ISSN(Online) : 2320-9801
ISSN (Print) : 2320-9798

International Journal of Innovative Research in Computer and Communication Engineering

*(An ISO 3297: 2007 Certified Organization)*

**Vol. 4, Issue 4, April 2016**

# Radiation Coupling between Via and Signal Traces in a Multilayer Printed Circuit Board

Avali Ghosh, Sisir Kumar Das, Annapurna Das

Assistant Professor, Dept. of ECE, GNIT, MAKAUT, Kolkata, India

Dean, GNIT, MAKAUT, Kolkata, India

Director, GNIT, MAKAUT, Kolkata, India

**ABSTRACT:** This paper describes the radiation coupling between via and signal traces in multilayer printed circuit board. A simple model of multilayer PCB having ground plane at the bottom of the dielectric substrate and signal traces at different layers is considered. A via is placed to interconnect the top and mid layer signal traces which is considered as small current element of moment $Idl$. The radiation fields from the via is computed using cylindrical scalar Helmholtz equation and Cylindrical transform in spectral domain. The results of near field radiation from via are obtained using MATLAB. The crosstalk analysis is carried out by simulation and modelling using Ansoft HFSS software tool.

**KEYWORDS**: Multilayer Printed Circuit Board, Signal Integrity, Electromagnetic Interference, Via

## I. INTRODUCTION

In multilayer printed circuit board, via plays an important role in signal integrity, power integrity and electromagnetic interference. Vias are used to route signal from one layer to another. Several authors[1-14] have described via model and its effect without any rigorous analysis of effect of via radiation on the nearby signal traces.

In this paper a multilayer printed circuit board is considered where the radiation coupling between via and signal traces are described. A multilayer PCB model having signal traces at different layers and ground plane at the bottom of the dielectric substrate is considered. A via is placed to interconnect the top and mid layer signal traces which is considered as small current element. The radiation fields from the via is computed using Helmholtz equation and cylindrical transform in spectral domain. The results of near field radiation from via are obtained using MATLAB. The crosstalk analysis is carried out by simulation and modelling using Ansoft HFSS software tool.

## II. RELATED WORK

In [1] authors deals with a simple equivalent model to simulate the discontinuity caused by vias and the crosstalk is solved by using multi- conductor transmission lines theory. A simple model for a cylindrical via hole in microstrip is considered in [2]. Authors verified a model based on a modification of the inductance of a cylindrical conductor by experimentally and by using numerical techniques. In [3] the effect of loading of a via fence on signal transmission in a microstrip line is investigated through parametric studies. Subsequently, a via fence structure is designed and optimized to reduce coupling between two adjacent traces. In [4] authors studied EMI resulting from the signal transitions through a DC power bus. Measurements were made on an experimental board, and numerical modeling was used to study the EMI resulting from the excited DC power bus. In [5] authors proposed parallel-plate waveguide (PPW) and its effectiveness is also verified by measurements of S-parameters of signal vias in simple test boards applied to the virtual islands with shorting vias. In [6] the return-current paths for single - ended microstrip - to - microstrip via transitions in conventional layer stack-ups are modeled and analyzed. Electromagnetic reliability (EMR) problems which occur in these layer stack-ups, because the return-currents are not properly managed are discussed. Finally, authors proposed a layer stack-up with well defined return-current paths, which overcomes the limitations of traditional layer stack-ups. In [7] the accuracy of the improved intrinsic via model and the conventional physics-based via model is investigated by comparing them with either analytical formula or numerical simulations for a via in a circular plate pair with various edge boundary conditions. In [7] an irregular plate pair with multiple vias is analyzed by

ISSN(Online) : 2320-9801
ISSN (Print) : 2320-9798

International Journal of Innovative Research in Computer and Communication Engineering

*(An ISO 3297: 2007 Certified Organization)*

**Vol. 4, Issue 4, April 2016**

the segmentation method that divides the platepair into a plate domain and via domains. In the via domains, all the parallel-plate modes are considered, while in the plate domain, only the propagating modes are included to account for the coupling among vias and the reflection from plate edges. Boundary conditions at both vias and plate edges are enforced and all parasitic components of via circuit are expressed analytically in terms of parallel-plate modes.

