Shielding Effectiveness of Rectangular Enclosure with Apertures and Real Receiving Antenna

Vesna Milutinović, Tatjana Cvetković
Republic Agency for Electronic Communications
Belgrade, Serbia
vesna.milutinovic@ratel.rs, tatjana.cvetkovic@ratel.rs

Bratislav Milovanović, Nebojša Dončov
Faculty of Electronic Engineering, University of Niš
Niš, Serbia
bata@elfak.ni.ac.rs, nebojsa.doncov@elfak.ni.ac.rs

***Abstract* – In this paper, a numerical model of rectangular enclosure with apertures and a real receiving dipole antenna is considered for the purpose of accurate electric shielding effectiveness calculation. Dipole antenna is often used in practice to measure the level of electromagnetic field at some points inside the enclosure in order to estimate its shielding efficiency. Transmission-line matrix (TLM) method enhanced with compact wire model is applied here to generate the numerical model that takes into account the presence of receiving dipole antenna inside the enclosure. Using the proposed model, impact of receiving antenna on electric shielding effectiveness is illustrated on the example of enclosure with three different patterns of rectangular apertures and compared with the case when antenna presence is neglected. A plane wave propagating in a direction normal to the front wall of enclosure is assumed as an external interference signal.**

***Keywords* – Enclosure, shielding effectiveness, receiving antenna, TLM method, compact wire model.**

I. INTRODUCTION

Most of the electronic equipment need a metallic enclosure in order to mechanically protect and to electrically shield the interior printed circuit boards (PCBs) and subsystems. The apertures or slots of various forms are essential parts of the shielding enclosure for outgoing or incoming cable penetration, control panels, heat dissipation, airing or other purposes. In order to minimize the electromagnetic interference (EMI) and electromagnetic susceptibility (EMS) risk due to inevitable discontinuites, the shielding enclosure with apertures should be designed based on analysis of electromagnetic (EM) coupling mechanism through apertures. The performances of a shielding enclosure is quantified by shielding effectiveness (SE) defined as the ratio of field strength in the presence and absence of enclosure.

The ability to accurately estimate the SE of an enclosure can be very valuable in electromagnetic compatibility (EMC) design process. A wide range of techniques are available for the calculation of SE, varying from quick analytical analysis, through to experimental measurement and the numerical simulation. It is very important that the coupling through the apertures is taken into account as their presence could significantly degrade the SE. There are several methods already developed for the calculation of SE of metal enclosures with apertures on their walls, such as analytical formulations [1], which relies on 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.

Differential numerical techniques in the time domain, such as the Finite-Difference Time Domain (FDTD) method [5] and the Transmission Line Matrix (TLM) method [6], owing to its characteristics, have found their application in solving many 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 the research presented in [7], 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, usually in anechoic chamber, to experimentally characterize the SE of enclosure, small dipole antenna, acting as receiver, is located inside the enclosure. It is connected by coaxial cable passing through wall aperture to the network analyser outside the enclosure. Such antenna is used to measure the level of EM field, coming from external interference source (usually represented by far-field antenna in experimental setup) through apertures, at different points in the enclosure in order to perform the SE calculation. Presence of receiving antenna of finite dimensions and its coaxial cable connection could significanlty affect the EM field distribution inside the enclosure [12] and thus affect the resuls for SE. Both either analytical/circular or numerical approaches mentioned above did not take into account these two factors.

In this paper, TLM method enhanced with compact wire model [13] to efficiently describe the receiving dipole antenna, is applied to create a numerical model of enclosure that can replicate the experimental setup used to measure enclosure's shielding efficiency. The impact of antenna cable connection on the SE is not considered can be neglected in the frequency range considered in the paper. Numerical model has been used here to calculate the SE of rectangular enclosure with one or three apertures of rectangular cross-section on the front wall. Plane wave which propagates in a direction normal to the front wall represents an emission from a far field antenna acting in the experimental setup as an external interference signal. Obtained numerical results illustrate the SE variation due to receiving antenna in comparison with the case when its presence is neglected.

II. TLM METHOD – COMPACT WIRE MODEL

The TLM method [6] is a numerical modelling technique based on temporal and spatial sampling of EM fields. In TLM method, a three-dimensional (3D) EM field distribution is modelled by filling the space with a network of transmission lines and exciting a particular field component in the mesh. EM properties of a medium are modelled by using a network of interconnected nodes. A typical node structure is the symmetrical condensed node (SCN), which is shown in Fig. 1.

