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Shielding Effectiveness of Rectangular Enclosure with Apertures on Two Different Sides

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Abstract On account of the significance of strength against electromagnetic obstruction in cutting edge life, the shielding effectiveness of a rectangular cavity with gaps on front and rears lighted by the plane electromagnetic wave is demonstrated in this paper. In the demonstrating process, the incident angle of the plane electromagnetic wave is considered. The opening is taken as the co planar strip line and the rectangular cavity is taken as a rectangular wave guide with one gap to front end and another gap on the back end. The shielding effectiveness is ascertained utilizing transmission line hypothesis. Contrasted with different creators some time recently, this system enhances the culmination of the model and processing rate which supplies great reference for designing practice.

Keywords Different sides, Plane electromagnetic wave, Rectangular aperture, Rectangular cavity, Shielding effectiveness

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1. Introduction

WITH the improvement of science and innovation, electromagnetic environment is turning out to be more unpredictable in our lives. Keeping in mind the end goal to oppose the impact of electromagnetic obstruction, electromagnetic shielding is a work in progress and utilized as a part of different fields. Though there are many numerical methods that can obtain accurate simulation data of electromagnetic calculation [1-4], the long calculation time and huge computation make its overkill for the applications of guiding engineering practice. So, the analytic method wins general concern of researchers. Now, there are two types of analytical methods mainly: the method based on Bethe aperture coupling theory [5], [6] and the method based on transmission line theory [7], [8]. The second type is discussed further in this paper. M. P. Robinson introduced transmission line theory into the electromagnetic shielding field first, and researched the shielding effectiveness of the rectangular cavity with the aperture irradiated by the plane electromagnetic wave [9], [10] in 1996, but the higher order modes of the electromagnetic field in the cavity, the polarization angle, and the incidence angle were ignored in the model. T. Konefal introduced an intermediate-level circuit model method in 2005 [11], but there are much more integral operations in the model which can increase the calculation time, and there is only one face with the aperture. F. A. Po'ad extended M. P. Robinson's model, and made the center of aperture free on the *x*-axis in 2006 [12-14]. Following Farhana Ahmad Po'ad, Shi Dan extended the model further, made the center of aperture free on the *x*- and *y*-axes and considered higher order modes of the electromagnetic field in the cavity in 2009 [15], [16]. Recently, J. R. Solin proposed a method for the field excited in a perfectly conducting rectangular cavity with a small aperture by an external field acting on the aperture [17], [18]. The model is becoming more and more perfect with the deepening of research, but the calculation of shielding effectiveness has always been limited to the center line of the front panel aperture in the cavity. In order to meet the actual conditions better, the cavity with apertures on two different side front and back panels are considered in the model and the shielding effectiveness is calculated.

2. Mathematical Formulation

Rectangular cavity with apertures on two different side front and back panels is shown in Figure 1.

Figure 2 shows an equivalent circuit of Figure 1. The long sides of the apertures are shown normal to the *E*-field, which is the worst case for shielding. The dimensions of the rectangular cavity are *a*, *b*, *d* in *x*-, *y*-, *z*- axes, respectively. The length of the rectangular aperture in the front panel is *l* and the width is *w*. The length of the rectangular aperture in the back panel is l_2 and the width is w_2.

The electric shielding at a distance 'p' from the apertures is obtained from the voltage at point 'p' in the equivalent circuit, while the current at 'p' gives the magnetic shielding. In Fig.2, the source of radiation to the front panel aperture is

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represented by voltage V_{0f} and the impedance Z_{0f} = 377 similarly the source of radiation to the back panel aperture is represented by voltage V_{0b} and the impedance Z_{0b} =377. Both voltages and impedance's are same. The typical impedance and the propagation constant of the enclosure by the shorted wave guide are represented as Z_{gf} , k_{gf} & Z_{gb} k_{gb} . We proceed by first finding equivalent impedance for the front panel aperture and then using simple transmission line theory to transform all the voltages and impedances to point P. Next we proceed by finding equivalent impedance for the back panel aperture and then using simple transmission line theory to transform all the voltages and impedances to point P. Since both the apertures are in parallel, the final voltage at 'p' is the sum of Vpf and Vpb.

2.1. Electrical and Magnetic Shielding Effectiveness of Front Panel Aperture

The aperture characteristic impedance is given by Gupta et al. [19-20] as

$$Z_{osf} = 120\pi^2 \left[\ln\left(2\frac{1+\sqrt[4]{1-h^2}}{1-\sqrt[4]{1-h^2}} \right) \right]^{-1} \tag{1}$$

Where $h = w_e / b$, $\phi = \frac{4\pi}{t}$ and the effective width w_e is

$$w_e = w - \frac{5}{\phi}\left[1+\ln(\phi w)\right] \tag{2}$$

To calculate the aperture impedance Z_{apf} , we transform the short circuits at the ends of the aperture through a distance *l*/2 to the center. This is represented by point *A* in the equivalent circuit. It is mandatory here to include a factor *l*/a to account for the coupling between the aperture and the enclosure.

$$Z_{apf} = \frac{1}{2}\frac{l}{a} jZ_{osf} \tan(k_0 l / 2) \tag{3}$$

According to Thevenin's theorem fusing Z_{0f}, V_{0f} and Z_{apf} results in an equivalent voltage & source impedance as

$$V_{1f} = \frac{V_{0f} Z_{apf}}{V_{0f} + Z_{apf}} \tag{4}$$

$$Z_{1f} = \frac{Z_0 Z_{apf}}{Z_0 + Z_{apf}} \tag{5}$$

For the TE_{10} mode of propagation, the waveguide has characteristic impedance:

$$Z_{gf} = Z_0 / \sqrt{1-(\lambda / 2a)^2} \tag{6}$$

And propagation constant:

