Analysis of Monitoring Dipole and Monopole Antennas Influence on Shielding Effectiveness of Enclosure with Apertures

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Abstract— **In this paper, numerical model of metal enclosure with apertures and monitoring antenna is considered for the purpose of accurate shielding effectiveness calculation. TLM method incorporating wire node model is used to account for the presence of monitoring dipole or monopole antennas used in practice to detect the level of electromagnetic field at selected points inside the enclosure. Numerical model is first verified through comparison with experimental results and then used to study an impact of physical parameters of considered antennas on shielding properties of rectangular enclosure and shift of its resonance frequencies. In addition, both antennas are mutually compared in terms of their influence on detected level of electromagnetic field inside enclosure.**

I. Introduction

Performances of electronic systems enclosed in enclosures, dominantly depend on the nature and existence of interconnecting paths, from the viewpoint of electromagnetic compatibility (EMC). In eliminating or reducing these interconnecting paths which cause coupling between electromagnetic (EM) energy sources and sensitive electronic systems, shielded enclosures have a major role. Wired and dielectric structures within the electronic system have also EM radiation excitation characteristics. The enclosures made from various material protect system, but they have a number of apertures with different size and patterns, used for airing, heat dissipation, control panels, outgoing or incoming cable penetration or other purposes, that can compromise its shield role. Therefore, it is very important to estimate shielding properties of enclosure in the presence of 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. There are several methods already developed for the calculation of SE of metal enclosures with apertures on their walls, such as analytical formulations like in [1,2], while in addition the solution in [2] was enhanced in [3] to allow for considering oblique incidence and polarization of incident plane wave and arbitrary location of apertures in relation to plane wave propagation. In solving many EMC problems in a wide frequency range, differential numerical techniques in the time domain found their application such as the finite-difference time domain (FDTD) method in [4], the methods of moments (MoM) in [5] and the transmission line matrix (TLM) method in [6]. Conventional approach based on fine mesh description of fine features such as slots and apertures, was used in [4] and [6]. Various factors, such as aperture patterns, their dimensions, number and orientation with the respect of enclosure walls or plane wave propagation direction, were analyzed in terms of their influence on the SE of enclosure by authors of this paper. The results of this analysis have been presented in [7,8]. In addition, an impact of plane wave excitation parameters on shielding properties of enclosure with multiple apertures has been considered by the authors in [9,10]. A conventional TLM method was also used as in [5] to numerically study these various effects at high frequencies in [7-10].

Aim of this paper is to investigate an impact of a small monopole/dipole antenna on the SE of enclosure, often used in an experimental setup to measure the level of EM field at some characteristic points in the enclosure. Antenna of finite dimensions could significantly affects the EM field distribution in closed environment as already experimentally shown in [12] for rectangular cavity. In a metal enclosure, this effect on the results of SE is numerically illustrated in [11]. The existing measurements presented in [2] and [3] is improved in this paper to include monopole and dipole antenna presence, respectively. This mentioned model did not take into account the presence of receiving antenna as one of possible causes for some differences between model and experimental SE results. The TLM method, incorporating compact wire model presented in [13], is also used here as in [12] to create a numerical model capable to take into account the antenna presence and its parameters such as length and radius and their impact on the SE of enclosure.

II. Compact TLM wire model

The TLM method [14] 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 link 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. Additional stubs can be attached to SCN to model inhomogeneous and lossy materials.

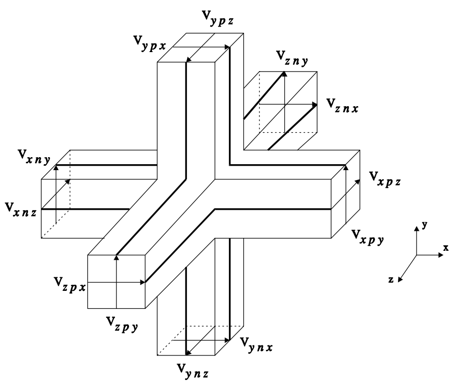

Figure 1. Symmetrical condensed node.

