Секция 21

RESULTS OF POSTGRADUATE AND MASTER STUDENTS' RESEARCH IN THE SPHERE OF ELECTRONICS AND CONTROL SYSTEMS

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Analytical model for evaluating shielding effectiveness of an enclosure with a partial dielectric cross-section filling

Ananalytical model is proposed for evaluating the shielding effectiveness (SE) of a rectangular enclosure with partial dielectric cross-section filling. In this model, the SE is calculated using the equivalent circuit method proposed by Robinson et al. A simple analytical expression based on the percentage of dielectric in the cross-section is used to calculate characteristic impedance and propagation constant of a filled enclosure. Both this model and the finite element method were used to calculate the SE of several test structures, and the results obtained in the range up to 1 GHz are in good agreement.
Key words: electromagnetic shielding, enclosure, equivalent circuits.

Electromagnetic shielding is one of the simplest and most reliable means used to protect radio-electronic equipment against the influence of radiated emissions. At the same time, the design of shielding structures with high shielding effectiveness (SE) is a difficult task. This is due to the fact that the SE value depends on many different factors (electro-physical properties of the shield material, the structure shape and size, the presence of apertures or the internal contents of the enclosure, etc.) [1]. It is obvious that a suitable mathematical tool is required to solve such complex problems.

In most cases, the developers of electromagnetic shields use numerical methods to calculate the SE [2–4]. Such methods are highly accurate and suitable for the analysis of complex and detailed shielding structures. However, they require large computational resources and time costs. For this reason, in the early stages of a shield design, it is advisable to use analytical models [5–7].

This work presents a new analytical model for evaluating the SE of an enclosure with partial dielectric cross-section filling. The model is based on a simple equivalent circuit transformation [5] which has low computational complexity and good accuracy in calculating the SE. It can be used to analyze enclosures filled with arbitrary dielectric contents, such as printed circuit boards, cable connectors, etc.

Theory

According to the model in [5], a rectangular enclosure with an aperture can be replaced by an equivalent circuit in which the incident plane wave is represented by the voltage source V_0 with the impedance Z_0=120π Ω, and the enclosure wall with an aperture is replaced by the impedance Z_{ap}. The enclosure is considered as a short-circuited waveguide with characteristic impedance Z_g and a propagation constant k_g. To calculate the SE, the equivalent circuit is transformed using the Thevenin's theorem and formulas for the input impedance of the transmission line.

To calculate the SE of an enclosure with an arbitrary dielectric filling, it is necessary to replace the short-circuited waveguide with a set of waveguide segments with different Z_g and k_g [8]. Taking into account the dielectric located in the cross-section of the waveguide, Z_g and k_g are determined as [9]

$$Z_g = \frac{Z_0 / \sqrt{\varepsilon_{\text{eff}}}}{\sqrt{1-(\lambda'/2a)^2}}, \quad (1)$$

$$k_g = \frac{2\pi}{\lambda'}\sqrt{1-(\lambda'/2a)^2}, \quad (2)$$

where a is the enclosure width, ε_{eff} is the effective value of relative permittivity in the waveguide cross-section, and $\lambda' = \lambda / \sqrt{\varepsilon_{\text{eff}}}$ (λ is a free space wavelength).

The ε_{eff} value can be calculated using a simple analytical expression based on the percentage of dielectric in the waveguide cross-section [10]. For example, for the structure partially filled with one dielectric material (Fig. 1), the ε_{eff} can be calculated as

$$\varepsilon_{\text{eff}} = \left(\frac{S^{\text{air}}}{\sqrt{\varepsilon_{\text{air}}}} + \frac{S^{\varepsilon_r}}{\sqrt{\varepsilon_r}} \right)^{-2}, \quad (3)$$

where ε_r is the relative permittivity of the filling material, $\varepsilon_{air} = 1$, and S^{air} and S^{ε_r} coefficients are defined as the ratio of the filling area to the total area of the waveguide cross-section:

$$S^{air} = \frac{a(b-h)}{ab} = \frac{b-h}{b}, \qquad (4)$$

$$S^{\varepsilon_r} = \frac{ah}{ab} = \frac{h}{b}, \qquad (5)$$

where h, a and b are the dimensions shown in Fig. 1.

