Improvement of Shielding for Electromagnetic Compatibility

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Received February 19, 2016; Accepted February 25, 2016; Published February 29, 2016

** Extended from a Conference: Preliminary results of this paper were presented at the ICEIC 2016. This present paper has been accepted by the editorial board through the regular reviewing process that confirms the original contribution.*

***Abstract*:** This paper presents methods to improve the effectiveness of electromagnetic shielding. The slit appears in an enclosure's surface to ventilate. Slits may also appear due to power supply lines or to serve as a communication link between electronic circuits inside and outside the box. We simulated electromagnetic radiation in different conditions in order to propose a method to improve the effectiveness of electromagnetic shielding to ensure electromagnetic compatibility using CST software (Computer Simulation Technology).

***Keywords*:** Electromagnetic shielding; Effectiveness of electromagnetic shielding; slit; Electromagnetic compatibility; CST.

1. Introduction

Nowadays, electrical appliances, electronics devices must have better quality while decreasing significantly in size. Therefore, the devices' components must work in higher frequency band in the condition of limiting space and high possibility of interference. In order for those devices to work properly, the manufacturers must ensure the electromagnetic compatibility (EMC) in aligning with the standards. Hence, it is necessary to find methods to reduce the electromagnetic radiation, leading to the interference of a device on others [1].

One method to reduce the electromagnetic radiation effect on other devices or to self protect the device from the effect of other devices in the surrounding environment is to use electromagnetic shielding. In addition, there are always slits on these shields for ventilating, communicating of power supplying… purposes. Without careful calculation, these slits may reduce the effectiveness of the shield. This paper presents methods to improve the effectiveness of shielding, in order to ensure EMC [1, 8].

2. Shielding box dimensions

A shielding box designed to ensure EMC is a rectangular box made of aluminum. Five faces of the box have depths of 0.635cm while the remaining one has a depth of 0.05cm. The slits created on the aluminum face are 0.05cm in depth. The inner dimension of the box is 22 x 14 x 30cm (Fig. 1).

The power supply is via coaxial cable of impedance 50Ω and the radius of the conductive core is0.085inch. The core of the cable is connected to the other end of the box by a copper wire of diameter 0.16cm to ensure the evenly distribution of electromagnetic radiation inside the box. The end of the wire is connected to a 47Ω resistor. This resistor, equivalent to the energy losses due to heat, is presented so that the simulation results become more reliable.

Simulation frequency range is from 700MHz to 1700MHz. The slits' dimensions are 4 x 3cm, 9 x 0.2cm [3].

Fig. 1 presents the dimensions of a shielding box. If the box is closed, electromagnetic radiation from the box to a

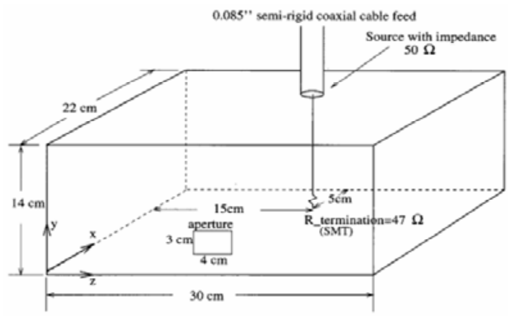


Fig. 1. Shielding enclosure dimension.

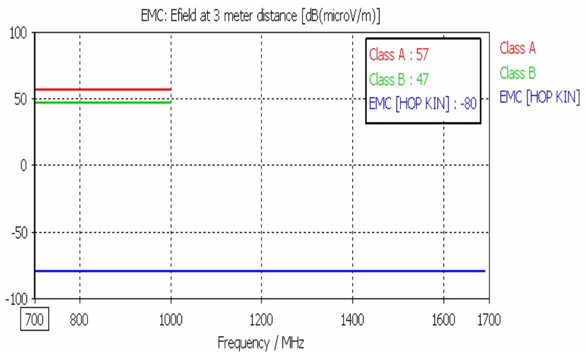
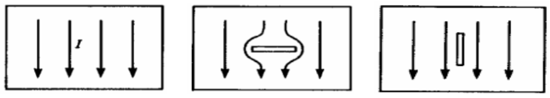


Fig. 2. Electromagnetic radiation of a closed shielding box at distance 3m from the box.



(a) (b) (c)

Fig. 3. Slits in a shielding box.

