A fast prediction for shielding effectiveness of double enclosures

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A Fast Prediction for Shielding Effectiveness of Double Enclosures *

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***Abstract*—A fast algorithm based on circuital modeling is proposed to predict shielding effectiveness (SE) of double enclosures with apertures on the common wall. The shielding effectiveness of the inner cavity can be predicted by using the voltage at any position inside the outer cavity to derive the equivalent voltage source at the apertures on the common wall. The results calculated by the proposed method are in agreement with the measured ones.**

Keywords—double enclosures; shielding effectiveness; circuital modeling

I. INTRODUCTION

Electromagnetic shielding is frequently used to effectively reduce emissions or improve the immunity of electronic equipment. Shielding effectiveness (SE), a crucial parameter to evaluate the shielding ability of an enclosure, can be estimated using two main categories of methods: full wave analysis [1-3] and fast prediction algorithms [4-6]. Among those approaches, the circuital modeling proposed by Robinson etc. has been developed quickly due to its ease of use and less time consuming [7-11]. As a result, it can be used to predict SE for many cases, including oblique incidence, off-centered apertures, multiple apertures on different walls, and so on.

Those approaches are mainly applied to predict SE of a single enclosure. However, some systems employ multi-enclosures to separate different electronic module, and apertures are often introduced on the common wall for the cable connection or ventilation. Thus, how to predict the SE of such a system is instructive for the shielding enclosure design.

A fast prediction algorithm based on the circuital model is presented here for double enclosures. The algorithm is described in detail in Section II, and is verified by experimental measurement in Section III.

II. ALGORITHM BASED ON CIRCUITAL MODEL

A rectangular double-enclosure with slot on common wall is shown in Fig.1. The dimension size of the whole enclosure is $a \times b \times (d_1+d_2)$. A slot with dimension of $l \times w$ is on the front wall, and another slot of $l_1 \times w_1$ is on the common wall, as shown in Fig.1.

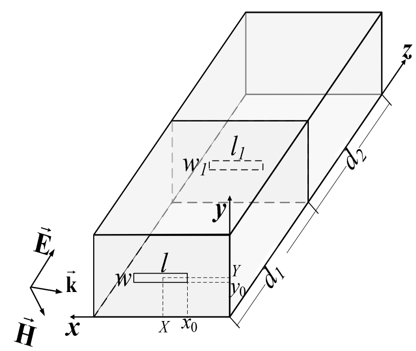


Fig. 1 Model of a double-enclosure

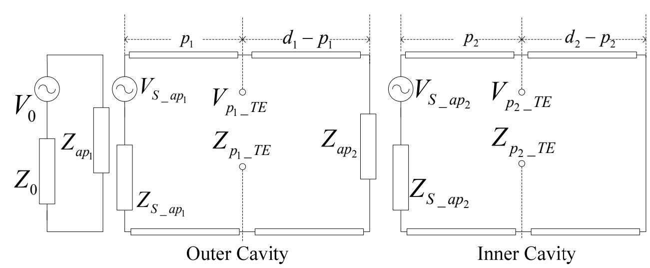


Fig. 2 Equivalent circuit of the double-enclosure

The equivalent circuit of the double-enclosure is illustrated in Fig.2. The double-enclosure is considered as two cascaded transmission lines excited by different voltage source. SE of the first (outer) cavity can be calculated using the circuital model based on extended Robinson's method [11]. Note the end of the outer cavity is not shorted anymore, while the second cavity (inner) can be considered as a short-ended transmission line. Both TE and TM modes can be taken into consideration in this circuital model. Here TE modes and y-polarized incident wave are taken as an example. The load impedance of the outer cavity Z_{L1_TE} equals the equivalent impedance of the inner aperture Z_{ap2} parallel connecting with the input impedance at the same position on the transmission line, as shown in Eq. (1).

