Investigation on Far End Crosstalk Saturation of Microstrip Differential Signal Pair

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Abstract — The far end crosstalk (FEXT) saturation of microstrip differential signal pair is investigated in this paper. It is found that coupled length, rise time of attack signal, spacing between differential signal pair and attack line, coupling level of differential line can significantly affect FEXT of differential noise which causes serious signal integrity issues. In the situation when the FEXT of differential noise reaches saturation, the minimum coupled length is mostly affected by the rise time of attack signal. Also, coupling level of differential line and spacing between differential signal pair and attackline are two major factors changing saturate value of FEXT.

Keywords—FEXT;differential signal pair;signal integrity.

I. INTRODUCTION

Nowadays, the field of electronic design develops faster and faster, IC is becoming large-scale, small size, high speed. With clock frequencies increase over GHz, the signal transmission attenuation and noise propagation of high-speed circuits are getting more seriously, which introduces serious signal integrity issues[1]-[5]. The microstrip differential signal pair is widely used in printed circuit board (PCB) to transmit high speed signal, i.e. the Low-Voltage Differential Signaling (LVDS). The differential noise is a serious problem degrading the performance of differential signal pair, which can also be converted to common-mode noise, then introducing electromagnetic interference (EMI) and the problem of signal integrity. Engineers all know the basic principle of differential traces, which is the length and spacing of two traces should be equal. But how much the coupled length should be is hard to estimate. Furthermore, the long coupled length will put the the differential FEXT of microstrip differential signal pair (we call it differential FEXT below) into saturation, which will lead to undesired EMI and signal integrity problems, such as parasitic noise, signal disorder and data asynchronous, etc[6]. Thus, the differential FEXT saturation of microstrip differential signal pair must be analyzed to predict the transmission characteristics accurately.

In this paper, Differential FEXT saturation of microstrip differential signal pair is investigated with Hyperlynx, which foucus on coupled length, rise time of attack signal, the spacing between differential signal pair and the attack line(we call it spacing below), and coupling level of differential line. The differential FEXT will reach saturation when coupled length is long enough, and rise time is a major factor affecting the minimum length when differential FEXT reaches saturation (we call it saturated length below), the saturate value is affected by spacing and the coupling level of differential line. Then, these rules can be used by engineers to avoid the problem of signal integrity and EMI.

II .THEORY DESCRIPTION

From Fig.1, line1 is attack line, line2 and line3 are differential signal pair. Attack line will introduce FEXT on differential line2 and differential line3. Because the spacing between attack line to differential line2 and attack line to differential line3 is different, FEXT on differential line2 and differential line3 is different, so FEXT can not be cancelled at the receiving end, which will be reflected in differential noise.

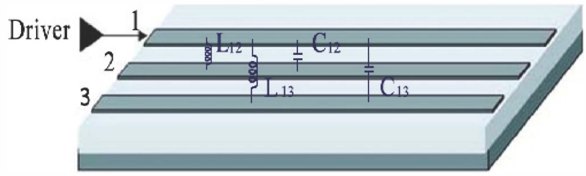


Fig.1. Crosstalk of single-ended to differential pair

The inductive and capacitive coupling causes crosstalk. according to the Kirchhoff's law between coupled line, the crosstalk coefficients of line1 to line2 and line1 to line3 can be described separately as follows[2]:

$$K_{12FEXT} = \frac{TD}{T_r}\left(\frac{C_{12}}{C_{11}} - \frac{L_{12}}{L_{11}}\right) \tag{1}$$

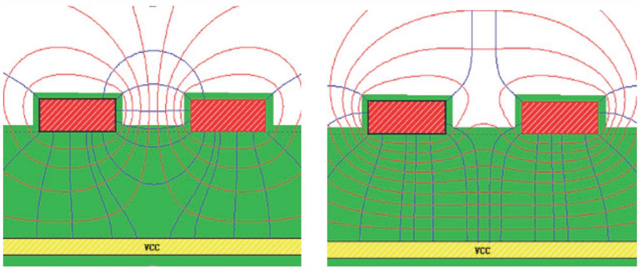
$$K_{13FEXT} = \frac{TD}{T_r}\left(\frac{C_{13}}{C_{11}} - \frac{L_{13}}{L_{11}}\right) \tag{2}$$

Actually the crosstalk includes attack line to differential line2, attack line to differential line3, differential line2 to differential line3, differential line3 to differential line2, By considering the most significant two crosstalk: attack line to differential line2 and attack line to differential line3. Then the crosstalk coefficients of differential FEXT can be obtained as follows:

$$K_{FEXT} = \frac{TD}{T_r}\left(\frac{C_{12}-C_{13}}{C_{11}} + \frac{L_{13}-L_{12}}{L_{11}}\right) \qquad (3)$$

Where C_{12} is mutual capacitance per-unit-length between attack line and differential line2, C_{13} is mutual capacitance per-unit-length between attack line and differential line3, L_{13} is the mutual inductance per-unit-length between attack line and differential line3, L_{12} is the mutual inductance per-unit-length between attack line and differential line2. T_r is rise time of the attack signal and TD is delay time. Based on equation(3), The differential FEXT increases continuously with the coupled length of microstrip differential signal pair getting longer or the T_r getting smaller, but the saturation of differential FEXT can't be observed in equation(3).

