Estimation of Electric Shielding Effectiveness of a Metallic Enclosure with off-centered Aperture

Mingyue Li^{#1}, Yougang Gao^{#2}, Dan Shi^{#3}, Yuanmao Shen^{#4}, Heyong Liu^{#5} Jing Bai^{#6}

[#]School of Electronic Engineering, Beijing University of Posts and Telecommunications 10 Xitucheng Road, Beijing, China

¹limin gy ue_0827@163.com

Abstract—This work is performed to investigate the effects of apertures on the electric shielding effectiveness of a rectangular metallic endosure with off-centered aperture by using an analytical formulation and simulation FEKO. The electric shielding effectiveness were calculated as a function of frequency, enclosure dimensions, aperture dimensions, position which was not in the centre within the enclosure by employing a transmission line equivalent circuit approach. In this work the model is extended to include higher order modes in the transmission line (TL) models. Theoretical values of shielding effectiveness are in good agreement with simulation FEKO.

Key words: apertures, off-centered circuit modelling, electric shielding, shielding effectiveness, shielded enclosure.

I. INTRODUCTION

Electromagnetic shielding is frequently used to reduce the emissions or improve the immunity of electronic equipment. The ability of a shielding enclosure to do this is characterized by its shielding effectiveness, defined as the ratio of field strengths in the presence and absence of the enclosure. At each point in an enclosure, we can define an electric shielding effectiveness S_E and a magnetic shielding effectiveness S_M . If apertures are present in a panel made of high conductivity material .The SE will depend mainly on the penetration of energy through the aperture rather than the walls. In this study the conductivity of the enclosure walls is sufficiently large that only aperture penetration is important and we present the results for the S_E .

SE of a rectangular enclosure has been studied by many authors. In some cases, numerical simulations are utilized to model the enclosure precisely [1], [2], [3]. It can model complex structures but often require much computing time and memory in order to model a problem with sufficient detail. This means that although they are good in predicting the shielding of a particular enclosure, it is difficult for designers to use them to investigate the effect of design parameters of S_E and S_M . A simplified analytical formulation method was proposed by [4] which provide much faster means of calculating SE and enabling the effect of design parameters to be investigated. Numerical methods that have been used to calculate shielding include transmission-line modeling [5], finite-difference time-domain (FDTD) method , and method of moments (MoM) [6].

Our aim here is to improve the technique developed by Robinson et al. [4] which using analytical formulation to determine the S_E and S_M of a metallic enclosure apertures by

taking into account the contributions of modes higher than TE_{10} mode in the enclosure. In this work the electric shielding effectiveness was calculated as a function of frequency, enclosure dimensions, aperture dimensions, aperture positions, observation points and especially the aperture is off-centered by employing a transmission line equivalent circuit approach. Some papers have investigated the SE of the metallic enclosure with off-centered aperture, but they just include that the aperture is changed along X axis. In our paper, we take into account the other case that the aperture is changed along Z axis. Our formulation applies only to rectangular enclosures with rectangular apertures, but these comprise a large proportion of shields used in practical design. Future works can be carried out to incorporate enclosures of various positions and sizes at frequencies higher than 1 GHz.

II. THEORY

In our paper, we follow closely the approach taken by Robinson et al., where a rectangular aperture in an empty rectangular enclosure is represented by the equivalent circuit shown in Figure 1. The radiating source is represented by voltage V_0 and impedance $Z_0=377\Omega$, the enclosure by the shorted waveguide whose characterize impedance and propagation constant are Z_g and K_g . We transform all the voltages and impedance to point P and proceed according to that of Robinson et al. with some improvements.

A. Slot Impedance

The aperture is represented as a length of coplanar strip transmission line, shorted at each end. Its characteristic impedance is given by an expression indicated by Gupta et al. [7]:

$$Z_{os} = 120\pi^{2} \left[\ln \left(2 \frac{1 + \sqrt[4]{1 - (w_{e}/b)^{2}}}{1 - \sqrt[4]{1 - (w_{e}/b)^{2}}} \right) \right]^{-1}$$
(1)

The effective width, W_e is given by

$$w_e = w - \frac{5t}{4\pi} \left(1 + \ln \frac{4\pi w}{t} \right) \tag{2}$$

where t is the thickness of the enclosure wall.

