Minimizing Differential Crosstalk of Vias for High-speed Data Transmission

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Abstract—**This paper presents the design of electrical interconnect for high-speed data transmission involving differential signal vias on printed circuit board (PCB). Between two channels of differential vias, with given intra pair via pitch and spacing from adjacent channel vias, there exists an offset angle where differential crosstalk is minimized. By studying single-ended terms of NEXT and FEXT relation in both time and frequency domain, it becomes clear that such phenomenon occurs once in every quadrant. The crosstalk reduction can be achieved without placing ground vias in between signal vias of two channels, giving more routing space in high-speed PCB designs.**

Keywords — signal integrity; differential via; crosstalk reduction;

I. INTRODUCTION

As demand for higher bandwidth continues to grow in telecommunication industry, each device requires enormous computational power and routing capability. Data rate for each signal channel continues to surge, as does signal density. As a result impedance discontinuities and unwanted noise, or electromagnetic coupling occurring between neighbor channels, significantly increase. For high-speed applicability and reduction in noise compared to single-ended data lines, differential signaling has become a preferred method for data transmission. Extensive study has been done in the microwave community to optimize transitions from one form of transmission line to another [1]-[4].

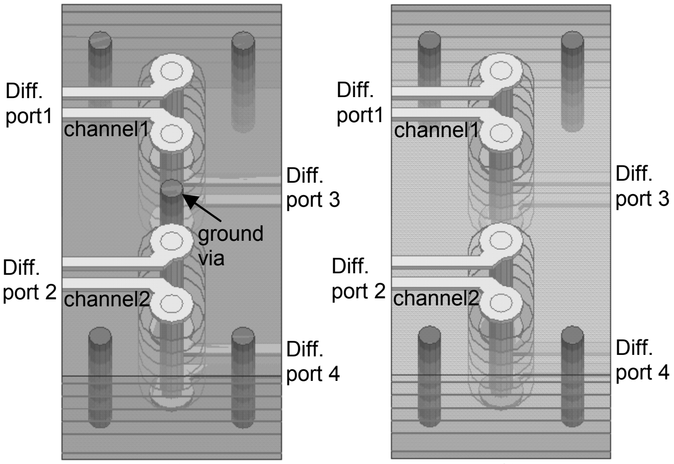
One key transition and contributor to channel crosstalk, which is often not thoroughly considered, is vias. At low data rate, plated-through-hole (PTH) vias have length that is equal to the PCB thickness no matter which layer signal is routed on. To simplify layouts, common via pads are used on every metal layer. When frequency of operation reaches beyond 10Gbps, vias are backdrilled and via pads are removed except on routing layers, to reduce shunt capacitances that cause the impedance to sag. Removing via stubs also improves crosstalk especially if the stub resonates within the frequency range of interest. Sufficient isolation between neighbor channels is required, so that receiver eye does not close due to impact from crosstalk. Long via stubs were introduced in [5] to balance LC coupling and reduce single-ended FEXT at low frequencies. Few papers could be found, however, to reduce differential FEXT and NEXT of vias at high frequencies.

In this work, we show how to reduce differential crosstalk between adjacent channel signal vias. Initial study shows that 1.35mm spacing between vias of two channels at 37.2˚/38.9˚ offset from signal propagating direction yields ~20dB improvement in NEXT and FEXT up to 20GHz compared to a side-by-side layout with the same spacing, without having to use ground vias in between. By studying single-ended terms of NEXT and FEXT relation in both time and frequency domain, it becomes clear that such phenomenon occurs once in every quadrant. The presented design technique, while applicable to any two adjacent differential channels requiring via transition, is of particular interest in routing high-density and high-speed connectors mounted on PCB where differential channel-to-channel pitch is in the order of 1-2mm and may lack space to place ground vias for the sole purpose of reducing crosstalk.

