pesc98®

RECORD

VOLUME 2

29th Annual
IEEE Power Electronics Specialists Conference

Formerly
POWER CONDITIONING SPECIALISTS CONFERENCE 1970-71
POWER PROCESSING AND ELECTRONIC SPECIALISTS CONFERENCE 1972

The 1998 PESC is Sponsored by the

IEEE POWER ELECTRONICS SOCIETY

IEEE® pels®

and the
IEICE OF JAPAN

EiC

In cooperation with the
IEEJ
and the
IEI OF JAPAN

98CH36196

Current Distribution Analysis on Printed Circuit Board

Tatsuya DOI[1)], Shiro YOSHIDA[2)], Norio MASUDA[2)], Hirokazu TOHYA[2)], and Yoshifuru SAITO[3)]

1) *Ashikaga Institute of Technology, Omae, Ashikaga, Tochigi 326-8558, Japan*
2) *NEC Corporation, Miyazaki, Miyamae, Kawasaki, Kanagawa 216-8555, Japan*
3) *Hosei University, Kajino, Koganei, Tokyo 184-8584, Japan*

ABSTRACT

This paper proposes a methodology for identifying a major electromagnetic radiation noise source from mother boards used in computers. Key idea is based on a combination of the discretized Helmhortz theorem and minimum norm strategy. Application of our methodology clarifies that the rotational current distributions work as one of the loop antennas. Thus, we have succeeded in identifying a major noise cause of the mother boards.

1. INTRODUCTION

In recent years, rapid growth of high frequency techniques causes an electromagnetic compatibility (EMC) problem. Leakage magnetic fields out of printed circuit boards (PCB) stimulates the miss operation and mutual action among the electronic devices. Previously, we have reported that the sampled pattern matching (SPM) method is a quite effective methodology in order to estimate the leakage magnetic field source out of notebook computers [1,2]. Even though we can evaluate the current distribution on the PCB, we have to classify the electromagnetic noise source components from an entire current distribution.

This paper proposes a method which classifies the noise source currents on the PCB used for the computer mother-boards. Key ideas is to classify the rotational and divergent current components. The rotational component of currents works as one of the loop antennas so that this component may cause an electromagnetic field noise source. By means of the Helmholtz Theorem, any vector can be represented as the summation of rotational and divergent vector fields [3]. This means that an arbitrary vector field is composed of both of the rotational and divergent vector fields. A rotational component can be obtained by taking a rotation of vector potential. Also, a divergent field can be obtained by taking a gradient of scalar potential. This means that we have to evaluate the vector and scalar potentials from the vector fields.

Generally, loop and line currents can be considered as basic model of magnetic field sources on a PCB. Loop currents work as one of the loop antenna. Also, line currents work as a series of dipoles. It is effective for EMC controls to identify dominant magnetic field sources as a set of basic models. Our new methodology makes it possible to identify basic magnetic field source models on a PCB.

In the present paper, at first, we formulate an inverse problem for identifying both of unknown scalar and vector potentials out of known vectors in two-dimensional current fields. The solution methodology to this inverse problem is the minimum norm method. Intensive numerical simulations were carried out in order to verify our methodology.

Secondly, experimental examinations using basic PCB models, such as a loop antenna and a micro strip line, are shown here.

Finally, we have applied our method to the practical PCB used for the mother board of computer.

As a result, it is revealed that the minimum norm method makes it possible to obtain the vector and scalar potentials from the given current fields. Thus, we have succeeded in classifying the rotational and the divergent current components as basic magnetic field source model, and identifying a major magnetic field noise source out of PCBs.

2. ROTATIONAL AND DIVERGENT COMPONENTS IDENTIFICATIONS

2.1 Frame Equation

According to the Helmholtz Theorem, an arbitrary vector $\mathbf{F}$ can be expressed by

0-7803-4489-8/98/$10.00

$$\mathbf{F} = \nabla \times \mathbf{V} + \nabla \phi, \tag{1}$$

where $\mathbf{V}$ and ϕ are the vector and scalar potentials, respectively. Eq.(1) means that an arbitrary vector field is composed of the rotational and divergent components. A rotational component can be obtained by taking a rotation of vector potentials $\mathbf{V}$. Also, a divergent field can be obtained by taking a gradient of scalar potentials ϕ.