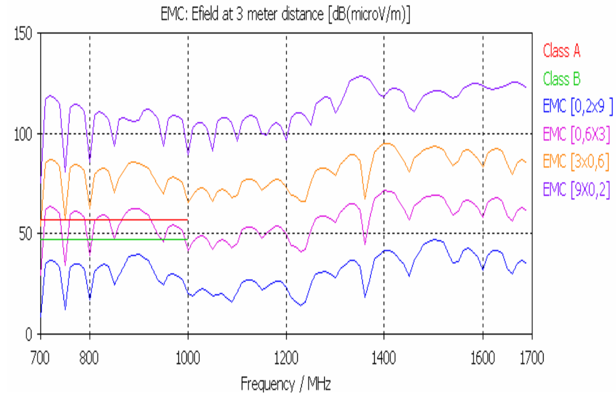


Fig. 4. Electromagnetic radiation at a distance of 3 meters for the enclosure's slit dimensions of 9x0.2; 3x0.6; 0.6x3; 0.2cmx9cm.

distance 3m surrounding environment is shown in Fig. 2.

Fig. 2 shows that the electromagnetic radiation at 3m from the box is -80dB [μV/m], which is far away from the standard A radiation (threshold 57dB [μV/m]) or standard B radiation (threshold 47dB [μV/m]) in the interested frequency range. Hence, in we can use a completely closed shielding box, electromagnetic isolation is very good, the effect on other devices can be neglected, which ensures electromagnetic compatibility.

However, slits must exist on the shielding box for ventilating, communication or power supply…. Hence, the study of the slits is required.

3. Enclosure with compatible aperture

Considering the metal shielding in Fig. 3(a), there are some induced currents appeared on the enclosure. The connection of these electrical currents causes the field distribution to oppose or reduce the radiation intensity of an incident field.

As long as the incident field encounters the enclosure, it induces the electrical currents flowing on the surface of the enclosure as shown in Fig. 3(a). In fact, this incident field acts as a reflecting field, which tends to resist the radiation of the next incident field. An existence of slits on the enclosure's surface causes an obstruction and a discontinuity of the induced currents illustrated in Fig. 3(b), resulting in a significant decrease in the shielding effectiveness. Therefore, in order to mitigate this problem, the slits are supposed to be laid out in parallel with the orientation of the induced current (Fig. 3(c)).

By doing so, the flow of the induced currents could be facilitated, leading to less impact of the slits on the effectiveness of the shielding [6, 7].

A shielding box containing slits with different dimensions 9 x 0.2, 3 x 0.6, 0.6 x 3, 0.2cm x 9cm (same area of 1.8cm^2) is exploited to verify the above analysis. The simulation results are indicated in Fig. 4.

It can be seen from Fig. 4, the electromagnetic radiation changes in accordance to the slit's dimensions. In particular, the larger the horizontal widths of the slits, the greater the electric field strength. In case that the enclosure requiring the slit area of 1.8cm^2, the slit dimension is supposed to be 0.2cm x 9cm. With this dimension, the slit is at least resistance to the induced current and the Efield (EMC[0.2 x 9]) at 3 meter distance is less than 47dB [μV/m], complying the class B and ensuring EMC.

4. Enclosure with multiple smaller slits

When the shielding enclosure has a big slit, it is possible to divide the big slit into multiple appropriate smaller slits in order to significantly improve the shielding effectiveness due to better induced-current flows [4].

The lengths of the multiple smaller slits have to be carefully chosen according to the frequency range of the electromagnetic radiation. Additionally, the chosen lengths are commonly much shorter than half wavelength (λ/2).

Comparing to the previous results, the shielding effectiveness of a box with 12cm^2 slit, divided into 15 small slits was improved. However, the electromagnetic radiation on the surrounding environment is still significant. Therefore, we continue to divide the 12cm^2 slit

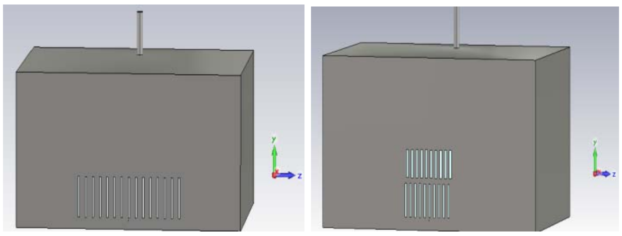


Fig. 5. Shielding box with 15 (left) and 20 (right) small slits, the total area of the slit is 12cm^2.

