Applied Electromagnetics III

Visualization of 2D Current Distributions along with Convolution Processing

Kanako Shiraishi, Seiji Hayano, and Yoshifuru Saito
(c/o Y.Saito Lab., Hosei University, Koganei, Tokyo 184-8584, Japan)

Abstract. In order to visualize the current distributions on a printed circuit board, we have tried to solve an inverse problem, for which the current distribution should be evaluated from the locally measured magnetic fields. This paper reveals that convolution among the independently evaluated currents from independently measured magnetic fields yields the most reliable current distributions.

1. Introduction

With the development of modern large-scale integrated circuits, the portable high speed and performance electronics are widely spreading in daily use. In these portable electronics are always constructed in thin shape for carrying as well as handling like one of notebooks. In order to inspect their operation and to find their fault parts without any decomposition, one of the reasonable methodologies is to searching for the current distributions in the electronics from the locally measured magnetic fields around them by inverse approach [1]. In such a meaning, visualization of the current distribution on a printed circuit board (PCB) without any decomposition is of paramount importance. However, the inverse solution tends to increase the noise effects essentially accompanying the magnetic field measurements.

To overcome this difficulty, this paper proposes a methodology, which makes it possible to extract the reliable current distributions flowing on a 2-dimensional planar printed circuit board. Key idea of our methodology is as follows: Most of the portable electronics have thin shape so that it is possible to measure the magnetic fields both upper and bottom surfaces. After independently evaluated current distribution by an inverse approach, from each of the measured magnetic field distributions, both the evaluated current distributions convolved. This yields the most reliable current distribution on a PCB.

2. Solution Strategy

2.1 Loop Current Model

Let us consider the problem to visualize the current distribution by measuring the local magnetic fields. Fig.1 shows a typical example of a loop current **J** and magnetic field **H**. As shown in Fig.2, let us assume that the current flowing surface is divided into a large number of the loop currents. The relationship between the loop current and x-, y- and z-magnetic field components is represented in terms of the elliptic integral functions. By means of this model, it is possible to derive a following system of equations,

$$\mathbf{Y} = C\mathbf{X}, \qquad C = \begin{bmatrix} C_{1,1} & C_{1,2} & . & C_{1,n} \\ C_{2,1} & C_{2,2} & . & C_{2,n} \\ . & . & . & . \\ C_{n,1} & C_{n,2} & . & C_{n,n} \end{bmatrix}, \tag{1}$$

where **Y**, **X** are matrix with values of the measured magnetic fields and loop current vectors with order n, respectively. C is a n^{th} order square system matrix, which is derived along with the elliptic integral functions. If it is possible to obtain an inverse matrix of C, then the loop currents vector **X** can be evaluated. Applying curl operation to this vector **X** yields the current vector distribution on the printed circuit board.

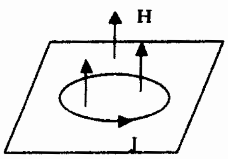


Fig.1. Relationship between the loop current **J** and magnetic field **H**.

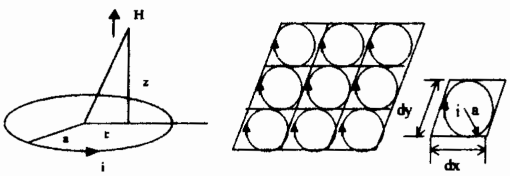


Fig.2. Subdivided loop currents model.

2.2 Simulation

Fig.3 shows an assumed model current vectors distribution on a 10 by 10 cm^2 printed circuit board. This current vector model gives the magnetic field distributions located at a parallel surface 1cm above from the printed circuit board. Fig.4 shows the x-, y- and z-magnetic field components. In Fig.4, the white, dark and black parts denote the high, low and zero magnetic field intensities, respectively. By means of Eq. (1) along with curl operation, it is possible to obtain the loop current vector distributions from any of the magnetic field components in Fig.4. Fig.5 shows the computed current vectors from the magnetic fields in Fig.4. Thus, we have succeeded in obtaining the model of current vectors, shown in Fig.3, from locally measured magnetic fields in the simulation.

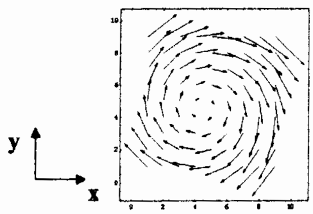
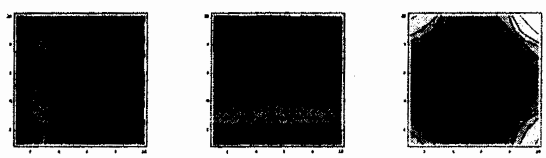


Fig.3. Model current vectors.



x-component *y*-component *z*-component

Fig.4. Magnetic fields caused by the model current vectors.

