Effect of non-functional structures on differential vias in high speed PCB

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Abstract

With the development of high-frequency and high-speed signal, the influence of differential vias on signal integrity can not be ignored. Aiming at the design requirements of low reflection, high transmission and impedance stability of differential vias in high-speed printed circuit board (PCB), this paper establishs the equivalent model of differential vias to determine the effect of non-functional structures(stub and non-functional pad). Then the non-functional structure is designed and simulated by using three-dimensional electromagnetic simulation software HFSS, and the differential performances of differential vias are analyzed and optimized by using S parameters and impedance changes in time domain， which can provide reference for the design of high-speed differential vias.

Keywords

High-speed PCB, differential vias, equivalent model, non-functional structure, differential performance.

1. Introduction

In high-speed PCB design, differential structures have many advantages in signal integrity compared to single-ended structures. Therefore, differential structures are often used in high-speed PCB design [1-3]. Differential vias are also widely used to connect different layers[4-6]. Although differential vias make the interconnection easy, the discontinuity of differential vias can seriously affect signal integrity, so it is important to study the characteristics of differential vias [7-9].
Analysis of differential via performance often requires modeling. At present, many studies on Modeling of vias have been carried out, but most of them focus on single vias. Extrapolation of single vias to differential vias is effective only when the capacitance and inductance coupling between adjacent vias is negligible, which is not applicable to differential vias[10]. Therefore, it is necessary to establish a model suitable for differential vias to analyze the characteristics of differential vias.

At present, the analysis and research of differential vias characteristics are mainly focused on the optimization of via structure. Document [11] studies how differential via stubs affect time domain transmission (TDT) waveforms and eye diagrams, and proposes an optimization scheme to mitigate the influence of differential vias stubs. Document [12] proposes a new differential via structure called face via structure to improve the impedance discontinuity of vias, and verify the performance of the proposed face via structure by the analog impedance、the measured impedance through the time domain reflectance response and equivalent circuit modeling. However, the influence of non-functional structures of differential vias on differential performance is seldom studied.

This paper analyses and predicts the differential via performance by establishing physical and circuit model and finds the influence of non-functional structures (stub and non-functional pad) on differential via performance, then establishes a physical model in 3D electromagnetic simulation software HFSS. In the models, there are three cases of non-functional structure, stub and non-functional pad, only stub, no stub or non-functional pad. By analyzing the impedance changes and S parameters of the differential signal in time domain, the performances of the differential vias are optimized, which provides a reference for the design of high-speed differential vias.

2. Differential vias model

2.1 Physical model

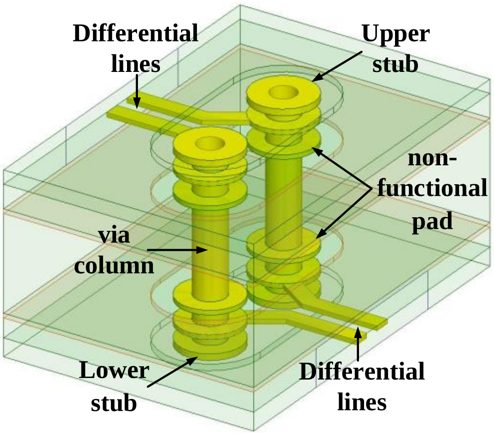


Fig.1 Differential vias physical model

A three-dimensional view of the differential vias physical model in the PCB stack is shown in Figure 1. The model mainly consists of two parts, a pair of differential lines and a pair of vias. The differential lines are distributed in different layers. The vias connect the differential lines from different layers. The via structure includes via column that transmits the signal, a non-functional pad on the via column and the upper and lower stub portions which are not used at both ends of the via column. Among them, the non-functional pad and the upper and lower stubs are non-functional structures. This part of the non-functional structure will significantly reduce the signal quality [13-14].

