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Retraction

Retracted: Electromagnetic Interference Simulation of Software Electronic Equipment Based on Efficient Time Domain Algorithm

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This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope
(2) Discrepancies in the description of the research reported
(3) Discrepancies between the availability of data and the research described
(4) Inappropriate citations
(5) Incoherent, meaningless and/or irrelevant content included in the article
(6) Manipulated or compromised peer review

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

[1] H. Zhang, R. K. Gupta, and B. Tiwari, "Electromagnetic Interference Simulation of Software Electronic Equipment Based on Efficient Time Domain Algorithm," *Journal of Sensors*, vol. 2022, Article ID 8134928, 7 pages, 2022.

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Research Article

Electromagnetic Interference Simulation of Software Electronic Equipment Based on Efficient Time Domain Algorithm

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In order to ensure the normal operation of software electronic equipment and better guide the electromagnetic protection design of software electronic equipment, a set of computational models and numerical methods are needed to analyze the electromagnetic interference problems of electronic equipment. To this end, a new field-path hybrid time domain algorithm is adopted to simulate the electromagnetic interference of broadband electromagnetic signals to software electronic equipment in the time domain; the results are compared with those of the FDTD method to verify the correctness and efficiency of the algorithm. The average calculation time of FDTD is 478.3 min, while that of the field-path hybrid time domain algorithm is 46.5 min. The results show that the simulation effect of the field-path hybrid time domain algorithm is consistent with that of FDTD and saves a lot of memory and computation time, which proves the correctness and efficiency of the algorithm.

1. Introduction

With the increasing complexity of the space electromagnetic environment, the electromagnetic interference of software electronic equipment is more and more serious. In order to ensure the normal operation of software electronic equipment, it is necessary to analyze the characteristics of electromagnetic interference to software electronic equipment, so as to provide a theoretical basis for the electromagnetic protection of software electronic equipment. However, the structure of the actual software electronic equipment is complex, including both the shield structure of the electric large size and the antenna, transmission line, circuit, and other multiscale fine structure, so it is difficult to directly test the electromagnetic interference of the software electronic equipment. Therefore, the study of an efficient numerical simulation method is of great significance to the analysis of electromagnetic interference of software electronic equipment. There are various coupling ways of electromagnetic waves to electromagnetic interference of software electronic equipment; on the one hand, electromagnetic waves enter through the coupling of power cables and signal lines connected to software electronic equipment; it can also be coupled through the holes and gaps in the shielding body of the software electronic equipment and then act on the transmission line coupling inside the software electronic equipment to generate interference signals; thus, interference is caused to the end circuit of transmission lines. On the other hand, there are antennas for receiving and transmitting signals; the electromagnetic wave can pass through the antenna on the software electronic equipment to join the electromagnetic energy into the antenna radio frequency front end, causing interference to the radio frequency circuit. Therefore, to analyze the electromagnetic interference of software electronic equipment, it is necessary to consider the electromagnetic coupling of space electromagnetic fields to transmission lines, shielding the cavity structure of software electronic equipment and antenna and the mixing of field and circuit in software electronic equipment, and a single field or circuit method cannot complete the electromagnetic interference analysis of electronic equipment.

The finite difference time domain method (FDTD) is an effective numerical method for computing electromagnetic fields first proposed by K.S. Bee in 1966. After more than 30 years of development, it has been widely used in many fields related to electromagnetic fields. As a numerical calculation method of electromagnetic fields, the finite-difference time domain method has some outstanding characteristics, including the following: (1) Direct time domain calculation. It directly converts Maxwell's curl equation with time variable into difference equation in Yee's grid space. In this difference scheme, the electric field or magnetic field component at each grid point is only related to its adjacent magnetic field or electric field component and the field value at that point in the previous step. It treats all kinds of problems as initial value problems so that the time domain characteristics of the electromagnetic field can be directly reflected. (2) Wide applicability. Since the direct starting point of the FDTD method is the Maxwell equation which summarizes the general law of electromagnetic fields, it indicates that this method should be widely applicable. It can simulate a variety of complex electromagnetic structures. The inhomogeneity, anisotropy, dispersion, and nonlinearity of the medium can be easily simulated. As long as the source and structure can be simulated correctly, the finite-difference time domain method can give the correct solution to any problem, either scattering, transmission, penetration or absorption, or transient or steady state problems. (3) The generality of the computational program. Since Maxwell's equations are the mathematical model for any problem computed by finite-difference time domain methods, its basic difference equations are invariant for a wide range of problems. (4) Simple and intuitive, easy to grasp. Since the FDTD method starts directly from Maxwell's equations and does not require any derived equations, it avoids the use of more mathematical tools, making it the simplest of all methods for calculating electromagnetic fields. At present, the optimization method of antielectromagnetic interference of information transmission medium is time-consuming. The filtering effect of the electromagnetic interference signal wave is poor.

