CHARACTERIZATION OF VIA STRUCTURES IN MULTILAYER PRINTED CIRCUIT BOARDS

Taras Kushta(1), Kaoru Narita(1), Yasushi Kinoshita(1), Hirokazu Tohya(1),
Takanori Saeki(2), Tomoyuki Kaneko(2), Hiroshi Kamiya(3), and Kouji Kitao(3)

(1) EMC Engineering Center, Production Technology Laboratories, NEC Corporation
1-1, Miyazaki 4-chome, Miyamae-ku, Kawasaki, Kanagawa 216-8555, Japan
t-kushta@ab.jp.nec.com

(2) System ULSI Development Division, NEC Corporation
1753, Shimonumabe, Nakaharaku, Kawasaki, Kanagawa, 211-8666, Japan

(3) NEC System Technologies, Japan
4-760, Kinuyama, Matsuyama, Ehime, 791-8025, Japan

ABSTRACT

Present study is devoted to mechanisms determining propagation of a high-speed signal in a via structure embedded in a multilayer printed circuit board and used as a part of interconnect paths between functional blocks including large-scale integration chips at frequency bands up to 20*GHz*. Proceeding from obtained qualitative and quantitative results some ways to improve electromagnetic performance of via circuits were defined. The investigations were conducted by the finite-difference time-domain algorithm mainly but for several reference via configurations modeling propagation mechanisms experimental data were also obtained for the comparative analysis and verification of simulation results.

INTRODUCTION

Interconnection circuits are one of the dominant components affecting on performance of high-speed high-density digital devices. Today data transmission rate between large-scale integration (LSI) chips achieved 5*Gb/s* and can be further improved [1] but distorting of waveforms and losses of signals in the interconnection circuits can become critical points in implementation of these high-speed data transmission technologies. Due to this circumstances accurate design, optimization of interconnects, and use of advanced structures and materials at the higher frequencies are ways in realization of high-performance and low-cost systems. A multilayer printed circuit board (PCB) which includes transmission lines to guide high-speed signals is an important type of the low-cost interconnect structures. The transmission lines can be divided into planar structures such as microstrip lines and striplines and vertical transmission lines such as vias. Here we pay attention to signal propagation in via configurations including high-density structures. Electromagnetic behavior of vias are dependent on the frequency band and it is well known that vias can considerably affect on performance of an interconnect path in multilayer PCBs at the higher frequency bands especially. In spite of computational consumption, the full-wave electromagnetic field simulation techniques are the most accurate, adequate and versatile theoretical methods to characterize interconnection circuits. We have used the finite-difference time-domain (FDTD) algorithm which is probably the most extensively used representative of above-mentioned techniques. Obtained numerical data by this algorithm for a number of simple and complex high-density via structures were generalized and used to determine several general design rules and leads to improve performance of the interconnect circuits embedded in a multilayer PCB without necessity of increasing the cost or the complexity of the manufacturing process as well as to define some simplified propagation models and mechanisms of high-speed signals in via configurations. The investigations were conducted by the theoretical approach mainly but for several via structures used in the comparative analysis experimental data were obtained also.

ANALYSIS OF VIA STRUCTURES

A via transition has a three-dimensional structure usually consisting of microstrip lines or striplines, rod, pads, and clearance hole (antipad). The FDTD method offers to estimate both propagation and radiation effects. We have investigated properties of via configurations embedded in six- and twelve-conductor-layer PCB's of the thickness 2.4*mm* for both types of PCB's with the relative permittivity of the filling dielectric material $\varepsilon = 3.8$ and loss tangent $\tan\delta = 0.016$. Considered dimensions of vias structures corresponded specimens applied in high-speed digital interconnection circuits including LSI chip interconnects.

One of the studied propagation models is a coaxial guiding channel [2] that can be formed in a multilayer PCB with signal and grounds vias. A model for which arrangement of signal and ground vias is shown in Fig.1 was studied experimentally and theoretically. In this model, the signal via and eight ground vias embedded in the six-conductor-layer PCB form a coaxial wave guiding structure with the characteristic impedance defined approximately by the well-known formula for round coaxial waveguide. For the considered model, coaxial waveguide characteristic impedance $Z_{coax} \approx 50\Omega$ with the distance between centers of two opposite ground vias $D = 3.0mm$, and signal via rod diameter $d = 0.65mm$. In the six-conductor-layer PCB, top and bottom were conductor layers that permitted the direct connections of top and bottom signal via pads to the semi-rigid coaxial cables with the impedances of 50Ω. Magnitudes of *S*-parameters obtained by the FDTD analysis and the measurements by means of the calibrated network analyzer HP8510C are shown in Figs.2 and 3. Theoretical and experimental data for return and insertion losses ($|S_{11}|$ and $|S_{21}|$, respectively) are in good agreement at the considered frequency band.

