**Proceeding of 1997 IEEE 6th Topical Meeting on Electrical Performance of Electronic Packaging, p. 135-138**

**0-7803-4203-8/97/$10.00© 1997 IEEE**

# Significance of Electromagnetic Coupling Through Vias in Electronics Packaging

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## Abstract

The investigation on the relative significance of electromagnetic coupling between vias and parallel traces is presented in this paper. This study shows that the coupling between vias can often be stronger than the coupling between traces and is therefore not negligible in signal integrity analysis of high-speed electronic packages.

## Introduction

Today's electronic systems, such as computers and digital communication systems are having a rapid increase in operation speed and package complexity. Electrical modeling of packages has become one of the critical issues in overall system designs. Improperly designed packages lead to signal integrity degradations such as signal delay, cross talk and ground noise, which limit the overall system performance.

With the number of traces and vias in packages continue to increase, it is very important to have accurate modeling of electromagnetic interactions between various components in packages. Electromagnetic coupling inside a package structure is mostly through traces and vias. There has been substantial study on coupling through parallel signal traces. The coupling between vias is often ignored in coupling analysis. This paper shows the relative significance of electromagnetic coupling through vias and parallel traces. It is found that the coupling between vias is often more significant than the coupling between traces, and can not be ignored in the overall coupling analysis.

In the following sections of this paper, formulas used for computing the coupling between traces and vias are presented. Then the contribution of the via coupling is compared with that of the trace coupling.

## Coupling Models

Consider the package structure shown in Figure 1, where two parallel signal traces on the upper signal layer are connected to the parallel signal traces on the lower signal layer by vias passing through metal planes. The total length of the traces is *L*. The center-to-center separation between two traces or two vias is *S*. *D* is the separation between the two internal metal planes.

The analytical frequency-domain solution of the coupling between two transmission lines in homogeneous media can be found in [1]. With matched terminations, the near end voltage-to-voltage coupling coefficient can be expressed as

$$2\,\frac{\sin(\beta L)}{\Delta\beta L}\left[j\omega M\cos(\beta L)+(j\omega)^2\,TK\,\frac{\sin(\beta L)}{\beta L}\right]$$

(1)

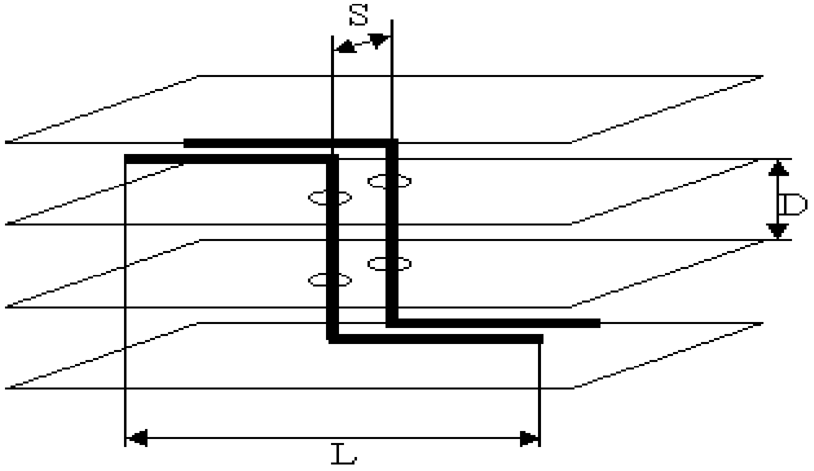

Figure 1 Sketch of the structure considered.

where $\Delta = \cos^2(\beta L) + j\omega \frac{\sin(2\beta L)}{\beta L}\tau + \left(j\omega \frac{\sin(\beta L)}{\beta L}\tau\right)^2$, $M = \frac{k}{2\sqrt{1-k^2}}$, $K = \frac{M}{\sqrt{1-k^2}}$,

$\tau = \frac{T}{\sqrt{1-k^2}}$ and $T = L/v$ is the one way delay time of the line. *k* is the coupling coefficient defined as $k = l_{12}\big/\sqrt{l_{11}l_{22}} = |c_{12}|\big/\sqrt{c_{11}c_{22}}$, where $l_{ij}$ and $c_{ij}$ are elements of inductance matrix and capacitance matrix.

The solution of via coupling between the two metal planes separated by a distance *D* can be found in [2-4]. The voltage-to-voltage coupling coefficient for two vias can be approximated as

$$\frac{\eta}{4Z_0} 2\pi \frac{D}{\lambda} H_0^{(2)}\left(2\pi \frac{S}{\lambda}\right)$$

(2)

where $Z_0$ is the characteristic impedance of the strip transmission lines, $\eta$ is the wave impedance and $H_0^{(2)}$ is the zero-order Hankel's function of the second kind. In (2), the metal planes are considered to be infinite large. That is, the effects of reflections from the edges of metal plane are not counted in this comparison.