$$Z_{L1\_TE} = \frac{Z_{ap_2} \cdot jZ_{gm'n'\_TE} \tan\left[k_{gm'n'} \cdot d_2\right]}{Z_{ap_2} + jZ_{gm'n'\_TE} \tan\left[k_{gm'n'} \cdot d_2\right]} \qquad (1)$$

where (m', n') represents TE modes inside the inner cavity, $Z_{gm'n'}$ and $k_{gm'n'}$ are waveguide impedance and propagation constant respectively. The equivalent impedance of the inner aperture Z_{ap2} is given by

$$Z_{ap_2} = \frac{1}{2} jC_m Z_{0S} \tan\left(k_0 l_1 / 2\right) \cdot n_{ap_2} \tag{2}$$

where []

$$C_m = \frac{\int_{x_0}^{x_0+l_1}\int_{y_0}^{y_0+w_1} \sin\left(\frac{m'\pi x}{a}\right)\sin\left(\frac{m'\pi(x-x_0)}{l_1}\right)\cos\left(\frac{n'\pi y}{b}\right)\cos\left(\frac{n'\pi(y-y_0)}{w_1}\right)\mathrm{d}x\mathrm{d}y}{XY} \tag{3}$$

is coupling coefficient between the aperture and the inner cavity, and n_{ap2} is the number of similar apertures. (X, Y) and (x_0, y_0) in (3) are the position of the aperture center and initial point respectively, as shown in Fig.1.

Then the input impedance of TE_{mn} mode at the position P_1 inside the outer cavity is given by

$$Z_{in\_p_1\_TE} = Z_{gmn\_TE} \frac{Z_{L1\_TE} + jZ_{gmn\_TE}\tan\left(k_{gmn}\cdot(d_1 - p_1)\right)}{Z_{gmn\_TE} + jZ_{L1\_TE}\tan\left(k_{gmn}\cdot(d_1 - p_1)\right)} \tag{4}$$

Let $V_{S\_p1\_TE}$ and $Z_{S\_p1\_TE}$ represent the equivalent source voltage and source impedance at position P_1, leading to

$$\begin{aligned} V_{S\_p_1\_TE} &= \frac{V_{S\_ap_1\_TE}}{\cos\left(k_{gmn}p_1\right) + j\left(Z_{S\_ap_1\_TE}/Z_{gmn\_TE}\right)\sin\left(k_{gmn}p_1\right)} \\ Z_{S\_p_1\_TE} &= Z_{gmn\_TE}\frac{Z_{S\_ap_1\_TE} + jZ_{gmn\_TE}\tan(k_{gmn}\cdot p_1)}{Z_{gmn\_TE} + jZ_{S\_ap_1\_TE}\tan(k_{gmn}\cdot p_1)} \end{aligned} \tag{5}$$

and [7]:

$$\begin{aligned} V_{s\_ap_1\_TE} &= v_0 \frac{Z_{ap1}}{Z_0 + Z_{ap1}} \\ Z_{s\_ap_1\_TE} &= \frac{Z_0 Z_{ap1}}{Z_0 + Z_{ap1}} \end{aligned} \tag{6}$$

where Z_0=120π, V_0 is the radiating source outside the double-enclosure, and Z_{ap1}, the impedance of the outer aperture, can also be calculated using formula (2) and (3) with (l_1, w_1) replaced by (l, w). Here, the $V_{S\_ap1\_TE}$ and $Z_{S\_ap1\_TE}$ are equivalent voltage and source impedance at the position of outer aperture, see Fig.2. As a result, the voltage at the position P_1 is obtained.

$$V_{p_1\_TE} = \frac{V_{S\_p_1\_TE} Z_{in\_p_1\_TE}}{Z_{S\_p_1\_TE} + Z_{in\_p_1\_TE}} F_{TE_{mn}} \tag{7}.$$

where F_{TE} is the mode factor and given by [11]

$$F_{TE_{mn}} = \sin(m\pi x / a)\cos(n\pi y / b)\,. \tag{8}$$

According to transmission line theory, the voltage and impedance at the position of inner aperture are expressed by

$$\begin{aligned} V_{o\_ap_2\_TE} &= \frac{V_{S\_p_1\_TE}}{\cos\left(k_{gmn}(d_1 - p_1)\right) + j\left(Z_{S\_p_1\_TE}/Z_{gmn\_TE}\right)\sin\left(k_{gmn}(d_1 - p_1)\right)} \\ Z_{o\_ap_2\_TE} &= Z_{gmn\_TE}\frac{Z_{S\_p_1\_TE} + jZ_{gmn\_TE}\tan(k_{gmn}\cdot(d_1 - p_1))}{Z_{gmn\_TE} + jZ_{S\_p_1\_TE}\tan(k_{gmn}\cdot(d_1 - p_1))} \end{aligned} \tag{9}$$