An example of arrangement of vias is demonstrated in Fig.4. This model represents a part of the high-density via configuration with $d = 0.25mm$ and $D = 2.0mm$, and embedded in the twelve-conductor-layer PCB. An interconnect path included the special pad for the LSI chip, the signal via and the stripline connected to the signal via at the fifth conductor layer. In Figs.5 and 6, results of the FDTD analysis presenting effect of the clearance hole diameter change are shown (in this theoretical analysis, filling dielectric material was considered as lossless one). As an outcome from these results, performance of signal via with the larger clearance hole diameter, d_{cle}, is higher. This effect can be explained in the frame of the above-mentioned physical model but describing the signal propagation as in a *corrugated coaxial waveguide* (see Fig.7 and 8) for which the smaller corrugation gives the better guiding characteristics (corrugation dimensions much smaller than the wavelength).

Corrugated coaxial waveguide model of a propagation channel in a via structure embedded in a multilayer PCB gives some useful design recommendations and possible ways to improve via transition performance as: 1) Simple expression to match impedances of the coaxial waveguide channel and the stripline or the microstrip line; 2) Coaxial guiding channels can have the property of the closed (shielded) structure if the number of ground vias increases; 3) Choice of the clearance hole diameter or the via rod diameter has to be consistent with the best signal propagation conditions in the corrugated coaxial waveguide channel.

Another propagation effect displaying in a multilayer PCB at the higher frequencies is demonstrated in Fig.9. Resonance stub shown in this figure can dramatically make worse the performance of a type of the via-stripline transition presented in the figure and distort the waveform of high-speed signals. In Fig.11 and 12, calculated magnitudes of *S*-parameters for the single via-stripline transition in the twelve-conductor-layer PCB are presented and resonance stub effect occurs at about $11.5GHz$. Our studies of a number of via configurations showed that addition of ground vias to the signal via transition shifts the resonance to the higher frequency and increases the *Q*-factor of this resonance structure. A blind-via shown in Fig.10 is one of possibilities to overcome the stub problem and improve performance of the via-stripline transition in a multilayer PCB. In Fig.11 and 12 data obtained by the FDTD method for the blind-via geometry (see Fig.10) are demonstrated. As a consequence from the theoretical analysis, the blind-via transition have substantially better electromagnetic characteristics than the usual via transition.

CONCLUSIONS

As outcome of theoretical and experimental studies, a number of effects in both single and complex via configurations were studied that gave a possibility to determine several generalized design rules and ways to improve performance of interconnections in high-speed high-density digital devices using via structures.

REFERENCES

[1] K.Tanaka, M.Fukaishi, M.Takeuchi, N.Yoshida, K.Minami, K.Yamaguchi, H.Uchida, Y.Morishita, T.Sakamoto, M.Soda, M.Kurisu, and T.Saeki, "A 100Gb/s Transceiver with GND-VDD Common-Mode Receiver and Flexible Multi-Channel Aligner," in *Proc. International Solid-State Circuits Conference*, San Francisco, Cal., pp.264-265, February 2002.

[2] E.R.Pillai, "Coax via – a technique to reduce crosstalk and enhance impedance match at vias in high-frequency multilayer packages verified by FDTD and MoM modeling," *IEEE Trans. Microwave Theory Tech.*, vol.45, pp.1981-1985, October 1997.