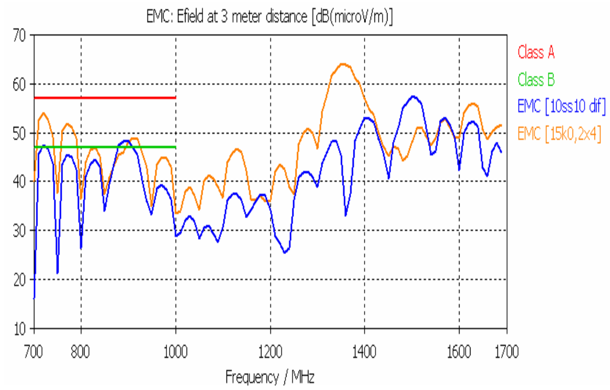


Fig. 6. Electromagnetic radiation at 3m away from the box having 15 or 20 small slits.

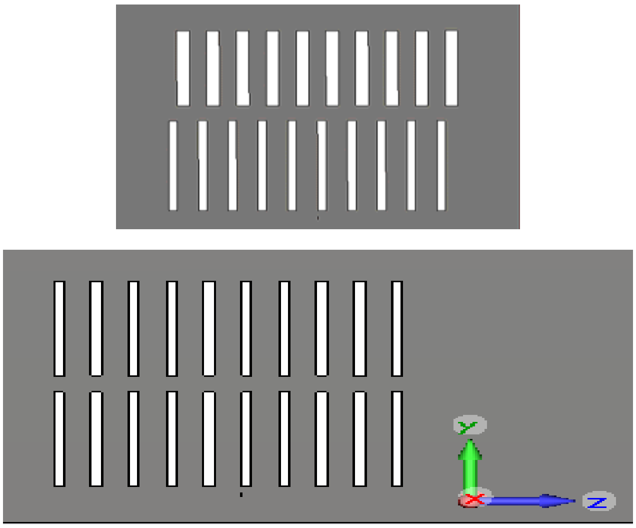


Fig. 7. Shielding box with 12cm2 slit, devided into 20 small slits of different sizes and distributions.

into 20 smaller slits as shown in Fig. 5 (right). The lower row has 10 small slits of dimension 0.2 x 3cm. The upper row has 10 small slits of dimension 0.3 x 2cm. The simulation result of this shielding box is presented in Fig. 6.

As can be seen from the simulation, when the 12cm^2 slit was divided into 20 smaller slits (Fig. 5), the electric field strength at 3m distance from the box is smaller than the result in case of divided into 15 slits, and more over, smaller than 57dB [μV/m]. This ensures the electromagnetic compatibility. The isolation effectiveness of the box was improved since the slits were shorter than previous

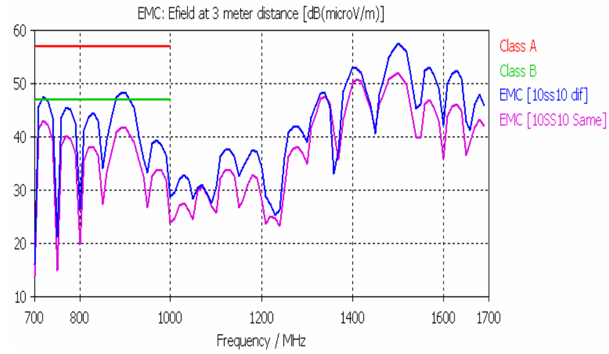


Fig. 8. Electromagnetic radiation at 3m distance from the box with 20 small slits (total area 12cm^2), different in sizes and distributions.

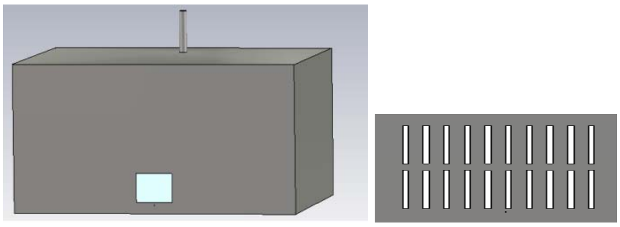


Fig. 9. A shielding box containing a slit with dimension of 4cmx3cm, which is divided into 20 smaller slits with dimension of 0.2cmx3cm.

