Investigating Shielded Enclosures with Double-layers Walls

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***Abstract* — In this paper the use of double-layers walls for shielded enclosures is proposed to increase the shielding effectiveness of them. The effect of distance between two layers and the offset between two apertures in the shielding effectiveness is investigated. The usefulness of inserting a box between two layers around apertures is also presented. To analyze enclosures with double-layers wall, the eigenvector expansion and the Bethe's approximation have been used.**

***Index Terms* — Shielded Enclosure, Shielding Effectiveness, Double layer Shielded.**

I. INTRODUCTION

Present day electromagnetic compatibility (EMC) rules of electric devices increase the importance of a careful design of shielding enclosures. Electromagnetic shielding is one of standard approaches that prevent coupling of undesired radiated electromagnetic energy into equipment otherwise susceptible to it. The ability of an enclosure to do this is characterized by its shielding effectiveness (SE), defined as the ratio of field strengths in the presence and absence of the enclosure. The efficiency of shielding enclosures is compromised by slots and apertures for heat dissipation, cable penetration, peripherals and displays.

Shielding effectiveness can be calculated by numerical simulation or by analytical formulations. Although, numerical methods are good at predicting the SE of a particular enclosure, it is difficult for designers to use them to investigate the effect of design parameters on SE. Numerical methods that have been used to calculate shielding include transmission-line modeling (TLM) [1], finite-difference time-domain (FDTD) method [2], and method of moments (MOM) [3]. Analytical formulation provides a much faster means of calculating shielding effectiveness, enabling the effect of design parameters to be investigated. Many of these are derived from Bethe's approximation of diffraction through holes [4] and apply only to electrically small apertures. Other formulations are derived from a power-balance method [5] and the widely quoted formula [6]. Other method to predicting the SE is considering the enclosure as a waveguide and assuming only a single mode of propagation (the TE_{10} mode) [7].

Radiation from slots and apertures is usually decreased with electromagnetic gasketing and using very conductive and thick walls. In this paper, we propose using double-layers walls for enclosures to decrease the radiation from apertures and so to increase the SE.

II. ANALYSIS OF ENCLOSURES WITH DOUBLE-LAYERS WALL

In this section, the enclosure with double-layers wall is analyzed. To analyze enclosures with double-layers wall, the eigenvector expansion [8] and Bethe's approximation [9] are used. Consider as depicted in Fig. 1 a rectangular enclosure with double-layers wall with dimensions of *a, b, c*. The distance between two layers is c_0 and there is an aperture on each layer. All walls have been assumed to be very thin perfect electric conductor. As a source, we use an x-directed thin electric dipole of length *2l* witch its center is located at (x_0, y_0, z_0). The current on this dipole is approximated as follows

$$J_x u_x = I_0 \sin[k(l-|x-x_0|)]\delta(y-y_0)\delta(z-z_0) \quad (1)$$

Where $I_0\sin(kl)$ is the current at the center of dipole. In this type of enclosures, the shielding effectiveness can be obtained in three following steps.

1. According to the Mendez method [9], first metalize the aperture No. 1 and determine the normal electric field E_n and tangential magnetic field H_t at the center of the aperture No. 1.The EM field in the cavity can be expanded in terms of eigenvectors, the expansion coefficients being expressed in terms of the source. In this problem the enclosure, consisting of a lossless medium included in a perfectly conducting shell, without apertures and that the sources are of electric type only. The EM field are therefore given by

$$\begin{aligned} \vec{E} &= -\frac{\eta}{jk}\sum_{i=1}^{\infty}\left\langle \vec{f}_i, \vec{J}^E \right\rangle \vec{f}_i + jk\eta\sum_{i=1}^{\infty}\frac{\left\langle \vec{E}_i, \vec{J}^E \right\rangle}{k^2-k_i^2}\vec{E}_i \\ \vec{H} &= -\sum_{i=1}^{\infty}\frac{k_i\left\langle \vec{E}_i, \vec{J}^E \right\rangle}{k^2-k_i^2}\vec{H}_i \end{aligned} \quad (2)$$