2.2 Circuit model

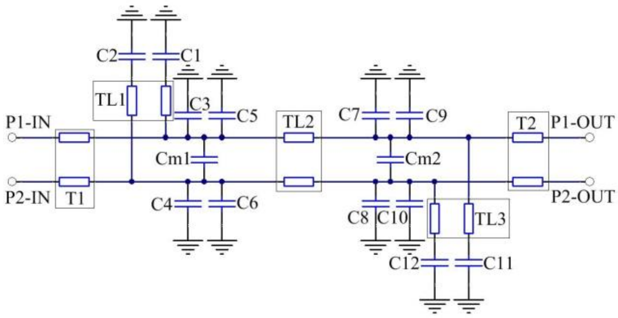


Fig.2 Differential vias circuit model

The circuit model of the differential via is shown in Figure 2. In the differential vias physical model of Figure 1, the via pads are located at the top, inside and bottom of the via, and the internal pads connect the signal lines to the vias. At high frequencies, since the capacitance of the internal pads on the signal line will cause shunt capacitance interference on the transmission line, the effect caused by each internal pad can be represented by a capacitance, including two pairs of pads that connect the via column to the signal lines and the two pairs of non-functional pads. Due to the symmetry of the differential via pairs, the four pairs of capacitors are equal, that is, the connection circular pads C3=C4 and C9=C10, the non-functional pads C5=C6 and C7=C8, and the capacitance values are determined by internal pad radius and geometric shape of back pad. The impedance effect produced by the via column is TL2.

If there is a stub at the top and bottom of the via, the stub portion will have an impedance effect and a capacitive effect on the signal. Due to the symmetry of the differential via pairs, it can be seen that C1=C2, C11=C12, when the length of stub at the top and bottom is consistent with the structure, the upper and lower parts of stub through differential vias are symmetrical, the impedance effect and capacitance effect of each stub portion are equal, that is, TL1=TL2, C1=C2=C11=C12, at this time, Because the geometry of the internal pad is the same, and the effective area of the pad is the same. It can be seen that C3=C4=C9=C10=C5=C6=C7=C8, and the mutual inductance capacitance between internal pads is equal, that is, Cm1=Cm2.

For the coupling strip lines connected to differential vias, when the lengths of the signal lines at both ends of the differential via are the same, the impedance effect produced by the signal line is coincident. But in actual cases, the length of the signal line is often much longer than the connection. So the impedance discontinuity caused by the connection is negligible in the actual high-speed channel, that is, T1=T2=0.

3. Simulation

In this paper, the full-wave three-dimensional electromagnetic simulation software HFSS is used to model high-speed PCB, differential traces and differential vias. The physical model PCB stack structure has 6 layers and the board thickness is 60.2 mil. The third and fourth layers are reference plane layers. The other layers are the signal layer or the power layer. The differential lines are distributed on the top and bottom layers of the PCB. The line width and line spacing are 6 mils. The differential lines are connected by differential vias. The internal diameter of the differential vias is 10 mils, the external diameter is 20 mils, and the via length is 60.2 mils. The electrical constant is 4.4.

3.1 Electric field distribution

The circuit model of Figure 2 shows that non-functional structures, including stubs and non-functional pads, can create capacitive effects, which can significantly degrade signal quality. Figure 3 shows the specific electric field distribution of the differential vias during signal transmission.

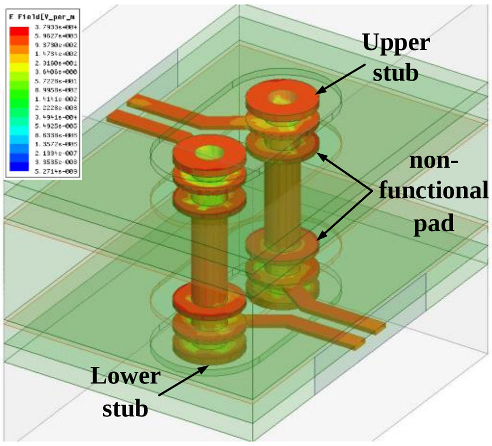


Fig.3 Differential vias electric field distribution

It can be clearly seen from Fig. 3 that a large part of the energy of the differential vias in the signal transmission process is concentrated on the stubs and the non-functional pads, which causes the attenuation of signal energy and increases the loss in the process of signal transmission.

