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Abstract The fast algorithm developed for calculating the resonant characteristics of the power/ground planes in multilayer PCBs, is extented to the case of that the pattern of the power/ground planes consists of several "segments" of rectangles, using the so-called segmentation method. Good agreements between the calculated and measured results have demonstrated the usefulness and accuracy of our fast algorithm and the segmantation method.

1. Introduction

It has been known that the resonances of the power/ground planes in multilayer printed circuit boards (PCB) not only cause radiated emission as EM interference, but also affect ground bounce due to switching noise in a digital system. With continuous increase of the clock rate, it seems reasonable to consider the power distribution system on a PCB as a dynamic electromagnetic system in which the propagation effects are important. In fact, the power/ground planes of a multilayer PCB must be considered as a parallel plate waveguiding system. Resonances characteristics of the power/ground planes have been accurately investigated with various models, such as a full cavity-mode resonator model [1, 2], a distributed lumped-element equivalent circuit model [3, 4], and numerical models based on a finite-element method [5] or a finite-difference time-domain method [6].

Based on a full cavity-mode resonator model, a fast algorithm for calculation of the impedance Z-matrix and then the resonant characteristics of the power/ground planes has been developed by us [7, 8] recently, assuming that the pattern of the power/ground plane is rectangular. When the pattern is entirely arbitrary, we must rely upon the numerical methods. However, in actual PCBs, an entirely arbitrary pattern of the power/ground plane is not very common; in many cases the pattern consists of several segments, which themselves have simpler shapes such as rectangles. In this paper, the fast algorithm is extented to the case of that the pattern consists of several segments of rectangles, using the segmentation method [9, 10, 11] that was proposed for analyzing the two-dimensional microwave planar circuits many years ago. In the segmentation method, the characteristics of the entire power/ground plane are computed by combining those of the segmented elements. Good agreements between the calculated and measured results have demonstrated the usefulness and accuracy of our fast algorithm and the segmantation method.

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2. Full Cavity-mode Model

The full cavity-mode resonator model is an analytical description of the impedance matrix (Z-parameters) of an unloaded power/ground plane structure (a bare board). For a rectangular power/ground plane structure with length a and width b (see Fig.1), an expression for fast calculation of the impedance between two ports on the power/ground planes has been developed [7] as follows:

$$Z_{ij} = \sum_{n=0}^{\infty} \frac{\omega \mu_d h a}{\mathrm{j}\, 2b} C_n \cos(k_{yn} y_i) \cos(k_{yn} y_j)$$
$$\times \mathrm{sinc}^2(k_{yn} \mathrm{w}) \frac{[\cos(\alpha_n x_-) + \cos(\alpha_n x_+)]}{\alpha_n \sin \alpha_n} \qquad (1)$$

where $\mathrm{sinc}(x) = \sin(x)/x$, $k_{yn} = n\pi/b$, $\alpha_n = a\sqrt{\kappa^2 - k_{yn}^2}$, $x_{\pm} = 1 - (x_i \pm x_j)/a$, (x_i, y_i) and (x_j, y_j) are the coordinates of the center of the ith and jth ports in the x- and y-directions, respectively, w is much less than the wavelengths of interest and represents the port half width, h is the dielectric thickness between the power/ground planes, ω is radian frequency, μ_d is the permeability of the dielectric, and $\mathrm{j} = \sqrt{-1}$. The constant C_n is assigned as $C_n = 1$ if $n = 0$, and $C_n = 2$ if $n \neq 0$. The complex transverse wavenumber κ is obtained as $\kappa^2 = \omega^2 \mu_d \varepsilon_d - \mathrm{j} 2 \omega \varepsilon_d Z_s / h$, where Z_s represents the surface impedance of the power/ground conductors. When the board is loaded with passive components or active devices, the impedance characteristics of the loaded board can be analyzed by considering the loaded board as a multi-port circuit network interconnected by the Z-matrix elements of the corresponding bare board.

