Impact of Plane Wave Excitation Parameters on Shielding Properties of Enclosure with Multiple Apertures

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Abstract- **In this paper the influence of parameters of plane wave excitation on shielding efficiency of enclosure with multiple apertures is analyzed. Two groups of two rectangular apertures placed on the adjacent enclosure walls, are considered. For analysis purposesTLM method implemented by means of commercial software is used. The numericalresults, proved to be valuable for the illustration of the effects of excitation parameters on the enclosureshielding performances.**

Keywords **–Electromagnetic shielding, multiple apertures, plane wave**

I. INTRODUCTION

The analysis of problems related to electromagnetic compatibility (EMC) is performed at the system design stage with the use of various numerical simulation techniques. The numerical method based onnetwork of transmission lines(Transmission Line Matrix – TLM) [1,2] and the finite difference method (Finite-Difference Time Domain – FDTD) [3] are widely applied to EMC analysis due to their characteristics. For analysis purpose, by using some of the previously mentioned methods, a detailed problem description in regards to the geometry and electromagnetic (EM) characteristics in the spatial domain is also required. In the time domain, their response to real excitation is simulated, while in the frequency domain the required parameters are calculated. With the use of numerical simulations we can determine the origin, nature and level of electromagnetic interference (EMI) that can affect the electronic system functioning. On the basis of the numerical analysis results, various procedures of electromagnetic protection can then be applied for reducing the coupling paths.

Shielded enclosures, surrounding the electronic system completely or partially, are commonly used as a solution to the problem of electronic system protection, i.e. reduction of the amount of EM radiation that reaches the system from the environment or is emitted into the environment by the system[4-5]. Materials with various EM characteristics and of various thicknesses are used for enclosures construction. In the practical application, enclosures usually have apertures on their walls in order to allow system access and control (connectors, cables, CD-DVD ROMs, etc), cooling and ventilation, or are due to imperfect technological realization. Therefore, electronic system performances in relation to EMC,besides the character of the excitation EM radiation source, the configuration of wire and dielectric structures within the system, also depend on the existence and nature of interconnection paths established through apertures enabling coupling between the EM source energy and sensitive electronic systems. The characterization of EM radiation penetrating into or out of the enclosure through apertures is shown in [6], for the purpose of estimating the impact of aperture existence on the enclosure shielding efficiency. Coupling through an aperture often has a dominant impact on the system operation in relation to EMC.

The level of EM radiation that penetrates into or out of the enclosure through the apertures, apart from the number of apertures, their geometry and mutual distance, can significantly depend on the excitation radiation parameters. Therefore, this paper discusses the effect of changing the polarization angle, azimuth and elevation of the electric field vector on the electric SE in the case of plane EM wave excitation. Multiple apertures, represented by two groups of two rectangular apertures, are assumed on the adjacent enclosure walls for system access and control purposes. Numerical TLM modelling method, implemented through a commercial software package, is used in order to estimate the efficiency of rectangular enclosure with multiple apertures over a frequency range up to 2 GHz. On the basis of the obtained numerical results, we have made appropriate conclusions, in relation to the effect of the analyzed excitation parameters on the enclosure shielding performances.

II. SHIELDING EFFECTIVENESS - SE

The parameter often used to estimate the enclosure performances is the shielding effectiveness (*SE*). The shielding effectiveness can be calculated with the use of a numerical simulation technique, in an analytical way and by measurements. It is expressed in dB and defined as the ratio between the incident field level in the appropriate point in the system without enclosure (E_i) and with enclosure (E_t) [1]:

$$SE = 20\log\left|E_i / E_t\right| \tag{1}$$

where E_i is the incident field level and $E_t$is the level of the field transmitted through the aperture.

*SE*is defined separately for electric (so-called electric *SE*) and magnetic field (so-called magnetic*SE*).Electric and magnetic *SE's*donot always have the same value. The minimum required *SE*value is 20dB. For most EMC problems, satisfactory effectiveness is in the range between 50 dB and 60 dB, but due to the increased number and complexity of electronic system it is desirable to achieve the highest possible effectiveness (about 100 dB).

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For the case of enclosure with perfectly conducting walls and with one rectangular aperture (i.e. slot because aperture length *l* is significantly larger than width *w*) placed at the center of the front wall (Fig.1), there is an analytical formulation of *SE*, based on the equivalent circuit model shown in Fig.2 [1,7].The model is derived for an excitation in the form of plane wave that propagates in a direction perpendicular to the front wall and whose electric field is polarized vertically in relation to the longer side of the aperture. In this case aperture has a considerable effect on the current flow induced on front wall leading to larger penetration of the incident field into enclosure.