2.2 Two Dimensional Vector Fields

Let us consider a potential, e.g. vector V_z and scalar ϕ in Fig.1, evaluation problem when the vectors, e.g. **F** in Fig.1, are given. Thus, we consider here an inverse problem for identifying both of unknown scalar and vector potentials out of known vectors in two-dimensional fields. In two dimensional vector fields, the rotational and divergent components are given by

$$\nabla \times \mathbf{V} = \begin{bmatrix} \mathbf{i}_x & \mathbf{i}_y & \mathbf{i}_z \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ 0 & 0 & V_z \end{bmatrix}, = \mathbf{i}_x \frac{\partial V_z}{\partial y} - \mathbf{i}_y \frac{\partial V_z}{\partial x}, \tag{2}$$

$$\nabla \phi = \mathbf{i}_x \frac{\partial \phi}{\partial x} - \mathbf{i}_y \frac{\partial \phi}{\partial y}. \tag{3}$$

In this case, solving an ill-posed system equations with a rectangular system matrix is essentially required because a number of the known field components is less than those of vector and scalar potentials. Discretization of Eq.(1) suggests that the vector $\mathbf{F}$ can be expressed by a sum of rotational $\mathbf{F}_V (= \nabla \times \mathbf{V})$ and a divergent $\mathbf{F}_S (= -\nabla \Phi)$ components as

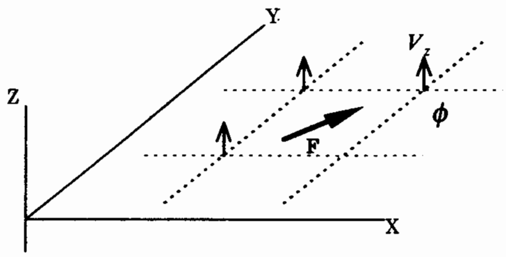


Fig.1. Two-dimensional model.

$$\begin{aligned} \mathbf{F} &= \mathbf{F}_V + \mathbf{F}_S, \\ &= D_V \mathbf{V} + D_S \Phi, \\ &= \begin{pmatrix} D_V & D_S \end{pmatrix} \begin{bmatrix} \mathbf{V} \\ \Phi \end{bmatrix}, \\ &= A\mathbf{f}, \end{aligned} \tag{4}$$

where A is a rectangular system matrix composed of the rotational D_v and divergent D_s operators. In the other words, the system equations have a larger number of unknowns than the number of equations.

2.3 Minimum Norm Solutions

One of the ways to solve the ill-posed system of equations (4) is the minimum norm method. The minimum norm method yields a unique solution vector whose norm takes a minimum value. Minimum norm solution of Eq. (4) is given by

$$\mathbf{f} = A^T \left(A A^T \right)^{-1} \mathbf{F}. \tag{5}$$

The minimum norm solution (5) provides the vector $\mathbf{V}$ and scalar Φ potential vectors in (4). Taking a rotation of the vector potential yields the rotational field components of the observed vector fields. Also, taking a gradient of the scalar potentials yields the divergent field components of the observed vector fields.

2.4 Simulation

Fig. 2(a) shows an observed vector fields. Figs. 2(b) and 2(c) show the minimum norm solution of vector and scalar potential distributions, respectively.

Figs. 3(a) and 3(b) are the rotational, divergent field components, respectively. Fig. 3(c) is the recovered vector fields by the summation of rotational and divergent fields, which exactly corresponds to the observed one.

By considering the simulation result shown in Fig.3(b), it is considered that the vector potentials shown in Fig. 2(b) mostly represent the electromagnetic field noise sources , because they are working as if loop antenna.