3. Segmentation Method

The expression given above for the rectanglar power/ground plane can be easily applied to those geometries which result from the connection of rectangles, by using the segmentation method [9, 10, 11]. This is illustrated in a simple example. The structure of Fig.1(a) can be decomposed into the casecade of two

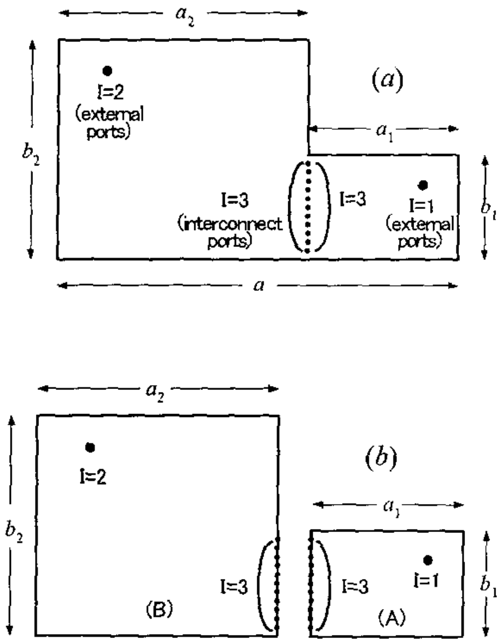

Figure 1: Principle of the segmentation method. (a) An example of the power/ground plane pattern to which the segmetation method can be applied, (b) Dividing into segments.

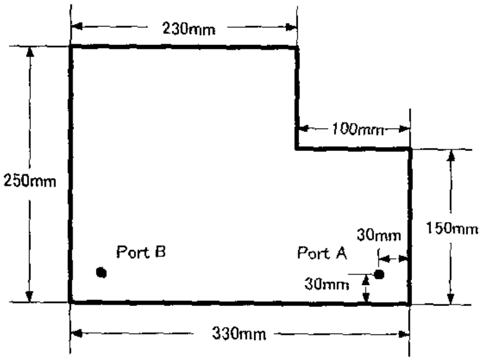

Figure 2: Dimensions of the board for simulation and measurement.

segments in Fig.1(b) for which the impedance matrices $[Z_A]$ and $[Z_B]$ can be computed with Eq.(1). By grouping the ports on the segments into the external ports (group 1 on Seg.(A) and group 2 on Seg.B) and the internal connected ports (group 3), the Z-matrices can then be written as

$$\begin{bmatrix} \vec{V}_{\mathrm{A1}} \\ \vec{V}_{\mathrm{A3}} \end{bmatrix} = \begin{bmatrix} [Z_{\mathrm{A11}}] & [Z_{\mathrm{A13}}] \\ [Z_{\mathrm{A31}}] & [Z_{\mathrm{A33}}] \end{bmatrix} \begin{bmatrix} \vec{I}_{\mathrm{A1}} \\ \vec{I}_{\mathrm{A3}} \end{bmatrix} \tag{2}$$

and

$$\begin{bmatrix} \vec{V}_{\mathrm{B2}} \\ \vec{V}_{\mathrm{B3}} \end{bmatrix} = \begin{bmatrix} [Z_{\mathrm{B22}}] & [Z_{\mathrm{B23}}] \\ [Z_{\mathrm{B32}}] & [Z_{\mathrm{B33}}] \end{bmatrix} \begin{bmatrix} \vec{I}_{\mathrm{B2}} \\ \vec{I}_{\mathrm{B3}} \end{bmatrix} \tag{3}$$

where $\vec{V}$ and $\vec{I}$ are the voltages and currents at the ports. Using the conditions imposed by the interconnection, that is

$$\vec{V}_{\mathrm{A3}} = \vec{V}_{\mathrm{B3}}, \ \vec{I}_{\mathrm{A3}} = -\vec{I}_{\mathrm{B3}} \tag{4}$$

the overall Z-matrix is then given as

$$\begin{bmatrix} \vec{V}_{\mathrm{A1}} \\ \vec{V}_{\mathrm{B2}} \end{bmatrix} = \begin{bmatrix} [Z_{11}] & [Z_{12}] \\ [Z_{21}] & [Z_{22}] \end{bmatrix} \begin{bmatrix} \vec{I}_{\mathrm{A1}} \\ \vec{I}_{\mathrm{B2}} \end{bmatrix} \tag{5}$$