## III. ANALYSIS OF VIA RADIATION

We consider a multi-layer board containing three traces on the top, one middle trace at the centre and a ground plane on the bottom. The centre trace on the top connects with the middle trace through a cylindrical via along z direction. As described in Fig. 1 traces 1 to 4 are considered signal lines terminated with 50 ohms. Trace 1 is excited by a rf signal. This signal is transported to trace 4 through the cylindrical via. Due to rf current flow through via there will be radiation from via which may induces rf currents on the adjacent traces. The radiation characteristics of via inside the dielectric is analysed using scalar Helmholtz equation.

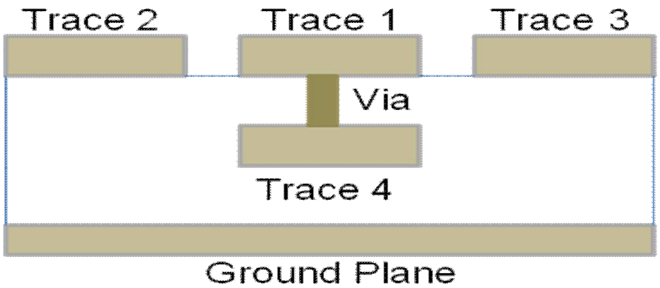


Fig. 1 Double layer PCB configuration with four traces above a ground plane and via between centre top trace and mid layer trace

For the vias current along z axis , wave function $\psi(x,y,z)$ is a solution to the three dimensional wave equation independent of $\phi$ and represents outward travelling waves along $\rho$ direction:

$$\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}+\frac{\partial^2}{\partial z^2}+k^2\right)\psi=0$$

By applying a Fourier transformation with respect to via axis z, equation 1 can be reduced to two dimensional equation

$$\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}+k_c{}^2\right)\bar{\psi}=0$$

where

$$\bar{\psi}(x,y,k_z)=\int_{-\infty}^{\infty}\psi(x,y,z)e^{-jk_z z}dz$$

The outward travelling wave generated from the source can be represented by

$$\psi=\frac{I_0 dl}{8\pi j}\int_{-\infty}^{\infty}H_0^2(\rho\sqrt{k^2-k_z^2})e^{jk_z z}dk_z$$

Three near field components $H_\phi$ , $E_\rho$ and $E_z$ around via inside the dielectric medium are

ISSN(Online) : 2320-9801
ISSN (Print) : 2320-9798

**International Journal of Innovative Research in Computer and Communication Engineering**

*(An ISO 3297: 2007 Certified Organization)*

**Vol. 4, Issue 4, April 2016**

$$H_\phi = -\frac{I_0 dl}{8\pi j}\int_{-\infty}^{\infty}\left(\sqrt{k^2-k_z^2}\right)H_0^{'2}(\rho\sqrt{k^2-k_z^2})e^{jk_z z}dk_z$$

$$E_\rho = \frac{1}{j\omega\varepsilon}\frac{I_0 dl}{8\pi j}\int_{-\infty}^{\infty}\left(\sqrt{k^2-k_z^2}\right)H_0^{'2}(\rho\sqrt{k^2-k_z^2})(jk_z)e^{jk_z z}dk_z$$

$$E_z = \frac{I_0 dl}{8\pi j}\left[-j\omega\mu\int_{-\infty}^{\infty}H_0^2(\rho\sqrt{k^2-k_z^2})e^{jk_z z}dk_z + \frac{1}{j\omega\varepsilon}\int_{-\infty}^{\infty}H_0^2(\rho\sqrt{k^2-k_z^2})(jk_z)^2 e^{jk_z z}dk_z\right.$$

## IV. FIELD COMPUTATION USING MATLAB

A MATLAB program is developed to find the above mentioned near field components. The results are shown in Fig 2 and Fig 3.