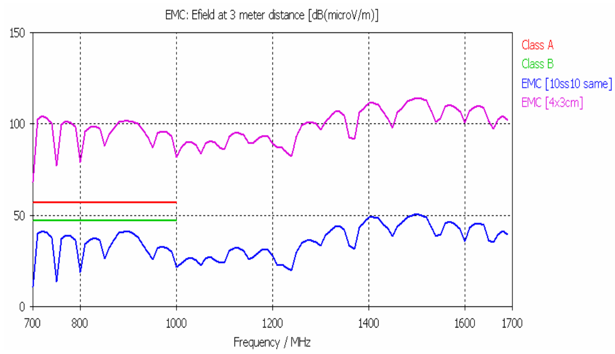


Fig. 10. Electromagnetic radiation at a distance of 3 meters for enclosures with big slit of 4cmx3cm and with 20 smaller slits 0.2cmx3cm.

case so the electromagnetic radiation to the surrounding environment was weaken. However, if those slits had the same size of 0.2 x 3cm and were distributed in parallel (Fig. 7), the isolation was even better. The simulation result was presented in Fig. 8.

Fig. 8 shows that if the 20 small slits of the box had the same size of 0.2 x 3cm, distributed in parallel, the isolation effectiveness was the best as comparing to other cases.

To verify the analysis, a shielding box containing a slit with dimension of 4cx3cm (12cm^2), which is divided into 20 smaller slits with dimension of 0.2cm x 3cm placed in parallel and in line as shown in Fig. 9, is used. The simulation results illustrated in Fig. 10 indicate that electric field strength of the box with 20 smaller slits at 3 meter distance is weaker than that of the box with the big slit of 4cmx3cm and less than 50dB [µV/m]. The shielding effectiveness is hence substantially enhanced (EMC [10ss10same]) [6].

5. Enclosure with waveguide slit

When the enclosure has the slit and requires the high shielding effectiveness, a slit of waveguide is recommended [1].

Generally, the slits on the shielding enclosure might be able to diminish the electromagnetic radiation if they have structures like waveguides. In a waveguide of a rectangular section, TE_{10} is widely used, while a waveguide of a circular cylindrical section commonly with TE_{11}. For the rectangular waveguide, the cut-off frequency is calculated as follows [2]:

$$f_{c,mn} = \frac{v_0}{2l}\sqrt{m^2+n^2} \quad (1)$$

With TE_{10} mode in the rectangular waveguide [2] hence:

$$f_{c,10} = \frac{v_0}{2l} = \frac{1.5x10^8}{l}, \quad (2)$$

where f_c is a cut-off frequency, l is a length of the rectangular waveguide.

For the circular cylindrical waveguide [5]:

$$f_c = \frac{6.9x^{\;9}}{d}, \quad (3)$$

where d is a diameter of the waveguide.

The loss caused by the rectangular waveguide can be determined by the following formular [2]:

$$\alpha_{mn} = \omega\sqrt{\mu_0\varepsilon_0}\sqrt{\left(\frac{f_{c,mn}}{f}\right)^2 - 1} \quad (4)$$

Assume that the incident wave frequency f is much smaller than the cut-off frequency f_c [2]:

$$\alpha_{mn} \cong \frac{2\pi f}{v_0}\frac{f_{c,mn}}{f} \quad \left(f \ll f_{c,mn}\right)$$
$$= \frac{2\pi f_{c,mn}}{v_0} \quad (5)$$

With TE_{10} mode hence [2]:

$$\alpha_{10} = \frac{\pi}{l} \quad (6)$$

The propagation loss of electromagnetic wave via a waveguide of length z (cross-section length) is proportional to $e^{-\alpha z}$. Therefore, the shielding effectiveness is

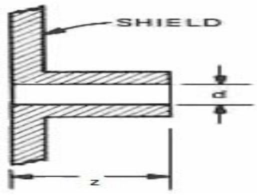


Fig. 11. Circular cylindrical waveguide with diameter of d and length of z.