II. DESIGN OF VIA OFFSET WITH ADJACENT CHANNEL

Conventional via transition where adjacent differential signal vias are close to each other, requires ground vias to be placed in between to reduce crosstalk. Fig. 1 illustrates an example of a via transition of two differential channels with and without a ground via placed in the middle. The channels are routed on microstrip lines using 8-layer, 1.4mm thick FR408 and 8mil drilled vias. Channel pitch is 1.9mm and inter differential pair via wall-to-wall distance is 1mm. Fig. 2 shows corresponding FEXT and NEXT of structures from Fig. 1 simulated using Ansys HFSS [6]. As can be seen by placing a ground via, both NEXT and FEXT improves ~15 dB up to 20GHz. Hence, the need for ground vias to suppress crosstalk is apparent.

A high-density high-speed connector may have 0.5mm pad-to-pad pitch, requiring 1.5mm pitch between adjacent channels using GSSG configuration. In this case, there is insufficient space to place a ground via in between adjacent channels at a side-by-side via transition. Therefore, staggering between channels is preferred as hinted in Fig. 3. In addition, when considering placing a ground via, adjacent channel needs to be placed further apart requiring more PCB real estate at the via field. Another drawback of using large ground via count at small pitch is the number of antipads required on a power plane inside PCB. Having many vias requires the same number of antipads on power planes, to avoid signal and ground from shorting with power, which may crowd current in the via field and produce unwanted heat. Therefore, a balance between consumption of PCB real estate at the via field and usage of ground vias is crucial.



(a) (b)

Fig. 1 PCB image of two differential channels routing through vias (a) with a ground via and (b) without a ground via between two signal pairs.

Fig. 3 illustrates a top view of a PCB with two channels of differential signal vias without ground vias in between. Direction of signal propagation is defined as y-axis and an axis perpendicular to it is defined as x-axis. Spacing between the two channel vias is 1mm in y-direction. Spacing in x-direction is referred as an offset. Angle α is defined as an offset angle from y-axis to a line connecting either left signal via of each channel (shown in Fig. 3), or right signal via of each channel. For a two adjacent channel differential vias, with given intra pair via pitch, and spacing between the two channel vias, there exists an angle α, where differential crosstalk is significantly reduced without placing shielding ground vias. The optimum angle is not necessarily the same for NEXT and FEXT as will be seen in the following example.

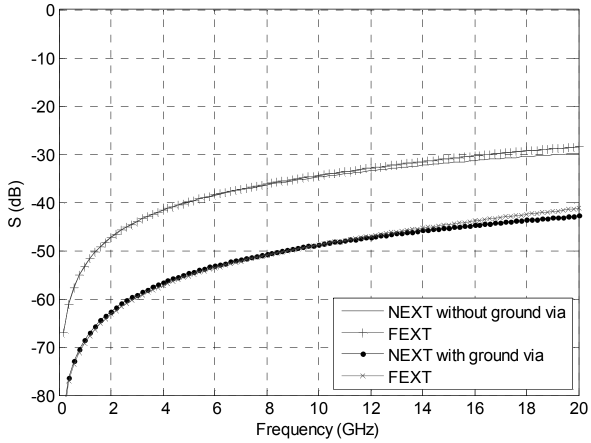


Fig. 2 NEXT and FEXT of via transition between two adjacent differential channels.

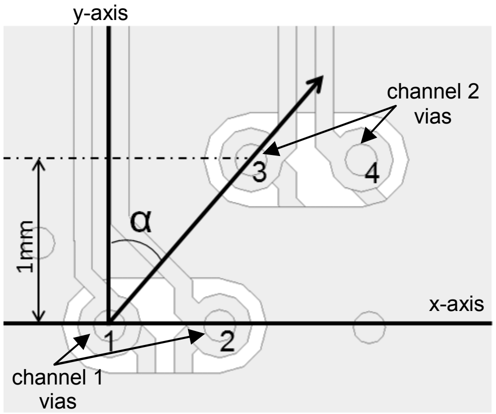


Fig. 3 Top view of two adjacent channel differential signal vias without shielding ground vias.

III. SIMULATION RESULT

Fig. 4 illustrates the simulated NEXT of structure explained in Fig. 3, in frequency domain. Offset angle α is swept from 0˚ to 62.1˚ while keeping y-direction spacing constant at 1mm. At 0˚ offset, NEXT reaches 30dB at 20GHz. Then, as α increases up to 37.2˚, improvement is observed. At 37.2˚, NEXT falls to almost 50dB at 20GHz. Performance starts to degrade beyond 37.2˚. At 90˚, due to infinite spacing, NEXT is expected to become 0.

