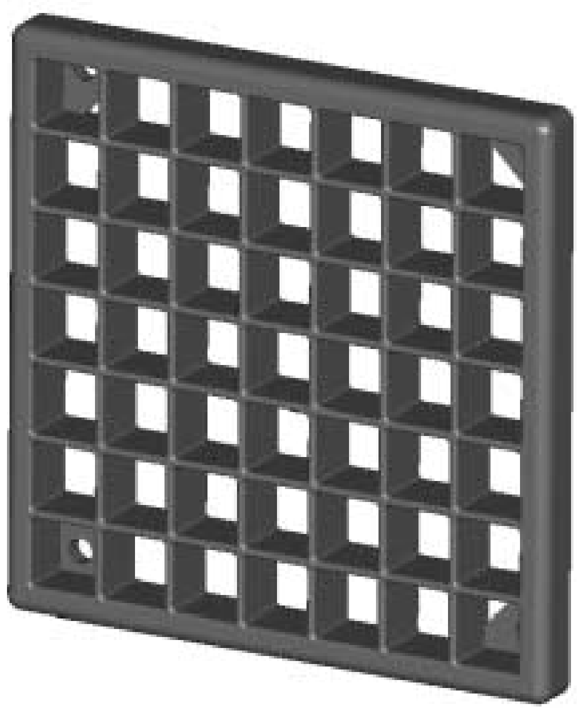
EMI Waveguide Apertures

Version 1.0

August 2001



IMPORTANT INFORMATION AND DISCLAIMERS

Version 1.0, August 2001

Revision History

Revision	Document Update	Date
1.0	Initial release	August 2001

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1 Scope

The purpose of this document is to provide an overview of the design and implementation of design guidelines and recommendations for Electromagnetic Compatibility (EMC) waveguide apertures for use in chassis enclosures.

The equations contained in this document have been verified to be applicable to chassis-sized structures. For these cases, the chassis enclosure is effectively located within the near field of the Electromagnetic Interference (EMI) source for all frequencies of interest (for frequencies greater than 1 GHz).

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1.1 Limitations of Document

- The equations and trends contained in this document have been verified to be applicable to chassis sized structures. Due to the small size of the enclosure used, there is an interaction between the noise source and the enclosure itself (due to near field effect). Although no extensive studies were carried out of this effect, it is believed that this has negligible affect on the design guidelines contained within this document.
- The EMI performance of waveguides has been experimentally verified up to 10 GHz. Theoretical extrapolations have been used to predict performance up to 12 GHz.

1.2 Reference Documents

Table 1. Reference Documents

Document Title	Document Number or Author
EMI Design Guidelines for U-Seams	Intel Corporation
Shielding Design - Methodology and Procedures	Donald R. J. White
Controlling Radiated Emissions by Design	Michel Mardiguian
Noise Reduction Techniques in Electronic Systems, Second Edition	Henry W. Ott

1.3 Terminology

EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
f_c	Cutoff Frequency
SE	Shielding Effectiveness
WGBC	Waveguide Beyond Cutoff

Throughout this document, length, width, and depth are defined as shown in Figure 1:

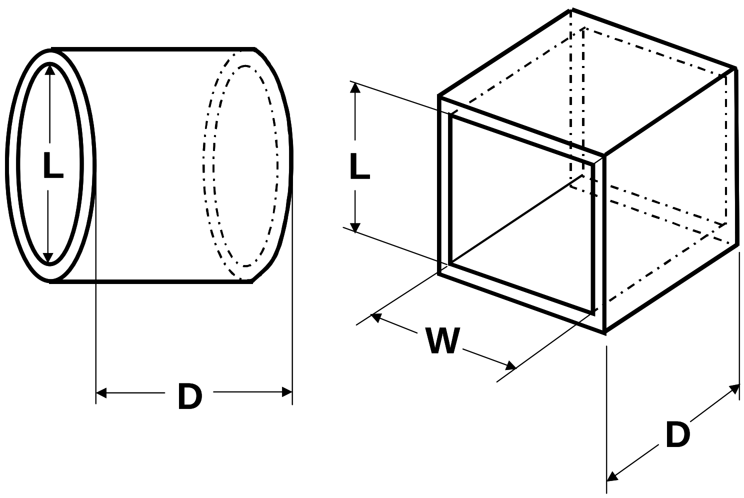

Figure 1. Aperture Measurement Definition

D	Depth of waveguide
L	Diameter of hole if round or Length of hole if Rectangular or Square
W	Width of hole if Rectangular or Square

Note: *All dimensions throughout this document are in millimeters (mm) unless otherwise specified.*

2 Overview

The purpose of waveguide apertures is to improve the thermal environment for the Processor Core Logic (PCL) components in chassis enclosures while significantly enhancing EMI performance. The PCL components consist of the processor, chipset, memory, and graphics components. To meet increasing thermal demands, the chassis must provide increased airflow and lower internal air temperatures. Typical chassis provide general EMI containment and cooling to the PCL components, but increasing thermal and EMI requirements require additional technology to facilitate this performance and maintain the balance between thermal and EMI performance.

Figure 2 shows an example of a panel containing an array of several waveguide apertures. This document outlines a method for designing such a panel to achieve desired EMI performance when thermal requirements are known.

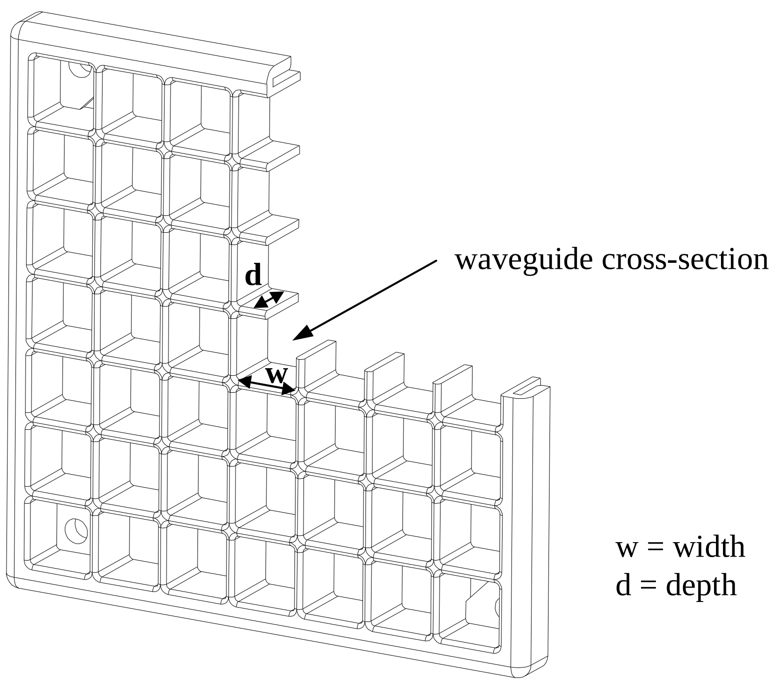

Figure 2. Waveguide Example (Cross-Section)

2.1 Basic Waveguide Operation

For the purposes of this document, a waveguide is essentially a hollow conducting tube that acts as a filter for EMI. Only EMI energy at very high frequencies can pass through it with little attenuation. When used to contain EMI in a chassis enclosure, a waveguide is generally designed such that all frequencies of interest are greatly attenuated by the waveguide (see Figure 3).

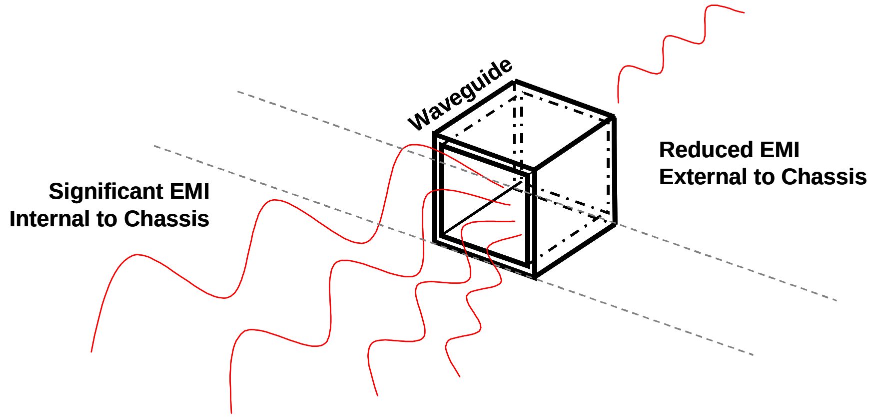

Figure 3. Basic Waveguide Operation

The EMI performance of a waveguide is governed by the surface geometry of the apertures (length and width), the aperture depth, the shape, and total number of apertures. This document describes how the waveguide aperture geometry can be varied to affect their ability to contain EMI.

3 Creating a Waveguide Design

3.1 Calculating EMI Performance of a Waveguide

The metric of waveguide EMI performance is determined by a combination of two parameters:

- Cutoff Frequency (f_c), which determines the maximum possible frequency of effectiveness.
- Shielding Effectiveness (SE), which determines the magnitude of the EMI attenuation and is a function of frequency.

These parameters are described in the following sections.

3.1.1 Cutoff Frequency

The Cutoff Frequency (f_c) is the frequency beyond which the waveguide no longer effectively contains EMI. This frequency is determined by the outside dimensions of the apertures. This can be theoretically calculated as shown below[1]:

- For round apertures: f_c = (6900*25.4)/length = 175260/length (MHz)
- For square apertures: f_c = (5900*25.4)/length = 149860/length (MHz)

Figure 4 shows how the Cutoff Frequency for round and square apertures varies as the outside aperture dimensions (length and width) are varied.

