112

IEEE Visualization 1999
Celebrating Ten Years

October 24 • October 29, 1999
San Francisco Airport Hyatt
San Francisco, California

THE INSTITUTE OF ELECTRICAL & ELECTRONICS ENGINEERS, INC.
IEEE COMPUTER SOCIETY

Sponsored by IEEE Computer Society Technical Committee on Visualization and Graphics in Cooperation with ACM/SIGGRAPH

IEEE Visualization 1999
Late Breaking Hot Topics
Proceedings

October 27-29, 1999
San Francisco, California, USA

Program Co-Chairs and Editors
Amitabh Varshney, Craig M. Wittenbrink, and Hans Hagen

Visualization Of The Currents On The Printed Circuit Boards

Hiroyuki Takahashi [1)], Seiji Hayano [2)], Yoshifuru Saito [3)]

[1)-3)] Graduate School of Engineering, Hosei University

Abstract

Modern electronics are always composed of the printed circuit boards (PCBs). When the currents on the PCBs are visualized without decomposing the electronics, then the testing and inspecting of the electronics are carried out in an extremely efficient manner.

This paper proposes one of the methodologies to visualize a current distribution on the PCBs from the locally measured magnetic fields. The current visualization from the magnetic fields is always reduced into a solution of the ill-posed inverse problems. This paper reveals that conventional least squares gives a reasonable solution of the inverse problem. Thus, we have succeeded in realizing a nondestructive testing methodology with high reliability

CR Categories and Subject Descriptors: G.1.3.[Numerical Analysis]:Numerical Linear Algebra-Linear systems(direct methods); J.6.[Computer-Aided Engineering]: Computer-aided design (CAD); K.7.3.[The Computing Profession]:Testing Certification.

Additional Keywords: Magnetic Fields, Nondestructive Testing, Printed Circuit Boards, Least Squares.

1 INTRODUCTION

Current visualization on the printed circuit boards is of paramount important information for the maintenance, inspection and electromagnetic compatibility engineering of the modern electronic devices. To evaluate the current distributions on the PCBs without decomposing or destroying the devices, it has to solve an inverse problem. The input and solution vectors of the inverse problem are the locally measured magnetic fields and currents on the PCBs, respectively. Fortunately, the magnetic fields are the vector quantity and penetrate most of the electrical insulation materials covering the electronic devices. Thereby, it is possible to measure the magnetic fields on a parallel surface to the PCBs. Furthermore, most of the modern electronic devices have the compact and thin shape, for examples, motherboards of the desktop and notebook types of personal computers [1,2].

This means that a distance between the field-measured surface and the PCBs can be estimated or given by a design sheet.Thus, the current visualization on the printed circuit boards is reduced into a two dimensional current searching on a flat surface from the local magnetic fields measured at a parallel surface to the current distributing surface.

Arranging the local magnetic fields caused by a unit loop currents on a PCB in column-wise, it is possible to establish a system matrix, whose number of rows and columns correspond to the number of magnetic field components and of loop currents, respectively. Also, arranging the locally measured magnetic fields in column-wise gives an input vector, whose order is equivalent to the number of measured magnetic field components. The currents to be visualized distribute on a flat surface of PCB and are represented by a set of loop current vectors, i.e., the currents can be represented by a single vector component. On the other side, the locally measured magnetic fields are composed of the x-, y- and z-components. Thereby, a number of loop current vectors is less than a number of the locally measured magnetic field components. Thus, the current searching problem from the locally measured magnetic fields is reduced into a solution of the least square type inverse problems.

Thus, we have visualized the current distribution by conventional least square method, which gives a reasonable current distribution on the PCBs. This current visualization on the PCBs leads to an extremely efficient nondestructive testing and inspecting of the electronic devices.

2 VISUALIZATION OF THE CURRENTS

2.1. Input Vector

Let us consider a measured magnetic field $H_{n\times n}$ with n by n resolution:

$$H_{n\times n} \in f_x(x_i, y_j), f_y(x_i, y_j), f_z(x_i, y_j),\quad i = 1,2,..,n, \quad j = 1,2,..,n, \tag{1}$$

where the functions f_x, f_y, f_z refer to the x-, y- and z-components of the magnetic fields; x_i, y_j denote the $i-th$ on x-axis and $j-th$ on y-axis locations of a measured surface, respectively.