3.2 Impact of non-functional structures

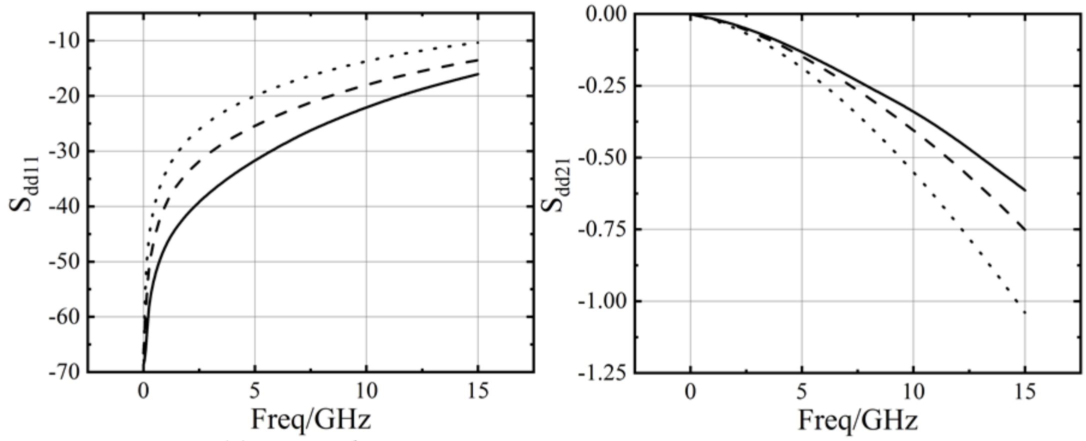
The above model is established, and there are three cases of non-functional structure, stub and non-functional pad, only stub, no stub or non-functional pad. After simulation, the following results are obtained. Figure 4 shows the difference between the signal return loss and the insertion loss of the differential vias.

It can be seen from Fig.4 that in the case where there are three non-functional structure, stub and non-functional pad, only stub, no stub or non-functional pad, the reflection coefficient S_{dd11} of the differential signals is sequentially decreased, the return loss is also reduced in turn. And the transmission coefficient S_{dd21} is sequentially increased, the insertion loss is sequentially decreased, and the signal integrity of the differential signals is sequentially improved.

The differential impedance changes in the simulation results are extracted. Figure 5 shows the differential impedance change of the differential vias in the time domain. Table 1 shows the specific range of change of the differential impedance of the three cases relative to the differential reference impedance value of the via of 100 Ω and the maximum percentage of change.

It can be seen from Fig.5 and Table 1 that in the case where there are three non-functional structure, stub and non-functional pad, only stub, no stub or non-functional pad, The range of change of the differential impedance is getting smaller and smaller compared to the differential reference impedance value of the via of 100 Ω. The maximum percentage of change is sequentially decreased, and the impedance continuity is improved.

According to the above analysis, removing the non-functional structure can effectively reduce the loss during transmission and improve the signal integrity of the differential signal.



(a) Return loss (b) Insertion loss

Fig.4 Return loss and the insertion loss of the differential vias.

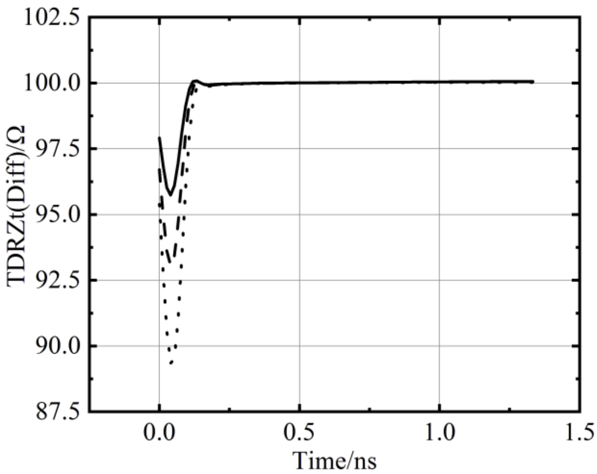


Fig.5 Differential impedance change comparison

Table 1 Differential impedance change range

Model	Differential impedance range/Ω	maximum percentage of change/%
stub and non-functional pad	[89.35,99.95]	10.6
only stub	[93.04,100.04]	7.0
no stub or non-functional pad	[95.74.0,100.06]	4.3

4. Conclusion

In this paper, the physics and circuit model of differential vias are used to analyze the differential signal of differential vias. Based on the PCB stack structure and wiring pattern design, the three differential via models of stub and non-functional pad, only stub, no stub or non-functional pad are used to simulate and analyze the time domain impedance return loss and insertion loss of the differential vias. The following conclusions can be drawn:

Non-functional structures in differential vias, including stubs and non-functional pads, attenuate a large portion of the signal energy during signal transmission, increasing losses during signal transmission.

