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Model for estimating the shielding effectiveness of an enclosure with a perforated wall

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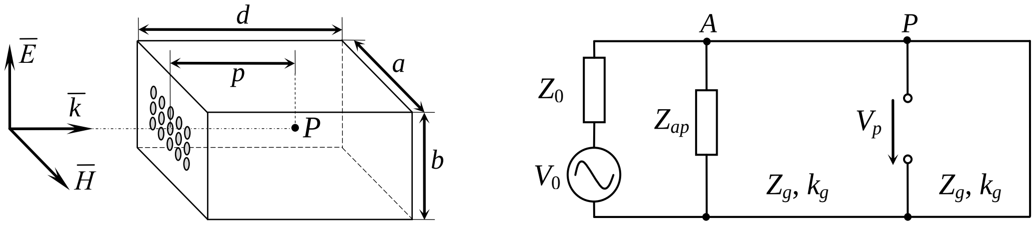
Abstract. In this paper, an analytical model for evaluating the shielding effectiveness of rectangular enclosures with a perforated wall was proposed. Apertures in the perforation can be performed in a staggered pattern, while the perforation can be situated at an arbitrary position on the enclosure wall irradiated by an electromagnetic field. The results of the SE calculations using the proposed model and finite element method are presented. They are in good agreement in the frequency range up to 1 GHz. The shielding effectiveness of the ABB FOX515 multiplexer enclosure used in the electric power complex was also evaluated.

1. Introduction

Shielded enclosures with perforated walls are used to ensure an optimal operation of the radioelectronic equipment (RE). A perforation provides natural or artificial air convection and thereby allows the components of the RE to be cooled. A large perforation area leads to a degradation of the shielding and mechanical properties of the enclosure. Therefore, in the early stages of RE designing, it is advisable to evaluate the shielding effectiveness (SE). Using analytical models, the SE can be obtained with the minimal computational costs. The existing models [1–3] make it possible to evaluate the SE of a rectangular enclosure with a perforation in the center of the wall irradiated by a plane wave. The perforation is often performed in a staggered pattern at an arbitrary position on the wall to preserve the mechanical properties of the structure with the maximum ability of the enclosure wall to pass air flow. In this paper, an analytical model for evaluating the SE of such structures is proposed.

2. Model of an enclosure with a perforated wall

The equivalent enclosure circuit (Figure 1) proposed in [4] is used to calculate the SE in this model. The incident plane wave is represented by the voltage V_0 source with the impedance Z_0=120π Ω. The enclosure is considered as a short-circuited segment of a transmission line with the characteristic impedance Z_g and the propagation constant k_g. The perforated front wall of the enclosure is replaced by the equivalent impedance Z_{ap}. The SE is calculated from the voltage V_p at the observation point P. To compute V_p, Thevenin's theorem and formulas for calculating the input impedance of the transmission line are used.



(a) (b)

Figure 1. Enclosure with perforated wall (a) and equivalent circuit for calculating the SE of enclosure (b).

2.1. The impedance of a staggered perforated wall

Figure 2 shows the geometry of the perforated wall. An array of the staggered apertures can be represented as two separate arrays with doubled horizontal distance between the apertures. Then Z_{ap} can be calculated as the sum of the two impedances Z_{array} of these arrays connected in series ($Z_{ap}=Z_{array\ 1}+Z_{array\ 2}$).

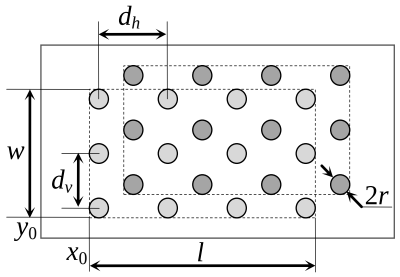


Figure 2. Geometry of a staggered perforated wall.

The impedance Z_{array} of a single array can be calculated as

$$Z_{array}=C_m Z_p \frac{l\,w}{a\,b}$$

where a and b are width and height of the front wall, C_m is the correction factor, Z_p is the equivalent perforation impedance. The apertures array width and height (Figure 2) are given by $l=d_h h$ and $w=d_v v$ where d_h and dv are the distances between the apertures, h and v are the number of apertures horizontally and vertically. The impedance Z_p is given by [2]

$$Z_p = j\frac{Z_0}{2}\left[1+\left(\frac{3d_h d_v \lambda}{16\pi r^3}\right)^2\right]^{-0.5} \cdot 10^{-0.8t/r}$$

where λ is the source wavelength, r is the apertures radius, t is the thickness of the perforated wall.