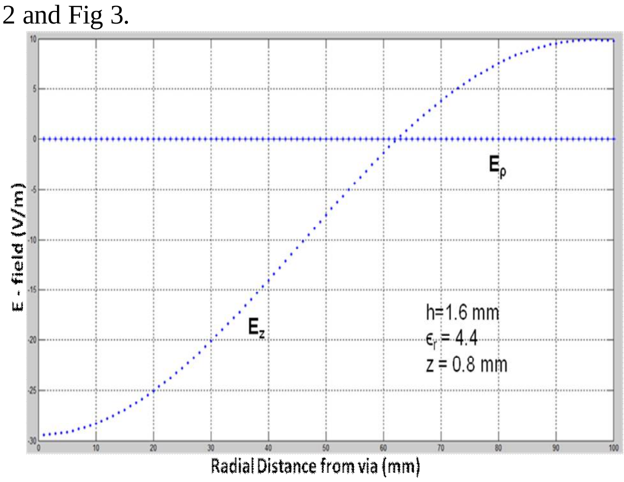


Fig. 2 MATLAB results of Electric field components inside the PCB substrate

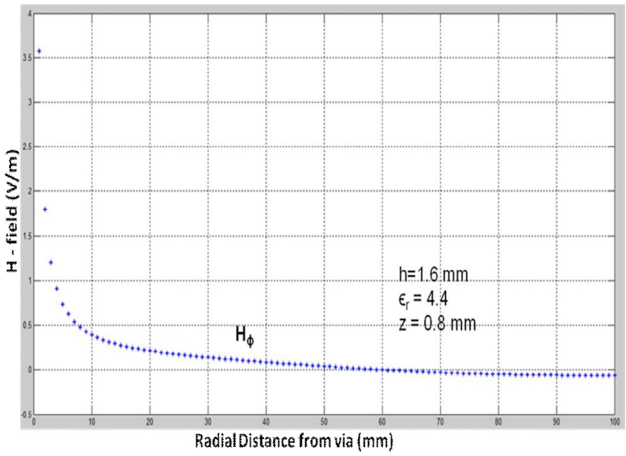


Fig. 3 MATLAB results of Magnetic field components inside the PCB substrate

From Fig 2, it is seen that field component Eρ perpendicular to via is zero at all distances as expected. The parallel component Ez shows variation with ρ and changes direction after some radial distance 62.5 mm.

From Fig 3, it is observed that the magnetic field is very high adjacent to via and it is decreasing very rapidly with increase of the distance from the via. Since the adjacent traces are close to via, the magnetic field component induces rf current on these traces. This results in crosstalk or coupled signal at Ports 3, 4, 5 and 6.

## V. CROSSTALK ANALYSIS WITH SIMULATION AND MODELLING USING ANSOFT HFSS

For the model, a FR4 material (εr = 4.4 and tanδ = 0.02) is used as the dielectric substrate with the substrate thickness of 3.2mm and a ground plane at the bottom . The width of the copper trace W = 3.1mm, which yields a characteristic impedance of 50Ω and the thickness of the copper trace t is assumed negligible i.e. t = 0.001mm. In this design three copper traces are on the top of the dielectric substrate and one copper trace is in between the dielectric substrate.

ISSN(Online) : 2320-9801
ISSN (Print) : 2320-9798

International Journal of Innovative Research in Computer and Communication Engineering

*(An ISO 3297: 2007 Certified Organization)*

**Vol. 4, Issue 4, April 2016**

As shown in Fig. 4, one of the trace was excited with RF source impedance of 50 Ohms and terminated with a 50 Ohms at the other end. Remaining traces are also terminated with 50 Ohms at both the ends. The coupling length of the 50 ohm traces are taken as 60mm corresponding to highest frequency of operation 2 GHz.

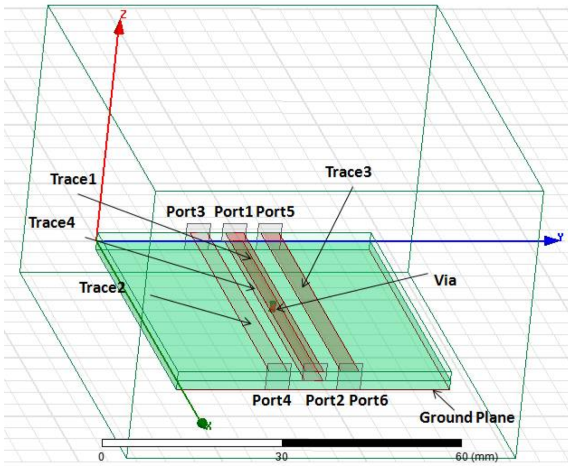


Fig 4 Double layer PCB configuration with four traces above a ground plane and via between centre top trace and mid layer trace