## Results and Examples

With equation (1) and (2), the coupling between traces and vias can be computed with different trace lengths, via separations and frequencies (wavelengths).

Figure 2 shows the computed results for the trace and via couplings. The trace coupling is presented as a function of the trace electrical length $L/\lambda$ with different values of trace coupling coefficient *k*. The via coupling is presented as a function of the via electrical length $D/\lambda$ with different $S/D$ ratios. The trace characteristic impedance $Z_0$ in (2) is chosen to be 50Ω.

From Figure 2, one can see that under certain conditions, the via coupling can be as strong as or ever larger than the trace coupling. Following two examples illustrates the time domain responses in via and trace coupling.

The structure of example one is the same as that shown in Figure 1. The strip lines are of width $W = 200$ μm and thickness $t = 35.6$ μm. The separation *S* between two lines is chosen to be 400 μm and 800 μm separately (two cases studied). The thickness of the dielectric media that surround traces is 435.6 μm. The relative dielectric constant of all dielectric layers is 4. The separation *D* between two internal metal planes is 400 μm. With the software in [5], the coupled voltage of the quite line at the near end is calculated. The results are shown in Figure 3. The source signal on the active line is a sine-square pulse with 1 V in amplitude, 44.5 Ohms of source impedance, and with 200 ps rise time, 200 ps duration time and 200 ps fall time.

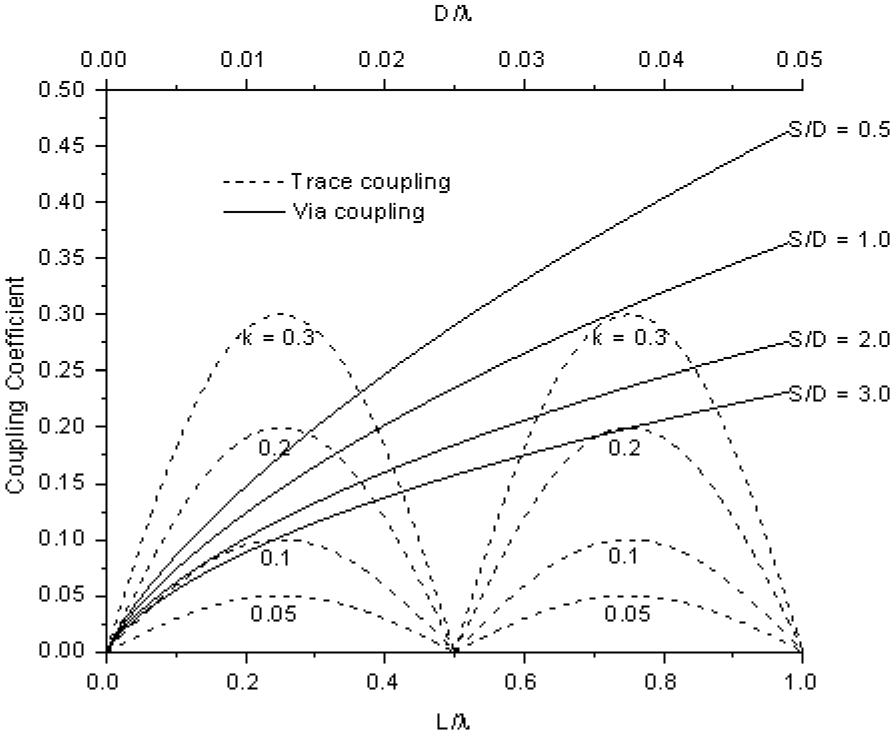

Figure 2 Coupling coefficients for trace and via coupling.

