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Hybrid Mom/Fem Modeling Of Loaded Enclosure with Aperture in EMI Problems

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***Abstract* - Hybrid formulation in frequency domain which combines Finite Element Method (FEM) and Method of Moments (MoM) to predict of electromagnetic field distribution inside enclosure with aperture is presented. While MoM is used for solving the surface integrals related with the aperture field components using equivalent surface currents, FEM is used for solving electromagnetic fields inside of the enclosure. Numerical results for the shielding effectiveness of dielectric slab loaded enclosure with aperture calculated by the hybrid method are presented and validated by comparing with literature.**

Index Terms— **FEM, Mom, Electromagnetic Interference, Shielding Effectiveness.**

I. INTRODUCTION

Coupling and interference in electronic devices such as computer, sensors, control and communication devices etc. is of increasing concern due to the presence of either intentional or un-intentional or external electromagnetic sources. Such sources can cause sufficient disruption to the circuit or logic to the point where the functionality and logic state of the electronic device can be altered due to such extraneous sources. To prevent from harms or to provide electromagnetic protection, electronic systems should be placed into a conducting enclosure. On the surface of this enclosure, there may be some apertures which cause a coupling between the parts into the enclosure and outer environment. There would be interference between the fields entering from the apertures and circuits inside the enclosure. The shielding enclosure contains apertures located on its walls and shielding efficiency is affected significantly by those apertures. The aim of shielding enclosure design is to minimize the effects of those apertures on shielding efficiency. To obtain shielding efficiency it is required that the EM fields inside enclosure are predicted. Shielding effectiveness (SE) is an important parameter which reflects the electromagnetic compatibility of the devices. It is defined in terms of the ratio of the observed fields in the absence of the shield, to the observed field in the presence of the shield measured at the same point and it is expressed in dB [1]. For evaluating the interference, all electromagnetic fields should be calculated. In analyzing on EMI problem, computing EM fields is analytically hard work because of the complex configuration of the structure. There are several methods for determining the shielding effectiveness of a enclosure with aperture. The main methods are: rigorous solution of the electromagnetic boundary problems by analytical approaches, numerical electromagnetic modeling, measurements and approximate formulas [2]. The analytical formulation which calculates the shielding effectiveness of an empty enclosure is presented by Robinson et al. [3] before. However, this formulation is valid only for rectangular boxes and is limited by the assumption of single mode. For complex enclosure configuration, to find EM fields analytically is very difficult. Thus the use of numerical methods is indispensable. The electromagnetic radiation from slots and apertures on shielding enclosures is studied with using FDTD technique in [4]. In [5], the shielding effectiveness of enclosures is performed experimentally and numerically with a electromagnetic simulator based on method of moments. Rajamani and Bunting [6], are presented a Modal/MoM method, which calculates the shielding effectiveness of an empty rectangular enclosure with rectangular apertures. In [7], the EM coupling of plane wave penetrating through apertures is examined with FDTD method and the electric field distribution inside the enclosure is obtained. A study of an enclosure with aperture using finite element time domain with a mass lumping technique was investigated by Benhassine et al [8]. The problem of calculating SE of a rectangular enclosure with perforated walls was formulated by Deshpande [9] by replacing the apertures with equivalent magnetic current sources and representing the fields radiated by such sources in terms of cavity Green's functions. In [10], the coupling of plane wave with a conducting wire placed inside a metallic cavity is examined using frequency and time domains FEM and induced voltage on wire is computed. In [11], a hybrid technique combining the finite difference method and the MoM is proposed to compute the shielding effectiveness of rectangular enclosure with apertures**.** A hybrid technique combining the finite element method and the MoM is presented to solve electromagnetic radiation problems from structures consisting of an inhomogeneous dielectric and perfectly conducting materials [12].

This paper presents a numerical method based on hybrid MoM/FEM to analyze the shielding effectiveness of loaded enclosure with aperture. In the formulation, the interior and exterior regions of the enclosure are separated by applying the field equivalence principle. Internal electromagnetic fields are discretized using the vector FEM while external fields are formulated by MoM. The purpose of this paper is present good performance of a hybrid MoM/FEM technique in frequency domain in structure with different slab size with loaded enclosure.