where

$$\begin{aligned} [Z_{11}] &= [Z_{\mathrm{A11}}] - [Z_{\mathrm{A13}}]\,[Y_{\mathrm{AB}}]\,[Z_{\mathrm{A31}}] && (6) \\ [Z_{12}] &= [Z_{\mathrm{A13}}]\,[Y_{\mathrm{AB}}]\,[Z_{\mathrm{B32}}] && (7) \\ [Z_{21}] &= [Z_{\mathrm{B23}}]\,[Y_{\mathrm{AB}}]\,[Z_{\mathrm{A31}}] && (8) \\ [Z_{22}] &= [Z_{\mathrm{B22}}] - [Z_{\mathrm{B23}}]\,[Y_{\mathrm{AB}}]\,[Z_{\mathrm{B32}}] && (9) \end{aligned}$$

with

$$[Y_{\mathrm{AB}}] = ([Z_{\mathrm{A33}}] + [Z_{\mathrm{B33}}])^{-1} \tag{10}$$

Note that, in the segmentation method, the interconnection is discretized into a finite number of ports, in which continuous voltage and current distributions along the interconnection are approximated by stepped functions. The number of ports used for the interconnection therefore determines the accuracy of the segmentation method.

4. Results and Discussions

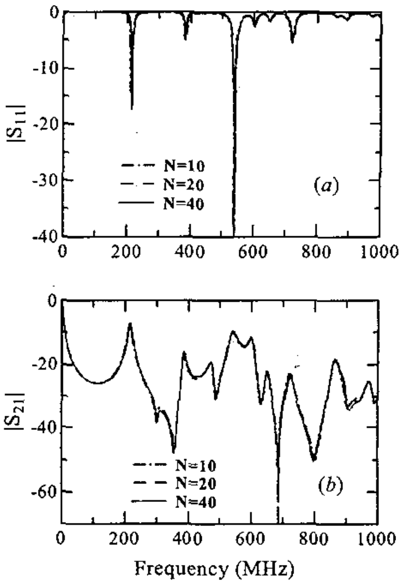

Figure 3: Calculated (a) $|S_{11}|$ and (b) $|S_{21}|$ for the board of Fig.2. N is the number of the ports used for the interconnection.

The overall scattering S-matrix can easily be obtained from the overall Z-matrix. For the board (h = 1.6mm) shown in Fig.2, the calculted results for S_{11} at the port A and S_{21} between the port A and the port B are plotted in Fig.3 with the different number N of the interconnected ports. The fact that the curves for N=10, 20 and 40 are almost coincident, means that the results converge quite quickly. The calculted S_{11} and S_{21} for N=20 are also compared to the measured ones in Fig.4, and very good agreement between them can be observed.

We have described above a fast algorithm for analyzing the resonant characteristics of the power/ground plane whose pattern consists of several segments of rectangles. The algorithm is easy to be applied for studying the practical interesting EMI problems, such as the ef-

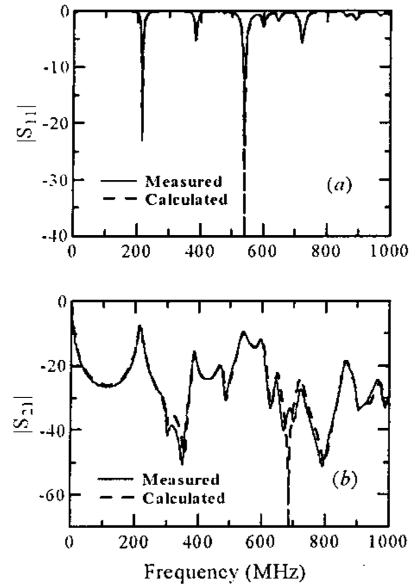

Figure 4: Comparisons between the calculated and measured (a) $|S_{11}|$ and (b) $|S_{21}|$ for the board of Fig.2.

fect of a slot on the power/ground plane, and the isolation effect by the partitioning of the power/ground plane.

Acknowledgement

This work is supported by the Project for the Suppression of Electromagnetic Noise, Research for the Future Program, Japan Society for the Promotion of Science (JSPS).

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