Numerical Model of Enclosure with Receiving Dipole Antenna for Shielding Effectiveness Calculation

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***Abstract* – Numerical model of rectangular enclosure with a real receiving antenna is considered in the paper in order to investigate an impact of antenna presence on electric shielding effectiveness. Dipole antenna, often used in experimental setup to measure the level of electromagnetic field at some characteristic points in enclosure, is described by using a compact wire model implemented into transmission-line matrix (TLM) method. Using the proposed model, impact of receiving antenna on shielding effectiveness is illustrated on several examples of enclosure with apertures and compared with the corresponding numerical and circuital approaches in which the antenna presence is neglected.**

***Keywords* – Enclosure, shielding effectiveness, dipole antenna, wire TLM model.**

I. INTRODUCTION

The most frequently used types of electronic equipment for electromagnetic (EM) protection, are metallic enclosures. The shielding enclosure performances are quantified by shielding effectiveness (SE), defined as the ratio of field strength in the presence and absence of the enclosure. Integral parts of the shielding enclosure are apertures of various forms, intended for heat dissipation, control panels, outgoing or incoming cable penetration, airing or other purposes. The shielding enclosure with apertures should be designed based on the analysis of the EM coupling mechanism through apertures, in order to minimize the EM interference (EMI) and susceptibility risk due to inevitable discontinuities.

There are many techniques used to calculate SE, from analytical methods to numerical simulations. Analytical formulations [1] are a quick tool based on the Fourier transformation and the model analogy. A more complex approach to this problem requires solving the sophisticated problem of scattering using the Mendez`s method [2]. Simple solution based on circuital approach has been proposed in [3] but with some limitations in terms of location of apertures, angle and polarization of incident plane wave and TE/TM modes that can take into account. Circuital approach has been modified in [4] to allow for considering oblique incidence and polarization and not to be limited by the location of aperture with respect of plane wave propagation direction. In that model, the SE of the enclosure with apertures on multiple sides can be simply calculated by superposition of one dimensional result, and the problem of SE considering the field with arbitrary incidence and polarization angle can be solved by vector decomposition.

Differential numerical techniques in the time domain, such as the Finite-Difference Time-Domain (FDTD) method [5] and Transmission Line Matrix (TLM) method [6], owing to their characteristics, have found their application in solving many electromagnetic compatibility (EMC) problems in a wide frequency range. In [7] TLM method has been successfully employed to calculate SE of shielding enclosure with apertures over a broad frequency band (up to 3 GHz). In parallel with this research, authors of this paper have conducted their own analysis of influence of various factors, such as aperture patterns, their dimensions, number and orientation with the respect of enclosure walls or plane wave propagation direction, on shielding efficiency of enclosure and the results have been presented in [8] and [9]. In addition, impact of plane wave excitation parameters of shielding properties of enclosure with multiple apertures has been considered by the authors in [10] and [11]. Again, TLM method was used in [8]-[11] to numerically study these various effects over a frequency range up to 2 GHz.

In practice, when EMC measurements are performed, to experimentally characterize the SE of enclosure, small dipole receiving antenna, is located inside the enclosure. Such antenna is used to measure the level of EM field, coming from external interference source through apertures, at the points in the enclosure in order to perform the SE calculation. Receiving antenna of finite dimensions could significantly affect the EM field distribution inside the enclosure [12] and thus affect the results for SE. Both either circuital or numerical approaches mentioned above did not take into account the presence of receiving antenna. Therefore, in this paper TLM method enhanced with compact wire model [13] to efficiently describe the dipole antenna, is applied in order to create a numerical model that can used to investigate the impact of receiving antenna on SE of enclosure. This model has been used here to calculate the SE of rectangular enclosure with one or two apertures of rectangular cross-section on the front wall and two adjacent walls, in the frequency range of up to 2GHz. Obtained numerical results illustrate the SE variation due to receiving antenna in comparison with the circuital or numerical case when its presence is neglected.

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II. COMPACT WIRE TLM MODEL

The modelling of thin wires is a permanent difficulty for all differential numerical modelling methods. The simplest solution is to model wires by using short-circuit nodes or shorted link-lines adjacent to the wire surface [6]. This, however, is rarely a practical proposition, as computational resource limitation and geometrical disparity between the modelled space and fine features in the EMC problems result in a rather crude rectangular shape model of the wire. This can cause shift of the resonances by 5-10% to lower frequencies, a problem which is referred to as 'resonance error'.

Sophisticated solution in the form of compact wire model or wire node, which can allow for accurate modelling of wires with a considerably smaller diameter than the node size, has been introduced in TLM method [13]. It use special wire network embedded within TLM nodes (Fig.1) to model signal propagation along the wires, while allowing for interaction with the EM field. In order to achieve consistency with the rest of the TLM model, the each segment of wire network within one TLM node is formed by using additional link and stub lines (Fig.2) and it is coupled with the electric field component parallel to its direction. The parameters of link and stub lines are chosen to model the per-unit length wire capacitance and inductance, while at the same time maintaining synchronism with the rest of the transmission line network.

