Analysis of Outdoor Emissions from Printed Circuit Board Enclosed in Metallic Box with Aperture

Jugoslav Joković, Nebojša Dončov, Bratislav Milovanović and Tijana Dimitrijević

Abstract - In this paper, an outdoor electromagnetic (EM) emissions from a printed circuit board (PCB) in metallic enclosure with aperture are considered. The Transmission Line Matrix (TLM) method is applied to account for the interactions between the PCB and the enclosure by including the basic physical features of the PCB with feeding and terminations realized through TLM wire ports. Numerical results of EM field components inside and outside the enclosure are mutually compared as well as with measurements and effect of the aperture presence on EM emissions from PCB are analysed.

Keywords – EM emissions**,** PCB, Enclosure, Aperture, TLM method.

I. Introduction

The rapid development and utilization of advanced digital techniques for information processing and transmission in modern communication systems have led to a further evolution of the semiconductor technology to nanometre regime. A number of complex components and devices, usually in high-density packaging, can be found in today's communication systems resulting in a very challenging electromagnetic (EM) field environment. Therefore, electromagnetic compatibility (EMC) [1] has become one of the major issues in design of these systems, especially some of their parts such as printed circuit boards (PCBs) and integrated circuits (ICs).

Clock rates that drive PCBs are now in the GHz frequency range in order to increase dramatically processing speed. Therefore, consideration of even a few higher harmonics of clock rates takes design of such circuits well into the microwave regime. PCBs are becoming increasingly more complex and as consequence quantifying their EM presence is more difficult. In the microwave frequency range, PCBs have dimensions of the order of several wavelengths and thus become efficient radiators and receivers of EM energy. In addition, high-density packaging, widely applied to the PCB design, could cause a significant level of EM interference (EMI) between neighbours PCBs, particularly when they are placed in an enclosed environment. These effects in combination with the driving down of device switching voltage levels are making signal quality/integrity and emission/ susceptibility critical EMC issues in next generation high-speed systems.

Differential numerical techniques, such as the finite-difference time-domain (FD-TD) method [2] and the transmission line matrix (TLM) method [3], are common tools for computational analysis of numerous EM and EMC problems. However, a full-wave three dimensional (3D) numerical simulation to accurately reproduce the EM field around a PCB usually requires substantial computing power and simulation run-time. Therefore, one efficient technique based on the equivalent principle [4], providing simplified equivalent dipole models to accurately predict radiated emissions without reference to the exact details of the PCB has been recently proposed [5]. The model has been deduced from experimental near-field scanning and it includes not only the excitation but also physical features of PCB such as its ground plane and dielectric body, both very important in closed environment. However, such model can be very complex and run-time consuming when it is incorporated into conventional calculation algorithms of FD-TD or TLM methods.

For some of the geometrically small but electrically important features (so-called fine features), such as wires, slots and air-vents, few enhancements to the TLM method have been developed [6-8]. These compact models have been implemented either in the form of an additional one-dimensional transmission line network running through a tube of regular nodes or in the form of an equivalent lumped element circuit, allowing to account for EM presence of fine features without applying a very fine mesh around them. Compared to the conventional approach, these models yield a dramatic improvement in computer resources required. Similar compact model could be developed for the PCB allowing for an efficient implementation into the TLM algorithm procedure and accurate representation of EM emissions and coupling of the PCB. Developing of such model has assumed that an extensive full-wave analysis has to be conducted in order to fully characterize EM presence of the PCB either in the free space or in an enclosed environment.

In this paper, we consider the basic test PCB placed in a rectangular metallic enclosure as typical closed environment for PCBs. It consists of L-shaped microstrip track on FR4 substrate [5]. In addition, an aperture on top enclosure wall (e.g. used for outgoing or incoming cable penetration from and to PCB) is also taken into account. The impact of radiated emission of this simple PCB structure, with wire feed and terminated probes at its ends, on EM field distribution is investigated. Numerical TLM

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results of EM field at resonances outside the enclosure are compared with corresponding results inside enclosure based on simulations and measurements [5]. The EM field patterns inside and outside the enclosure are compared in order to analyse of aperture presence impact on radiated EM emissions from PCB.