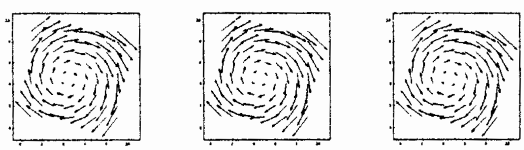
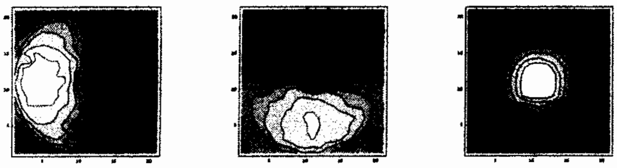


Fig.5. Computed current vectors, where the left, center and right figures are computed from x-,y-, and z-components in Fig.4, respectively.

3. Experimental Verification

3.1 Three Dimensional Magnetic Fields

Fig.6 shows the magnetic fields, which have been measured at a parallel surface located 0.8cm above from a 21 by 21 cm² current carrying coil surface. In much the same way in the simulation, we computed the current distributions from these magnetic fields. The tested current carrying coil has a doughnut-shaped, so that a good solution has been obtained only from the magnetic fields in direction of z-axis as shown in Fig.7. This means that the most dominant magnetic field is the perpendicular magnetic fields to the flat coil. According to the simulation results, shown in Figs.3-5, any of the magnetic field components had yielded the same current vectors. However, only the perpendicular/z-component magnetic fields have to be employed for the practical current vectors evaluation.



x-component *y*-component *z*-component

Fig.6. Measured magnetic fields

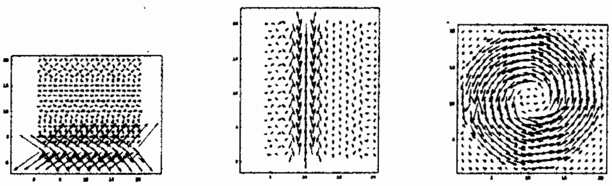
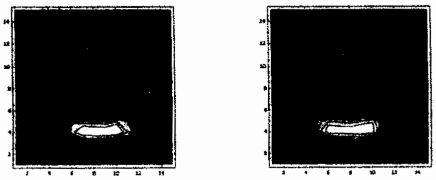


Fig.7. Computed current vectors, where the left, center and right figures are computed from *x*-,*y*-, and *z*-components in Fig.6, respectively.

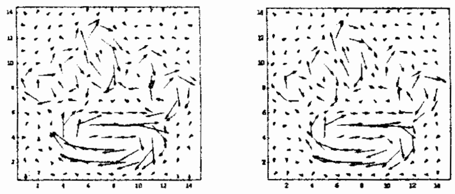
3.2 Perpendicular Magnetic Fields

Most of the portable electronics using PCB are always constructed in thin shape. Also, consideration of the most dominant magnetic field component leads to the measurement of the perpendicular magnetic field components at the upper and bottom surface of the PCB. Fig.8 shows the magnetic fields measured at each of the upper and bottom parallel surfaces located 0.8cm away from the tested 15 by 15 cm² current carrying coil. Fig.9 shows the computed current distributions. To check up the validity of the results in Fig.9, we calculated a correlation coefficient between them. The obtained correlation coefficient is 0.92, which means that we have measured both perpendicular magnetic fields with fairly good accuracy.



Upper Bottom

Fig.8. Measured magnetic fields.



Upper Bottom

Fig.9. Computed current vectors.

3.3 Convolution Strategy

Because of the noise, accompanying the magnetic field measurements, the computed current vectors in Fig.9 become the noisy ones. After normalizing the current vectors, convolution between them is carried out. This convolution extracts the common current vectors from the independently computed current vectors in Fig.9, and reduces the noise effects. Fig.10 shows the extracted current vectors together with the tested coil.

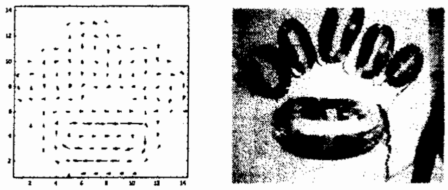


Fig.10. Current vector distribution (left) together with the tested coil (right).

4. Conclusion

In the present paper, the simulation employing loop current model has revealed that each of magnetic field components satisfied the system equation leads to an exact current distribution. However, practical experiment has led to employ the perpendicular magnetic fields to the PCB in order to compute the current vector distribution. After normalizing the current vectors, convolution between the independently computed current vectors has extracted the current vector distribution reflecting on the shapes of the current carrying coils. Thus, this paper has proposed one of the methodologies to visualize the current distributions from the locally measured magnetic fields.

References

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