http://dx.doi.org/10.5755/j01.eee.18.10.3071 ELEKTRONIKA IR ELEKTROTECHNIKA, ISSN 1392-1215, VOL. 18, NO. 10, 2012

A Novel and Efficient Technique for Improving Shielding Effectiveness of a Rectangular Enclosure using Optimized Aperture Load

M. Bahadorzadeh[1], A. A. Lotfi-Neyestanak[2]
[1]Departmentof Electrical Engineering, Mashhad Branch, Islamic Azad University, Mashhad, Iran, phone: +98 912 527 8633, e-mail:
[2]Department of Engineering, Shahr-e-Rey Branch, Islamic Azad University, Tehran, Iran
m.bahadorzadeh@mshdiau.ac.ir

***Abstract*—An efficient and practical method to enhance the shielding effectiveness of a rectangular enclosure with aperture against electromagnetic interferences is presented. In this paper an extra aperture as a matched load instead of a shorted waveguide has been proposed. Transmission line matrix method was used for simulation the rectangular enclosure under electromagnetic plane waves and the result was verified by analytical method and CST software. A complete range of simulations were performed to find the optimum size for second aperture. The proposed method resulted in a very good improving of shielding effectiveness of enclosure especially in resonant frequency.**

***Index Terms*—Electromagnetic shielding, transmission line matrix methods, pulse circuits.**

I. INTRODUCTION

Nowadays by using higher portion of electromagnetic spectrum, electrical and electronic devices used in power and communication respectively are expected to be shielded in order to increase reliability and immunity. In addition, the equipment is commonly housed into metallic boxes.

In such structures, the external electromagnetic fields can directly couple energy into the interior through apertures or slots. Sometimes the energy may interfere with or destroy the electrical and electronic systems.

Electromagnetic shielding is considered as a powerful approach that prevents coupling of unwanted radiated electromagnetic energy into protected equipment, but the efficiency of shielding enclosures is degraded because of the existence of the slots and apertures for signal and power cable penetration , heat dissipation, peripherals and displays.

In the electromagnetic compatibility (EMC) point of view these elements, produce a path for penetration of high power electromagnetic pulse (HEMP) into enclosures that should be studied as well.

The shielding effectiveness (SE) which is defined as the ratio of field strengths in the absence to the presence of the enclosure (1) represents the ability of an enclosure to reduce the effects of undesired emissions

$$SE = 20\log\left(\frac{E_0}{E_s}\right). \tag{1}$$

One of the most critical problems about SE parameter of a rectangular enclosure is about its resonant frequency. At this frequency the shielding effectiveness parameter will significantly decrease and the magnitude of the coupled electric and magnetic fields will be greater than the absence of the enclosure. In this study the focus has been on the resonant frequency of enclosure as a crucial problem.

II. THEORY

Numerical methods have been used to calculate shielding effectiveness include finite-difference time-domain (FDTD) method [1] and method of moments (MoM) [2]. Also a circuit model for calculation of shielding effectiveness has been presented by Robinson et al. [3], [4]. As it is shown in Fig. 1 enclosure has been modelled by a shorted waveguide. The aperture is represented as a length of coplanar strip transmission line, shorted at each end. For this coplanar strip line the width of the line is equal to the height of the enclosure and the distance between lines is equal to the width of the slot.

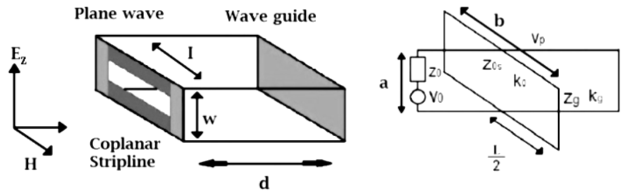

Fig. 1. Rectangular enclosure with an aperture and its equivalent circuit (a=300 mm, b=120 mm, d= 300 mm), (l=100 mm , w=15 mm).