Compact TLM wire model, which allows for accurate modelling of wires with a considerably smaller diameter than the node size, has been introduced in [14]. It use special wire network formed by using additional link and stub lines (Fig. 2) whose characteristic impedance parameters, Z_w and Z_{ws}, 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. This wire network is embedded within the TLM nodes to model signal propagation along the wires, while allowing for interaction with the EM field (Fig. 3). Coupling between the additional link and stub lines with the rest of TLM node is achieved through points *A* and *B*.

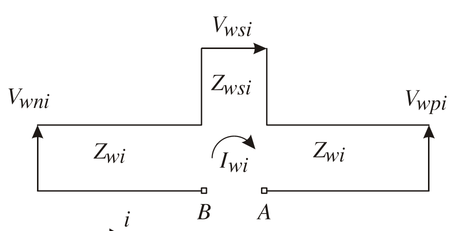

Figure 2. Wire network for a wire running in *i*-direction.

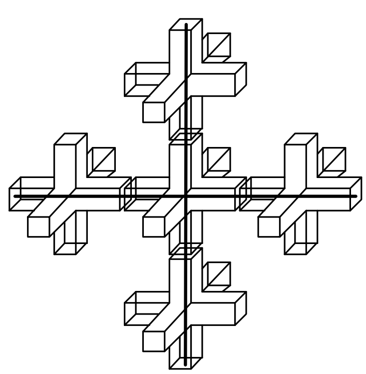

Figure 3. Wire network embedded within the TLM nodes.

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 wire running direction [14].

III. Numerical Analysis

A. Results for the presence of receiving dipole antenna

For numerical calculation of the SE for various radii of receiving dipole antenna, rectangular metal enclosure, with dimensions (300x400x200) mm (Fig. 4a) is considered in this paper first. One rectangular aperture of dimensions lx$2s$ = 50 mm x 30 mm exists on the front enclosure wall of thickness 2 mm in zy-plane (Fig. 4b). Aperture is symmetrically placed around the centre of the front wall. A plane wave of normal incidence to the frontal panel and with vertical electric polarization is used as an excitation. Dipole antenna of length 100 mm, oriented along z-axis, is used to measure the level of EM field inside the enclosure. Choice of geometry and dimensions of enclosure and aperture, type of excitation, location of antenna (5 mm off the enclosure center in x-direction) and its length were governed by experimental arrangements presented in [3]. It should be noted that in [3] the radius of the receiving antenna used in the measurements is not specified as well as characteristics of balun placed between antenna and cable to enhance the antenna efficiency.

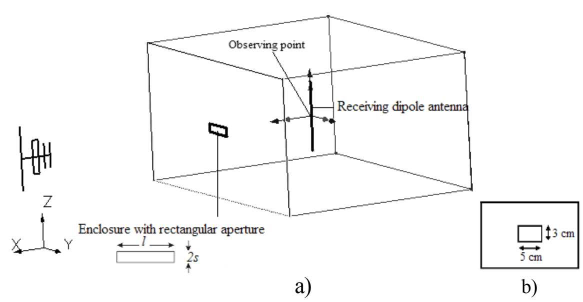

Figure 4. a) Rectangular metal enclosure with receiving dipole antenna, b) frontal panel with one rectangular aperture.

Numerical model, incorporating the compact TLM wire description of dipole antenna, is used to calculate the SE for various radii of receiving antenna of considered enclosure. The receiving antenna is represented as z-directed 100 mm long wire having the radius of 0.08 mm, 0.4 mm and 1.6 mm. SE results, obtained by numerical TLM models without and with antenna, for one aperture (50 x 30) mm on the front wall, are shown in Fig. 5 together with measurement results [3]. It can be seen that numerical results follow well the shape of the SE curve obtained by measurements, however there is a difference regarding the level of SE which depends of the wire radius.

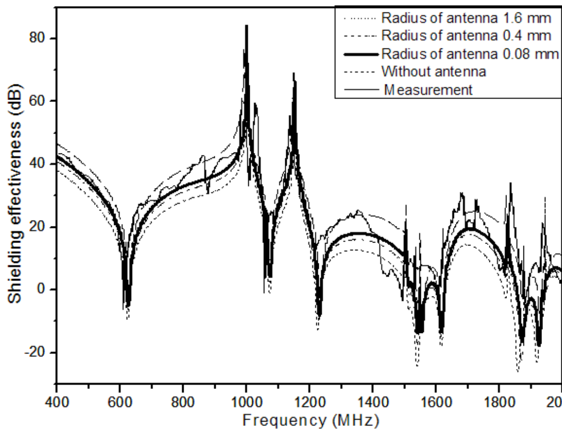

Figure 5. SE_z of metal enclosure (300x400x200) mm with rectangular aperture (50 x 30) mm on the front wall - numerical TLM model for various radii of dipole antenna.