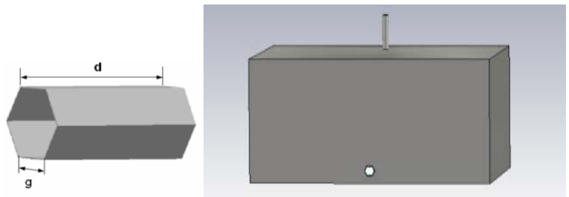


Fig. 12. Shielding box with hexagonal waveguide slit.

related to a rectangular waveguide [2]:

$$SE_{dB} = 20log_{10}e^{\alpha_{10}z} = \alpha_{10}z20log_{10}e$$
$$= 27.3\frac{z}{l} \quad (7)$$

Similarly, for the circuilar cylindrical waveguide [5]:

$$SE_{dB} = 32\frac{z}{d} \quad (8)$$

For a hexagonal waveguide, the shielding effectiveness SE can be equated in the mathematical terms as [9]:

$$SE_{dB} = 17.5\frac{d}{g}\sqrt{1-\left(\frac{gf}{96659}\right)^2} - 20\log_{10}\frac{2kg}{\pi}\cos\phi - 20\log_{10}\frac{2Rg}{f} \qquad \frac{f_c}{f} > 5R \quad (9)$$

g: Edge of the hexagonal waveguide (mm)
d: Length of the waveguide (mm)
f: Operating frequency (MHz)
f_c: Cut-off frequency
R: Proportional to g (with g = 3,18mm then R = 1, with g = 1mm then R=3.18).

The above results demonstrate that the electromagnetic wave quickly attenuates as long as passing through the waveguides and is proportional to the waveguide length. These waveguides are not only used for ventilation purpose but also restricting the propagation of the electromagnetic radiation.

Figs 13 and 14 show that the effectiveness of the box with hexagonal waveguide slit was better than boxes with slits. This effectiveness changes with the length and the width of the waveguide.

Particularly, in this section, a simulation of a shielding box containing a hexagonal slit with g = 6.36 mm, a waveguide length of 6.35, 9.54 and 25.44mm respectively is carried out. The simulation results are indicated in Fig. 14.

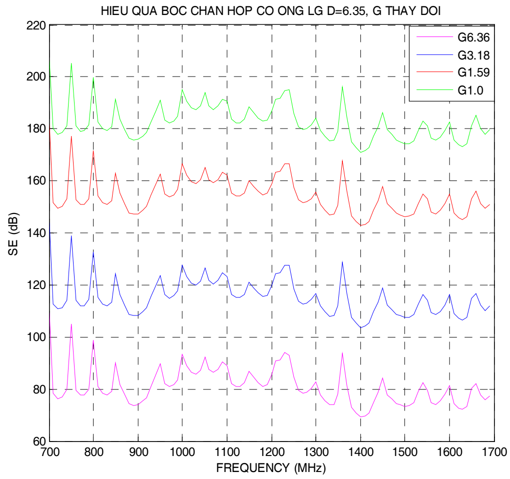


Fig. 13. Shielding effectiveness of enclosure with hexagonal waveguide slit of widthlength d = 6.35mm and variable width.

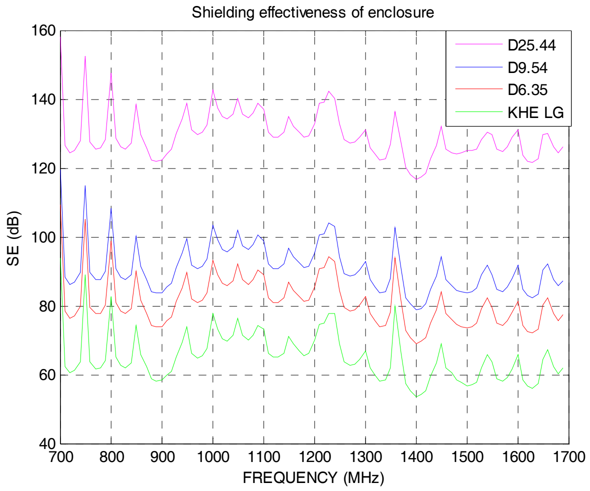


Fig. 14. Shielding effectiveness of enclosure with hexagonal waveguide slit of width g = 6.36mm and variable length.

As can be seen from Fig. 14, the shielding effectiveness of the enclosure containing waveguide slit is higher than that of enclosure containing slit LG. Changes in the length and width of the waveguide result in changes in the shielding effectiveness. A waveguide with a length to wide ratio of 4:1 or higher has the shielding performance of above 110dB, as illustrated on the Fig. with D = 25.44mm (D25.44).

6. Enclosure with beehive-like slit

When the enclosure requires large slits for ventilation system, it is recommended to exploit beehive-like waveguides.