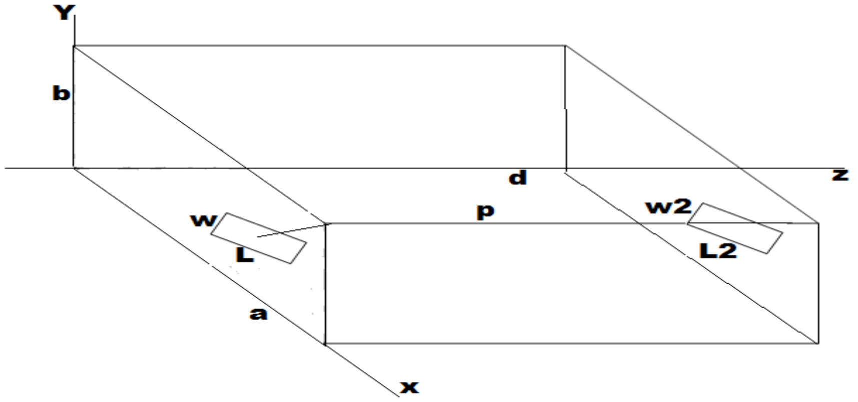

Figure 1. Rectangular enclosure with two apertures on front and back panels

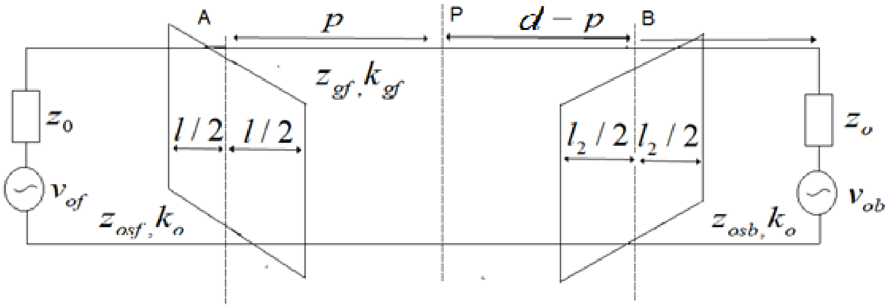

Figure 2. Equivalent Circuit of rectangular enclosure

$$k_{gf} = k_0 * \sqrt{1-(\lambda/2a)^2} \tag{7}$$

Where $k_0 = 2\pi/\lambda$

Then V_{1f}, Z_{1f} and the short circuit at the terminal of the wave guide to P are transformed by attributing an equivalent voltage V_{2f}, source impedance Z_{2f} and load impedance Z_{3f}.

$$V_{2f} = \frac{V_{1f}}{Cos(k_{gf}P) + j(Z_{1f}/Z_{gf})\sin(k_{gf}p)} \tag{8}$$

$$Z_{2f} = \frac{Z_{1f} + jZ_{gf}\tan(k_{gf}p)}{1 + j(Z_{1f}/Z_{gf})\tan(k_{gf}p)} \tag{9}$$

$$Z_{3f} = jZ_{gf}\tan k_{gf}(d-p) \tag{10}$$

The voltage at P is now $V_f = \dfrac{V_{2f}Z_{3f}}{V_{2f} + Z_{3f}}$ (11)

And the current at *P* is $I_f = \dfrac{V_{2f}}{V_{2f} + Z_{3f}}$ (12)

When the enclosure is absent, the load impedance at 'p' remains simply as Z_{0f}. The voltage at 'p' is $V_f^1 = V_{0f}/2$ and the current is $I_f^{\ 1} = V_{0f}/2Z_{0f}$

2.2. Electrical and Magnetic Shielding Effectiveness of Back Panel Aperture

The back panel aperture characteristic impedance Z_{osb} and aperture impedance Z_{apb} are obtained by replacing w by w_2 and l by l_2 in equations (2) & (3).

According to Thevenin's theorem fusing Z_{0b}, V_{0b} and Z_{apb} results in an equivalent voltage

$$V_{1b} = \frac{V_{0b}Z_{apb}}{V_{0b} + Z_{apb}} \tag{13}$$

And source impedance: $Z_{1b} = \dfrac{Z_0 Z_{apb}}{Z_0 + Z_{apb}}$ (14)

For the TE_{10} mode of propagation, the waveguide has characteristic impedance $Z_{gb} = Z_{gf}$ and propagation constant $k_{gb} = k_{gf}$.

Then V_{1b}, Z_{1b} and the short circuit at the terminal of the wave guide to P are transformed by attributing an equivalent voltage V_{2b}, source impedance Z_{2b} and load impedance Z_{3b}.

$$V_{2b} = \frac{V_{1b}}{Cos(k_{gb}(d-p)) + j(Z_{1b}/Z_{gb})\sin(k_{gb}(d-p))} \tag{15}$$

$$Z_{2b} = \frac{Z_{1b} + jZ_{gb}\tan(k_{gf}(d-p))}{1 + j(Z_{1b}/Z_{gb})\tan(k_{gf}(d-p))} \tag{16}$$

$$Z_{3b} = jZ_{gb}\tan(k_{gb}p) \tag{17}$$

The voltage at P is now $V_b = \dfrac{V_{2b}Z_{3b}}{V_{2b} + Z_{3b}}$ (18)