Figure 5 shows that the SE with the receiving antenna, placed in enclosure, regardless of wire radius value, has a constant lower value across the considered frequency range than the curve for the SE obtained without receiving antenna. This drop in the SE level can be explained due to nature of numerical model to account for two-ways interactions between antenna and EM field. i.e. induced wire current causes that wire behaves as a second emitter and it has a return influence on EM field inside the enclosure. When radius of antenna is increasing resonant frequencies shift towards lower frequencies. Numerical model is capable to explicitly account for dependence of wire capacitance and inductance per unit length on radius [14,18].

The level of SE and the first resonant frequency obtained by numerical model without antenna and with antenna with various radius for receiving dipole antenna are shown in Table 1.

TABLE I.
SE AT THE FIRST RESONANT FREQUENCY FOR VARIOUS RADII OF RECEIVING DIPOLE ANTENNA

r (mm)	f (MHz)	SE (dB)
1.6	623	-9.5
0.4	624.5	-6.6
0.08	625.1	-4.9
without antenna	626.6	-0.4

Numerical model, incorporating the compact TLM wire description of dipole antenna, is also used to calculate the SE for various length of receiving antenna of considered enclosure. The receiving dipole antenna is represented as z-directed long wire having the length 6 cm, 10 cm, 14 cm and 18 cm and radius 0.08mm. SE results, obtained for various length of receiving antenna and one aperture (50 x 30) mm on the front wall, are shown in Fig. 6.

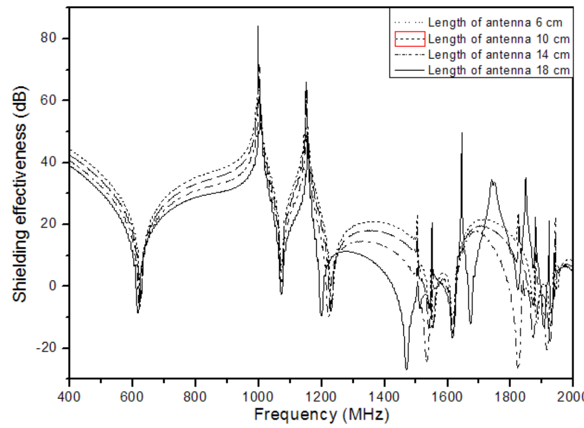

Figure 6. SE_z of metal enclosure (300x400x200) mm with rectangular aperture (50 x 30) mm on the front wall - numerical TLM model for various length of dipole antenna.

It can be seen (Fig. 6) that when length of antenna is increasing, the level of SE obtained by TLM model is decreasing in considered frequency range. Resonant frequencies shift towards lower frequencies when length of antenna is increasing. The results for the SE shows that the SE curves remains the same with a constant lower value for the SE from the 0 to 1 GHz. In the rest of frequency range the curve for the length of antenna 6cm, which is smaller than the half wavelength, has a bigger drop in the SE level, resonant frequencies and additional peaks.

The level of SE and the first resonant frequency obtained by numerical model with antenna with various lengths and radius 0.08mm for receiving dipole antenna are shown in Table 2.

TABLE II.
SE AT THE FIRST RESONANT FREQUENCY FOR VARIOUS LENGTH OF RECEIVING DIPOLE ANNENNA

Length (cm)	f (MHz)	SE (dB)
6	626.3	-3
10	625.1	-4.9
14	622.7	-6.9
18	617.8	-8.6

B. Results for the presence of receiving monopole antenna

For numerical calculation of the SE for monopole receiving antenna, rectangular metal enclosure, with dimensions (300x300x120) mm (Fig. 7a) is considered also. One rectangular aperture of dimensions lx2s = 100 mm x 5 mm and lx2s = 200 mm x 30 mm exists on the front enclosure wall of thickness 3 mm in zy-plane (Fig. 7b). Aperture is symmetrically placed around the centre of the front wall. A plane wave of normal incidence to the frontal panel and with vertical electric polarization is used as an excitation. Choice of geometry and dimensions of enclosure and aperture, type of excitation and location of antenna (center of the enclosure) were governed by experimental arrangements presented in [2]. As in the case of a dipole antenna, in [2] is not specified the radius and the length of the receiving monopole antenna used in the measurements.