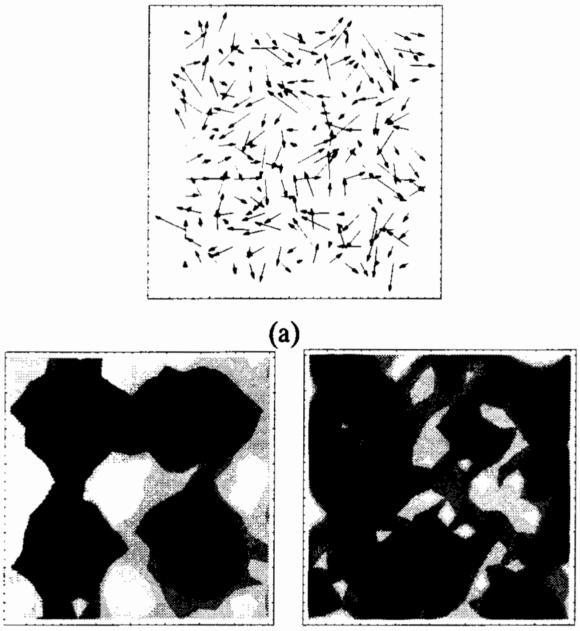

(a)
(b) (c)

FIG. 2. An example. (a) Observed vector fields, (b) vector potential, and (c) scalar potential distributions..

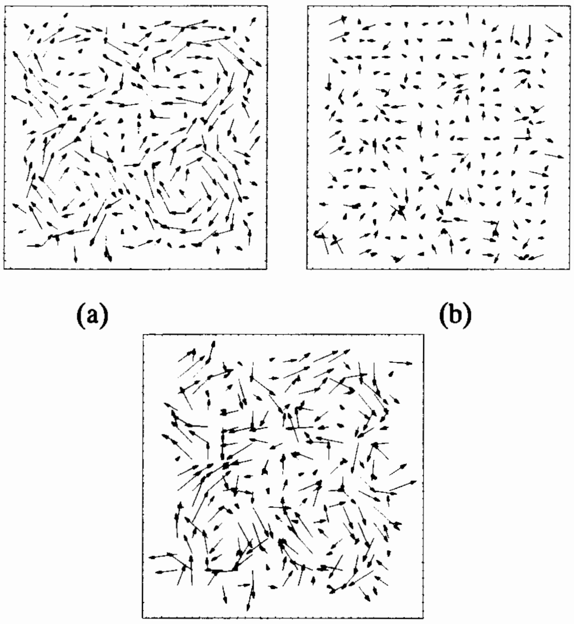
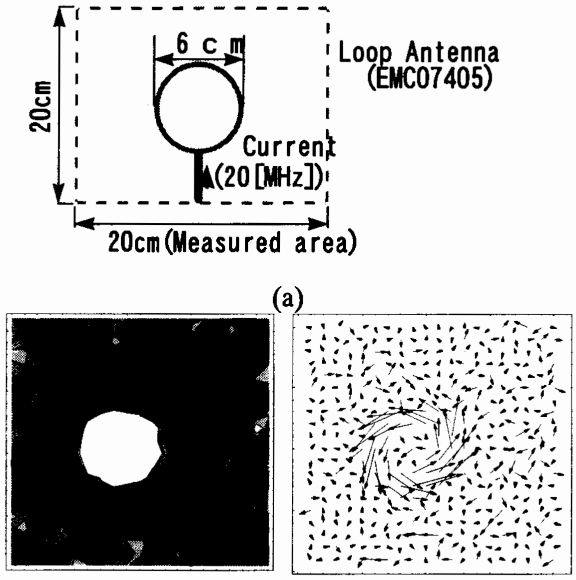

(a) (b)
(c)

FIG. 3. (a) Rotational vector fields, (b) divergent vector fields, and (c) recovered vector fields obtained by the summation of rotational and divergent fields.