The arrays can be shifted relative to each other due to the use of the correction factor C_m obtained in [5] from the ratio of the field strength in the aperture and the enclosure. When the enclosure excited in the TE_{10} mode, this correction factor can be calculated as

$$C_m = \frac{\int_{x_0}^{x_0+l}\int_{y_0}^{y_0+w} \cos(\pi y/b)\cos\left[\pi(y-y_0)/w\right]\sin(\pi x/a)\sin\left[\pi(x-x_0)/l\right]dydx}{XY}$$

where x_0, y_0 are the coordinates of the apertures array beginning (Figure 2) and X, Y are the coordinates of the apertures array center.

Using the proposed approach, Z_{ap} can be calculated for an enclosure with a staggered perforation in the arbitrary position on the front wall. Moreover, apertures with different sizes can be taken into account in two arrays. This approach can also be improved for more complex geometric structures, if the perforation can be represented as n arrays. In this case, Z_{ap} will be calculated as the sum of all Z_{array} impedances for each of n arrays.

2.2. Shielding effectiveness calculation

After calculating the impedance Z_{ap}, SE can be calculated by transforming the equivalent enclosure circuit. At the first step, the source is transformed to point *A* (Figure 1b) on the equivalent circuit using Thevenin's theorem. The voltage and impedance can be calculated as $V_1=V_0Z_{ap}/(Z_0+Z_{ap})$ and $Z_1=Z_0Z_{ap}/(Z_0+Z_{ap})$. After that, the voltage and source impedance relative to the observation point *P* are calculated as [4]

$$V_2 = V_1\left[\cos\left(k_g p\right) + j\frac{Z_1}{Z_g}\sin\left(k_g p\right)\right]^{-1},$$

$$Z_2 = Z_g\frac{Z_1 + jZ_g\tan\left(k_g p\right)}{Z_g + jZ_1\tan\left(k_g p\right)}$$

where $Z_g = Z_0\left[1-\left(\lambda/2a\right)^2\right]^{-0.5}$, $k_g = k_0\left[1-\left(\lambda/2a\right)^2\right]^{0.5}$ and $k_0 = 2\pi/\lambda$.

Load impedance is given by

$$Z_3 = jZ_g\tan\left(k_g\left(d-p\right)\right).$$

The resulting voltage at the observation point *P* can be calculated as $V_p=V_2Z_3/(Z_2+Z_3)$. Then the SE at the point *P* inside the enclosure is given by

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

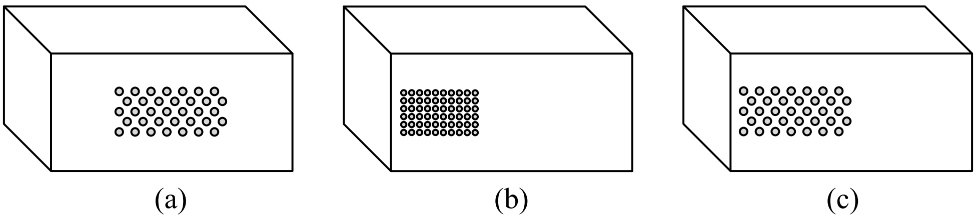
Using the presented analytical expressions, the SE can be calculated at any observation point located on the axis passing through the center of the perforation, perpendicular to the front wall when the enclosure excited in the TE_{10} mode. To evaluate the SE taking into account the higher modes TE_{mn}, the equivalent circuit transformations are performed $m\times n$ times. And the resulting voltage at the point *P* is calculated as the sum of all V_p [5].

3. Validation of the model

A comparison of the SE results obtained using the proposed model and the finite element method (FEM) was performed. A rectangular enclosure with the dimensions of 300×120×300 mm^3 and three different perforated walls was used for the calculations. An evaluation of the SE for the enclosure of the ABB FOX515 multiplexer used at electric power enterprises was also performed.