And the current at *P* is $I_b = \dfrac{V_{2b}}{V_{2b} + Z_{3b}}$ (19)

When the enclosure is absent, the load impedance at 'p' remains simply as Z_{0b}. The voltage at 'p' is $V_b^1 = V_{0b}/2$ and the current is

$$I_b^{\ 1} = V_{0b}/2Z_{0b}.$$

Finally in the presence of the enclosure the total voltage at 'p' is

$$V_p = V_f + V_b \tag{20}$$

In the absence of the enclosure the total voltage at 'p' is

The electric and magnetic shielding are, therefore, given by

$$SE = -20\log_{10}\left|2V_p/V_0\right| \tag{21}$$

$$SM = -20\log_{10}\left|2I_p Z_0/V_0\right| \tag{22}$$

3. Results

3.1. Electric Shielding Effectiveness

We consider a rectangular box of size (300X120X300) mm^3.The box is assumed to be excited by a plane wave with normal incidence for studying the SE of a rectangular box with a front panel aperture as the case (a) and front & back panel apertures as case (b). Figure 3a & Figure 3b shows the variation of the electric shielding effectiveness as a function of frequency by using TLM method. In both the cases the enclosure resonates at approximately 700MHZ frequency and SE decreases with frequency below the resonant frequency. The overall shielding effectiveness has decreased by 14 dB in case (b) when compared to the case (a). The comparison between the case (a) and case (b) is shown in Table 1.

When the electric shielding effectiveness is calculated at three different positions within the (300X120X300) mm^3 enclosure with an (100X5) mm^2 front panel aperture, the SE increments with distance from the aperture as shown in Figure 4a. But it is observed that SE decreases with the increased distance when two (100X5) mm^2 apertures taken at front and back panels as shown in Figure 4b. Compare results are shown in Table 2.

When the shielding effectiveness is calculated at center in (300X120X300) mm^3 enclosure with two different apertures of sizes (100X5) mm^2 and (200X30) mm^2, one at a time on the front panel the shielding effectiveness of larger aperture at lower frequencies is worse than that of the smaller aperture as shown in Figure 5a. It yields to the same result when two same size apertures are placed in front & back panels as shown in Figure 5b. The overall shielding effectiveness is decreases by 14 dB in case (b) when compared to the case (a) shown in Table 3.

Figure 6a and Figure 6b shows the calculated SE at the centre of the boxes of (222X55X146) mm^3, (480X120X480) mm^3 with the same aperture (100X5) mm^2 at front panel and front & back panels respectively. It can be seen from these figures that the small box does not resonate below 1GHz, while the big box shows resonances at 440 and 980MHz. Compare results are shown in Table 4.

3.2. Magnetic Shielding Effectiveness

We consider a rectangular box of size (300X120X300) mm^3.The box is assumed to be excited by a plane wave with normal incidence for studying the SM of a rectangular box with a front panel aperture as the case (a) and front & back panel apertures as case (b). When the magnetic shielding effectiveness is calculated at three different positions within the (300X120X300) mm^3 enclosure with an (100X5) mm^2 front panel aperture at p=150, 200 and 270mm. The enclosure resonance at 700MHz can be seen at p = 200mm and p=270mm, but is less evident at the center of the box (p=150mm). This is expected from the mode structure of the resonance. At low frequencies, *SM* increases with distance from the aperture (as does *SE*), but is almost independent of frequency as shown in Figure 7a. But it is observed that SM decreases with the increased distance when two (100X5) mm^2 apertures taken at front and back panels as shown in Figure 7b.

Table 1.

Frequency(MHZ)	**Robinson Method(RM) Shielding Effectiveness(dB)**	**Present Method(PM) Shielding Effectiveness(dB)**
100	124	110.3
339.3	92	78.25
719.7	9.294	-4.569
1000	46.72	32.86

Table 2.

Frequency (MHZ)	**For P=150mm**		**For P=270mm**	
	RM Shielding Effectiveness (dB)	**PM Shielding Effectiveness (dB)**	**RM Shielding Effectiveness (dB)**	**PM Shielding Effectiveness (dB)**
100	124.1	110.3	163.4	97.89
339.3	93.86	79.99	130.4	71.96
719.7	9.294	-4.569	32.08	21.87
1000	41.99	32.86	50.36	44.12

Table 3.

Frequency (MHZ)	**For 100X5mm aperture**		**For 250X30mm aperture**	
	RM Shielding Effectiveness(dB)	**PM Shielding Effectiveness(dB)**	**RM Shielding Effectiveness(dB)**	**PM Shielding Effectiveness(dB)**
100	124.1	110.3	88.17	74.31
339.3	93.86	79.99	55.42	41.56
719.7	9.294	-4.569	-19.17	-33.7
1000	41.99	32.86	27.89	14.03

Table 4.