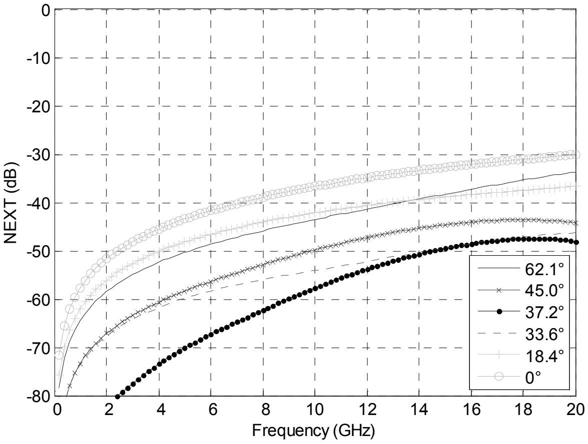


Fig. 4 Frequency-domain NEXT of vias between two differential pairs with respect to offset angle.

Insights can be gained by viewing the step response in time domain. Fig. 5 shows that, for 1 volt input at 20%-80% rise time of 50ps, NEXT varies in both magnitude and polarity with different offset angles. At 0˚ offset, NEXT shows a positive value with highest magnitude. Then, as α increases, magnitude reduces, swaps to negative polarity and starts increasing in magnitude. At 37.2˚, NEXT floats around 0mV. Although, crosstalk will never be 0 due to individual delay, or phase angle, difference of single-ended terms, 37.2˚ offset shows smallest differential NEXT, as verified also in frequency domain in Fig. 4.

Fig. 6 illustrates a plot of simulated differential FEXT of structure described in Fig. 3, in frequency domain. Offset angle α is swept from 0˚ to 62.1˚. At 0˚ offset, FEXT reaches 26dB at

20GHz. Then, as α increases up to 38.9˚, significant improvement is observed. At 38.9˚, FEXT drops to 50dB at 20GHz. Performance starts to degrade beyond 38.9˚. At 90˚, due to infinite offset spacing, FEXT is expected to be 0.

When the time-domain step response (at 1 volt input and 50ps rise time) is viewed with various offset angles, shown in Fig. 6, one can observe similar trend as NEXT, however, in opposite direction. At 0˚ offset, FEXT shows a positive value with highest magnitude. Then, as α increases, magnitude reduces, swaps to negative polarity and starts increasing in magnitude. At 38.9˚ offset, FEXT float around 0mV, which is in line with frequency domain response showing smallest value at the same angle, in Fig. 7.

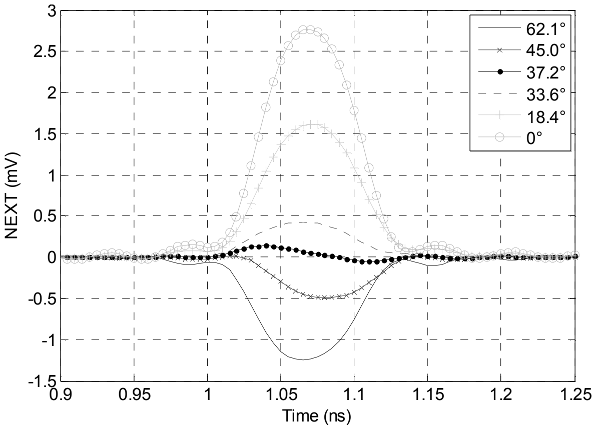


Fig. 5 Time-domain NEXT of vias between two differential pairs with respect to offset angle.

