Comparison and Improvement of Shielding Effectiveness Calculation Methods for a Metal Enclosure with Apertures at broad Frequencies

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Abstract

The comparison of transmission line model(TLM), intermediate level circuit model(ILCM) and modal based method of moments(M-MOM) to predict the SE of enclosures has been studied in this paper. Results show that the three methods can predict reliable SE at lower frequency, while M-MOM can provide more precise SE than other two. Two modifications are considered for TLM and M-MOM, respectively, and improvement in the results has been observed.

1. Introduction

With the rapid developments in high-speed electronics and the wide applications of wireless technologies, the electromagnetic environment has become more and more complex, resulting in the interference to sensitive electronic equipments. Shielding enclosures are frequently used to protect the electronic system from electromagnetic radiation. However, the integrity of shielding enclosures is often compromised by slots and apertures for ventilation, input/output cable penetration and connector ports and so on. Consequently, shielding effectiveness (SE) prediction of enclosures with apertures has increasingly attracted researchers' interests and become an important task in electromagnetic compatibility (EMC) field.

Many methods, both analytical and numerical, have been proposed to predict SE for enclosures with slots or apertures. Transmission line model (TLM) [1], intermediate level circuit model (ILCM) [2] and modal based method of moments (M-MOM) [3] are three efficient methods to predict SE of enclosures and have been studied or improved in many researches. Most researches, however, concern about a frequency band up to 1.3GHz [1, 3]. If they work well at higher frequencies is still a question. Moreover, any comparison of the three methods has not been studied.

In this paper, comparison of these methods are investigated firstly by changing the size, type, locations of the apertures for both normal and oblique incidence at a wide frequency range up to 3GHz. Then, an improvement of coupling coefficient C_m calculation is proposed in order to improve the accuracy of SE prediction using TLM at higher frequencies. At the meantime, the frequency offset of the SE calculated by M-MOM at high frequencies are modified. Results show that those improvements are effective.

2. Comparisons

A plane wave polarized in y direction is incident upon a rectangular enclosure with an aperture in the front panel, as shown in fig. 1. The dimension of the enclosure is 30 × 20 × 40 cm^3. The three methods are employed to calculate the SE of the center point inside the enclosure and results are compared to those simulated by CST. Table 1 lists five kinds of apertures used in simulation.

Table 1 Aperture size used in calculation model (Unit: cm)

Case	l	w	Apertures Type	Case	l	w	Apertures Type
1	8	2	Normal	4	8	2	Off-center
2	16	2	Long slot	5	8	2	oblique incidence
3	8	8	Square				

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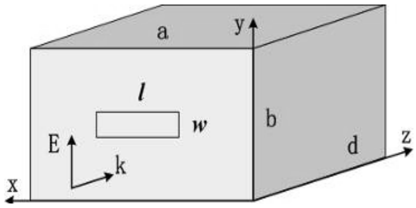

Fig.1 Conditions of an incident plane wave and the cavity

Results for the cases in Table 1 are shown in fig. 2 to fig. 6. Generally, all of the three methods can precisely predict the resonant frequencies and their results have good agreements with those simulated by CST at the frequencies lower than about 1.5GHz. Difference of the results between these methods and CST mainly due to the different approximations used in these methods. TLM does not consider the electromagnetic wave reradiation outside through the aperture, and both ILCM and M-MOM treat the front panel of the enclosure as an infinite plane. Especially, due to increased electrically size of the aperture and the enclosure, the approximations in these methods are degraded and further reduce the accuracy of these algorithms. Moreover, the increased number of modes makes the field change intensely. As a result, SE at higher frequencies has a worse accuracy than at lower frequency. Note, there is an aperture resonant effect at the frequency $f = c/2l$, which is 1.875GHz corresponding to l=8cm. This occurs only when the depth of apertures is taken into consideration.