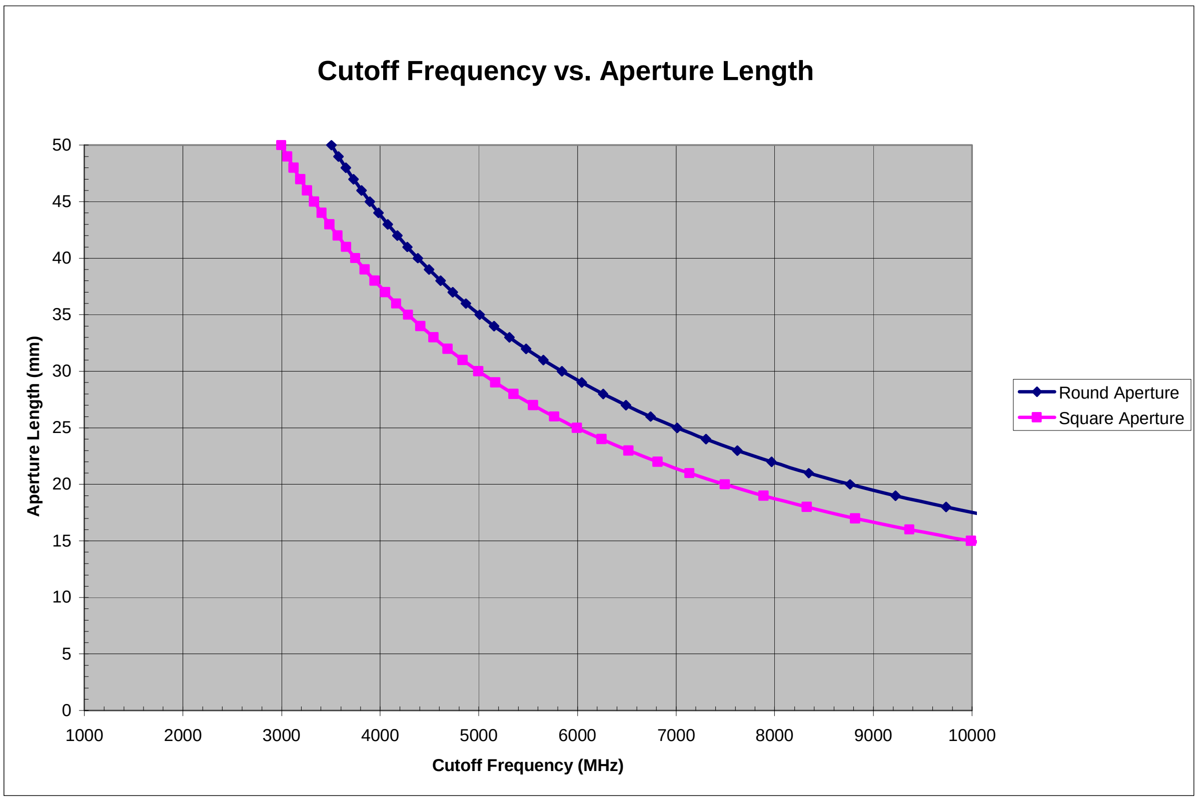

Figure 4. Cutoff Frequency vs. Length for Square and Round Apertures

3.1.2 Shielding Effectiveness

The Shielding Effectiveness (SE) of a waveguide represents the amount of EMI attenuation that the waveguide offers at a given frequency. This is dependent on several factors. These include the surface geometry of the aperture (length and width), depth, shape of aperture, and the total number of apertures.

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[1] *Noise Reduction Techniques in Electronic Systems, Second Edition*

3.2 Benefit of Waveguide vs. Sheet Metal

Up to the Cutoff Frequency of the waveguide, the waveguide presents a significant advantage compared to the same pattern in sheet metal. The plot in Figure 5 shows the measured and calculated benefit of 1" round waveguide apertures relative to that of an identical aperture pattern in sheet metal.

Waveguide Panel detail: 1" (25.4 mm) round; **1" (25.4 mm) deep**; 50 holes total; f_c = 6900 MHz

Sheet Metal Panel detail: 1" (25.4 mm) round; **0.048" (1.22 mm) deep**; 50 holes total; f_c = 6900 MHz

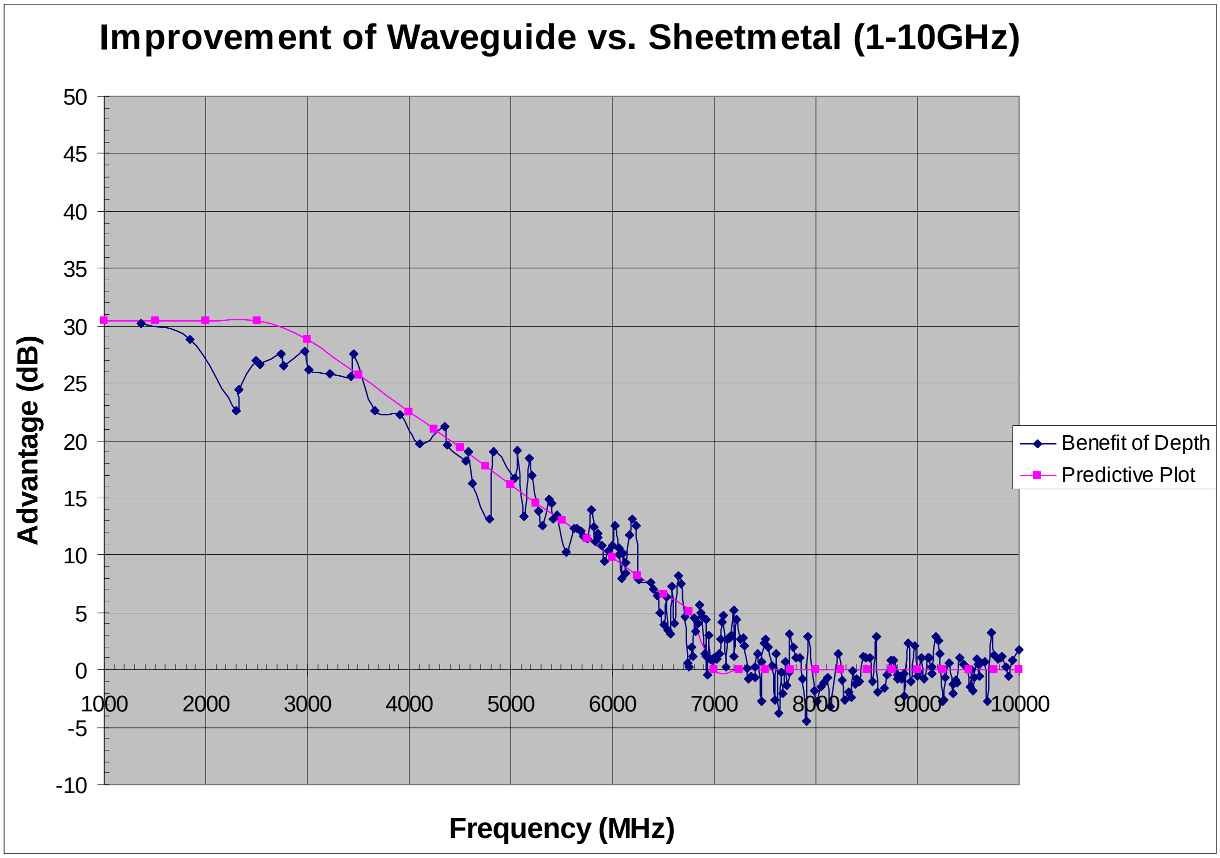

Figure 5. Improvement of Waveguides over Same Aperture Pattern in Sheet Metal

Also shown is a more realistic example using an actual chassis hole pattern. Figure 6 shows a theoretical comparison of a waveguide and sheet metal for 0.375" square holes.

Panel 1 detail: 0.375" (9.525 mm) square; **0.375" (9.525 mm) deep**; 500 holes total; f_c = 15,733 MHz

Panel 2 detail: 0.375" (9.525 mm) square; **0.048" (1.22 mm) deep**; 500 holes total; f_c = 15,733 MHz

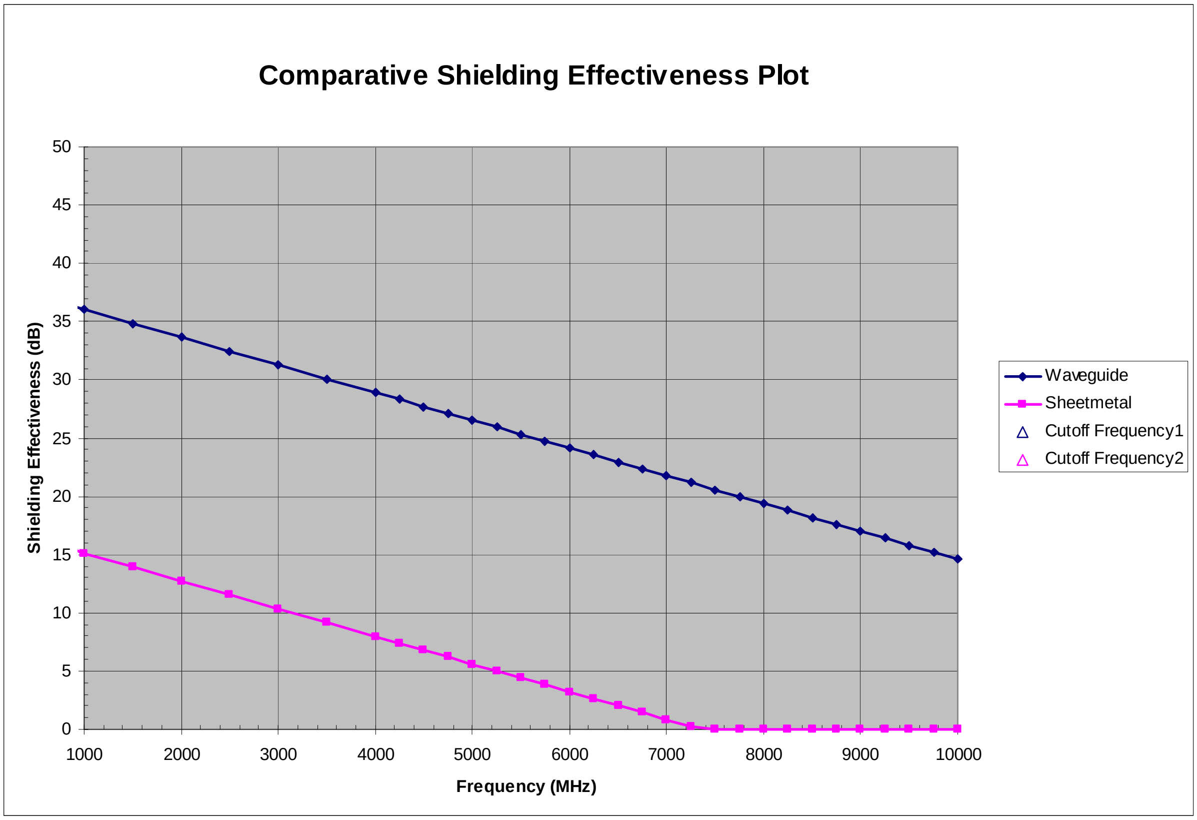

Figure 6. Theoretical Comparison of Waveguides over Same Aperture Pattern in Sheet Metal

3.3 Waveguide Design Considerations

3.3.1 Parameter Summary

Cutoff Frequency (f_c)

- Cutoff Frequency depends on the outside dimensions of the aperture. Increasing the aperture size decreases f_c, and decreasing the aperture size increases f_c. A 1" square hole for example, has a lower f_c than a 1" round hole because the square hole has a larger overall dimension along its diagonal.