II. MODELLING PROCEDURE

A. TLM method

In TLM method, a 3D EM field distribution in a PCB structure in enclosure is modelled by filling the space with a network of transmission lines and exciting a particular field component in the mesh by voltage source placed on the excitation probe. EM properties of a medium in the substrate and enclosure 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. To operate at a higher time-step, a hybrid symmetrical condensed node (HSCN) [3] 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 within the substrate and cells with arbitrary aspect ratio suitable for modelling of particular geometrical features, such as microstrip track, are applied. External boundaries of arbitrary reflection coefficient of enclosures are modelled in TLM by terminating the link lines at the edge of the problem space with an appropriate load.

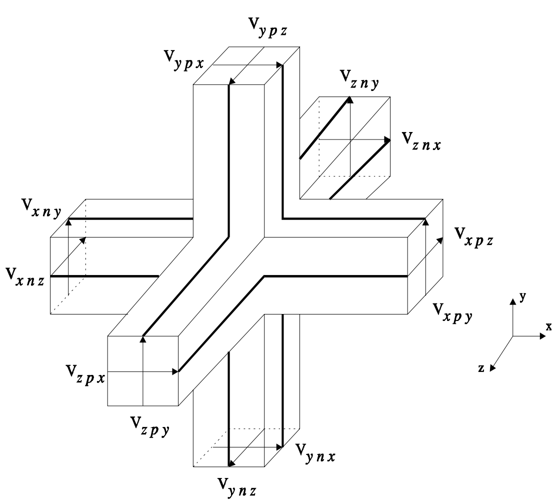


Fig. 1. Symmetrical condensed node

B. Compact wire TLM model

In TLM wire node, wire structures are considered as new elements that increase the capacitance and inductance of the medium in which they are placed. Thus, an appropriate wire network needs to be interposed over the existing TLM network to model the required deficit of electromagnetic parameters of the medium. In order to achieve consistency with the rest of the TLM model, it is most suitable to form wire networks by using TLM link and stub lines (Fig. 2) with characteristic impedances, denoted as Z_{wy} and Z_{wsy}, respectively.

An interface between the wire network and the rest of TLM network must be devised to simulate coupling between the EM field and the wire.

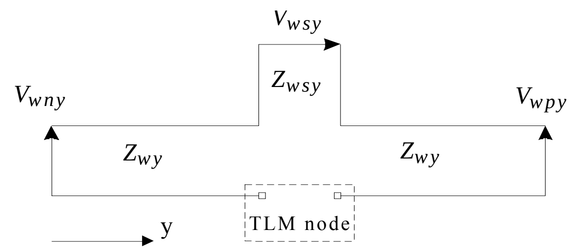


Fig. 2. Wire network

In order to model wire elements, wire network segments pass through the centre of the TLM node. In that case, coupling between the field and wire coincides with the scattering event in the node which makes the scattering matrix calculation, for the nodes containing a segment of wire network, more complex. Because of that, an approach proposed in [6], which solves interfacing between arbitrary complex wire network and arbitrary complex TLM nodes without a modification of the scattering procedure, is applied to the modelling of microstrip structures.

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 [6].

Following the experimental approach that using inner conductor of coaxial guide as a probe, numerical characterisation of EM field inside the cavity can be done by introducing wire ports at the interface between wire probes and enclosure walls.

III. NUMERICAL RESULTS

TLM simulations are carried out to determine the EM emissions from basic PCB structure in form of the test board with a microstrip printed on the dielectric substrate, placed in metallic enclosure with an aperture [5]. The numerical TLM model of EM emissions from this board inside the enclosure are verified with reference results based on equivalent dipole simulations and measurements [5, 9].