Frequency (MHZ)	**480X120X480 enclosure**		**222X55X146 enclosure**	
	RM Shielding Effectiveness (dB)	**PM Shielding Effectiveness (dB)**	**RM Shielding Effectiveness (dB)**	**PM Shielding Effectiveness (dB)**
100	120.5	115.5	168.3	83.07
339.3	83.39	75.61	141.6	58.95
719.7	30.94	80.95	109.6	39.82
1000	35.87	26.94	76.01	28.22

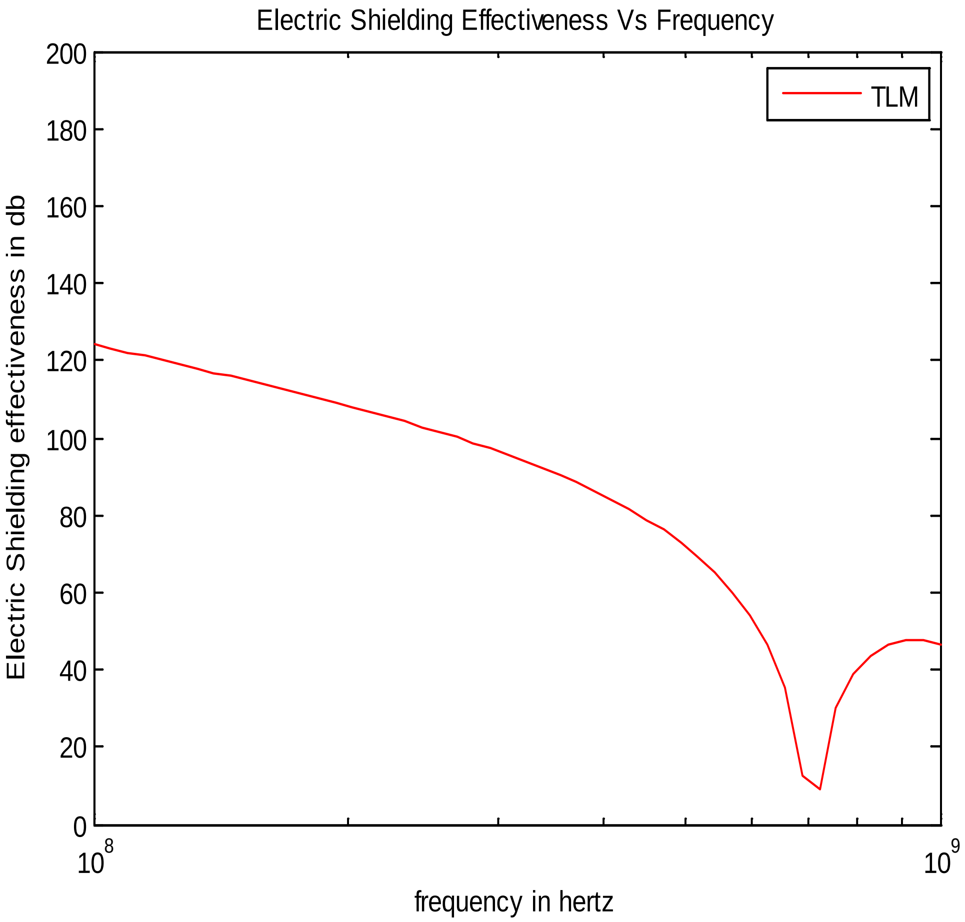

Figure 3a. Calculated SE using transmission line formulation in 300X120X300mm^3 box with 100X5mm^2 front panel aperture

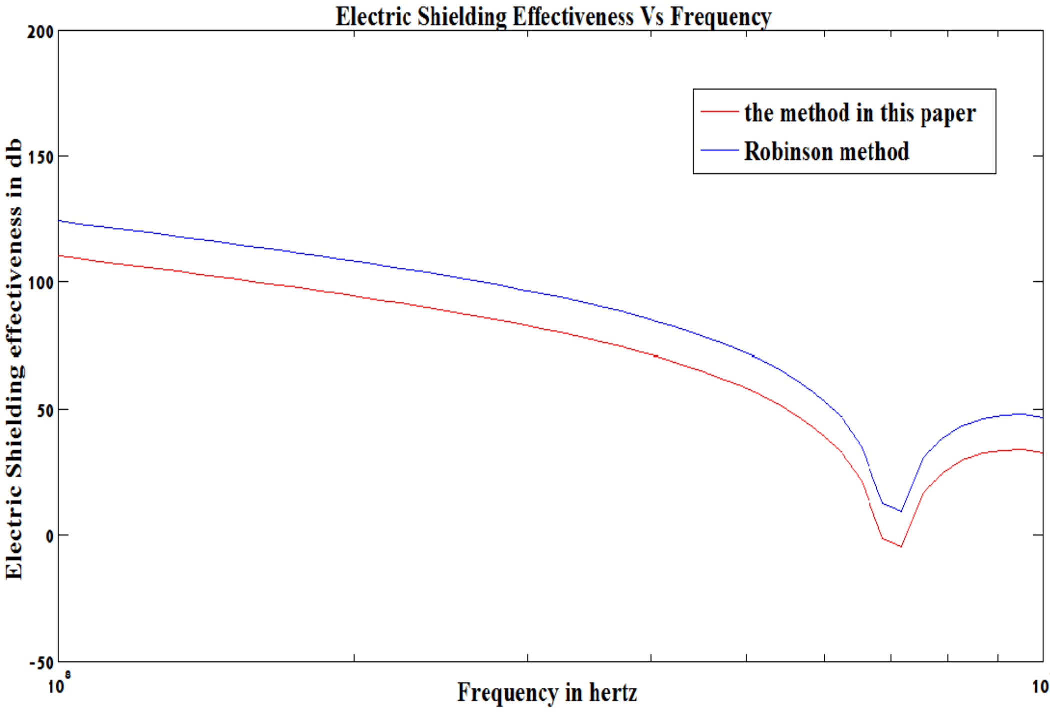

Figure 3b. Calculated SE using transmission line formulation in 300X120X300mm^3 box with two 100X5mm^2 apertures at front and back panels

