Full Wave Characterization of a Through Hole Via Discontinuity in Multi-Layered Packaging

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Abstract– The frequency dependent propagation characteristics of a via penetrating through a hole in a ground plane in multi-layered packaging were investigated by a full wave numerical approach. [1]

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I. Introduction

To cope with the ever increasing circuit demand of higher density and faster operating speed, the multi-layer modules have become the indispensable trend of the present high performance packaging systems [1]. In the multi-layer modules, there are striplines and/or microstrip lines for the signal transmission as well as the vias for the connections between signal lines at different layers [2]. The adjacent two conducting plates in the multi-layer packaging environment form a radial waveguide. The current on the vertical via will excite electromagnetic waves propagating inside the radial waveguide, so called the radial waves. Since the radial dimension of the conducting plates is much larger than the via height, the occurrence of the radial waves is noticeable even in low frequencies and have attracted researchs' attentions in the recent years [3]-[5].

This paper deals with the frequency dependent propagation characteristics of a through hole via in multi-layer packaging environment. The excited radial waves due to the via will interact with the TEM waves along the transmission lines and show more complicated mode transition mechanism. Numerical results investigate the frequency dependent propagation characteristics for the via structures with various parallel plate separations and via heights.

II. Statement of the Problem

Figs.1(a) and (b) show a typical through hole via structure in multi-layered packaging and its quasi-static equivalent circuit, respectively. Consider TEM waves of amplitudes A_1 and A_2 incident from the upper and lower transmission lines, respectively. It is of interest to calculate the amplitudes B_1 and B_2 of the reflected TEM waves in the transmission lines and the amplitudes C_1 and C_2 of the excited radial waves due to the presence of the via. The problem can be decomposed into an antenna problem and a short circuit problem. A matrix-penciled moment method has been developed to deal with the same structure in the absence of upper and lower parallel plates [6]. The analysis follows a similar procedure and will be neglected here.

III. Numerical Examples

For simplicity, we consider only the numerical examples of symmetrical structure with via height $h_1 = h_2 = h$ and parallel plate spacing $D_1 = D_2 = D$ and transmission line radius $a_1 = a_2 = a$ are presented here, although the present analysis can handle the asymmetrical structure without any difficulty. Assume that a TEM mode of unit amplitude is incident from the line 1 ($A_1 = 1$) while line 2 is terminated with a matched load ($A_2 = 0$).

To verify the validity of this study, consider a through hole via structure with $a = 60\mu$m, $b = 180\mu$m, $h = 1.8$ mm, and $D = 3.6$ mm. Fig.2 compares the results obtained by the present analysis and the finite-difference time-domain (FD-TD) method, which are denoted by the solid and dashed curves, respectively. In FD-TD simulation, the circular wire and hole are replaced by square ones with size $2a$ and $2b$, respectively. The solution region is truncated into a rectangular box and is discretized using $80 \times 160 \times 120$ uniform orthogonal mesh, that is, 4.8 mm in width by 9.6 mm in length by 7.2 mm in height. The discrepancy between these two sets of curves is reasonable since the structures considered in these two analyses are slightly different and probably even more, the absorbing boundary condition works not well for both the radial waves and TEM waves.

Figs.3(a) and (b) show the magnitude and phase of the reflection and transmission coefficients for the via structures with $h/a = 30$, and D/h as the parameter. The solid curves standing for the limiting case $D/h \rightarrow \infty$ are obtained in the previous analysis [6]. The effects due to the presence of two outer plates can be depicted from the comparisons between the dashed and solid curves. The reflection coefficient is significantly reduced but the transmission coefficient remains almost the same. In other words, significant amount of energy is coupled to the radial waves. At low frequencies, the power loss is found to be a linear function of the frequency in the present case rather than a quadratic dependence if the two outer plates are absent. Using a frequency dependent resistance $R = \gamma kh(\frac{h}{D})\eta$ to account for the power loss, the via can be modeled as a RLC circuit shown in Fig.1(b). The coefficient γ is empirically found to be about 1/5 and slightly increases versus the frequency. Based on this model, the reflection coefficient at the quasi-static limit can be approximately given by

$$\Gamma \cong \frac{R}{Z_0} + j\omega(\frac{L_e}{Z_0} - C_e Z_0) \tag{1}$$

where L_e and C_e are excess inductance and capacitance of via, respectively, and $Z_0 = \frac{\eta}{2\pi}\ln(\frac{2D}{a\pi}\sin(\frac{h}{D}\pi))$ is the characteristic impedance of the transmission line. As the ratio D/h decreases, L_e will increase and Z_0 will decrease while C_e is relatively invariant. Consequently, the phase of Γ shown in Fig.3(b) varies from -90^o to a positive value, *i.e.*, the via behaves more inductively. At a suitable ratio of via height h and separation D, the via becomes resonant when the capacitance and inductance effects cancel out and minimun reflection is achievable.

Fig.4 shows the ratio of the separation to the minimun reflection height versus frequency and $h/a = 20$ or 30. The curves are drawn by curve fitting the numerical results obtained at several different frequencies. It can be found that the optimal D/h ratio decreases as the frequency increases. These curves are helpful for designing a multi-layered packaging system with minimun reflection.