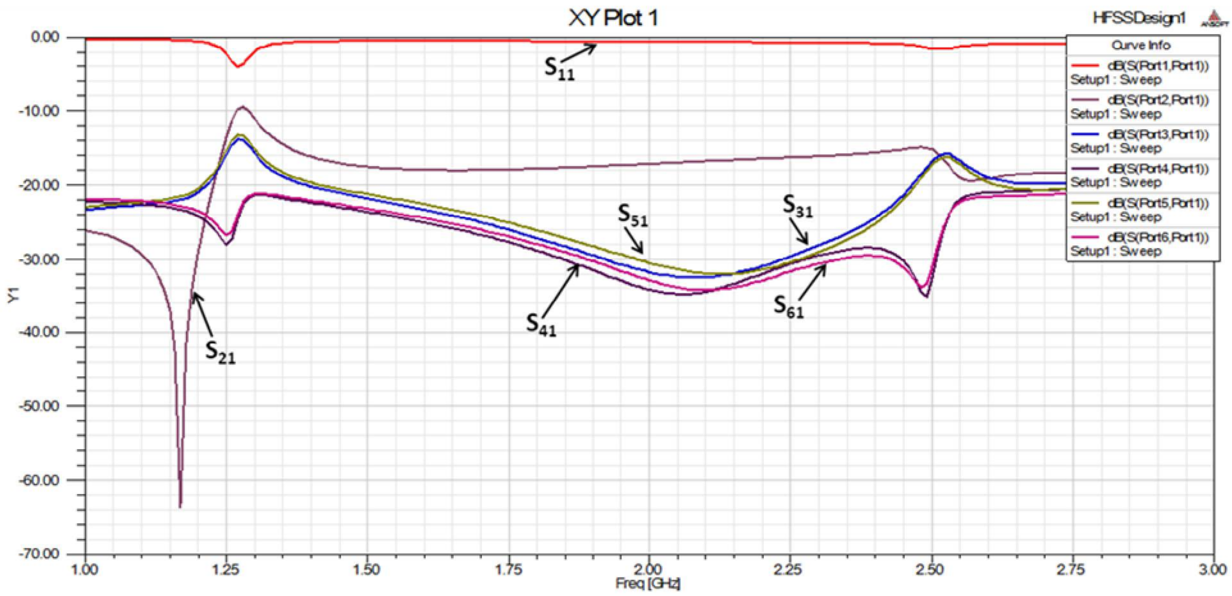


Fig. 5 NEXT and FEXT results obtained by using HFSS

From Fig. 5 it is seen that via produces radiated coupling to adjacent lines in the range of -12 to -35 dB over the frequency range from 1 GHz to 3 GHz. $S_{21}$ varies rapidly in between 1 to 1.3 GHz and then it becomes approximately -16 to -18 dB within the range of 1.3 to 2.5 GHz. Similarly $S_{31}$, $S_{41}$, $S_{51}$ and $S_{61}$ vary rapidly at around 1.25 GHz. Afterwards these values decreases slowly upto a frequency of 2.25 GHz. Subsequently $S_{31}$ and $S_{51}$ increase to -16 dB and become steady at -20 dB. Whereas $S_{41}$ and $S_{61}$ have tendency to decrease upto frequency 2.5 GHz and again increase to a steady value of -20 dB.

ISSN(Online) : 2320-9801
ISSN (Print) : 2320-9798

**International Journal of Innovative Research in Computer and Communication Engineering**

*(An ISO 3297: 2007 Certified Organization)*

**Vol. 4, Issue 4, April 2016**

## VI. Conclusion and Future Work

In this paper radiation coupling between via and signal traces in a multilayer printed circuit board is described. A multilayer PCB model having signal traces at different layers and ground plane at the bottom of the dielectric substrate is considered. As a simple model a via is placed to interconnect the top middle trace and a mid layer signal trace. Since the substrate thickness is very small ( h<< wavelength), the via is considered as a small current element. The radiation fields from the via is computed using Helmholtz equation and cylindrical transform in spectral domain. The results of near field radiation from via are obtained using MATLAB. The induced current on the adjacent traces results in crosstalk which is analyzed by simulation and modeling using Ansoft HFSS software tool. Thus the purpose of via connections from layer to layer may cause interference to adjacent lines.