The characteristic impedance of this slot is given by Gupta et al. [3] as shown in Fig. 2 the shunt impedance of the aperture can be modelled as (2)

Manuscript received November 20, 2011; accepted June 8, 2012.

$$Z_{ap} = \frac{l}{a}(Z_{aphalf} \parallel Z_{aphalf}) = \frac{1}{2}\frac{l}{a} jZ_{os} \tan\frac{K_0 l}{2}, \qquad (2)$$

where the l is the length of aperture, a is the length of the strip line, K_0 is free space wave number and Z_{os} is the characteristic impedance of coplanar strip transmission line which could be formulated as (3)

$$Z_{os} = 120\pi^2 \left[\ln\left(2\frac{1+\sqrt[4]{1-(w_e/b)^2}}{1-\sqrt[4]{1-(w_e/b)^2}} \right) \right]^{-1}. \qquad (3)$$

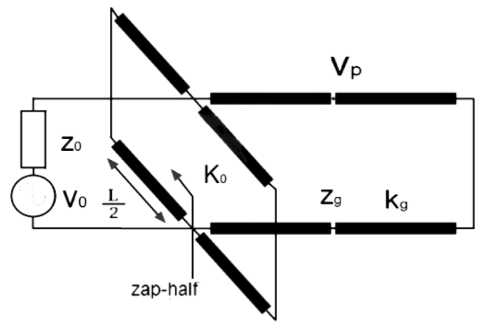

Fig. 2. Impedance of aperture and its equivalent circuit.

A plane wave with a normal electric field to the length of the aperture, which is the worst case for shielding effectiveness, is used for illuminating the rectangular enclosure. The radiating source is modelled by voltage and impedance and the enclosure was modelled by the shorted waveguide. Its characteristic impedance and propagation constant are respectively represented by Z_g and K_g.

The equivalent voltage and source impedance for the dominant mode of propagation (TE_{10}), the voltage at the observation point (v_p) can be found as (4)–8() and (9) by using the'venin's theorem:

$$v_1 = \frac{Z_{ap}}{Z_o + Z_{ap}} v_o, \qquad (4)$$

$$Z_1 = Z_o \parallel Z_{ap}, \qquad (5)$$

$$\begin{bmatrix} v_1 \\ i_1 \end{bmatrix} = \begin{bmatrix} 1 & Z_1 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} \cos k_g p & jZ_g \sin k_g p \\ j\frac{1}{Z_g}\sin k_g p & \cos k_g P \end{bmatrix} \begin{bmatrix} v_2 \\ i_2 \end{bmatrix}, \qquad (6)$$

$$v_2 = \frac{v_1}{\cos k_g P + j\frac{Z_1}{Z_g}\sin k_g P}, \qquad (7)$$

$$Z_2 = Z_g \frac{Z_1 + jZ_g \tan k_g P}{Z_g + jZ_1 \tan k_g P}. \qquad (8)$$

According to the method in order to improve the shielding effectiveness the factor $\xi = \frac{Z_3}{Z_2 + Z_3}$ has a significant role. For finding the best result for ξ factor, it is assumed that an aperture acts like a termination load for waveguide model of the enclosure. The equivalent circuit for this new model is shown in Fig. 5.

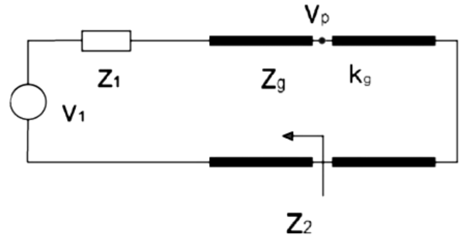

Fig. 3. Thevenin equivalent circuit.

