Design Equation of Shielding Effectiveness of Honeycomb

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1. Introduction

There are many apparatus and control rooms with electronic equipment that are very sensitive to external electromagnetic interference. On the other hand, the electronic equipment may produce radiated energy that affects communications and measuring equipment existing in the near or far field environment. Shielding is necessary to remove mutual interference or unexpected EM field, however, it is not possible to completely shield apparatus because apertures with diffracting perforated shields are necessary for thermal conditioning, for the passage of power and signal cables and for ventilation. The diffracting perforated shield consists of a matrix of metallic waveguide. A highly efficient geometry for this kind of shield is the honeycomb structure because gaseous media can pass through it at high flow rates [1].

2. Shielding Effectiveness of a waveguide

The theory of the guided waves gives the following approximated expression for the attenuation constant [2];

$$\alpha = \omega(\mu\varepsilon)^{\frac{1}{2}}\left[(\frac{f_c}{f})^2 - 1\right]^{\frac{1}{2}} \tag{1}$$

where f_c is the cutoff frequency of the waveguide.

Substituting the cut-off frequency into Equation (1), this equation can be converted to an expression which is useful to estimate the attenuation constant in dB for a given conductor geometry. The equation of a rectangular [3], a circular and a hexagon are summarized in Table 1. These equations are the SE (Shielding Effectiveness) for 1 cell of each waveguide. In the equations in the Table, d in millimeter is a waveguide length and g in millimeter is a transverse dimension of waveguide. f is operating frequency in MHz. Fig.1 (a) is hexagonal waveguide, while Fig.1 (b) shows comparison between the numerical simulation and analytic equation given in Table 1.

ISBN: 89-86522-77-2 94460©KEES

Table 1 SE of various waveguides

	Rectangle	Circle	Hexagon
SE_{dB}	$SE_{dB}=27.3\frac{d}{g}\sqrt{1-(\frac{gf}{150000})^2}$	$SE_{dB}=31.95\frac{d}{g}\sqrt{1-(\frac{gf}{175800})^2}$	$SE_{dB}=17.5\frac{d}{g}\sqrt{1-(\frac{gf}{96659})^2}$

3. Shielding Effectiveness analysis of the number of waveguides

In Ref. [4] infinite array of parallel-plate waveguides is analyzed by Wiener-Hopf method. The resulting equation in Ref. [4] is shown below. The first term of the Equation (2) is the SE of unit cell of rectangular waveguide, while the second term is the SE of infinite array of parallel-plate waveguides [5]:

$$SE=27.3\frac{d}{g}-20\log_{10}\frac{2kg}{\pi}\cos\phi \quad dB \tag{2}$$

where, k is wavenumber, g is a transverse dimension of waveguide, and ϕ is a angle of a incident wave.

When adding each term in Table 1 to the second term of Equation (2), we can derive new SE equation. Equation (3) is SE of the honeycombs:

$$SE_{dB}=17.5\frac{d}{g}\sqrt{1-(\frac{gf}{96659})^2}-20\log_{10}\frac{2kg}{\pi}\cos\phi \tag{3}$$

Fig.2 shows the comparison between numerical data and attenuation derived from the equation for hexagonal waveguide. In Fig.2 (b), it is clear that the graph of Equation (3) disagrees with FEM simulation in the low frequency region. The graph of Equation (3) decreases in log scale, while the numerical simulation converges to 85 dB.

The well-known SE equation for hexagonal geometry has been modified by adding the third term to better approximate the low frequency behavior, specially when the value the normalized frequency is greater than five times of R. The R (R=3.18/g) is the rate of a transverse dimension of waveguide and determines when we need to supplement the third term as well as the value of the third term. Fig.3 (a) shows the cross section of hexagonal waveguide and Fig.3 (b) represent the values of g and R. Fig. 3 (c) reveals the comparison between the new SE equation and full-wave simulation results. SE of both is dependant of g variation and both converge to SE value of each g in the low frequency.

$$SE_{dB}=17.5\frac{d}{g}\sqrt{1-(\frac{gf}{96659})^2}-20\log_{10}\frac{2kg}{\pi}\cos\phi-20\log_{10}\frac{2Rg}{f} \qquad \frac{f_c}{f}>5R \tag{4}$$

where, g = transverse dimension of waveguide in millimeter

d= length of waveguide in millimeter

f = operating frequency in MHz

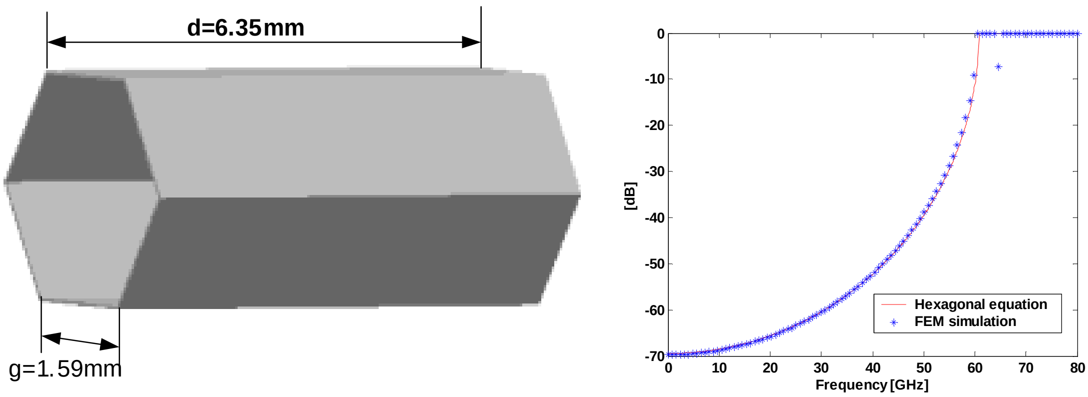
f_c= cut-off frequency

R= the rate of g (the standard is g=3.18 mm)