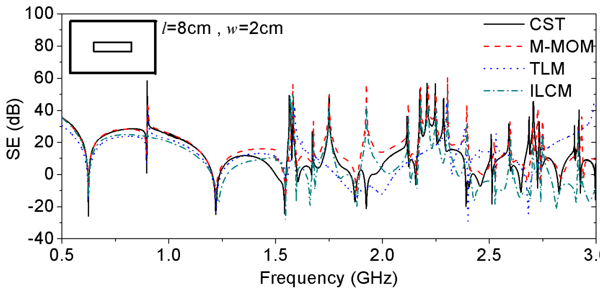

Fig. 2 Comparisons of the three methods in case 1

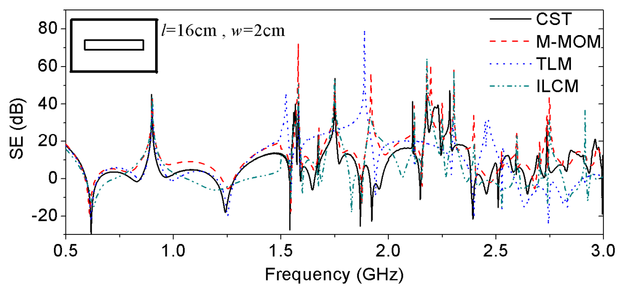

Fig. 3 Comparisons of the three methods in case 2

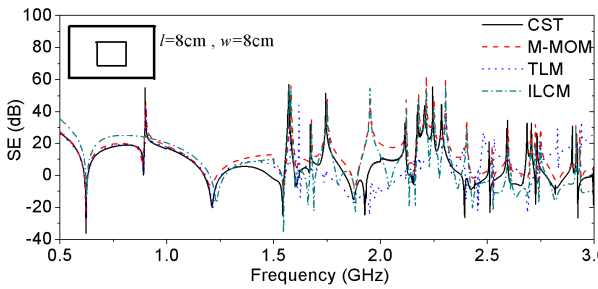

Fig. 4 Comparisons of the three methods in case 3

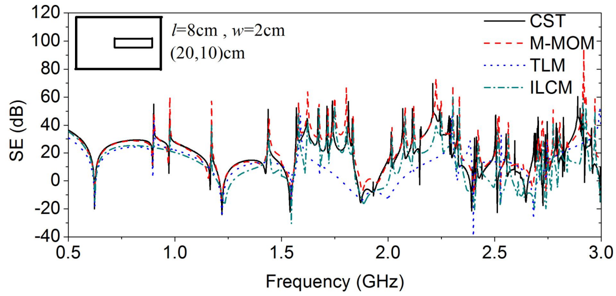

Fig.5 Comparisons of the three methods in case 4

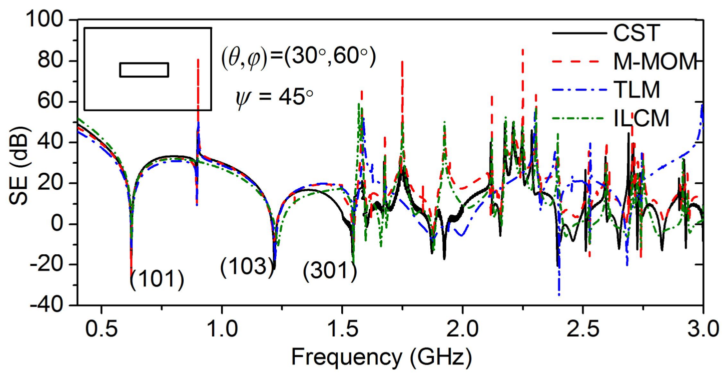

Fig. 6 Comparisons of the three methods with oblique incidence

From the results in Fig.2 to Fig. 6, M-MOM and ILCM are much better than TLM at higher frequency and for electrically large apertures. However, they call for the size of the apertures far smaller than the front panel of the enclosure.

3. Improvement of TLM and M-MOM

The previous calculation results show that TLM cannot predict resonant frequencies at higher frequency precisely, because in traditional TLM, the difference between modes inside the cavity and in aperture has never been considered. Here in order to consider the difference, the coupling factor used in TLM is modified as the following equation (1), where (p, q) is used instead of (m, n) to represent the modes in the aperture at high frequencies. Fig. 7 shows the coordinate system used in the equation.

$$C_m = \frac{1}{XY}\int_{x_0}^{x_0+l}\int_{y_0}^{y_0+w}\left(\sin\left(\frac{m\pi x}{a}\right)\cos\left(\frac{n\pi y}{b}\right)\cdot\sin\left(\frac{p\pi\left(x-x_0\right)}{l}\right)\cos\left(\frac{q\pi\left(y-y_0\right)}{w}\right)dxdy\right) \tag{1}$$

Fig.8 shows the results calculated by the improved TLM. Compared to the traditional TLM, the improved one able to predict more precise results at higher frequency.