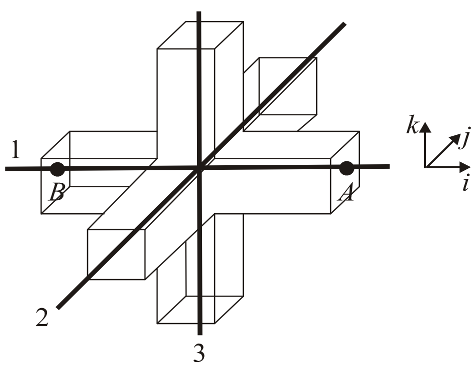

Fig.1. Wire segments embedded within the symmetrical condensed TLM node

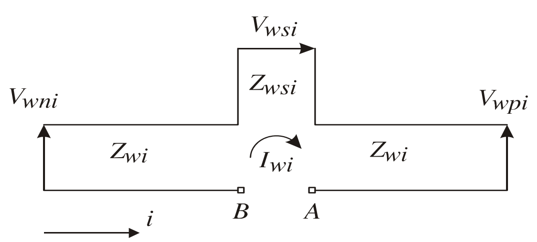

Fig.2. Link and stub lines network for straight wire segment running in *i* direction

The single column of TLM nodes, through which wire conductor segments pass, can be used to approximately form the fictitious cylinder which represents capacitance and inductance of wire per unit length. Its effective diameter, different for capacitance and inductance, can be expressed as a product of factors empirically obtained by using known characteristics of TLM network and the mean dimensions of the node cross-section in the direction of wire running [13]. For an example, for the node containing *i*-directed straight wire segment, as depicted in Fig.2, the effective diameters of fictitious cylinder for wire capacitance and inductance can be defined as:

$$d_{Ci} = 2k_{Ci}\Delta i_c \tag{1}$$

$$d_{Li} = 2k_{Li}\Delta i_c \tag{2}$$

respectively, where Δi_c represents mean cross-section dimensions of TLM node in i direction, $\Delta i_c=(\Delta j+\Delta k)/2$. Empirically found factors k_{Ci} and k_{Li} for the wire located in free space are:

$$k_{Ci} = 0.0511k_i^2 + 0.0194k_i + 0.617 \tag{3}$$

$$k_{Li} = 0.34 \tag{4}$$

and for the wire above the ground:

$$k_{Ci} = 0.0223k_i^2 + 0.024k_i + 0.606 \tag{5}$$

$$k_{Li} = 0.347 \tag{6}$$

Parameter k_i depends on time- and space-step discretization and EM properties of medium represented by TLM node and it can be calculated as:

$$k_i = 2\Delta t/(\sqrt{\varepsilon\mu}\Delta i_c) \tag{7}$$

Once the effective diameters are known, the per-unit length wire capacitance and inductance can be calculated as:

$$C'_{wi} = 2\pi\varepsilon/\ln(d_{Ci}/d_w) \tag{8}$$

$$L'_{wi} = \mu\ln(d_{Li}/d_w)/2 \tag{9}$$

where d_w is a real wire diameter. Wire per-unit length capacitance is then modelled by the link line of characteristic impedance Z_{wi}:

$$Z_{wi} = \frac{\Delta t}{\Delta i\, C'_{wi}} \tag{10}$$

while the wire per-unit length inductance is modelled by short-circuit stub of characteristic impedance Z_{wsi}:

$$Z_{wsi} = L'_{wi}\frac{\Delta i}{\Delta t} - Z_{wi} \tag{11}$$

III. RESULTS

For analysis purposes we used the rectangular enclosure with the following dimensions: l_x = 300 mm, l_y = 300 mm and l_z = 120 mm. The front wall of the enclosure was made of the 3 mm conductive material with rectangular apertures having different dimensions and numbers: one 50 mm x 10 mm aperture, one 50 mm x 30 mm aperture and two 50 mm x 10 mm apertures. We have calculated the enclosure SE for a plane wave of normal incidence to the front wall and vertical (z) electric polarization as excitation, as shown in Fig.3.

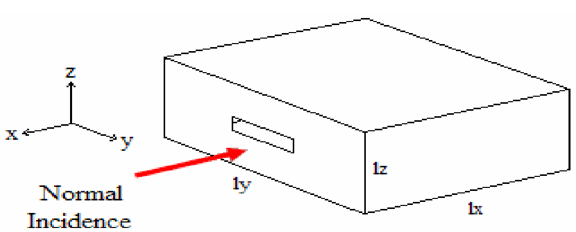

Fig.3. Rectangular enclosure with a rectangular aperture

In the first case, for calculating SE using the numerical model, we assumed that the presence of the receiving antenna could be neglected (empty enclosure). The SE was calculated at the point of the enclosure (145 mm, 150 mm, 60 mm) for all specified patterns of rectangular apertures, by using the conventional TLM method (Fig.4).