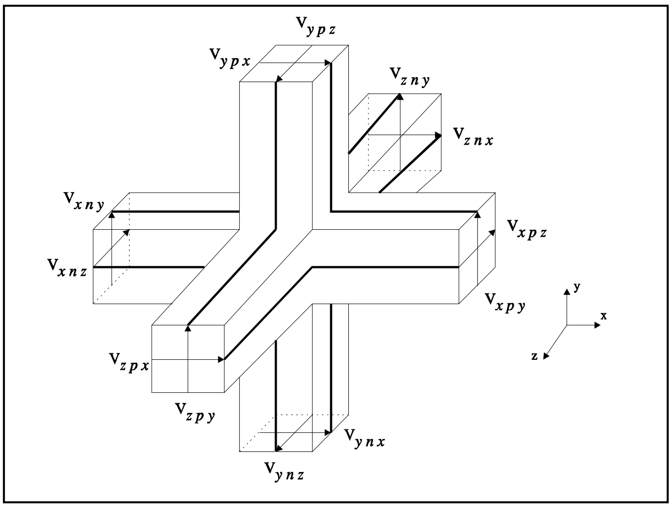

Fig.1. Symmetrical condensed node

To operate at a higher time-step, a hybrid symmetrical condensed node (HSCN) [6] is used. An efficient computational algorithm of scattering properties, based on enforcing continuity of the electric and magnetic fields and conservation of charge and magnetic flux, is implemented to speed up the simulation process. For accurate modelling of this problem, a finer mesh and cells with arbitrary aspect ratio suitable for modelling of particular geometrical features are applied. External boundaries of arbitrary reflection coefficient are modelled in TLM by terminating the link lines at the edge of the problem space with an appropriate load.

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 [13]. It use special wire network embedded between nodes to model signal propagation along the wires, while allowing for interaction with the electromagnetic field. In order to achieve consistency with the rest of the TLM model, this wire network is formed by using additional link and stub lines. The parameters of these lines are chosen to model the capacitance and inductance increased by the wire presence, while at the same time maintaining synchronism with the rest of the transmission line network. An interface between the wire network and the rest of TLM network must be devised to simulate coupling between the electromagnetic field and the wire.

The single column of TLM nodes, through which wire conductor passes, 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 the illustrative purpose, an example of the simplest wire node containing *i*-directed straight wire segment is depicted in Fig.2.

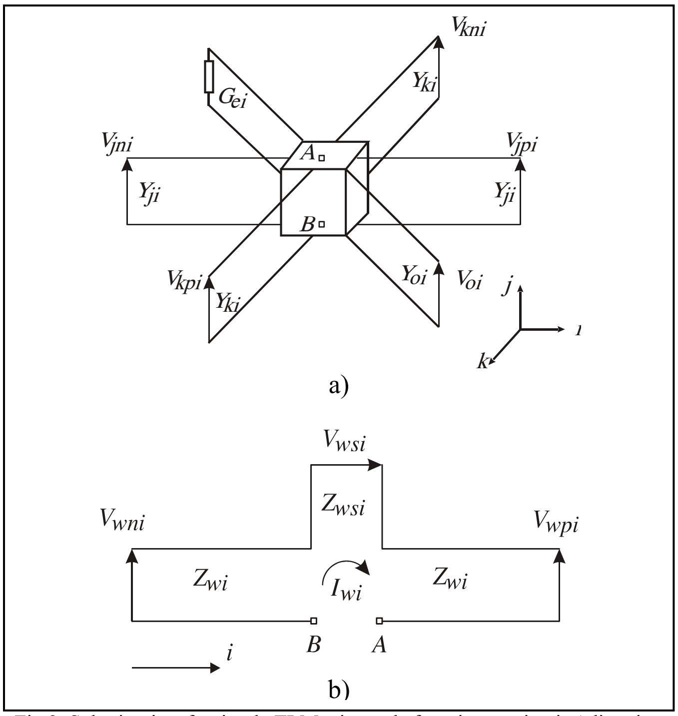

Fig.2. Sub-circuits of a simple TLM wire node for wire running in *i* direction: a) ordinary node ports coupling with E_i field component, b) wire network