Arranging the components of magnetic field $H_{n\times n}$ into a column-wise form gives an input vector $\mathbf{Y}$ with $3\times n\times n$ -*th* order as

Postal Address

[1)-3)] 3-7-2 Kajino Koganei Tokyo, 184-8584, Japan

E-mail Address

[1)] *takahashi@ysaitoh.k.hosei.ac.jp,*

[2)] *hayano@k.hosei.jp,*

[3)] *ysaitoh@ysaitoh.k.hosei.ac.jp,*

Telephone Number

[1)-3)] +81-42-387-6200

$$
\begin{aligned}
\mathbf{Y} = [&f_x(x_1,y_1), f_x(x_2,y_1),.., f_x(x_n,y_1), f_x(x_1,y_2), f_x(x_2,y_2),..,\\
&f_x(x_n,y_2),.., f_x(x_{n-1},y_n), f_x(x_n,y_n),\\
&f_y(x_1,y_1), f_y(x_2,y_1),.., f_y(x_n,y_1), f_y(x_1,y_2), f_y(x_2,y_2),..,\\
&f_y(x_n,y_2),.., f_y(x_{n-1},y_n), f_y(x_n,y_n),\\
&f_z(x_1,y_1), f_z(x_2,y_1),.., f_z(x_n,y_1), f_z(x_1,y_2), f_z(x_2,y_2),..,\\
&f_z(x_n,y_2),.., f_z(x_{n-1},y_n), f_z(x_n,y_n)]^T.
\end{aligned}
$$

2.2. System Matrix

Let us assume the $m \times m - th$ unit loop currents on a PCB:

$$
C^{(k)}_{m \times m} \in u(x_i, y_j),
$$
$$
i = 1,2,.., m, \qquad j = 1,2,.., m, \qquad k = 1,2,.., m \times m, \tag{3}
$$

where a functions $u(x_i, y_j)$ takes 1 at the position (x_i, y_j) on a surface of PCB.

By means of the unit loop current model, the magnetic fields with n by n resolution are represented by

$$
\begin{aligned}
&D^{(k)}_{n \times n} \in G^{(k)}_x(x_i, y_j), G^{(k)}_y(x_i, y_j), G^{(k)}_z(x_i, y_j),\\
&i = 1,2,.., n, \qquad j = 1,2,.., n, \qquad k = 1,2,.., m \times m,
\end{aligned} \tag{4}
$$

where $G^{(k)}_x(x_i, y_j), G^{(k)}_y(x_i, y_j), G^{(k)}_z(x_i, y_j)$ are the Green's functions transferring the effects of the $k - th$ unit current to the measured position (x_i, y_j) in terms of the x-, y- or z-component of the magnetic fields, respectively [3]. Thereby, $k - th$ column vector of a system matrix is given by

$$
\begin{aligned}
\mathbf{d}^{(k)} = [&G_x(x_1,y_1), G_x(x_2,y_1),.., G_x(x_n,y_1), G_x(x_1,y_2), G_x(x_2,y_2),..,\\
&G_x(x_n,y_2),.., G_x(x_{n-1},y_n), G_x(x_n,y_n),\\
&G_y(x_1,y_1), G_y(x_2,y_1),.., G_y(x_n,y_1), G_y(x_1,y_2), G_y(x_2,y_2),..,\\
&G_y(x_n,y_2),.., G_y(x_{n-1},y_n), G_y(x_n,y_n),\\
&G_z(x_1,y_1), G_z(x_2,y_1),.., G_z(x_n,y_1), G_z(x_1,y_2), G_z(x_2,y_2),..,\\
&G_z(x_n,y_2),.., G_z(x_{n-1},y_n), G_z(x_n,y_n)]^T.
\end{aligned} \tag{5}
$$

Thus, a system matrix with $3 \times n \times n$-*th* rows and $m \times m$-*th* columns is given by

$$
D = [\mathbf{d}^{(1)}, \mathbf{d}^{(2)},.., \mathbf{d}^{(m \times m)}]. \tag{6}
$$

