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Numerical Solution of Shielding Effectiveness

Abstract. *The paper deals with the numerical solutions of electromagnetic shielding effectiveness using the finite element method. The main goal of the paper is to propose a new approach to shielding effectiveness definition based on the numerical solution of high-frequency electromagnetic field.*

Streszczenie. *W pracy przedstawiono symulację efektywności ekranowania elektromagnetycznego przy pomocy metody elementów skończonych. Głównym celem autorów jest propozycja nowej definicji efektywności ekranowania opartej na numerycznej symulacji pola elektromagnetycznego wysokiej częstotliwosci. (**Numeryczna analiza efektywności ekranowania)***

Keywords: Electromagnetic Compatibility, Shielding Effectiveness, Modelling, Numerical Methods, Finite Element Method, Shielding Enclosure
Słowa kluczowe: Kompatybilność elektromagnetyczna, ekranowanie, efektywność ekranowania, modelowanie, metody numeryczne, metoda elementów skończonych

Introduction

One of important tasks connected with the development of electrical devices is to provide their electromagnetic compatibility. This consists of the design of shielding which can effectively decrease the interference and increase the susceptibility of the device. The influence of the shielding for near field is defined by the *coefficient of the shielding*.

Electromagnetic shielding

Electromagnetic shielding is the most commonly used tool for suppressing of radiative coupling. Methods of electromagnetic shielding can be divided into two main groups:

- passive shielding,
- active shielding.

In both cases the important question is how to evaluate the quality of shielding. One of approaches to this question is based on the *shielding effectiveness*(SE). The general approach to the shielding effectiveness theory defines SE for electric (or magnetic) field as the ratio between the absolute value of electric field at a given point in space without the shield and the absolute value of electric field at the same point in space with the shield. This relation reads

$$(1)\qquad K_{\mathrm{SE}} = \frac{E_1(X)}{E_2(X)}, \qquad K_{\mathrm{SH}} = \frac{H_1(X)}{H_2(X)},$$

where E_1 is electric field strength and H_1 is magnetic field strength at a point X without shielding, E_2 and H_2 are similar strengths at the same point X with shielding. More often, variable shielding effectiveness is defined by expressions

$$(2)\qquad SE_{\mathrm{E}} = 20\log|K_{\mathrm{SE}}|, \quad SE_{\mathrm{H}} = 20\log|K_{\mathrm{SH}}|$$

is used. For far field the shielding effectiveness is defined by

$$(3)\qquad SE_{\mathrm{P}} = 10\log\frac{P_1(X)}{P_2(X)},$$

where P_1 is the measured power at a given point without shielding and P_2 is the measured power at the same point with shielding.

Measurement of shielding effectiveness

Measurements of SE are performed in the anechoic chamber. The anechoic chamber is used due to elimination of standing waves. The walls of the chamber act as a free space, because the characteristic impedance of the wall is the same at the free space impedance. The measurement chain is depicted in Fig. 1. The harmonic signal from the generator is amplified by the amplifier and radiated by a transmitting antenna. In the first step, only receiving antenna or field probe is placed without *device under test*(DUT). The signal from a receiving antenna or field probe is measured by the measuring receiver. In the second step, the receiving antenna is located inside the the shielding enclosure (DUT), but at the same place as in the first step. The measurement is repeated and shielding effectiveness of the shielding enclosure is evaluated based on equation (2). The used frequency range depends on the working frequencies of the electronic device, which will be situated in the shielding enclosure. Most common tests are within related the frequency range from hundreds of kilohertz up to gigahertz.

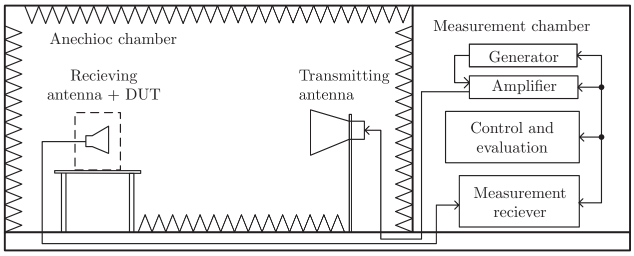

Fig. 1. The principle of shielding effectiveness measurement

New approach to shielding effectiveness

As the shielding effectiveness is a local parameter, it cannot take into account some phenomena like the local resonance. It is useful, therefore, to define *the global shielding effectiveness* by the expression

$$(4)\qquad GSE_{\mathrm{E}} = 20\log\left(\frac{\int_V |E_1|\mathrm{d}V}{\int_V |E_2|\mathrm{d}V}\right)$$

for electric field and by the expression

$$(5)\qquad GSE_{\mathrm{H}} = 20\log\left(\frac{\int_V |H_1|\mathrm{d}V}{\int_V |H_2|\mathrm{d}V}\right)$$

for magnetic field. For far field is global shielding effectiveness defined using instantaneous power by the expression

$$(6)\qquad GSE_{\mathrm{P}} = 10\log\left(\frac{\int_V P_1\mathrm{d}V}{\int_V P_2\mathrm{d}V}\right).$$

Illustrative example

As an example of numerical calculation of shielding effectiveness, an instrument case was chosen. The geometry of the model consists of the shielding with a slot representing a technological hole, the source of cylindrical wave, and the area bounded with a matched boundary (see Fig. 2).