For differential signal pair, there are two propagation modes: odd mode and even mode. Both of them can transmit signal without distortion. The electric and magnetic field configurations for odd mode and even mode are shown in Fig.2.



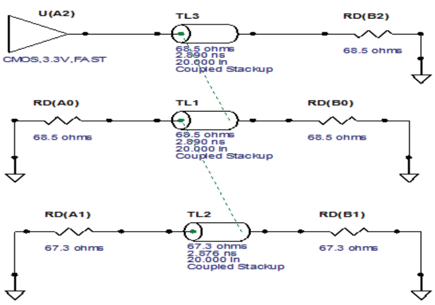
(a) (b)

Fig.2.Electric and magnetic field configurations for(a)odd mode and(b)even mode

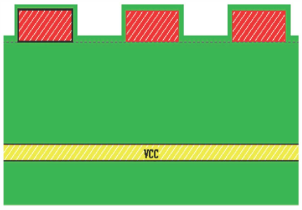
The transmission speed of odd mode and even mode is determined by effective dielectric constant (Ɛr) which can be found in the field. The speed will be faster when the effective dielectric constant is lower. When the signal is transmiting in the microstrip, the Ɛr of the two modes is different. Ɛr is smaller in the odd mode, then the transmission speed is faster than the even mode. And the far-end noise occurs.

III. EXPERIMENTAL RESULTS

Three coupled microstrip lines are shown in Fig.3, the TL1 and TL2 is microstrip differential signal pair, and their terminations are well matched, so the reflection is eliminated, then crosstalk is left only. TL3 is attack line.



(a)



(b)

Fig.3.(a)Topology of the circuit(b)Side view of the traces

The trace width is 6 mil, the substrate thickness is 8 mil, trace thickness is 1.8 mil, and the substrate used is FR4, with the Ɛr is 4.4, the trace separation between TL1 and TL2 is 6 mil, which is tight coupling for the differential signal pair, so is for the TL3 and the TL1, the spacing between TL3 and TL2 is 12 mil. In this condition, the differential impedance is 100Ω. The line length L is a variable parameter.

A. Differential FEXT Changes With Coupled Length

Fig.4 plots differential FEXT with the L changes from 10 to 55 inches, the separation is 5 inches. And rise time of driving signal is 200ps, the magnitude is 3.3V.

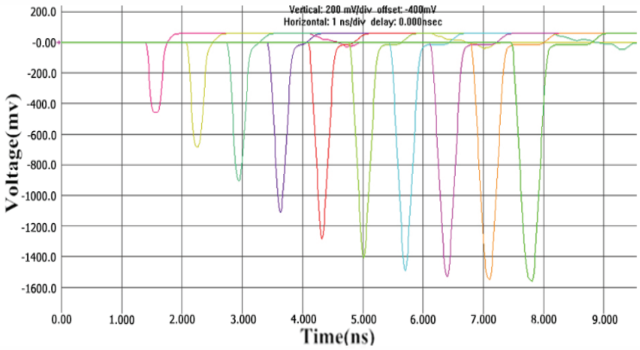


Fig.4.Differential FEXT changes with coupled length

The differential FEXT increases with the coupled length getting longer. When differential FEXT reaches saturation, the minimum length is 45 inches. and the limitation value is 1.54V which is nearly half of the driving signal whose value is 3.3V. Such a big value would affect the circuit performance seriously, so the length of the differential signal pairs should be controlled rigorously.

B. Rise Time Affecting Differential FEXT

Changing rise time of driving signal to be 100ps, differential FEXT changes with the length is shown in Fig.4. The coupled length changes from 10 to 45inches, the separation is 5inches.