3. EXPERIMENTAL EXAMINATIONS OF MAGNETIC FIELD SOURCE MODELS

3.1 Loop Antenna

Fig. 4 shows an experimental examination using a loop antenna as magnetic field source. Figs. 4(a) and 4(b) show the schematics diagram and measured magnetic fields on the loop antenna, respectively. The magnetic fields was measured at equi-spaced 441 (21x21) locations on a parallel surface $200x200mm^2$ using an oscilloscope (SONY TEKTRONIKS TDS684B). The 20 MHz current was flowing through the loop antenna. And the magnetic fields was measured on the measured surface of 5mm distance from the loop antenna. Fig. 4(c) shows the current distribution calculated from the magnetic field distribution in Fig.4(b).



(a)
(b) (c)

Fig.4 Observed current distribution by a loop antenna. (a) Loop antenna (EMCO7405-901), (b) measured magnetic fields, (c) current distribution.

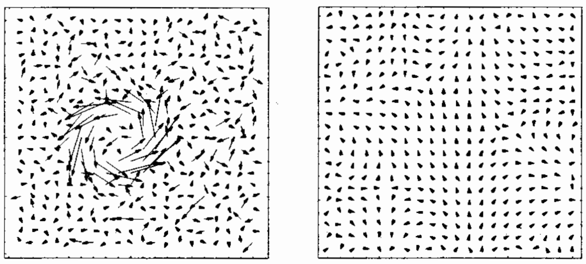

(a) (b)

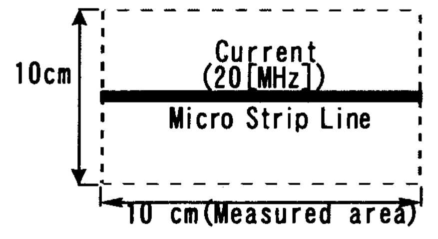
Fig.5 Results by means of the Eqs. (4) and (5). (a)Rotational and (b)divergent vectors of the current distribution in Fig.4(c).

To classify the observed current distribution into the rotational and divergence components, our new method Eqs.(4) and (5) were applied to the current distribution. Fig. 5(a) and 5(b) show the rotational and divergent field components. Comparison of both results makes it clear that the rotational field component is the dominant magnetic field source excited by the loop antenna.

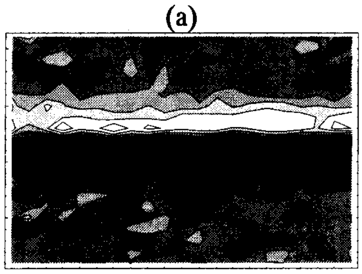
3.2 Micro Strip Line

Fig. 6 shows an experimental examination using a micro strip line as magnetic field source. Figs. 6(a) and 6(b) show the schematics diagram and measured magnetic fields on the micro strip line, respectively. The magnetic fields was measured at equi-spaced 441 (21x21) locations on a parallel surface $100x100mm^2$. The other measurement conditions were similar to the case of the loop antenna. Fig. 6(c) shows the current distribution calculated from the magnetic field distribution in Fig.6(b).

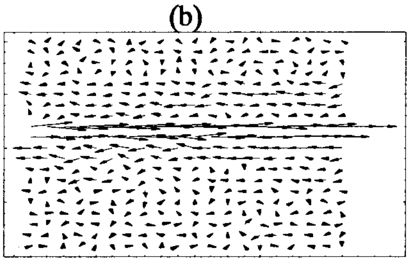
Fig. 7(a) and 7(b) are the rotational and divergent current vectors, respectively.



(a)

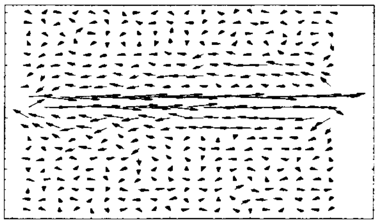


(b)

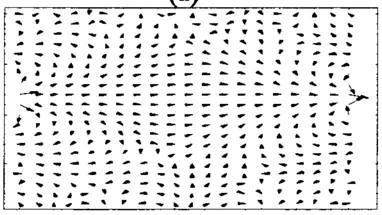


(c)

Fig.6 Observed current distribution by a micro strip line. (a)Schematics diagram, (b)measured magnetic fields, (c)current distribution.



