Development of a magnetic field model and insertion into a commercial electromagnetic simulator

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Abstract

To take into account certain ElectroMagnetic Compatibility (EMC) aspects and especially to evaluate the magnetic fields radiated by electronic components, different radiated emission models have been created. Within IRSEEM, a magnetic field model based on equivalent sources (electric dipoles) placed on a plane has been developed. Thus, this paper presents the modelling procedure that requires magnetic near-field measurements and matrix inversion methods. Concerning the measurements of the field radiated by the component under test, a near-field test bench with a loop antenna is used to quantify the tangential components of the magnetic field in amplitude and phase. Then, these data are used as input to determine the parameters of the model: the orientation in the plane and the current of each dipole. The aim of our study is to insert this model into one of the most commonly used commercial electromagnetic tools (based on Finite Element Method) to make it helpful for engineers. In this context, a macro has been developed to draw and define each dipole in the software. The modelling and insertion procedure are validated by the characterization of a passive circuit such as a 90° hybrid coupler and an active component (microcontroller).

Key Words: *Near-field measurement, radiated emission model, electromagnetic simulation software, EMC engineering.*

1. Introduction

Due to the miniaturization of components in electronic boards, coupling effects can appear and consequently disturb their normal operation. In order to predict the radiation and coupling before conception, radiated emission models of components [1–4] become necessary for electronic board designers.

These models work without additional tools to calculate magnetic fields in near or far field regions. Nevertheless, to predict, for example, the coupling between the component and the tracks of a printed circuit board (PCB), supplementary tools are necessary. Thus, to facilitate the engineer's work, some electromagnetic

tools have been developed [5, 6] by laboratories. To avoid these proprietary tools, we propose a generic model that can be inserted into one of the most commonly used commercial electromagnetic simulation software: Ansoft HFSS (High Frequency Structure Simulator) based on Finite Element Method.

In this paper, our model, which predicts radiated emissions at different heights above the component, is quickly presented. In previous works [7], this model has been validated with several devices (active and passive) for different frequencies between 100 kHz and 1 GHz. For modelling, information about magnetic field close to the device is required. The way of obtaining this information is also presented. Next, the process to insert the model into Ansoft HFSS is explained in detail.

In the last part of this paper, we validate the model and its insertion into HFSS using a 90° hybrid coupler. Finally, as an application, a microcontroller used in a modem card is modelled and HFSS simulations are compared with measurements.

2. Presentation of the model and its insertion into a commercial electromagnetic software

2.1. Structure of the model

The model is based on an array of elementary electric dipoles (current lines) placed on a XY-plane and that radiates a magnetic field equivalent to the one radiated by the component. A scheme is shown in Figure 1.
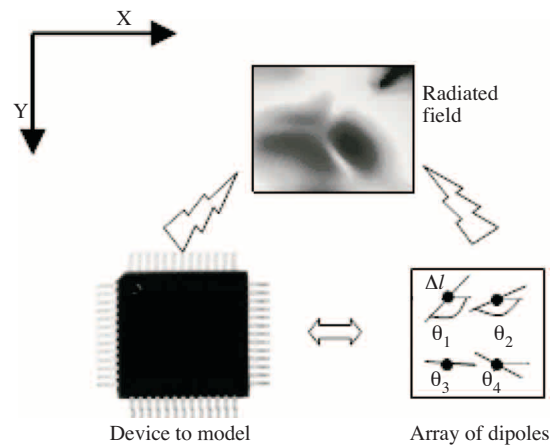

Figure 1. Principle of the model.

Each electric dipole is characterized by a complex current intensity (I) and an orientation (θ) in the XY-plane. The number of dipoles, their length (Δl) and their position are fixed by the user. Thus, building the model consists in determining the unknown parameters, i.e. I and θ, for each dipole. For this purpose, we use the following procedure.

2.2.   Mathematical analysis

The magnetic field $\vec{H}$ created by an elementary electric dipole placed in the XY-plane can be calculated from the magnetic vector potential $\vec{A}$ [8]. Therefore, the mathematical expressions of the three components are:

$$H_x = \frac{I}{4\pi}\Delta l\frac{e^{-jkR}}{R^2}\left(\frac{z-z_0}{R}+j\frac{\omega\left(z-z_0\right)}{c}\right)\sin\theta = \alpha_x\sin\theta \tag{1}$$

$$H_y = -\frac{I}{4\pi}\Delta l\frac{e^{-jkR}}{R^2}\left(\frac{z-z_0}{R}+j\frac{\omega\left(z-z_0\right)}{c}\right)\cos\theta = \alpha_y\cos\theta \tag{2}$$

$$\begin{aligned}H_z = \frac{I}{4\pi}\Delta l\frac{e^{-jkR}}{R^2}\Big[&\left(-\frac{x-x_0}{R}+j\frac{\omega(x-x_0)}{c}\right)\sin\theta \\ &+\left(\frac{y-y_0}{R}+j\frac{\omega(y-y_0)}{c}\right)\cos\theta\Big] = I\left[\alpha_{z1}\sin\theta + \alpha_{z2}\cos\theta\right]\end{aligned} \tag{3}$$

where

- (x,y,z) are the coordinates of the point M where magnetic field is evaluated;