II.FORMULATION OF THE PROBLEM

In this section, is presented the hybrid MoM/FEM formulation for modeling loaded rectangular enclosure with aperture. The geometry of the loaded enclosure is shown in Fig. 1. The enclosure contains a lossy dielectric slab which fills cross section of the enclosure. For walls of the enclosure are considered to be perfectly conducting, the penetration of fields is only through the aperture. It is considered that the enclosure is illuminated by a y-polarized plane wave impinging normally on the aperture in the front wall.

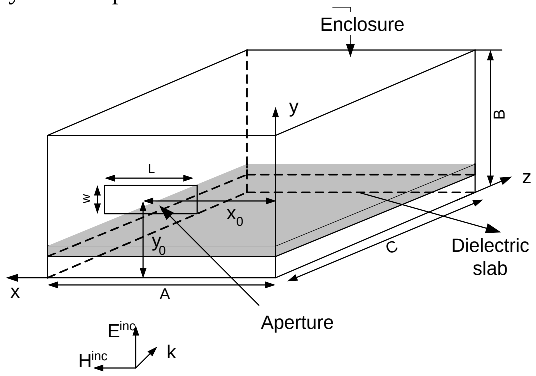

Fig 1: Geometry of loaded rectangular enclosure with aperture [14].

Assume the surface of the enclosure with the aperture is an infinite-width perfect-conductor ground plane, then, this problem could be separated into two regions by Schelkunoff equivalence principle. The first region represents the inner volume and the second represents the free half-space limited by ground plane. The finite element formulation for the inner region is initialized by applying the Galerkin Procedure to the vector wave equation which depends on the frequency defining the electric field. The problem domain is discretized with tetrahedral elements. Electric field, in the discretized domain, can be expressed as

$$\vec{E} = \sum_{n=1}^{N} \vec{w}_n e_n \tag{1}$$

where e_n is unknown coefficient associated with edge of the element, $\vec{w}_n$ is basis function and N is degree of freedom. After discretisation, the wave equation changes into the following matrix equation:

$$\left\{[S] + j\omega\mu_0[T_1] - \omega^2\mu_0[T_2]\right\} e = b \tag{2}$$

Where [S], $[T_1]$, $[T_2]$ are finite element matrices. Clearly, the expression of the element matrices can be written as following:

$$[S]_{ij} = \int_{V_e} \nabla\times\vec{w}_i \cdot \nabla\times\vec{w}_j \, dV \tag{3a}$$

$$[T_1]_{ij} = \int_{V_e} \sigma \vec{w}_i \cdot \vec{w}_j \, dV \tag{3b}$$

$$[T_2]_{ij} = \int_{V_e} \varepsilon_0 \varepsilon_r \vec{w}_i \cdot \vec{w}_j \, dV \tag{3c}$$

$$b_i = j\omega\mu_0 \int_S \vec{w}_i \cdot \left[\hat{n}\times\vec{H}\right] dS \tag{3d}$$

Here, V_e is the integral over a tetrahedral element and $\{b\}$ contains the boundary condition on the aperture. As the equivalence field theorem, an aperture placed on a perfect-conductor plane is equivalent to a magnetic current distribution. The EM radiation from the aperture to either the free-space or to the inside of the enclosure is equivalent to the radiation which is caused by that magnetic current source.

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The tangential magnetic field on the aperture can be determined by applying the boundary conditions. The tangential magnetic field on the aperture should be continuous. Therefore, using the boundary condition which the tangential components are equal to each other, we can have the following equation.

$$\hat{n}\times\vec{H}^{inc} + \hat{n}\times\vec{H}^{ext} = \hat{n}\times\vec{H}^{int} \quad (4)$$