- In general, a good design target is to plan for 10-15 dB of Shielding Effectiveness with f_c at a minimum of the third harmonic of the highest fundamental frequency of concern. For example, if the highest operational frequency of concern in a system is 1 GHz, a good waveguide design should provide 10-15 dB of EMI attenuation up to at least 3 GHz. Note that current regulations specify that EMI measurements must be taken up to the fifth harmonic of the highest frequency. Depending on your system, the design target may need to be adjusted.

- An effort should be made to optimize f_c. An f_c that is much higher than necessary for a particular design may burden the design with unnecessary additional cost in excess material. An f_c that is too low may limit the performance of the waveguide below the desired level.

Number of Apertures (N)

A change from N to 2N in a waveguide panel decreases the Shielding Effectiveness by approximately 3 dB for frequencies below the Cutoff Frequency. The plot in Figure 7 shows the predicted effect of changing the number of apertures by a factor of two.

Panel 1 detail: 0.590" (15 mm) square; 0.590" (15 mm) deep; **50 holes total**;
f_c = 9,991 MHz

Panel 2 detail: 0.590" (15 mm) square; 0.590" (15 mm) deep; **25 holes total**;
f_c = 9,991 MHz

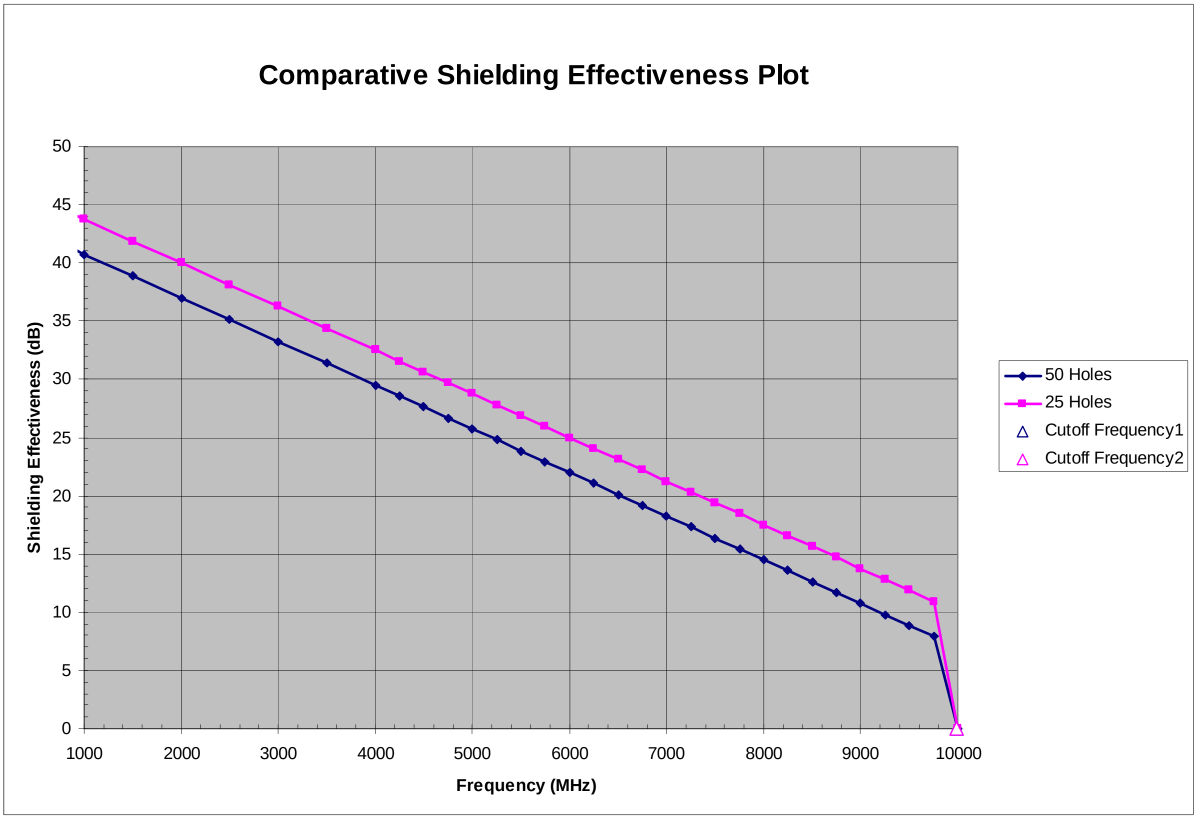

Figure 7. Effect of Reducing Total Waveguide Hole Count by a Factor of Two

Aperture Surface Geometry (length and width)

A change from round holes to square holes reduces Shielding Effectiveness by approximately 8 dB. The plot in Figure 8 shows the predicted effect of changing the aperture geometry from round to square.

Panel 1 detail: 0.590" (15 mm) **round**; 0.590" (15 mm) deep; 50 holes total; f_c = 11,684 MHz

Panel 2 detail: 0.590" (15 mm) **square**; 0.590" (15 mm) deep; 50 holes total; f_c = 9,991 MHz

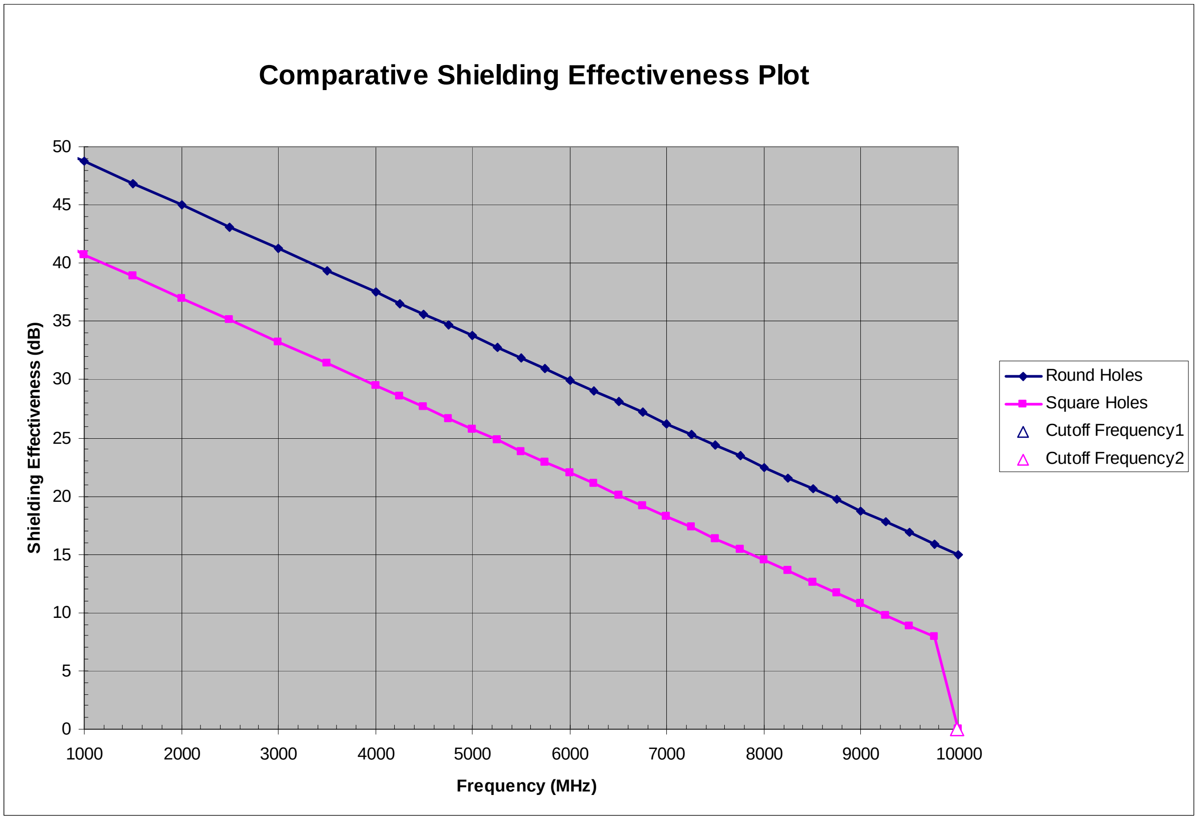

Figure 8. Predicted Performance of Round vs. Square Waveguide Aperture Pattern

In the previous example, changing aperture geometry from round to square also reduced the Cutoff Frequency from 11,684 MHz to 9,991 MHz for a total of 1693 MHz. The effect of aperture geometry on Cutoff Frequency is a function of the largest dimension of the aperture.

Square holes provide less Shielding Effectiveness than round holes (all other parameters remaining constant), but they have their advantages as well. The benefit of square holes is that they can generally be used to improve the open area percentage considerably and reduce material and tooling costs. By adjusting aperture size (increasing this size decreases f_c, and decreasing size increases $f_{c)}$, the Cutoff Frequency can be adjusted and the depth further adjusted to achieve desired EMI performance.

Aperture Depth

An increase in depth increases the Shielding Effectiveness approximately according to the following equations[2]:

For round apertures: ΔSE= 32*depth/length (dB)

For square apertures: ΔSE= 24*depth/length (dB)

The examples on the following pages show the effect of depth on Shielding Effectiveness for both round and square holes.

