

# Modification of FDTD-MAS Method for EMI Estimation with Surrounding Large Objects in Analytical Space

Tatsuro Kiso<sup>#1</sup>, Tetsuo Iwaki<sup>#2</sup>, Takashi Kasuga<sup>\*3</sup> and Hiroshi Inoue<sup>†4</sup>

<sup>#</sup>SHARP CORPORATION

*Ichinomoto-cho 2613-1, Tenri City, Nara Prefecture, Japan*

<sup>1</sup>kiso.tatsuroh@sharp.co.jp

<sup>2</sup>iwaki.tetsuo@sharp.co.jp

<sup>\*</sup>Nagano National College of Technology

*Tokuma 716, Nagano City, Nagano Prefecture, Japan*

<sup>3</sup>kasuga@ee.nagano-nct.ac.jp

<sup>†</sup>Akita University

*Tegatagakuen-cho 1-1, Akita City, Akita Prefecture, Japan*

<sup>4</sup>inoueh@ipc.akita-u.ac.jp

**Abstract**— The emissions of electromagnetic interference (EMI) depend on the structures of electrical equipment such as the chassis, cables, printed circuit boards (PCBs), and LSI. In order to predict the EMI emitted by some equipment, it is necessary to create an accurate model of the detailed structure of a radiation source, because the conduction and radiation of EMI depend on the microstructure of the equipment. However, the electromagnetic analysis of a large space with a fine pitch requires considerable time using basic simulation methods such as the finite differential time domain (FDTD) method [1]. The FDTD multiple analysis space (FDTD-MAS) method was proposed to simulate the microstructure (of, for example, PCBs) and surrounding large space efficiently. In the FDTD-MAS method, the small space near a radiation source is calculated by the fine-pitch FDTD method, while the surrounding large space is calculated by the coarse-pitch FDTD method. However, for the use of the FDTD-MAS method, no structures should exist within the surrounding space.

We propose a novel simulation method—modified FDTD-MAS—to eliminate this restriction. The computational results obtained using the new method are compared with the measured results and the results computed by the original FDTD-MAS method.

**Keywords:** FDTD, FDTD-MAS, Radiation, EMI, Estimation

Therefore, the analytical accuracy and speed achievable using an electromagnetic analysis method such as the finite differential time domain (FDTD) method is not sufficient for use in actual product development [1].

To resolve this issue, Kasuga et al. proposed the FDTD-multiple analysis space (FDTD-MAS) method [2]. In this method, the electromagnetic field radiated from the internal space, which includes small structures and noise sources, is analyzed by a fine-pitch FDTD method and the radiation pattern is recorded; then, the external space, which encloses the inner space, is analyzed by a coarse-pitch FDTD method using the recorded radiation pattern. However, for the use of the FDTD-MAS method, no structures should exist within the external space. Our proposed method—modified FDTD-MAS—eliminates this restriction.

First, we explain the basic theory and calculation of FDTD-MAS, and we then explain the modified FDTD-MAS method. The application of the modified FDTD-MAS method to a real problem is then described, and its performance is evaluated by comparing the analytical results with those of the original FDTD-MAS method and the measured results.

## I. INTRODUCTION

The electromagnetic interference (EMI) in electronic devices such as flat-panel TVs becomes a major issue with their increasing complexity. Therefore, a method that can simulate the EMI during the product design stage is required in order to analyze and then solve this problem. However, with the increasingly fine line pitch of printed circuit boards (PCBs) and the increasing panel size of TVs, the structures of these devices have become more complex. For example, if the line pitch of a PCB is 200  $\mu\text{m}$  and the panel size of a TV is 2 m, the dynamic range of the structure is approximately 10000.