- (x_0,y_0,z_0) are the coordinates of the centre of the dipole;

- Δl corresponds to its length;

- k is the wave number $(2\pi/\lambda, \lambda$ the wavelength);

- R corresponds to the distance between the M-point and the centre of the dipole ;

- α_x, α_y, α_{z1} and α_{z2} are constants depending on the above five points discussed;

- I is the current flowing through the dipole;

- θ represents the orientation of the dipole in the XY-plane.

Since the model is built with N dipoles, the magnetic field created by all of them at a point j in space is obtained as the sum of the individual contributions of each dipole:

$$H_{xj} = \sum_{i=1}^{N} I_i\alpha_{xij}\sin\theta_i \tag{4}$$

$$H_{yj} = \sum_{i=1}^{N} I_i\alpha_{yij}\cos\theta_i \tag{5}$$

$$H_{zj} = \sum_{i=1}^{N} I_i\left[\alpha_{z1ij}\sin\theta_i + \alpha_{z2ij}\cos\theta_i\right]. \tag{6}$$

Thus, to determine the parameters I and θ of the model we need the magnetic field at a certain height above the device. To obtain the cartographies of the magnetic field, near-field measurements have been carried out. We then calculate the orientations using the least-square inverse method as formulated below:

$$\left[\alpha_{xij}\right]^{-1}\left[H_{xj}\right] = \left[I_i\sin\theta_i\right] = [A] \tag{7}$$

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$$[\alpha_{yij}]^{-1}[H_{yj}] = [I_i \cos\theta_i] = [B] \tag{8}$$

$$\theta_i = \tan^{-1}\left(\frac{A_i}{B_i}\right). \tag{9}$$

Once these angles are known, the currents are obtained by means of the following equation:

$$[I] = \left[\begin{array}{c} \alpha_{xij}\sin\theta_i \\ \alpha_{yij}\cos\theta_i \end{array}\right]^{-1} \left[\begin{array}{c} H_{xj} \\ H_{yj} \end{array}\right]. \tag{10}$$

Knowing all the values of I and θ, we are capable of calculating the magnetic field at any distance above the height at which the measurements were done.

2.3. Obtaining the cartographies

To carry out the measurements required for modelling, the near-field test bench developed within IRSEEM is used [9, 10]. This test bench (Figure 2) is constituted by a three axes robot. A differential probe whose surface is 4mm^2 is connected to the robot arm. The robot, commanded by a PC, moves the probe above the circuit (with a maximum mechanical resolution of 5 μm in the three directions) and does the data acquisition measured by a network analyzer. These data consist of magnitude and phase of the magnetic field. To measure the magnetic field radiated by an active circuit, a special setup is used. In this case, the network analyzer works in "External Source" mode with an external phase reference (radiated signal picked up from the circuit with another probe) [7].
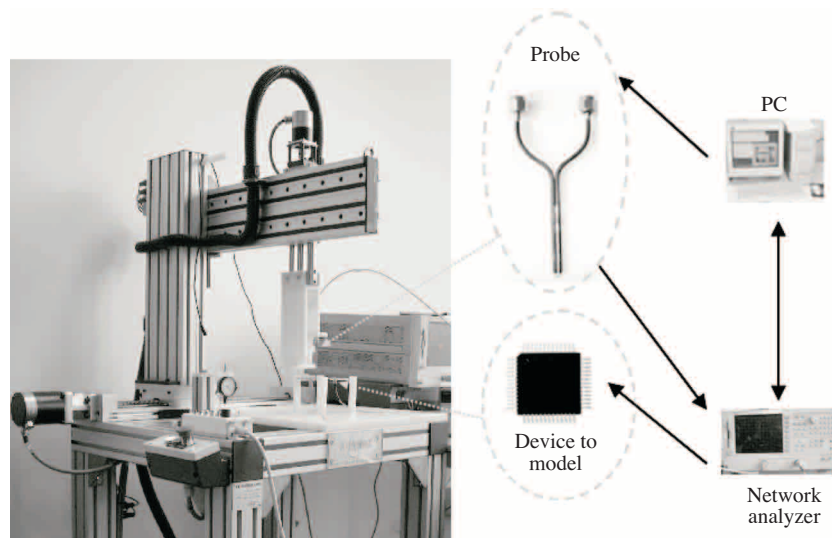

Figure 2. Measurement setup.