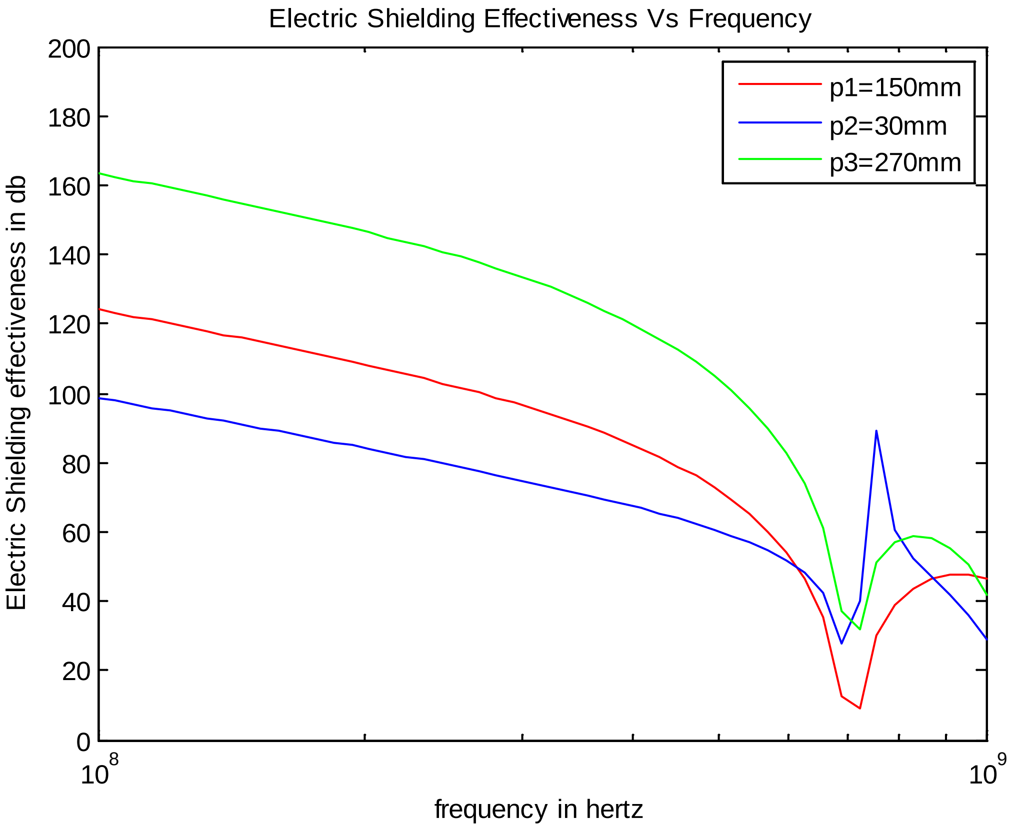

Figure 4a. Calculated SE at three different positions in 300X120X300mm^3 box with 100X5mm^2 front panel aperture

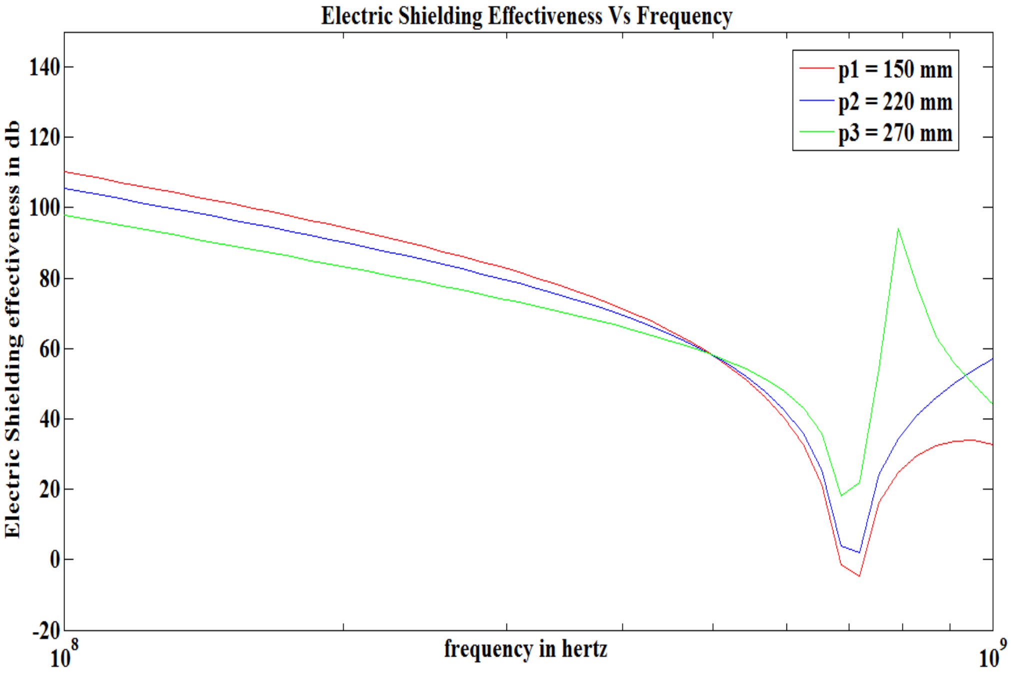

Figure 4b. Calculated SE at three different positions in 300X120X300mm^3 box with two 100X5mm^2 apertures at front and back panels