## II. THEORY

### A. FDTD-MAS method

The FDTD-MAS method is an analytical technique that is used to analyze the electromagnetic field distribution of a wide space rapidly through two different analysis phases. The first phase involves the calculation of the internal analysis space (IAS); the internal space, including small structures and wave sources, is analyzed in detail by the fine-pitch FDTD method. The second phase involves the calculation of the external analysis space (EAS); the external space that encloses the internal space and that contains no other structures around the internal space is analyzed by the coarse-pitch FDTD

method. In the sub-grid FDTD method —most popular coarse-fine-mesh concatenated simulation method—, the fine-meshed regions and the coarse-meshed regions are calculated using bidirectionally concatenated. On the other hand, the calculation of the FDTD-MAS method is one-way concatenated.

For the sake of simplicity, we have only explained the two-dimensional FDTD method in this paper. Fig. 1 shows an electric field cell and the arrangement of electromagnetic variables. The electric field variables are arranged in parallel at the center of the edges of the rectangle, and the magnetic field variables are arranged vertically at the center of the rectangle.

In the FDTD-MAS method, a natural number  $R_a$  ( $>0$ ) is used to indicate the ratio of the mesh size in the EAS calculation to that in the IAS calculation. Then, in the EAS calculation, the number of electric field cells in the same area as that in the IAS calculation becomes the reciprocal of  $R_a$  per axis. In addition, the time step of the EAS calculation is multiplied by  $R_a$ .

Moreover, the conversion boundary (CB) encloses radiation sources, including peripheral structures with radiation sources. The CB is assumed to be a closed curve comprising the edges of the electric field cell in the mesh used in the EAS calculation.

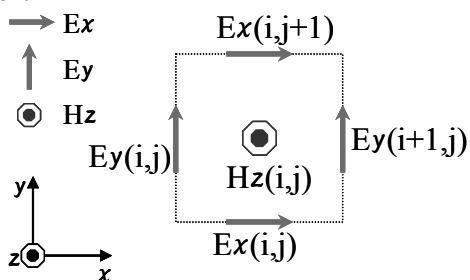


Fig. 1 Electric Field Cell in FDTD Method and Arrangement of Electromagnetic Field Variables

### 1) IAS calculation

In the IAS calculation, whole analytical space is divided by a fine mesh that is suitable for modeling a peripheral structure with a noise source. Moreover, for an infinite void space to exist around the CB, the analysis is conducted by installing suitable void cells around the CB and then enclosing them with an absorption barrier such as PML. The electric field variables at the positions where those of the EAS calculation on the CB exist are recorded in the electric field file every time the electric field of the EAS calculation is calculated. Because it does not influence the value of the electromagnetic field distribution outside the CB in the EAS calculation phase, we have not discussed this in this paper, although the magnetic field variables on the CB are recorded in the FDTD-MAS method [2].

### 2) EAS calculation

In the EAS calculation, the analysis area is set as the space within the range in which the electromagnetic field distribution around the CB is to be analyzed. An absorption barrier such as PML is arranged around the space. Here, the

electric field variables on the CB are overwritten with the values which were recorded in the IAS calculation and the electromagnetic field distribution outside of the CB is analyzed.

### B. Modified FDTD-MAS method

By using the FDTD-MAS method, the radiation from a peripheral structure with a noise source can be calculated in the IAS calculation phase, and the propagation of the electromagnetic field beyond the peripheral structure can be calculated in the EAS calculation phase.

However, in the EAS calculation phase, it is impossible to correctly respond to an electromagnetic field that is penetrating the CB. This is because the values of the variables on the CB are determined without the surrounding condition of the EAS calculation phase. Therefore, when other scatterers or other wave sources exist outside the CB, an accurate calculation result is not obtained. In the modified FDTD-MAS method, in order to deal with cases where other scatterers and other wave sources exist outside the CB, we define three other conditions in the EAS calculation. The first is C—here, the electromagnetic field is with other scatterers and/or other wave sources existing outside the CB. The second is C0—here, the electromagnetic field is free of the influence of scatterers and other wave sources outside the CB. The third is Ce—this is the electromagnetic field defined as the error  $C - C_0$ .