In wave-oriented theory, the loss caused by the beehive-like waveguide can be determined by a following formular [9]:

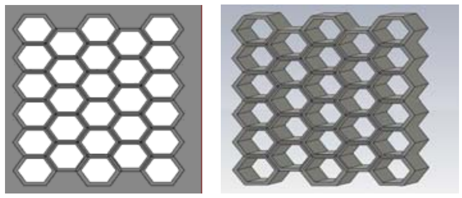


Fig. 15. Shielding enclosure with beehive-like slit.

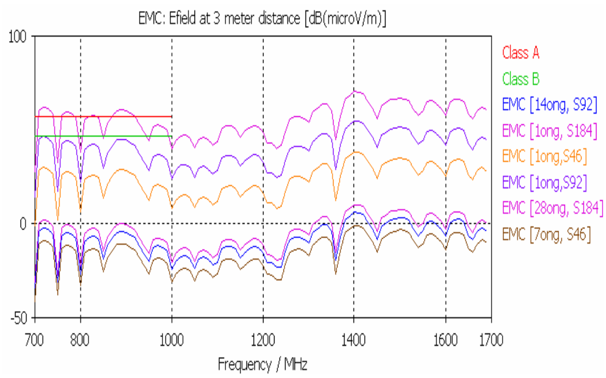


Fig. 16. Electromagnetic radiation at a distance of 3 meters for enclosure with beehive-like slit of different numbers of waveguides.

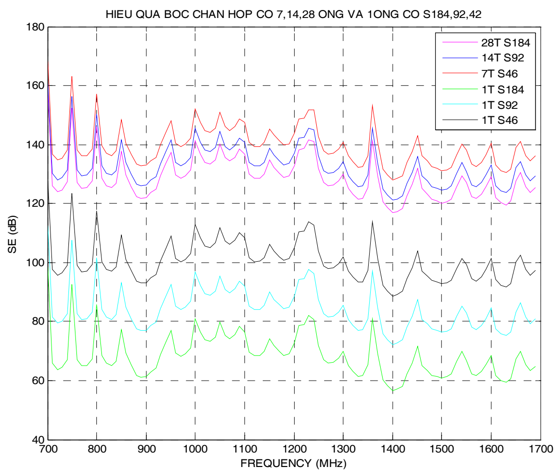


Fig. 17. Shielding effectiveness of enclosure with beehive-like slit of different numbers of waveguides.

$$\alpha = \omega(\mu\varepsilon)^{\frac{1}{2}}\left[\left(\frac{f_c}{f}\right)^2 - 1\right]^{\frac{1}{2}} \qquad (10)$$

f_c is a cut-off frequency of the waveguide.

In this section, we simulated the shielding enclosure with beehive-like slit (g = 1.59mm) having a numbers of waveguides varied from 7, 14 to 28 corresponding to total areas of 46, 92 and 184mm^2 respectively, in addition to a waveguide with cross-section area corresponding to the waveguide length in any cases with similar values, 6.35mm.

As can be seen from Fig.16, changes in waveguide widths result in changes in the cross-section area, going up

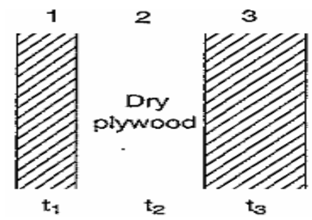


Fig. 18. Double shield.

from 46 to 92, and can reach to 184mm^2, leading to considerable rise in electromagnetic radiation. Thus, the shielding effectiveness of the enclosure is remarkably decline. On the other hand, for the enclosure with the beehive-like slit, while a number of waveguides grow from 7 to 14, and even reach to 28, and the slit area increases from 46 to 92, and even reach to 184mm^2, measured E field at 3 meter distance is less than 0dB [μV/m], and approximately 0dB[μV/m] in the chosen frequency range. Besides, the shielding effectiveness of the enclosure is very high and more or less the same when the slit area is doubled or quadrupled from 46 to 92 and 184mm^2.

Shielding box with beehive-like slit has rather high isolation effectiveness (more than 110dB). If the total area of the slit was doubled, the isolation effectiveness declined negligible. On the other hand, if there was a hexagonal waveguide in the box, the effectiveness significantly smaller. If the total slit area was doubled, the isolation effectiveness rapidly declined (more than 50dB) since the width of the waveguide was increased.

7. Enclosure with double shield

For a big enclosure, two independent metal shields separated by a dry plywood are commonly used.