2.3. System Of Equations

Denoting a solution vector $\mathbf{X}$ with order $m \times m$, a system of equations is formally written by

$$
\mathbf{Y} = D\mathbf{X}. \tag{7}
$$

In most case, a number of equations $3 \times n \times n$ is much greater than a number of unknowns $m \times m$, so that it is possible to apply a conventional least squares mean as [4]:

$$
\mathbf{X} = [D^T D]^{-1} D^T \mathbf{Y}. \tag{8}
$$

2.4. Visualization Of The Currents On The PCBs

By considering the input vector Y in Eq. (2) and the column vector $\mathbf{d}^{(k)}$ in Eq. (5), it is revealed that the elements in the solution vector X are corresponding to the weights $w_i (i = 1,2,.., m \times m)$ to the unit loop currents in Eq. (3). This means that a visualized current $V_{m \times m}$ is given by

$$
V_{m \times m} = \sum_{i=1}^{p} w_i C^{(i)}_{m \times m}. \tag{9}
$$

3. EXAMPLES

3.1. Magnetic Fields By The Unit Loop Currents

Fig. 1 shows sample examples of the magnetic fields $D^{(k)}_{n \times n}, k = 1,11,201,211,381,391$, caused by the unit loop currents $C^{(k)}_{m \times m}, k = 1,11,201,211,381,391$, on a PCB.

In Fig.1, we set the parameters m=20 and n=16, so that our problem is reduced into compute the $m \times m = 400$ loop currents from the $3 \times n \times n = 768$ magnetic fields.

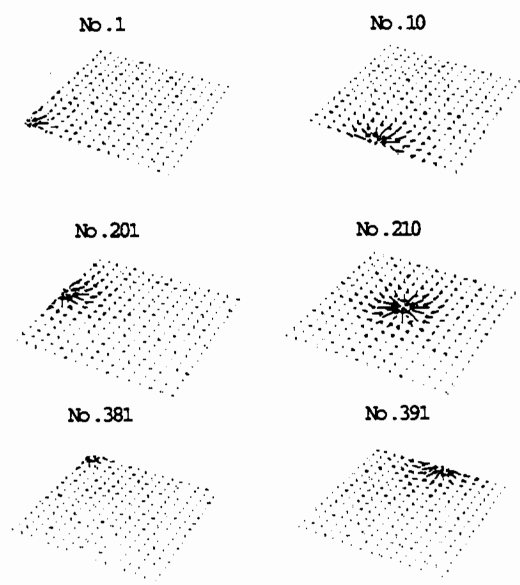


Fig.1: Sample examples of the magnetic fields caused by the unit loop currents.m=20,n=16

3.2. Measured Magnetic Fields

Fig.2 shows the model measured magnetic fields above the keyboard surface of a notebook type personal computer [1,2].

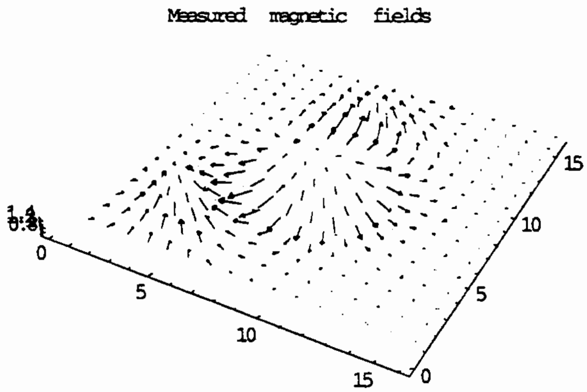


Fig.2: Measured magnetic fields at the keyboard of a notebook type personal computer.

3.2. Least Squares Solution

By means of Eq.(2), the input vector Y in Eq.(7) was constructed from the magnetic fields in Fig.2. Also, a system matrix D with $3 \times n \times n = 768$ rows and $m \times m = 400$ columns was derived by Eqs. (5), (6) and the magnetic fields in Fig. 1. Fig.3 shows the least squares solution vector X .

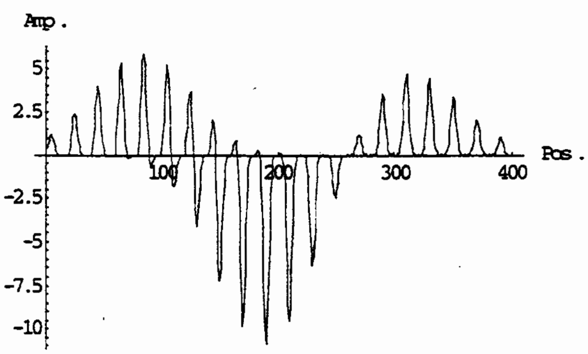
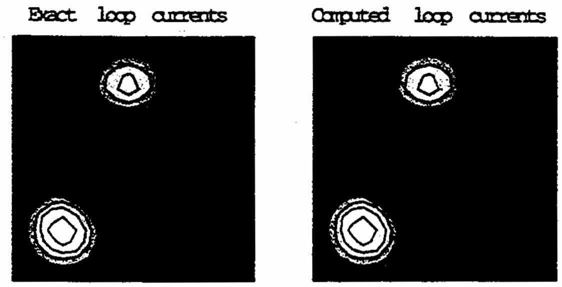


Fig.3: Solution vector X.