2.4. Insertion process

For this task, we have used an electromagnetic simulation tool commonly used in industries: HFSS. This software [11] supports the use of Microsoft VBScript to execute macros based on the Microsoft Visual Basic programming language. Therefore, we have taken advantage of this capacity to integrate the model into HFSS.

In order to carry out the integration, it is necessary to export the calculated model to a text file. This file contains the information about the centre of the dipoles, their length, their orientation and their current (magnitude and phase) in columns. The integration algorithm can be divided into five stages:

1. Definition of general information: units of measurement are asked to the user.

2. Input text file: the input text file containing the characteristics of the dipoles is requested.

3. Creating graphical dipoles: each dipole is designed as a thin rectangular structure where a current source, represented by an arrow, is injected (Figure 3). Firstly, the macro reads the coordinates of the centre and the length so as to build a dipole in the x-axis. Next, it is excited with the current value (magnitude and phase) following the x-direction. Finally, the orientation is read and the dipole is turned with this value on the XY-plane. Once the first dipole is created, the process for the others is the same until the whole model is completely generated in HFSS.
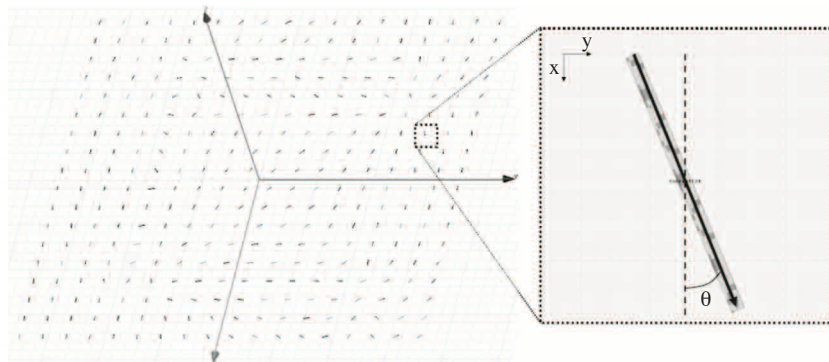

Figure 3. Dipole set in HFSS.

4. Excitation: HFSS only considers, by default, the first designed source as the exciting source by putting its scale factor equal to 1 and 0 to the others. In the model, all sources should be active because all take part in the radiation so they are all activated by applying 1 to the scale factors.

5. Simulation settings and analysis: in this stage, the frequency and some simulation parameters (maximum delta energy, number of passes for convergence and the mesh size) are required.

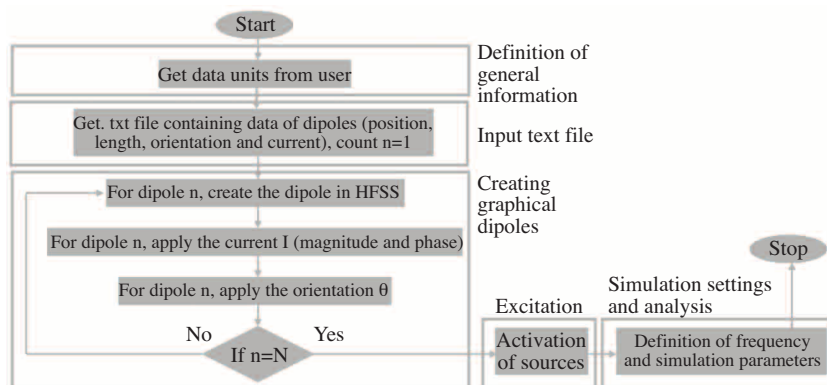The whole algorithm for the insertion of the N dipoles is shown in Figure 4.

Figure 4. Integration algorithm in HFSS.

At the end of the process, the user can add other structures around the model (e.g. tracks of PCB). In this paper, we only validate the insertion of the model in open space.

3. Validation of the model and its insertion into an electromagnetic software

To validate the process of insertion, a simple circuit has been modelled: a 90° hybrid coupler in microstrip technology and working at 960 MHz (Figure 5). The model is built from the measurements of magnetic field at 2 mm above the device.
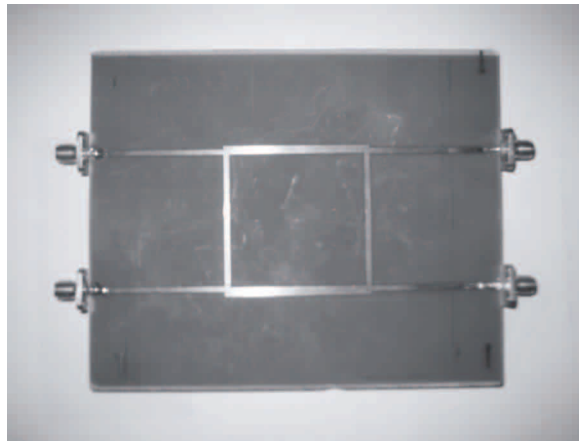

Figure 5. 90° hybrid coupler.