Where $k=\omega\sqrt{\varepsilon\mu}$ is the wavenumber at the operating frequency and $\eta=\sqrt{\mu/\varepsilon}$ is the characteristic impedance of the medium. The $\vec{f}_i$'s are the electric irrotational eigenvectors that are solutions to

$$\begin{aligned} &\nabla^2 \nu_i + \mu_i^2 \nu_i = 0 \quad in\ V \\ &\nu_i = 0 \qquad on\ S_V \end{aligned} \quad (3)$$

$$\vec{f}_i = \frac{\nabla v_i}{\mu_i}$$

Where μ_i is the eigenvalue of this eigenvector, and $\vec{E}_i$, $\vec{H}_i$ are the electric and magnetic solenoidal eigenvectors that are solutions to

$$\begin{aligned} &\vec{\nabla}\times\vec{\nabla}\times\vec{E}_i - k_i^2\vec{E}_i = 0 \quad in\ V \\ &u_n \times \vec{E}_i = 0 \qquad\qquad on\ s_V \end{aligned} \tag{4}$$

Where k_i is the eigenvalue of this eigenvector, and $H_i = \nabla \times E_i / k_i$.

The eigenvectors for a rectangular cavity are given in the Appendix

2. The fields in the cavity No. 2, leaking through the aperture No. 1 are determined as the fields from an electric and a magnetic dipole placed in the center of the aperture No. 1 but radiating in cavity No. 2 and repeat step 1 to determine the normal electric field E_n and tangential magnetic field H_t at the center of the aperture No. 2.

3. The fields in front of enclosure leaking through the aperture No. 2 are determined as the fields from an electric and a magnetic dipole placed in the center of the aperture No. 2 but radiating in free space.

To obtain E_n and H_t in the center of apertures in steps 1 and 2, the interior problem of enclosure can be solved by eigenvector expansion method [8]. In this method, the enclosure has been considered ideal, i.e. consisting of a lossless medium, perfectly conducting walls and without any aperture. Also, the dipole moments in step 2 and 3 are given by

$$\vec{p} = \varepsilon_0 \alpha_e E_n u_n \tag{5}$$

$$\vec{m} = \alpha_m \vec{H}_t \tag{6}$$

where α_e and α_m are the scalar electric polarizability and 2-by-2 magnetic polarizability tensor, respectively. Their values for rectangular aperture of length *L* and width *W* (*L*>*W*) located in the (*y*, *x*) plane and with *L* taken along the *y* direction, are as follows

$$\alpha_e \approx W^2 L \frac{\pi}{8}(1 - .56635\frac{W}{L} + 0.1398\frac{W^2}{L^2}) \tag{7}$$

$$\alpha_{mx} \approx W^2 L \frac{\pi}{8}(1 + 0.3221 W / L) \tag{8}$$

$$\alpha_{my} \approx \frac{0.264 L^3}{\ln(1 + 0.66 L / W)} \tag{9}$$

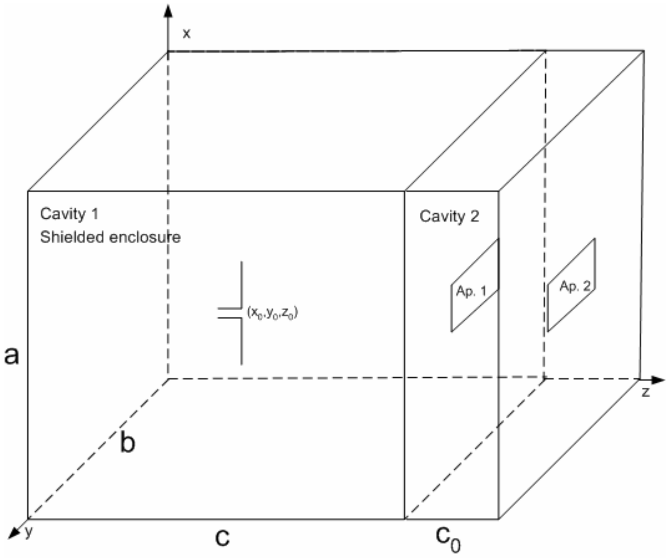

Figure1 Geometry of the rectangular enclosure with double wall and two apertures on two walls

