Shielding effectiveness evaluation for shielding box with holes

Yinhan Gao [1, a], Juxian Wang [2, b], Tianhao Wang [1, c], Kaiyu Yang [1, d]

[1]State Key Laboratory of Automobile Simulation and Control, Jilin University, Changchun 130022, China

[2]College of Instrumentation & Electrical Engineering, Jilin University, Changchun 130061, China

[a]yinhan@jlu.ed.cn, [b]wjx0621@126.com, [c]wangtianhao2006@126.com, [d]yangky@jlu.edu.cn

Abstract. For evaluating the shielding effectiveness (SE) of metal shielding box with holes, this paper gives the electric field shielding effectiveness (EFSE) and magnetic field shielding effectiveness (MFSE) evaluation index. Then the figurate apertures on the rectangular metal board can be equivalent to electric dipole and magnetic dipole, and the SE formula of round whole and square hole for electric field and magnetic field at any point are derived. Lastly, the SE under these two types of hole is evaluated by simulation. By simulation it is concluded that the square hole should be chose if holing is necessary for mental shielding box. All these have guiding significance for the design of shielding box in practical application.

Keywords: EFSE, MFSE, Shielding box, Round whole, square hole.

1. Introduction

With the improvement of signal frequency and the increase of equipment power, space electromagnetic environment has become increasingly complex. As an important part of protective measures for electronic system, most electromagnetic energy in space can be shielded by shielding box. Although the seamless metal board owns the super shielding ability for electromagnetic wave, holing is inevitable for shielding box because of ventilation and heat dissipation, thus the integrity of shielding box is broken. Therefore, how to effectively estimate SE of shielding box with holes has important theoretical guiding significance [1-3].

The shielding ability and effect of shielding box are usually evaluated by SE. The SE is closely related to the integrity, size, shape and location of the shielding box. This paper gives the SE evaluation index firstly, and then the EFSE and MFSE formula for round hole and square hole at any point are derived. Lastly, the SE under these two types of hole is evaluated by simulation. All these have guiding significance for the design of shielding box.

2. The SE derivation

SE is defined as: in the same position the electric field intensity E_0 without shield is divided by the electric field intensity E_s with shield, shown in formula (1). Or in the same position the magnetic field strength H_0 without shield is divided by the magnetic field strength H_s with shield, shown in formula (2). Their entire units are decibels (dB).

$$SE_E = 20\lg\left(\frac{E_0}{E_s}\right) \tag{1}$$

$$SE_H = 20\lg\left(\frac{H_0}{H_s}\right) \tag{2}$$

For closed shielding box, SE formula is as type (3) shown.

$$SE = A + R + B \tag{3}$$

Where A is the absorption attenuation, R is the reflection loss, B is the multiple reflection loss, and their calculation formulas are shown below.

$$A = 0.313t\sqrt{f\mu_r\sigma_r} \tag{4}$$

$$R = C + 10\lg\left(\frac{\sigma_r}{\mu_r}\right)\left(\frac{1}{f^n r^m}\right) \tag{5}$$

$$B = 20\lg\left(1 - e^{-2t/\delta}\right) \tag{6}$$

Where t is the thickness of shielding shell, f is the interfering signal frequency, μ_r is the relative magnetic conductivity, σ_r is the relative electrical conductivity, r is the distance between the field source and the shielding box. For formula (5), the constant values are shown in table 1.

Table 1 The value of formula (5)

Field type	C	n	m
Plane wave	168	1	0
Electric field	321.7	3	2
Magnetic field	14.6	-1	-2

For formula (6), when the shielding box is thicker or the field source frequency is higher, the loss absorbed by shielding box is relatively great. When A>10 dB, multiple reflection loss can be neglected. When the shielding box is thinner or the field source frequency is lower, absorbing losses is small. When A<10 dB, the effect of multiple reflections on SE must be taken into account.

When design shielding box, ventilation and heat dissipation problems often need to be considered, thus there are hole arrays in the shielding box. Through the aperture principle, transforming the larger vent hole into a series of smaller hole arrays with equal area can effectively increase SE. For the small figurate apertures, the electric dipole and magnetic dipole can be expressed as:

$$\begin{cases} \overrightarrow{P_{es}} = 0 \\ \overrightarrow{P_{ms}} = \dfrac{jwk^2 a_{ay} P_{e0}}{2\pi}\left[\dfrac{j}{kl} + \dfrac{1}{(kl)^2}\right] e^{-jkl}\overrightarrow{e_y} \end{cases} \tag{7}$$

Where $k = \omega\sqrt{\mu\varepsilon}$, μ is the medium permeability, ε is the dielectric constant, l is the distance from field source to the aperture, a_{ay} is the polarization on the Y axis.