IV. Conclusion

In this study, a full wave approach was proposed for investigating the frequency dependent propagation characteristics of a through hole via in the multi-layered packaging. The results were found to be in reasonable agreement with those based on the FD-TD simulation. By adjusting a suitable ratio of via height and separation of two plates, the via can achieve minimun reflection. Also presented was the equivalent circuit of the through hole via in multi-layer structure which includes non-negligible resistance to signify the presence of the excited radial waves. A quasi-static equivalent circuit model was given to explain the electrical performance associated with the via in multi-layered environment.

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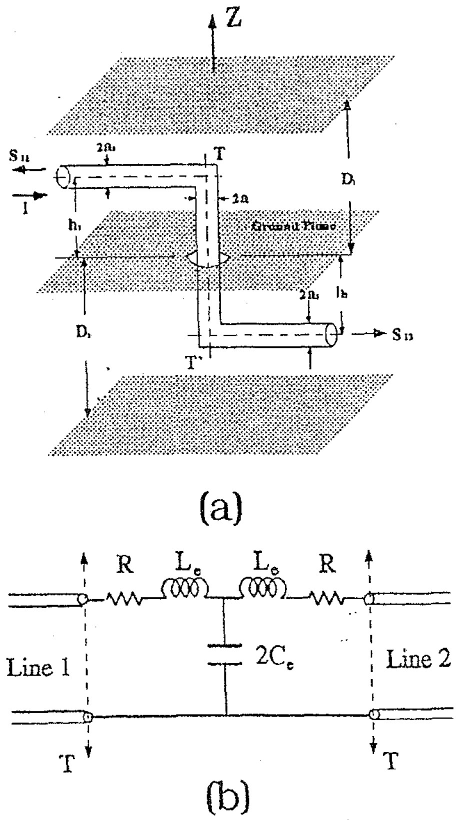

Figure 1: (a) A typical through hole via structure in multi-layered packaging and (b) its equivalent circuit.

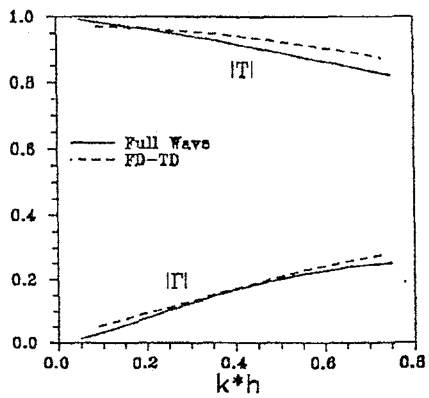

Figure 2: Comparison between the results by the present approach and the FD-TD technique, which are denoted by solid and dashed curves respectively.

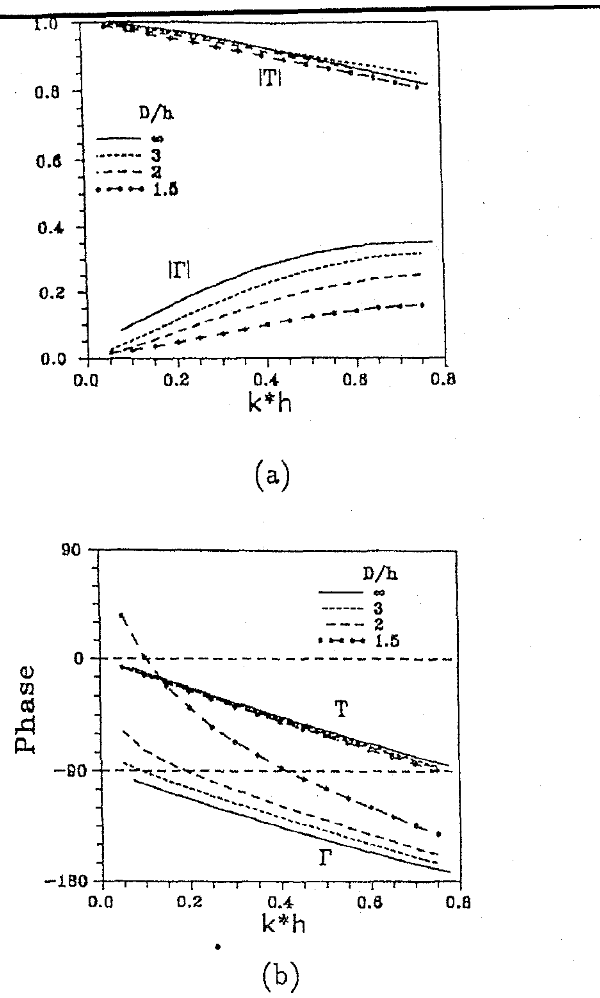

Figure 3: Comparison between this study and the previous research [6] which are denoted by dashed curves and solid curves, respectively, (a) amplitude, (b) phase. The via structures have parameters $h/a_1 = 30$.

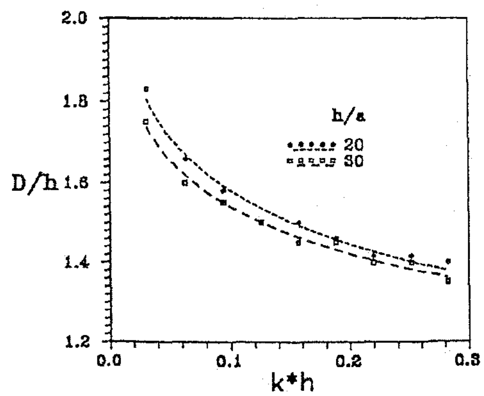

Figure 4: The optimum ratio D/h of minimun reflection versus frequency for the via structures and h/a as a parameter.