Wideband Worst-Case Model of Electromagnetic Field Shielding by Metallic Enclosure with Apertures

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***Abstract*—A worst-case wideband model for estimation of effectiveness of electric and magnetic field shielding by a rectangular metallic enclosure, the walls of which can contain rectangular or circular apertures, is developed. The model is based on a combination of analytical solutions of the following two problems: transmission of electromagnetic radiation through the aperture and propagation of the radiation in lossy waveguides. The analytical solutions ensure high computational efficiency of the model in a wide frequency range. The developed model makes it possible to estimate the effectiveness of external field shielding by a metallic board-system hull (the hull of a car, aircraft, ship, etc.) the internal compartments of which can be approximated by a rectangular waveguide. In order to do this, it is necessary to define the amplitude-frequency characteristic (AFC) for the loaded Q-factor of the compartment under consideration. Such AFC takes into account the presence of objects inside the compartment as well as the field absorption in the compartment walls, and it can be calculated (analytically or numerically) or measured. The developed model is validated by comparison of calculation results obtained by the model with known experimental results and with results of numerical simulation (ratios of the wavelength to the maximum dimension of the enclosure from 0.1 to 1000 are examined). Examples of modeling of the shielding enclosures containing the apertures of various sizes and shapes (circular, rectangular with different ratios of the sides) are considered; the number of apertures is varied from 1 (window) to 1000 (mesh).**

Keywords—electromagnetic shielding; waveguide theory; apertures; reverberation chambers; Q-factor

I. Introduction

Electromagnetic field shielding is used extensively to solve EMC problems [1]–[6]. One of the problems is a minimization of wideband electromagnetic pulse impact on electronic equipment installed inside board-system compartments with conducting walls (e.g., inside a car, aircraft, ship) [6], [7]. As a rule, there are apertures in the walls [8], [9]. So, a shielding effectiveness model intended for express-analysis of EMC must be applicable in a wide frequency range, provide a high computational efficiency, and have a worst-case behavior (i.e., eliminate an underestimation of field amplitudes in a shielded zone) [10].

Low-frequency models of shielding by solid metallic walls [11] and by walls containing apertures [8] provide the high computational efficiency but they are not applicable at high frequencies. Analytical models based on transmission line theory [3] and its generalization [12], as well as deterministic models based on waveguide and resonator theory [13], [14], do not have the worst-case behavior because the solutions are jagged at high frequencies as result of resonances. Methods of computational electromagnetics [9], [15], [16] require a high computational burden and lead to the jagged solutions at high frequencies, too. Experimental methods [5] – [9], [17], [18] are expensive, and their results are valid only for fixed positions of the equipment and personnel inside the system compartment.

The objective of this paper is to develop a wideband computationally-effective worst-case model of electromagnetic field shielding by a metallic enclosure with apertures in the walls.

II. Physical Model of Shielding by Rectangular Metallic Enclosure with Apertures in Walls

A shielding enclosure is defined as a rectangular parallelepiped with apertures in walls (Fig. 1). The walls of thickness h are made from a conducting material with conductivity σ and relative permeability μ. A system environment is air with relative permittivity $\varepsilon = 1$.

Shielding coefficients K_E and K_H for electric and magnetic components of the electromagnetic field are defined as a ratio of field amplitudes in an observation point in the shielded zone to field amplitudes in the point when the shield is absent. Shielding effectiveness S_E (S_H) is the inverse quantity to the shielding coefficient (as a rule, it is expressed in dB) [1, p. 718], [2, p. 317]:

$$K_E = |E'|/|E_0|, \qquad K_H = |H'|/|H_0|,$$
$$S_E = -20\lg(K_E), \quad S_H = -20\lg(K_H), \tag{1}$$

where $|E'|$ is the electric field amplitude in the shielded zone; $|E_0|$ is the incident electric field amplitude; $|H'|$ and $|H_0|$ are the corresponding amplitudes of the magnetic fields.