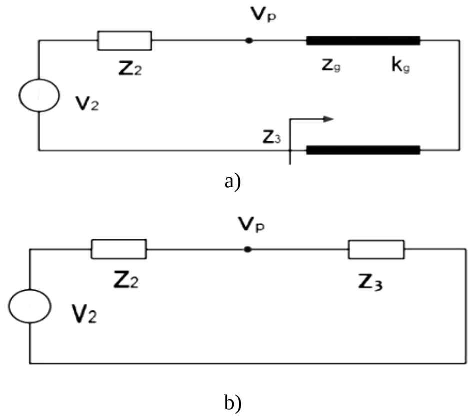

Fig. 4. Voltage at the observation point for the mode (TE_{10}).

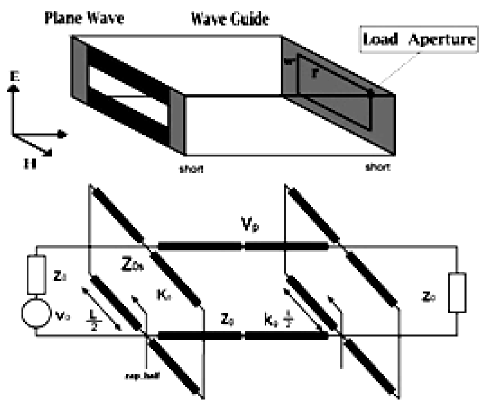

Fig. 5. The equivalent circuit for an enclosure with aperture load.

$$v_p = \frac{Z_3}{Z_2 + Z_3} v_2. \qquad (9)$$

III. Results

A. Symmetrical shielding box

As shown in Fig. 5 a shielding box with mentioned dimensions was simulated. First by keeping symmetric of enclosure regarding to the direction of impinging plane wave, the size of the load aperture selected as the same of the main aperture. So that the Z_2 impedance will be equal to Z_3 impedance and ξ parameter will be equal to 0.5 (ξ=0.5). A comparison between an enclosure with aperture load and a short circuit waveguide based on analytical transmission model was performed. The result has been shown In Fig. 6. It is evident that using an aperture load would improve the shielding effectiveness parameter about 5 dB in resonant frequency of the cavity.

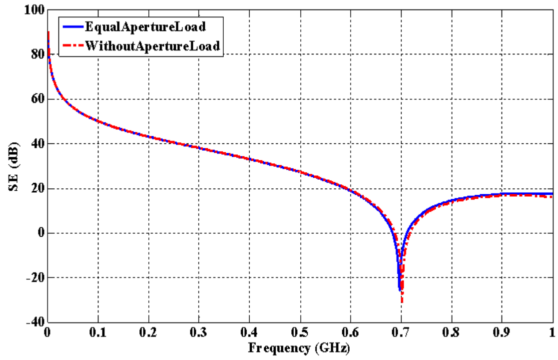

Fig. 6. Different SE for an aperture load enclosure and a short circuit enclosure based on TL model.

B. No symmetrical shielding box

In the case that the direction of the impinging plane wave is specified, a no symmetrical shielding box can be utilized. The optimum size for the aperture load in the back wall of the cavity at resonant frequency (0.7 GHz) should be evaluated. The shielding effectiveness parameter was calculated for a range of aperture's length in this frequency. The width of the apertures considered constant in all simulations, as shown in Fig. 7 and the maximum value for SE parameter was found for the length about 215(mm) at frequency 0.7 GHz which is about 14 dB.

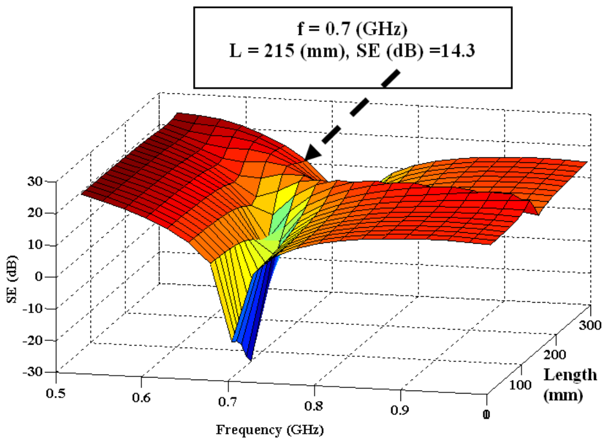

Fig. 7. Shielding effectiveness versus frequency and length.