Some components of the shield [8]:

$$\alpha_R = 20log_{10}\frac{\left|1+\frac{Z_{m1}}{\eta 0}\right|}{2} + 20log_{10}\frac{\left|1+\frac{\eta_{\eta 2}}{Z_{m1}}\right|}{2} + 20log_{10}\frac{\left|1+\frac{Z_{m3}}{\eta_{\eta 2}}\right|}{2} + 20log_{10}\frac{\left|1+\frac{\eta_{\eta 0}}{Z_{m3}}\right|}{2} \quad (11)$$

$$\alpha_A = 8{,}686(\alpha_1 t_1 - \alpha_2 t_2 + \alpha_3 t_3) = 8{,}686(\alpha_1 t_1 + \alpha_3 t_3) \qquad \alpha_2 \rightarrow 0 \quad (12)$$

$$\alpha_{IR} = 20log_{10}\left|\left(1-v_1 e^{-2K_1 t_1}\right)\right| + 20log_{10}\left|\left(1-v_2 e^{-j2\beta_2 t_2}\right)\right| + 20log_{10}\left|\left(1-v_3 e^{-2K_3 t_3}\right)\right| \quad (13)$$

In the special case, the two metal shields are made of same material, with a similar thickness, assuming that the loss caused by wood is negligible, absorption loss and reflection loss are all caused by a single shield. At a resonant shielded cavity, the shielding effectiveness of the double shield can reach to 6dB higher than that of using two separate shields with a same thickness. Simulation results of the enclosure using double shield of 0.2cmx9cm,

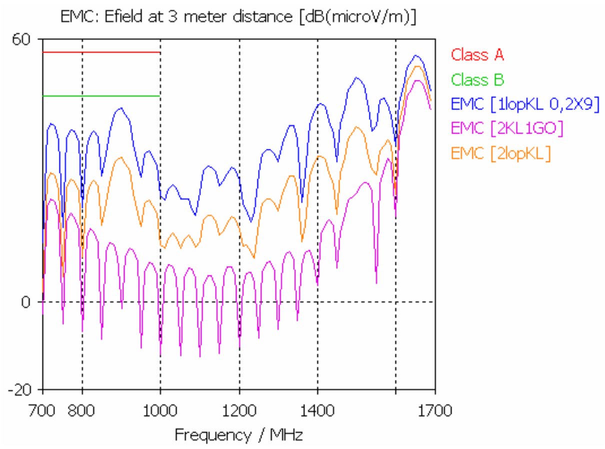


Fig. 19. Electromagnetic radiation at a distance of 3 meters for enclosure with double shield.

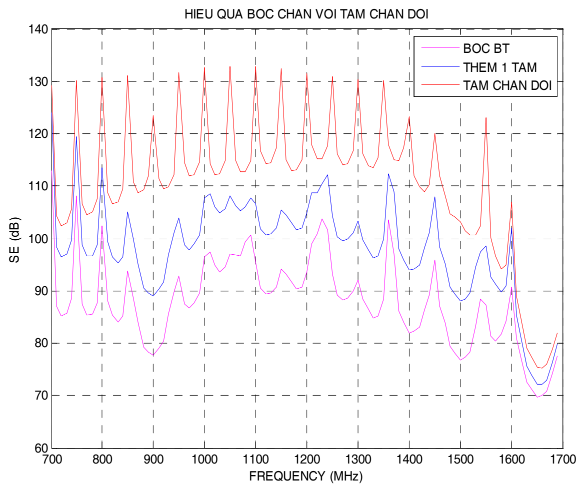


Fig. 20. Isolation effectiveness when using the double shield enclosure.

with inside and outside walls made of same material, separated by a 5mm plywood are shown in Fig. 19.

The simulation results (Fig. 20) demonstrate that when the enclosure having the metal shield, measured E field at 3 meter distance remarkably decreases, leading to higher shielding effectiveness. However, when the enclosure using the double shield with the plywood separating the two metal shields (EMC[2KL1G]), the shielding effectiveness of the enclosure is improved, compared to the case using two distinct shields with a same total metal thickness.

8. Conclusion

In order to ensure the standard of electromagnetic compatibility, the shielding effectiveness is required to be 100dB or higher. To achieve the standard, designing a enclosure is the simplest way. However, the enclosure is commonly designed with slits with purposes of ventilation, communication and power supply. Therefore, calculating and designing enclosures with different styles of slits such as hexagonal waveguides, beehive-like waveguide or double shield are highly recommended for high shielding effectiveness.

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