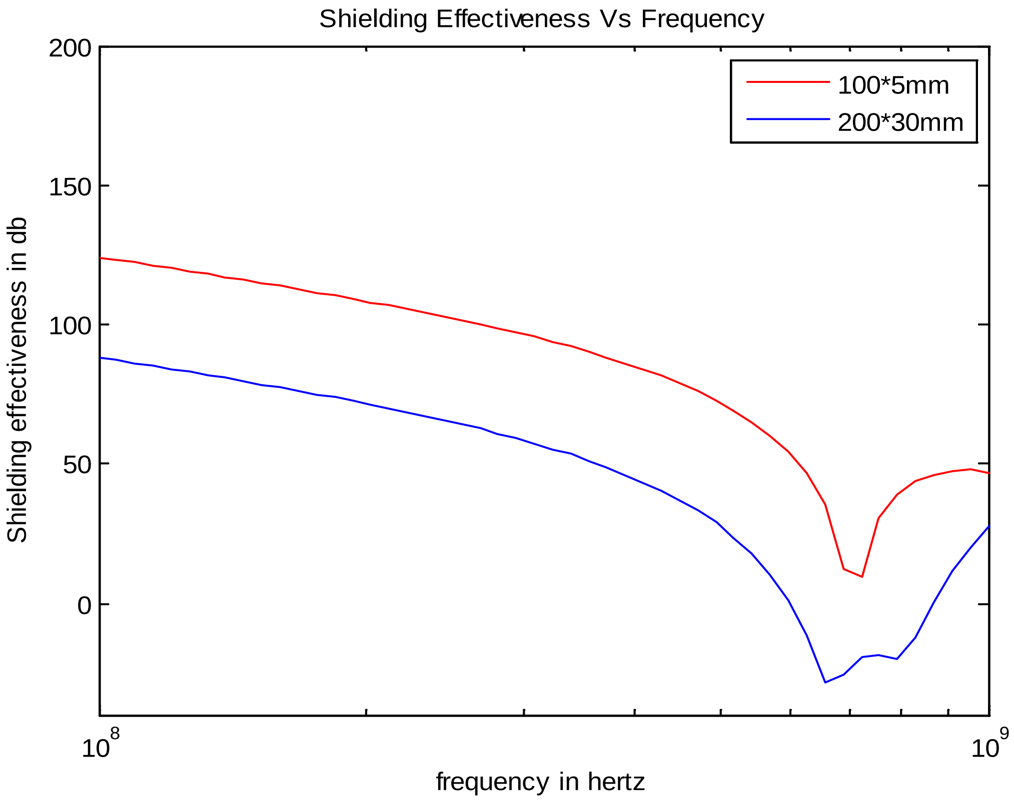

Figure 5a. Calculated SE at center in 300X120X300mm^3 box with two 100X5mm^2 and 200X30mm^2 apertures at front panel only

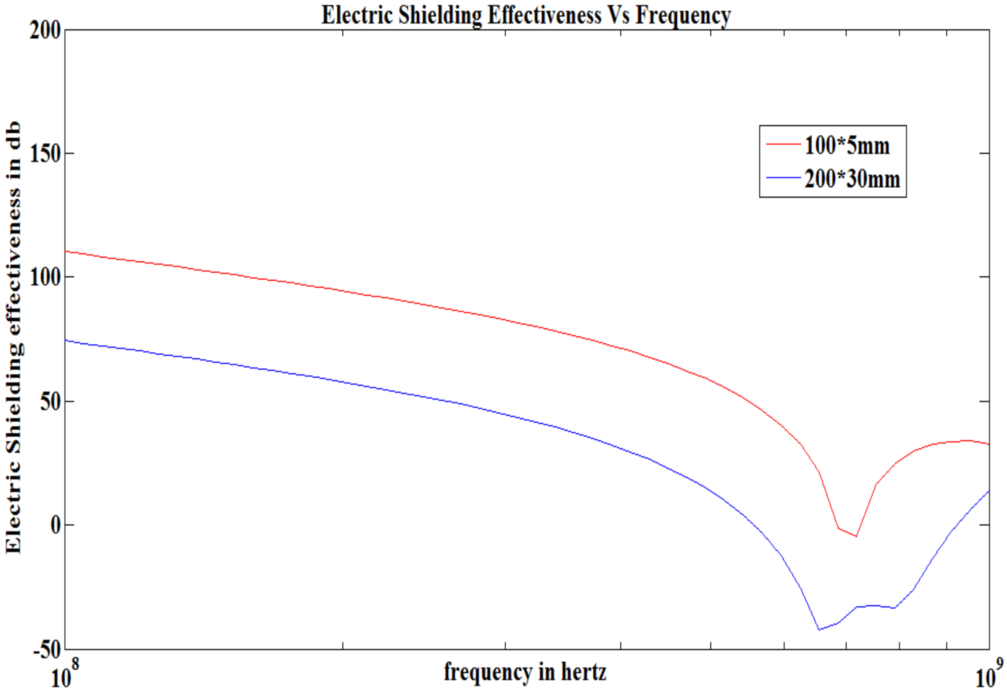

Figure 5b. Calculated SE at center in 300X120X300mm^3 box with two 100X5mm^2 and 200X30mm^2 apertures at front & back panels