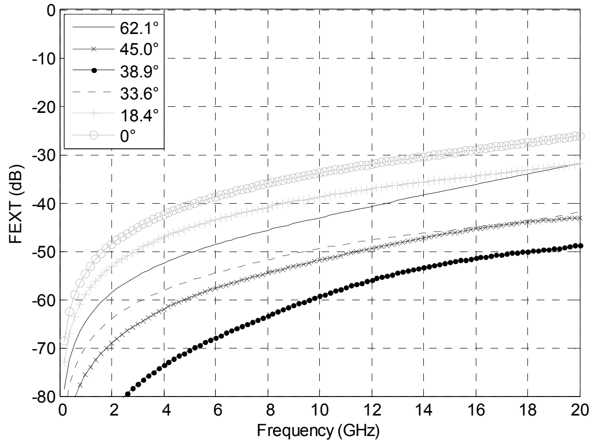


Fig. 6 Frequency-domain FEXT of vias between two differential pairs with respect to offset angle.

To explain the above phenomenon, the four single-ended terms of differential crosstalk are considered. Figs. 9 and 10 illustrate the differential and corresponding single-ended terms of NEXT/FEXT at optimum angles 37.2˚/38.9˚ previously determined. Note that the differential NEXT (Sdd21) and FEXT (Sdd41) are given by

$$Sdd21=S31+S42-S32-S41 \tag{1}$$

$$Sdd41=S71+S82-S72-S81 \tag{2}$$

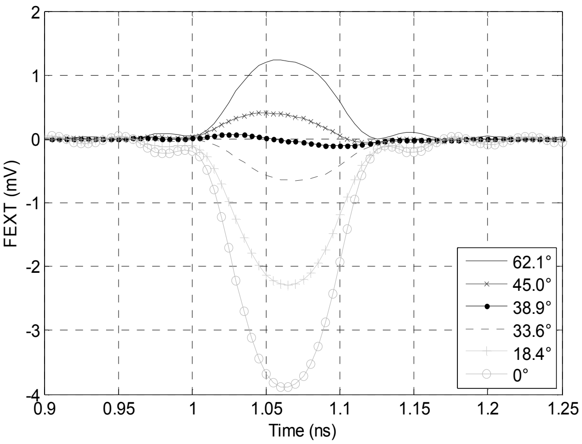


Fig. 7 Time-domain FEXT of vias between two differential pairs with respect to offset angle.

where the port definition is shown in Fig. 8. The first two terms of Eq. (1), S31 and S42, represent the two lines in Fig. 9a with medium magnitude and the second two terms S32 and S41 represent the largest and smallest magnitude single-ended terms. When summed, single-ended terms nearly cancel each other and differential output hovers around 0mV represented by Sdd21. The relation for FEXT terms work out the same way. The first two terms of Eq. (2), S71 and S82, represent the two lines in Fig. 10a with medium magnitude and the second two terms S72 and S81 represent the largest and smallest magnitude single-ended terms. When summed, single-ended terms nearly cancel each other and differential output hovers around 0mV represented by Sdd41. The result is also apparent in frequency domain graphs shown in Figs. 9b and 10b, where

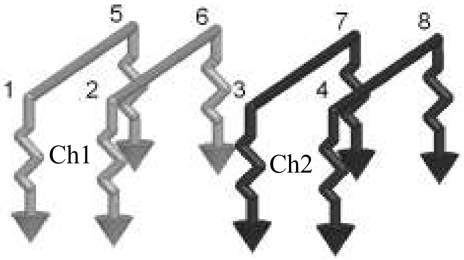
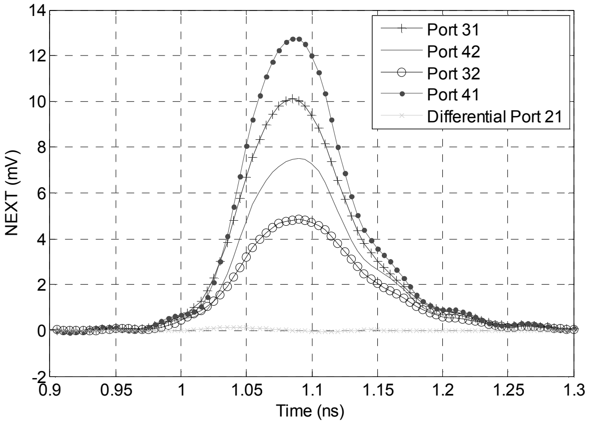
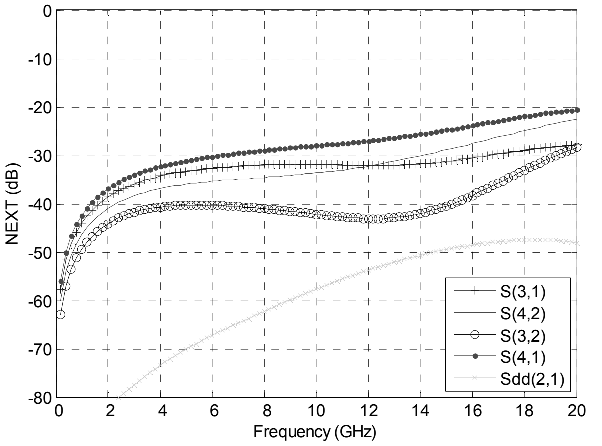


