Magnetic Shielding Effectiveness and Simulation Analysis of Metalic Enclosures with Apertures

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Abstract

The effect of magnetic shielding effectiveness has been investigated for apertures on metallic enclosure and has been calculated as a function of enclosure dimensions, aperture dimensions position within the enclosure. The calculation magnetic shielding depends upon the frequency and polarization of the applied field, the dimensions of the enclosure and the apertures, the number of apertures, and the position within the enclosure. Analytical formulation confirms that long thin apertures are worse than round or square apertures of the same area. For a typical sized enclosure, the theory predicts that doubling the length of a slot reduces magnetic shielding effectiveness and by about 12 dB, while doubling the width only reduces magnetic shielding effectiveness and by about 2 dB. Calculations using the new formulation show that doubling the number of apertures reduces magnetic shielding effectiveness and by about 6 dB. However, dividing a long slot into two shorter ones increases magnetic shielding effectiveness and by about 6 dB.

1. Introduction

Electromagnetic shielding is generally used to decrease the emissions or to improve the immunity of the equipment. While the integrity of shielding enclosure for a digital design is compromised by slots and apertures for heat dissipation, airing I/O cable penetration or other purpose. These apertures and slots become the coupling route of electromagnetic interference (EMI) from the interior to outside [1-4]. That's why it effects the shielding effectiveness.

Shielding effectiveness can be calculated by the numeric methods are FDTD, FEM, MoM, TLM and etc., empirical / semi-emprical methods or by some simulations which is one that, CST Microwave Studio (CST-MWS) based on the Finite Integration Technique (FIT) or by analytical metods are comprised of theoretical formulas [5-9]. In this paper the analytical formulation presented provides a fast means of investigating the effect of design parameters on the shielding effectiveness of an enclosure [1,2].

In section 2, an analytical formulation for electrical (ESE) and magnetic shielding effectiveness (MSE) has been calculated as function of frequency, aperture size, enclosure size. In section 3, according to the formula the effects of aperture size, enclosure size, probe location, aperture shape, multiple apertures, aperture configuration have been analyzed and the results have been compared.

2. Analytical Formulation

The equivalent impedance of an aperture has been calculated by the method of circuit modeling, and the voltage and current have been calculated by transmission theory. Electrical shielding effectiveness is belong to the voltage at point P and magnetic shielding effectiveness is belong to the current at point P. Figure1 shows metallic enclosure and its equivalent circuit. At its equivalent circuit, the source impedance has been assumed as free space impedance of $Z_0 \approx 377\Omega$, and the source voltage is V_0. The first step is to define an equivalent impedance of slot followed by transforming voltages and impedances to point P as a second step. The enclosure has been represented as short waveguide whose characteristic impedance Z_g and propagation constant k_g are defined as below [1,2]:

$$Z_g = Z_0 / \sqrt{1-(\lambda/2a)^2} \tag{1}$$

$$k_g = k_0 \sqrt{1-(\lambda/2a)^2} \tag{2}$$

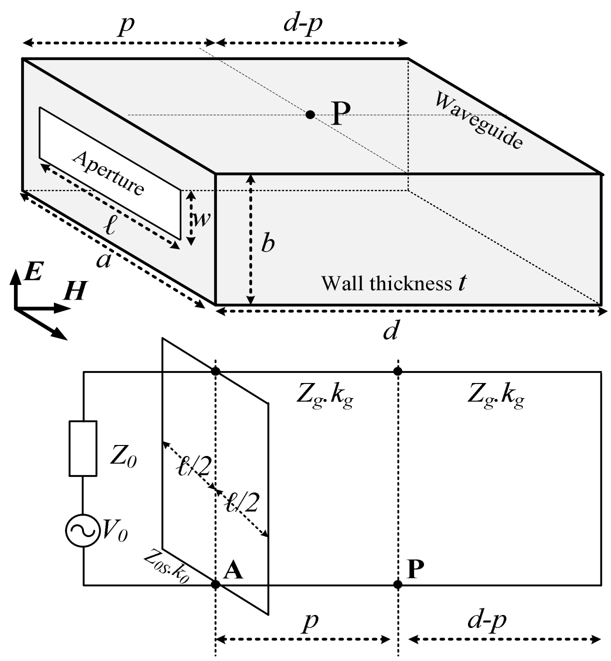

Fig. 1. Rectangular enclosure and its equivalent circuit [1]