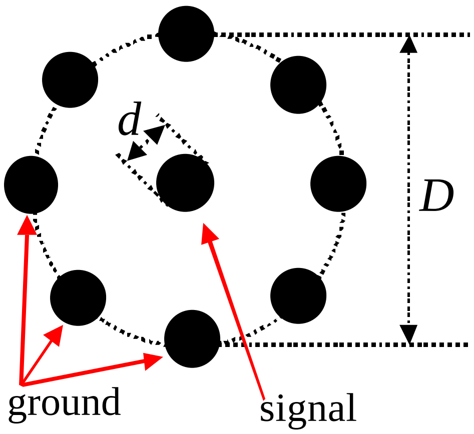

Fig.1. A coaxial waveguide model

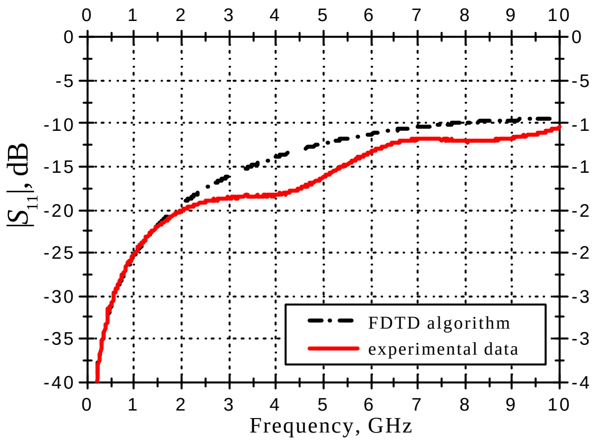

Fig.2. Magnitudes of return losses for the coaxial waveguide model

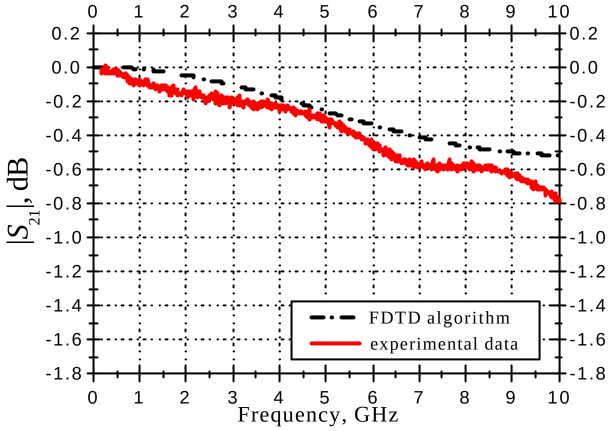

Fig.3. Magnitudes of insertion losses for the coaxial waveguide model

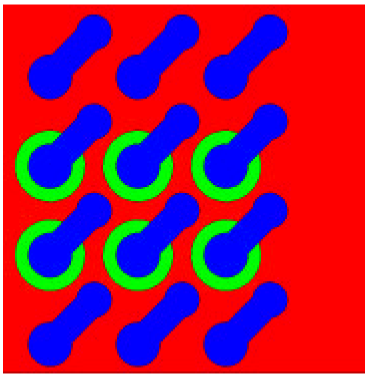

Fig.4. A part of high-density via structure for the LSI chip

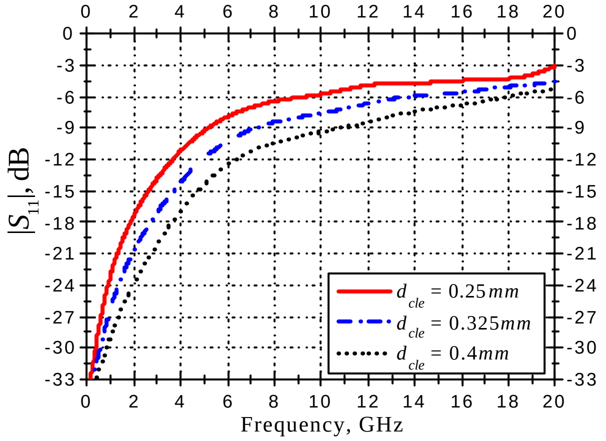

Fig.5. Effect of the antipad diameter change (return losses)

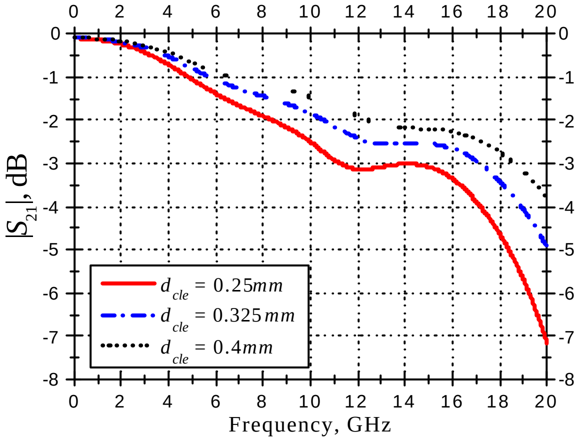

Fig.6. Effect of the antipad diameter change (insertion losses)

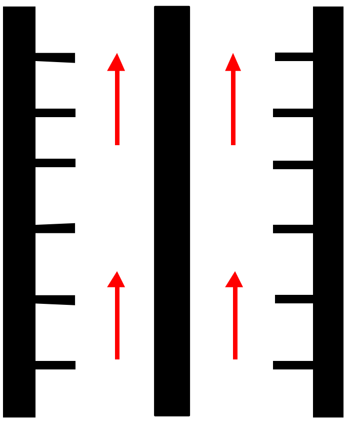

Fig.7. Corrugated coaxial waveguide model (signal propagation)