## REFERENCES

1. Shulan Li, Yuan'an Liu, Zhanhai Song, Hefei Hu,'Analysis of Crosstalk of Coupled Transmission Lines by Inserting Additional Traces Grounded with Vias on Printed Circuit Boards', Asia Pacific Conference on Environmental Electromagnetics, CEEM'2003, Nov. 4-7,2003, Hangzhou, China
2. M.E.Goldfarb and R.A.Puce1, 'Modeling via hole grounds in microstrip',IEEE Microwave Guided Wave Lett., vol. 1, no.6, pp.135-137, June 1991
3. Asanee Suntives, Arash Khajooeizadeh, Ramesh Abhari, 'Using Via Fences for Crosstalk Reduction in PCB Circuits', 1-4244-0293-X/06/$20.00(c) 2006 IEEE
4. Wei Cui, Xiaoning Ye, Bruce Archambeault, Doug White, Min Li, James L. Drewniak, 'EMI Resulting from Signal Via Transitions through the DC Power Bus', 2000 IEEE International Symposium on Electromagnetic Compatibility, Volume 2, 21-25 Aug. 2000 Page(s):821 - 826 vol.2.
5. Seungki Nam Yonggyoo Kim Yonghoon Kim Jang, H. Hur, S. Song, B. Jaehoon Lee Jichai Jeong , 'Performance analysis of signal vias using virtual islands with shorting vias in multilayer PCBs', IEEE Transactions on Microwave Theory and Techniques, Volume: 54, Issue: 4, Part 11315- 1324, June 2006.
6. Ivan Ndip, Florian Ohnimus, Stephan Guttowski, Herbert Reichl, 'Modeling and Analysis of Return-Current Paths for Microstrip-toMicrostrip Via Transitions',IEEE Electronic System-Integration Technology Conference (ESTC 2008), London, UK, September 1-4, 2008.
7. Yao-Jiang Zhang, Jun Fan, ' Recent Development of Via Models: Hybrid Circuit and Field Analysis', IEEE Electr. Design Adv. Package. Syst. Symp., Dec 2010.
8. Y.-J. Zhang, and J. Fan, 'An intrinsic circuit model for multiple vias in an irregular plate pair through rigorous electromagnetic analysis', IEEE Trans. Microwave Theory Tech., vol. 58, no. 8, pp. 2251-2265, Aug 2010.
9. R. F. Harrington, ' Time-Harmonic Electromagnetic Fields', McGraw-Hill Book Company, 1961

## BIOGRAPHY

**Avali Ghosh**, B.E. from Nagpur University, M.Tech from WBUT and registered for PhD in MAKAUT Kolkata. She worked as lecturer in G.H.Raisoni College of Engineering, Nagpur during 2005- 2008 and as Project Manager in Agape Inc, Nagpur during 2008-2009. Currently she is Assistant Professor in the Department of ECE, GNIT, Kolkata. Her field of interest is EMI/EMC, Signal Integrity and Microstrip Antennas.

**Sisir Kumar Das,** B.Tech, M.Tech and Ph.D ,was teaching M.Tech course in Delhi university(1977-1980) and worked as scientist in Ministry of IT and Communication during 1980-2007. Presently he is Dean-Research & Administration, GNIT, Kolkata. He is Co-Author of the book **Microwave Engineering** published by Tata McGraw-Hill, Author of the book **Antenna and Wave Propagation** published by Tata McGraw-Hill and written three chapters in the book **Engineering EMC**, IEEE Press. He was an Associate Editor of the IEEE trans. on EMC (1994-2000) and Chief editor of EMC Journal (India) during 1998-2007, and 2014 onwards.

**Annapurna Das** , M.Tech, Ph.D, worked in the Department of ECE, Anna University during 1985-2007 where she was a Professor. Presently she is Director, GNIT, Kolkata. She is author of a book **Microwave Engineering, 2nd edition** and co-author of **Antenna and Wave Propagation**, published by Tata McGraw-Hill.