[2] *Noise Reduction Techniques in Electronic Systems, Second Edition*

Example 1

Panel 1 detail: 0.787" (20 mm) **round; 1.181" (30 mm) deep**; 50 holes total; f_c = 8763 MHz

Panel 2 detail: 0.787" (20 mm) **round; 0.787" (20 mm) deep**; 50 holes total; f_c = 8763 MHz

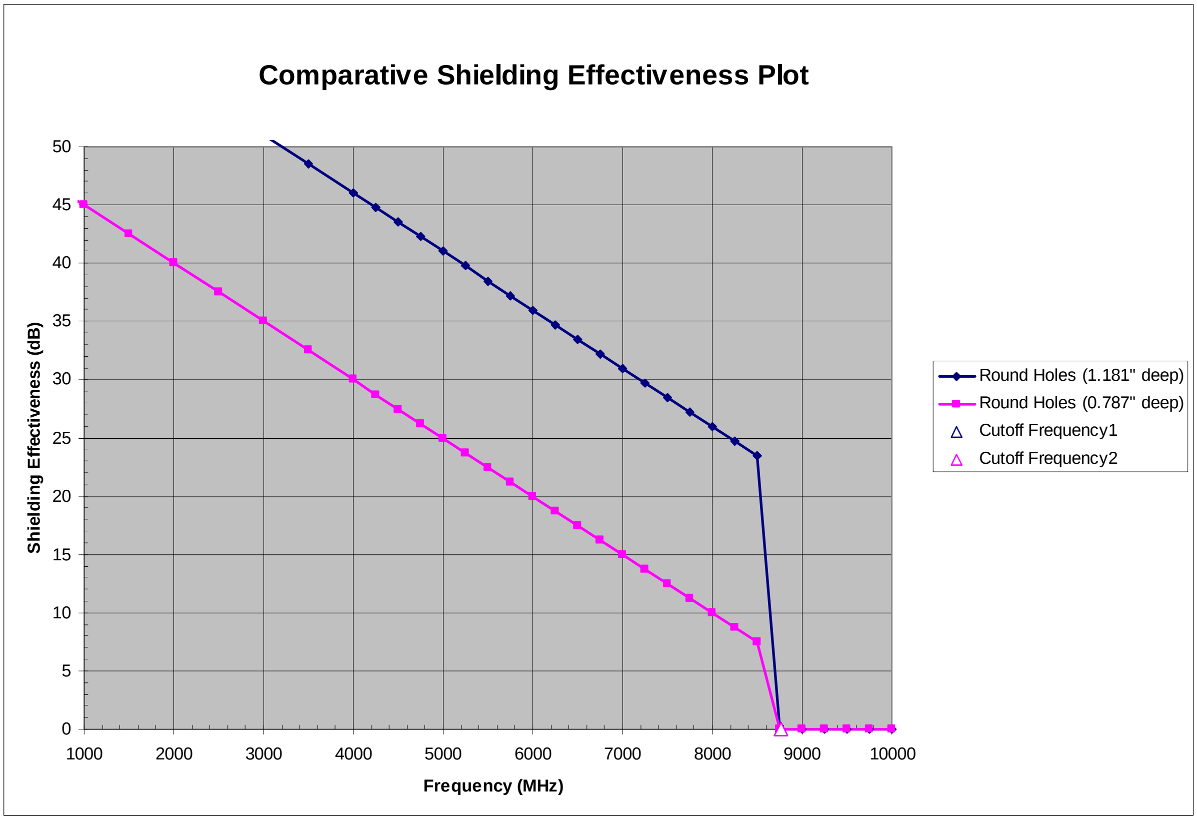

Figure 9. Effect of Changing the Depth for a Round Waveguide

In the case shown above, a depth change from 1.181" to 0.787" for **round holes** results in a **16 dB** change in performance up to the Cutoff Frequency.

Example 2

Panel 1 detail: 0.787" (20 mm) **square; 1.181" (30 mm) deep**; 50 holes total; f_c = 7493 MHz

Panel 2 detail: 0.787" (20 mm) **square; 0.787" (20 mm) deep**; 50 holes total; f_c = 7493 MHz

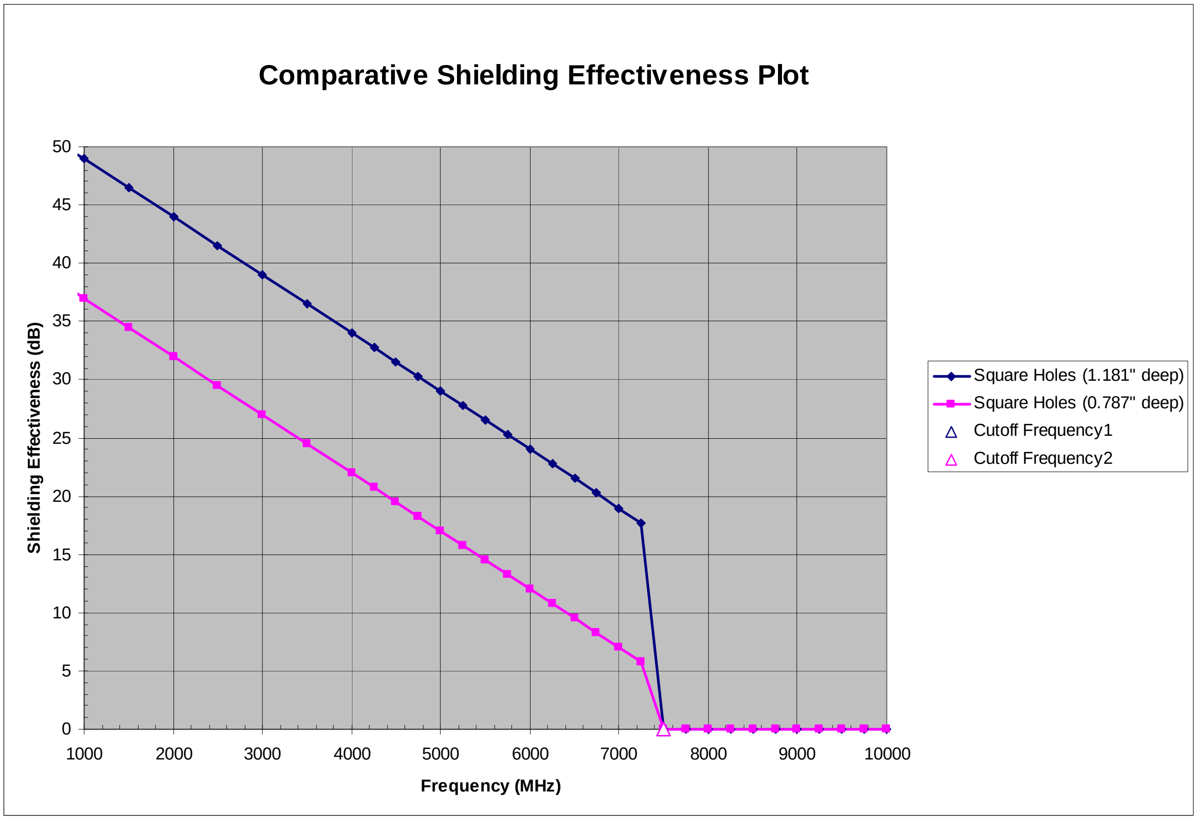

Figure 10. Effect of Changing the Depth for a Square Waveguide

In the case shown above, a depth change from 1.181" to 0.787" for **square holes** results in a **12 dB** change in performance up to the Cutoff Frequency.

3.4 Thermal and EMI Tradeoff

The primary function of a waveguide is to facilitate improved cooling of the PCL components (by way of reduced pressure drop at a given air flow rate) while enhancing the EMI performance of the chassis. Thermal performance of a waveguide aperture pattern is governed by the waveguide insert geometry (percent open area, hole shape, depth, insert size, number of holes in the insert) and by the geometry of the approach section of the duct. Each of these features has an impact on the overall flow resistance of the insert. Airflow resistance and EMI containment must be balanced in determining the proper geometry for the waveguide.

In general, increasing open area percentage reduces the pressure drop of the waveguide. Open area percentage is defined as the ratio of cross sectional area in the flow direction that is unobstructed (summation of the hole area) to the total cross sectional area of waveguide hole pattern (the total of area of holes plus material; generally the same area as the flow duct). Square holes generally have better thermal performance than round holes due to the higher density with which square holes can be manufactured. There is a tradeoff with EMI performance by utilizing square holes; however, increasing the depth can compensate for much of this degraded EMI performance. There is also a pressure drop trade-off with hole depth, but the pressure drop is less sensitive to increased hole depth than to reduced open area.n practice, an open area of greater than 70 % is both desirable and achievable while maintaining satisfactory EMI performance. Figure 11 shows a comparison between the thermal performance of a sheet metal aperture pattern and that of a waveguide aperture pattern with approximately the same EMI performance (7 dB @ 7 GHz) and total cross-section.

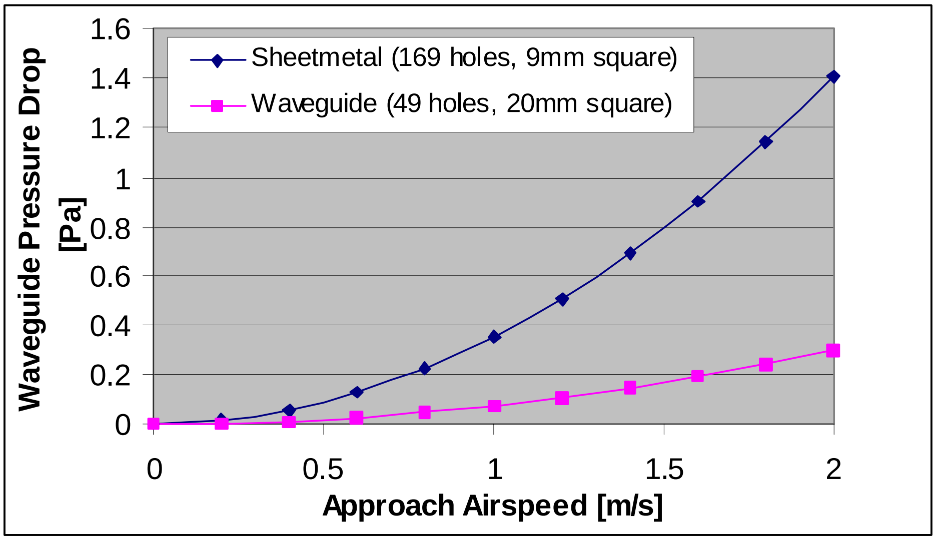

Figure 11. Thermal Benefit of Waveguide over Sheet Metal

Note: *For the example above, 0.060" spacing between holes was assumed.*

3.5 Cost and Performance Tradeoff

When designing a waveguide panel, there are many choices available and it is important to understand the trade-off between cost due to material volume and EMI performance. When larger holes are used, depth must be added to achieve the same EMI performance as a design with smaller, shallower holes. Fewer deep holes may prove to be more expensive (due to more total material required) than several shallow holes for a fixed area, however, larger holes provide a greater percentage of open area resulting in a higher performance thermal solution. In the example below, five waveguide panel options have been designed with roughly the same EMI performance at 10 GHz to show the trade-offs involved with material usage and percentage open. These waveguide panel designs are shown in Figure 12 and their EMI performance is shown in Figure 13. To illustrate this trade-off, these panels were designed for a minimum performance of 13.7 dB at 10 GHz. With the exception of the array of 25 apertures (which is only effective up to 8.7 GHz due to the large dimensions of the apertures), all shielding effectiveness curves in Figure 13 intersect at this point.