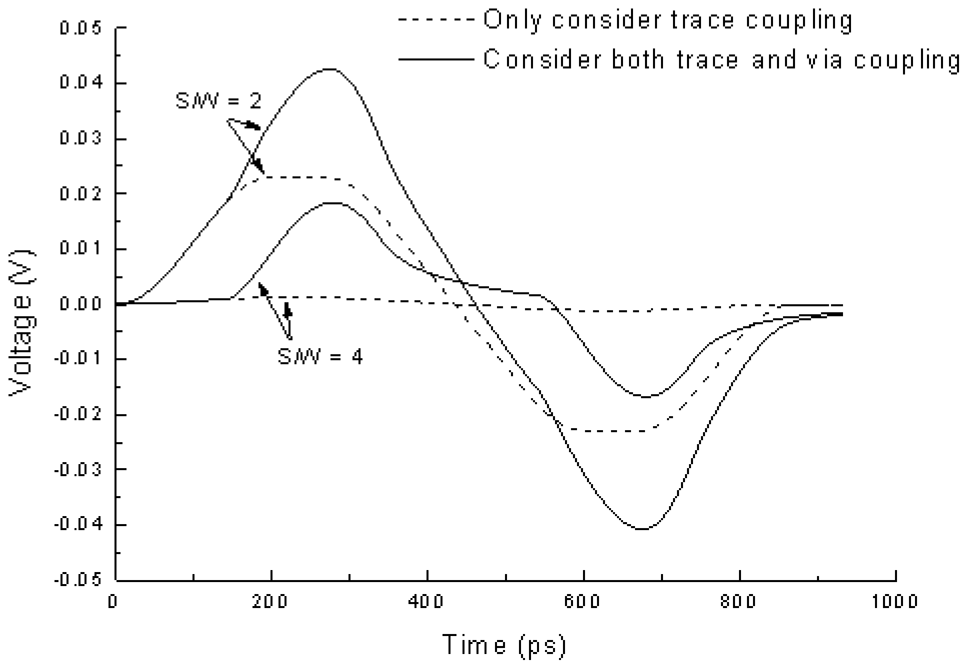

Figure 3 Coupling on the near end of the quite strip line.

From Figure 3, one can see that significant error can be introduced without considering the coupling between vias.

The structure of example 2 is similar to that in Figure 1. The top and the bottom metal planes are removed together with the dielectric layer above the upper signal layer and the dielectric layer below the bottom signal layer. So the signal traces considered here are all microstrip lines. Here the thickness of the dielectric media under the upper signal layer and above the bottom signal layer is 100 μm. Other geometric parameters are the same as those of example one. The coupled voltages on the near end and the far end of the quite signal trace are plotted in Figure 4.

Again one can see that the coupled signal waveforms are quite different depending on whether the coupling between vias are considered.

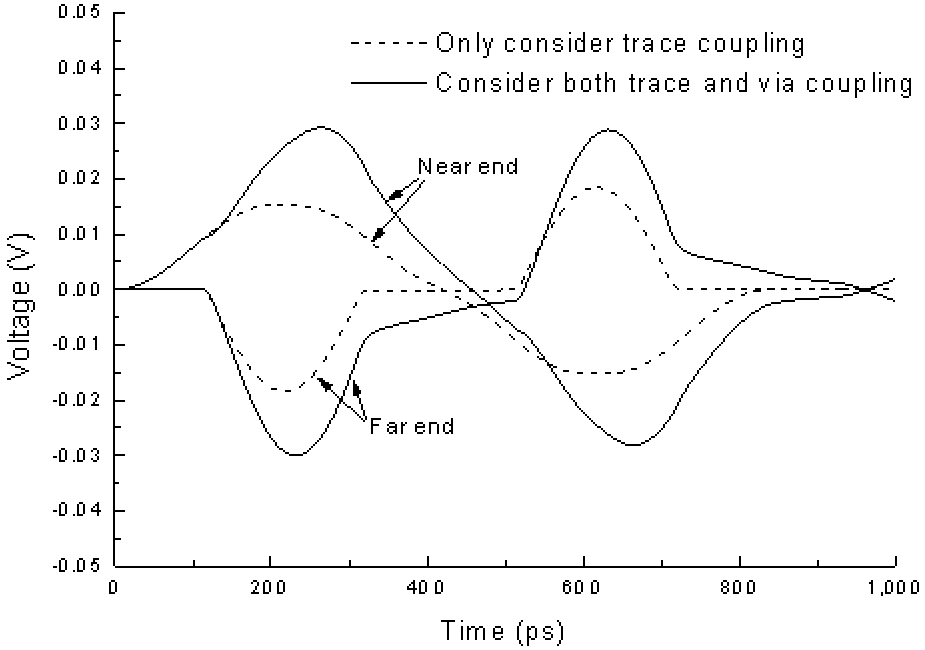

Figure 4 Coupling on the near end and the far end of the quite microstrip line.

## Conclusion

It is found that the electromagnetic coupling between vias has a significant contribution towards the overall coupling between signal interconnects. In order to accurately estimate the package electrical performance, the coupling between vias must be considered in signal integrity analysis for high-speed electronic packages.

## Acknowledgment

The work is supported in part by the National Science Foundation under grant MIP-9357561, the Integrated Electronics Engineering Center at the State University of New York at Binghamton, and the Advanced Research Projects Agency under grant F49620-96-1-0341.

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