A new field-path hybrid time domain algorithm is adopted to simulate the electromagnetic interference of broadband electromagnetic signals to electronic equipment from the time domain perspective; the results are compared with those of the FDTD method to verify the correctness and efficiency of the algorithm. Figure 1 is a flow chart of electromagnetic wave collection of software electronic devices based on an efficient time domain algorithm.

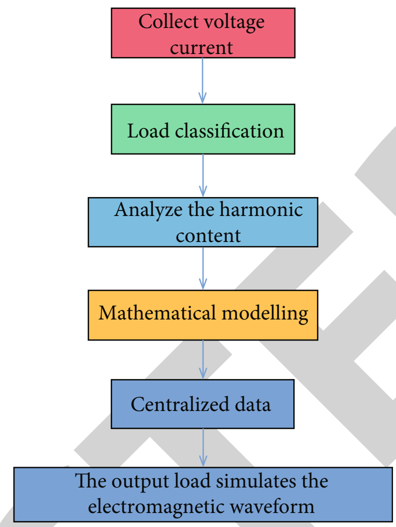

Figure 1: Electromagnetic wave flow chart of software electronic devices based on efficient time domain algorithm.

To solve this problem, Shang and Zhao proposed an intelligent emi optimization method based on the least mean square error (LMS) algorithm. Firstly, the electromagnetic interference analysis equation is used to describe the reflection and resonance effect of the electromagnetic interference signal in the transmission process when the information transmission distance is fixed. Combined with Fourier transform analysis, the electromagnetic interference signal is located, and the waveform of interference signal is corrected and recovered. Secondly, the LMS algorithm is used to adjust the parameters of the adaptive filter; after parameter optimization, the interference signal wave in the information transmission medium is filtered through the filter. Finally, the intelligent optimization of antielectromagnetic interference is completed [1]. Liu and Liu proposed a prediction method to reduce electromagnetic interference in the radio static region of the QTT station. Firstly, the applicability of the existing radio wave propagation model is analyzed according to the topographic data of the QTT site and the topographic characteristics of the wireless quiet area. The Longley-Rice and two-ray models are selected as the algorithm of the QTT radio wave propagation model. Through the simulation analysis of radio wave propagation, the path loss when the potential interference point reaches the QTT feed aperture is obtained [2]. Liu et al. studied a wideband interference suppression algorithm based on delay compensation. The incident angle of the interference source is adjusted to the normal direction of the array by means of delay compensation to rotate the array, thus eliminating the dispersion effect of broadband signals [3]. Liang et al. proposed a method to evaluate the intentional electromagnetic interference (IEMI) caused by coupling with a high power electromagnetic field (HPEM) in a linear multiport system. Firstly, a method based on the Lorentz reciprocity theorem is proposed to simulate the field coupling in any direction of incident and polarization, thus reducing the number of full wave numerical simulation required. Then, three constrained optimization problems are identified to describe the worst case related to the different radiation sensitivity effects of the system ports. That is, under the assumption of limited bandwidth and limited energy density, the spectrum and waveform of high power electromagnetic fields are calculated to maximize the dissipated energy, peak value, and rectification pulse of the induced voltage waveform [4]. Fang and Cao established the three-dimensional electromagnetic field simulation model of SVC and its nearby area, compared it with the field space magnetic field and induced current, and verified the equivalence of the model. On this basis, the influence of different reactor heights on the improvement of electromagnetic interference and the change of inductance value is analyzed [5]. Wen and Yao analyzed the basic principle of electromagnetic interference filter of power automation equipment, established the differential mode and common mode circuits of ideal filter by using PSPICE, and established the high-frequency filter circuit model; at the same time, the influence of parasitic parameters on the filter and the typical interference of the filter on the power system are simulated [6]. Electromagnetic interference (EMI) is an important issue to be considered in the safe operation of the CBTC system in railway environment. Kuang et al. considered the electromagnetic interference of the wireless local area network (WLAN) in subway stations to the CBTC system and the interference of the CBTC system in tunnels to WLAN equipment in car [7]. Hou et al. based on transmission line theory established the equivalent circuit model of different forms of secondary cables such as ordinary cable, coaxial cable, and twisted pair cable. On this basis, the response of three signal cables under the action of space plane electromagnetic waves is analyzed in the frequency domain [8].