This straight wire segment couples with the electric field component parallel to its direction and as a result, the first sub-circuit of the wire node (Fig.2a) contains only ordinary TLM ports associated with the E_i field component. These are ports from the link lines polarized in the *i*-direction (pulses V_{jni}, V_{jpi}, V_{kni}, and V_{kpi}, and characteristic admittances Y_{ji}, and Y_{ki},) and from the open-circuit stub coupling with E_i (pulse V_{oi} and characteristic admittance Y_{oi}). A shunt conductance G_{ei} is also included in Fig. 2a to allow for lossy media. The second part of the wire node is the wire sub-circuit (Fig.2b) modelling a wire running in the *i* direction. It contains two link lines of the impedance Z_{wi} to model pulses travelling along the wire (V_{wni} and V_{wpi}) and a short-circuit stub of the impedance Z_{wsi}, associated with the pulse V_{wsi}, which is used to make up for any deficit in the modelled wire inductance. Coupling between the two sub-circuits of the wire node is achieved through points *A* and *B*.

III. NUMERICAL RESULTS

An enclosure with rectangular cross-section dimensions: l_x = 30 cm, l_y = 40 cm and l_z = 20 cm and with rectangular apertures on front wall is considered here (Fig. 3). The frontal panel of the enclosure is made of 2 mm conducting wall with different patterns of rectangular apertures and their numbers as shown in Fig. 4. A plane wave of normal incidence to the frontal panel and with vertical (z) electric polarization is used as an excitation.

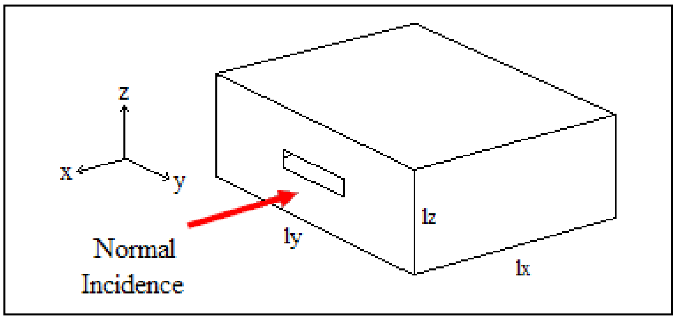

Fig.3. Rectangular enclosure with a rectangular aperture

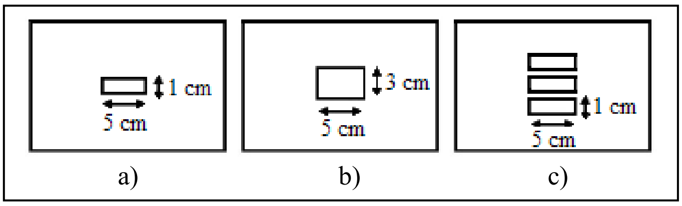

Fig.4. Frontal panel with one or three apertures of different size

First, it is assumed that the presence of receiving antenna can be neglected in the numerical model (empty enclosure). The SE is calculated at the point of the enclosure (14.5 cm, 20 cm, 10 cm) for all three considered patterns from Fig.4 by using conventional TLM method (Fig.5). It can be seen from Fig.5 that a shape of the SE curves for all considered patterns remains the same, including the values of resonant frequencies. This indicates that the patterns and number of apertures considered in them only affect the level of attenuation to which EM field propagating through apertures is exposed. As expected, the level of SE increases with the decrease of frontal panel area covered by apertures. Also, it can be shown that similar results can be obtained by using the modified circuital approach in [4]. However, as it will be shown next, these results deviate to some extent from the case when presence of receiving antenna is included in the model.

Next, the receiving dipole antenna is included in the numerical model of enclosure by using the compact wire model described in section II. Antenna is modelled as z-directed 10 cm long wire probe of two radius values: 0.08 cm and 0.16 cm. Its position within the enclosure is defined by points (14.5 cm, 20 cm, 5 cm) and (14.5 cm, 20 cm, 15 cm). The numerical results for the SE of enclosure, calculated at the centre point of the receiving dipole antenna (14.5 cm, 20 cm and 10 cm) and at the centre point of enclosure (15 cm, 20 cm, 10 cm) for all three considered aperture patterns are shown in Figs. 6 and 7. For comparison purposes, numerical results obtained when receiving antenna is not included in the model are also given on these figures. It can be seen that the presence of receiving antenna underestimate the shielding efficiency of enclosure as the level of SE is always lower in comparison with the case when enclosure is empty. SE is even lower when wire probe radius is bigger. Also, there is a tendency to slightly shift some of the resonant frequencies of enclosure.