3.1. Analysis of typical structures

The geometry of the used enclosures is shown in Figure 3. A staggered array of 6×14 apertures r=4 mm is made in the center of the first enclosure wall (Figure 3a). The distances between the centers of the apertures are d_h=14 mm and d_v=10 mm. The second enclosure (Figure 3b) contains an array of 6×10 apertures r=2 mm centered at X=50 mm, Y=60 mm from the lower left corner of the front wall. The distances between the centers of the apertures are $d_h=2d_v$=12 mm. The third enclosure (Figure 3c) has parameters similar to the enclosure in Figure 3a. Wherein, the perforation is shifted to the left (X=52 mm, Y=60 mm). The SE calculations were performed at the point P=150 mm in the frequency range 1–1000 MHz. Only TE_{10} modes were considered. In all cases, the thickness of the enclosure wall was 1 mm.



(a) (b) (c)

Figure 3. Geometry of enclosures with a perforated wall selected for the model validation.

The results of the SE calculation for the enclosure with the perforation in the center (Figure 3a) are presented in Figure 4. The results were obtained using the proposed model, the FEM, and the models [1, 3]. It can be seen that the SE results obtained using [1] are in the best agreement with the FEM. The difference between the results is not more than 1.5 dB. The worst result (up to 12 dB difference) was obtained using the proposed model. This is due to the fact that the correction factor C_m was used when Z_{ap} calculating.

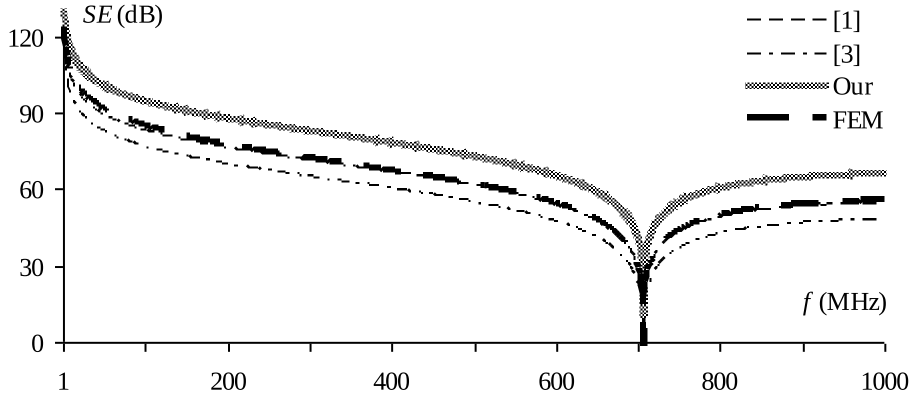


Figure 4. SE of the enclosure with perforation in the center of the front wall.

The frequency dependences of the SE calculated by the FEM and the proposed model for the enclosures in Figures 3b and 3c are presented in Figure 5. It can be seen that the results are in good agreement. The difference between the calculation results for the frequency dependencies does not exceed 7 dB (Figure 5a) and 2 dB (Figure 5b). Thus, the proposed model is the best suited for evaluating the SE of enclosures with the staggered perforation at an arbitrary location on the front wall.

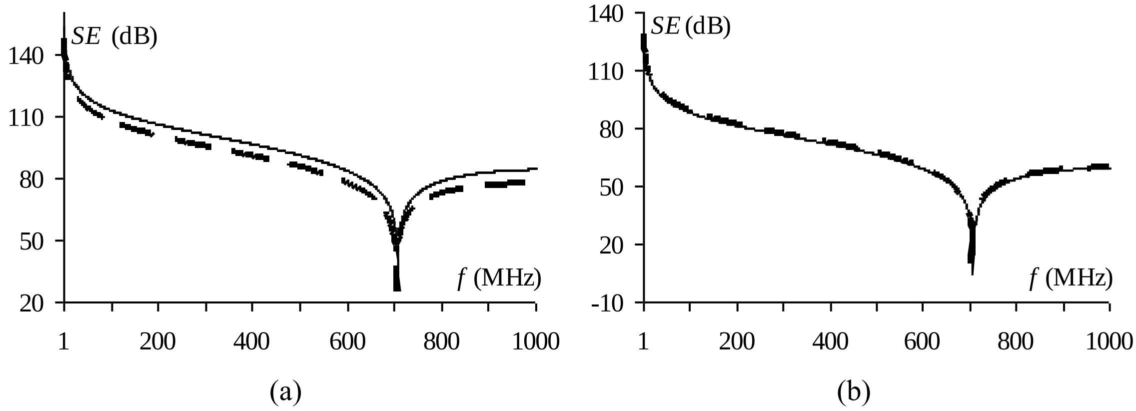
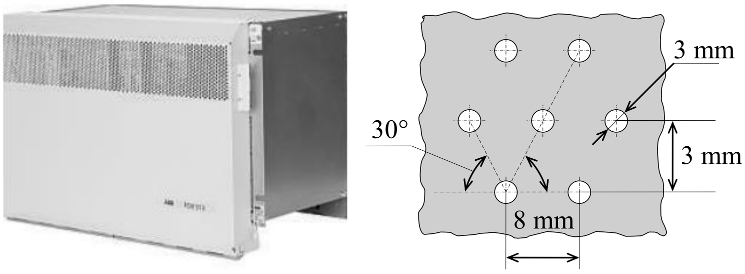