With the development of information technology and electronic communication, the problems of electromagnetic interference and electromagnetic wave pollution are becoming more and more serious. Carbon materials are considered good candidates for new electromagnetic shielding materials because of their good electrical conductivity, light weight, stable chemical properties, good thermal properties, environmental friendliness, easy processing, and excellent mechanical properties. In recent years, carbon-based electromagnetic shielding materials have made great progress [9]. Graphite has electromagnetic wave attenuation and high electrical conductivity. In this study, Hwang et al. analyzed the EMI-SE performance and electrical conductivity of composites prepared by changing the size of graphite filler (average size: 6-100 m); the resulting properties are explained by the relative dielectric constant and geometric properties of the filler [10].

On this basis, the FDTD-TL algorithm is combined with the circuit analysis method to study the new field-path hybrid time domain algorithm; the transient response of each component of the circuit equipment is calculated, and the electromagnetic interference characteristics of the space electromagnetic field on the through-wire terminating circuit of the electronic equipment are analyzed.

2. Research Methods

For the numerical simulation of the shield structure of software electronic equipment, the FDTD method combined with automatic mesh generation technology is adopted; fast modeling of the shielding structure of software electronic equipment in the FDTD program is realized, and the excitation field of the transmission line network is obtained. For the analysis of electromagnetic interference of the transmission line network, the proposed time domain S parameter cascading technology is adopted to decompose the transmission line network into two parts: transmission line and circuit; in order to avoid modeling the circuit structure directly, the effect of the circuit on the transmission line is equivalent through its time domain S parameter. Then combined with the transmission line equation, the transient responses on the transmission line and at the end of the circuit are calculated. In each time step, the transmission line excitation field calculated by the FDTD method is introduced into the transmission line equation as the equivalent distribution source term, so as to realize the cooperative calculation of space electromagnetic field-transmission line-circuit. The following details the transmission line network excitation field and electromagnetic interference analysis of the implementation process.

2.1. Extraction of Transmission Line Network Excitation Field. Consider that the equivalent fractional source term is calculated from the space incident electric field and is independent of the scattering field of the transmission line. Therefore, when calculating the excitation field of the transmission line network, the transmission line is similarly removed. After the transmission line is removed, the structure model of the shielding body of software electronic equipment is established by CAD software, including shielding shell structure of software electronic equipment and circuit shielding cavity structure, and then saved as STL format file. Using the FDTD method and automatic mesh generation technology to read the STL file, the structure model of the shielding body of software electronic equipment can be quickly modeled in the FDTD program. Then, the FDTD program is used to simulate the full wave of the model to obtain the incident electric field energy e_x^{ex} and e_y^{ex}, namely, the excitation field of the transmission line.

2.2. Electromagnetic Interference Analysis of Transmission Line Network. The time domain S parameter cascading technology combines the transmission line equation with the time domain S parameter of the circuit and divides the transmission line network into two parts: transmission line and circuit; the action of the circuit on the transmission line is equivalent through the time domain S parameter of the circuit, and then, the transient response of the transmission line and the circuit port in each section of the transmission line network is calculated by using the transmission line equation, realizing the data exchange between each section of the transmission line. The following takes two port transmission line networks as an example to elaborate the realization process of time domain S parameter cascade technology.