The incident electromagnetic wave is perpendicular to the wall of the shielding enclosure with apertures, and a polarization of the incident wave is defined by the electric field vector perpendicular to the longest side of rectangular aperture that provide the worst-case behavior of the model.

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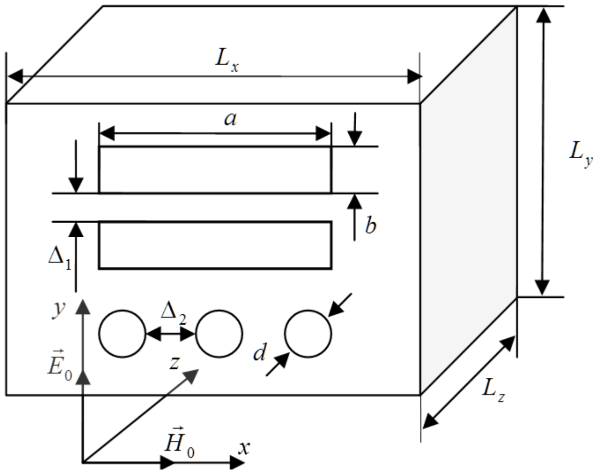

Fig. 1. Geometry of the shielding enclosure with apertures in the wall. L_x, L_y, L_z, are dimensions of the enclosure; d is the circular aperture diameter; a and b are the rectangular aperture length and width, respectively; Δ is the minimum distance between the neighbouring aperture boundaries

In the developed model, a short dipole is considered as a source of electromagnetic radiation. A distance r from the source of a frequency f to the illuminated wall determines calculation methods of the shielding effectiveness [1], [2]. If this distance is less than a critical distance $r_c = c/(2\pi f)$ (where c is the speed of light in free space), then the electric field shielding and the magnetic field shielding should be considered separately. If $r > r_c$, then the shielding models for the electric as well as for the magnetic field lead to the equal results and the electromagnetic field (or plane wave) shielding is considered [1], [2], [8], [11].

To develop the model, a rectangular waveguide of dimension $L_x \times L_y$ is assigned to the shielding enclosure. The waveguide cutoff frequency (frequency of fundamental mode TE(1,0)) is $f_c = c/(2\max(L_x, L_y))$. Propagation constant γ and characteristic impedance Z for a lossless waveguide are defined by the formulae:

$$\gamma = \frac{2\pi f}{c}\sqrt{1-(f_c/f)^2},\ Z = Z_0 \Big/ \sqrt{1-(f_c/f)^2}, \qquad (2)$$

where $Z_0 = 120\pi$ is characteristic impedance of free space.

A sum of reverberation components and Line of Sight (LOS) fields determines the worst-case model [6], [19]. Reverberation components represent distributions of the electric and magnetic fields arising due to multiple reflections from the walls inside the enclosure. The worst-case model of the reverberation components is based on a simplified deterministic model defined by the fundamental mode of a waveguide assigned to the enclosure.

The low-frequency band $f < f_c$ and the high-frequency band $f \geq f_c$ are defined to develop the model. The shielded zone can contain absorbers. Absorber characteristics are defined empirically.

III. Simplified Deterministic Model

A. Shielding Effectiveness of Combined Walls

A concept of combined wall is introduced to describe a non-uniform wall consisting of regions. The region is an area of the wall defined by a single set of parameters: the wall thickness, characteristics of the wall material, aperture dimensions and a distance between the aperture boundaries.

The shielding effectiveness of the solid wall is calculated according to the model developed in [11], and the shielding effectiveness of the wall with uniformly distributed apertures is calculated according to the model developed in [8].