III. NUMERICAL EXAMPLES

In this section, the usefulness of using double-layers walls for enclosures is verified. Consider a cubic box with side of 50 cm and with two 2×1 cm^2 apertures in the center of two layers of one of the walls.

Fig. 2, shows the obtained SE of the above enclosure for different values of c_0 (c_0 =0.5, 1, 2, 3 and 4 cm). The SE has been obtained by calculating the electric field at 3 m in front of the box due to an x-directed short dipole of 2 cm in the center of the cavity No. 1 (x_0 = 25 cm, y_0 = 25 cm, z_0 = 25 cm). From Fig. 2, one sees that the SE is increased by increasing the distance between two layers. Table 1 gives us, the SE in two resonance frequencies (424 and 735 MHz) and in two non-resonance frequencies (300 and 600MHz) for different value of c_0. We see that, adding the second layer with 5 mm distance from the first layer to the enclosure wall, SE has been increased 20 and 18 dB in two resonance frequencies and approximately 17 dB in two non-resonance frequencies. Therefore one may conclude that the effect of using double wall in resonance frequencies is more than that in non-resonance frequencies.

We can displace two apertures of two layers with respect to each other. Fig. 3 shows the obtained SE of the above enclosure for different values of the offset between two apertures, where the aperture No. 2 is fixed in center of second layer and the position of aperture No. 1 is varied (5 cm in directions x and y). It is seen that the SE has been increased with offset at each direction. The offset in both directions increases SE more than the offsets in one direction.

Now the effect of inserting a box between two layers around apertures is studied.Fig.4 depicts the geometry of the rectangular enclosure with double wall and a box between two layers around apertures.

Fig. 5, shows the obtained SE of the above enclosure for different values of the dimension of box between two layers. It is seen that the SE has been increased with increase the dimension of box . The maximum SE obtain when the dimension of box is equal to the dimension of the enclosure wall.

From the above concepts, it is concluded that as the hollow volume between two layers increases, the SE increases.

IV. CONCLUSION

An idea has been proposed to decrease the radiation from the apertures locating on the wall of the enclosures. In this idea, double-layers conductive plates are used as the wall of the enclosures. The shielding effectiveness (SE) for such enclosures is dependent to the distance between two walls and the offset between two apertures. Increasing the distance between two layers and/or the offset between two apertures increases the SE. This advantage is more obvious in the resonance frequencies.

TABLE I
THE SE OF A 50 cm SIDE CUBIC BOX WITH A SMALL APERTURE FOR DIFFERENT VALUES OF c_0

SE [dB]	f=300 MHz	f=424 MHz	f=600 MHz	f=735 MHz
no added layer	75.96	13.81	77.45	22.62
c_0=5 mm	92.61	34.18	94.38	40.59
c_0=10 mm	98.91	40.48	100.77	46.79
c_0=20 mm	105.97	47.57	108.22	53.48
c_0=40 mm	115.28	56.97	119.33	61.4