3.1. Modelling the 90° hybrid coupler

Figure 6 shows the set of dipoles obtained after the process of modelling. The shape of the coupler is also represented. The distribution of the current through the dipoles is shown as well. We can see that the highest values of current are on the same position as the microstrip lines and the corresponding dipoles follow their orientations. So, in this simple case, we can find the actual radiation sources by looking for the highest currents.
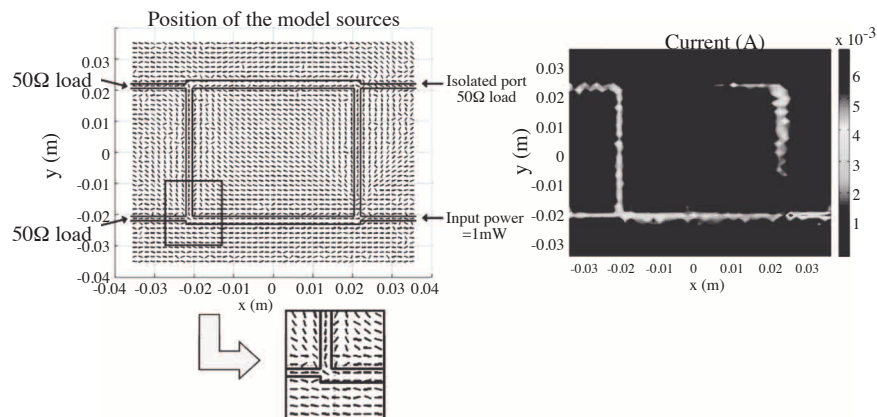

Figure 6. Set of dipoles on the XY-plane and distribution of the current.

3.2.   Validation of the results obtained by integration

The insertion of the model into HFSS applied to the 90° hybrid coupler is now presented. First of all, a model with uniformly spread 18 × 18 dipoles is integrated into the software. To reduce the time of insertion and simulation, we have simplified the model (reduced to 100 dipoles) by only keeping dipoles with the highest current values (threshold of 20% of the maximum current value), i.e. along the microstrip lines (Figure 7).
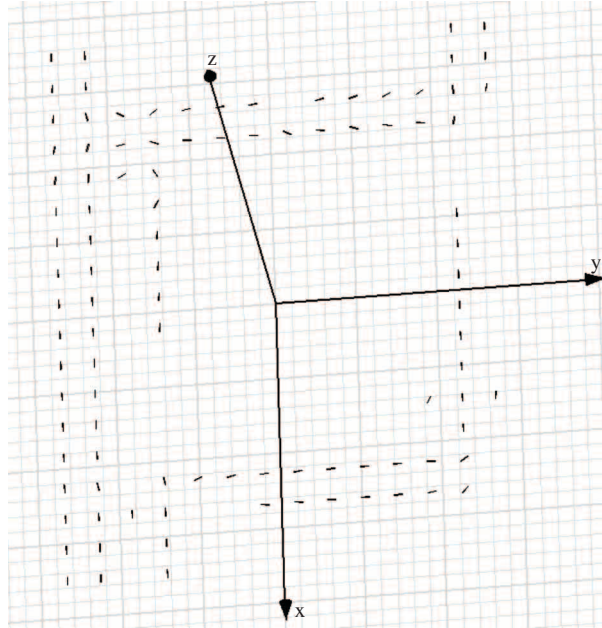

Figure 7. Dipole set in HFSS (100 dipoles).

Figure 8 and Figure 9 show the magnitude and phase of magnetic field respectively at a height of 2 mm whereas Figure 10 and Figure 11 show them at a height of 1cm.

To quantify the differences between measurement and simulation we define the following error:

$$error = \sum \frac{(|H_{measured}| - |H_{simulated}|)^2}{\sum |H_{measured}|^2} \tag{11}$$

Table 1 Contains the errors obtained for 324 and 100 dipoles at 2 mm and 1 cm above the device.

Quite good results have been obtained at both heights using 18 × 18 dipoles and that allows us to validate the integration process into a commercial electromagnetic simulation tool.

The results obtained with 100 dipoles show a good accordance in magnitude and phase at the microstrip line positions but as there are no dipoles around, they are less accurate in those regions. However, in general, we obtain pretty good results especially in magnitude.