In condition C0, the electromagnetic variables of FDTD are calculated in the IAS calculation phase, and the magnetic field in the neighborhood of the CB is calculated in the new phase; the calculated variables around the CB are recorded. In the EAS calculation phase, the electromagnetic variables of FDTD in condition C are calculated outside the CB, and those in condition Ce are calculated inside and on the CB.

Because the electromagnetic field variables are calculated in different conditions irrespective of whether or not they are in the CB, the compensation scheme of the electromagnetic field calculation around the CB is applied to the usual FDTD method.

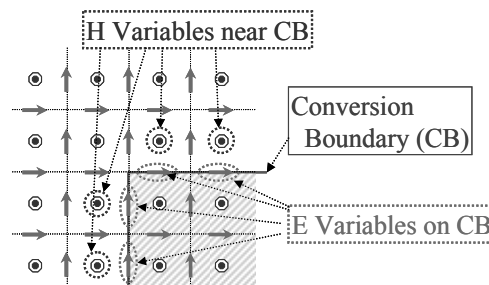


Fig.2 Electromagnetic Field Variables around CB

We explain the analytical procedure of the modified FDTD-MAS method in detail using Fig. 2. In this figure, the painted cells are inside the CB, the electric field variables surrounded by broken lines are electric variables on the CB, and the magnetic field variables surrounded by broken lines are the CB neighborhood magnetic field variables.

In this work, the CB neighborhood magnetic field variables are magnetic field variables that exist outside the CB and at

least one of the neighborhood electric field variables is an electric variable on the CB.

### 1) IAS calculation

We set the analytical conditions and perform the IAS calculation of the FDTD-MAS method.

### 2) Calculation of magnetic field in neighborhood of CB

The EAS calculation of the FDTD-MAS method is applied to the model with the number of cells of space installed outside of the CB. Every time the magnetic field is calculated, the magnetic field variables of the CB neighborhood are recorded in the CB neighborhood magnetic field file.

### 3) EAS calculation

The structures in the CB are approximated using the mesh of the EAS calculation and they are then arranged in the CB. Scatterers and/or other structures are arranged outside the CB. The EAS calculation of the modified FDTD-MAS method is described below.

#### i. Calculation of electric field variables

The electric field variables are calculated by the FDTD method. However, we add a compensation term to the equation used to calculate the electric field variables on the CB. The compensation term is calculated using the CB neighborhood magnetic field variables of C0 that were recorded in the file.

$$E_x^{n+1}(i, j) = \alpha_E E_x^n(i, j) + \beta_E \{H_z^n(i, j) - H_z^n(i, j-1)\} + ME_x^{n+1}(i, j) \quad (1a)$$

$$ME_x^{n+1}(i, j) = -\beta_E \{HO_z^n(i, j) - HO_z^n(i, j-1)\} \quad (1b)$$

Eqs. 1a and 1b show the expressions of the electric field variables  $E_x^{n+1}$  on CB.  $\alpha_E, \beta_E$  are assumed to be coefficients that are used for the calculation of the electric field in the FDTD method.  $HO_z^n(\cdot, \cdot)$  are magnetic field variables of C0 that are recorded to the CB neighborhood magnetic field file if they are at the position of the magnetic field variables of the CB neighborhood. Otherwise, they are set to 0. A similar calculation is used for the electric field variables  $E_y^{n+1}$  on CB.

$$H_z^{n+1}(i, j) = H_z^n(i, j) + \alpha_H \{E_x^{n+1}(i, j+1) - E_x^{n+1}(i, j)\} - \beta_H \{E_y^{n+1}(i+1, j) - E_y^{n+1}(i, j)\} + MH_z^{n+1}(i, j) \quad (2a)$$

$$MH_z^{n+1}(i, j) = \alpha_H \{EO_x^{n+1}(i, j+1) - EO_x^{n+1}(i, j)\} - \beta_H \{EO_y^{n+1}(i+1, j) - EO_y^{n+1}(i, j)\} \quad (2b)$$

#### ii. Calculation of magnetic field variables

The magnetic field variables are calculated by the FDTD method. However, we add a compensation term to the equations used to calculate the magnetic field variables on the CB. The compensation term is calculated using the electric field variables on the CB of C0 that are recorded in the file.

