Shielding Effectiveness for Metallic Enclosures with Various Aperture Shapes

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***Abstract*— In this paper, we present our study on the shielding effectiveness (SE) of a metallic rectangular enclosure with various aperture shapes and numbers. We calculate the SE value for various apertures such as rectangle, square, pentagon, hexagon and circle. The best SE value is obtained with the pentagon shaped aperture. We have calculated the SE value of the enclosure with multiple apertures to observe the variation of SE with the number of apertures. We also present the SE value of an enclosure with apertures including inductive iris. Preliminary results reported here look very promising for future studies. We use CST Microwave Studio and transmission line method in the calculations.**

***Index Terms*— Pentagon aperture; hexagon aperture; shielding effectiveness; metallic enclosure with an aperture; shielding design.**

I. INTRODUCTION

Electromagnetic shielding is a widely used effective method for protecting electronic devices from man-made or natural sources of electromagnetic interference (EMI). Protection of electronic devices from EMI can be achieved by shielding with metallic enclosures in which the electronic devices are placed. The performance of the shield is quite generally defined to be Shielding Effectiveness (SE), which is the ratio of power at the receptor without the shield and with the shield [1-10].

In the design of shield without aperture, the thickness of the given conductor is calculated in order to obtain the desired shielding effectiveness (SE) value. In real applications, these shield structures need to have apertures. For example, apertures for ventilation, display, input or output ports, power supply cable, etc. These holes are unavoidable apertures on the shielding enclosures and cause dramatical reduction in the shielding effectiveness value.

When the thin shield contains the apertures, its shielding effectiveness value is determined mainly by the aperture size in terms of the wavelength of the interference source. It is almost independent of the electrical characteristics of conducting material and its thickness. For the case of thick structures, the aperture can be considered as a waveguide and its SE value depends on aperture size, shape and thickness of the shielding material. From previous studies and experiments it is known that the aperture shape affects the SE value and best SE value is obtained to be the honeycomb (hexagonal) shape [2].

Another weak point of metallic enclosure is the natural resonant frequency of the box itself. In the resonant frequency, naturally, the SE of enclosure has a minimum value and device in the enclosure is vulnerable to the interference. Designers have to pay attention to choose the appropriate dimension and geometry for the enclosure [3].

In this paper, we present our studies of the shielding effectiveness of a metallic rectangular box with various aperture shapes and numbers. In the first part of the study, we calculate the SE value of various apertures such as rectangular, square, circular, pentagon and hexagonal shapes. Obtained results show that the best aperture shape to improve the SE is the pentagon. However, the SE performance of the hexagonal shape is very close to the pentagon, the difference being around 1 dB over the simulated frequency range up to 1000 MHz. In this part of the study we have used frequency and transient domain solvers of CST Microwave Studio.

In the second part of the study, we have calculated the SE value of a metallic enclosure with hollow and multiple square apertures using transmission line method (TLM). Multiple apertures are modeled with short circuit parallel stubs. The reduction of the SE value with increasing number of square apertures on the wall of a rectangular enclosure is observed. We compared TLM results with those of CST Microwave Studio and found good agreement. We have also observed that the total area of the apertures cause a change in the natural resonance frequency of the rectangular box.

To improve the SE value of the enclosure with specific aperture size, the apertures can be coated with inhomogeneous lossy materials as in Refs. [6-7]. The other way to obtain better SE may be done by inserting irises inside the aperture similar to the iris waveguide filters. To improve the SE value of the enclosure, we have inserted an iris into the aperture and obtained better SE performance comparing to the hollow one.

This paper is organized as follows. Section II describes the problem geometry and related definitions used throughout this paper. In Section III, we present our results and compare the performance of different apertures. Section IV presents conclusions and our plan for future studies.