According to [2, p. 311], the shielding effectiveness is considered for electric and magnetic components that defines the electromagnetic field energy transfer in a shielded zone. It is supposed that the radiation power transferred by the electric and magnetic components of the electromagnetic field is proportional to the square of the corresponding vector intensity [4]. So, the shielding effectiveness can be calculated by the ratio of the power $P_{tr(E,H)}$ for the radiation penetrating through the wall to the incident radiation power $P_{0(E,H)}$ according to (1):

$$S_E = -10\lg(P_{tr\,E}/P_{0E}),\ \ S_H = -10\lg(P_{tr\,H}/P_{0H}). \qquad (3)$$

For the wall consisting of N regions with different shielding effectiveness, the radiation power penetrating through the region with a number i does not depend on the radiation power penetrating trough the other regions. So, the shielding effectiveness of the combined wall $S_{G(E,H)}$ is calculated by summation the power ratios defined for each region:

$$S_{G(E,H)} = -10\lg\left(\sum_{i=1}^{N} 10^{-S_{i(E,H)}/10} A_i / A_0\right), \qquad (4)$$

where $S_{i(E,H)} = -10\lg(p_{tr\,i(E,H)}/p_{0(E,H)})$, $p_{tr\,i(E,H)}$ is a radiation flux density penetrating through the region with the number i of the area A_i, $p_{0(E,H)}$ is an incident radiation flux density ($p_{0(E,H)} = const$), $A_0 = A_1 + A_2 + ... + A_n$ is the total area of the wall.

B. Attenuation of Electromagnetic Oscillations inside Shielding Enclosure

The electric field energy accumulated inside the shielding enclosure of the volume V is $W_{ac\,E} = \varepsilon_0 \left\langle |E|^2 \right\rangle_V V/2$, where $\varepsilon_0 = 8.85 \cdot 10^{-12}$ F/m and the notation $\langle\ \rangle_V$ correspond to the volume averaging. By analogy, the accumulated magnetic field energy is $W_{ac\,H} = \mu_0 \left\langle |H|^2 \right\rangle_V V/2$, $\mu_0 = 4\pi \cdot 10^{-7}$ H/m.

In future, a stationary mode of the electromagnetic field in the shielded zone is considered, therefore the equality $P_{loss} = P_{in}$ is true, where $P_{in\,(E,H)}$ is the power of radiation sources, $P_{loss\,(E,H)}$ is the loss power for the electric (*E*) and magnetic (*H*) fields.

Q-factor of the shielding enclosure defines the loss power by the following formula $P_{loss(E,H)} = 2\pi f\, W_{ac(E,H)} / Q$, where $Q = 2\pi W_{ac} / \Delta W_{loss}$ and ΔW_{loss} is the energy loss per one period T. The accumulated energy for stationary mode is $W_{1(E,H)} = P_{in(E,H)} Q / 2\pi f$.

If there are absorbers inside the shielded zone (equipment, personnel, etc), then the Q-factor can be defined experimentally by measurements of Insertion Loss (*IL*) [6]: $IL = \langle P_r / P_{in} \rangle_V$, where P_r is a power received by ideal isotropic antennas installed inside the shielding enclosure. The accumulated energy in stationary mode $W_{1(E,H)}$ is expressed through the averaged received power $\langle P_r \rangle_V$:

$$W_{1E} = 4\pi\varepsilon_0 Z f^2 \langle P_r \rangle_V V / c, W_{1H} = 4\pi\mu_0 f^2 \langle P_r \rangle_V V / (Z c), \quad (5)$$

where Z is defined by (2) for the low attenuation and for the high-frequency band. When $Z \approx Z_0$ (for frequencies $f >> f_c$), (5) takes the following form [7, p. 10]: $Q_E = Q_H = (8\pi f^3 V / c^3) IL$.

If there are no absorbers inside the shielded zone, then the loss power is defined by an absorption in the enclosure walls (the corresponding power is P_W) and by radiation leaving the shielded zone though the walls (the power denoted as P_{out}): $P_{loss} = P_W + P_{out}$, and an intrinsic Q-factor of the system (Q_0) can be defined in terms of the shielding effectiveness of the enclosure walls.