It is evident that increasing in the length of the aperture from 100 mm to 215 mm would improve the shielding effectiveness about 27 dB.

A comparison between a shielding box without aperture load and with an optimum aperture load by using transmission line model is represented in Fig. 8.

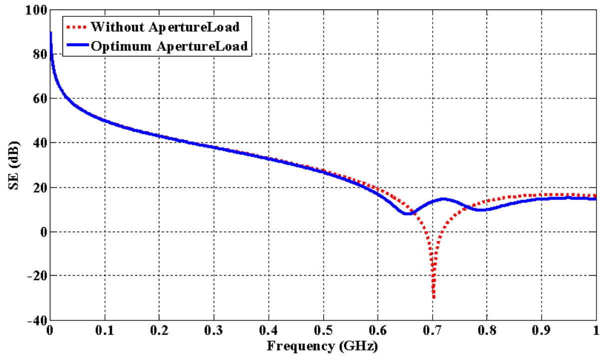

Fig. 8. Comparison of SE parameter of optimum aperture load and short circuit shielding box by using TL model.

An optimum aperture load in the back wall of the cavity result in positive SE parameter over all frequency range. It is representing that the coupled electric filed will not resonate and even has been attenuated in the resonant frequency of a simple shielding enclosure.

C. Aperture load optimization regarding to reflection coefficient

The standing wave which is produced in a short circuit waveguide results in the resonance of the shielding box. In order to minimize the magnitude of the coupled standing wave, the reflection coefficient should be reduced as much as possible. The reflection coefficient is introduced as (6)

$$\Gamma = \frac{Zg - Z_L}{Zg + Z_L}, \tag{6}$$

where Γ – reflection coefficient, z_g – characteristic impedance of waveguide at TE_{10} mode, Z_L – load impedance.

By considering the transmission line model of the cavity loaded aperture structure, the reflection coefficient is calculated for different size of aperture and the result is shown in Fig. 9.

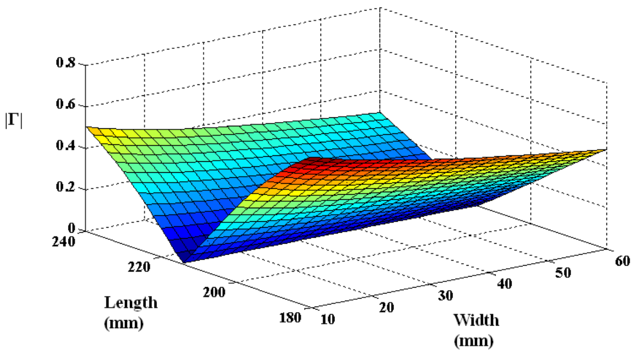

Fig. 9. Reflection coefficient for different length and width at f=0.7 GHz

The reflection coefficient has got a minimum if the length of the aperture to be about 215 mm which is equal to the length of a half wave dipole at the resonant frequency (f=0.7 GHz , λ=428 mm). So for an impedance matching condition the length of the aperture should be selected $\lambda_r/2$ where λ_r is the wavelength of the resonant frequency of the cavity.

A Gaussian excitation signal was used as the amplitude of the electric field of an exciting plane wave. The electric field is in z direction and the plane wave is illuminating structure depicted in Fig. 5.

The reflected electric wave at the centre of the shielding box is presented in time domain in Fig. 10. It is clear that when we have an optimum aperture load at the back wall, by passing the time, the amplitude of the reflecting electric waves is being damped drastically, meanwhile for a shielding box without aperture load the amplitude of the electric field of the reflecting wave is being damped very slowly.