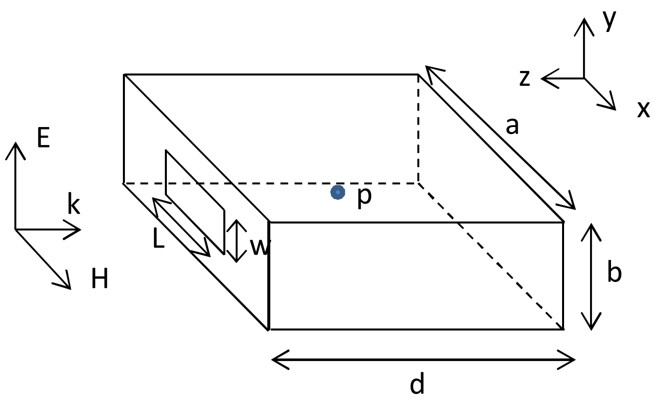
II. PROBLEM GEOMETRY

The rectangular box with an aperture and its transmission line model, which we base our calculations are given in Fig.1a and Fig. 1b, respectively [10]. The air-filled closed rectangular box with an aperture is made of a good conductor with dimensions *a*, *b* and *d*. The enclosure is illuminated by a plane wave with the electric and magnetic field vector directions as shown in Fig.1a. To obtain the worst condition for the shielding effectiveness value, the wave is propagating normally through the aperture.

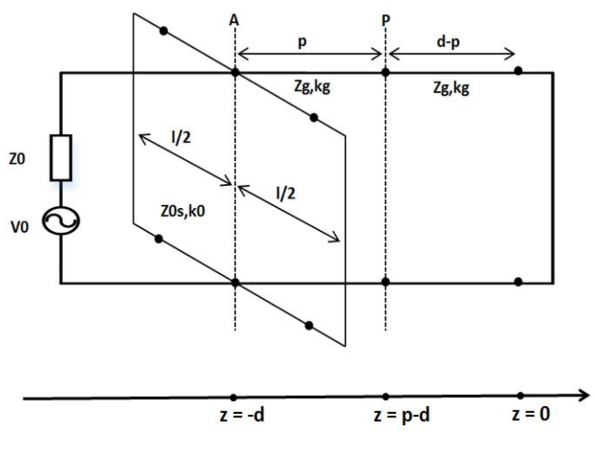
The resonant frequency of the rectangular cavity resonator is given by

$$f_{mnp} = \frac{1}{2\sqrt{\mu\varepsilon}}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2 + \left(\frac{q}{d}\right)^2} \qquad (1)$$

where m, n and q are integers. μ and ε are the permeability and permittivity, respectively, of the medium inside the box.



(a)



(b)

Fig.1. a) The rectangular box with an aperture. b) Transmission line model of the box.

The electric field shielding effectiveness in dB for the geometry shown in Fig.1a is

$$SE_{dB}^{E} = 20log|E_{inc}(p)/E_{box}(p)| \qquad (2)$$

Where E_{inc} and E_{box} are measured or calculated electric field strength at the same point (point *p* in the figure) without and with the shield (box), respectively.

In the transmission line model given in Fig. 1b, radiating source is represented by voltage V_0 and free space wave impedance Z_0. The rectangular encloser can be replaced by short circuited transmission line whose characteristic impedance Z_g and propagation constant k_g, respectively. Similarly the aperture is represented by a short circuited stub with slot impedance Z_{0S} and free space wave number k_0.

The transmission line model details and the definitions of the parameters in Fig. 1b can be found in the paper of Robinson et al.[10]. For the transmission line model the electric field shielding effectiveness can be calculated using the ratio of the voltage at *p* without and with the enclosure as follows

$$SE_{dB}^{E} = 20log|V_0/2V_p| \qquad (3)$$

where V_p is the voltage at point *p* in Fig. 1b.

III. SIMULATION RESULTS AND DISCUSSION

A. Single Aperture

For easy comparison with previous studies [8-10], the dimensions of the box and its thickness in this study are chosen to be 300 mm, 120 mm, 300 mm and 1.5 mm, respectively. In the simulation incident field is a normally incident plane wave with unit amplitude and the electric field is computed at the center of enclosed cavity to simulate the worst condition for SE.

TE_{101} mode is the dominant mode of the rectangular cavity in case of $a>b<d$ as ours. Hence the resonance frequency of the box without aperture is approximately 707 MHz. Due to the reactive perturbations caused by the aperture; the resonance frequency of the rectangular box with aperture will be the slightly different from that of the box without aperture.

Fig. 2 shows that the results of our simulation for the same metallic enclosures with different apertures. In Fig. 2, the shielding effectiveness variations of the enclosure shown in Fig.1a are given when the aperture shape is taken as a square, a circle, a pentagon and a hexagon. For proper comparison, the square sides and circle diameter ($2r$) are chosen equal and w=L=$2r$=50 mm. Similarly the pentagon and the hexagon sides are chosen such that they coincide with the square and the circle sizes.