Using a computer of 3.20 GHz and 2 GB RAM, the simulation time of the model is 67 minutes using 324 dipoles and 21 minutes using 100 dipoles.
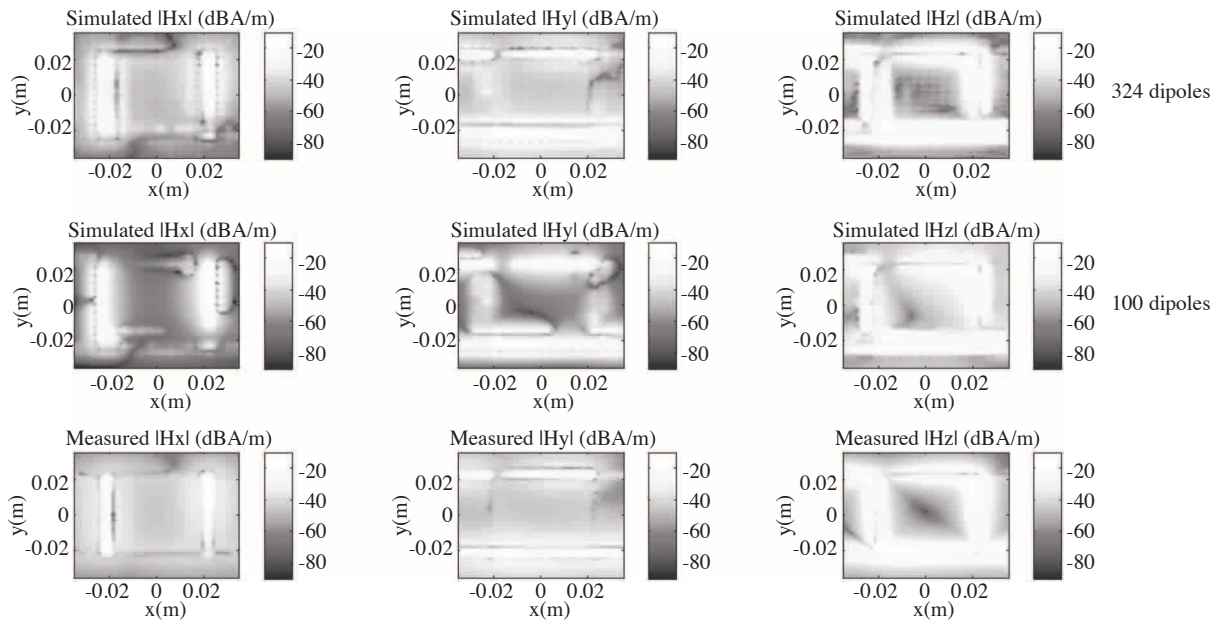
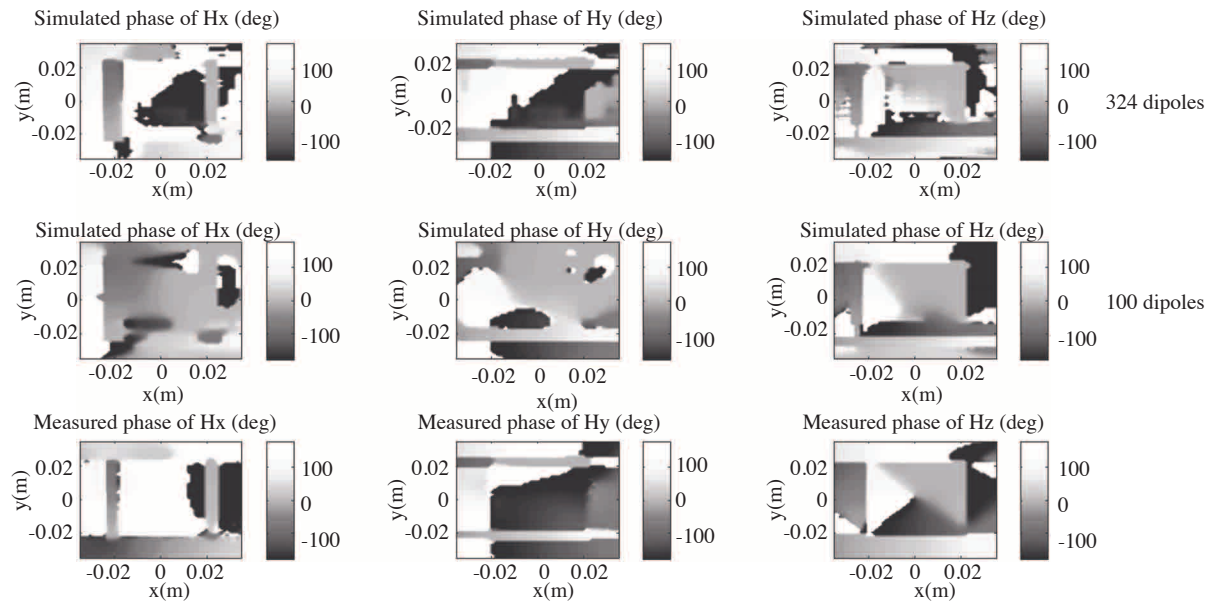**Figure 8.** Magnitude of simulated (HFSS) and measured H-field at 2 mm.