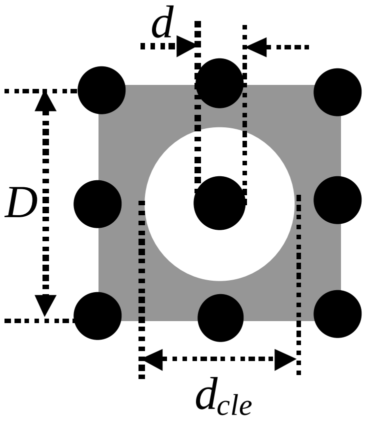

Fig.8. Corrugated coaxial waveguide model (top view)

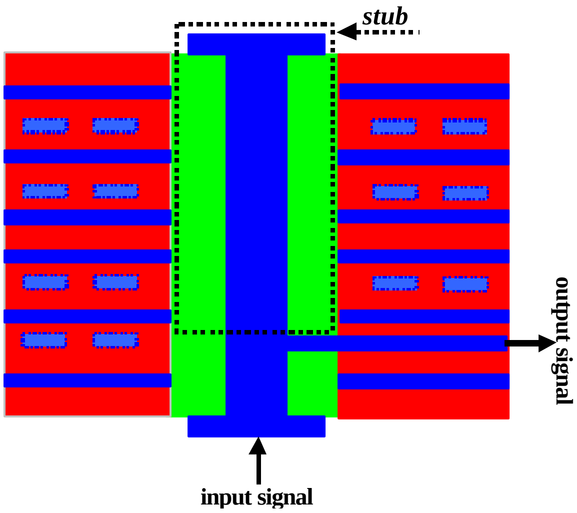

Fig.9 Resonance stub effect at the via-stripline transition in the twelve-conductor layer PCB

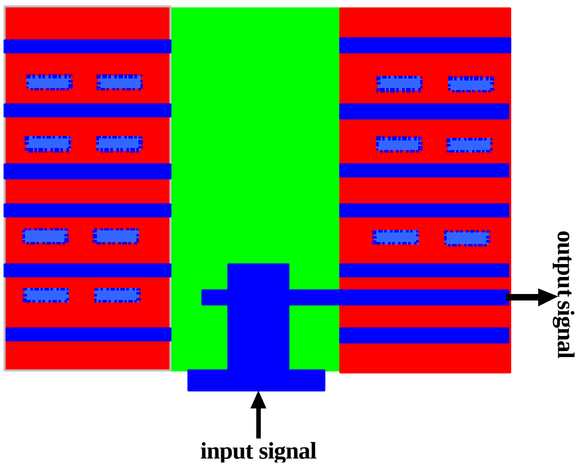

Fig.10. A blind-via geometry.

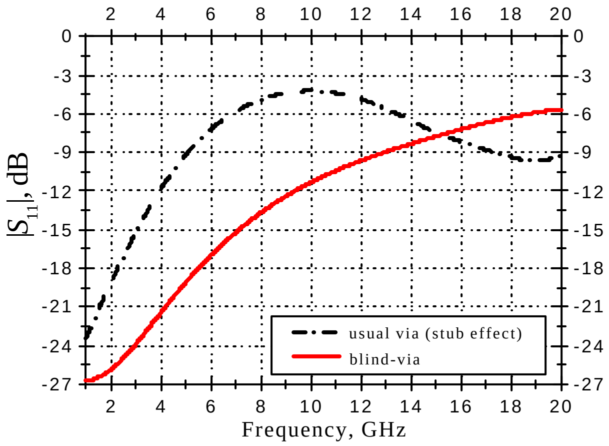

Fig.11. Magnitudes of return losses

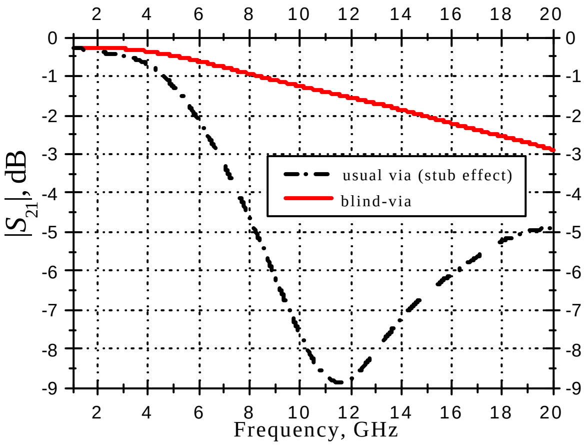

Fig.12. Magnitudes of insertion losses