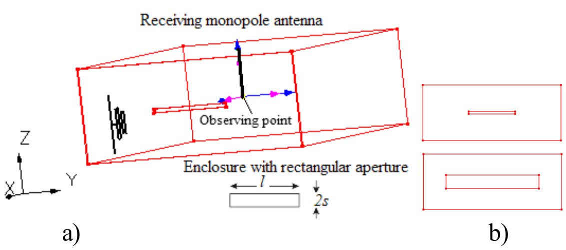

Figure 7. a) Rectangular metal enclosure with receiving monopole antenna, b) frontal panel with one rectangular aperture.

Numerical model, incorporating the compact TLM wire description of monopole antenna, is used to calculate the SE for various radii of receiving antenna of considered enclosure. Monopole antenna of length 60 mm, oriented along z-axis, is used to measure the level of EM field inside the enclosure, having the radius of 0.08 mm and 1.6 mm. SE results, obtained by numerical TLM models without and with antenna, for one aperture (100 x 5) mm and for one aperture (200 x 30) mm on the front wall, are shown in Fig. 8 and Fig. 9 together with measurement results [2]. As expected, the level of SE is higher in the case of aperture (100 x5) mm as surface of this aperture is smaller than the surface of aperture (200 x 30) mm.

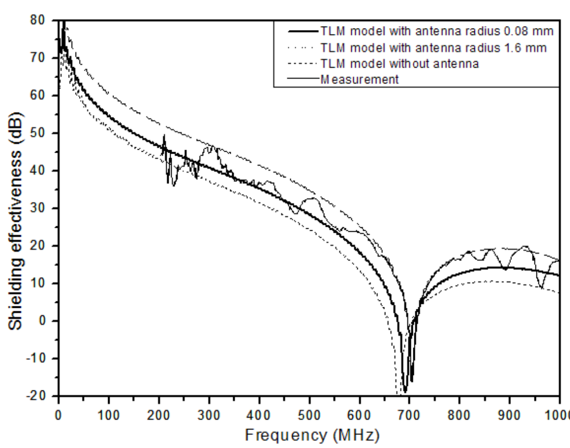

Figure 8. Numerical model and measurements for SE_z of metal enclosure (300x300x120) mm with rectangular aperture (100 x5) mm on the front wall with and without monopole antenna.

The SE with the receiving antenna placed in enclosure has a constant lower value across the considered frequency range than the curve for the SE obtained without receiving antenna. It can be seen that numerical TLM model without and with antenna provides the results that follow the experimental results curve. The level of SE and the first resonant frequency obtained by numerical model without antenna and with antenna with various radius for receiving monopole antenna are shown in Table 3.

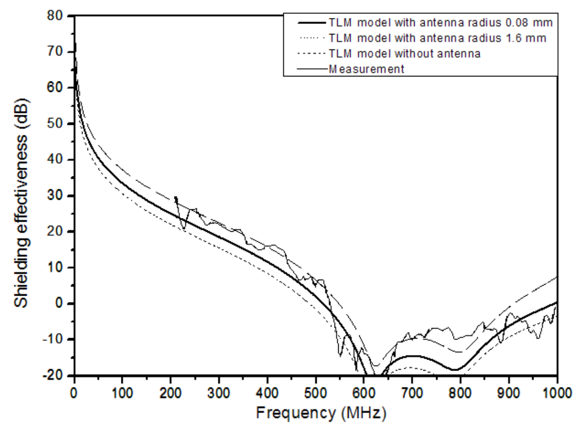

Figure 9. Numerical model and measurements for SE_z of metal enclosure (300x300x120) mm with rectangular aperture (200 x 30) mm on the front wall with and without monopole antenna.