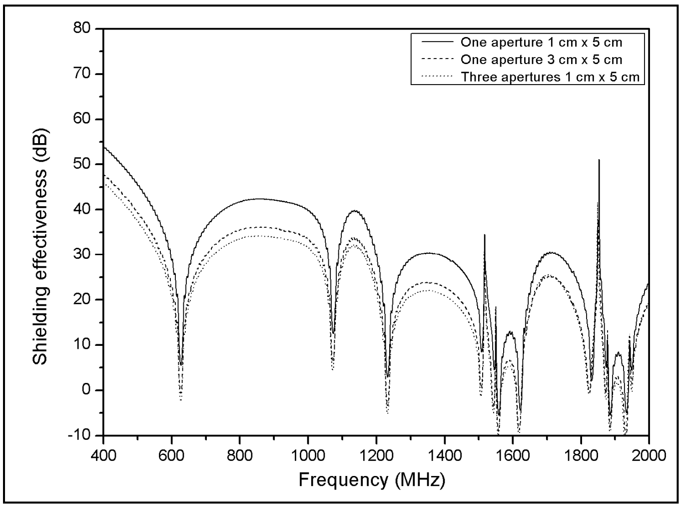

Fig.5. Numerical results for the SE of enclosure at the point 14.5 cm x 20 cm x 10 cm for enclosure without antenna presence

IV. CONCLUSION

TLM method, enhanced with compact wire model, has been used here to generate numerical model that can provide a tool for analysis of the impact of receiving dipole antenna on electric shielding effectiveness of enclosure. Given example confirm that the antenna presence affects the EM field distribution inside the enclosure and thus affect the results for the level of SE as well as location of resonant frequencies. In future research a detail investigation of antenna dimensions and location influence on SE, including cable connection, will be carried out both numerically and experimentally.

