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Simulation of Electromagnetic Disturbances in Uninterruptible Power Supplies Using Hybrid Numerical Methods

Abstract*. In this paper the Electromagnetic disturbances and susceptibility of metallic enclosures which are used in shielding of high voltage industrial power supplies have been studies. Basic parameters in shielding design for uninterruptible power supplies which is important in EMC considerations, have been investigated. The aperture size and position and the distance between two shielded power supplies and their effects on electromagnetic parameters such as electric field intensity, shielding effectiveness, return loss, and resonant modes have been studied. This study is performed by using a new hybrid simulation method that utilizes TLM modelling in near field and Method of Moment in far field.*

Streszczenie. *W artykule przeanalizowano zakłócenia elektromagnetyczne, podatność metalowej obudowy oraz parametry ekranowania źródeł zasilania bezprzerwowego na podstawie nowej metody hybrydowej z zastosowaniem metod TLM w strefie bliskiej oraz MoM dla pola dalekiego. (**Symulacja zakłóceń elektromagnetycznych źródeł zasilania bezprzerwowego z zastosowaniem hybrydowych metod numerycznych**).*

Keywords: Electromagnetic Compatibility (EMC), Electromagnetic Disturbances (EMD), Transmission Line Modelling (TLM).
Słowa kluczowe: kompatybilność elektromagnetyczna, zaburzenia elektromagnetyczne, modelowanie linii transmisyjnej.

Introduction

EMC which is known as the system ability to adapt to its own electromagnetic environment without any unwanted interference to the other systems is a critical issue in circuit designing. Electromagnetic shielding has been widely used to reduce the unwanted radiations from the electrical equipment and also increase the immunity of circuits and systems against any harmful external emission.

The ability of a typical shielding to perform any of these missions can be measured by a parameter named Shielding Effectiveness (SE) which is defined as the proportion of the electric field strength in the absence of the shield to the its strength at the presence of the shield. This definition of SE is completely depends on the shielding box parameters like the size of enclosure and the shape and the location and the size of the apertures.

Regarding to regulations in EMC area, an effective analysis of the SE parameter is very important. In this regard, two comprehensive methods are suggested and used which are analytical and numerical methods.

The analytical methods [1] are very fast estimation tools which try to simplify any given structure to achieve a specified precision. So these methods are not suitable for complicated geometrical structures.

On the other hand, numerical methods such as Finite Difference Time Domain (FDTD) [2], Method of Moments (MoM) [3], and Finite Element Method are used to simulate geometries with any desired complexity and extract the SE parameter.

Another numerical technique which is used to evaluate EMC problems is Transmission Line Modelling (TLM) method [4]. The major characteristic of the TLM method is its ability to model geometries with any given material properties. It is also capable of calculating the results in a wide range of frequencies.

Comparison between different numerical methods has been made in many recent works. In [5] the FDTD method was compared with MoM in shielding evaluation of a typical EMC problem. On the other hand, Sewell [6] made a comparison between experimental, analytical, and TLM methods.

In this paper after introducing the main EMC problems a hybrid method which is a combination between TLM and method of methods will be introduced to evaluate the low frequency and high frequency electromagnetic interferences. Then this newly defined hybrid method will be used to evaluate the SE parameter of a rectangular metallic shielding enclosure which is illuminated by an electromagnetic disturbance , and finally the interferences between two shielded power system equipments in terms of the distance to each other and the size of the apertures will be investigated

Hybrid Modeling

From the interference point of view, two scenes exist to exchange unwanted electromagnetism energy. The first one is to propagate and receive energy through radiation and the second one is through electromagnetic conduction. The mechanism of these two is quite the same and based on Maxwell's equations but the difference is in solving methodology. Whereas solving the first kind is more complicated, tend is to change problems of the first kind to equal problems of the second one.

Analysis of electromagnetic problems in complicated environments like areas with complex structures or non-homogeneous materials are very difficult. The flexible nature of numerical methods like TLM has made them suitable to analyze this kind of environment by Discretization them into separate elements named mesh [7, 8].

The weakness of these numerical methods is in the simulation of free space radiations, as the meshing the free space requires infinite number of memory and time resources.

Methods with integral equation basis like MoM are useful in simulation of free space radiation. Despite the fact that this method cannot be utilized in any desired geometry [9], in this study it has been used in conjunction with a flexible method like TLM. So the discrete behaviour of TLM has been used beside the free space modelling behaviour of MoM in the same time.

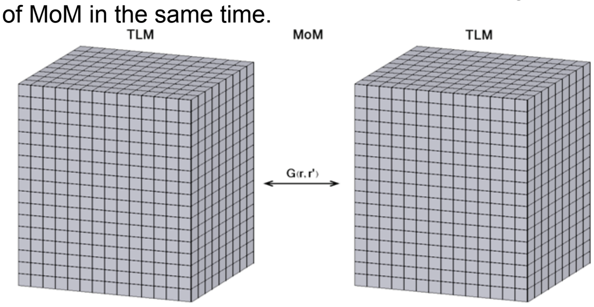

Fig.1. Definition of the hypothetical sub domains in the proposed hybrid simulation

In this proposed hybrid method, any given electromagnetic structure will be surrounded in a hypothetical sub domain as shown in figure 1. Two distinct analyses would be done inside and outside the area.