For the transmission line network structure, two transmission lines are cascaded through a circuit. According to transmission line theory, the total time domain voltage $V1(t)$ (or $V2(t)$) on the circuit port can be viewed as the superposition of the time domain incident wave voltage $A1(t)$ (or $A2(t)$) and reflected wave voltage $B1(t)$ (or $B2(t)$).

According to the connection nodes of the transmission line and the circuit, the transmission line network is decomposed into three parts: transmission line 1, transmission line 2, and the circuit; the port connecting each transmission line to the circuit is connected with a matching load equal to the characteristic impedance of each transmission line, where Z_{e1} and Z_{e2}, respectively, represent the characteristic impedance of transmission line 1 and transmission line 2.

For each section of the transmission line, the electromagnetic coupling model of the space electromagnetic field to the transmission line is established by using the transmission line equation, and then, the incident voltage $A1\,(t)$ and $A2\,(t)$ on the circuit port are calculated by using the FDTD-TL algorithm.

For the circuit with a complex structure, direct modeling is difficult. Considering the external characteristics of the circuit, the circuit is regarded as a multiport network; the effect of the circuit on each transmission line is equivalent through its S parameter; then, the reflected voltage $b1\,(w)$ (or $B2\,(W)$) of the circuit port can be expressed as

$$\begin{bmatrix} b1(\omega) \\ b2(\omega) \end{bmatrix} = \begin{bmatrix} S11(\omega) & S12(\omega) \\ S21(\omega) & S22(\omega) \end{bmatrix} \begin{bmatrix} a1(\omega) \\ a2(\omega) \end{bmatrix} = \begin{bmatrix} S11(\omega)a1(\omega) + S12(\omega)a2(\omega) \\ S21(\omega)a1(\omega) + S22(\omega)a2(\omega) \end{bmatrix}. \quad (1)$$

The S parameter of the circuit is converted to the time domain by FFT transformation and then convolved with the calculated incident wave voltage $A1\,(t)$ and $A2\,(t)$, so as to obtain the time domain reflection voltage $b1\,(t)$ and $B2\,(t)$ of the circuit port:

$$\begin{bmatrix} b1(t) \\ b2(t) \end{bmatrix} = \begin{bmatrix} S11(t) * a1(t) + S12(t) * a2(t) \\ S21(t) * a1(t) + S22(t) * a2(t) \end{bmatrix}. \quad (2)$$

By superplacing the incident voltage $A1\,(t)$ and $A2\,(t)$ with the reflected voltage $B1\,(t)$ and $B2\,(t)$, the total voltage from the circuit port can be obtained as follows:

$$\begin{bmatrix} V1(t) \\ V2(t) \end{bmatrix} = \begin{bmatrix} a1(t) + b1(t) \\ a2(t) + b2(t) \end{bmatrix}. \quad (3)$$

3. Result Analysis and Discussion

The electromagnetic coupling problem of the single-conductor transmission line, single-multiconductor transmission line, and transmission line network connection circuit in a shielded body is simulated by using the field-circuit hybrid time domain algorithm; the results are compared with those of the FDTD method to verify the correctness and efficiency of the algorithm.

Example 1. Figure 2 shows the electromagnetic coupling model of the single-conductor transmission line terminating the lumped circuit in the shielded body; the size of the shielded body is length Lc = 60 cm, height Hc = 50 cm, and width Wc = 40 cm; there are three narrow slits on the panel of the shield body, the distance between the slit and the left panel is $d0 = 10$ cm, the length of the slit is $Ls = 20$ cm, the width is $ws = 2$ cm, and the spacing is $ds = 10$ cm; transmission length $l = 0.4$ m, height $h = 1$ cm, radius 2 mm, load $R1 = 50\,\Omega$, the circuit is placed in the shielded cavity, the cavity size is $2\,\text{cm} \times 2\,\text{cm} \times 2\,\text{cm}$, and component parameters are $R2 = 100\Omega$, $L = 1.0\,\mu$H, $C = 2.0$ pF. The incident wave dimension is a Gaussian pulse with the waveform $E_0 \exp(-4\pi(t - t_0)^2/\tau^2)$; among them, E_0=1000 V/m, pulse width τ=2 ns, $t_0 = 0.8\tau$, and illuminate the shield vertically.