TABLE III.
SE AT THE FIRST RESONANT FREQUENCY FOR VARIOUS RADII OF RECEIVING MONOPOLE ANENNA

r (mm)	f (MHz)	SE (dB)
1.6	677	-22.5
0.08	690.3	-18.8
without antenna	703.5	-13

FOR APERTURE (100 X5) MM ON THE FRONT WALL

r (mm)	f (MHz)	SE (dB)
1.6	612.4	-26.5
0.08	618.4	-22.5
without antenna	623.7	-17.4

FOR APERTURE (200 X30) MM ON THE FRONT WALL

Impact of antenna presence on the SE in comparison with the case when antenna is excluded from numerical model can be also observed. The difference between the measured level of SE (SEmeas) and the level of SE obtained by TLM model without (SE_1) and with (SE_2) antenna of radius 0.08mm in considered frequency range for both aperture patterns is given in Table 4.

As it can be seen, the antenna presence has a considerable impact on EM field level inside the enclosure. Results for SE obtained using antenna with radius 1.6 mm are lower than results obtained using antenna with radius 0.08 mm. The average value of difference between measured and numerical model results given in Table 4 is around 3.2 dB in the considered frequency range.

TABLE IV.
COMPARISON BETWEEN MEASURED LEVEL OF SE (SEMEAS.) AND THE LEVEL OF SE OBTAINED FROM TLM MODEL WHEN ANTENNA IS EXCLUDED (SE_1) AND INCLUDED (SE_2) WITH RADIUS 0.08 MM

f (MHz)	SEmeas. (dB)	SE_1 (dB)	SE_2 (dB)	|SEmeas-SE_1| (dB)	|SEmeas-SE_2| (dB)
200	44.11	51	46.7	6.89	2.59
300	45	45.4	40.9	0.40	4.10
400	36.8	40.4	35.3	3.60	1.50
500	32.65	33.9	28.4	1.25	4.25
600	23.48	24.5	18.1	1.02	5.38
700	-3	-10.9	-3.8	7.90	0.80
800	16.4	18	12.8	1.60	3.60
900	16.6	21.2	14.2	4.60	2.40
1000	16.1	21	12.2	4.90	3.90

FOR APERTURE (100 X5) MM ON THE FRONT WALL

f (MHz)	SEmeas. (dB)	SE_1 (dB)	SE_2 (dB)	|SEmeas-SE_1| (dB)	|SEmeas-SE_2| (dB)
200	29.8	28.8	25	1.00	4.80
300	21.9	22.4	18.5	0.50	3.40
400	16.3	15.7	11.6	0.60	4.70
500	5.5	6.5	1.8	1.00	3.70
600	-13.8	-11.9	-18.2	1.90	4.40
700	-9.8	-9.7	-14.5	0.10	4.70
800	-9.3	-13.4	-17.9	4.10	8.60
900	-2.4	-0.9	-6.2	1.50	3.80
1000	-0.8	7.5	0.5	8.30	1.30

FOR APERTURE (200 X30) MM ON THE FRONT WALL

Numerical model, incorporating the compact TLM wire description of monopole antenna, is also used to calculate the SE for various length of receiving antenna of considered enclosure. It is represented as z-directed long wire having the length 3 cm, 4 cm, 5 cm and 6 cm and radius 0.08mm. SE results, obtained for various length of receiving monopole antenna and one aperture (100 x 5) mm on the front wall, are shown in Fig. 10.

The results for the SE with various lengths (Fig. 10) were obtained for the case when monopole antenna is connected to the top plate. If monopole antenna is connected to the down plate, the results would be the same like it is shown in Fig.11 for radius 0.08 mm and 1.6 mm with rectangular aperture (100 x 5) mm on the front wall. The similar conclusions can be derived for aperture pattern (lx2s = 200 mm x 30 mm on the frontal wall) considered in [2].

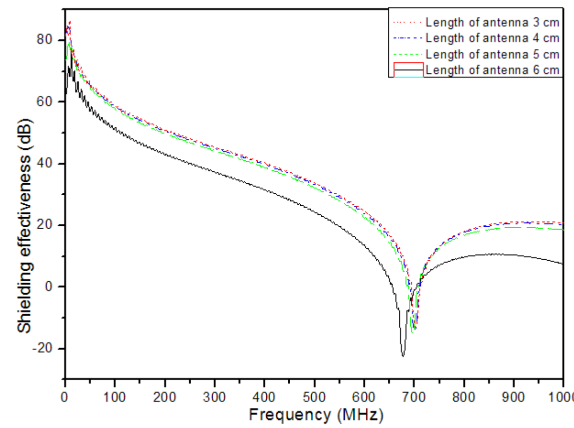

Figure 10. SE_z of metal enclosure (300x300x120) mm with aperture (100 x 5) mm on the front wall - numerical TLM model for various length of monopole antenna.