(a)



(b)

Fig.7 Results by means of the Eqs. (4) and (5). (a)Rotational and (b)divergent vectors of the current distribution in Fig.6(c).

The result in Fig. 7(a) has suggested that the divergent field components are the dominant vectors at the both edges of micro strip line where the current flows into or out of the observed field. On the other hand, the result in Fig. 7(b) has suggested that the rotational field components are the dominant vectors at the central part of micro strip line where the current flow is continuously flowing.

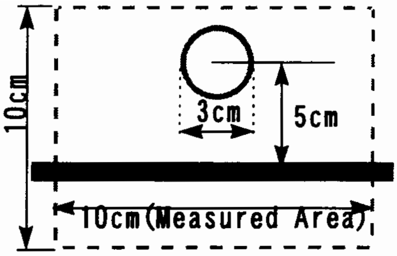
3.3 Loop Antenna and Micro Strip Line

Fig. 8 shows an examination employing both of the loop antenna and micro strip line as the magnetic field exciting source.

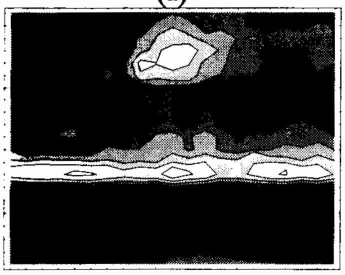
Figs. 8(a) and 8(b) show the schematics diagram and measured magnetic fields on the micro strip line, respectively. The magnetic fields was measured at equi-spaced 441 (21x21) locations on a parallel surface. The other condition of measurement was $200x200mm^2$ similar to when employing the loop antenna. Fig. 8(c) shows the current distribution obtained by the Eqs (4) and (5) from the magnetic field distribution in Fig.8(b).

Figs. 9(a) and 9(b) are the rotational and divergent current vectors, respectively.

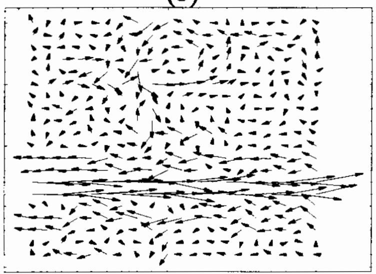
As shown in Fig. 9, rotational components exist mainly on the center part of micro strip line as well as on the loop antenna. On the other side, major divergent component exists on the both edges of micro strip line.



(a)

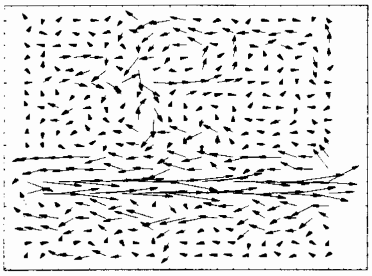


(b)

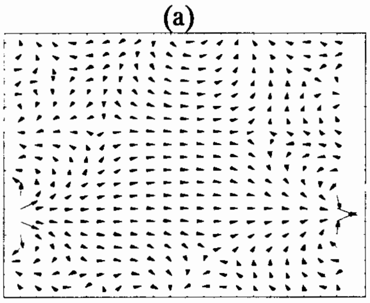


(c)

Fig.8 Observed current distribution by both the loop antenna and micro strip line. (a)Schematic diagram, (b)measured magnetic fields, (c)current distribution.



(a)



(b)

Fig.9 Results by means of the Eqs. (4) and (5). (a)Rotational and (b)divergent current vectors obtained by the current distribution in Fig.8(c).