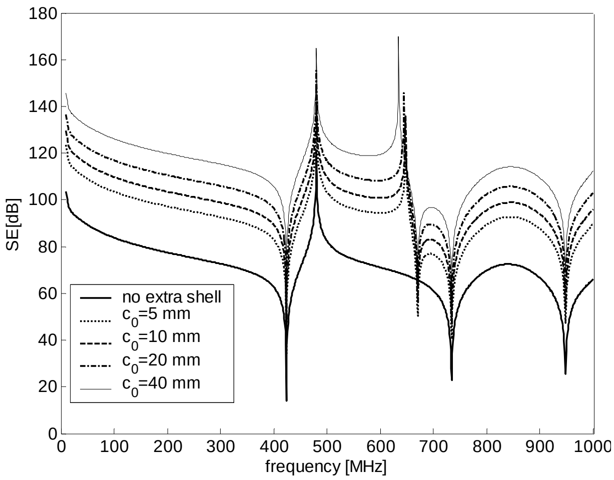

Figure 2 SE of 50-cm side cubic box with small aperture. Comparison between different values of c_0

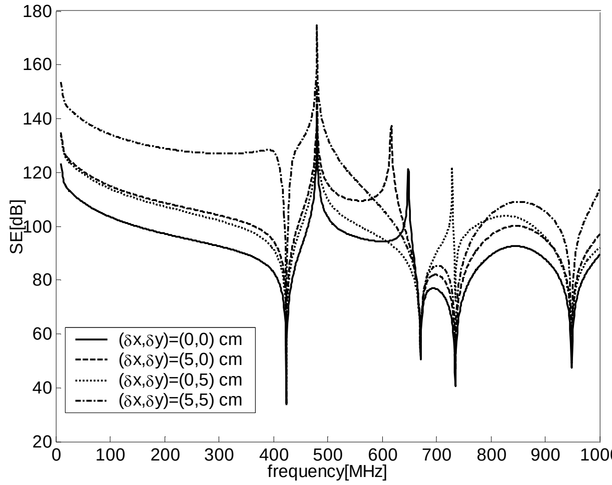

Figure 3 The SE of 50 cm side cubic box with c_0 = 5 mm. Comparison between different values of offset between two apertures

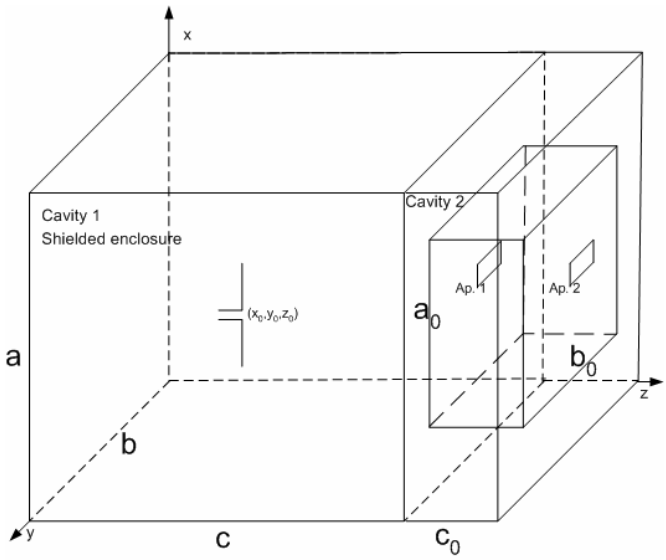

Figure 4 Geometry of the rectangular enclosure with double wall and a box between two layers around apertures

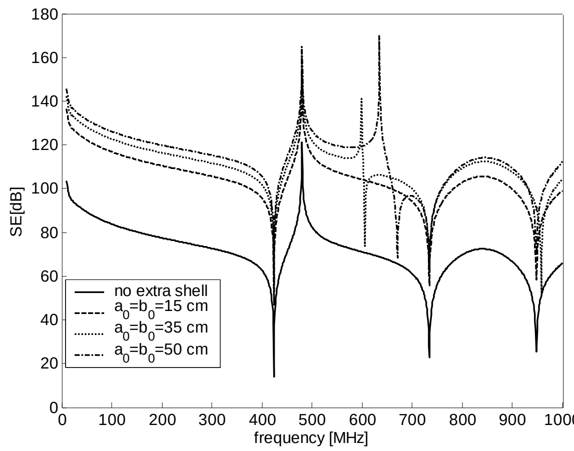

Figure 5 The SE of 50 cm side cubic box with c_0 =4 cm Comparison between different values of the dimension of extra shell