The transient voltage of the circuit port is calculated by using the field-path hybrid time domain algorithm. Figure 3 shows the corresponding waveform of the circuit port voltage calculated by the two methods. The grid size and time required by the two methods are shown in Table 1.

As can be seen from Table 1, the calculation time of FDTD is 460 minutes, while that of the field-path hybrid time domain algorithm is 45 minutes; the field-path hybrid time domain algorithm has obvious advantages and is more efficient.

Example 2. Figure 4 shows the electromagnetic coupling model of the transmission line network composed of the single-conductor transmission line-circuit-multiconductor transmission line in the shielded body, and the incident waveform and size of the shielding body are the same as the above example. Length of single-conductor transmission line $l = 0.2$ cm, height $h = 1$ cm, radius $r = 2$ mm, load $R1 = R3 = R5 = 50\Omega$, $R2 = R4 = R6 = 100\Omega$; the circuit is placed in a shielded cavity with a size of $2\,\text{cm} \times 2\,\text{cm} \times 2\,\text{cm}$; component parameters are $R0 = 100\Omega$, $C0 = 2.0$ pF. The transient voltage response of the circuit port is calculated by using the field-path hybrid time domain algorithm. Figure 5 shows the circuit port voltage response waveform calculated by the two methods, and the grid size and time required by the two methods are shown in Table 2.

As can be seen from Table 2, the calculation time of FDTD is 500 minutes, while that of the field-path hybrid time domain algorithm is 48 minutes. The results are consistent with Example 1, indicating that the field-path hybrid time domain algorithm has obvious advantages.

Example 3. Figure 6 shows the electromagnetic coupling model of the transmission line network composed of three single-conductor transmission lines and circuits in the shielded body; similarly, the shape of incident wave and the size of the shielded body are the same as those in the above example. The length of three single-conductor transmission lines $l = 0.2$ cm, height $h = 1$ cm, radius $r = 2$ mm, load $R1 = 50\Omega$, $R2 = 100\Omega$, $R3 = 150\Omega$; the circuit is placed in a shielded cavity with a size of $2\,\text{cm} \times 2\,\text{cm} \times 2\,\text{cm}$; component parameters are $R0 = 100\Omega$, $C0 = 2.0$ pF. The voltage response of the circuit port and load $R3$ are calculated by using the field-path hybrid time domain algorithm. Figures 7 and 8, respectively, show the voltage response waveform of the circuit port and the voltage response waveform of load $R3$ calculated by two methods; the grid size and time required by the two methods are shown in Table 3.

As can be seen from Table 3, the calculation time of FDTD is 475 minutes, and that of the field-path hybrid time domain algorithm is 46.5 minutes, which is consistent with the results of the first two examples.

Figure 9 shows the comparison of calculation time between FDTD and field-path hybrid time domain algorithm in three examples. As can be seen from Figure 9, the

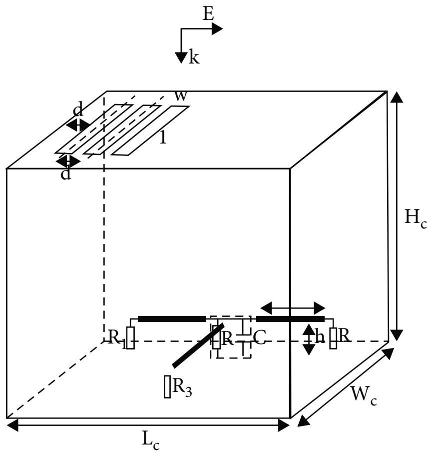

Figure 2: Model of electric cross-silk junction of single conductor transmission line in shielded cavity.

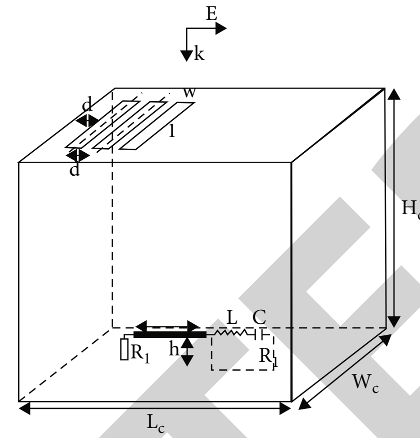

Figure 4: Electromagnetic coupling model of single-multiconductor transmission line terminating circuit in shielded cavity.

