LETTER

Current Estimation on Multi-Layer Printed Circuit Board with Lumped Circuits by Near-Field Measurement

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SUMMARY Current distribution on a 2-layer PCB with lumped circuits is estimated by measuring the near electric field. In this method, the current estimation model is made without considering the electrical parameters of lumped circuits. Experimental results are demonstrated and compared with the numerical results, confirming the validity of this method.
key words: *measurement, current distribution, near-field, PCB, lumped circuit*

1. Introduction

Recently, the electromagnetic interference problem has become more and more serious with the miniaturization of electric devices and the increase of the operation frequency. It is known that the radiation from the printed circuit board (PCB) in electric devices is caused when the differential mode is destroyed and the common mode appears on the transmission line. Therefore, if we know the current distribution on the transmission line, we can estimate where and why the common mode is occurred in order to take some EMC solutions on the PCB designing.

The previous researches employed the equivalent source approach which is an effective method for estimating far field from the electric devices by determining the equivalent source around the devices through the near field measurement [1]–[3]. However, this method can only give the virtual current distribution, but not the real one.

The current distribution can be estimated as the solution of inverse problem [4]–[7]. However, the electromagnetic field integral equation for the inverse problem was established by using the Green's function which is unavailable for a complicated structure like the multi-layer PCB.

A method has been proposed to estimate the current distribution on a multi-layer PCB [7]. In this method, the microstrip transmission line is divided into several current segments which are electrically small. Mutual impedance between each segment and the receiving probe is numerically evaluated by finite difference time domain (FDTD) method. By measuring the near-field on the PCB and solving the inverse problem, current distribution on the multi-layer PCB can be obtained. However, so far, this method has been only applied to a microstrip line, or a microstrip line with a slit which is equivalent to a series capacitance. Therefore, it is necessary to investigate the effectiveness of this method in dealing with the real lumped circuits whose electrical parameters are usually unknown.

In this paper, the present method is applied to a 2-layer PCB with various kinds of lumped circuits. First, it is described how to establish the current estimation model when lumped circuits are inserted into microstrip line. Then, an experiment is performed to three kinds of PCB which have a capacitor, an inductor and a resistor, respectively. Experimental estimation results are presented and compared with numerical results calculated by FDTD method to demonstrate the validity of the present estimation method.

2. Approach for PCB with Lumped Circuits

Consider a multi-layer PCB, as shown in Fig. 1, on which the microstrip transmission line and lumped circuits exist. An analysis model of the multi-layer PCB to estimate current distribution is shown in Fig. 2. In the estimation model, all the lumped circuits are removed because they do not ra-

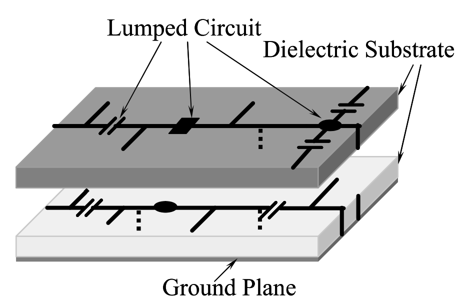

Fig. 1 Model of a multi-layer PCB with lumped circuits.

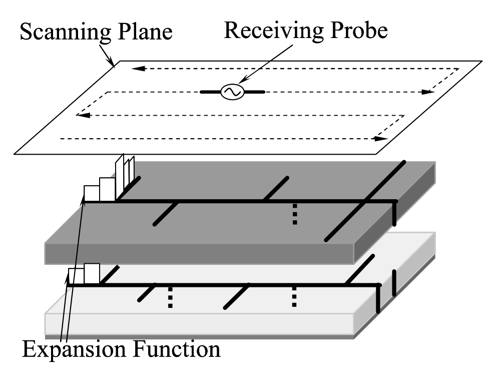

Fig. 2 Current estimation model of the PCB shown in Fig. 1.

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diate electromagnetic field. This means there is no need to have the electrical parameters of the lumped circuits in advance. Besides, the position of the feeding point is also unnecessary factor in the estimation model. The conducting microstrip line on the PCB is divided into electrically small segments on which the current has a pulsed distribution. When the near electric field above the PCB is measured by using a dipole antenna as the receiving probe, the following equation can be obtained.

$$V_i = \sum_{j=1}^{N} Z_{ij} I_j (i = 1, 2, \ldots M) \quad (1)$$

where N is the total number of current segments, M is the total number of measuring points, V_i is the open voltage on the receiving probe, I_j is unknown coefficients of current to be estimated and Z_{ij} is the mutual impedance between the jth current segment and the probe at the ith position, which is numerically evaluated by FDTD method. I_j can be obtained as the solution of Eq. (1) [7].

