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Pulse responses of a printed circuit board with a via and a bump

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1. Introduction

In this paper, pulse propagation characteristics are investigated for the fundamental multi-layered printed circuit model with a via and a bump as shown in Fig.1. The via is connected to the circular pads of conductor (labeled pad 2 and pad 3 in Fig.1) through the hole of conductor 1. The bump is put between pad 1 and pad 2. Pad 1 is connected to the transmission line labeled line 1.

Numerical results for pulse propagation are compared a bump-via connected structures with a via connected structures without a bump. The finite-difference time-domain (FDTD) method [1][2] has been successfully used for the analysis of our problem. FDTD method can analyze the pulse propagation characteristics as the boundary value problem for Maxwell equations. Numerical simulation can provide quantitative and accurate results which are difficult to measure directly.

2. Analysis

2.1 Analysis models The coordinate system and the structures of a multi-layered printed circuit board with a bump and a via are shown in Figs.1,2, and 3. Fig.2 shows the cross section on *x-z* plane of the bump-via model (BV model) whose striplines separated by dielectric layers are connected by both a via and a bump. BV model is a fundamental model throughout this paper and a part of structure in the practical PCB taken as BV model. BV model is consisted of five layered structures of three dimensions. Layer 1, layer 3, and layer 4 are dielectric substrates of the relative permittivity ε_r =3.4. Layer 2 and layer 5 are the air (ε_r =1.0). The detail of striplines, pads, and conductors placed into each layer are as follows.

(1) Layer 1 : The layer is composed of a dielectric sheet on the conductor1. The stripline (line1) of width w_d and the pad (pad1) of radius a_{bp} are put on the dielectric sheet.
(2) Layer 3 : The layer which is put on a bump is composed of a dielectric sheet of thickness c_3. The conductor2 with a through hole is out on the sheet.
(3) Layer 4 : The layer is a dielectric sheet on which the line2, pad3 and line3 are put. A via perpendicularly passes through the layer.

The conductor (conductor 2) with the clearance hole of radius a_{clr} is placed between layer 3 and layer 4. Pad 1 and pad 2 are connected by the bump of radius a_b, and pad 2 and pad 3 are connected by the via passing through a clearance hole of conductor 2.

Fig.3 shows the cross section on *x-z* plane for the via model (V model) whose striplines separated by dielectric layers are connected by only a via. V model is the structure prepared in order to discuss the influence to pulse response due to the bump of BV model. Pad 2 and the bump are removed and pad 1 and pad 3 of radius a_{vp} are directly connected by the via. The relative permittivity of layer 2 is ε_r =3.4.

In Figs.1,2, and 3, line 1 ~ line 3, pad 1 ~ pad 3, conductor 1, conductor 2, a via, and a bump are the perfect conductor of thickness h_m. All dielectric sheets are lossless.

2.2 Analysis method A transient analysis of a pulse propagation for BV model and V model is computed by FDTD method[1][2]. The cell size Δ is defined as $\Delta=\Delta x=\Delta y=\Delta z$. The time step Δt is determined so as to satisfy the stability condition of Courant [9]. Ten layered PML[1] is imposed as the absorbing boundary condition around the each model. An incident excitation pulse is a Gaussian pulse defined as :

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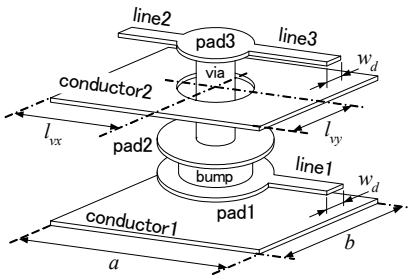

Fig.1. Configuration of a via and a bump

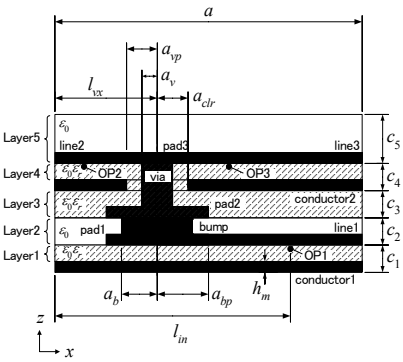

Fig.2. Cross section of the bump-via model (BV model)