The aperture has been indicated as a length of coplanar strip transmission line, and the total width is equal to the height of enclosure b and aperture width is w. The transition between free space and waveguide is identified that it is considered of aperture as a length of coplanar strip transmission line. The effective width is given as below:

$$w_e = w - \frac{5t}{4\pi}\left(1 + \frac{4\pi w}{t}\right) \tag{3}$$

where t is the enclosure wall thickness. If $w_e < b/\sqrt{2}$, the characteristic impedance of transmission line may approximately be [1,2]:

$$Z_{0s} = 120\pi^2 \left[\ln\left(2\frac{1+\sqrt[4]{1-(^{w_e}/_b)^2}}{1-\sqrt[4]{1-(^{w_e}/_b)^2}} \right) \right]^{-1} \tag{4}$$

as discussed by Gupta at all [12]. The short circuits at the ends of the aperture through a distance $\ell/2$ are transformed to the impedance at point A (on center of aperture) is Z_{ap}. Also ℓ/a factor must be included to account for the coupling between aperture and enclosure. So short circuit impedance is:

$$Z_{ap} = \frac{1}{2}\frac{l}{a} jZ_{0s} \tan\left(\frac{k_o l}{2}\right) \tag{5}$$

Z_0, v_0 and Z_{ap} are identified the source voltage $v_1$and the source impedance Z_1 are shown as below:

$$v_1 = v_0 Z_{ap}/(Z_0 + Z_{ap}) \tag{6}$$

$$Z_1 = Z_0 Z_{ap}/(Z_0 + Z_{ap}) \tag{7}$$

Then an equivalent voltage v_2, and source impedance Z_2 and load impedance Z_3 are shown as below

$$v_2 = \frac{v_1}{\cos k_g p + j\left(\frac{Z_1}{Z_g}\right)\sin k_g p} \tag{8}$$

$$Z_2 = \frac{Z_1 + jZ_g \tan k_g p}{1 + j\left(\frac{Z_1}{Z_g}\right)\tan k_g p} \tag{9}$$

$$Z_3 = jZ_g \tan k_g (d - p) \tag{10}$$

The voltage at P is:

$$v_p = v_2 Z_3/(Z_2 + Z_3) \tag{11}$$

The load impedance at P point is simply Z_0 without enclosure means reference calculation. The MSE is given as below:

$$MSE\ (dB) = -20\log_{10}\left|\frac{i_p}{i_p{}'}\right| = -20\log_{10}\left|\frac{2 i_p z_0}{v_0}\right| \tag{12}$$

3. Result And Analysis

In this section; the affects of an enclosure size, aperture size, probe location, aperture shape, multiple apertures and aperture configuration have been analyzed by analytical formulation.

3.1. Affect of Enclosure Size

700 x 120 x 160 mm, 750 x 160 x 200 mm and 800 x 200 x 240 mm size enclosures having an aperture size of 150 x 37.5 mm have been investigated and Fig.3 indicates magnetic shielding effectiveness. In the case of magnetic shielding effectiveness, larger the enclosure size increases the shielding effectiveness, and smaller the enclosure size increases the resonance frequency as shown in Fig.3. After 900MHz, they close each other about overlapping.

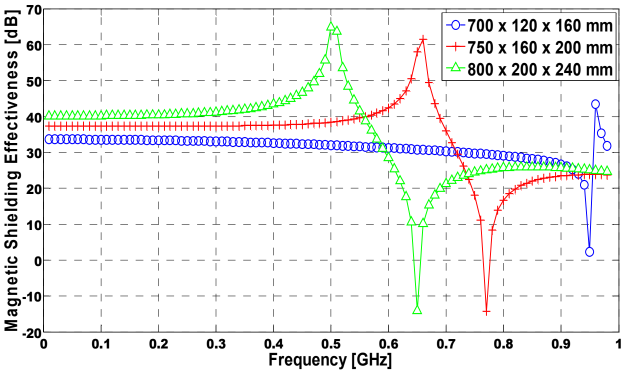

Fig. 3. Theoretical MSE for different enclosures having 150 x 37.5 mm size aperture.

3.2. Affect of Aperture Size

160 x 160 x 800 mm size enclosures having square type aperture size of 55 x 55 mm, 75 x 75 mm and 95 x 95 mm have been investigated Fig.4 indicates a magnetic shielding effectiveness. For the magnetic shielding effectiveness performance, smaller the aperture size increases shielding effectiveness, and they track each other with 10dB difference for whole band. Resonance frequencies are so close to each other around 960MHz.