EMC'09/Kyoto



Fig.1:Rectangular Enclosure with aperture and its equivalent circuit

We have refers to C_m which is the aperture modal coupling to account for the coupling between aperture and the enclosure when considering modes higher than TE₁₀ mode, C_m is give by Farhana et al.[8]:

$$C_{m}^{y} = \frac{\int E_{m}^{y} E_{ap}^{y} dx}{X} = \frac{\int_{x_{0}}^{x_{0}+l} \sin(\frac{\pi mx}{a}) \sin\left(\frac{\pi (x-x_{0})}{l}\right) dx}{X}$$
(3)

In this paper, we have extended to the aperture impendence to include the factor C_n .

$$C_{n}^{x} = \frac{\int E_{n}^{x} E_{ap}^{x} dz}{Z} = \frac{\int_{z_{0}}^{z_{0}+w} \sin(\frac{\pi nz}{b}) \sin\left(\frac{\pi (z-z_{0})}{w}\right) dz}{Z}$$
(4)

So the shunt impedance of the aperture of length 1 and width w, respectively, is

$$Z_{ap}^{y} = \frac{1}{2} C_{m}^{y} j Z_{os} \tan(k_{0} l/2)$$
 (5)

$$Z_{ap}^{x} = \frac{1}{2} C_{n}^{x} j Z_{os} \tan(k_{0} l/2)$$
(6)

B. Electric Shielding Effectiveness

By Thevenin's theorem, combining Z_0 , v_0 and Z_{ap} gives an equivalent voltage

$$\begin{array}{l} v_{m0} = v_0 \, Z_{ap}^{y} / \left(Z_0 + Z_{ap}^{y} \right) \\ v_{1n} = v_0 \, Z_{ap}^{x} / \left(Z_0 + Z_{ap}^{x} \right) \end{array}$$
(7)

$$Z_{m0} = Z_0 Z_{ap}^{y} / (Z_0 + Z_{ap}^{y}))$$

$$Z_{1n} = Z_0 Z_{ap}^{x} / (Z_0 + Z_{ap}^{x}))$$
(8)

For the m-th TE_{m0} and n-th TE_{1n} transverse electric modes of propagation , the enclosure is represented by a cavity formed by a section of shorted waveguide whose characteristic impedance, respectively, is

$$Z_{m0}^{y} = Z_{0} / \sqrt{1 - \left(\lambda m / 2a\right)^{2}}$$
(9)

$$Z_{1n}^{x} = Z_{0} / \sqrt{1 - (\lambda n / 2d)^{2}}$$
(10)

And the propagation constant is represented respectively by

$$k_{m0}^{y} = k_{0} / \sqrt{1 - \left(\lambda m / 2a\right)^{2}}$$
(11)

$$k_{1n}^{x} = k_{0} / \sqrt{1 - (\lambda n/2d)^{2}}$$
(12)

where $k_0 = 2\pi/\lambda$, We now transform v_{m0} , v_{1n} , Z_{m0} , Z_{1n} and the short circuit at the end of the waveguide to P, giving an equivalent voltage v_{lm0}^y , v_{l1n}^y , source impedance Z_{lm0}^y , Z_{l1n}^x , and load impedance Z_{m0}^y , Z_{r1n}^x .

$$v_{lm0}^{y} = \frac{v_{m0}}{\cos k_{m0}^{y} p_{y} + j (Z_{m0}/Z_{m0}^{y}) \sin(k_{m0}^{y} p_{y}) \sin(\frac{m\pi p_{x}}{a})}$$
(13)

$$Z_{lno}^{x} = \frac{V_{ln}}{\cos k_{ln}^{x} p_{y} + j (Z_{ln}/Z_{ln}^{x}) \sin(k_{ln}^{x} p_{y}) \sin\left(\frac{n\pi p_{y}}{d}\right)} \int Z_{lmo}^{y} = \frac{Z_{m0} + j Z_{m0}^{y} \tan k_{m0}^{y} p_{y}}{1 + j (Z_{m0}/Z_{m0}^{y}) \tan k_{m0}^{y} p_{y}}$$
(14)

$$Z_{l1n}^{x} = \frac{Z_{1n} + jZ_{1n}^{x} \tan k_{1n}^{x} p_{x}}{1 + j(Z_{1n}/Z_{1n}^{x}) \tan k_{1n}^{x} p_{x}}$$
(15)

$$Z_{m0}^{y} = j Z_{m0}^{y} \tan k_{m0}^{y} \left(d - p_{y} \right)$$
 (16)

$$Z_{r1n}^{x} = j Z_{1n}^{x} \tan k_{1n}^{x} \left(a - p_{x} \right)$$
(17)

The voltage at P is

$$v_{pmo}^{y} = v_{lm0}^{y} Z_{rm0}^{y} / (Z_{lmo}^{y} + Z_{rm0}^{y})$$
(18)

$$v_{p1n}^{x} = v_{l1n}^{x} Z_{r1n}^{x} / \left(Z_{l1n}^{x} + Z_{r1n}^{x} \right)$$
(19)

$$V_{tm0}^{y} = \sum_{m} v_{pmo}^{y}$$
(20)

$$V_{t1n}^{x} = \sum_{n} v_{p1n}^{x}$$
(21)

$$V_t = \sqrt{V_{tm0}^{y^2} + V_{t1n}^{x^2}}$$
(22)

In the absence of the enclosure, the load impedance at P is simply Z_0 and the voltage at P is $v_p' = v_0/2$, so the electric shielding is, therefore, given by

$$S_{E} = -20\log_{10} \left| V_{t} / v_{p}' \right| = -20\log_{10} \left| 2V_{t} / v_{0} \right|$$
(23)

Copyright © 2009 IEICE

EMC'09/Kyoto

III. RESULT

For the validation of the present technique, we consider a rectangular enclosure of size ($300 \text{mm} \times 120 \text{mm} \times 300 \text{mm}$) with a rectangular aperture of size ($100 \text{mm} \times 5 \text{mm}$) located in front of the wall. We calculated it with MATLAB and simulation with FEKO, the result is as show in the Figure 2 to Figure 4.