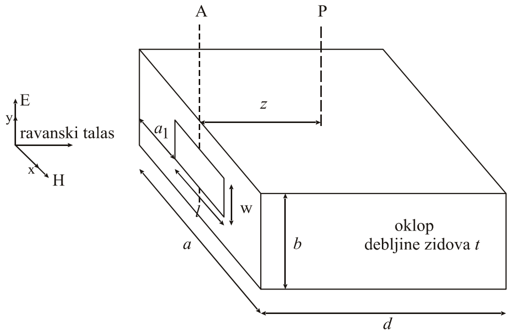


Fig.1. An enclosure with the rectangular cross section and single rectangular aperture

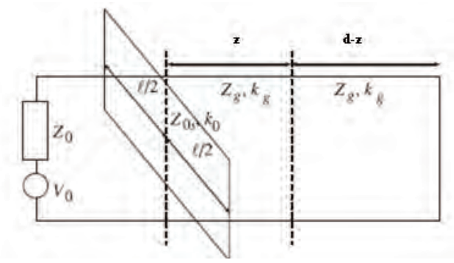


Fig.2. Equivalent circuit model of enclosure with a rectangular aperture, excited by a plane wave

The elements of the equivalent circuit model from Fig.2 represent the source of EM radiation, the aperture and enclosure itself. The incident plane wave is described with voltage generator, where V_0 represents the incident field amplitude and $Z_0$is the free space impedance ($Z_0 \approx 377\ \Omega$). The rectangular aperture is represented by a coplanar stripline that is short-circuited on both ends, where the total width of the coplanar stripline equals the height of the enclosure *b*, while the distance between strips equals the width of the aperture. The enclosure excited by the field generated at the aperture and short-circuited on the other end is describedas a short-circuited rectangular waveguide in which the TE_{10} mode propagates along the z-axis.

With the application of the Thevenin's Theorem, the calculation of the electric field within the enclosure at the distance *z*from the wall with rectangular aperture is reduced to calculation of voltage $V(z)$ in the equivalent circuit. Since in the absence of enclosure the electric field at the same point is equal to a half of the voltage V_0, electric *SE* is:

$$SE = 20\log\left(\frac{V_0}{2V(z)}\right) \qquad (2)$$

The described model for calculation of the electric *SE* takes into consideration the existence of only one aperture situated in the center of a wall. If there are*n*apertures on the same wall placed at a distance where their mutual coupling can be neglected, equivalent circuit model should be modified to include *n* coplanar striplines, short-circuited on both ends and connected in series.

However, in reality enclosures can have multiple apertures on several wallsand incident plane wave polarization and propagation directioncan be different from the simplified case shown in Fig.1. In that case more complex techniques for the electric *SE*calculation should be used.It is necessary to perform decomposition of the electric field vector into *x*, *y* and*z* components.The calculation of voltage $V(z)$ at the point at the distance *z* from the enclosure wall with apertures can be obtained through superposition of the voltage components as described in [8]. Such process can be very complicated, time-consuming and restricted by aperture dimensions and their mutual arrangement that can be taken into account. Therefore, in order to conduct an efficient analysis of plane wave propagation and polarization direction influence on the electric *SE*of the enclosure with multiple apertures represented by two groups of two rectangular apertures on the adjacent walls, numerical TLM method, implemented through a commercial software package, is applied in this paper and numerical simulation results are presented in the following section.

III. Numerical Analysis

For the calculation of the electric *SE*with the use of numerical TLM simulation, in this paper we used a metal enclosure with the rectangular cross-section whose dimensions are 300x120x300mm. An enclosure has two groups of two rectangular apertures the same size (30x20 mm) on adjacent walls as shown in Fig.3. The thickness of perfectly conductive walls of enclosure with rectangular apertures was t = 3 mm. The distance between the apertures was selected for the purpose of reducing their mutualcoupling effect and impact on *SE*. The frequency range of interest in this paper is from 0 to 2 GHz. We have already analyzed the effect of incident plane wave parameters on *SE*of an enclosure with two rectangular apertures of the same dimensions but situated only on one wall of the enclosure [9]. Fig. 3 shows the proposed enclosure model with plane wave parameters that we will change for the purpose of analyzing their impact on *SE.*