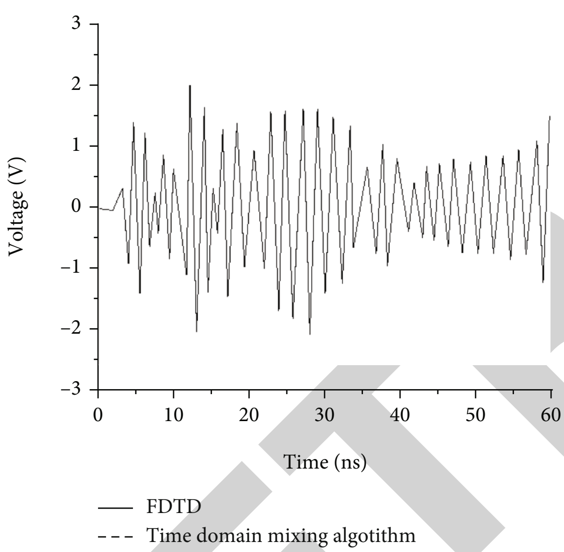

Figure 3: Voltage response waveform of the circuit port.

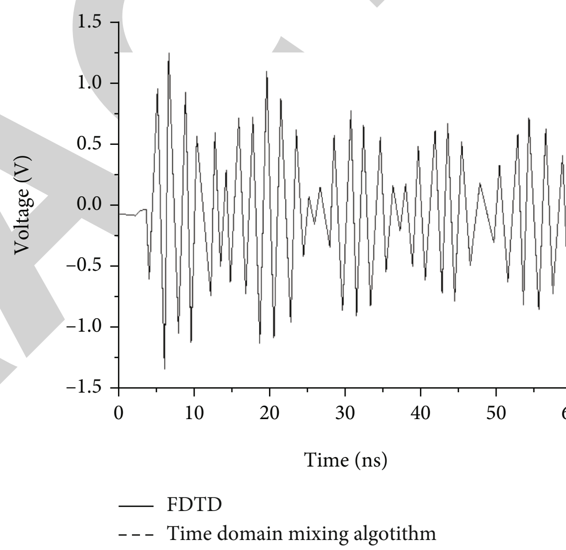

Figure 5: Circuit port voltage response waveform.

Table 1: The memory and computation time required by the two methods in Example 1.

The numerical method	The grid size (mm)	Computation time (min)
FDTD	2	460
Field-path hybrid time domain algorithm	5	45

Table 2: Grid size and calculation time required by the two methods in Example 2.

The numerical method	The grid size (mm)	Computation time (min)
FDTD	2	500
Field-path hybrid time domain algorithm	5	46

calculation time of the field-path hybrid time domain algorithm is greatly reduced compared with FDTD. Table 4 shows the average calculation time of FDTD and field-path hybrid time domain algorithm. The average calculation time of FDTD is 478.3 minutes; however, the average calculation time of the field-path hybrid time domain algorithm is only 46.5, which is close to 10 times of the relationship between the two, and the field-path hybrid time domain algorithm greatly improves the efficiency.

It can be seen from Figures 3, 5, 7, and 8 that the calculation results of the field-channel hybrid time domain algorithm are in good agreement with the simulation results of the FDTD method, which verifies the correctness of the algorithm used to simulate the electromagnetic coupling problem of the transmission line network inside software electronic equipment. At the same time, the calculation time required by the field-path hybrid time domain algorithm is much less than that of the FDTD method, and part of the mesh size required is larger than that of the FDTD method.

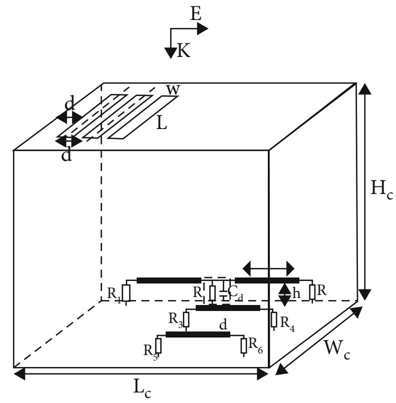

Figure 6: Electromagnetic coupling model of three single-conductor transmission line terminators in shielded cavity.