From the results shown in Fig.2, we can conclude that a pentagon aperture gives the best performance among the others. The resonant frequency of the enclosure with a square is 711 MHz, whereas with the others apertures (pentagon, hexagon and circular) it has the same value of 712 MHz. The difference between the pentagon and the square apertures in the SE value is roughly 8 dB far from resonance frequency. The difference between the pentagon and the hexagon apertures in the SE value is not very much and nearly 1 dB over the simulated frequency range up to 1000MHz.

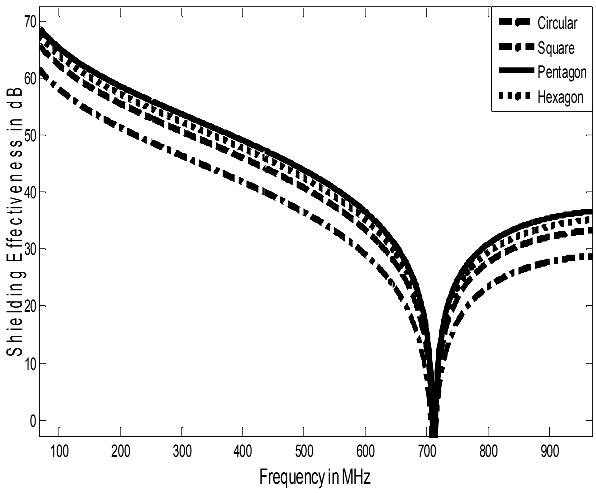


Fig. 2. Electric field SE of the rectangular box with different apertures (*a*=*d*=300 mm, *b*=120mm)

B. Multiple Apertures

It is a well-known fact that multiple apertures reduce the total effectiveness of shielding. This reduction is calculated by $(-10 \log_{10}(n))$ and where n is the total number of apertures. In this part of the study, we have defined different number of apertures on the box and calculated its SE value.

The geometry of the multiple-aperture case based on our calculations is given in Fig. 3 and the calculated SE values are shown in Fig. 4. The calculation is performed with the same rectangular box dimensions and the square aperture length is equal to 50 mm. In the calculations, dimensions of apertures are kept constant and only their number is changed. In the two-aperture case, the apertures are placed side by side along the *x*-direction and in the middle of the wall. For four-aperture case, the wall has only four apertures in the middle of the wall as shown in Fig.3. In the calculations, the distance between the apertures is chosen to be small as 2mm, and the material of the box is aluminum.

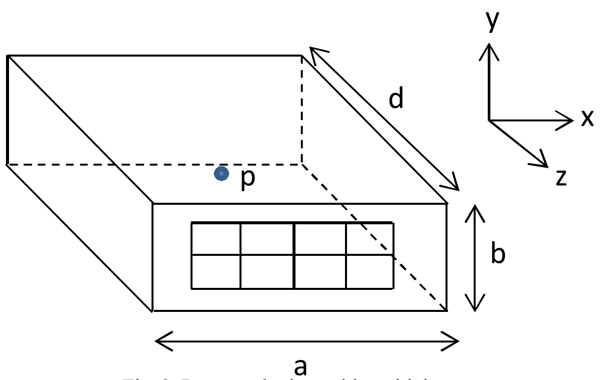


Fig. 3. Rectangular box with multiple apertures.

We choose the number of apertures to be 2, 4 and 8 in order to fix the reduction of SE value with -3dB. However, we observe that the reduction in SE with increasing number of apertures is much larger than the expected value of 3dB. This result stems from two reasons, one is our geometry, which is a closed box, and the other reason is that the formula is an approximation and more convenient for small apertures.

The change in resonance frequency of the enclosure is given in Table I. Increasing number of apertures and total aperture size on the wall of the enclosure cause the decrement of the natural resonance frequency of the shield.

Fig.5 shows the simulation results of CST and transmission line method for an enclosure with four square apertures. In the calculation, the square aperture length and the distance between the apertures are chosen 20mm and 10mm, respectively. The multiple apertures are simulated by short circuited parallel stubs in transmission line model. There is good agreement between the results of CST and TLM.