The radiation penetrates through the illuminated wall and multiple reflections from a back and front walls arise inside the enclosure. Herein and below, the quantities noted by index *f* correspond to the front wall and noted by index *b* correspond to the back. So, the shielding effectiveness of the front (back) wall is S_{Gf} (S_{Gb}) and the wall area is A_f (A_b). The shielding effectiveness of both walls is defined by (4) for the case $A_f = A_b$: $S_{G2} = 0.5(S_{Gf} + S_{Gb})$. If the averaged power incident to the wall on the inside of the shielded zone for stationary mode is P_{st}, then the shielding effectiveness of the enclosure walls takes the form $S_{G2} = -10\lg(P_{out} / P_{st})$. In case of empty enclosure with the metallic walls containing apertures, the losses defined by the absorption in the walls are less than the losses defined by the radiation leaving the shielded zone ($P_W << P_{out}$) and $P_{loss} \approx P_{out}$. Finally, an intrinsic Q-factor of empty metallic enclosure is defined by the following expression: $Q_0 = 2\pi P_{st} / P_{out} = 2\pi \cdot 10^{S_{G2}/10}$.

Analytical definition of a loaded Q-factor in the presence of absorbers is based on the following formula [20, p. 171]: $Q_{load}^{-1} = Q_0^{-1} + \sum_{k=1}^{M} Q_k^{-1}$, where Q_k is the Q-factor of absorber with the number k located inside the shielded zone and M is the number of absorbers. If the absorbers inside the compartment represent the metallic equipment cases, then Q_k for each case can be calculated based on the case shielding effectiveness in framework of the developed technique.

C. Simplified Model for Distribution of Electric and Magnetic Field Amplitudes inside the Shielding Enclosure

Field amplitudes in an observation point with coordinates $(0,0,z)$ inside the shielding enclosure ($0 < z < L_z$) can be expressed by infinite sum describing a composition of coherent waves reflected from the enclosure walls. Wave amplitudes decrease when the reflection occurs because the walls have a finite shielding efficiency, and the resulting complex amplitudes of the electric and magnetic field intensities in the observation point can be represented as the sum of the decreasing geometric progression [10]:

$$\begin{aligned} E(z,f) &= |E'| \left[\exp(-j\gamma' z) + R_b(\exp(-j\gamma'(2L_z - z))\right] G(f), \\ H(z,f) &= |H'| \left[\exp(-j\gamma' z) - R_b(\exp(-j\gamma'(2L_z - z))\right] G(f), \quad (6) \\ G(f) &= (1 - R_f R_b \exp(-j\gamma' 2L_z))^{-1}, \end{aligned}$$

where $j = \sqrt{-1}$ is imaginary unit; $|E'|$ and $|H'|$ are the wave amplitudes defined by the averaged power penetrating through the illuminated wall and calculated according to (1) and (4); γ' is the propagation constant taking into account the attenuation [3]:

$$\begin{aligned} &\gamma' = \gamma A(Q),\ Z' = Z A(Q),\ A(Q) = 1 + \xi(Q) - j\xi(Q), \\ &\xi(Q) = \sqrt{1 - \left(4\pi / \ln(1 - 2\pi / Q)\right)^2}, \end{aligned} \quad (7)$$

where γ and Z are defined by (2); $A(Q)$ is parameter describing the attenuation; R_f, R_b are reflection coefficients of the front and back wall respectively.

Reflection coefficients $R_{f,b}$ for normal incidence of the radiation from the inside of the shielded zone on the walls are defined by formula [20, p. 35]:

$$R_{f,b} = \left(Z_{f,b} - Z'\right) / \left(Z_{f,b} + Z'\right), \quad (8)$$

where Z' is defined by (7) and $Z_{f,b}$ is a characteristic impedance of the front (back) wall region providing a maximum value of the reflection coefficient at given frequency. The choice of the maximum value of $R_{f,b}$ is necessary to develop the AFC worst-case model based on the simplified deterministic model.