APPENDIX

The eigenvectors in (3) and (4) for a rectangular cavity of sizes a×b×c along the xyz axes, respectively, are given by the following expressions:

$$x_{mn}^2 = \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 \; k_{mnl}^2 = \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 + \left(\frac{l\pi}{b}\right)^2$$

$$\varepsilon_p = \begin{cases} 2 & if \quad p \neq 0 \\ 1 & if \quad p = 0 \end{cases}$$

Irrotational eigenvectors and eigenvalues are

$$f_{mnl} = \frac{1}{k_{mnl}}\sqrt{\frac{8}{abc}}\left(\frac{m\pi}{a}\cos\frac{m\pi x}{a}\sin\frac{n\pi y}{b}\sin\frac{l\pi z}{c}u_x + \frac{n\pi}{b}\sin\frac{m\pi x}{a}\cos\frac{n\pi y}{b}\sin\frac{l\pi z}{c}u_y + \frac{l\pi}{c}\sin\frac{m\pi x}{a}\sin\frac{n\pi y}{b}\cos\frac{l\pi z}{c}u_z\right)$$

$$\mu_{mnl} = k_{mnl}$$

TM-Mode eigenvectors and eigenvalues are

$$E'_{mnl} = \frac{-2}{x_{mn}k_{mnl}}\sqrt{\frac{\varepsilon_l}{abc}}\left(\frac{ml\pi^2}{ac}\cos\frac{m\pi x}{a}\sin\frac{n\pi y}{b}\sin\frac{l\pi z}{c}u_x + \frac{nl\pi^2}{bc}\sin\frac{m\pi x}{a}\cos\frac{n\pi y}{b}\sin\frac{l\pi z}{c}u_y - x_{mn}^2\sin\frac{m\pi x}{a}\sin\frac{n\pi y}{b}\cos\frac{l\pi z}{c}u_z\right)$$

$$H'_{mnl} = \frac{2}{x_{mn}}\sqrt{\frac{\varepsilon_l}{abc}}\left(\frac{n\pi}{b}\sin\frac{m\pi x}{a}\cos\frac{n\pi y}{b}\cos\frac{l\pi z}{c}u_x - \frac{m\pi}{a}\cos\frac{m\pi x}{a}\sin\frac{n\pi y}{b}\cos\frac{l\pi z}{c}u_y\right)$$

$$(\, k'_{mnl} = k_{mnl}; m \neq 0, n \neq 0 \,)$$

TE-Mode eigenvectors and eigenvalues are

$$E''_{mnl} = \frac{1}{x_{mn}}\sqrt{\frac{2\varepsilon_m\varepsilon_n}{abc}}\left(\frac{n\pi}{b}\cos\frac{m\pi x}{a}\sin\frac{n\pi y}{b}\sin\frac{l\pi z}{c}u_x - \frac{m\pi}{a}\sin\frac{m\pi x}{a}\cos\frac{n\pi y}{b}\sin\frac{l\pi z}{c}u_y\right)$$

$$H''_{mnl} = \frac{1}{x_{mn}k_{mnl}}\sqrt{\frac{2\varepsilon_m\varepsilon_n}{abc}}\left(\frac{ml\pi^2}{ac}\sin\frac{m\pi x}{a}\cos\frac{n\pi y}{b}\cos\frac{l\pi z}{c}u_x + \frac{nl\pi^2}{bc}\cos\frac{m\pi x}{a}\sin\frac{n\pi y}{b}\cos\frac{l\pi z}{c}u_y - x_{mn}^2\cos\frac{m\pi x}{a}\cos\frac{n\pi y}{b}\sin\frac{l\pi z}{c}u_z\right)$$

$$(\, k''_{mnl} = k_{mnl}; \{m, n\} \neq \{0,0\}, l \neq 0 \,)$$

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