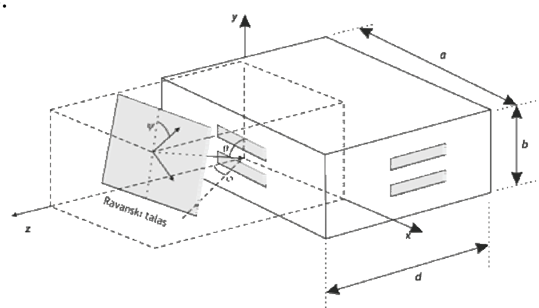
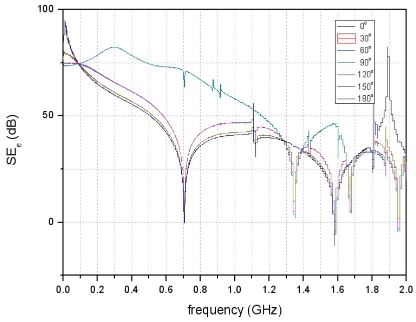
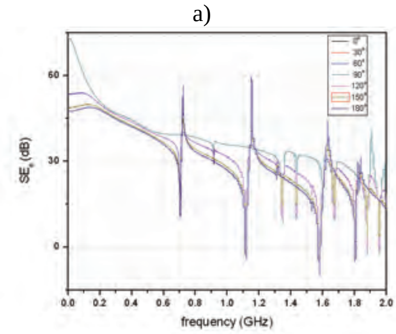


Fig.3. An enclosure with two groups of two rectangular apertures on adjacent walls and with plane wave parameters (angles ψ, θ i φ)

The polarization angle ψ of the plane wave electric field vector propagating in the direction that is vertical to one wall of the enclosure with apertures (θ=90° and φ=0°) is changed within the range from 0° to 180°, with steps of 30°.The change of SE_e is given in Fig.4, at the point in the center of the enclosure (Fig.4a), and at the point closer to the front wall with apertures (Fig.4b).



a)



b)

Fig.4. SE_e of the proposed enclosure model depending on the polarization angle of the electric field vector, observed in: a) the center of the enclosure, and b) a point closer to the front wall apertures

It can be noticed that a change of the polarization angle of the electric field vector from 0° to 90°, results in increase of SE_e.Highest value of SE_e, for the proposed enclosure model,is reached for the angle ψ=90°, (the electric field has the x component only), which is especially visible at the point in the center of the enclosure. Further change of the polarization angle of the electric field vector up to 180° results in reduction of the SE_e. We can also observe overlapping of curves for 0° and 180°, 30° and 150°, and 60° and 120°. The effect of polarization change is higher at the point closer to the apertures. Electric effectiveness at this point is 20dB lower than at the point in the center of the enclosure.

Fig.5 shows the change of SE_e within the observed frequency range for the polarization angle of the electric field vector ψ=90° for the proposed enclosure model at three points within the enclosure (point coordinates are given in the graph). With increasing the distance from the apertures the electric effectiveness increases. The SE_e will be highest at the point that is farthest from theapertures (point 150,60,30), while at points in the vicinity of the apertures it is considerably lower.

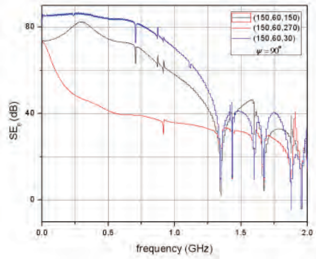


Fig.5 The change of SE_e for ψ=90° at various points within the enclosure

Fig.6 shows the change of SE_e at the first and second resonant frequency as function of the polarization angle at center point of enclosure, whose coordinates are given in the graph.

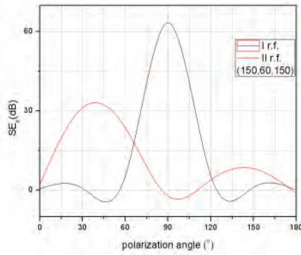
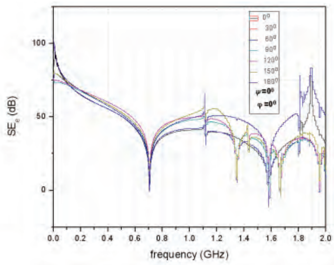


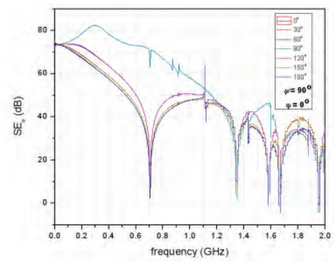
Fig.6. The change of SE_e with polarization angle at center point of enclosure at the first and second resonant frequency

The most critical case, from the aspect of electric effectiveness, is the point situated in the vicinity of apertures in *y-z* plane.The highest effectiveness is recorded at the point that is furthest from the apertures.