Finally, for the simplified deterministic model of the field distribution defined by the fundamental mode of the waveguide assigned to the shielding enclosure, one can write for the system of reference presented in Fig. 1:

$$\begin{aligned} E_{y10}(x,y,z,f) &= -jE(z,f)\cos(\pi x/L_x), \\ H_{x10}(x,y,z,f) &= jH(z,f)\cos(\pi x/L_x), \\ H_{z10}(x,y,z,f) &= H(z,f)\sin(\pi x/L_x), \end{aligned} \quad (9)$$

where $E(z,f)$ and $H(z,f)$ are defined by (6).

IV. Worst-Case Model for AFCs of Electric and Magnetic Fields inside the Shilding Enclosure

A. Elimination of Irregularity in Spatial Distribution of Reverberation Component

To develop the worst-case model, the averaged amplitudes $|E'|$ and $|H'|$ are replaced in (6) by maximum amplitude values $|E_{\max}'|$ and $|H_{\max}'|$. Integration of the harmonic functions in (9) over the cross section of the waveguide leads to the following value of the electric field amplitude $|E_{\max}'| = 2|E'|$. The maximum value for the magnetic field amplitude is $|H_{\max}'| = 2\max(|H_x|,|H_z|) = 2|H'|$ because a phase difference between the projections of the magnetic field intensity to the axis x and z is $\pi/2$.

Taking into account the higher modes of the waveguide, one can establish that the dependence of deterministic solution on the coordinate y as well as on the coordinate x is described by harmonic functions [13], [14]. Replacement of the harmonic functions by 1 for $x \in (-L_x/2, L_x/2)$ and $y \in (0, L_y)$ provide the worst-case behavior of the model but leads to breaking of boundary conditions on the metallic walls.

The value equal to 2 should be an applicable worst-case estimation of the term $\exp(-j\gamma' z) \pm R_b(\exp(-j\gamma'(2L_z - z))$ in (6) for the high-frequency band because the magnitude of the reflection coefficient R_b is less than 1 (see (8)).

Formulae for the electric and magnetic field reverberation components take the form based on (9), (6) and (1):

$$E_{sm}(f) = 4|E_0|K_E G(f),\ H_{sm}(f) = 4|H_0|K_H G(f). \quad (10)$$

To develop the worst-case model, it is necessary to specify the illuminated wall as the wall with the maximum value of the shielding coefficients K_E and K_H.

B. Worst-Case Model of Reverberation Component AFC

The propagation constant has complex values in the low-frequency band (see (2) and (7)). Substitution of γ' in (6) leads to the decreasing of the field amplitudes for waves propagating inside the enclosure, and the magnitude of the term $G(f)$ defined by (6) is directly substituted in (10) for the low-frequency band model.

The term $G(f)$ has maximum values at resonance frequencies in the high-frequency band. A set of these frequencies can be obtained from the following equation

$$\exp(-j\gamma' 2L_z) = 1, \Rightarrow \gamma' L_z = \pi m, \quad m = 1,2,3... \quad (11)$$

The propagation constant (7) defined by the Q-factor depend on the frequency, and the perturbation theory can be used for solution of (11). A set of resonance frequencies for a lossless system in zero-order of perturbation theory $f_0(m)$ is obtained: $f_0(m) = c/2\sqrt{(m/L_z)^2 + (\max(L_x, L_y))^{-2}}$.

Then the frequencies obtained in zero-order approximation are substituted in the expression for the Q-factor $Q(f_0(m))$ and a refined set of resonance frequencies is obtained in the first-order of perturbation theory:

$$f_1(m) = \frac{c}{2}\sqrt{\left(\frac{m}{L_z A(Q(f_0(m)))}\right)^2 + \left(\frac{1}{\max(L_x, L_y)}\right)^2}. \quad (12)$$

It is empirically established, that the first-order perturbation theory results (12) provide a sufficient accuracy for the future development of the worst-case AFC model.