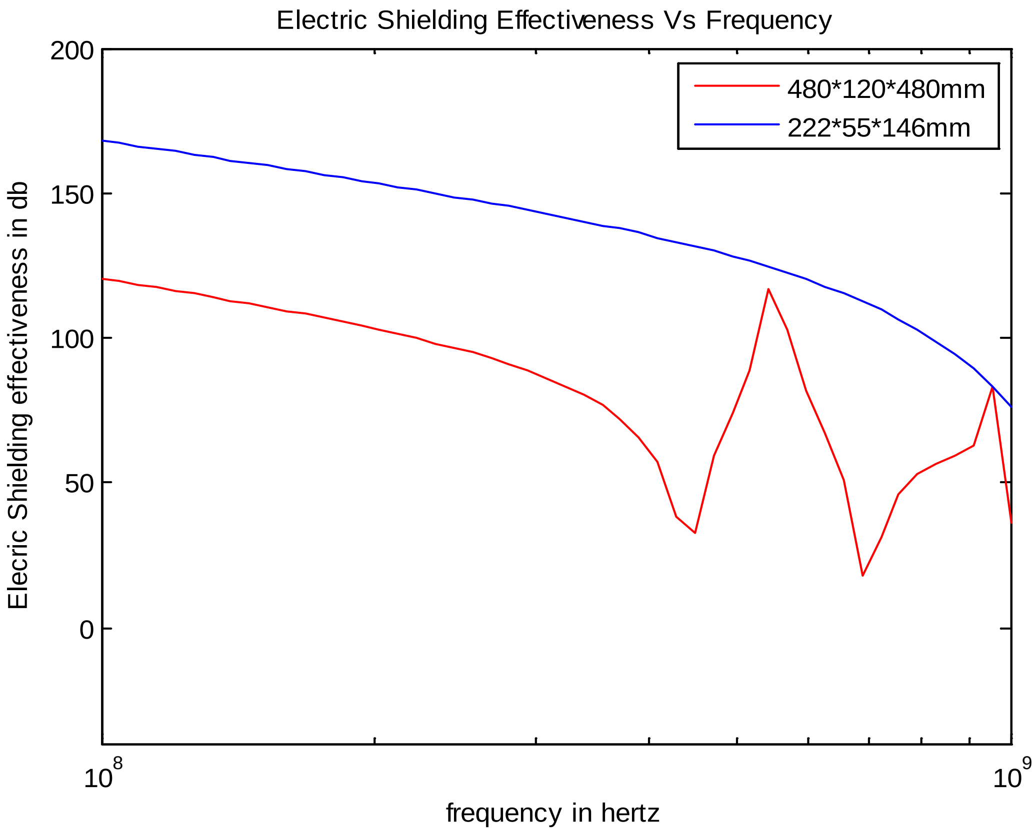

Figure 6a. SE of 222X55X146mm^3 and 480X120X480mm^3 boxes with the same aperture of 100X5 mm^2 size at front panel

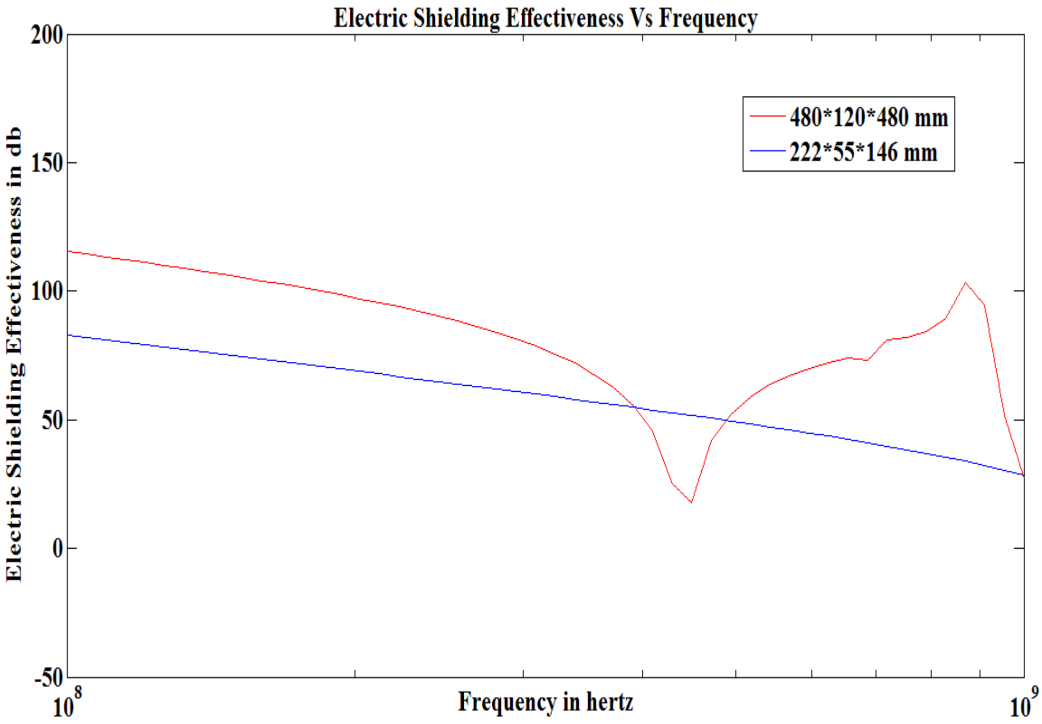

Figure 6b. SE of 222X55X146mm^3 and 480X120X480mm^3 boxes with the same aperture of 100X5 mm^2 size at front and back panels