Taking the impedance of the inner aperture into consideration, the equivalent source voltage and impedance at the position of inner aperture are given by

$$\begin{aligned} V_{S\_ap_2\_TE} &= V_{o\_ap_2\_TE}\frac{Z_{ap_2}}{\left(Z_{o\_ap_2\_TE} + Z_{ap_2}\right)} \\ Z_{S\_ap_2\_TE} &= Z_{o\_ap_2\_TE}\frac{Z_{ap_2}}{\left(Z_{o\_ap_2\_TE} + Z_{ap_2}\right)} \end{aligned} \tag{10}$$

Therefore, the equivalent source voltage and impedance at the position P_2 inside the inner cavity can be expressed as

$$\begin{aligned} V_{S\_p_2\_TE} &= \frac{V_{S\_ap_2\_TE}}{\cos\left(k_{gm'n'}p_2\right) + j\left(Z_{S\_ap_2\_TE}/Z_{gm'n'\_TE}\right)\sin\left(k_{gm'n'}p_2\right)} \\ Z_{S\_p_2\_TE} &= Z_{gm'n'\_TE}\frac{Z_{S\_ap_2\_TE} + jZ_{gm'n'\_TE}\tan\left(k_{gm'n'}p_2\right)}{Z_{gm'n'\_TE} + jZ_{S\_ap_2\_TE}\tan\left(k_{gm'n'}p_2\right)} \end{aligned} \tag{11}$$

The inner cavity is shorted at the end, leading to the input impedance and voltage at position P_2 as

$$Z_{in\_p_2\_TE} = jZ_{gm'n'\_TE}\tan\left[k_{gm'n'}\left(d_2 - p_2\right)\right] \tag{12}$$

$$V_{p_2\_TE} = \frac{V_{S\_p_2\_TE} Z_{in\_p_2\_TE}}{Z_{S\_p_2\_TE} + Z_{in\_p_2\_TE}} F_{TE_{m'n'}} \tag{13}$$

Similarly, the voltage of TM modes can be deduced as

$$V_{p_2\_TM} = \frac{V_{S\_p_2\_TM} Z_{in\_p_2\_TM}}{Z_{S\_p_2\_TM} + Z_{in\_p_2\_TM}} F_{TM_{m'n'}} \tag{14}$$

Therefore the total voltage at position P_2 is given by the superposition of V_{p2_TE} and V_{p2_TM}.

$$V_{p_2} = \sum_m\sum_n V_{p_2\_TE} + \sum_{m'}\sum_{n'} V_{p_2\_TM} \tag{15}$$

According to the definition of shielding effectiveness, SE at position P_2 inside the inner cavity is given by

$$SE = -20\log_{10}\left|\frac{2V_{p_2}}{V_0}\right| \tag{16}$$

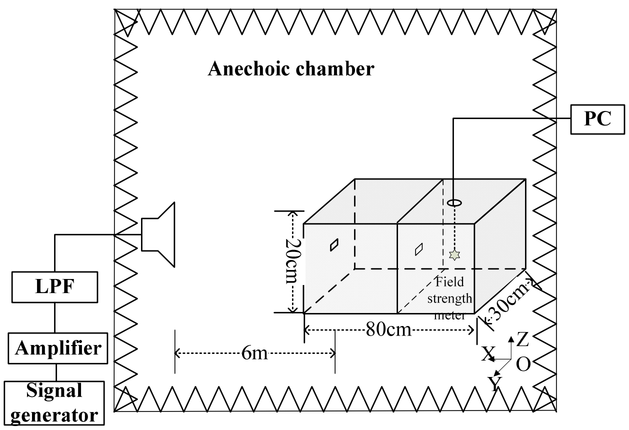
Note, though all the modes inside the enclosure can be considered in formula (15), the error of SE will increases if there are too many modes. We found from many trials that SE can be predicted accurately when the number of mode is less than about 13.