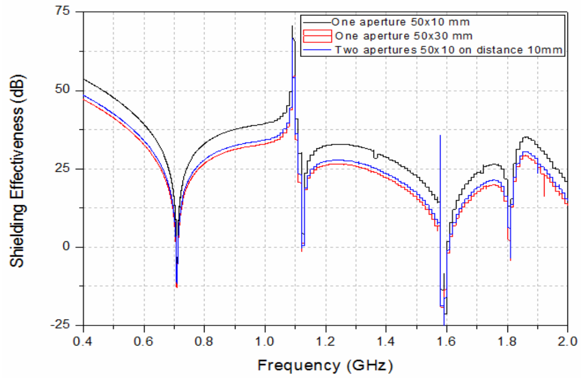

Fig.4. Numerical results for the SE of enclosure without antenna at the point 145 mm x 150 mm x 60 mm

As can be seen from Fig.4, the shape of the SE curves for all considered patterns of apertures remains the same, including the values of resonant frequencies. This indicates that the patterns and the number of apertures only affect the level of attenuation to which EM field propagating through apertures is exposed. As expected, the level of SE decreases with the increase of area covered by apertures. However, as it will be shown next, these results deviate to some extent from the case when the receiving antenna is included in the model.

For calculating SE when the receiving dipole antenna is included in the numerical model of the enclosure by using the compact wire model described in section II, the antenna is modelled as z-directed 80 mm long wire having the diameter of 1.6 mm. Its position within the enclosure is defined by points (145 mm, 150 mm, 20 mm) and (145 mm, 150 mm, 100 mm). The numerical results for the SE of enclosure, shown in Fig.5, are calculated at the centre point of the receiving dipole antenna (145 mm, 150 mm and 60 mm). In comparison with the case when enclosure is empty, it can be seen that the antenna presence significantly decreases the SE of enclosure in the whole frequency range.

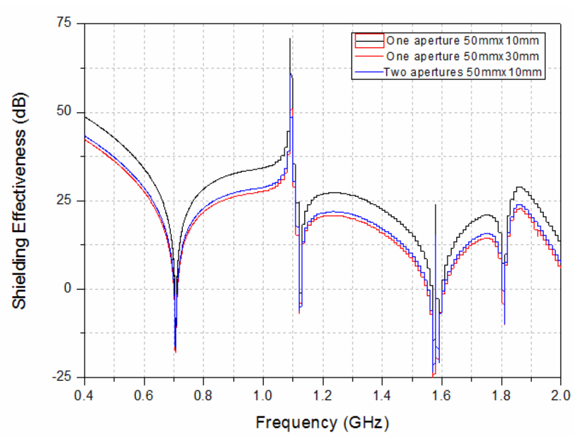

Fig.5. Numerical results for the SE of enclosure with antenna at the point 145 mm x 150 mm x 60 mm

Next, we presented numerical results obtained when the receiving antenna was not included in the model, when the receiving antenna was included in the model, and the modified circuital model results described in [4]. The calculated SE of the receiving dipole antenna at the centre point (145 mm, 150 mm and 60 mm) and of the empty enclosure at the same point, are shown in Figs.6, 7 and 8, for all considered aperture patterns. In the same figures the SE values obtained by circuital/analytical model are also shown.

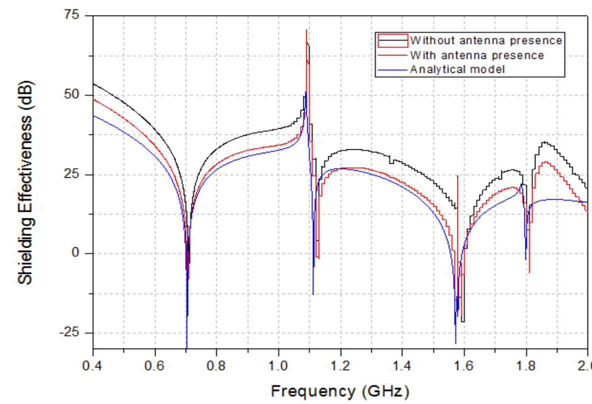

Fig.6. Results for SE of enclosure, with one aperture of dimension 50 mm x 10 mm, at the point 145 mm x 150 mm x 60 mm