For constant polarization of the electric field vector (ψ= 0° and ψ=90°)and constant azimuth (φ=0°) we changed the elevation angle (the excitation position in the elevation plane around the enclosure wall with apertures) from 0° to 180°, with step of 30°. Fig. 7 illustrates the effect of the electric SE_e change at the point in the center of the enclosure for ψ= 0°, φ=0°and ψ=90°, φ=0°.



a)



b)

Fig.7. *SE* due to the change of the elevation angle of the electric field vector for a) ψ= 0°,φ=0° and b) ψ=90°, φ=0°

It can be concluded that a change of the elevation angle of the electric field vector for ψ=0° and φ=0° to the second resonant frequency has no considerable effect on SE_e (curves partially overlap). For ψ=90° and φ=0° the highest electric *SE* is for θ=90°.

Fig.8 shows the change of SE_ein the function of the elevation angle with ψ =90°,φ=0°and ψ =0°, φ=0°, at the first resonant frequency.

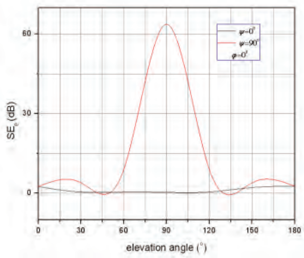
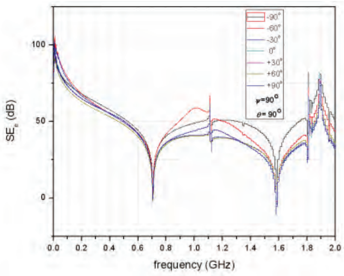
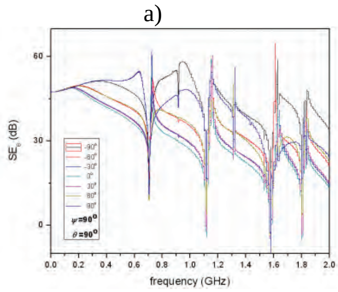


Fig.8. SE_e in the function of the elevation angle for ψ=90°, φ=0° and ψ =0°, φ=0°on the first resonant frequency

In the following case, as shown in Fig.9, we analyzed the effect of a change of azimuth of the electric field vector, from -90° to 90°, with steps of 30° on SE_e with constant polarization angles ψ =90° and the elevation θ=90°.



a)



b)

Fig.9. SE_e of the proposed enclosure model depending on angle φ a) in the center of the enclosure, b) at a point closer to the front side with apertures

With a change of azimuth, for the proposed enclosure modelthe curves for electric effectiveness mostly overlap up to the first resonant frequency. Between the first and the second resonant frequency, the highest SE_e is for φ = -60°, and above the second resonant frequency for φ = -90°.

IV. Conclusion

Shielded enclosures, as one of the most frequent types of electromagnetic protection, have apertures on their walls. The purpose of the apertures is various, for access to the system for its control and power supply, the need for cooling and removal of surplus heat from the system, etc. Through the apertures the EM radiation penetrates into the enclosure, i.e. the space outside it, which degrades its protective function. Assuming that conductance of the enclosure walls is very high, the EM coupling through the apertures has dominant impact on functioning of the electronic systems regarding EMC. For evaluation of the shielding effectiveness, in this work we applied the numerical TLM method, implemented through an appropriate software package. The proposed enclosure model is rectangular and has two rectangular apertures at fixed mutual distance on two adjacent sides of the enclosure. We analysed the effect of excitation parameters of a plane EM wave, polarization, elevation and azimuth of the electric field vector on the electric *SE* of the enclosure. Based on the results obtained through numerical simulation, we can select an optimal position of the system in the enclosure, so that the influence of EM interference on the electronic system is minimal. For most practical EMC problems, excitation in the form of a plane wave represents approximation of real excitation. Under real conditions, when EM radiation reaches the enclosure at an approximate angle, the situation is more complex. In the upcoming period, the authors intend to carry out detailed investigation of the excitation parameter impact on the system shielding function.

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