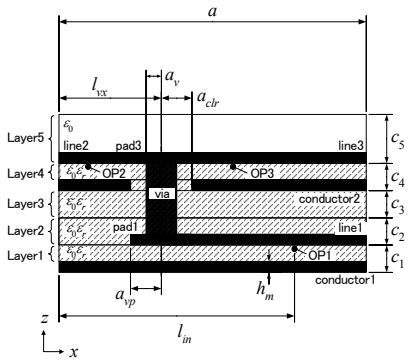

Fig.3. Cross section of the via model (V model)

$$E_z^{inc} = \exp\left\{-\frac{(t-3T)^2}{T^2}\right\} \quad \cdots\cdots(1)$$

where T=0.5ps. E_z^{inc} is uniformly excited under line 1 at $x=l_{in}$ in Figs.2 and 3.

3. Numerical results

The sizes of BV model and V model in Figs.2 and 3 are denoted in Table.1. These data are practical values which are used for the printed circuit board[3]. We set three observation points (OP1, OP2, and OP3 in Figs.2 and 3) for clarifying the status of pulse propagating from line 1 to line 2 and line 3. OP1 (at x=250[μm] and y=70[μm]) is just under line 1. OP2 (at x=25[μm] and y=70 [μm]) and OP3 (at x=175 [μm] and y= 70[μm]) is just under line 2 and line 3, respectively. The distance from OP2 to the center of the via is same as that from OP3 to the center of the via.

Table 1. The size of each part of the analysis model [μm]

a=300	c_5=30	l_{vx}=100
b=140	a_v=15	l_{vy}=70
c_1=25	a_{vp}=30	h_m=10
c_2=25	a_b=35	l_{in}=250
c_3=25	a_{bp}=50	w_d=20
c_4=25	a_{clr}=30,40,50	

Fig.4 shows a convergence test of the amplitude of E_z against the cell size Δ of FDTD on OP1 for BV model. From Fig.2, it is found that the relative error to the extrapolated true value of the amplitude of E_z can be kept less than 5% by taking Δin the range of $\Delta \leq 2.5$ [μm]. In the following numerical analysis, the relative error of the amplitude of E_z is always kept below 5% by selecting Δ carefully.

Fig.5 shows pulse responses observed on OP1. The results of the BV model and V model are indicated by the solid line and the broken line, respectively. b_i (as labels of BV model) and v_i (as labels of V model) at the response waveforms are utilized as a help of the considerations throughout numerical results. In Fig.5, b_1 and v_1 are the excited pulse. b_1 has a larger peak value of response than the peek value of v_1. This is because the permittivity of each model in layer2 is different. b_2 and v_2 are the reflection waves from a bumps and/or a via. The response after b_2 and v_2 is continued decreasing by a multiple reflection generating in the substrate.

Fig.6 shows pulse responses observed on OP2. In the case of V model, v_2 due to the influence of multiple reflection is continued after v_1 which the excited pulse is arrived on OP2 by propagating through the via. BV model also has a similar response. However, a large distortion of waveform is observed for BV model, thus having a complicated structure with a bump.

Fig.7 shows pulse responses observed on OP3. In the case of BV model, b_1 at OP3 is larger than that of OP2, and b_2 at OP3 is smaller than that at OP2. In the case of V model. Whereas the response time at the peak value of b_1 and v_1 at OP2 is same, the peak value of b_1 for OP3 is later than that of v_1.

In Figs.5,6 and 7, a clearance hole of radius a_{clr} which is made into conductor 2 had been fixed at a_{clr}=30[μm].

To compare with the responses in Figs.6 and 7 we computed the responses when a_{clr} is 30[μm], 40[μm], and 50[μm].