Eqs. 2a and 2b show the expressions of the CB neighborhood magnetic field variable  $H_z^{n+1}$ .  $\alpha_H, \beta_H$  are assumed to be coefficients that are used for the calculation of the magnetic field in the FDTD method.  $EO_{x \text{ or } y}^{n+1}(\cdot, \cdot)$  are electric field variables of C0 on the CB that are recorded in the electric field file on the CB if they are at the position of the electric field variables on the CB. Otherwise, they are set to 0.

## III. EVALUATION

### A. Verification 1 (to evaluate the effect of modification)

#### 1) Condition

First, we verify whether the CB response to external electromagnetic waves is computed correctly. This is an improved feature of the modified FDTD-MAS method as compared to the original one. Fig. 3 shows the evaluation model used for this verification. Neither wave sources nor other structures are arranged in the CB, and a small dipole antenna is arranged outside the CB as a wave source in the EAS calculation phase. This evaluation model is analyzed using the modified and the original FDTD-MAS methods (Case 1.1 and 1.2, respectively). Moreover, the small dipole antenna is analyzed as a reference by the FDTD method (Case 1.3). These analytical results are then evaluated.

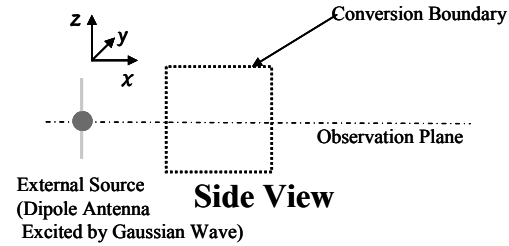


Fig.3 Evaluation Model for Verification 1

#### 2) Results

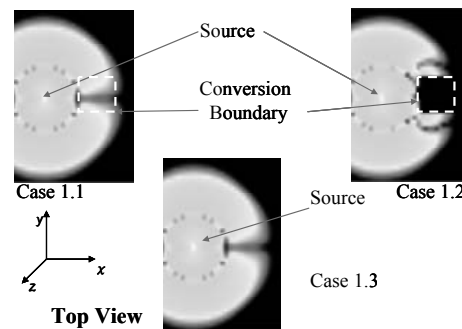


Fig.4 CB Response to Electromagnetic Wave from Outside the CB

Fig. 4 shows the distribution of the electric field element at a certain time in the observation plane. In Case 1.2, the wave reflected by the CB is observed. On the other hand, it can be confirmed that wave disordering does not occur. Moreover, the numerical error margin between Cases 1.1 and 1.3 is  $1e-6$  or less in all the points against the observation value.

## B. Verification 2 (Verification under more complex condition)

### 1) Condition

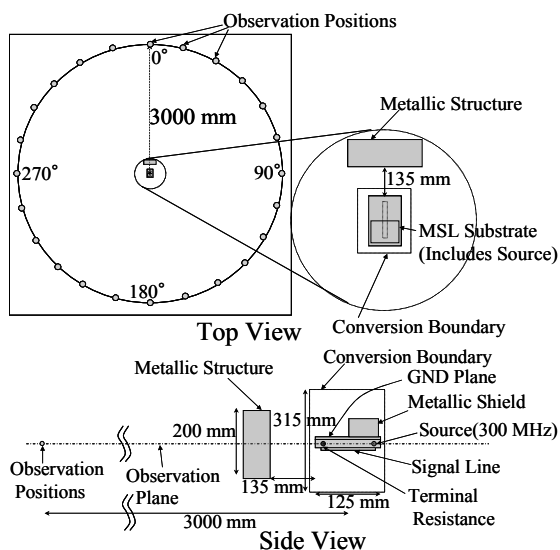


Fig.5 Object Structure to be Analyzed or Measured

Fig. 5 shows the object structure to be analyzed and measured. A 300 MHz AC voltage source is connected with the microstripline (MSL) substrate as a wave source. A metallic structure is arranged around the MSL substrate. This object structure is analyzed using the modified and original FDTD-MAS methods. Moreover, a similar structure is measured and compared with the analytical results.