The set of the resonance frequencies defined for the simplified deterministic model is substituted in (10) to calculate the amplitudes of fields. Straight lines connect the points corresponding to the simplified deterministic model AFC resonances. So, a term $G_{hf}(f)$ replacing the term $G(f)$ in (10) for the high-frequency band worst-case model is

$$G_{hf}(f) = \begin{cases} |G(f_1(1))| & f \in (f_c, f_1(1)), \\ |u f + v| & f \in [f_1(1), \infty). \end{cases}$$
$$u = \Delta G/\Delta f_1, v = (G(f_1(m))f_1(m+1) - G(f_1(m+1))f_1(m))/\Delta f_1, \quad (13)$$
$$\Delta G = G(f_1(m+1)) - G(f_1(m)), \Delta f_1 = (f_1(m+1) - f_1(m)).$$

Amplitudes at resonance frequencies for higher modes unconsidered by the simplified model do not exceed the values obtained by (13) that provides the worst-case behavior of the field AFC model for the high-frequency band:

$$E_{hf}(f) = 4|E_0|K_E G_{hf}(f),\ H_{hf}(f) = 4|H_0|K_H G_{hf}(f). \quad (14)$$

A transition between the frequency bands is based on the introduction of connecting functions eliminating the discontinuity arising at the frequency f_c when the function $G(f)$ in (10) is replaced by the function $G_{hf}(f)$ defined by (13). The connecting functions take the form:

$$E_{con}(f) = E_{lf}(l_1 f_c)(1 - F_{tr}(f)) + E_{hf}(l_2 f_c)F_{tr}(f),$$
$$H_{con}(f) = H_{lf}(l_1 f_c)(1 - F_{tr}(f)) + H_{hf}(l_2 f_c)F_{tr}(f), \quad (15)$$

where $E_{lf}(f)$ and $H_{lf}(f)$ are defined by (6); $E_{hf}(f)$ and $H_{hf}(f)$ are defined by (10) with the function $G_{hf}(f)$ instead of $G(f)$; $F_{tr}(f)$ is the weighting function:

$$F_{tr}(f) = 3(\chi(f))^2 - 2(\chi(f))^3, \chi(f) = (f/f_c - l_1)/(l_2 - l_1). \quad (16)$$

It is empirically established that the choice of parameters $l_1 = 0.9, l_2 = 1.1$ does not lead to underestimation of the field value near the cutoff frequency f_c, because f_c does not depend on the Q-factor (see (12)).

The wideband worst-case AFC model of the electric (magnetic) field reverberation component takes the form:

$$E\{H\}_{REV\,wc}(f) = \begin{cases} E\{H\}_{lf}(f, z) & f \in (0, 0.9f_c) \\ E\{H\}_{\text{con}}(f) & f \in [0.9f_c, 1.1f_c] \\ E\{H\}_{hf}(f) & f \in (1.1f_c, \infty) \end{cases} \quad (17)$$

C. Taking into Account the Line-of-Sight Fields

The description of LOS fields is based on the worst-case model of electromagnetic radiation diffraction by aperture in conducting screen developed in [19]:

$$E\{H\}_{LOS\,wc}(f) = \begin{cases} E\{H\}_C(f, d, \theta, \varphi, x, y, x); \\ E\{H\}_R(f, a, b, \theta, \varphi, x, y, x), \end{cases} \quad (18)$$

where θ and φ are the angles between the direction of the incident ray and the normal to the screen (axis z) in the planes (yz) and (xz) respectively. A local coordinate system with the origin placed in the center of the rectangular (*R*) or circular (*C*) apertures for the LOS fields description is used.