For BV model, Figs.8 and 9 show pulse responses observed at OP2 and OP3, respectively. The

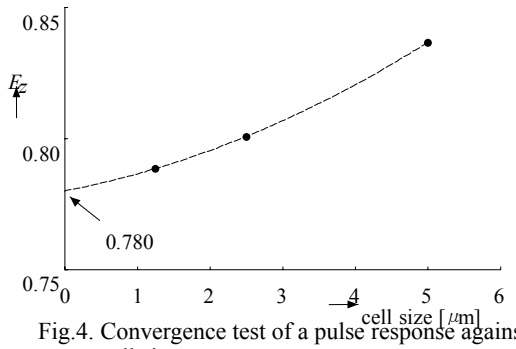

Fig.4. Convergence test of a pulse response against the cell size

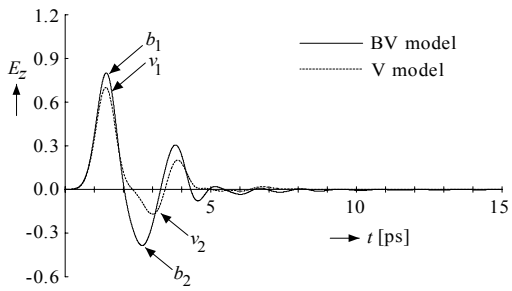

Fig.5. Pulse responses at OP1 for BV model and V model

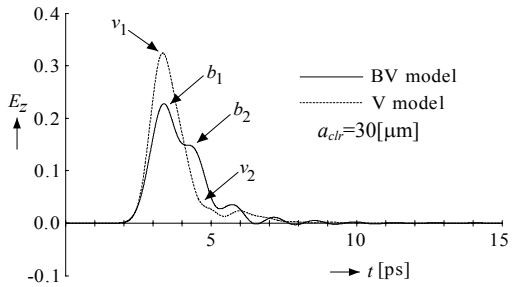

Fig.6. Pulse responses at OP2 for BV model and V model

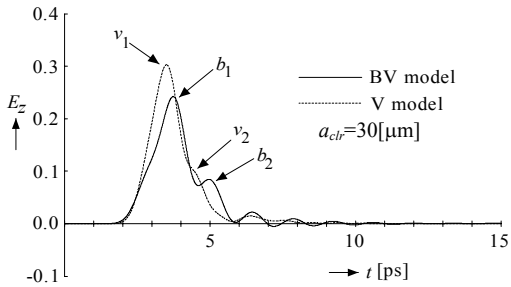

Fig.7. Pulse responses at OP3 for BV model and V model

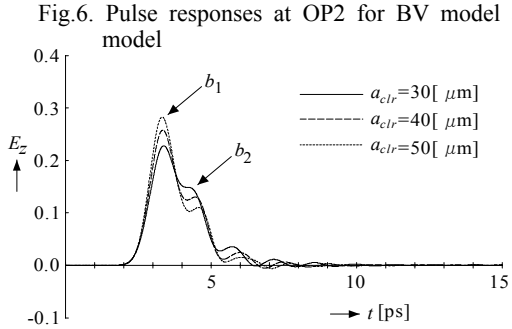

Fig.8. Pulse responses at OP2 for BV model when varying a clearance hole radius a_{clr}

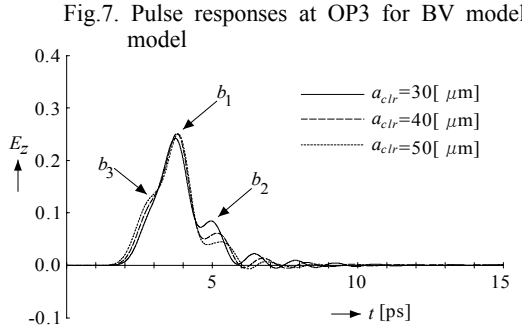

Fig.9. Pulse responses at OP3 for BV model when varying a clearance hole radius a_{clr}

following results are found from the figures.