We analyzed the structures using the modified and original FDTD-MAS methods (Cases 2.1 and 2.2, respectively) by setting the CB to enclose the MSL substrate and arranging a metallic structure outside the CB. In both case,  $R_a$  is 9. In the IAS calculation, the analytical space is divided into  $146 \times 440 \times 1380$  by  $0.1 \text{ mm} \times 0.1 \text{ mm} \times 0.02 \text{ mm}$  cells. In the EAS calculation, the analytical space is divided into  $146 \times 440 \times 1380$  by  $0.9 \text{ mm} \times 0.9 \text{ mm} \times 0.18 \text{ mm}$  cells. We use a cluster with 14 Pentium 4 3.2GHz CPUs for these analyses.

We also measured the vertical electric field at the observation positions at a distance of 3 m from the center of the MSL substrate (Case 2.3).

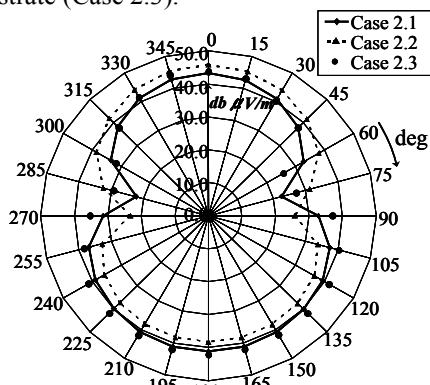


Fig.6 Directional Characteristics of the Vertical Electric Field at a Distance of 3 m.

## 2) Results

The calculation times are listed in Table 1. The calculation time in Case 2.1 is almost equal to that in Case 2.2. This indicates that the overhead caused by the modification is minimal.

Fig. 6 shows the directional characteristics of the vertical electric field at a distance of 3m from the center of the MSL substrate. In Case 2.1, the error margin relative to Case 2.3 in the peak direction ( $0^\circ$ ) is very small (0.5 dB). The characteristics of the null directions ( $75^\circ$ ,  $285^\circ$ ) are also in good agreement. On the other hand, in Case 2.2, the error margin relative to Case 2.3 is approximately 2.5 dB in the peak direction. The characteristics of the null directions differ from those of Case 2.3.

Table 1 Calculation Time

Case	Method	IAS calc time	EAS calc time
Case 2.1	Modified FDTD-MAS	57588 s (+ 677 s*)	6943 s
Case 2.2	Original FDTD-MAS	57588 s	6754 s

\* Time required to calculate CB neighborhood magnetic field values

## C. Discussion

By using the modified FDTD-MAS method, the accuracy does not deteriorate even if the scatterers are arranged outside the CB; therefore, the method is confirmed to have a sufficient analytical ability. Because the error margin is 0.5 dB in verification 2, we consider that our proposed method is suitable for estimating the radiation of the object structure in this condition. However, we must evaluate our method in more complex conditions for use in real EMI problems.

Moreover, because the scatterers and/or wave sources that exist outside the CB need to be considered only in the EAS calculation phase, if the conditions outside the CB change, only the EAS calculation needs to be re-calculated. Therefore, for use of designing metallic shields, etc., our method has a major advantage compared with the sub-grid FDTD method.

## IV. CONCLUSION

In this study, we have proposed the modified FDTD-MAS method that improves upon the original FDTD-MAS method in the manner in which it deals with scatterers and/or other wave sources outside the CB. In order to estimate the analytical precision, a test structure including an MSL substrate and a surrounding metallic structure was analyzed by the modified and original FDTD-MAS methods, and the analytic results were then evaluated by a comparison with the measurement results.

The results reveal that our proposed method can be used in conditions in which the original FDTD-MAS method cannot be applied.

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