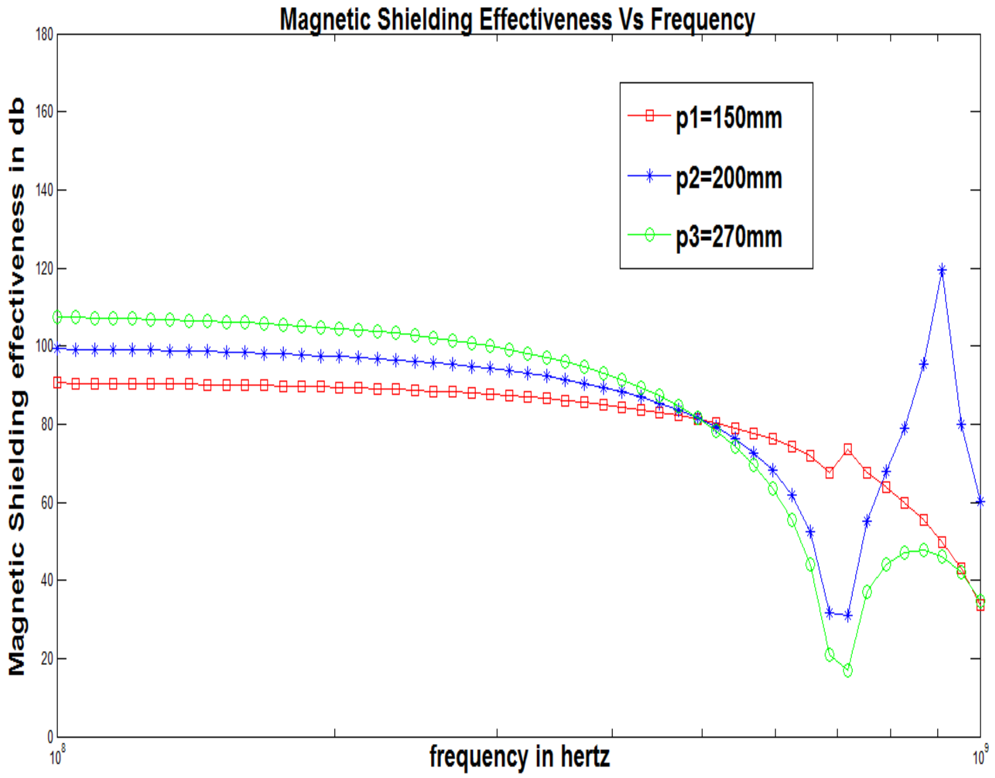

Figure 7a. Calculated SM at three different positions in 300X120X300mm^3 box with 100X5mm^2 front panel aperture

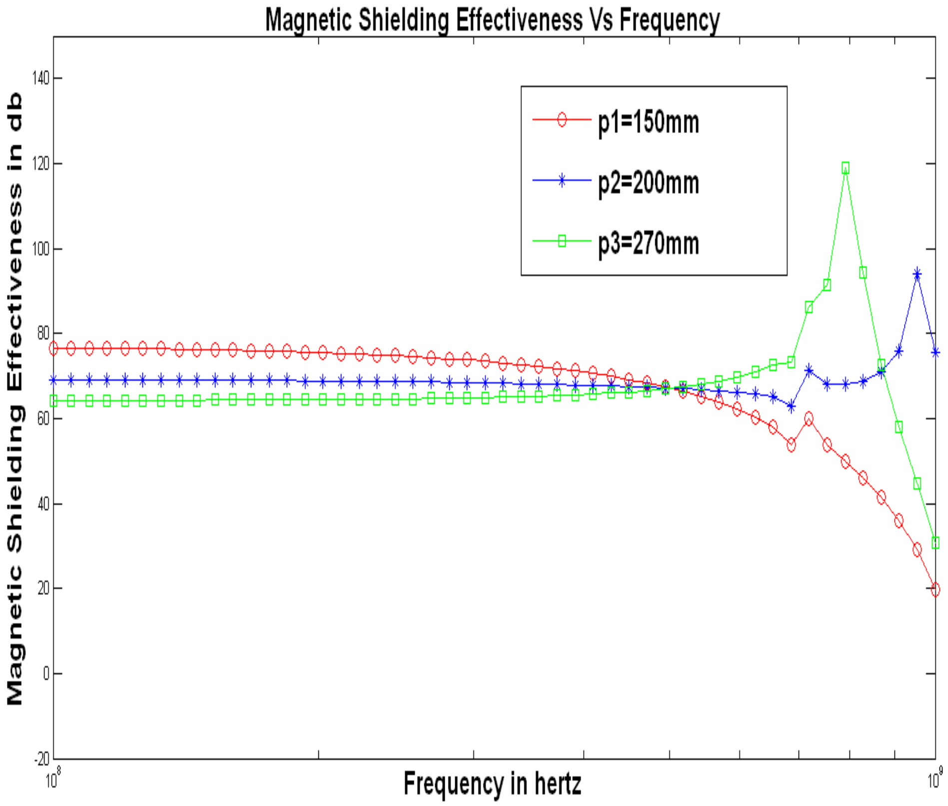

Figure 7b. Calculated SM at three different positions in 300X120X300mm^3 box with two 100X5mm^2 apertures at front and back panels

4. Conclusions

The shielding effectiveness of a rectangular cavity with apertures in different panels (front & back) irradiated by the plane electromagnetic wave is modeled in this paper and the results were compared with single aperture at front panel only.

The calculation of electric shielding using transmission line depends on the frequency and applied field's polarization and the enclosure's dimensions and aperture(s) dimensions, the quantity and position of the apertures within the enclosure. Compared to the referenced authors, the method proposed in this paper improves the completeness of the model and the computation speed which supplies good reference for engineering practice. But the simulation results show that the overall shielding effectiveness is decreased by 14dB compared to the referenced author.

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