Fig.2: Calculated and FEKO analysis of S_E at point P of $300 \times 120 \times 300$ mm enclosure with 100×5 mm off-centered aperture (Y = 3b/4).



Fig.3: Calculated and FEKO analysis of SE at point P of $300 \times 120 \times 300$ mm enclosure with 100×5 mm off-centered aperture (Y = 3b/4)





Figure 2 to Figure 4 shows the calculated and simulations of FEKO S_E at different points P for a off-centered aperture (Y = 3b/4), size 100×5 mm. We can see that they are good agreement, both above and below cut-off frequency of 500 MHz. The reasonably good agreement between analytical formulation and simulation of FEKO shows that the contributions of higher order modes must be taken into account when analyzing the shielding effectiveness for off-centered apertures. From Figure 3 we can see that the result is not very good agreement between 800M and 1100M, the reason probably is that the observation is near to the aperture, modes higher than TE_{10} affected the shielding effectiveness obviously.

IV. CONCLUSION

The calculation of electric shielding effectiveness depends upon the frequency, polarization of the applied field, the dimensions of the enclosure, the aperture, wall thickness, the number of apertures, and the position within the enclosure. The formulation described in this paper takes into account the off-centered aperture on one face of the enclosure, we have refers to C_m and C_n which is the aperture modal coupling to account for the coupling between aperture and the enclosure when considering modes higher than TE₁₀ mode . It gives good agreement with simulation over wide frequency range. It can predict the electric shielding effectiveness of the rectangular aperture of arbitrary location on one face of the rectangular enclosure. The existence of a peak in the shielding effectiveness for the off-centered aperture is an interesting observation and further theory investigate need to be carried out to understand this phenomenon. The results generated from this research can be used by designers of practical shielded enclosures.

REFERENCES

- K.S. Kunz, and R.J. Luebbers, The Finite Difference Time Domain Method for Electromagnetic. CRC Press, Boca Raton, 1993.
- [2] C. Christopoulos, The Transmission Line Modeling Method TLM. IEEE Press, New York, 1995.
- [3] P.P. Silvester and R.L. Ferrari, Finite Elements for Electrical Engineers. Cambridge University Press,2pndP Edition, Cambridge, 1990.
- [4] M.P. Robinson, T.M. Benson, C. Christopoulos, J.F. Dawson, M.D.Ganley, A.C. Marvin, S.J. Porter, and D.W.P. Thomas, "Analytical formulation for the shielding effectiveness of enclosures with apertures," IEEE Trans. Electromagn. Compat., vol. 40, no. 3, pp. 240-247, Aug. 1998.
- C. H. Kraft, "Modeling leakage through finite apertures with TLM," in IEEE Int. Symp. Electromagn. Compat., Chicago, IL, Aug. 1994, pp.73–76.
- [6] G. Cerri, R. De Leo, and V. M. Primiani, "Theoretical and experimental evaluation of the electromagnetic radiation from apertures in shielded enclosures," IEEE Trans. Electromagn. Compat., vol. 34, pp. 423–432, Nov. 1992.
- [7] K. C. Gupta, R. Garg, and I. J. Bahl, Microstrip Lines and Slotlines. Norwood, MA: Artech House,1979, ch. 7.
- [8] Farhana Ahmad Po"ad,Mohd Zarar Mohd Jenu,C.Christopoulos and D.W.P.Thomas, "Estimation of Electric and Magnetic Shielding Effectiveness of a Metallic Enclosure with Aperture", IEEE Trans.Electromagn.Compat., Sep.2006
- [9] F. Sarto, M.S. Sarto, M.C. Larciprete, and C. Sibilia, "Transparent films for electromagnetic shielding of plastics," Rev. Adv. Mater. Sci., vol. 5, no. 4, pp. 329–336, 2003.

EMC'09/Kyoto

[10] Attari et al., 'Application of the Transmission Line Matrix Method to the Calculation of the Shielding Effectiveness for Metallic Enclosures', IEEE International Symposium on Antennas and Propagation Sociery, Vol.2002

[11] Azaro et al., 'A circuital Approach to Evaluating the Electromagnetic Field on Rectangular Apertures Backed by Rectangular Cavities', IEEE Transactions on Microwave Theory and Techniques, vol. 50, No. 10,October 2002