The basic test PCB is a 2-mm wide L-shaped microstrip track (l_1=40mm, l_2=20mm) on one side of a $PCB_x\times PCB_y\times PCB_z$=(80×50×1.5)$mm^3$ board made from FR4 substrate with relative permittivity ε_r =4.5. The geometry of the board is shown in Fig. 3. The test board PCB is mounted on the bottom of an enclosure in the form of rectangular metallic box with dimensions $a\times b\times c$=(284×204×75)mm^3. The PCB is powered by external RF signals via probe (with radius of 0.5mm) placed at one end of microstrip track (point A).

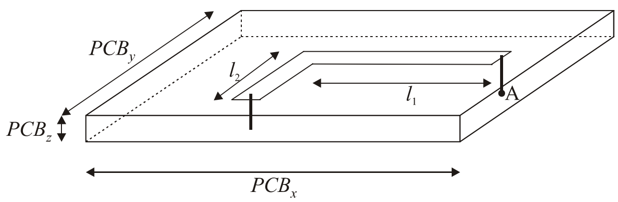


Fig. 3. Geometry of basic test PCB

It this structure, the enclosure is modeled through setting reflection coefficients of metallic walls, while feed and terminated probes are described by using the compact wire model applying generator and loads in TLM wire ports at the ends of microstrip track. Also, the aperture is incorporated into the TLM model together with the enclosure, in order to simulate the real enclosed environment problem. According to the experimental setup, an aperture with dimensions $a_1\times b_1$= (60×10)mm^2, placed on the top wall of the enclosure above the PCB, is modeled (Fig 4).

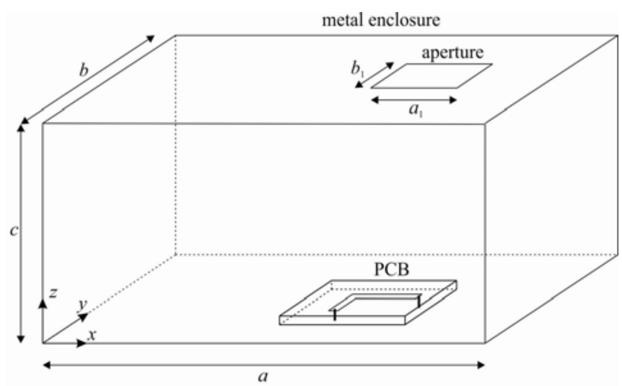


Fig. 4. TLM model of basic test PCB in enclosure with aperture

When a PCB is inside an enclosure, it is of particular interest to investigate the behavior near the resonant frequencies of the enclosure. Since the PCB causes difference in frequency and also changes peak field magnitude, the modeling of PCB elements is essential in enclosed environment simulations. Therefore, numerical results of resonant frequencies in the modeled closed environment structure with the PCB are analyzed. Also, enclosure should be taken into account when outdoor emission EMC compliance test of PCB is conducted.

Fig 5. presents the TLM simulation results of resonant frequencies obtained from vertical electric field sampled above the PCB, at points z=35mm (inside enclosure) and z=90mm (outside enclosure), corresponding to center of aperture in xy plane (x=210mm, y=108mm). Presented results of resonances, presented in Table I, are in a good agreement with results based on simulations and measurements [5].

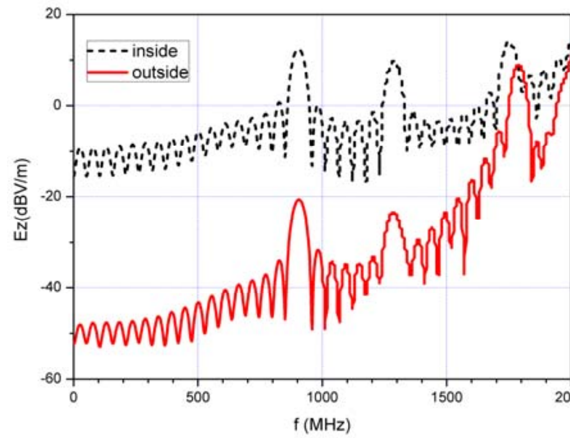


Fig. 5. TLM numerical results of vertical component of electrical field from basic test PCB in enclosure with aperture