3. Experimental Results

A 2-layer PCB shown in Fig. 3 and Table 1 is used as the model for current estimation. Figure 4 shows the geometry of the microstrip transmission line on each layer, which is divided into 28 segments, numbered as in Fig. 5. The length of each segment is 0.025 λ. On the top layer, the microstrip line is excited by a voltage of 1.5 GHz continuous wave between the ground plane and the segment 17, and the lumped circuit is implemented at the segment 21. Three kinds of the lumped circuits, i.e. an inductor, a capacitor and a resistor are used, respectively. Impedance of each lumped circuit is shown in Table 2. Needless to say, the information about the feeding point and the lumped circuit element is not used in the current estimation. On the other hand, the microstrip line on the middle layer is not fed and is only electrically coupled with the microstrip line on the top layer.

The scanning plane to measure the near-field is shown in Fig. 6. A dipole antenna which has the length of l_p is used as a receiving probe. The dipole probe scan the area of $S_x \times S_y$ corresponding to measuring points of $M_x \times M_y$ at the distance of d_z from the surface of the PCB. The interval of measuring points are s_x and s_y in x and y direction, respectively. The stability of the inverse problem due to the uncertainty of near-field measurement has a large effect on the accuracy of current estimation. We have performed many measurements to investigate relation between the accuracy of current estimation and measurement parameters including the scanning resolution, scan area and the probe position [7]. The measurement parameters which were determined based on the previous study are shown in Table 3.

The estimated current distribution and the FDTD solu-

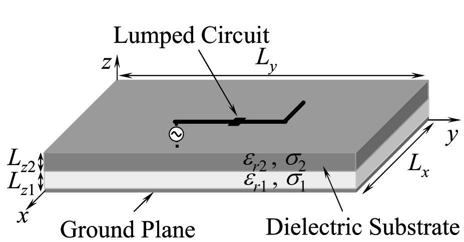

Fig. 3 2-layer PCB.

Table 1 Configuration of 2-layer PCB shown in Fig. 3.

L_x, L_y, L_{z1}, L_{z2} [λ]	0.8, 0.8, 0.008, 0.008
σ_1, σ_2 [S/m]	2.13×10^{-3}, 2.13×10^{-3}
ε_{r1}, ε_{r2}	4.4, 4.4

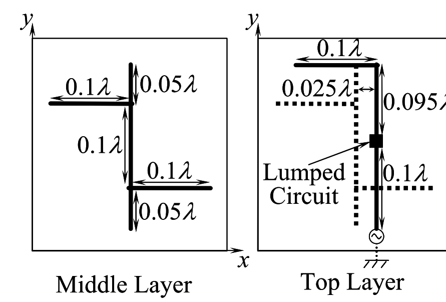

Fig. 4 Geometry of microstrip transmission line on each layer of the 2-layer PCB shown in Fig. 3.

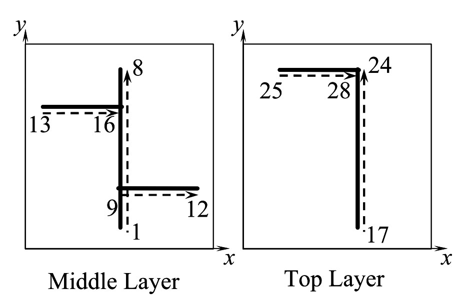

Fig. 5 Current estimation model of PCB shown in Fig. 3.

Table 2 The impedance of lumped circuits included in PCB shown in Fig. 2.

Capacitor	4pF
Inductor	1nH
Resistor	11Ω

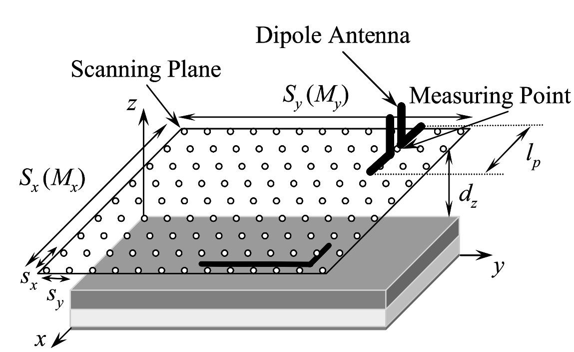

Fig. 6 Scanning plane for near-field measurement.