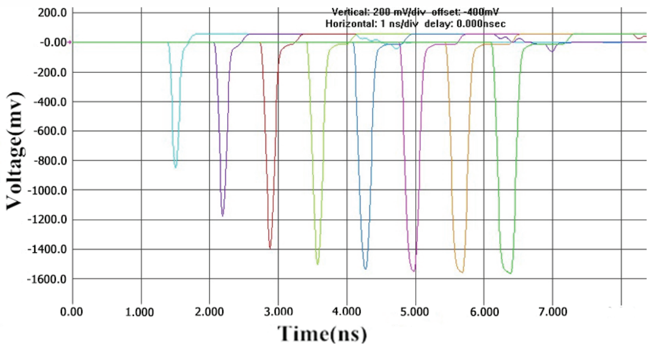


Fig.5.Differential FEXT changes with coupled length

From Fig.5, when differential FEXT reaches saturation, the minimum length is 35 inches, which is shorter than 45 inches when rise time is 200ps. And the saturate value is 1.55V which is almost same as before 1.54V. So this can conclude that the smaller the rise time is, the shorter the saturate length is, and the saturate value keeps constant which has nothing to do with rise time. When rise time is small, the circuits designer should design the coupled length carefully, especially recently, rise time is becoming smaller and smaller, most has reaching picosecond level.

C. The Spacing Between Differential Signal Pair And The Attack Line Affecting Differential FEXT

As shown in Fig.6, then changing the spacing between differential signal pair and attack line TL3 from 6 to 12 inches, and rise time keeps 100ps. Differential FEXT changes with length is shown in Fig.7. Coupled length changes from 10 to 45 inches, the separation is 5 inches.

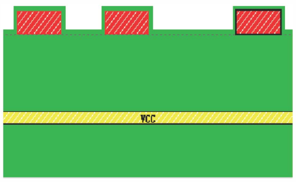


Fig.6.Side view of the traces

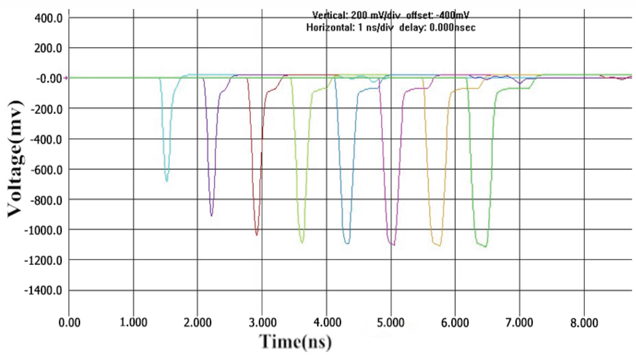


Fig.7.Differential FEXT changes with coupled length

As shown in Fig.7, the saturated length is 30 inches which is slightly shorter than 35 inches before, and the limitation is nearly 1.1V which is much smaller than 1.55V before. So changing the spacing can decrease the differential FEXT obviously.

D. Coupling Level of Differential Line Affecting FEXT

Now consider the spacing between differential line, changing from 6 to 12inches, which is weak coupling for differential signal pair, and the spacing between differential signal pair and the attack line keeps constant, showed in Fig.8, rise time keeps 100ps. Differential FEXT changes with length is shown in Fig.9, where coupled length changes from 10 to 45inches, the separation is 5inches.

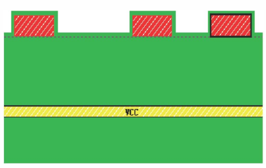


Fig.8.Side view of the traces

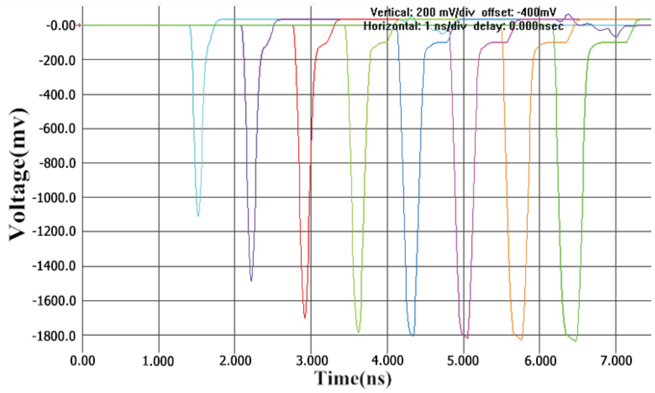


Fig.9.Differential FEXT changes with coupled length

As shown in Fig.9, the saturated length is 35inches, which is same as the case of tight coupling and the saturate value is 1.8V, which is bigger than 1.55 before. So the differential FEXT of weak coupling is bigger than tight coupling. Engineers should consider coupling levels of differential signal pair to reduce differential noise.

IV CONCLUSIONS

In this paper, the differential FEXT of microstrip differential signal pair is investigated in detail. When coupled microstrip line is longer, the differential FEXT is bigger, until reaches saturation. And rise time is a major factor, the smaller it is, the shorter saturated length is. When the spacing is smaller, the saturation value is bigger, The more tightly coupled the differential pair, the more equal the noise generated on the two lines, and the less the differential noise. In general, the coupled length of microstrip differential signal pair,the spacing between differential signal pair and the attack line, rise time, the coupling level of differential line, should be considerd when designing microstrip differential signal pair .

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