Figure 9. Phase of simulated (HFSS) and measured H-field at 2 mm.

Table 1. Errors between simulations and measurements.

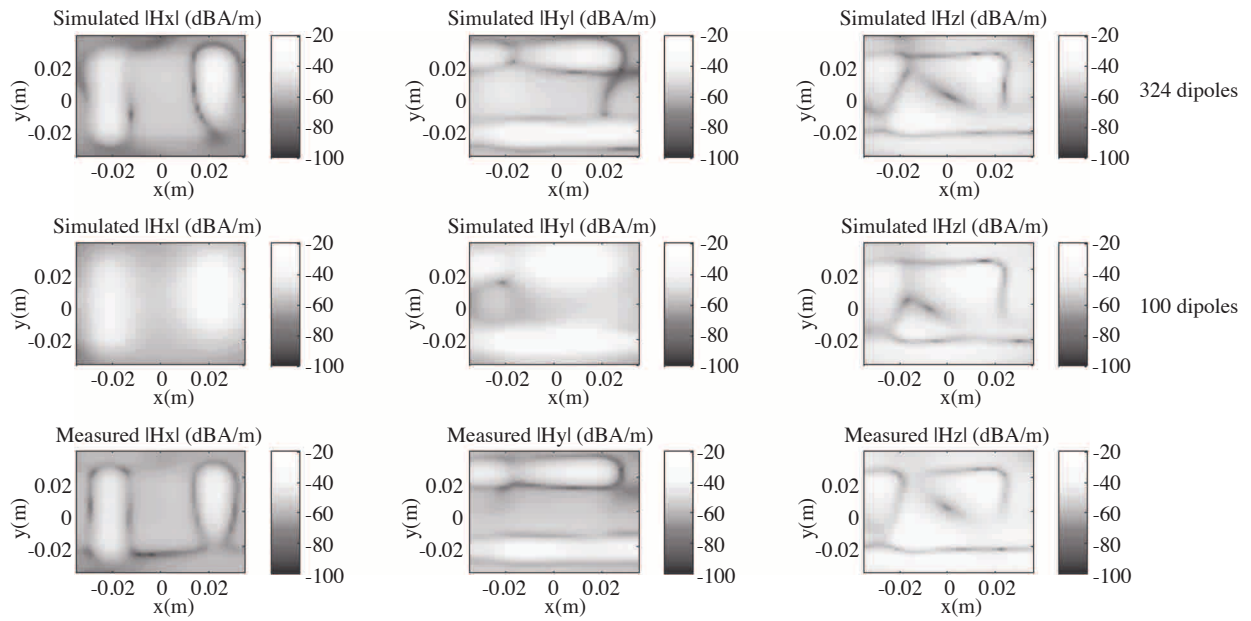| Dipoles	2mm			1cm		
	Hx	Hy	Hz	Hx	Hy	Hz
324	0.0082	0.0134	0.0076	0.0027	0.0054	0.0038
100	0.0098	0.0161	0.0090	0.0721	0.0679	0.0048

Figure 10. Magnitude of simulated (HFSS) and measured H-field at 1 cm.
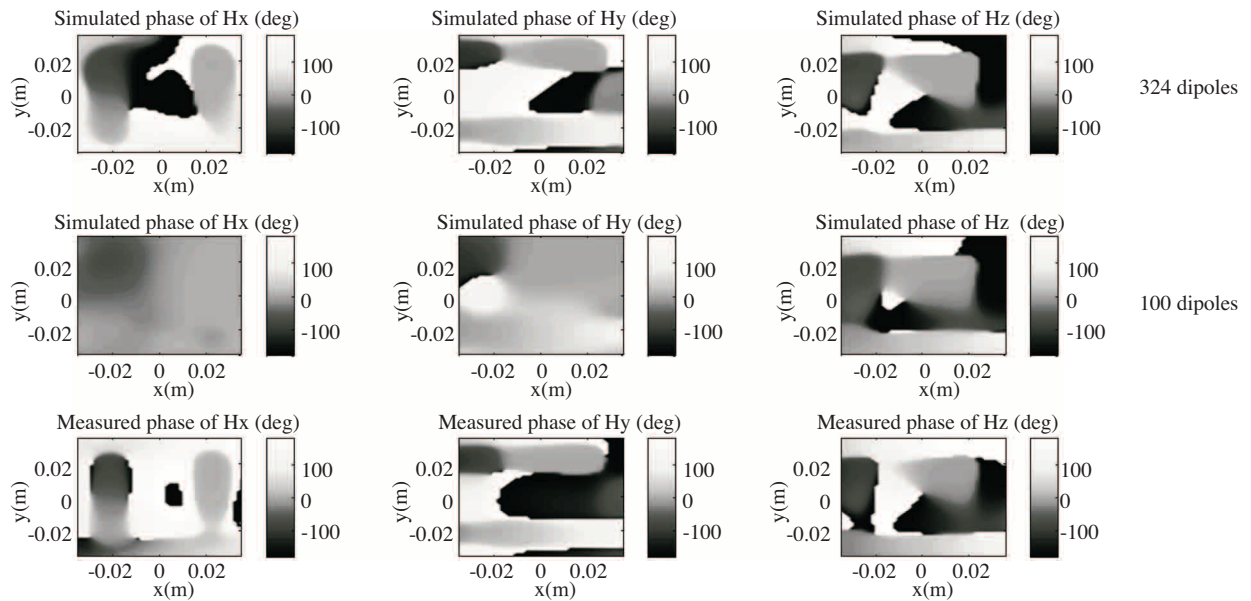

