A = \pi r^2$) with a radius of λ/2.

Frustratingly, even then this approximation fails. Note the counter-intuitive statement that if the size of the openings are made smaller so that more are enclosed by area (A), shielding will be degraded. This conclusion is simply not the case. Bereuter and Chang provided a comprehensive analysis of this fallacy as applied to honeycomb shielding.[4]

For lower frequency applications where only moderate shielding is required, the least costly approach is to use perforated materials or woven or knitted screening. However, for those critical applications, requiring highly effective shielded ventilation panels and/or outstanding airflow characteristics in a restricted area, honeycomb materials combine the best airflow with the best attenuation. Honeycomb is constructed of small adjacent electrically-connected tubes (small waveguides) made from thin metal foil strips assembled in parallel. This produces a material that is approximately 97% open area. Honeycomb does have greater directional characteristics compared with holes in thin materials, but the airflow through the honeycomb is not as turbulent. Also, the directional characteristics allow honeycomb vent panels to be constructed in drip-proof or visually secure configurations.

Despite the impressive figures provided by some shielding materials. (High performance honeycomb can provide 120 dB attenuation at 18 GHz, and a solid aluminum access panel 40 mils thick provides an absorption loss of 3500 dB), in-



For a multiple array of N equal length slots, *i.e.*, the length-to-width ratio is greater than 10:1, the degradation is proportional to the combined length of the slots; and the shielding is calculated from:

$$SE\ (dB) = k \log (\lambda/2L) - 20 \log N$$

Area 2 = 10 L • W, and is equal to Area 1, the nearly square opening.

*Figure 2. Shielding degradation is proportional to the combined length of the slots.*

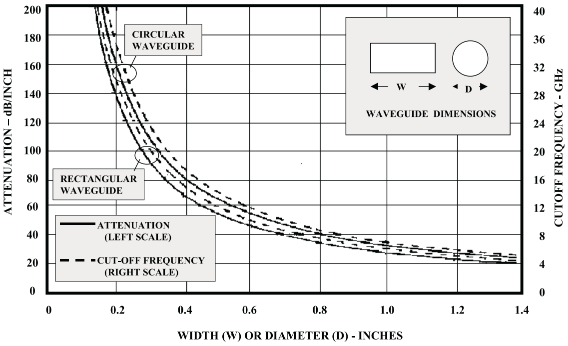


*Figure 3. Waveguide attenuation and cutoff frequency.*

stallation remains key to truly effective shielding. Any panel that is not adequately bonded into the enclosure behaves as a lossy antenna structure sitting in a hole. Grounding the panel at one point will reduce the antenna efficiency and may even solve radiation problems at low frequencies, but it will not eliminate leakage from the rest of the seam. For example, if the 120-dB honeycomb were improperly installed over a small 6-in. muffin fan, the perimeter leakage could limit the enclosure attenuation at 100 MHz to about 20 dB!

The best installation methods are welding, brazing, soldering or riveting—in that order. But these methods preclude easy access for maintenance and repair. Installing closely spaced threaded fasteners or clamps permits, but does not facilitate, field removal.

RF gaskets also play a vital role in shielding effectiveness. With the exception of enclosures made from foil, manufacturers generally use RF gaskets to minimize leakage of large apertures. For example, ventilation panels are generally provided with conductive springs to maintain contact across the seams. Depending upon the seam design used, gaskets will eliminate the need for fasteners or at least will permit them to be spaced further apart.

## THREE BASIC SEAM DESIGNS

There are three basic seam designs; the isolated seam (not a seam at all, just a butt joint), the compression seam, and the shear seam. These are illustrated in Figure 4.

The isolated seam is popular in weight-sensitive applications because there are no overlapping surfaces that increase material content. Also, the shielding material does not need to handle gasket compression forces and can be very thin—in fact, foil can be used. This static (fixed) configuration is used frequently in lightweight spacecraft and satellite applications.

Clearly, any RF sealing approach must bridge the gap between the shield materials. For one-time applications (not intended to be opened periodically), conductive tape is often used to seal the seams. For applications where the seam may be opened, the gap is typically bridged by spring finger configurations that can apply forces to both sides, or by elastomers that are configured to fit into the gap. If elastomers are used, the shield material thickness must be adequate to handle the edge loading without buckling. One approach to circumventing this problem is to increase the material thickness at the foil edge. The material that is added to increase the edge strength does not have to be conductive.

The compression seam is the most popular in situations where there were no initial plans for EMC protection for the enclosure. At the last minute when everything is failing, it is possible to convert an unshielded box with a simple compression seam into a shielded enclosure by adding an RF gasket and more fasteners to the design. This configuration also creates a static joint. In this application, panels overlap the perimeter of the apertures and can be sealed using any type of gasket material. Since the gasket material compression forces are normal to the panel, uniformly spaced threaded fasteners or clamps must be used around the perimeter to maintain the RF seal. The thinner the shield material, the greater the number of fasteners required to assure intimate contact along the seam. As enclosure configurations become smaller and as the choice of complex gaskets becomes quite limited, form-in-place and printed gaskets are used.

The shear seam is the only dynamic configuration and differs considerably from the other two types. This type of joint is constructed in several different configurations, *viz*., pan-edge, knife-edge, modified knife-edge, and/or longitudinal. These designs align the mechanical forces parallel to the panel surfaces and can thus eliminate the need for fasteners. Because of their lower compression forces, metal-finger gasket materials are normally used for this application. It is, however, possible (with some design modification to minimize shear loading) to use fabric-over-foam materials. Besides affording the highest shielding effectiveness over the widest frequency range, shear seam arrangements using metal RF gaskets offer the advantage of being self-cleaning. Because of the considerable difficulty in retrofitting when using shear seams, this design configuration should be determined at the beginning of the project. When this is done, the shear configuration is lower in overall cost than the compression configuration because of the savings in fasteners and the labor to install them.

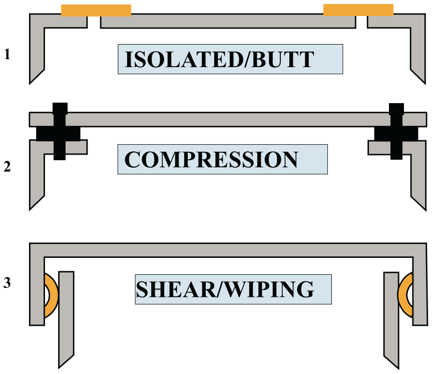


*Figure 4. Three basic seam designs.*

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4. Wolfgang A. Bereuter and David C. Chang. "Shielding Effectiveness of Metallic Honeycombs." *IEEE Transactions on EMC,* Vol. EMC-24, No. 1. February 1982.

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**RON BREWER**, *Vice President, EMC/Technical Services, is a NARTE-certified EMC/ESD engineer, who has spent over 30 years in the EMC/ESD/TEMPEST engineering field. His EMC experience includes project level design, development, and evaluation of many different types of electronic systems to various FCC/EU/CISPR and military standards. Ron has been named a Distinguished Lecturer by the IEEE EMC Society. He earned degrees in Engineering Science and Physics from the University of Michigan, Ann Arbor. Ron can be reached at Laird Technologies, (570) 424-8510 or visit www.lairdtech.com.* ■