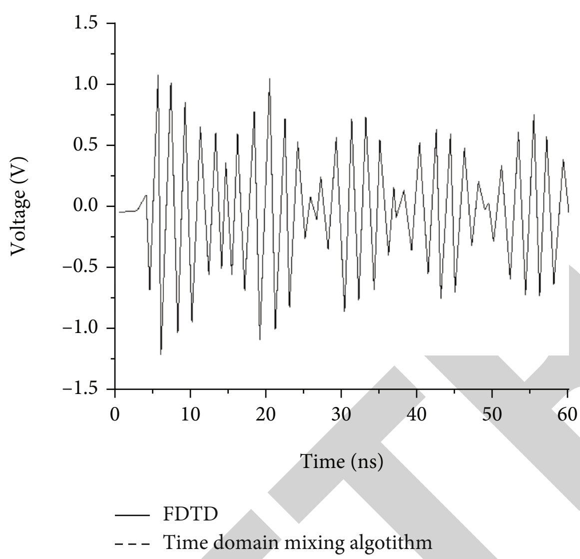

Figure 7: Circuit port voltage response waveform.

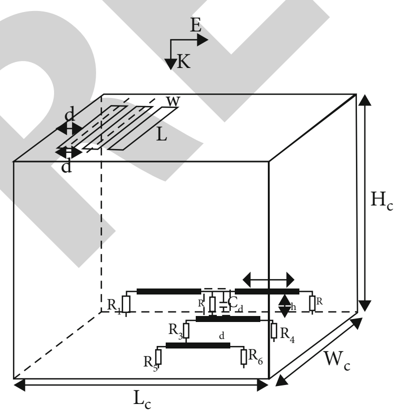

Figure 8: Waveform of voltage response in $R3$.

It saves a lot of memory and computation time and verifies the high efficiency of the field-path hybrid time domain algorithm.

Table 3: Grid size and calculation time required by the two methods in Example 3.

The numerical method	The grid size (mm)	Computation time (min)
FDTD	2	475
Field-path hybrid time domain algorithm	5	46.5

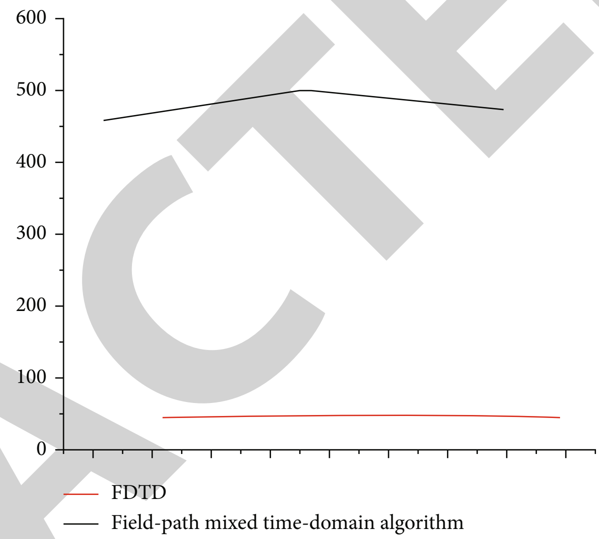

Figure 9: Comparison of calculation time between FDTD and field-path hybrid time domain algorithm.

Table 4: Average calculation time of FDTD and field-path hybrid time domain algorithm in three examples.

The numerical method	Average calculation time (min)
FDTD	478.3
Field-path hybrid time domain algorithm	46.5

4. Conclusions

In order to study the interference of software electronic equipment by electromagnetic waves, the FDTD-TL algorithm and circuit analysis method are combined to study a new field-path hybrid time domain algorithm; the transient response of each component of the circuit equipment is calculated, and the electromagnetic interference characteristics of the space electromagnetic field on the transmission line network of the software electronic equipment are simulated and analyzed.

Numerical verification results: in the numerical simulation, the mesh size of FDTD is 2 mm, and the mesh size of the field-path hybrid time domain algorithm is 5 mm. The average calculation time of FDTD is 478.3 min, while that of the field-path hybrid time domain algorithm is 46.5 min.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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