(1) b_1 at OP2 increases as a_{clr} is increased, on the other hand b_1 at OP3 does not change.
(2) When a_{clr} is changed from 30[μm] to 50[μm], the modification at b_1 on OP3 is smaller than that at OP2.
(3) For OP3, b_2 decreases as a_{clr} is increased.
(4) The rise of response on OP2 is not almost influenced by the size of a_{clr}.

When the pulse excited from OP1 was arrived to OP2 or OP3, the large pulse distortion was observed in BV model,. If the clearance hole radius was set up larger, the pulse distortions at OP2 were improved. This means that less distortion of the pulse responses on OP2 and OP3 is trade-off for the size of the clearance hole. From these results, it is necessary to find out fundamental causes of the pulse distortion arising in BV model. We discuss the influence of the bump which is put between pad 1 and pad 2. The bump radius is a_b and the radiuses of pad 1 and pad 2 are equally a_{bp}. When radius a_{bp} of pad 1 and pad 2 is reduced from a_{bp}=50[μm] (original size in Table.1) to a_b=30[μm] (same size as the via pad (pad 3) with radius a_{vp}), pulse responses at OP2 and OP3 are shown by solid lines (a_{bp}= a_{vp}) in Figs.10 and 11, respectively. The responses of V model in Figs.6 and 7 are also indicated by broken lines ($a_b \neq a_v$). The rise time in BV model becomes slightly earlier than that in V model. The large pulse distortion in BV model is not almost observed. As a result, it is concluded that the pulse distortion on OP2 and OP3 is depended on the radius of the pads added to the bump. From above results, it is found that the pulse distortion on a stripline after propagating the bump part can be minimized if the bump pad radius can be small (as much as the via pad radius) by designing the bump radius as small as possible.

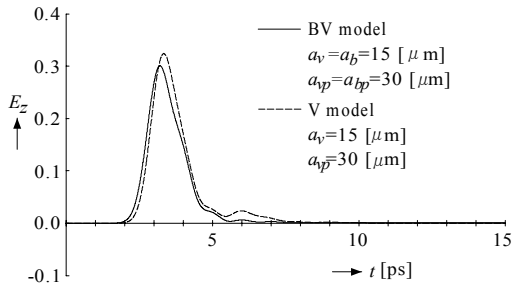

Fig.10. A comparison of a pulse response (solid line) of BV model and a pulse response (broken line) of V model at OP2. a_b and a_{bp} of BV model is set up similarly to a_v and a_{vp} of V model, respectively

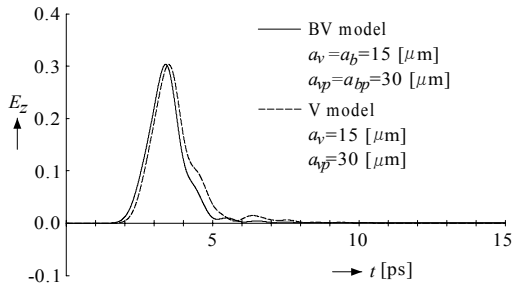

Fig.11. A comparison of a pulse response (solid line) of BV model and a pulse response (broken line) of V model at OP3. a_b and a_{bp} of BV model is set up similarly to a_v and a_{vp} of V model, respectively

4. Conclusions

In this paper, pulse propagation characteristics in multi-layered PCB with a via and a bump were investigated. We proposed BV model (with a via and a bumps) and V model (with a via). V model was prepared as a comparison model to discuss the influence of a bump. The main results are as follows.

(1) The pulse responses for BV model are distorted comparing with those for V model.

(2) In BV model, although the radius a_{clr} of a clearance hole located into conductor plate can be controlled (in the range of 30[μm] ≤ a_{clr} ≤ 50[μm]), an improvement effect to a pulse response is trade-off by the propagation direction of pulse.

(3) It is found for BV model that the pulse distortion on a stripline after propagating the bump can be minimized if the bump pad radius is nearly equal to the via pad radius.

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