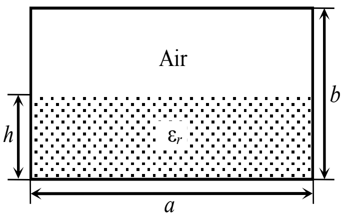

Fig. 1. Cross-section of an enclosure with a partial dielectric filling

Following the procedure from [10], the ε_{eff} value can be calculated for an arbitrarily filled cross-section of the enclosure (it is important that expressions (3)–(5) be changed when the ε_{eff} is calculated for an arbitrary shaped dielectric or a set of dielectrics). Using this value and (1)–(2) in the enclosure equivalent circuit, the SE can be calculated for a structure with an arbitrary shape dielectric inhomogeneity. Herewith, to calculate the impedance Z_{ap} and to transform the obtained equivalent circuit, it is necessary to use analytical expressions from [5].

Validation of the model

To validate the proposed model, we performed calculations of the SE for the standardized aperture rectangular enclosure with dimensions of a=d=300 mm and b=120 mm [11]. Two cases were considered. In the first case, the enclosure bottom was completely coated with a dielectric material (ε_r=3) 20 mm high (see the structure in Fig. 1). In the second case, two rectangular dielectric obstacles (ε_r=5) with a length of 100 mm and a height of 30 mm were located inside the enclosure (the geometry of this structure is shown in Fig. 2).

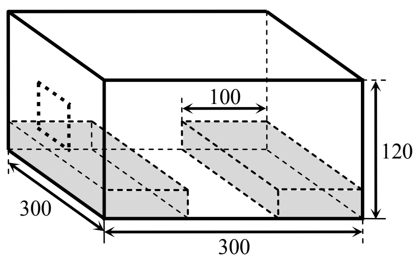

Fig. 2. Geometry of the enclosure populated with two rectangular dielectric obstacles

In both cases, the calculations were performed in the frequency range of 1–1000 MHz at the observation point located in the center of the enclosure. Frequency dependencies of the SE were also obtained by full-wave simulation based on the finite element method (FEM). When calculations were performed by the FEM, adaptive mesh refinement was used. The initial number of cells per wavelength was 40, and the mesh refinement percentage did not exceed 30% of the total number of elements at each step.

The SE calculation results for the first case are presented in Fig. 3. It can be seen that the frequency dependencies obtained using the FEM and the proposed model are in good agreement. However, at the frequency of about 1 GHz, the dependence obtained by the FEM shows a more significant resonance. The average value of the absolute error for the results is 4.4 dB.

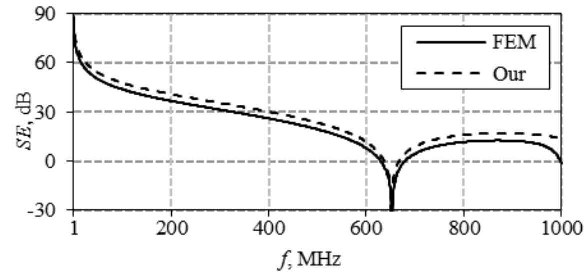

Fig. 3. The SE calculation results for the enclosure with a coated bottom

The results of the SE calculation for the enclosure populated with two rectangular dielectric obstacles are shown in Fig. 4. As can be seen, in this case, the frequency dependencies obtained by the FEM and the proposed model diverge slightly more than for the first structure (Fig. 3). For example, there is a small (about 10 MHz or 1.5%) difference between the first resonant frequencies of the case. In addition, a more significant divergence of the second resonant frequencies is observed (by 26 MHz or 3%). Nevertheless, the average value of the absolute error is lower than for the dependencies in Fig. 3 and is only 3.7 dB.

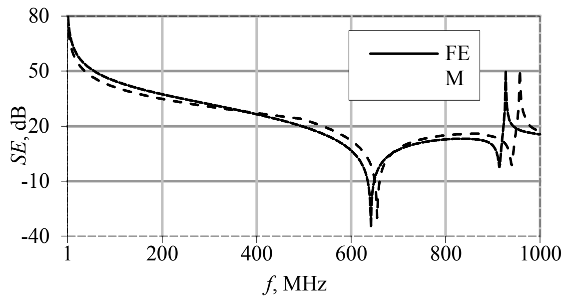

Fig. 4. The SE calculation results for the enclosure populated with two dielectric obstacles

Thus, the results presented in this section prove that the proposed model can be used for evaluating the SE of an enclosure with partial dielectric filling with acceptable accuracy.

Conclusion

A new analytical model has been developed for evaluating the SE of an enclosure with partial dielectric cross-section filling. Its results are in good agreement with the results obtained by the FEM. The model can be applied to enclosures filled with arbitrary shape dielectric contents, such as printed circuit boards, cable connectors, etc. At the same time, the SE calculation by the analytical model, in contrast to the FEM, takes significantly less time. Thus, the proposed model can be useful in the process of designing modern shielding structures.

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