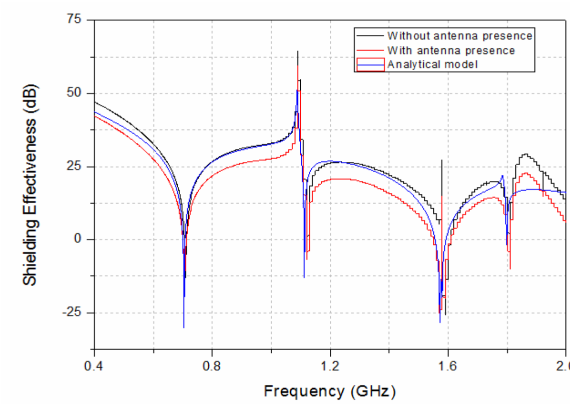

Fig.7. Results for SE of enclosure, with one aperture of dimension 50 mm x 30 mm, at the point 145 mm x 150 mm x 60 mm

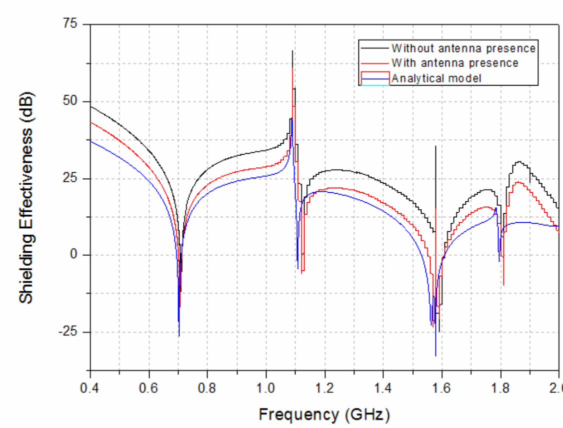

Fig.8. Results for SE of enclosure, with two apertures of dimension 50 mm x 10 mm, at the point 145 mm x 150 mm x 60 mm

It can be seen that the presence of the receiving antenna significantly reduces the shielding efficiency of the enclosure, as the SE level is always lower in comparison with the case when the enclosure is empty. Although the presence of antenna is neglected in the circuital approach, the SE values of enclosures with one and two 50 mm x 10 mm apertures are lower than the numerical results obtained. For the enclosure with one 50 mm x 30 mm aperture dimensions, the results obtained by circuital approach practically coincide with the numerical results obtained for an empty enclosure. Also, there is a tendency to slightly shift the resonant frequencies of enclosure.

Finally, the rectangular enclosure with apertures on multiple sides for oblique incident plane wave is considered. Numerical results for SE at the point 145 mm x 150 mm x 60 mm obtained by using TLM method with and without compact wire model and results obtained using circuital approach at the same point are shown in Fig.9. Two groups of two rectangular apertures of dimension 50 mm x 10 mm are placed on the adjacent enclosure walls while an obliquely incident wave with the azimuth angle 60°, elevation angle 90°, and polarization angle 30° is used as excitation. It can be seen that the presence of the receiving antenna significantly reduces the SE of the enclosure and that results obtained using circuital approach are lower than the numerical results.

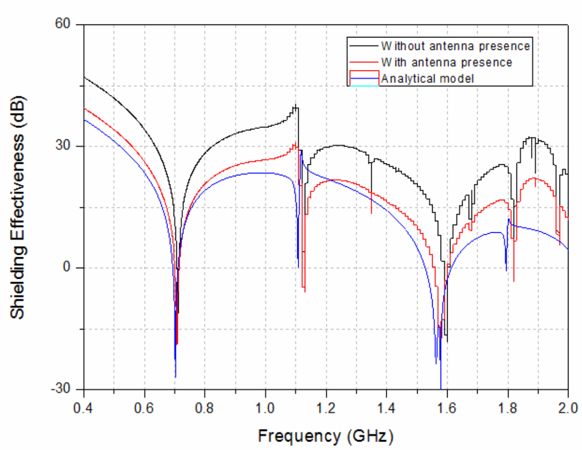

Fig.9. Results for SE of enclosure, with two groups of two rectangular apertures of dimension 50 mm x 10 mm placed on the adjacent enclosure walls, at the point 145 mm x 150 mm x 60 mm

IV. Conclusion

The TLM method, enhanced by the compact wire model, has been used here to generate a numerical model that can provide a tool for analysing the impact of the receiving dipole antenna on the enclosure electric shielding effectiveness. The given example confirm that the antenna presence affects the EM field distribution inside the enclosure and thus affects the SE level results, as well as the location of resonant frequencies. The results of circuital approach do not coincide in all cases with the numerical simulation results, but this fast analytical method can be used for approximate calculation of SE of enclosures. Future research will comprise numerical estimation of antenna impact on SE for given antenna dimensions and also modification of the circuital model in order to include the presence of the receiving antenna, since it is a real element in the measurement process.

Acknowledgement

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