Algebraic addition of the reverberation component and the LOS field amplitudes corresponds to the worst-case behavior of the developed model:

$$E\{H\}_{wc}(f) = E\{H\}_{REV\,wc}(f) + \sum_{k=1}^{N} E_k\{H_k\}_{LOS\,wc}(f) \quad (19)$$

where k is the aperture number, N is the number of apertures in the illuminated wall. Formula (19) is applicable for electrically large as well as for electrically small apertures. To increase a computation efficiency of the model in the case of a big number of identical electrically small apertures (mesh), the following simplified formula can be used:

$$E\{H\}_{wc}(f) = E\{H\}_{REV\,wc}(f) + N' E_1\{H_1\}_{LOS\,wc}(f, 0, 0, z) \quad (20)$$

where z is the distance from the illuminated wall to the observation point; $N' = \min(N, \rho \cdot (c/f)^2)$; ρ is the number of the apertures per unit area.

V. Validation of Developed Model

Validation of the model is carried out by comparison of the calculation results for the magnetic and electric field shielding effectiveness obtained by the model with known experimental results [3], [8] – [12] and numerical simulations by FDTD method. The following cases have been analyzed: rectangular metallic boxes of dimensions $300\times120\times300$ and $483\times120\times483$ mm with brass walls of thickness 1.5 mm. There are the following types of apertures in the illuminated wall: single rectangular aperture with dimensions 10×10, 5×100, 100×100 mm; single circular apertures of diameters 10 and 50 mm; three rectangular apertures of dimensions 160×4 mm; three circular apertures of diameter 20 mm; 21 circular apertures of diameter 12 mm (the minimum distance between the neighboring aperture boundaries in the last three cases is 5 mm). The shielding by a mesh made from copper wire of diameter 0.02 mm with a 0.15 mm grid was analyzed. Frequency range of the analysis is from 10 kHz to 3 GHz. Comparison results for one of the cases are presented in Fig. 2.

The model is also validated by considering an important practical situation. A $2.1\times1.5\times2.3$ m compartment of a car with 5-mm-thick walls made from steel 1010 is modeled; there are 0.5×0.3 m apertures in the walls. Absorbers are placed in the compartment. To obtain the insertion loss IL and the loaded Q-factor Q_{load} of the compartment, the energy source (radiating dipole) and receivers are modeled inside the compartment. The power P_{in} radiated by a dipole mounted inside the compartment is calculated and averaged by the dipole position and orientation. The electric and magnetic field intensities are computed in various points inside the compartment and corresponding power received by the isotropic antenna P_r is calculated and averaged by its position. Calculated Q-factor is substituted in the simplified deterministic model (9) and in the worst-case model (17) in order to analyze a situation in which the plane electromagnetic wave is incident normally on the wall with the aperture. This situation is also simulated numerically by FDTD, and the comparison of the results is presented in Fig. 3.

Cases of underestimation of the field amplitudes by the model are not established during the comparison.

VI. Conclusion

In this paper, the wideband computationally-effective worst-case model of electromagnetic field shielding by a metallic enclosure with apertures is developed. The model can be applied for estimation of intensity of the electric and magnetic components inside a vehicle compartment which can be approximated by rectangular waveguide.

Further development of the model can be associated with more accurate calculation of absorbed energy inside the compartment by the use of detailed parameters of materials.