The tangent electric and magnetic fields intensities are the only conjunction between the areas inside and outside of the hypothetic sub domains. These tangent field intensities are used in the free space green function to calculate any desired far field radiation.

Theory

The most common shielding enclosures are metallic plates with small apertures over their bodies, which sometimes cause problems regarding heat and voice transfer. Design of these metallic enclosures has to meet three major criteria:

1. Attenuating or removing any unwanted radiation from the source
2. Decreasing the coupling factor
3. Decreasing the receiver sensitivity to EMI

In figure 2 a typical metallic enclosure with wall thickness of t and l×w size aperture, undergoes an electromagnetic plane wave disturbance with $Ex_{(max)}$=1 (v/m) that has a Gaussian distribution . The plane of this interfering electromagnetic wave was placed 0.5 meter away from the shielding box. The aperture length is orthogonal to the electric field which is the worst case regarding to coupling disturbances.

The observation point is placed in distance p inside the enclosure on the normal vector of the aperture. As pointed out before, the SE parameter is the proportion of electric or magnetic field in absence of the enclosure to the situation where it is presence.

(1) $$\text{Electric SE} = 20\log_{10}\left(\frac{E_{x_0}}{E_{x_1}}\right)$$

where: E_{x_0} – Electric field in the absence of shield , E_{x_1} – Electric field in the presence of shield.

For an enclosure with infinite conductivity, the values of electric and magnetic SE are similar. But in general theses values are not the same. The calculation of the SE parameter is depend on frequency, aperture geometry and dimensions, enclosure geometry and dimensions, thickness of the metallic walls, and the position of the observation point.

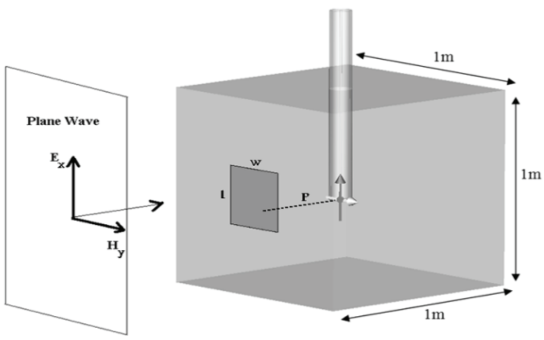

Fig. 2. Typical shielding enclosure including an aperture

Results

The electromagnetic plane wave coupled inside a shielding box through an aperture will be evaluated using figure 2. This figure represents a typical power supply that would include power switches, transformers, high power inverters and etc. In this figure a coaxial cable with radius of 50 mm and length of 900 mm is placed inside the box. The electric field intensity which has been coupled inside the box of figure 2 in the absence of the cable has been plotted in figure 3.

Aperture size effect on the coupled electric field intensity E_x is plotted in figure 3. As it is shown, the aperture size in mm has a great impact on the coupled electromagnetic field. On the other hand, while the aperture size is bellow 300 mm, it has no major influence on the resonant frequency of the shielding box and only changes the field intensity.

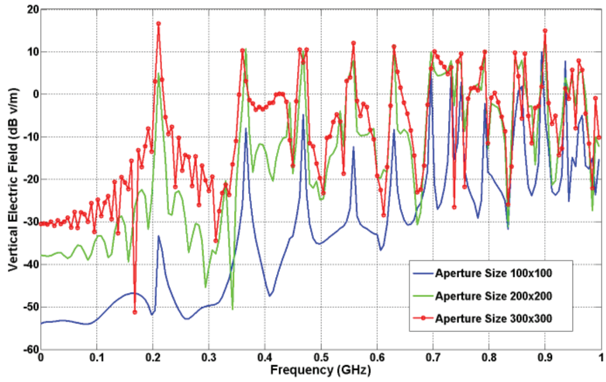

Fig. 3. Effect of the aperture size on the coupled vertical electric field inside the enclosure.

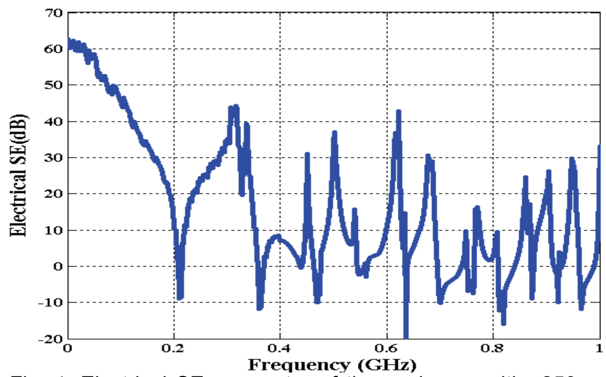

Fig. 4. Electrical SE parameter of the enclosure with 250 mm × 250 mm aperture size

In figure 4 the electrical SE parameter of the vertical component of the electric field (for the enclosure of figure 2) has been plotted. The aperture size is supposed to be 250 ×250 mm. same results could be achieved by using magnetic field intensity. The first resonant frequency of shielding enclosure occurs in 210 MHz which according to table 1, coincides with the $f_{r(110)}$ resonant mode and so on.