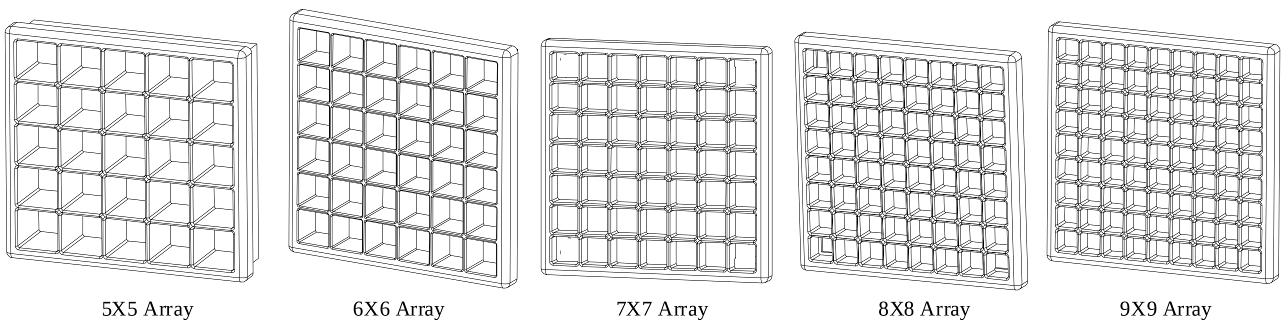

Figure 12. Waveguide Design Options

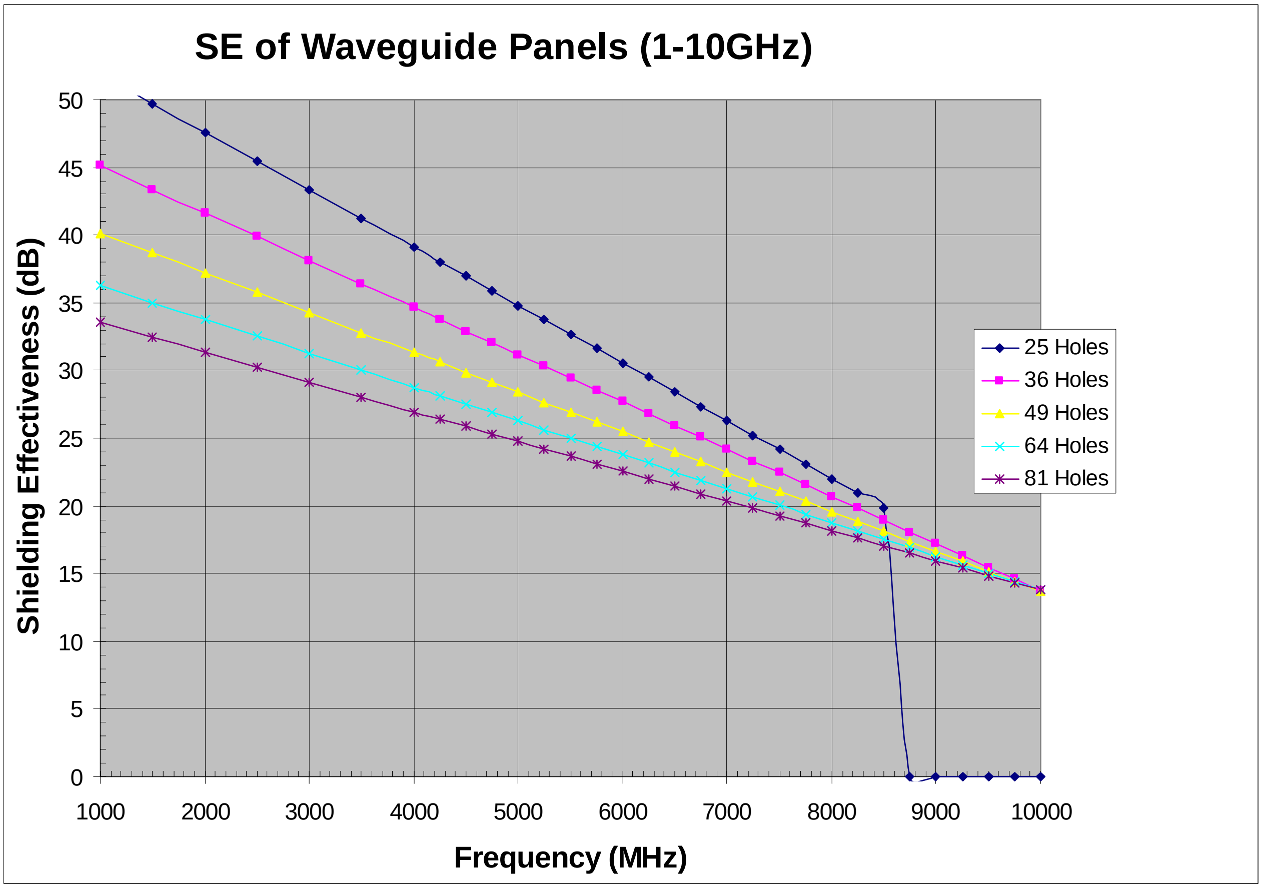

Figure 13. Waveguide EMI Performance Prediction for Each Panel

See Table 2 for the details of each waveguide panel design.

Table 2. Tradeoffs of Waveguide Design

	Waveguide Parameters							
Design Variation	**Aperture Array**	**Aperture Dimensions (in)**	**Aperture Depth (in)**	**Spacing Between Holes (in)**	**% Open**	**Material Volume (in^3)**	**Cutoff Frequency (GHz)**	**SE at 10 GHz (dB)**
25 Aperture Design	5X5§	0.672 sq.	0.945	0.060	81.6%	2.918	8.7§	0§
36 Aperture Design	6X6	0.550 sq.	0.598	0.060	78.7%	2.267	10.7	13.7
49 Aperture Design	7X7	0.463 sq.	0.394	0.060	75.9%	1.840	12.7	13.7
64 Aperture Design	8X8	0.397 sq.	0.264	0.060	72.9%	1.546	14.9	13.7
81 Aperture Design	9X9	0.347 sq.	0.184	0.060	70.5%	1.233	17.0	13.7

§ 5X5 array panel has 0 dB of Shielding Effectiveness at 10 GHz since this is beyond this panel's Cutoff Frequency of 8.7 GHz.

The 'Material Volume' column in Table 2 shows that considerably more material is required when an aperture design uses larger, but deeper holes in order to maintain roughly the same EMI performance at a given frequency. The benefit, however, is that the larger apertures result in a larger percentage of open area. This example illustrates that a larger open area percentage can require significantly more material to achieve roughly the same EMI benefit, and therefore can cost considerably more. Avoiding thermal and EMI over-design is the key to optimizing a waveguide design for cost efficiency. Figure 14 shows a plot of percentage open area versus material volume. Since the cost of a waveguide design will be primarily dictated by its material volume, the importance of avoiding thermal over-design becomes apparent. The goal should be to design with the smallest acceptable percentage open area is chosen and this will result in the smallest necessary material volume used.

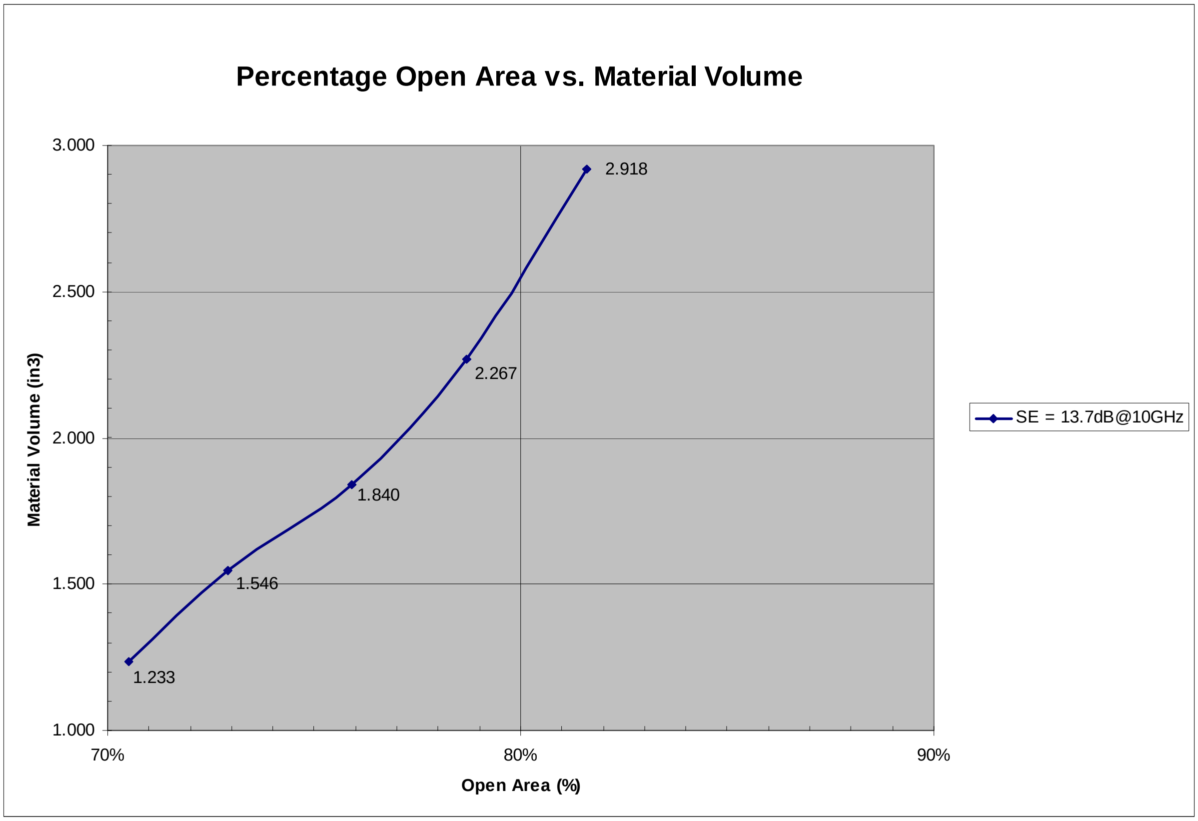

Figure 14. Percentage Open Area versus Material Volume for SE of 13.7 dB at 10 GHz

4 Alternate Waveguide Design Options

This section describes some basic techniques for designing quasi-waveguides using sheetmetal. By adding thickness to sheetmetal apertures, absorption loss, which is the loss due to waveguide depth, can be added to increase the shielding effectiveness of chassis apertures. This added depth can be achieved in sheetmetal in a number of ways, but only two options are discussed here.

