PLACEMENT OF ICS ON PCBS INSIDE RECTANGULAR ENCLOSURES USING STOCHASTIC AND OPTIMIZATION APPROACHES

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ABSTRACT

EMI reduction inside rectangular enclosures during early PCB design stages is presented. The whole framework suggests the correct IC placement using heuristic methods. The ICs on PCBs inside rectangular enclosures can be modeled in terms of small magnetic dipoles. Two different models of source configurations are examined. The first one is a simplified model of a symmetrically placed source grid and the second an ATX motherboard source model. The results for both source grid models taken with the two different optimization methods are presented. Finally the conclusions and their application in PCB design are discussed.

INTRODUCTION

New technologies in telecommunications and computer industry are constantly emerging. Integrated circuits with faster clock speeds are being manufactured. Motherboards and other PCBs (Printed Circuit Boards) become more complex. The problem of predicting EMI (Electromagnetic Interference) levels and complying with regulatory EMC standards is very common. It is advantageous to be able to make estimation for the EMI potential from PCBs during design process. The interaction between the sources and the enclosure is described by using the dyadic Green's function [1]. The electric current density on enclosure walls, which are assumed to be perfect electric conductors, is found using closed form expressions. Crawhall [2] used the concept of a mapping matrix in order to describe the interaction between the walls and multiple sources inside a cavity. He also produced Monte Carlo simulations in order to find induced current magnitude margins for random source positions. The authors have extended Crawhall's method using finite length current sources and different source configurations approximating more accurately the real conditions [6].

FORMULATION

For the rectangular cavity with dimensions a, b and c, along x, y and z-axis respectively (see Fig.1), the expressions for dyadic Green's function of the magnetic and electric vector potential are given in [1], [2] and [6].
For a small magnetic dipole source the current density inside the cavity is given by:

$$\overline{J}_m(\overline{r}') = (m_x\hat{x} + m_y\hat{y} + m_z\hat{z})\delta(\overline{r} - \overline{r}') \tag{1}$$

m_x, m_y, m_z are the components of the magnetic dipole moments in the $\hat{x}, \hat{y}$ and $\hat{z}$ directions respectively.

The surface current density $\overline{J}_s$ on the walls due to magnetic current moment m_z has the following form:

$$\begin{aligned}\overline{J_s} &= \frac{m_z}{ab}\sum_m\sum_n e_m e_n\left[\frac{1}{k^2}\left(\frac{\sin(k_g z')}{\sin(k_g c)}\right)\right]\times \\ &\left\{-k_y\left[\cos(k_x x)\sin(k_y y)\cos(k_x x')\cos(k_y y')\right]\hat{x}\right. \\ &\left.+k_x\left[\sin(k_x x)\cos(k_y y)\cos(k_x x')\cos(k_y y')\right]\hat{y}\right\}\end{aligned} \tag{2}$$

In (2) the coefficients are given as follows:

$$
\begin{aligned}
&k = \omega\sqrt{\mu_0\varepsilon_0} = \frac{2\pi}{\lambda} \\
&k_x = \frac{m\pi}{a}, k_y = \frac{n\pi}{b}, k_z = \frac{l\pi}{c} \\
&k_c^2 = k_x^2 + k_y^2 \\
&k_g^2 = (k^2 - k_c^2) \\
&e_i = \begin{cases} 1 & \mathrm{i} = 0 \\ 2 & \mathrm{i} \neq 0 \end{cases}
\end{aligned}
\tag{3}
$$