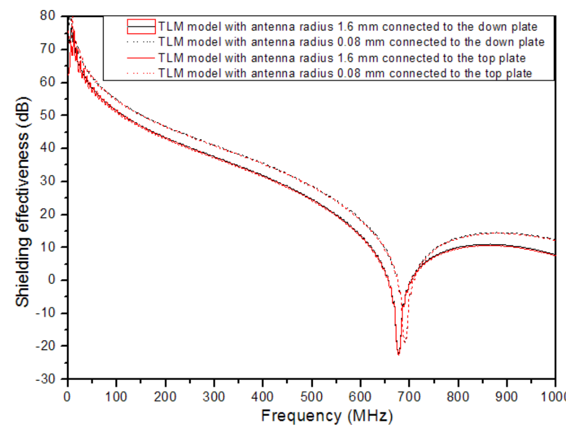

Figure 11. SE_z of metal enclosure (300x300x120) mm with rectangular aperture (100 x 5) mm on the front wall - numerical TLM model for monopole antenna connected to the down and top plate.

It can be seen that when length of antenna is increasing, the level of SE obtained by TLM model decreasing in considered frequency range. Resonant frequencies shift towards lower frequencies when length of antenna is increasing. This drop in the SE level is bigger for length of antenna 6cm than one obtained for other given lengths, as well as for drop of resonant frequency like in Table 5.

TABLE V.
SE AT THE FIRST RESONANT FREQUENCY FOR VARIOUS LENGTH OF RECEIVING MONOPOLE ANENNA

Length (cm)	f (MHz)	SE (dB)
3	702.2	-13.2
4	700.2	-14.4
5	696.5	-15.1
6	677.1	-22.5

Finally, numerical results for enclosure, with dimensions (300x400x200) with aperture (50 x 30) mm on the front wall and with monopole and dipole antenna with radius 0.08mm and lenght 10cm are compared in terms of their ability to exactly account SE. The results for the SE obtained by both antennas (Fig. 12) shows that from the 0 to 1 GHz the SE curve for the case when antenna is dipole, including the values of resonant frequencies, follow the curve for TLM model without antenna better than curve for TLM model with monopole antenna. In the rest of frequency range they are mostly overlapping, including the values of resonant frequencies.

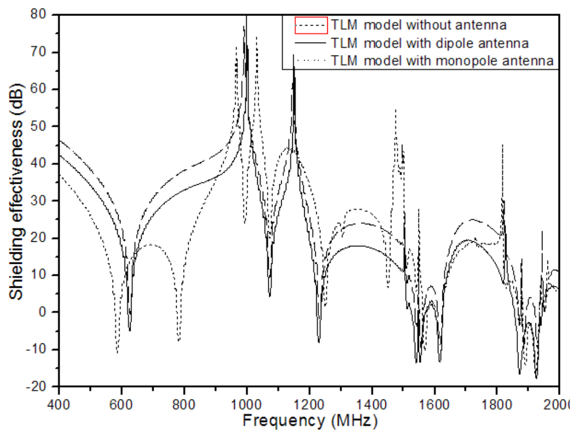

Figure 12. SE_z of metal enclosure (300x400x200) mm with rectangular aperture (50 x 30) mm on the front wall - numerical TLM model for dipole antenna, monopole antenna and without antenna.

IV. Conclusions

An impact of parameters like radius and length of small dipole or monopole antenna, used to measure the level of EM field at some characteristic points in the enclosure, on the SE of enclosure is investigated in this paper. Model based on TLM method with compact wire, have been used to accurate estimate the SE of enclosure with apertures. Obtained results shows that the coupling due to receiving antenna presence, inevitable in the measurement process, can be very significant especially regarding the resonant frequencies locations and level of SE in considered frequency range. Therefore, this impact has to be taken into account during the experimental characterization in order to correctly estimate the SE of metal enclosure. Numerical TLM model is capable to accurately account for not just passive but also active presence of dipole antenna inside the enclosure.

Acknowledgment

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