Table 3 Scanning parameters for near-field measurement.

$l_p\,[\lambda]$	0.2
$d_z\,[\lambda]$	0.025
$S_x, S_y\,[\lambda]$	0.3, 0.3
M_x, M_y	13, 13
$s_x, s_y\,[\lambda]$	0.025, 0.025

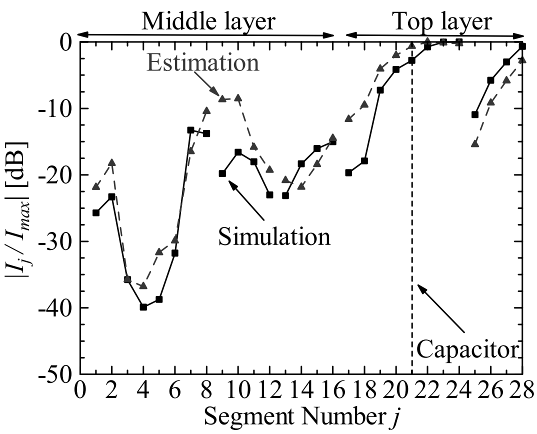

Fig. 7 Estimated current distribution compared with FDTD solution when capacitor of 3pF is included on the top layer.

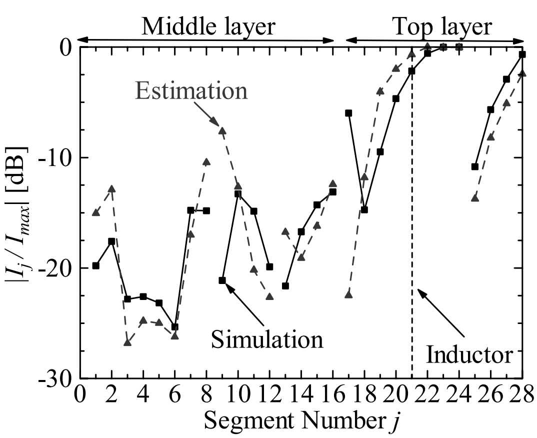

Fig. 8 Estimated current distribution compared with FDTD solution when inductor of 1nH is included on the top layer.

tion are shown together in Figs. 7, 8 and 9 for three kinds of lumped circuits at the segment 21, respectively. Note again that the estimation results can be obtained without any electrical parameters of these lumped circuits, while the position of the feeding point and the impedance of the lumped circuits are known factors in the FDTD calculation. In each case, the position of the maximum current value is estimated accurately and estimated current shows acceptable agreement with the FDTD solution. However, relatively large difference is observed at the segment 1 because this segment includes the feed point which is not considered in the estimation model. Furthermore, the current at the discontinuous points near junction of stubs such as segment 8 and 9 is also hardly estimated accurately because the near-field at these positions has a very complicated distribution and it is

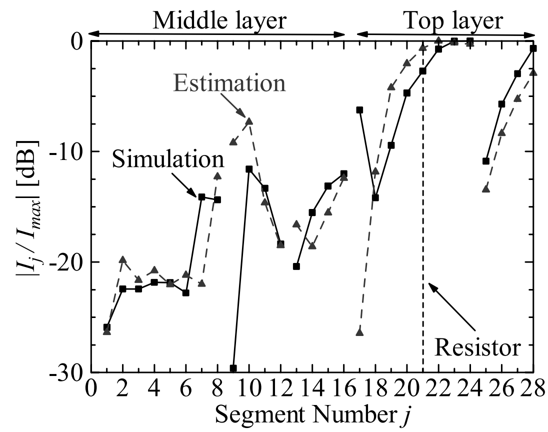

Fig. 9 Estimated current distribution compared with FDTD solution when resistor of 11 Ω is included on the top layer.

difficult to measure the near-field accurately at a fine resolution.

4. Conclusions

Current distribution on a 2-layer PCB with various kinds of lumped circuits has been estimated by measuring the near electric field. It has been discussed how to treat lumped circuits in the current estimation model. Experimental estimation results show acceptable agreement with the FDTD solution, confirming the validity of the method. It can be said that this method is practical and useful because the current estimation can be carried out without any information about the lumped circuits and the feeding point. It should be noted that it has been assumed in the present study that the radiation is caused only by the current on the transmission line and the lumped elements do not radiate because they are assumed to be electrically infinitely small. However, in practical situations, electrically large lumped elements may exist in the PCB. This situation is out of the scope of the present study.

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