The aperture size affects some resonant frequencies of the shielded box and causes some new resonant frequencies which are known as cavity-slot modes that are emerged in plotted shielding effectiveness of enclosure [10].

It could be shown that in low frequency portion, the shielding box has a better performance in reduction the electric field of disturbing electromagnetic wave but by increasing the frequency, the magnetic SE will be better than the electric SE.

Table 1. The enclosure resonant modes and its frequencies

Mode	Resonant Frequency [GHz]
TM_{110}	0.210
TM_{111}	0.259
TM_{210}	0.335
TM_{220}	0.42

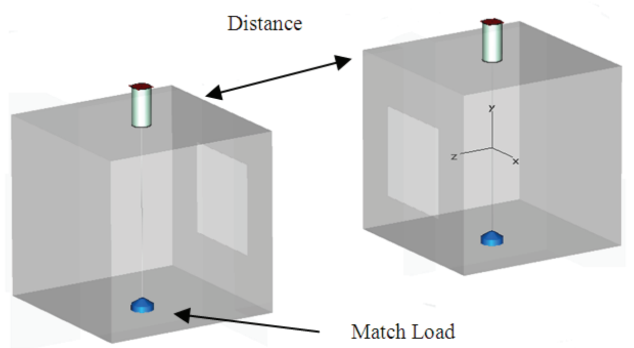

Fig. 5. Two disturbing shielded high voltage power systems in different distances to each other

A typical problem of two interfering shielded power systems is represented in figure 5. Each circuit is fed through a coaxial cable with radius of 50 mm and length of 900 mm which is placed inside the box and used as the reference port to investigate the interference. The result is represented in Fig. 6 where it is clear that by increasing the distance the disturbance is reduced in low frequency but in high frequency portion of spectrum the disturbance power is approximately the same.

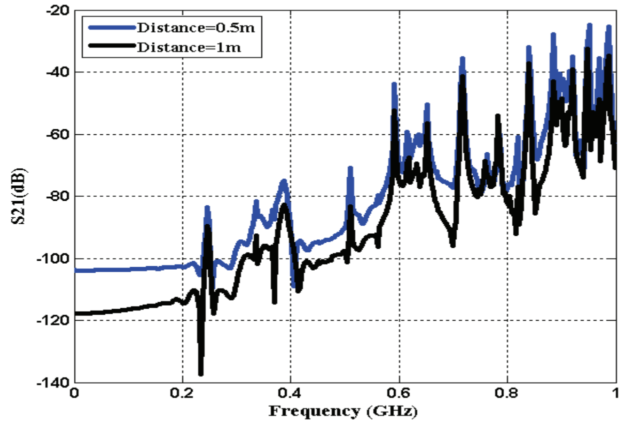

Fig.6. S_{21} scattering parameter as a criterion for evaluating the disturbing at two different distances (aperture size is 100 mm ×100 mm)

Finally the effect of the size of aperture on the coupled disturbance in each system has been studied. Each aperture acts as a radiator antenna and the effective aperture area has a significant role on the efficiency and the gain of an aperture antenna. According to figure 7 it is evident that a larger aperture has a grater disturbance but there is some frequencies that in which because of the cavity-slot resonance the larger aperture has less coupled disturbances.

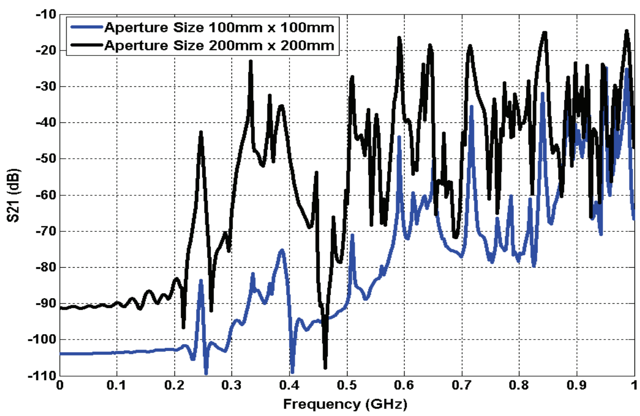

Fig. 7. S_{21} scattering parameter for different size of apertures

Conclusion

The Electromagnetic disturbance problem for the metallic enclosures with apertures has been solved. A hybrid numerical method has been used, including TLM method for the simulation of the near field radiations and also MoM for the far field radiations. The coupled electromagnetic field inside the box by a plane wave and by another high power system was evaluated. The effect of the aperture size on the coupled electric field and the magnetic SE and electrical SE parameters were analyzed. In another case, unwanted coupling between two shielded high power system was investigated.

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