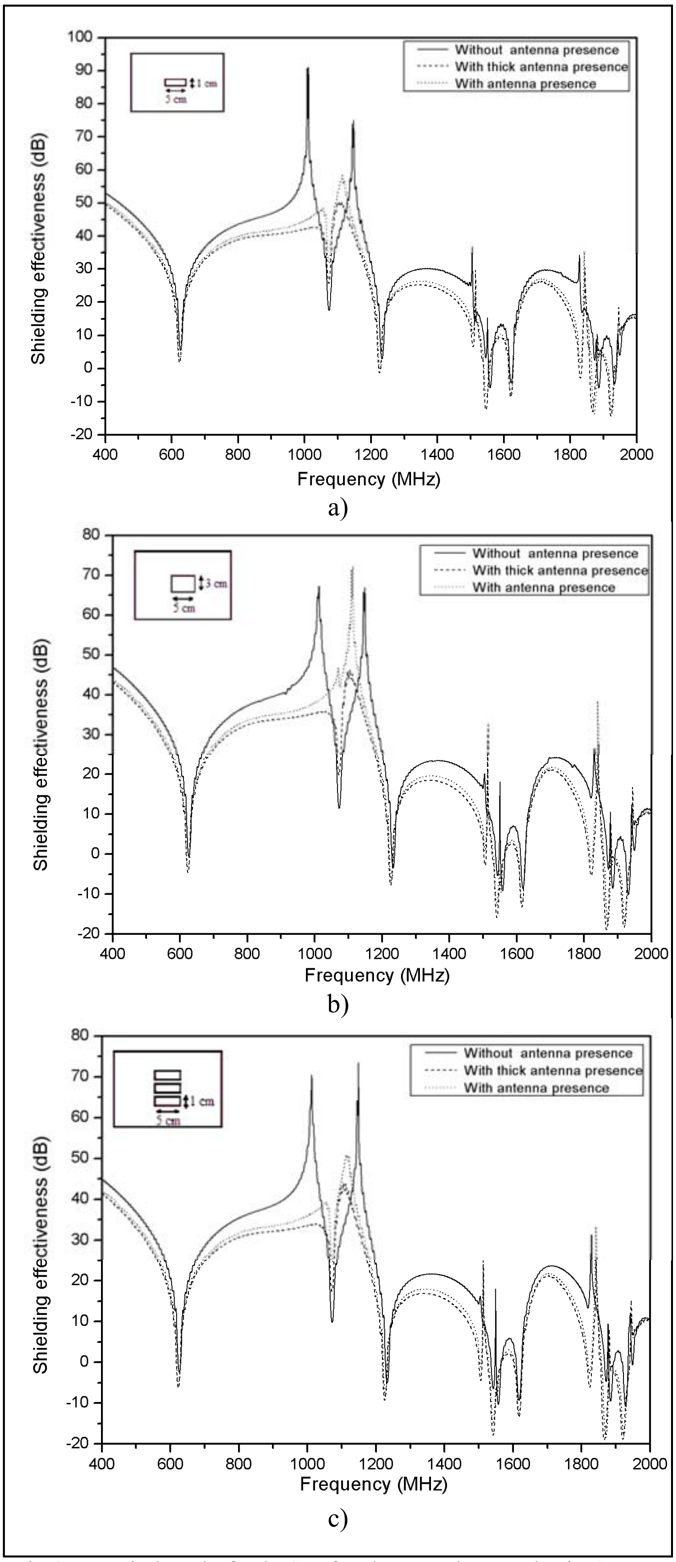

Fig.6. Numerical results for the SE of enclosure at the central point 15 cm x 20 cm x 10 cm with a) 1 cm x 5 cm aperture, b) 3 cm x 5 cm aperture and c) three apertures 10 cm x 5 cm

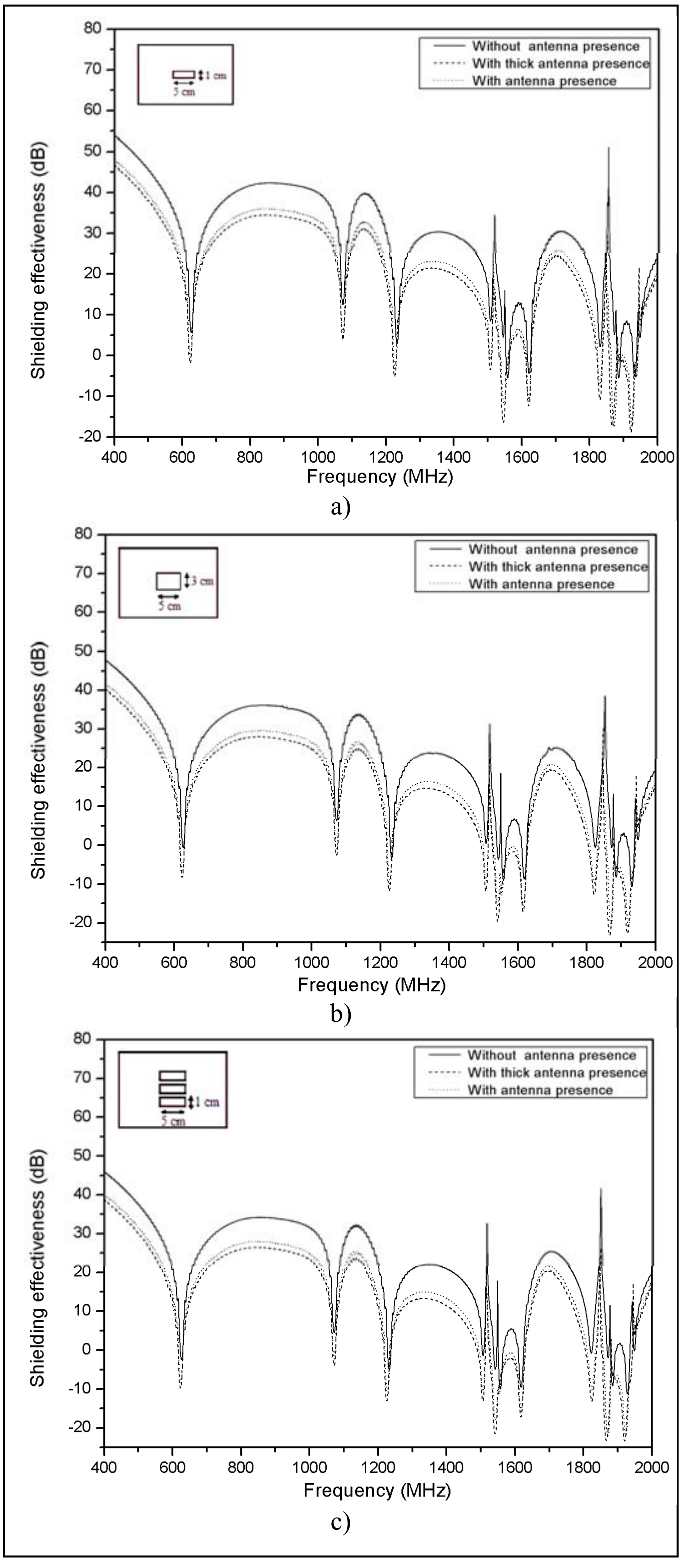

Fig.7. Numerical results for the SE of enclosure at the point 14.5 cm x 20 cm x 10 cm with a) 1 cm x 5 cm aperture, b) 3 cm x 5 cm aperture and c) three apertures 10 cm x 5 cm