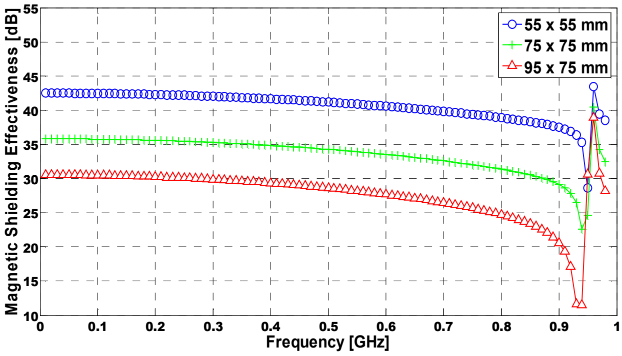

Fig. 4. Theoretical MSE for 160 x 160 x 800 mm size enclosure having different apertures.

3.3. Affect of Probe Location

A 160 x 160 x 800 mm size enclosure having an aperture size of 75 x 75 mm has been investigated for three different probe locations. D=160 mm is the depth of an enclosure, and p indicates the probe location chosen as 40, 80 and 120 mm, respectively (see Fig.1). Calculated magnetic shielding effectiveness is shown in Fig.5 for the probe distance of 80mm that it is at the center of an enclosure. 40dB of dramatic deviation in magnetic shielding effectiveness (MSE) has been observed with short probe location between 300 and 770 MHz band. At 770MHz, MSE for 80mm location deviates by about 40dB then others.

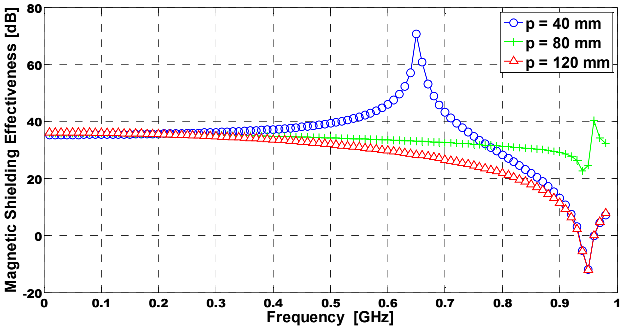

Fig. 5. Theoretical MSE for varying probe location in 160x160x800 mm size enclosure having 75 x 75 mm aperture.

3.4. Affect of Aperture Shape

Same sizes of three different enclosures have been chosen with constant probe location. While varying aperture dimensions were chosen, aperture area was fixed as 100mm^2. MSE has been investigated, and results are shown in Fig.6, MSE for whole three has a resonance frequency of 960MHz. Square type aperture has 14dB better MSE then 25 x 4 mm size rectangular aperture, and 13dB worse MSE then 4x25mm size rectangular aperture. MSE responses are more smooth and about flat for whole band.

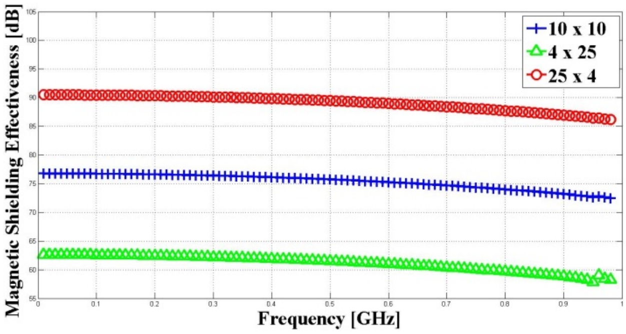

Fig. 6. Theoretical MSE for 160x160x800 mm size enclosure having different aperture shape

3.5. Affect of Multiple Apertures

In this section, 160 x 160 x 800 mm size enclosures having different number of apertures on them were chosen. Aperture size was chosen as 25 x 4 mm Fig.7 for indicates MSE for n={1, 3, 5} apertures positioned on an enclosure. MSE for all options become smooth and deviate by about 10dB from each other.

3.6. Affect of Aperture Configuration

While the total aperture area was kept constant as 400 mm^2, MSE has been investigated for varying aperture dimensions. Those are one 100x 4 mm size aperture, 4 times 25x4 mm aperture and 8 times 10x5 mm aperture, respectively. Results show that increased number of holes on an enclosure decreases MSE for a constant total aperture size. As shown in Fig.8, it is observed that there is a dramatic decrease in MSE, while the numbers of holes increase.