III. Verification With Measurement Results

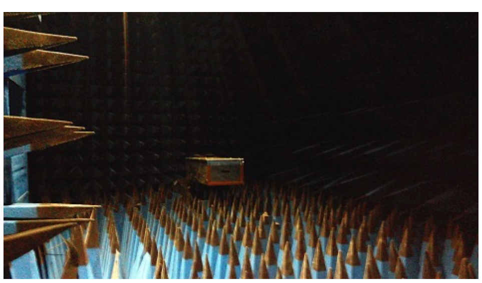
In order to validate the proposed method, a double-enclosure prototype with a dimension size of 30 × 20 × 80 cm^3 is manufactured, as shown in Fig. 3. The size of the slots on the front and common walls are $l \times w = l_1 \times w_1 = 8 \times 2\ cm^2$, and the two enclosures have the same size.

A vertically polarized plane wave is incident to the double-enclosure. An EP600 field strength meter is used to measure the electric field at the frequency range of 0.6GHz~1.5GHz with and without the enclosure. Then the shielding effectiveness at center of outer and inner cavities are obtained, and compared to the calculated SE using the proposed method. Results are shown in Fig.4.

We can see a good agreement between measurement and calculation for SE at the center of outer enclosure. However, errors can be found for SE of inner enclosure, especially at low frequency. The reason is that the field inside the inner enclosure is very weak due to double shielding layer, and the field strength meter cannot detect the field below 0.018V/m, leading to measurement errors of the electric field strength. The two enclosures have the same size, so resonances occur at the same frequencies. Totally 16 modes can be excited in each cavity in the frequency range up to 1.5GHz, and only 3 resonances can be observed in Fig. 4, since electric field strength of other modes becomes nearly zero at the center of the cavity. The curves drop down at around 1.5GHz due to a resonance occurs at about 1.55GHz.



(a)



(b)

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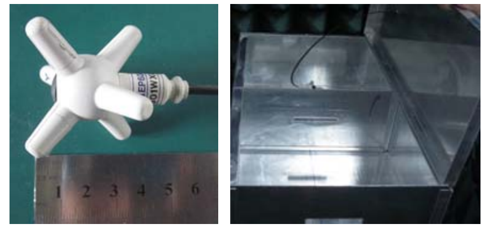
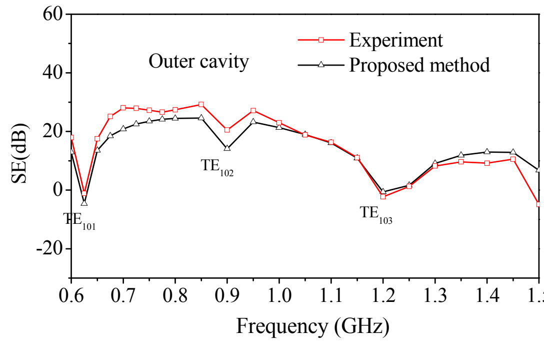
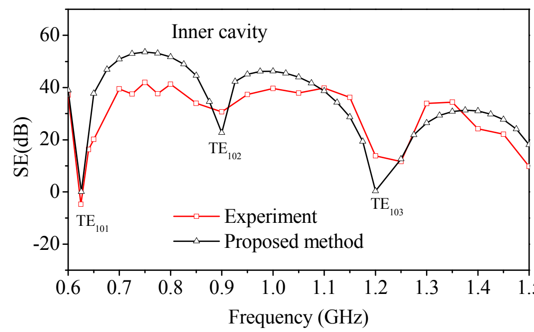


(c) (d)

Fig.3 Experimental system: (a) block diagram, (b) picture of the system, (c) field strength meter and (d) double-enclosure prototype.



(a)



(b)

Fig.4 Calculated and measured SE at center of (a) outer and (b) inner enclosure.

IV. Conclusion

A fast SE prediction algorithm based on circuital model is presented for double-enclosures. Calculated results are in agreement with measured ones. That demonstrates the validation of the proposed method. By regarding the cavities connected to the same enclosure through different apertures as parallel transmission lines, the proposed algorithm may be extended to calculated SE of multi-enclosures.

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