4.1 Sheetmetal Design Options

For some applications, implementation of a waveguide panel may be difficult or expensive and the enclosure design may not immediately need the extra shielding effectiveness that a waveguide provides. For such cases, the creation of deeper apertures in sheetmetal may be a flexible and cost-effective option.

Options considered here include:

- Stacked Sheetmetal Quasi-Waveguide**
- Waveguide Add-on Panel

None of the above options creates a perfect waveguide due to imperfections at the aperture and mounting interfaces, but are capable of adding to the shielding effectiveness considerably compared to that of a single sheetmetal aperture pattern. These are described in the following sections.

4.1.1 Stacked Sheetmetal Quasi-Waveguide

This technique simply adds (stacks) one or more sheetmetal panels inside the chassis with an identical pattern to that of the chassis aperture pattern. This increase in overall depth results in an increase in the absorption loss through the aperture that increases the shielding effectiveness in this area. A chassis design can provision for this option by adding mounting holes for the additional panels at the perimeter of the aperture pattern. An example of this can be seen in Figure 15.

** Only the stacked sheetmetal quasi-waveguide option has been analyzed for the purposes of this document.

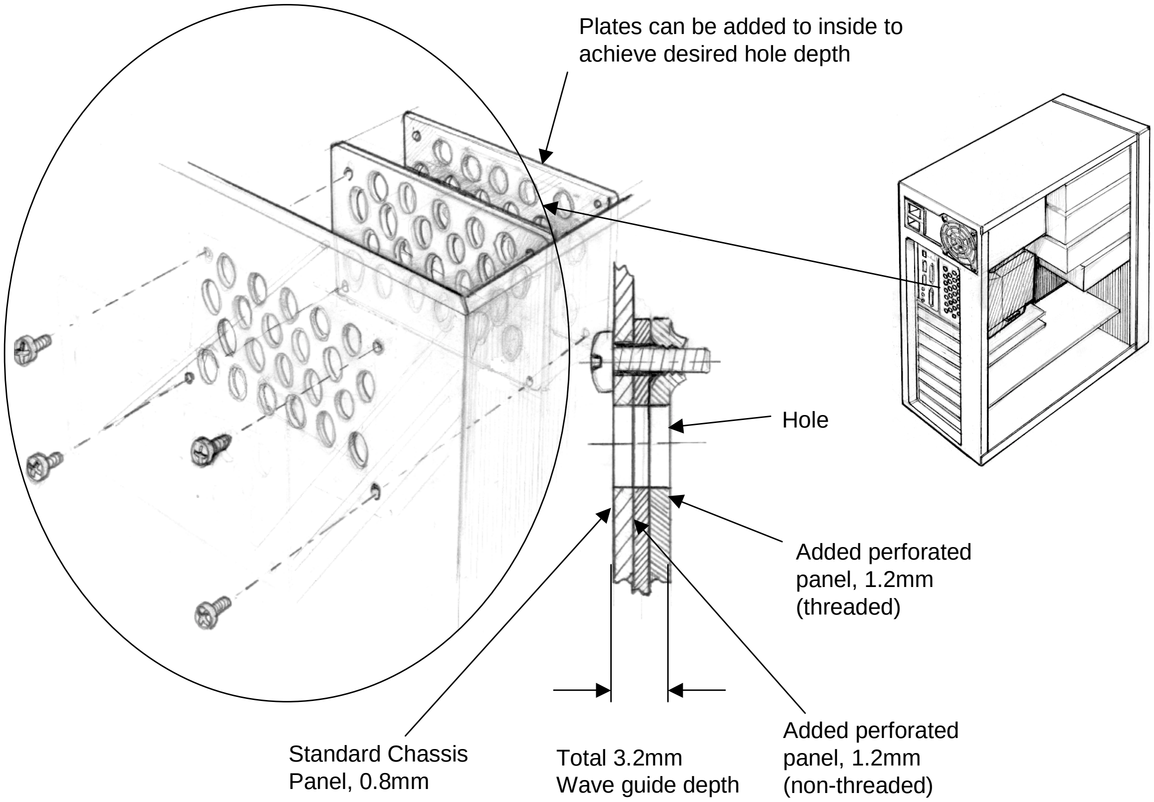

Figure 15. Stacked Sheetmetal Quasi-Waveguide Concept

4.1.2 Waveguide Add-on Panel

This technique simply adds a waveguide panel inside the chassis with an identical aperture pattern to that of the chassis aperture pattern. As above, this increases the overall depth and results in an increase in the absorption loss through the aperture that increases the shielding effectiveness in this area. A chassis design can provision for this option by adding mounting holes for the additional panels at the perimeter of the aperture pattern. An example of this can be seen in Figure 16.

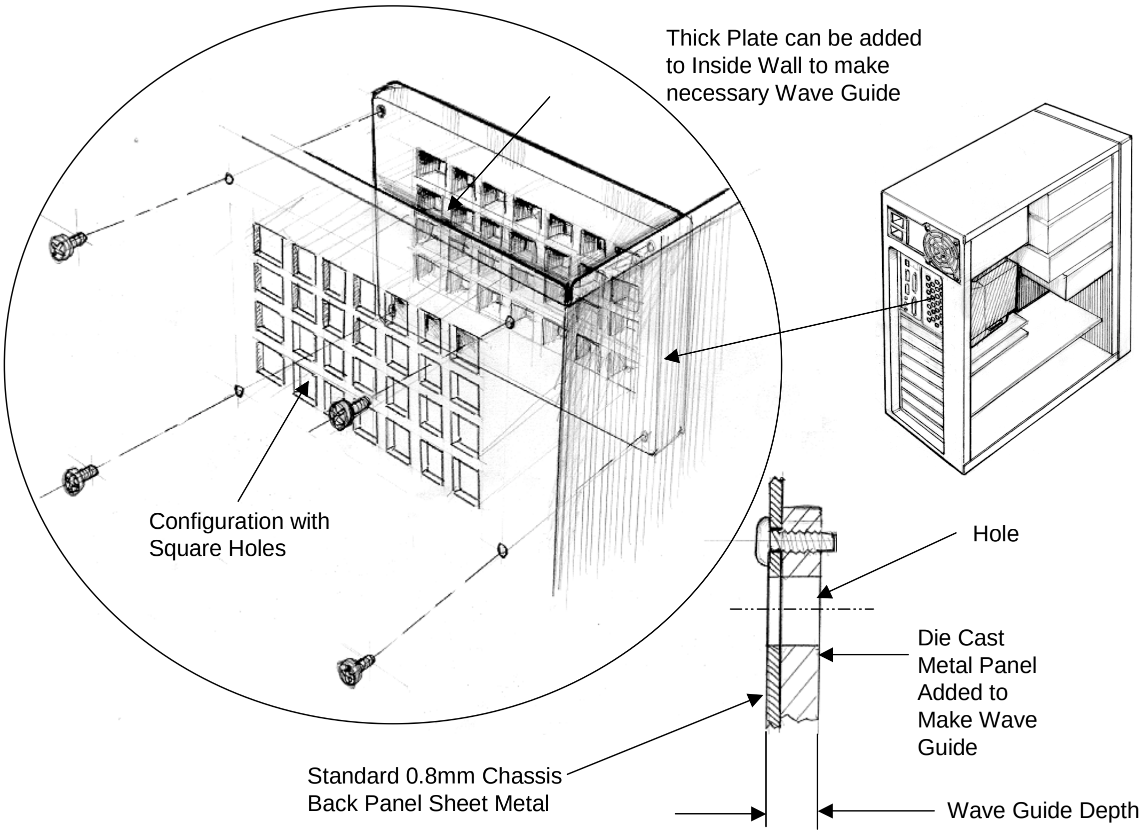

Figure 16. Waveguide Add-on Panel Concept

4.2 Benefit of Stacked Sheetmetal vs. Sheetmetal

Up to the Cutoff Frequency of the stacked sheetmetal (see section 3.1.1), stacking identical patterns of apertures presents a significant containment advantage compared to the same pattern in a single layer of sheet metal.

The following plots show the measured shielding effectiveness of a 9.5-mm aperture array (200 apertures @ 1 mm thick) with no added layers of sheetmetal (Figure 17), a single added layer of sheetmetal (Figure 18), two added layers of sheetmetal (Figure 19), and four added layers (Figure 20). Each added layer is 1 mm thick and contains the identical aperture pattern. Contained in each of these plots is a predictive plot based on a predictive tool. As sheetmetal layers are added and the structure becomes progressively thicker, it performs closer to that of an ideal waveguide. In this example, each increase in overall thickness of 1 mm increases the overall shielding effectiveness by roughly 2.5 dB.