If n possible cavity sources exist and m wall points of interest are taken into account then the amplitude mapping of every source to a specific point on the wall is represented by a matrix A nXm [2]. In A a matrix element ρ_{ij} represents the disturbance on j^{th}-point caused by the i^{th}-source. Disturbances caused by multiple sources in the same reference wall point can be summed using the principle of superposition. The deterministic values calculated in the mapping matrix are accurate enough only if all the source characteristics (magnitude, polarization and phase) are modeled correctly.
The accurate prediction of electromagnetic emission from multiple source systems is a difficult or even impossible task due to their complexities. A stochastic approach has the advantage of proving a quantification of major trends in such systems. Monte Carlo simulation is a powerful tool that has been applied successfully in many different engineering problems [3]. Monte Carlo simulations are performed based on source existence probability distributions and source amplitude probability levels. The mapping matrices are evaluated using the dyadic Green's functions. A loop is performed with an adequate number of iterations. During the loop process a random set of sources is generated according to a known probabilistic distribution (binomial for this case). All the elements ρ_{ij} of the mapping matrix are multiplied by a Bernoulli random variable, ζ_{ij} that lies in the set of values [0,1]. The result is a new matrix A'. The value of the random variable ζ_{ij} depends on the probability distribution chosen. When the loop ends, the statistical processing of the data begins. Matrix A' is calculated for every iteration. The results are statistically processed and the wall points of the probable larger current density values are found. The statistical analysis of the results involves calculation of the 90^{th} percentile values. The 90^{th} percentile gives the value below of which lie the 90% of the samples.
It has been shown in [6] that the y-current component in (2) coming from the magnetic dipoles parallel to z-axis presents particular interest since is anti-symmetric and has the highest values (among anti-symmetric components). This was the reason for the selection of this component in the following results.
In the examples given below the objective is to reduce current values in the bottom wall row for two different opposite walls (Fig.1). The cost function is given by:

$$
E_{\cos t} = \sum_1^N \left(\sum_1^M \left| J_s^{Wall1} \right| + \left| J_s^{Wall4} \right| \right) \tag{4}
$$

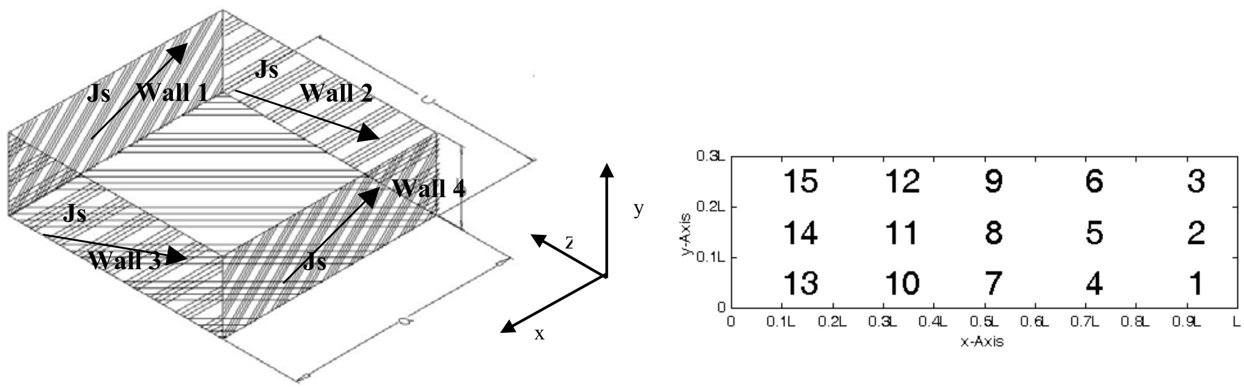

Fig.1 Rectangular enclosure geometry and wall points on walls of interest

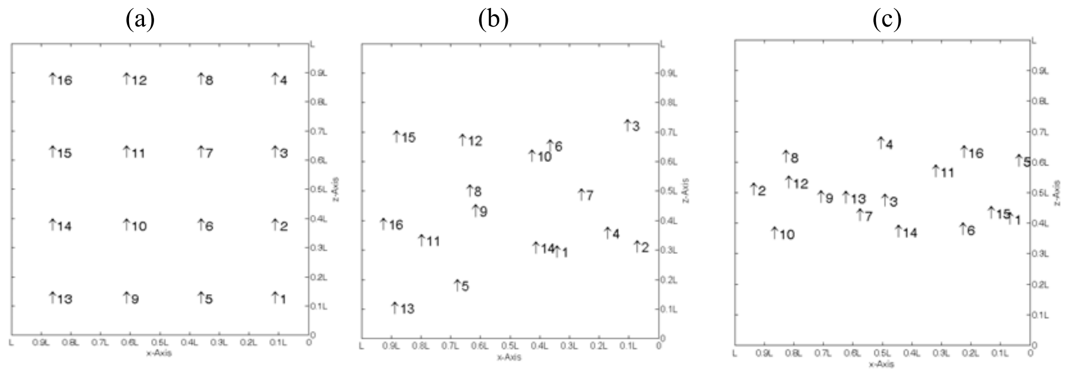

Fig.2 Source grids (a) initial symmetrical grid (b) optimized by simulated annealing and (c) optimized by genetic algorithms.