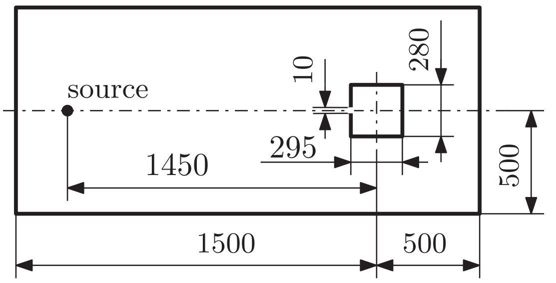

Fig. 2. Geometry of the model of electromagnetic shielding

Numerical calculation of the shielding effectiveness

The model can be described by the Helmholtz equation in the form

$$\Delta \boldsymbol{E} + \omega^2 \mu \varepsilon \boldsymbol{E} = 0, \tag{7}$$

supplemented with the following boundary conditions:

- The shielding box is modelled as a perfect conductor using boundary condition

  $$\boldsymbol{n} \times \boldsymbol{E} = 0, \tag{8}$$

- Along the boundary of the modelled area the scattering boundary condition reads

  $$\boldsymbol{n} \times (\nabla \times \boldsymbol{E}) = \mathrm{j}\boldsymbol{k} \left[E_z - (1 - \boldsymbol{kn}) E_{0z} e^{-\mathrm{j}r} \right], \tag{9}$$

  where E_0 is electric field strength of an incidental wave and r is distance of the source.

Experiment

The experimental measurement of shielding effectiveness of the shielding enclosure was performed in the semi-anechoic chamber at the University of West Bohemia (see Fig. 3). The dimensions of the chamber are 8.84 x 4.955 x 5.75 meter, which is sufficient for three meter measuring distance. An LPDA antenna BTA-M produced by Frankonia was used as the transmitting antenna and an electric field probe HI-6105 produced by ETS Lingren was used as the receiving probe. The starting frequency for measuring of SE was set to 500 MHz, the ending frequency 2500 MHz. We use frequency step 50 MHz. Output power of the amplifier was set automatically to the field strength at the receiving probe, which was 1 V / m. The values of output power were saved for the next measurement, where the device under test was examined. Shielding effectiveness of the DUT was calculated from the formula (1). The theoretical values of the SE of the circular aperture in an infinitely large perfect shielding plate are given by formula:

$$\mathrm{SE} = 20 \log \frac{\lambda}{2\varpi r}, \tag{10}$$

where λ represents the wave length and r represents the radius of the circular aperture. The theoretical results are not influenced by cavity resonance of the shielding enclosure. The cavity resonance depends on the dimension of the enclosure and the frequency of the resonance can be calculated using the equation

$$f_r = \frac{1}{2\sqrt{\mu\epsilon}} \sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2 + \left(\frac{p}{c}\right)^2}, \tag{11}$$

where μ represents permeability, ϵ permittivity, a, b and c stands for the dimension of cavity. Symbols m, n and p represent TE (transversal electric) and TM (transversal magnetic) resonance mode.

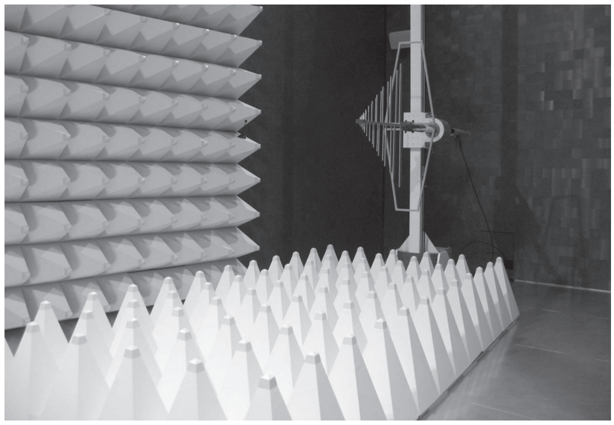

Fig. 3. Semi-anechoic chamber at University of West Bohemia

The model was solved for a wide range of frequencies and the results were compared with measurement. The comparison of measured and calculated values of the GSE_{E} on frequency are depicted in Fig. 7.