Figure 5. Results of calculating the SE by the analytical model (—) and FEM (– –) for enclosures in Figure 3b (a) and 3c (b).

3.2. Multiplexer enclosure

The multiplexer enclosure has dimensions of 445×270×278 mm^3 and thickness of 1.5 mm (Figure 6a). The upper part of the front wall contains an array of 108×15 apertures with a radius of r=1.5 mm. The apertures are staggered at an angle of 30° (Figure 6b). The upper part of the front wall has a bevel at an angle of 45° (4 mm to the top row of the apertures).

The SE calculations were performed at the point P=139 mm in the frequency range 1-1000 MHz. Only higher modes TE_{mn} were taken into account in the calculations by the analytical model. The SE frequency dependences obtained by the proposed model and the FEM are shown in Figure 7. At a frequency of 750 MHz in the dependence obtained by FEM, the resonance is partially smoothed. In addition, at frequencies up to 50 MHz, the SE values are lower than those obtained by the analytical model. This is due to the fact that the calculations of the analytical model did not take into account the bevel on the upper part of the front wall. In this case, the dependencies are in good agreement, and the average absolute error is 1.52 dB.



(a) (b)

Figure 6. Enclosure of the ABB FOX515 multiplexer (a) and the geometry of perforation (b).

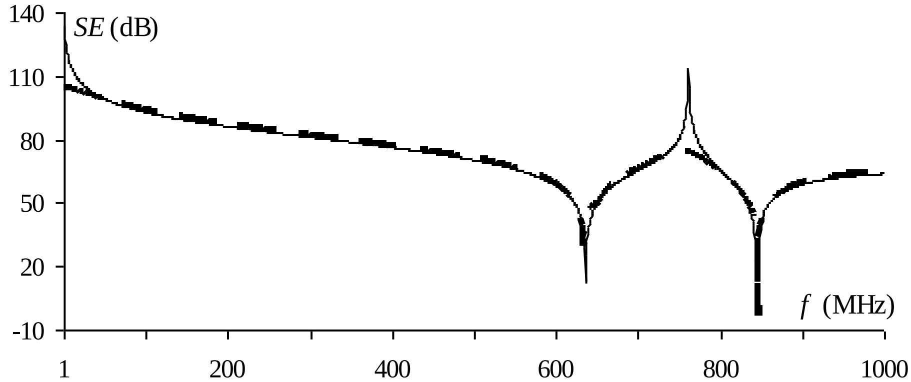


Figure 7. Results of calculating the SE by the analytical model (—) and FEM (– –) for the multiplexer enclosure

4. Conclusion

The new analytical model has been developed to estimating the SE of rectangular enclosures with a perforated front wall. The result of the SE calculations for enclosures with a staggered perforation in an arbitrary position on the front wall are in good agreement with the results obtained by the FEM. Moreover, the SE calculation by the analytical model, as compared to the FEM, takes significantly less time. Thus, the proposed model can be useful for the design of shielding structures with ventilation holes.

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References

[1] Dehkhoda P *et al* 2008 *IEEE Transactions on Electromagnetic Compatibility* **50(1)** 208–12
[2] Nie B L *et al* 2018 *IEEE Transactions on Electromagnetic Compatibility* **60(5)** 1376–83
[3] Ren D *et al* 2016 *IEEE Transactions on Electromagnetic Compatibility* **58(4)** 1033–41
[4] Robinson M P *et al* 1998 *IEEE Transactions on Electromagnetic Compatibility* **40(4)** 240–8
[5] Shi D *et al* 2007 *Int. Conf. on Electromagnetic Compatibility* **4** 361–4