With shield, the field for any point on the z axis is as follows:

$$\begin{cases} \overrightarrow{E_s} = -\dfrac{jw\mu_0 k^2 P_{ms}}{4\pi}\left[\dfrac{j}{kl} + \dfrac{1}{(kl)^2}\right] e^{-jkl}\overrightarrow{e_x} \\ \overrightarrow{H_s} = -\dfrac{jk^3 P_{ms}}{4\pi}\left[\dfrac{j}{kl} + \dfrac{1}{(kl)^2} - \dfrac{1}{(kz)^3}\right] e^{-jkl}\overrightarrow{e_y} \end{cases} \tag{8}$$

Without shield, the field for any point on the z axis is as follows:

$$\begin{cases} \overrightarrow{E_0} = -\dfrac{jw\mu_0 k^2 P_{e0}}{4\pi}\left[\dfrac{j}{kR} + \dfrac{1}{(kR)^2} - \dfrac{1}{(kR)^3}\right] e^{-jkR}\overrightarrow{e_x} \\ \overrightarrow{H_0} = -\dfrac{jk^3 P_{e0}}{4\pi}\left[\dfrac{j}{kR} + \dfrac{1}{(kR)^2}\right] e^{-jkR}\overrightarrow{e_y} \end{cases} \tag{9}$$

Where $R = l + z$,z is the distance from the point on the Z axis to the origin O.

Derived by the formula (9) it can be known that EFSE and MFSE at any point on the Z axis are as follows:

$$SE_E = 20\lg\frac{2\pi}{k^3 a_{my}}\left|\left[\frac{j}{kR} + \frac{1}{(kR)^2} - \frac{1}{(kR)^3}\right] \times \left[\frac{j}{kl} + \frac{1}{(kl)^2}\right]^{-1} \times \left[\frac{j}{kz} + \frac{1}{(kz)^2}\right]^{-1}\right| \tag{10}$$

$$SE_H = 20\lg \frac{2\pi}{k^3 a_{my}} \left| \left[\frac{j}{kR} + \frac{1}{(kR)^2} \right] \times \left[\frac{j}{kl} + \frac{1}{(kl)^2} \right]^{-1} \times \left[\frac{j}{kz} + \frac{1}{(kz)^2} - \frac{1}{(kz)^3} \right]^{-1} \right| \tag{11}$$

Based on reference[4], formulas (10) and (11) can be simplified as follows .

For the round hole on the rectangular board, shown in Fig.1, formula (12) and (13) are given the EFSE and MFSE.

$$SE_E = 20\lg\left(\frac{c^2}{d^3} \sqrt{l_1 \times l_2} \right) + \frac{41.8t}{d} + 2.68 \tag{12}$$

$$SE_H = 20\lg\left(\frac{c^2}{d^3} \sqrt{l_1 \times l_2} \right) + \frac{32t}{d} + 3.83 \tag{13}$$

Where t is the thickness of shielding board, c is the round hole interval, d is the round hole diameter and l_1, l_2 are the length and width of shielding board, respectively.

For the square hole on the rectangular board, shown in Fig.2, formula (14) and (15) are given the EFSE and MFSE.

$$SE_E = 20\lg\left(\frac{c^2}{b^2} \sqrt{l_1 \times l_2} \right) + \frac{38.6t}{b} \tag{14}$$

$$SE_H = 20\lg\left(\frac{c^2}{b^2} \sqrt{l_1 \times l_2} \right) + \frac{27.3t}{d} \tag{15}$$

Where t is the thickness of shielding board, c is the square whole interval, b is the side length of square hole and l_1, l_2 is the length and width of shielding board, respectively.

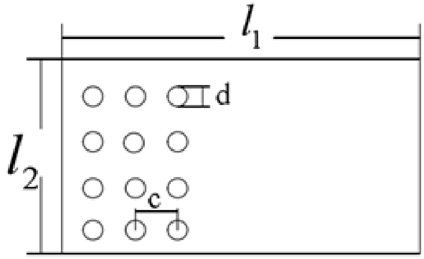

Fig.1 Round hole array on the rectangular board

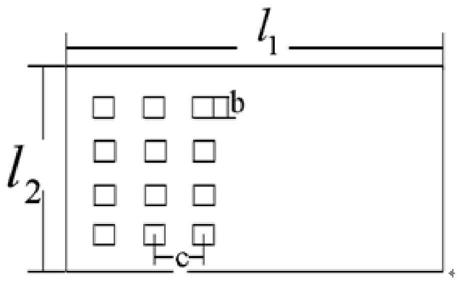

Fig.2 Square hole array on the rectangular board

3. The SE simulation for rectangular board

Based on EFSE and MFSE formulas, Implementing modeling and simulation through Matlab for round holes on rectangular shielding board, and its results is shown in Fig. 3 and Fig.4. The modeling parameters are set as: $l_1 = 1200mm$, $l_2 = 600mm$, $t = 0.5mm$, c is a variable from 1mm to 50mm and its variable delta is 1mm, d are equal to 1mm,5mm,10mm,15mm, respectively. By the analysis of Fig.3 and Fig.4, when the round hole intervals increases, the SE is enhanced, and it changes from craggedness to flatness in 1-10mm; When the aperture increases, the SE decreases sharply, and it also becomes flat with the increase of aperture.