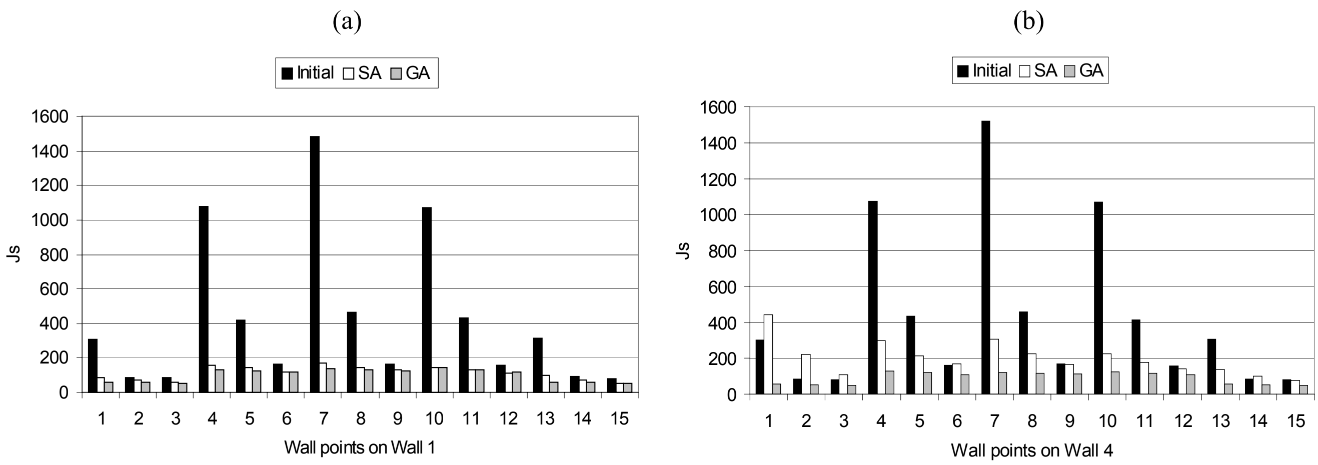

Fig.3 90th Percentile current values for Walls 1 and 4

Where N is the number of sources, M the number of wall points selected and J_s^{Wall1}, J_s^{Wall4} is the current surface density in wall 1 and 4 respectively. The variables of the cost function are the x and z coordinates of the sources. Two different methods of stochastic optimization Simulated Annealing (SA) and Genetic Algorithms (GA) are used for the minimization of (2). In order to find the best possible outcome Monte Carlo simulation is applied to the results of both optimization methods.

NUMERICAL RESULTS

Two different models of source configurations are examined. The first one is a simplified model of a symmetrically placed source grid (Fig 2a) and the second an ATX motherboard source model (Fig. 4a). ATX is an industry standard but motherboards from different vendors differ in design although they use the same architecture principles. Therefore ATX motherboards have ICs placed at asymmetric positions but within the rules of a common architecture. An ATX motherboard model can be made by dividing the motherboard in distinct areas each having sources with different existence probabilities and different magnitude distributions.

Figs 2b-2c show the optimized grids produced by SA and GA respectively. The Monte Carlo simulation results for both walls are given in Figs 3a-3b. In all points the new values are significant smaller than the initial ones up to two orders of magnitude. GA values are smaller than those produced by SA but within a small margin.

The same method was applied again for the ATX source configuration shown in Fig 4a. The optimized grids are given in Figs 4b-4c. The Monte Carlo simulation results for this case are shown in Figs 5a-5b. For wall 1 SA and GA performs satisfactory giving smaller values than the initial ones. Again the GA gives better results. It must be pointed out that due to asymmetrical source configuration wall 1 presents higher current values than wall 4.