3.4. Visualization Of The Currents

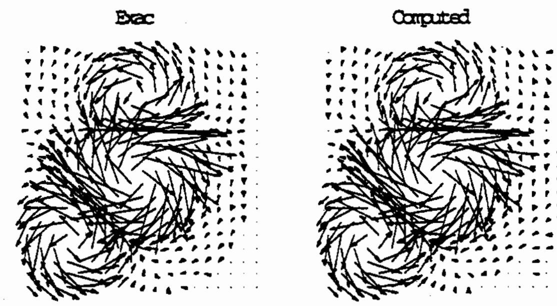
By means of Eq.(9), the computed loop currents distribution on the PCB is obtained as shown in Fig.4 together with exact ones.

Fig.5 shows the current vector distribution obtained by taking a rotation of the loop current vectors in Fig. 4.



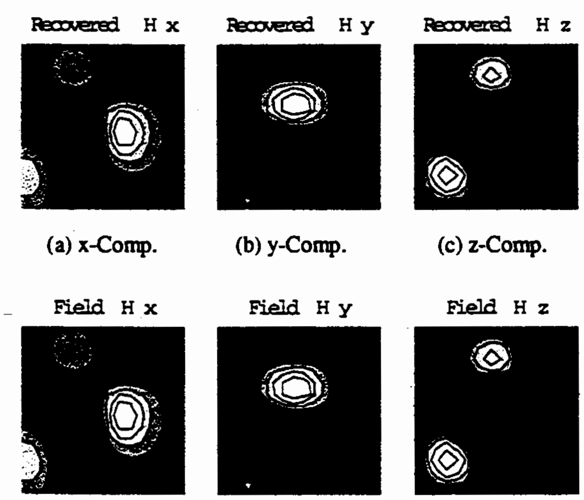
(a) (b)

Fig.4: (a) Exact and (b) Computed loop current distributions.



(a) (b)

Fig.5: (a) Exact and (b) Computed current vectors distributions



(a) x-Comp. (b) y-Comp. (c) z-Comp.

(d) x-Comp. (e) y-Comp. (f) z-Comp.

Fig.6: (a) - (c) Computed and (d) - (f) measured magnetic field distributions. The x-, y- and z-Comps refer to the x, y and z components, respectively.

By observing the current vectors, a small difference between the exact and computed vectors may be found, however major computed vectors are well corresponding to the exact ones.

Fig.6 shows the measured magnetic field distributions. From the results shown in Fig.6, it is obvious that the least squares method gives a good solution. This makes it possible to visualize the current distribution on the PCBs.

4. CONCLUSION

As shown above, we have proposed a new inverse approach to visualizing the current distribution on the PCBs by measuring the local magnetic fields around the electronic devices. Initial simulation based on the least squares has led to a successful result. More precisely, the three-dimensional magnetic fields around the electronic devices can be measured, but the currents are distributing on the two-dimensional PCB surface. Further the two-dimensional currents can be represented in term of the single vector component, i.e. loop current vector.

Thereby, a condition for which the number of unknown loop currents is less than the number of given magnetic fields has led to use the least squares. As a result, it has been suggested that the nondestructive testing and inspecting of the electronic devices can be carried out in a quite efficient manner.

References

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

[2] T.Doi, S.Hayano, I.Marinova, N.Ishida and Y.Saito ," Defect recognition in conductive materials by local magnetic field measurement," Journal of Applied Physics,Vol.75, No.10, May, 1994, pp.5907-5909.

[3] Y.Midorikawa, J.Ogawa, T.Doi, S.Hayano and Y.Saito, " Inverse analysis for magnetic field source searching in thin film conductor ", IEEE Transaction on Magnetics, Vol.MAG-33, No.5, Sep.,1997, pp.4008-4010.

[4] G.Strang, " Linear Algebra and its Applications ", 1976, Academic Press, Inc.