Removing non-functional structures in differential vias, including stubs and non-functional pads, can effectively reduce losses during transmission and improve signal integrity of differential signals.

The above conclusions provide a basis for differential via design and high-frequency characteristic impact analysis, and have certain guiding significance for differential via design in high-speed PCB.

Acknowledgements

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References

[1] Wu X, Grassi F, Manfredi P, Ginste D V. Perturbative statistical assessment of PCB differential interconnects[C]. 2018 IEEE 22nd Workshop on Signal and Power Integrity (SPI), 2018: 1-4.

[2] Z. B. Gao, X. X. Hao, Y. F. Li, M. J. Wang. Design and optimization for high-speed BGA packaging and PCB differential interconnection structure[J]. Modern Electronics Technique, 2017, 40(22): 137-141. (In Chinese)

[3] Y. Y. Zeng. Signal Integrity Study of Differential Transmission Lines Based on Low Voltage Differential Signal[D]. Xidian University, 2017. (In Chinese)

[4] J. Fan, X. Ye, J. Kim, B. Archambeault, A. Orlandi, "Signal Integrity Design for High-Speed Digital Circuits: Progress and Directions", IEEE Transactions on Electromagnetic Compatibility, vol. 52, no. 2, pp. 392-400, May 2010.

[5] S.H. Hall, G.W. Hall, J.A McCall, Advanced Signal Integrity for High-Speed Digital Designs, Wiley, 2009

[6] E. Laermans, I. Geest, D. Zutter, F. Olyslager, S. Sercu, D. Morlion, "Modeling complex via hole structure", IEEE Trans. Adv. Package, vol. 25, no. 2, pp. 206-214, May 2002.

[7] G. Dong, Y. Biao, D. Xidong and L. Yuan, "Research on the influence of vias on signal transmission in multi-layer PCB," 2017 13th IEEE International Conference on Electronic Measurement & Instruments (ICEMI), Yangzhou, 2017, pp. 406-409.

[8] S. Theepak, G. Kumar Srivastava, B. Devadas, R. Selvapriya and C. M. Nandakumer, "Crosstalk and field analysis of arc shape coaxial via for high speed digital signals," 2017 IEEE 21st Workshop on Signal and Power Integrity (SPI), Baveno, 2017, pp. 1-4.

[9] X. Y. Gao, L. J. Yang. Analysis on Signal Integrity Problem in High-speed Serial Channel[J]. Communications Technology, 2013(6): 44-47. (In Chinese)

[10] E. Laermans, J.D. Geest, D.D. Zutter, F. Olyslager, S. Sercu, D. Morlion, "Modelling differential via holes", Electrical Performance of Electronic Packaging 2000 IEEE Conference on, pp. 127-130, 2000.

[11] G. Shiue, C. Yeh, L. Liu, H. Wei and W. Ku, "Influence and Mitigation of Longest Differential via Stubs on Transmission Waveform and Eye Diagram in a Thick Multilayered PCB," in IEEE Transactions on Components, Packaging and Manufacturing Technology, vol. 4, no. 10, pp. 1657-1670, Oct. 2014.

[12] D. Seo, H. Lee, M. Park and W. Nah, "Enhancement of Differential Signal Integrity by Employing a Novel Face Via Structure," in IEEE Transactions on Electromagnetic Compatibility, vol. 60, no. 1, pp. 26-33, Feb. 2018.

[13] Michael Rowlands, J. Huang, "How long is too long? A via stub electrical performance study", Proc. of DesignCon 2009, January 2009.

[14] Z. X. Zhou. Analysis and Optimization of Differential Vias [J]. Electronic Science and Technology, 2016, 29(06): 100-102+106. (In Chinese)