Fig. 8 Port number definition for Eqs. (1) and (2) with transmission lines representing signal vias.



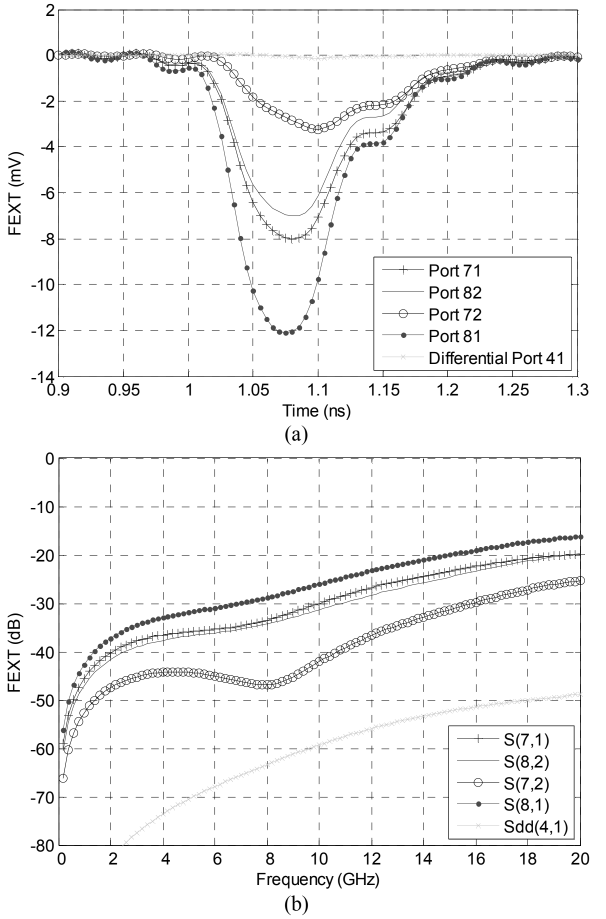
(a)



(b)

Fig. 9 (a) Time-domain and (b) frequency-domain NEXT of vias between two differential pairs at optimum offset angle of 37.2˚.

differential crosstalks are significantly reduced. When the offset angle is not optimized, both (1) and (2) produces a positive or negative value because the first two terms and second two terms are not balanced, and reduction in differential crosstalk may not be achieved as seen from Figs. 4 to 7.



(a)

(b)

Fig. 10 (a) Time-domain and (b) frequency-domain FEXT of vias between two differential pairs at optimum offset angle of 38.9˚.

IV. CONCLUSION

This paper showed how to minimize crosstalk between two adjacent differential channels via transitions through an optimum offset angle. In this study, 1.35mm spacing between vias of two channels at 37.2˚/38.9˚ offset from signal propagation direction gave as much as 20dB improvement in NEXT and FEXT up to 20GHz compared to a side-by-side layout with the same spacing. By studying single-ended terms of NEXT and FEXT relation in both time and frequency domain, it becomes clear that single-ended terms nearly cancel and differential crosstalk is minimized. As an added advantage, this technique enables reduction in ground vias while reducing crosstalk, which is beneficial for routing in such an area as via field on PCB surrounding a high density connector.

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