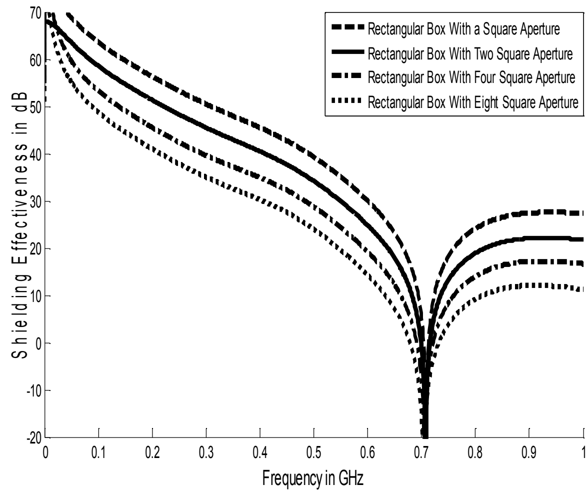


Fig. 4. Electric field SE of the rectangular box with various number of apertures (*a*=*d*=300mm, *b*=120mm)

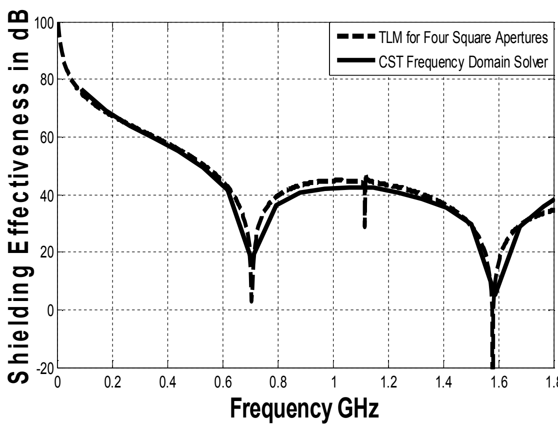


Fig. 5. Comparison of Transmission Line Model and CST results.

TABLE I. RESONANCE FREQUENCIES

Number of Apertures	1	2	4	8
Resonance frequency (MHz)	711	709	707	698

C. Aperture with an iris

To improve the SE value of rectangular box with an aperture, an iris [11] is inserted in the middle of the aperture. CST simulation result is given in Fig. 6. In the simulation the aperture length, width and depth are 64 mm, 32mm and 20mm, respectively. We obtain approximately 4 dB higher SE values with the waveguide with iris compared with the same waveguide without iris.

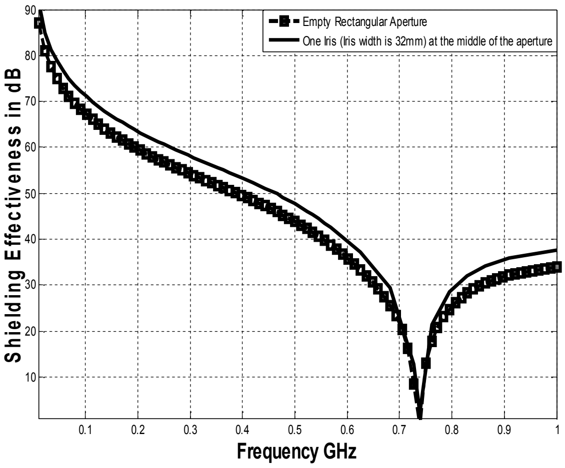


Fig. 6. Electric field SE of rectangular box with a rectangular waveguide below cut off.

IV. CONCLUSIONS

We have calculated the electric field shielding effectiveness of a metallic rectangular closed box with apertures of different shapes. The best SE is obtained with the pentagonal aperture, in contrast to the previously known hexagonal shape. However, hexagonally shaped aperture's SE value is a very close the SE value of pentagon shape. Therefore, considering the stacking of the hexagonally shaped apertures' being easier than the pentagonal shaped ones to construct for instance an air ventilation structure, we can use hexagonal shape at the cost of a slight loss from the maximum achievable effectiveness of shielding. Secondly, we analyzed a shielding box with multiple square aperture to realize and observe its impacts on SE value and the resonance frequency of the box. In the last part of the study we observed waveguide with iris gives better SE value than the hollow waveguide.

For future work, we intend to analyze the enclosure with waveguide iris using the transmission line model. We are planning to optimize the size and number of irises to obtain better SE value with shorter waveguides.

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