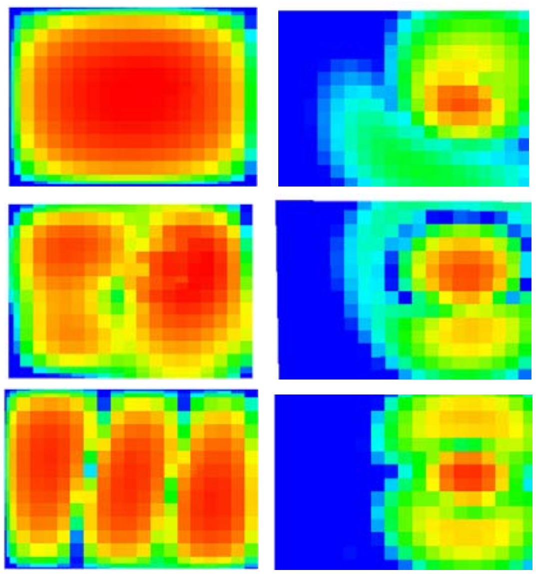
TABLE I
COMPARISON OF MEASURED AND TLM RESULTS

PCB in enclosure	Measured [5]	TLM simulation	
		inside	outside
Resonant frequencies (MHz)	900	903	905
	1290	1285	1288
	1740	1749	1789

Fig. 6 shows the simulation results of electric field component at resonant frequencies, in horizontal planes, sampled at z= 35 mm and z= 90 mm above the PCB representing EM emissions inside and outside enclosure, respectively. The patterns of E_z given by the TLM simulation at resonant frequencies (Fig.6.a), illustrating EM field distribution of an enclosure due to the physical presence of a PCB and aperture, have a very good agreement with corresponding results based on equivalent dipole simulations and measurements [5]. Since the results of E_z field component at resonant frequencies outside the enclosure (Fig.6.b), are sampled at plane 15 mm above the aperture, TLM mesh is extended to the space above top wall of the enclosure, where the aperture is placed.

Generaly, the patterns representing EM emissions outside the enclosure are different from corresponding results representing emissions inside enclosure and dominantly determined by aperture position. It can be seen that emissions outside of enclosure are much smaller compared with levels at corresponding resonances inside the enclosure.

Obtained numerical results illustrating EM emissions confirm that the impact of the aperture is not critical for resonances when its dimension is much smaller than the volume of the enclosure so that do not disturb EM field distribution inside the enclosure. However, aperture determines the level of EM field radiated outside the enclosure. In the case of the third resonance (at 1749 MHz) having peak corresponding to the aperture position, x=(180÷240)mm, the level of EM field outside enclosure is more increased than in case first and second resonances.



a) b)

Fig. 6. Patterns of E_z at resonances, given by the TLM simulation of PCB in enclosure with aperture: a) inside, b) outside

IV. CONCLUSION

Starting that one of the main interests in EMC tests is the intensities and distributions of the radiated fields from equipment under test (EUT), results are presented here of the EM emissions from basic PCB structure placed in enclosure with aperture. A method applied to determine radiated emissions from a PCB using a model based on TLM modelling of a test board in an enclosure with an aperture, to account for the interactions between the physical presence of the PCB and the enclosure.

The values of resonances obtained using TLM simulation are compared with reference values found experimentally by observing the field magnitude inside the enclosure. The patterns of EM emissions at enclosure resonances inside and outside the enclosure with aperture are compared and impact of aperture on EM emissions are analyzed.

The simulation results of test boards show that the inclusion of basic features, such as the microstrip track and substrate, in addition to the wires elements for feeding and terminations, permit an accurate prediction of emitted fields to be made in enclosure that have interactions with the PCBs inside. Generally, it is demonstrated here that the TLM method have the potential to characterize emissions from PCB structures in realistic environments such as an enclosure with an aperture and making it possible to perform system EMC studies.

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