D. Result verification

For checking the validity of the method, the structure was simulated by CST as a FDTD based software and transmission line matrix (TLM) method.

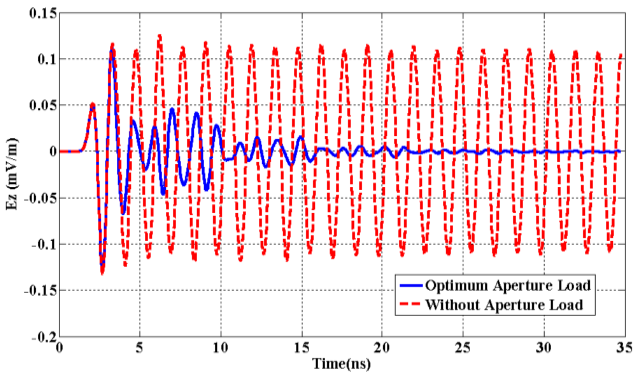

Fig. 10. Time domain electric field strength at the centre of aperture.

The dimension of the shielding box is (a=300 mm, b=120 mm, d=300 mm) and the size of the main aperture is (l=100 mm, w=15 mm). An optimum aperture with dimensions (l=215 mm, w=15 mm) is located at the centre of the back wall. As depicted in Fig. 11 the results for different methods represent a good agreement.

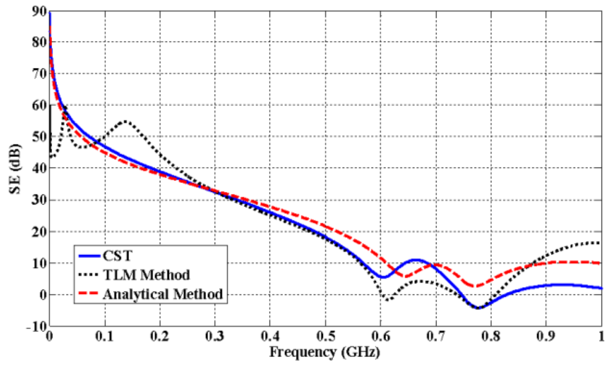

Fig. 11. Evaluation of shielding effectiveness parameter by using different methods.

IV. Conclusions

In this paper, an efficient and practical method to enhance the shielding effectiveness of a rectangular enclosure with aperture against electromagnetic pulses is represented. In this method using an extra aperture as a matched load instead of a shorted waveguide has been proposed. Transmission line matrix method was used for simulation the rectangular enclosure under electromagnetic interferences and the results were verified by analytical method. Transmission line matrix method and CST software were used to find the optimum size for second aperture. The extra aperture in the end of enclosure acts as a matched load which reduces the amplitude of the reflecting waves rapidly in time domain and improves the SE of enclosures significantly.

References

[1] K. S. Kunz, R. J. Luebbers, *The Finite Difference Time Domain Method for Electromagnetics*. Orlando, FL: CRC, 1993.

[2] G. Cerri, R. Leo, 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, 1992. [Online]. Available: http://dx.doi.org/10.1109/15.179275

[3] C. H. Kraft, „Modeling leakage through finite apertures with TLM", in *IEEE Int. Symp. Electromagn. Compat.*, Chicago, IL, 1994, pp. 73–76

[4] M. P. Robinson, T. M. Benson, C. Christopoulos, J. F. Dawson, M. D. Ganley, A. C. Marvin, S. J. Porter, D. W. P. Thomas, „Analytical formulation for the shielding effectiveness of enclosures with apertures", *IEEE Transactions on Electromagnetic Compatibility*, vol. 40, 1998, pp. 240–248. [Online]. Available: http://dx.doi.org/10.1109/15.709422

[5] K. C. Gupta, R. Garg, I. J. Bahl, *Microstrip Lines and Slot lines*. Norwood, MA: Artech House, 1979, ch. 7.