On the other hand, it has been accepted in industry that the shielding effectiveness of honeycomb geometry depends on the number of honeycombs. To verify this concept, various honeycomb structures having different N have been designed and simulated in the FEM domain. As we see in Fig.4, the shielding effectiveness is almost independent of the number of waveguides N, rather it depends on the size and the length of individual honeycomb.

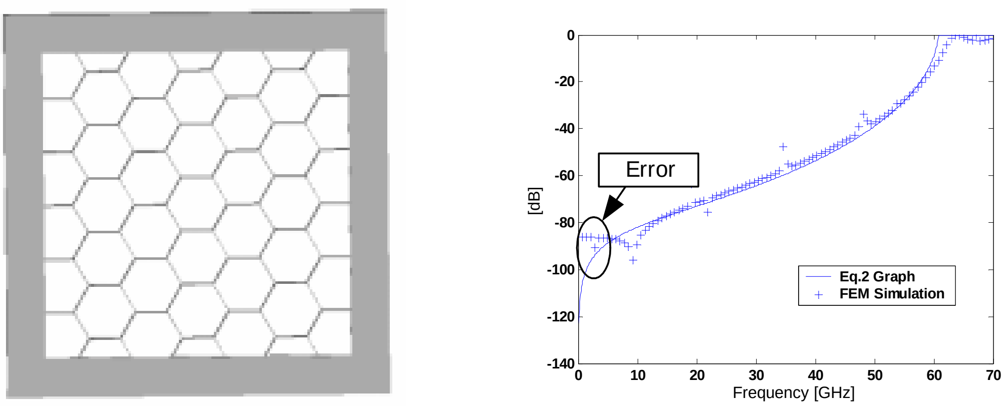
4. Conclusions

In this paper, modified shielding effectiveness equation has been proposed for waveguides (circular, rectangular, hexagonal) and its validity has been compared for honeycomb model based on 3-dimensional FEM simulations. The modified SE is obtained by adding low frequency correction term to the conventional. Furthermore, on the contrary to the conventional wisdom, it is proved that the SE depends on not the number of N but the transverse dimension and the length of one cell of honeycombs.



(a) (b)

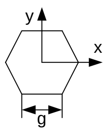
Fig.1. Hexagonal waveguide and comparison SE



(a) (b)

(g=1.59 mm, d=6.35 mm, ϕ=90° Honeycombs dimension: 20mm by 20mm)

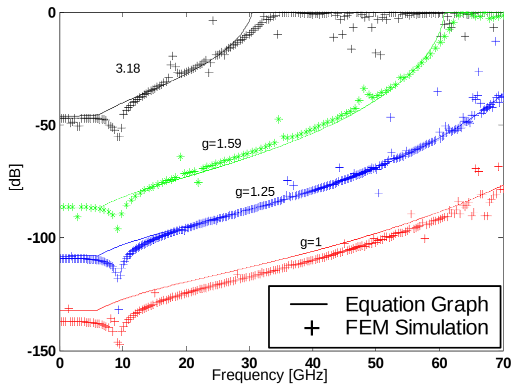
Fig.2. Honeycomb model and SE of Equation (3)



(a)

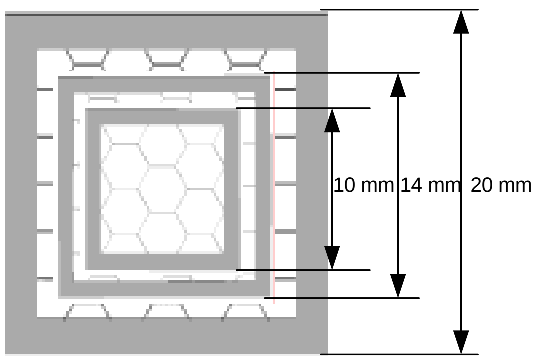
g (mm)	R
3.18	1
1.59	2
1.25	2.544
1	3.18

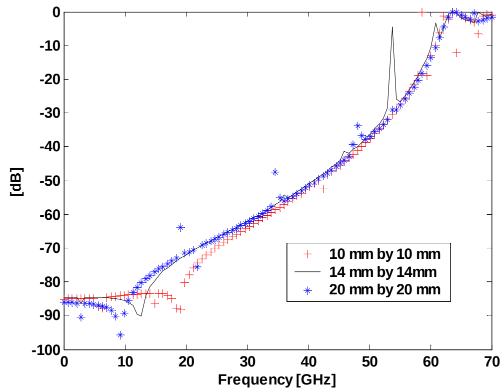
(b)



(c)

Fig.3. SE of g change and Equation(4).(d=6.35mm, ϕ=90˚)





(a) (b)

Fig.4. Honeycombs model and SE of N variation

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