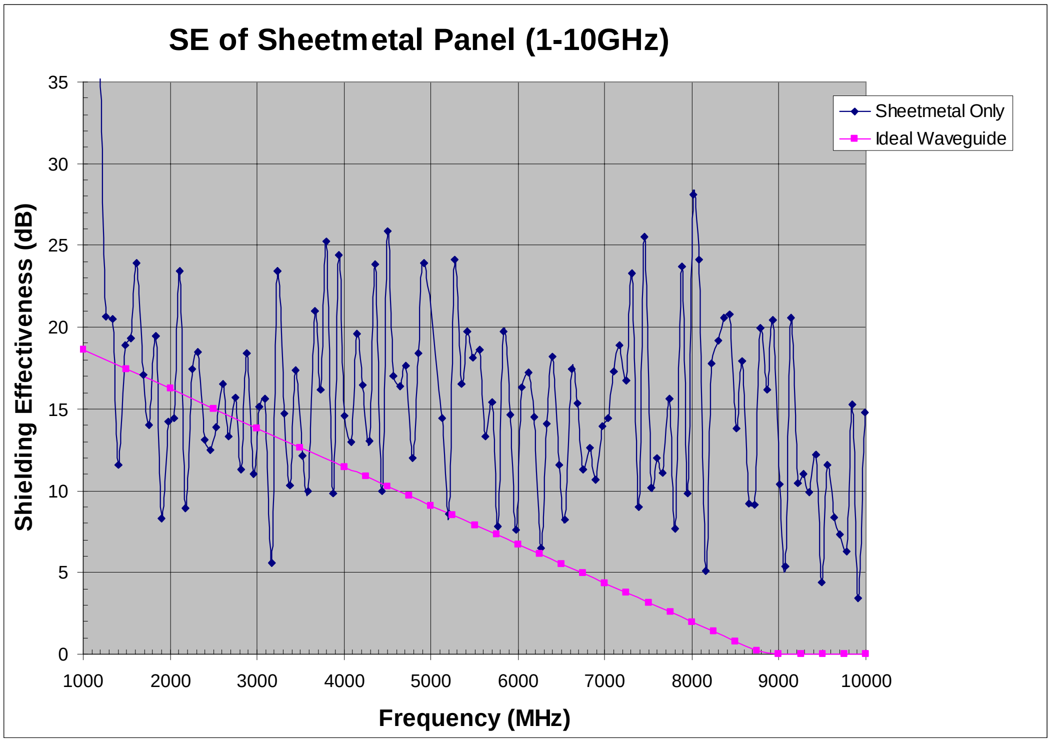

Figure 17. SE of Sheetmetal Panel Only

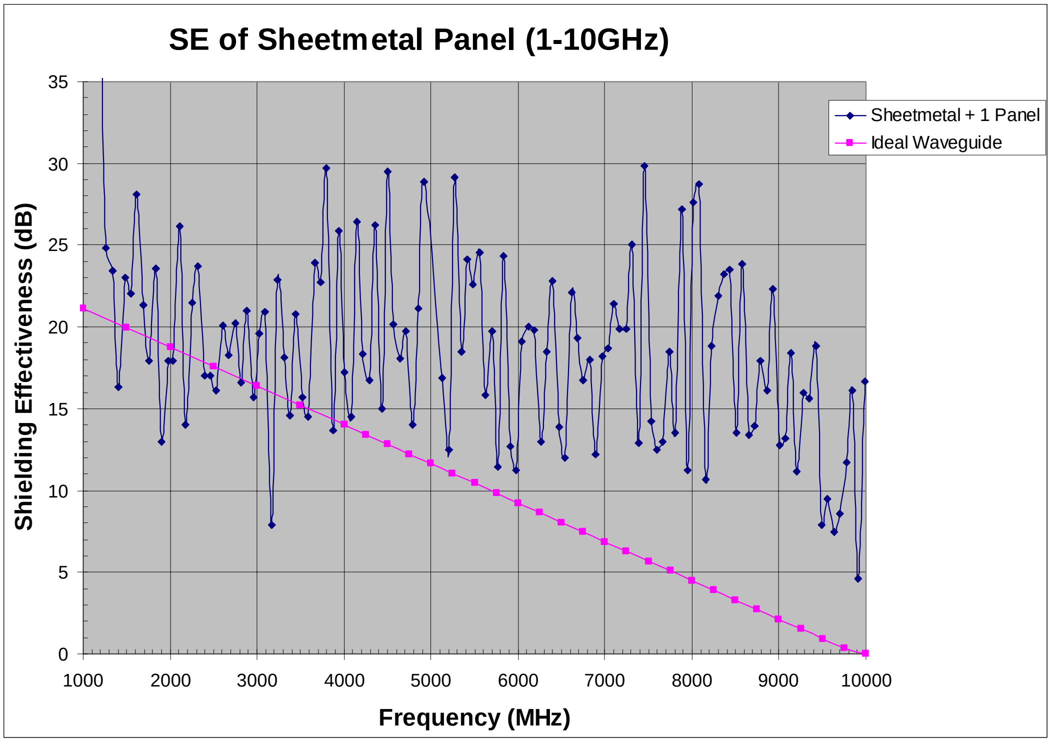

Figure 18. SE of Sheetmetal Panel with One Stacked Panel

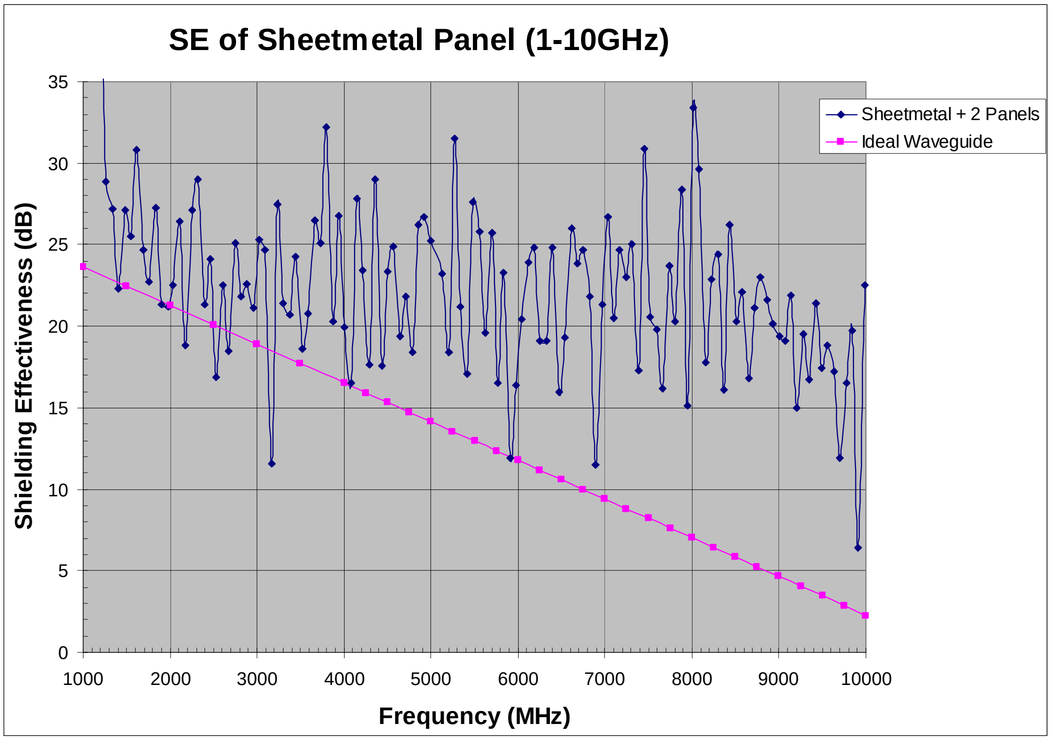

Figure 19. SE of Sheetmetal Panel with Two Stacked Panels

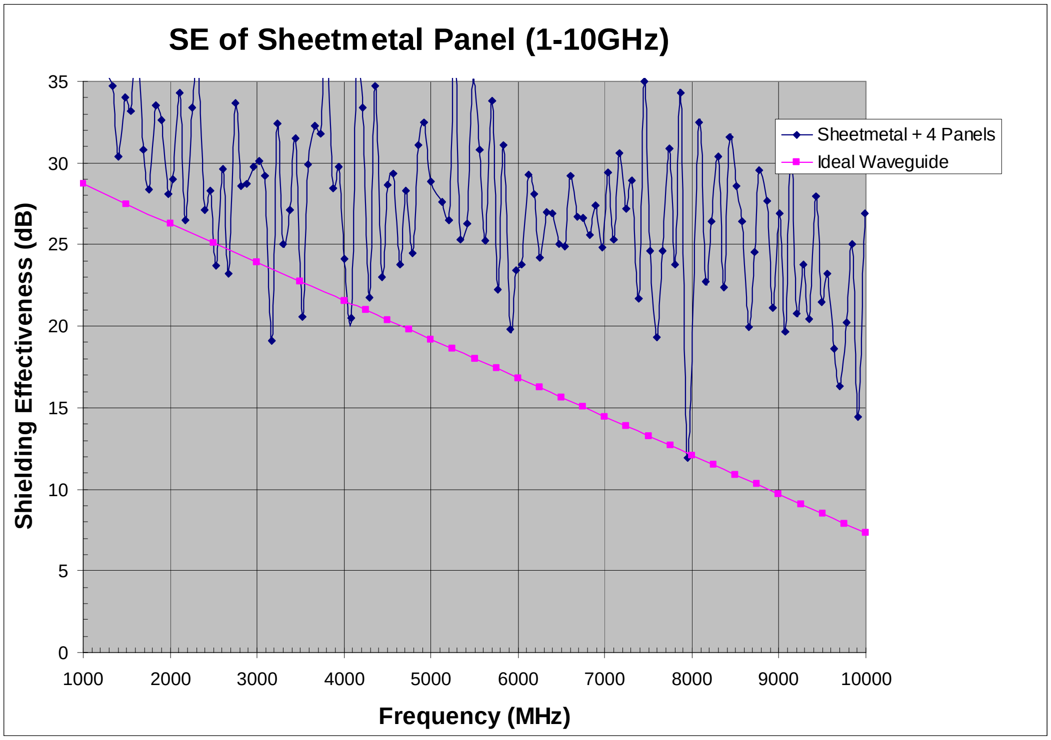

Figure 20. SE of Sheetmetal Panel with Four Stacked Panels

The plot below shows an overlay of the sheetmetal only and the same sheetmetal panel with four layers of 1-mm thick aperture panels. The overall effect in this example is an increase in shielding effectiveness in this area of roughly 10 dB 2.5 dB/mm).