Based on EFSE and MFSE formulas, Implementing modeling and simulation through Matlab for square holes on rectangular shielding board, and its results is shown in Fig. 5 and Fig.6. The modeling parameters are set as: $l_1 = 1200mm$, $l_2 = 600mm$, $t = 0.5mm$, c is a variable from 1mm to 50mm and the variable delta is 1mm, b are equal to 1mm, 5mm, 10mm, 15mm, respectively. By the analysis of Fig.3 and Fig.4, when the square hole intervals increases, the SE is enhanced, and it changes from craggedness to flatness in 1-10mm; When the side length of square increases, the SE decreases sharply, and it also becomes flat with the increase of side length.

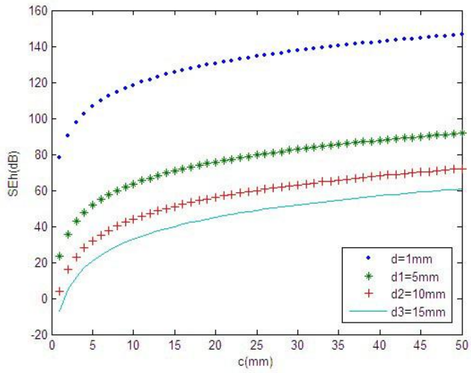

Fig.3 The MFSE for round hole array on the rectangular board

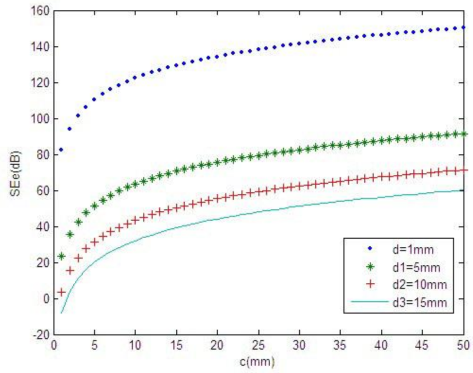

Fig.4 The EFSE for round hole array on the rectangular board

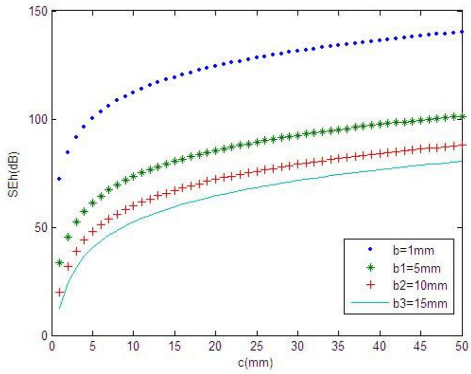

Fig.5 The MFSE for square hole array on the rectangular board

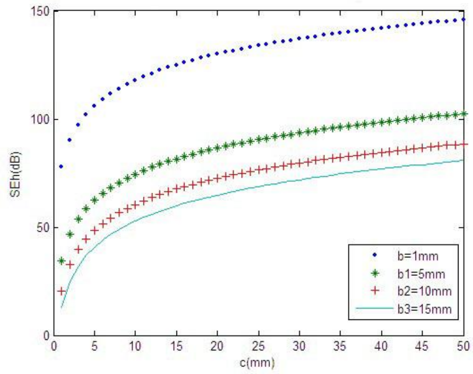

Fig.6 The EFSE for square hole array on the rectangular board

When the aperture d=1mm, side length b=1mm and c=50mm, by comparing Fig.3 and Fig.5, it can be found that the MFSE for round hole and square holes are 146.31dB and 140.1dB, respectively, and their difference is 6.2dB; by comparing Fig.4 and Fig.6, the EFSE for round hole and square holes are 150.1dB and 145.8dB, respectively, and their difference is 4.3dB. Therefore, it can be concluded that round hole should be chosen if it is necessary to open holes for rectangular shielding block.

4. Conclusion

This paper firstly gives the SE evaluation index for shielding box with holes, and then through the model equivalence and deduction, the EFSE and MFSE formulas are given, finally simulated contrast for EFSE and MFSE under different holes are done. It thus draws a conclusion that under the same condition the SE for round hole is better than the rectangular hole. All these have guiding significance for the design of the shielding box in practice.

References

[1] SHI Dan. Shielding effectiveness analysis of enclosure with aperture irradiated by oblique incident plane wave [J]. Chinese Journal of Radio Science, 2011, 26(4): 678-682

[2] WU Gang, ZHANG Xingang, LIU Bo. Prediction for shielding effectiveness of rectangular metallic enclosure with aperture [J]. High Power Laser and Particle Beams, 2011, 23(3): 743-748

[3] Jong J S, Dong G K, Jong H K, et al. Circuital modeling and measurement of shielding effectiveness against oblique incident plane wave on apertures in multiple sides of rectangular enclosure[J]. IEEE Transactions on Electromagnetic Compatibility, 2010, 52(3): 566-577.

[4] Wu Qun, Fu Jiahui, Meng Fanyi. Electromagnetic compatibility principle and technology [M]. Harbin: Harbin industrial university press, 2009.