Figure 11. Phase of simulated (HFSS) and measured H-field at 1 cm.

4. Application to an active circuit

In this section, we apply the model to a microcontroller used in a modem card whose dimensions are 20×20 mm^2 and working at 28 MHz. The model is obtained from measurements at 4 mm above the circuit.

As in the case of the 90° hybrid coupler, the model of the microcontroller is reduced to 44 dipoles by taking the dipoles with a current value greater than the 20% of the maximum current value. Both sets (uniformly

spread 196 dipoles and reduced 44 dipoles) are inserted into HFSS. Figures 12 and 13 show a comparison between simulated and measured magnetic field at 4 mm.
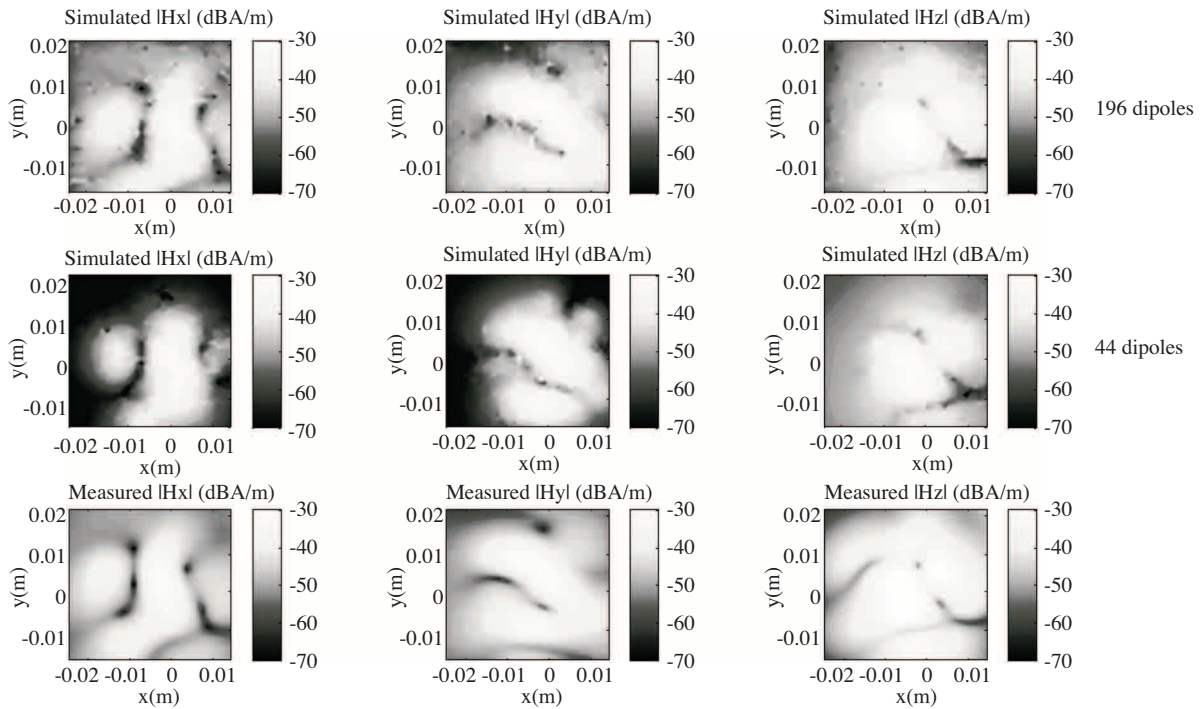