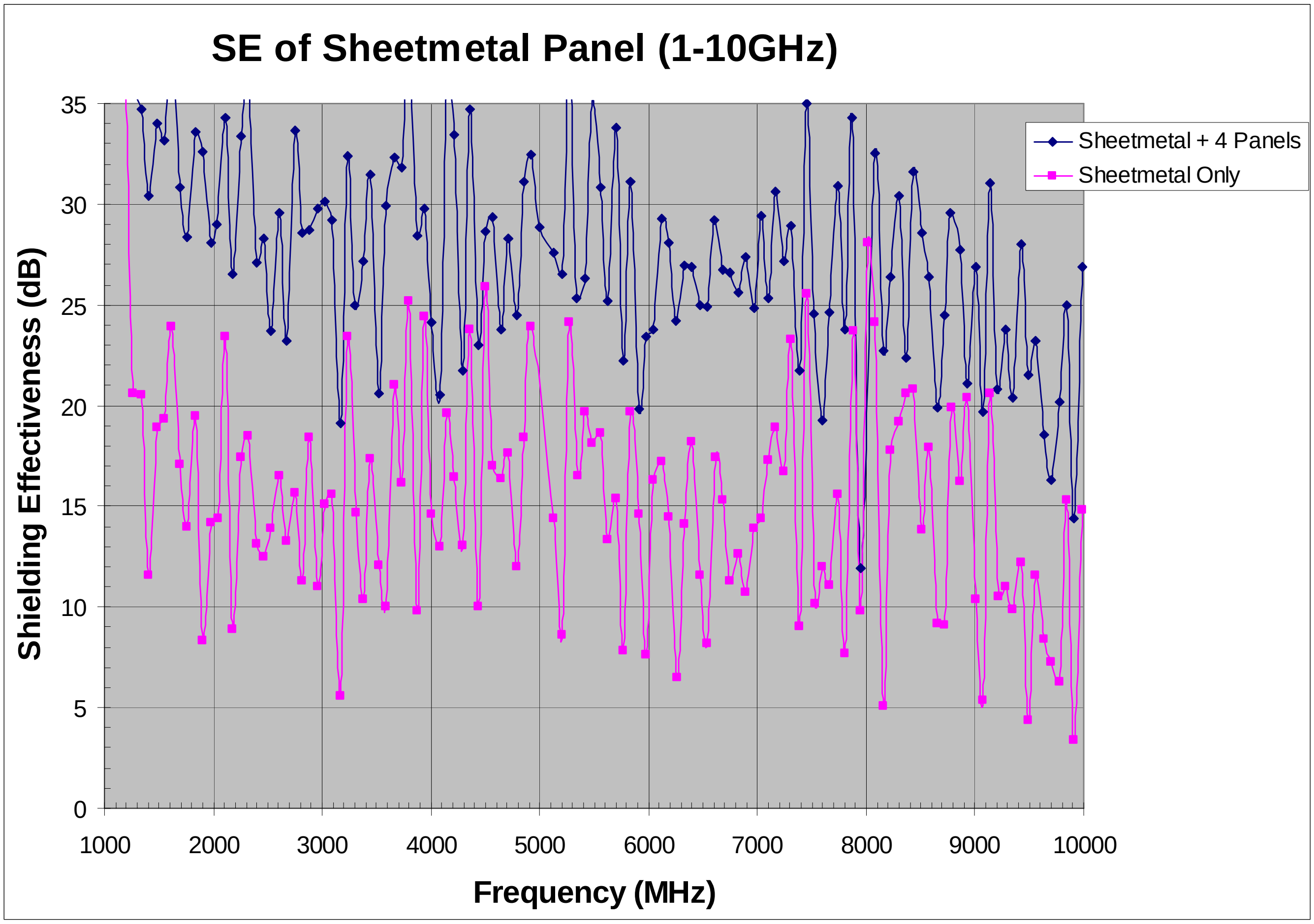

Figure 21. Overlay of Sheetmetal Panel and Sheetmetal Panel Plus Four Stacked Panels

4.3 Cost and Implementation Benefits

Using stacked sheetmetal to create a quasi-waveguide can be a very inexpensive way to increase the shielding effectiveness of a chassis enclosure in this area and allows designers the flexibility to 'upgrade' existing chassis for improved performance as required. Cost is incurred only when the desired frequency of containment increases, requiring extra panels to be installed. However, the designer must provision for mounting holes in the chassis tooling.

4.4 Stacked Sheetmetal Design Considerations

A few things must be considered in order to get the maximum benefit out of this implementation:

1. Gaps between layers of sheetmetal will reduce their ability to contain EMI and should be kept as small as possible.

2. Layers of sheetmetal should be mounted such as to ensure that they mount snuggly with minimal gap. Screw locations should be provided every 3-4 inches or as required.
3. Adding layers of sheetmetal will add extra weight to the chassis design. Make sure that structural requirements can be met with this in mind.

5 Design Requirements

The following section describes the basic design requirements for waveguide apertures when integrating them into a system. These requirements can be met with a number of design variations.

To ensure compliance to product regulation requirements when integrating a waveguide design into a system, consult with the Product Regulations Engineer that supports the business group and system design.

5.1 Compliance with EMC Requirements

EMC is regulated by different regulatory bodies in different geographies. For example, the Federal Communication Commission (FCC) regulates emissions for products sold in the United States. Products must comply with the EMC regulations in the geographic areas where the product will be marketed and sold. It is therefore imperative to ensure the system complies with the EMC regulations. Refer to your product regulations group for current information about regulations. Typically, Intel® products comply with the following EMC regulations:

- FCC, CFR 47, Part 15
- CISPR 22 / EN55022
- EN55024

5.2 Compliance with Safety Regulations and Requirements

Different geographic areas require safety certifications. For example, UL is required for products sold in the United States. Products must comply with safety regulations in the geographic areas where the product will be marketed and sold. It is therefore imperative to ensure the system complies with safety regulations, and the system is designed to comply with safety standards. Refer to your product regulations group for current information and safety design requirements. Typically, Intel products comply with the following safety standards:

- UL/CSA 950
- IEC 60 950
- EN60 950

5.2.1 Basic Safety Design Awareness

When designing, the following areas must be considered with respect to compliance of safety standards.

- Operators cannot have access to shock hazards (42.4 Vpk or 60 V----dc); energy hazards (=>240 VA); mechanical hazards (rotating fans, rollers, etc).
- Ventilation openings–there are safety specifications for ventilation openings that are on the top, side, and bottom of enclosures. Refer to 950-based safety standards for requirements.
- Plastics must be flame retardant and approved by UL. Levels of flame retardant will vary depending on location of plastic. Plastic parts must be purchased from UL-approved suppliers.

Consult with the product safety engineer to ensure designs comply with regulatory requirements where products are sold.

5.3 Acoustic Considerations

Because waveguide apertures can generally be larger with a larger percentage of open area, use of waveguides may lead to increased acoustic noise. In addition, flow generating devices, such as a fan, should not be placed in the direct proximity of the waveguide as this may introduce additional noise. Care should be taken in the system design to minimize the acoustic noise originating from or transmitting through the waveguide apertures.

5.4 Material Options

Waveguides must be made of electrically conductive materials. Examples of materials include aluminum, steel, magnesium alloys, zinc, and metal coated plastics. Compatible metals should be used in the enclosure; otherwise, galvanic corrosion may occur. Materials of various conductivity have not been evaluated at this time.

5.5 Waveguide Attachment to Chassis Enclosures

A waveguide insert can be mounted to a chassis enclosure using screws, rivets, or snap-attach features. Where utilized, EMI, structural, safety and security considerations should be taken into account.

5.5.1 EMI Considerations

If the waveguide design attaches to the chassis enclosure as a separate part, care must be taken at the perimeter of the attachment to ensure that EMI leakage does not occur. One effective method is through the use of U-seams at the perimeter of the waveguide hole pattern. An example of this is shown in Figure 22.

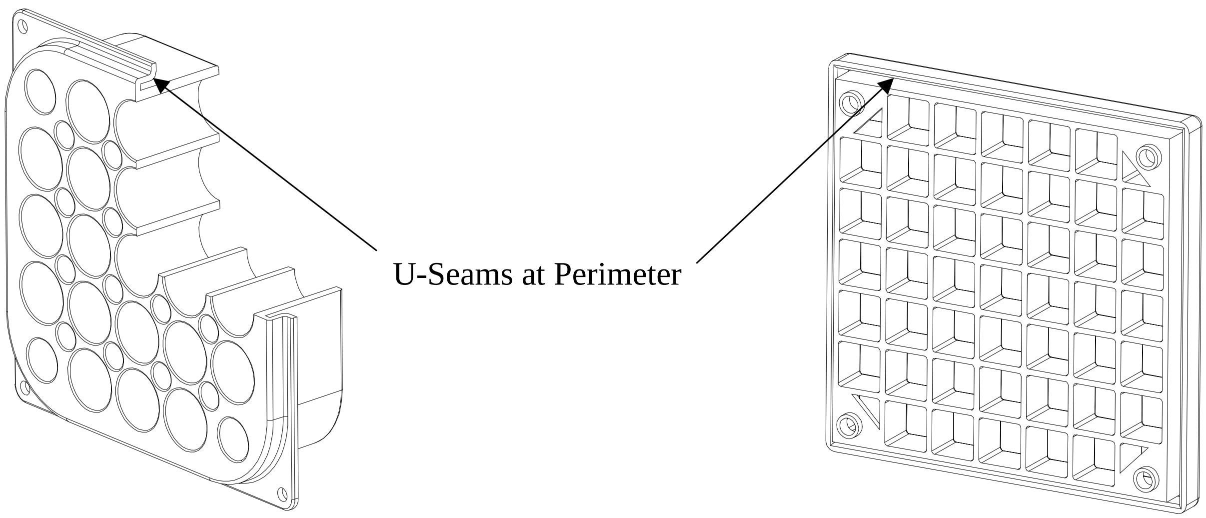

Figure 22. U-Seams Integrated into Perimeter of Waveguide Designs

For detailed information on U-seam design, see the *EMI U-Seams* Document

5.5.2 Security Considerations

For systems that require security features allowing users to lock system panels, extra design considerations need to be taken for waveguide attachment. Secure attachment designs allow the waveguide to be removable only from the inside of the enclosure or by using special tools.

5.5.3 Structural Considerations

Where waveguides attach to chassis enclosures, ensure that they are designed to meet structural (shock and vibration) requirements.