The unknown tangential magnetic field on the aperture boundary surface $\hat{n}\times\vec{H}$ would be

$$\hat{n}\times\vec{H} = \sum_{n=1}^{Ns} J_n \vec{f}_n \quad (5)$$

and this expression can be placed into (3a) equation. Here, $\vec{f}_n$, n the basis function and J_n is the amplitude of this basis function. For this boundary surface, a relation is existing which can be expressed

$$\vec{w}_n = \hat{n}\times\vec{f}_n \quad (6)$$

The integral equation, which is an inner product of the equality in (3) and the test function selected using Galerkin method, could be transformed into the following matrix form:

$$\left[h^{inc}\right] + \left[Y^{ext}\right]\{e\} = \left[Y^{int}\right]\{J_s\} \quad (7)$$

here, $\{e\}$ is the unknown electric field amplitude vector on the aperture, $\left[h^{inc}\right]$, $\left[Y^{ext}\right]$ and $\left[Y^{int}\right]$ are the matrix which could be achieved by using the inner products of magnetic field on the aperture.

Consequently, the integral equation which depends on the unknown electric field on the aperture is turned into a matrix equation using MoM. Next step is to place the right-hand side of the matrix equation into the system equation of the finite element method. If (5) is placed into the right hand-side of (3d), $\{b\}$ would be as following

$$b = j\omega\mu \sum_{j=1}^{Ns} J_j \int_{S_a} \vec{w}_i \cdot f_j dS \quad (8)$$

If we rewrite $\{b\}$ as $\{b\}=[B]\cdot\{J\}$, then the frequency domain finite element matrix of (2) would be as following:

$$([S] + j\omega\mu_0[T_1] - \omega^2\mu_0[T_2])\ \{e\} = [B]\{J\} \quad (9)$$

III.NUMERICAL RESULTS

In this section, we present some numerical results obtained using the hybrid MoM/FEM method described in the previous sections. To validate efficiency of the numerical model, the hybrid method is applied to empty and loaded enclosure with aperture. The dimensions of the rectangular enclosure is chosen as A=30cm, B=12cm and C=30cm. The aperture whose length and width are 10cm and 0.5cm is located at the center of front wall (x_0=15cm and y_0=6cm). It is considered that the enclosure is illuminated by a y-polarized plane wave impinging normally on the aperture in the front wall. In FEM mesh, enclosure is separated into 7x3x6 hexas, and each hexa is separated into 5 tetras. The unknown number in the mesh is 1105. With the presented MoM/FEM hybrid method, the electric field distribution into the enclosure is calculated. The method is applied to rectangular enclosure with rectangular aperture in the front wall. The walls of the enclosure are assumed to be thin and perfect conductor.

A. Empty Enclosure

The shielding effectiveness at center of the enclosure is calculated with the method and the results is compared by Robinson [3] (Fig. 2). As shown in Fig. 2, the results are very good agreement.

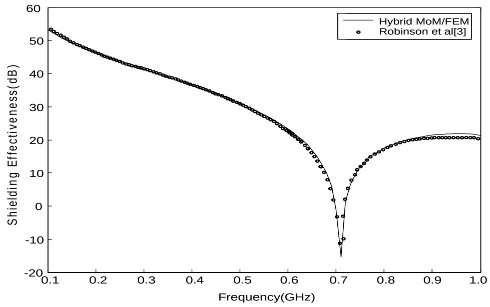

Fig 2: Simulations Results for the Shielding Effectiveness at the Center Of Enclosure with Aperture

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B. Dielectric Slab Loaded Enclosure

In the case of loaded enclosure, the shielding effectiveness is calculated with the hybrid MoM/FEM technique. The effect of the presence of dielectric slab inside the enclosure was examined by Feng et al. [11].