Figure 12. Magnitude of simulated (HFSS) and measured H-field at 4 mm.
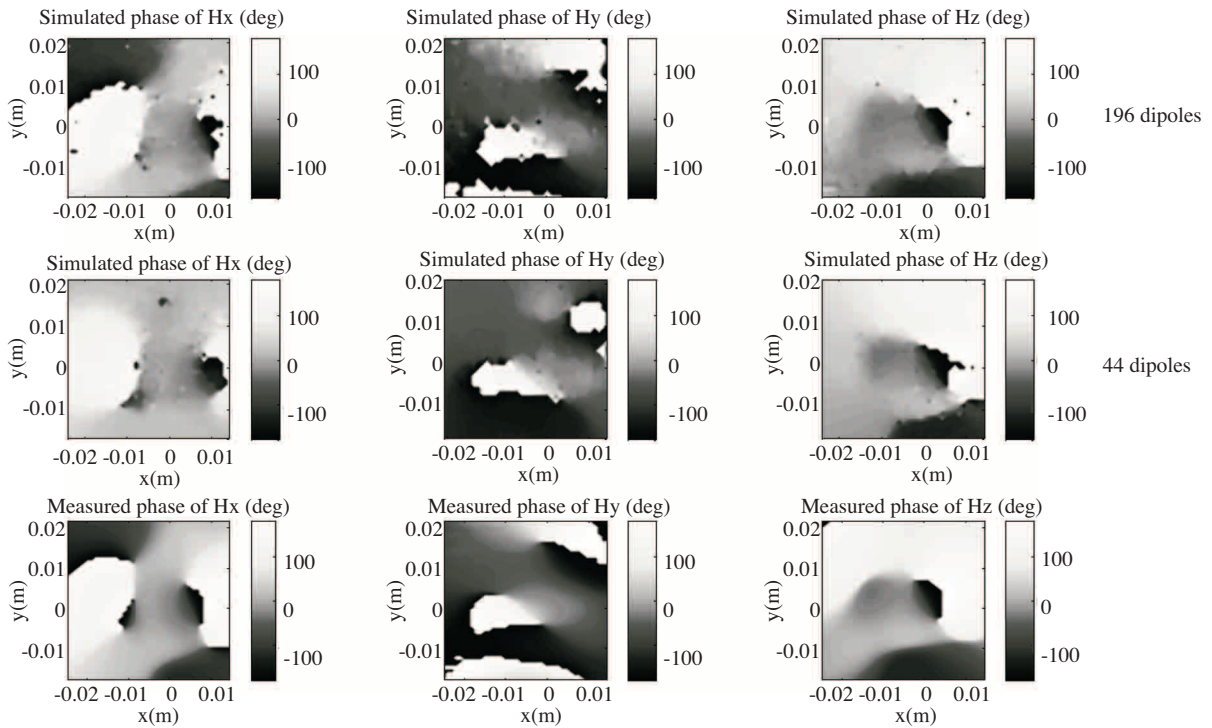

Figure 13. Phase of simulated (HFSS) and measured H-field at 4 mm.

Table 2 contains the errors obtained for 196 and 44 dipoles at 4mm above the device using (11).

Table 2. Errors between simulations and measurements.

Dipoles	Hx	Hy	Hz
196	0.0161	0.0122	0.0955
44	0.1542	0.1141	0.2033

We achieve a good agreement in magnitude and phase using 196 dipoles. For 44 dipoles, we obtain a very acceptable accordance in magnitude and in phase. In this case, some differences in level appear in the positions where the intensity of measured field is smaller, i.e. in the positions where the model gives equivalent dipoles with low current levels (dipoles not chosen for the reduced set).

The simulation time of the model into HFSS is 33 minutes for the set of 196 dipoles and 11minutes for the set of 44 dipoles with a computer of 3.20 GHz and 2 GB RAM.

5.   Conclusion

A simple method to model the magnetic radiation emanating from electronic components at any height has been presented. The model is based on a set of dipoles characterized by an orientation and a current. In order to build the model, cartographies of x and y components of magnetic field $\vec{H}$ at a close height over the device are required. This model predicts not only the Hx and Hy components but Hz as well. Moreover, the radiated magnetic field at any height above the device (greater than the measured height) can also be simulated. We also highlight the generic character of our model because no information about the internal architecture and the materials of the device is needed to apply the model, i.e. we can consider the component as a black box. Otherwise, the most restrictive aspect is that the phase measurements are necessary. This can become more complex for active circuits because a stable phase reference on the circuit is required and that does not always exist.

In addition, the integration process of the obtained model into a commercial tool such as HFSS by means of a macro written in Visual Basic language has been explained. We point out that the insertion and simulation time of the model into HFSS can be long (67 minutes to simulate 324 dipoles). In addition, if we work at a low frequency, the mesh defined for the Finite Element Method will be very small compared to the wavelength and this will require high-performance computers.

To validate the process, the integration into HFSS has been applied to a microstrip 90° hybrid coupler and a microcontroller with pretty good results in magnitude and phase. A reduction of the number of sources has been carried out using both circuits and a good agreement is obtained especially in magnitude.

As future work, the final objective of integration is to study the coupling of the modelled device with other components close to it. The results obtained with HFSS will be compared to measurements.

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