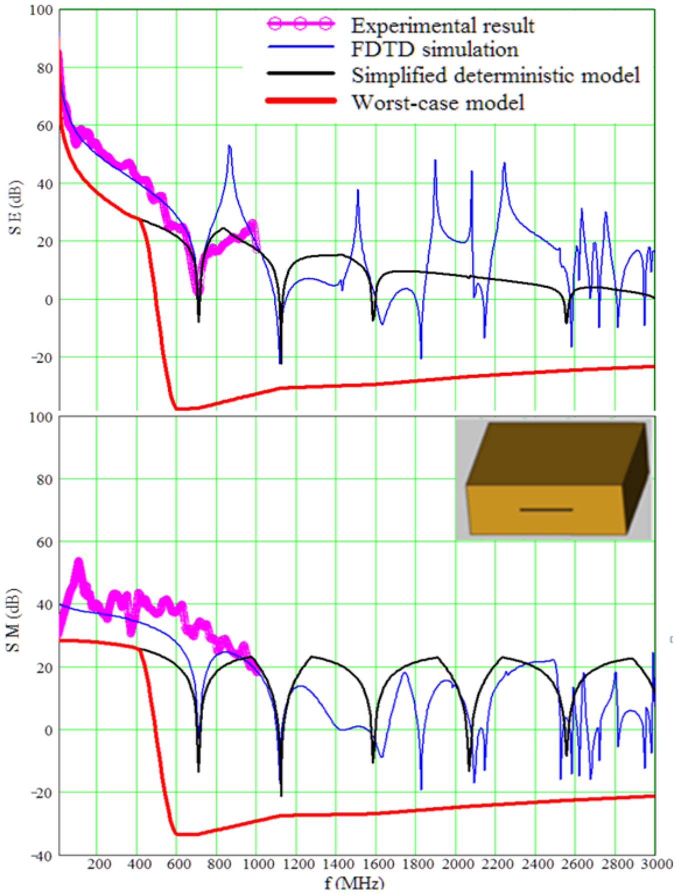

Fig. 2. AFC of shielding effectiveness for a rectangular box (of dimensions 300x120x300 mm) with a single rectangular aperture (of dimensions 5x100 mm) in the illuminated wall. Coordinates of the observation point are (0, 120, 150) mm

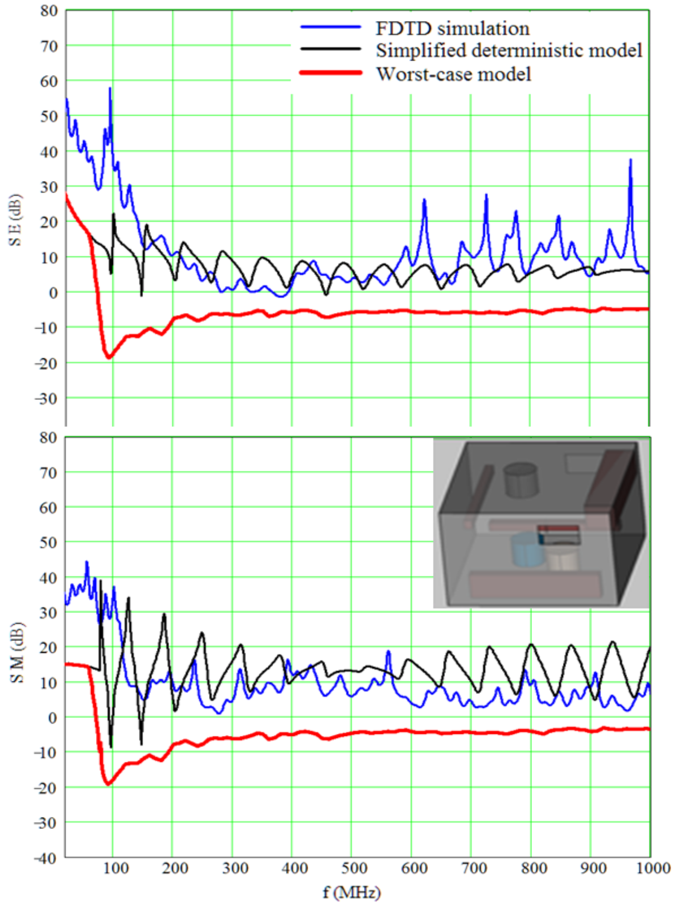

Fig. 3. AFC of shielding effectiveness for a 2.1x1.5x2.3 m compartment with steel walls containing two 0.3x0.5 m apertures. The compartment is filled by absorbers. Coordinates of the observation point are (0, 0.75, 1.15) m

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