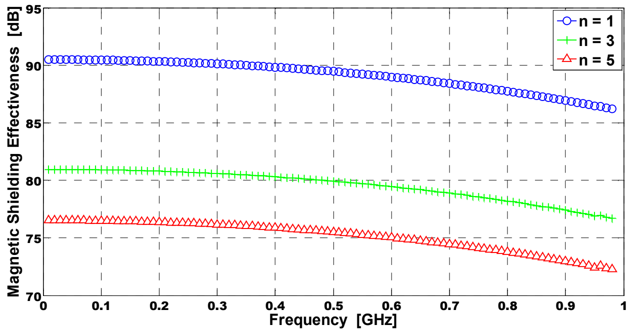

Fig. 7. Theoretical MSE for 160x160x800 mm size enclosure having 1,3 and 5 times 25x4 mm apertures on it

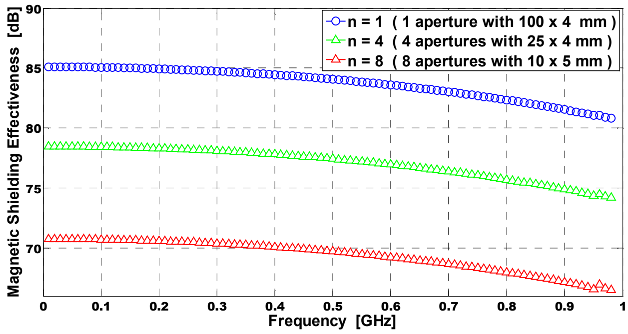

Fig. 8. Theoretical MSE for 160x160x800 mm size enclosure having different number of aperture (total area equals 400mm^2).

4. Conclusions

For magnetic shielding effectiveness (MSE); larger the enclosure size increases the shielding effectiveness, and smaller the enclosure size increases the resonance frequency. Smaller the aperture size increases shielding effectiveness, and they track each other with 10dB difference for whole band. When the probe distance is in center of enclosure depth (it is 80mm here), shielding effectiveness deviates by about 40dB then others. Square type aperture has 14dB better MSE then 25 x 4 mm size rectangular aperture, and 13dB worse MSE then 4x25mm size rectangular aperture. MSE decreases with the number of apertures. that increased number of holes on an enclosure decreases MSE for a constant total aperture size and it is observed that there is a dramatic decrease in MSE, while the numbers of holes increase.

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5. References

1. Robinson M. P., Benson T. M., Christopoulos C., Dawson J. F., Ganley M. D., Marvin A. C., Porter S. J. and Thomas D. W. P., “Analytical Formulation for the Shielding Effectiveness of Enclosures with Apertures”, *IEEE Transactions on Electromagnetic Compatibility*, Vol. 40, No. 3, August 1998.
2. Konefal T., Dawson J. F., Marvin A. C., Robinson M. P., and Porter S. J., “A Fast Multiple Mode Intermediate Level Circuit Model for the Prediction of Shielding Effectiveness of a Rectangular Box Containing a Rectangular Aperture” *IEEE Transactions On Electromagnetic Compatibility*, Vol. 47, No. 4, November 2005,pp:678-691.
3. Helhel S., Ozen S., Basyigit I. B., Kurnaz O., Yoruk Y. E., Bitirgan M., and Colak Z., “Radiated Susceptibility of Medical Equipments in Health Care Units: 2G and 3G Mobile Phones as an Interferer”, *Microwave And Optical Technology Letters* DOI 10.1002/mop / Vol. 53, No. 11, November 2011.
4. Basyigit I. B. , Tosun P. D., Ozen S. and Helhel S., “An Affect of the Aperture Lenght to Aperture Widtg Ratio on Broadband Shielding Effectiveness”*, UrsiGass2011*, August.
5. Shim J., Kam D. G., Kwon J. H., Kim A. J., “Circuital Modeling And Measurement Of Shielding Effectiveness Against Oblique Incident Plane Wave On Apertures In Multiple Sides Of Rectangular Enclosure”, *IEEE Transactions On Electromagnetic Compatibility*, Vol. 52, NO. 3, August 2010, pp: 566-577.
6. Wang B. Z., “Small-hole formalism for the finite-difference time-domain analysis of small hole coupling”, *Electron. Lett.*, vol. 30, no. 19, pp. 1586–1587, Sep. 1994.
7. Cerri G., Leo R. D., and Primiani V. M., “Theoretical and Experimental evaluation of the electromagnetic radiation from apertures in shielded enclosures”, *IEEE Trans.*
8. Nie B. L, Du P. A., Yu Y. T., and Shi Z., “Study of the Shielding Properties of Enclosures With Apertures at Higher Frequencies Using the Transmission-Line Modeling Method”, *IEEE Transactions on Electromagnetic Compatibility*, Vol. 53, No. 1, February 2011
9. Gupta K. C. “Microstrip Lines and Slotlines”, *Norwood, MA: Artech House, 1979*, ch. 7