REFERENCES

[1] H. H. Park and H. J. Eom, “Electromagnetic penetration into a rectangular cavity with multiple rectangular apertures in a conducting plane” IEEE Trans. Electromagn. Compat., vol. 42, no. 3, pp. 303–307, Aug. 2000

[2] H. A. Mendez, “Shielding theory of enclosures with apertures” IEEE Trans. Electromagn. Compat., vol. EMC-20, no. 2, pp. 296–305, May 1978.

[3] Robinson, M. P., T. M. Benson, C. Christopoulos, J. F. Dawson, M. D. Ganley, A. C. Marvin, S. J. Porter, and D. W. P. Thomas, “Analytical formulation for the shielding effectiveness of enclosures with apertures” IEEE Trans. Electromagn. Compat., vol. 40, no. 3, pp. 240–248, Aug. 1998.

[4] Jongjoo Shim, Dong Gun Kam, Jong Hwa Kwon, Joungho Kim, ”Circuital Modeling and Measurement of Shielding Effectiveness against Oblique Incident Plane Wave on Apertures in Multiple Sides of Rectangular Enclosure” IEEE Trans. Electromagn. Compat., vol. 52, mo. 3, pp. 566–577, Aug. 2010.

[5] K.S. Kunz, R. J. Luebbers: The Finite Difference Time Domain Method for Electromagnetics, CRC Press, Boca Raton, FL, 1993.

[6] C. Christopoulos: The Transmission-Line Modelling (TLM) Method, IEEE Press in association with Oxford University Press, Piscataway, NJ, 1995.

[7] Bao-Lin Nie, Ping-An Du, Ya-Ting Yu, and Zheng Shi “Study of the Shielding Properties of Enclosures With Apertures at Higher Frequencies Using the Transmission-Line Modeling Method” IEEE Trans. Electromagn. Compat., vol. 53, no. 1, pp. 73–81, Feb. 2011.

[8] Milovanović, B., Dončov, N., Milutinović V., Cvetković, T., “Numerical characterization of EM coupling through the apertures in the shielding enclosure from the viewpoint of electromagnetic compatibility”, Telecommunications - Scientific journal published by the Republic Agency for Telecommunications – RATEL, no.6, pp.73-82, 2010.

[9] V. Milutinović, T. Cvetković, N. Dončov, B. Milovanović, “Analysis of the shielding effectiveness of enclosure with multiple circular apertures on adjacent walls”, ICEST 2011, Proceedings of Papers, vol. 3, pp.685-688, Niš, Serbia, June 2011.

[10] Cvetković, T., Milutinović V., Dončov, N., Milovanović, B., “Analysis of the influence of polarization and direction of propagation of a incident plane wave on the effectiveness of rectangular enclosures with apertures”, INFOTEH, Proceedings of Papers, vol. 10, Ref.B-I-6, pp.90-94, Jahorina, March 2011.

[11] Milutinovic V., Cvetkovic, T., Doncov, N., Milovanovic, B., “Analysis of enclosure shielding properties dependence on aperture spacing and excitation parameters”, TELSIKS 2011, Proceedings of Papers, vol. 2, pp. 521-524, Serbia, Nis, Octobar 2011.

[12] Joković J., Milovanović, B., Dončov, N., “Numerical Model of Transmission Procedure in a Cylindrical Metallic Cavity Compared with Measured Results”, International Journal of RF and Microwave Computer-Aided Engineering, vol. 18, no. 4, pp. 295-302, July 2008.

[13] Wlodarczyk, A. J., Trenkic, V., Scaramuzza, R., Christopoulos, C., “A Fully Integrated Multiconductor Model For TLM”, IEEE Transactions on Microwave Theory and Techniques, vol. 46, no. 12, pp. 2431-2437, December 1998.