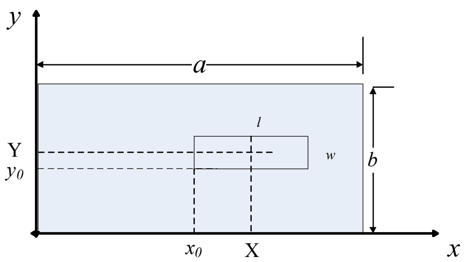

Fig. 7 coordinate system

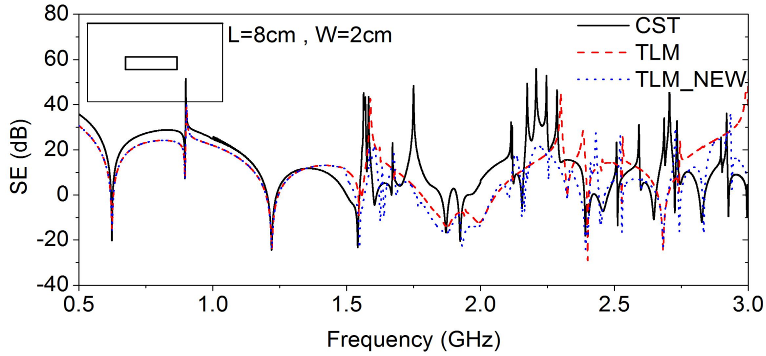

Fig. 8 Comparisons between TLM and improved TLM

Although M-MOM has the best accuracy among the three methods, it can be seen in Fig.2 to Fig.6 that the resonant frequency has an offset in some extent at higher frequency band. Apertures contained by a cavity equals to a deformation in the cavity wall, which will affect the resonant frequencies in the case. However, this is not considered in M-MOM method. The perturbation techniques are applied to eliminate the offset. The change of resonant frequency is given by:

$$\omega-\omega_0 \simeq \omega_0 \frac{\int_{\Delta V}\left(\mu\left|\vec{H}_0\right|^2-\varepsilon\left|\vec{E}_0\right|^2\right)dV}{\int_{V_0}\left(\mu\left|\vec{H}_0\right|^2+\varepsilon\left|\vec{E}_0\right|^2\right)dV} \tag{2}$$

where ΔV and ω_0 are the volume change caused by the aperture and resonant frequency, respectively. Fig. 9 (a) and (b) show the modified results when the frequency offset is considered. The maximum frequency offset fixed is 5MHz and 20MHz in Fig. 9 (a) and (b) respectively. The modified results show a better agreement to those simulated by CST.

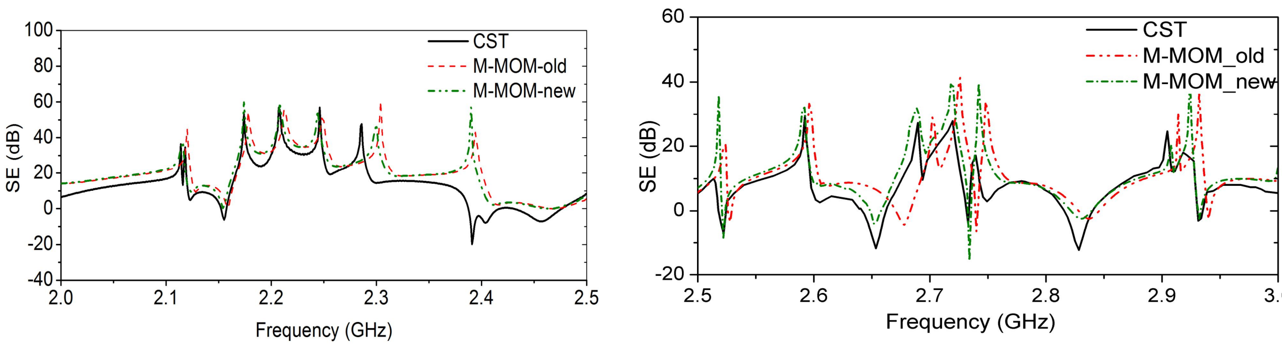

Fig. 9 SE calculated by the improved M-MOM: (a) 2-2.5GHz and (b) 2.5-3GHz.

4. Conclusion

The comparisons of TLM, ILCM and M-MOM to predict the SE of enclosures has been studied in this paper. Results show that the three methods can predict reliable SE at lower frequency, while M-MOM can provide more precise SE than other two. Two modifications are considered for TLM and M-MOM, respectively, and improvement in the results has been observed.

5. Acknowledgments

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6. References

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