4. CURRENT DISTRIBUTION ON COMPUTER MOTHER BOARD

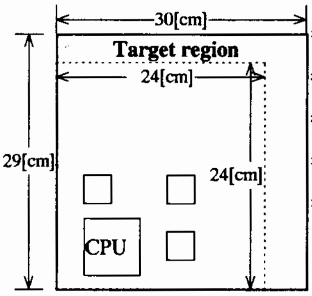
4.1 Searching for The Magnetic Field Source Currents

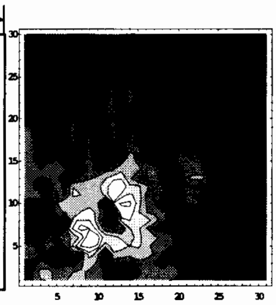
Fig. 10 shows a result employing the sampled pattern matching method for the magnetic field source searching on a PCB [1,2]. Figs. 10(a) and 10(b) show the schematic diagram and a measured magnetic fields distribution on the PCB, respectively. The 80MHz magnetic fields were measured by means of a spectrum analyzer. The frequency of 80 [MHz] was equivalent to the CPU clock frequency. Fig. 10(c) shows an estimated current density distribution from the measured magnetic fields in Fig. 4(b).

4.2 Classification of Rotational and Divergent Currents

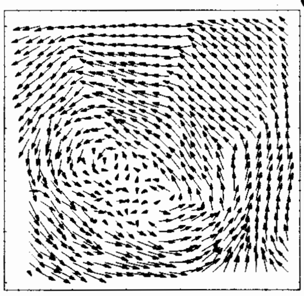
In order to obtain the loop current components from the current density vectors in Fig. 10(c), we applied the minimum norm strategy Eq.(5) to the current distribution in Fig.10(c). Figs. 11(a) and 11(b) are the rotational and divergent field components of the current densities, respectively.

Obviously, Fig. 11(a) shows that the rotational current density distribution is working as one of the loop antennas, so that this radiates the major electromagnetic noise fields.



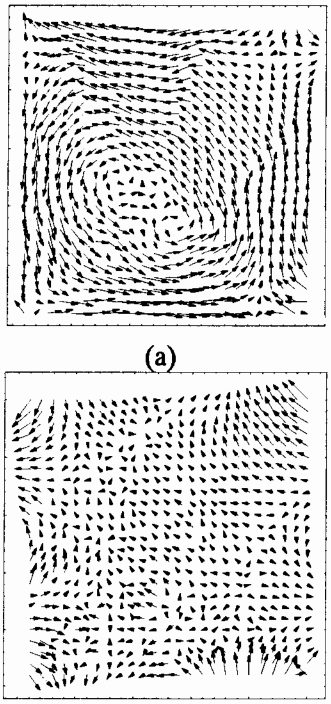


(a) (b)



(c)

FIG.10. (a) Schematic diagram of a PCB used for a computer mother-board, (b) a measured magnetic field distribution on the PCB, and (c) estimated current density distribution.



(b)

FIG.11. (a) Rotational vector fields, and (b) divergent vector fields.

5. CONCLUSIONS

As shown above, we have clarified that the current density distribution can be classified into the rotational and divergent components. This means that the major electromagnetic noise source could be identified. Thereby, it is possible to reduce the electromagnetic noise radiated from PCB. The simulation results have verified that the minimum norm strategy makes it possible to classify the rotational and divergent components from the given vector fields.

Further, the experimental examinations have shown that rotational current component corresponds to dominant current flow. Also, the divergent current component corresponds to input or output of the currents. Therefore, the examinations have verified to be able to identify dominant magnetic field sources out of observed current distributions.

Finally, we have applied our methodology to the practical PCB used for the mother boards of computer. In this case, the circulating current density distribution which is working as a loop antenna has been identified.

References

[1] T.Doi, S.Hayano, and Y.Saito, "Magnetic field distribution caused by a notebook computer and its source searching", J. Appl. Phys., Vol. 79, No.8, pp.5214-5216, 1996.

[2] H.Saotome, K.Kitsuta, S.Hayano, and Y.Saito, "A neural behavior estimation by the generalized correlative analisys", IEEE Trans. on Magn., Vol. 29, No. 2,pp.1389-1394, 1993.

[3] M.Hino, "Introduction to Fluid Mechanics", 1st edition, Asakura-Shoten, 1992, Tokyo, (in Japanese).