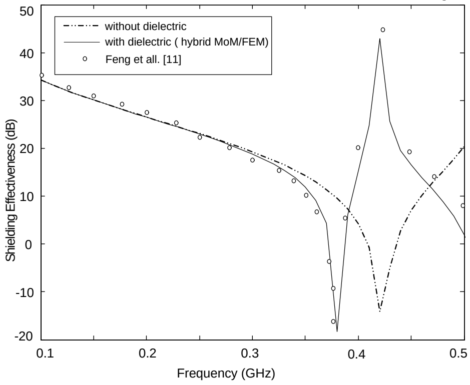

Fig 3: Effect of presence of dielectric slab on shielding effectiveness

In this study, A 50x50x50cm enclosure filled with a dielectric slab($\varepsilon_r = 6$) was considered. The aperture size is 10x20cm. The SE of the enclosure is measured 20cm away from the aperture. In the same enclosure, at the same point without the dielectric loading is given for comparison in Figure 3. The first resonance of the enclosure becomes 0.37 GHz with the presence of the filling dielectric slab. Around the frequency 0.42GHz there is much less EM energy coupled into the enclosure through the aperture. It seen that simulated results and Feng et al.[11] are in good agreement[13]. Finally, the effect of the change of dielectric slab size inside the enclosure is examined. The enclosure size was taken as 30x12x30cm (Fig.1). The dielectric slab is characterized by $\varepsilon_r = 2.65$ and $\sigma = 0.22$ S/m and dielectric slab thickness is 1cm. Dielectric slab is placed at the distances, t=3cm for xz plane. FEM mesh is constructed by separating the enclosure into 13x6x12 hexas and each hexa is separated into 5 tetras. The unknown number in the mesh is 4744. The dimension of the enclosure and aperture are same through all computations.

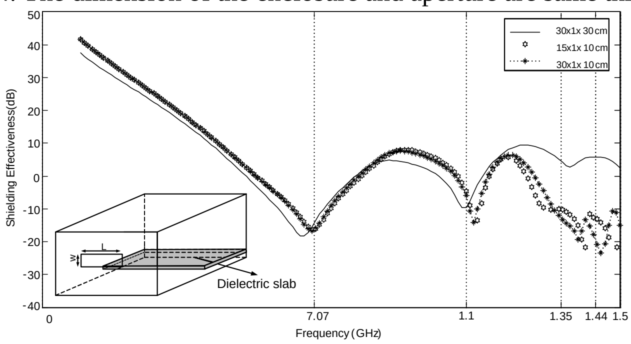

Fig 4: Effect of different dielectric slab sizes on shielding effectiveness (15cm, 6cm, 15cm)

The shielding effectiveness change with three different dimensions of dielectric slab placed into the enclosure is shown in fig. 4 and 5 from two different observation point respectively. Slab dimensions are 30x1x30cm, 10x1x10cm and 15x1x10cm respectively. The observation points used to calculate the shielding effectiveness are P1(15,6,15cm) and P2(15,6,27cm).

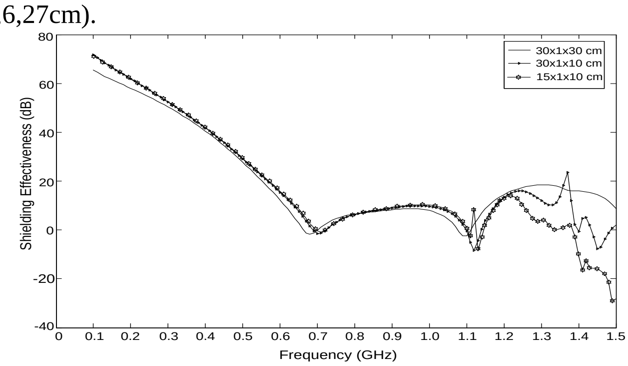

Fig 5: Effect of Different Dielectric Slab Sizes on Shielding Effectiveness (15cm, 6cm, and 27cm)

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When the whole slab is placed, an increase in shielding effectiveness at high frequencies is occurred and, it can be seen that the value of the shielding effectiveness at the second observation point is higher than the value at the first observation point.

IV.CONCLUSION

The shielding effectiveness of loaded enclosure with aperture has been investigated using hybrid MoM/FEM in frequency domain. The use of the FEM allows the potential application of the hybrid method to very complex geometry, in a very efficient way and without the absorbing boundary condition. Shielding effectiveness with the dielectric slab placed in different enclosure cross-sections is studied. We observed that the shielding effectiveness curves vary significantly as the dielectric slab size is changed. The method can be applied to EMI problems that involve the coupling between enclosures through aperture. By changing the sizes of dielectric slab inside the enclosure, the optimum configuration can be found. The method can be readily extended to evaluate the SE of enclosure with other geometries.

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