(a) (b) (c)

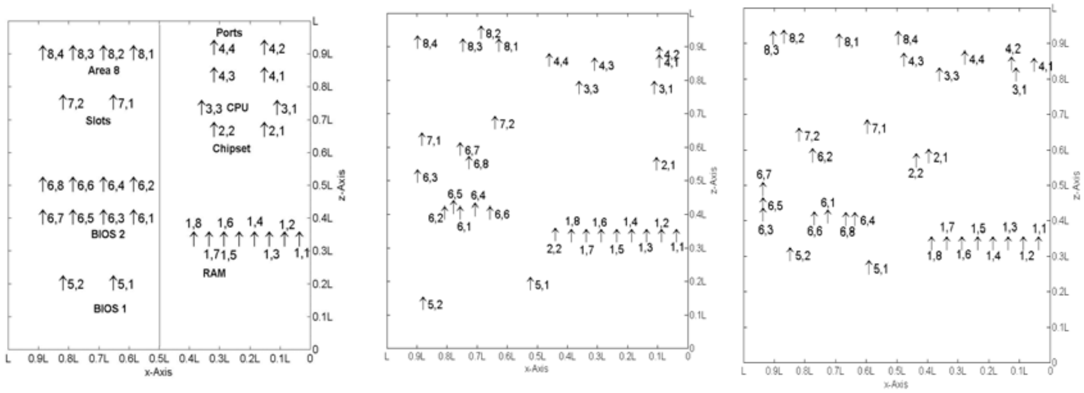

Fig.4 Source grids (a) initial ATX grid (b) optimized by simulated annealing and (c) optimized by genetic algorithms.

(a) (b)

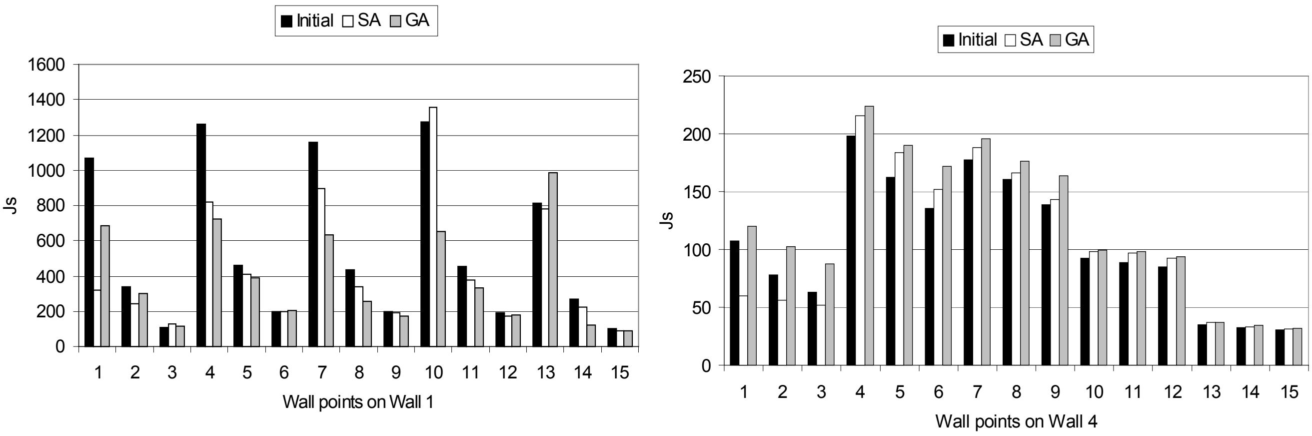

Fig.5 90th Percentile current values for Walls 1 and 4

Results for wall 4 indicate a small increase in current values (less than 8%). There is a trade-off between the reduction in wall 1 and the increase in wall 4. The results have shown that Monte Carlo simulation combined with stochastic optimization methods can be a useful tool in predicting and reducing emission level margins. Similar methods can be applied for a variety of equipment. PCB designers can easily apply these techniques in order to make early risk limiting decisions during the design process.

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