Results

The main reason for using any global (or integral) definition of shielding effectiveness follows from figures Fig. 4 and Fig. 5. The numerical calculations were performed for two relatively close frequencies. For frequency $f = 2.5$ GHz electric field id distributed uniformly, on the other hand, frequency $f = 2.102$ GHz is close to the natural frequency of the shielding box and standing waves appear. In this case, of course, the values of electric field measured at different points differ significantly.

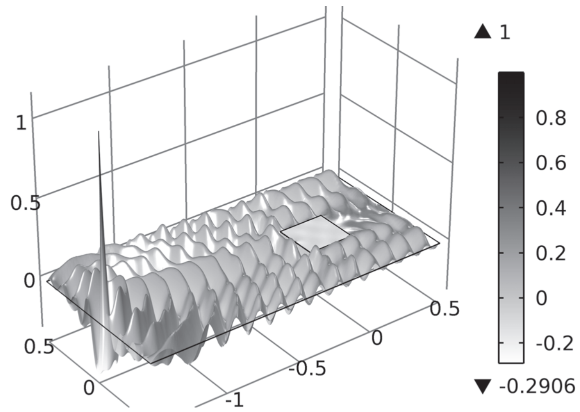

Fig. 4. The E_z component of the electric field for frequency $f = 2.500$ GHz.

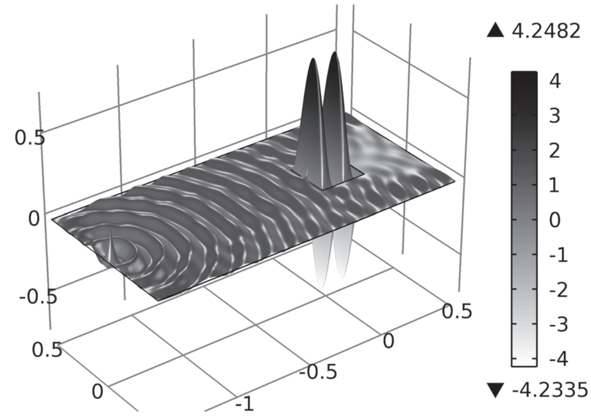

Fig. 5. The E_z component of the electric field for frequency $f = 2.102$ GHz, for which cavity resonance occurs.

Both measurement and calculation were performed for a wide range of frequencies. Figure Fig. 6 shows a comparison between the theoretical shielding effectiveness and measured shielding effectiveness. On the measured curve the influence of cavity resonances is evident. Figure Fig. 7 shows a comparison between the calculated values of GSE and measured values of SE. It is obvious that GSE respects resonances and, therefore, better approximates the measured data.

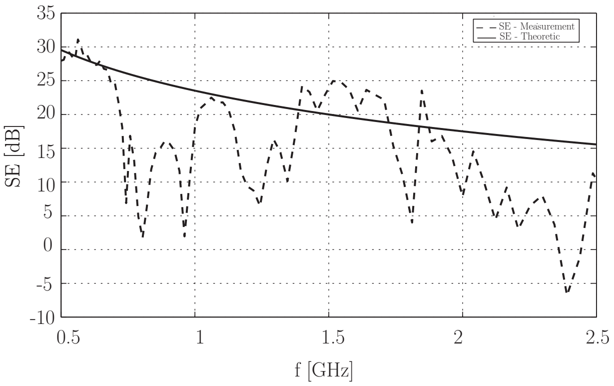

Fig. 6. Comparison between theoretical and measured values of SE.

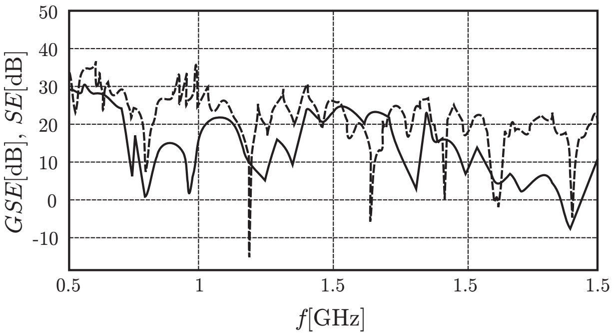

Fig. 7. Dependence of measured (solid line) and calculated (dashed line) shielding efficiencies on frequency

Conclusion

The comparison between the measured and calculated values of SE shows that the classical (pointwise) definition of the shielding effectiveness is not appropriate for describing the influence of shielding. In many applications it is necessary to consider phenomena which are difficult to describe by any pointwise variable. It appears that integral definitions leads to better compliance with measurement, however, yet the compliance is still not perfect. It seems to be useful to develop a methodologies of GSE measurement and numerical calculations simultaneously.

Acknowledgement

This research has been supported by the European Regional Development Fund and the Ministry of Education, Youth and Sports of the Czech Republic under the Regional Innovation Centre for Electrical Engineering (RICE), project No. CZ. 1.05/2.1.00/03.0094, by Grant project GA CR P102/11/0498 and by grant SGS-2010-18.

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