Research on Near-End Crosstalk and Far-End Crosstalk of High Speed Digital Circuit

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Abstract: Digital signals can be viewed as high speed digital signal when the transmission distance within the rise time of signal is in comparison with the length of interconnection line. The signal integrity will occur when the high speed digital signal is transmitting in the interconnection line. In this paper, with the aid of ADS(Advance Designer System) software, the research on near-end crosstalk and the far-end cross talk problem in high speed digital circuit is presented which has guiding significance for the design of high speed digital circuits.

1. Introduction

Due to the rapid development of electronics industry, the operating frequency of electronic system grows higher and higher. In [1] the development trend of the electronics industry is clearly described. From this paper we are acknowledged that there is a continuous improvement of system operating frequency. As technology continues to evolve, the system-level operating frequency will be rapidly improved. The upcoming 5G mobile communication is likely to raise the working frequency to more than 30GHz [2-5]. Since the majority of chips used in electronic systems are digital chips, the signals transmitted in interconnects are digital signal, that is 0 or 1 signal. There are also analog signals. For the high frequency analog signal, the analysis method used is mainly based on microwave technology analysis while for the high-frequency digital signal, the analysis method used is mainly based on the signal integrity analysis. A digital signal will be vied as high frequency digital signal when the transmission distance of signal is comparable to the length of interconnect line and the corresponding circuit will become a high speed digital circuit in which there will be signal integrity issue [6-7]. The signal integrity issue is generally including near-end crosstalk, far-end crosstalk, switching noise and etc [8-9]. This paper mainly focuses on the near-end crosstalk and far-end crosstalk problems, so as to provide ideas for reducing crosstalk problem.

2. Qualitative analysis of near-end crosstalk and far-end crosstalk

High-speed digital signals will couple to adjacent networks as they travel through a network. The coupled signals are harmful noise to adjacent networks, which is known as crosstalk. In high-speed digital circuits, crosstalk exists between any pair of networks. The network where the signal source is located is an attack network while the network that generates noise is a victim network. The varying voltage signal (*dv/dt*) and varying current signal (*di/dt*) will generate varying fringing fields that will induce currents and voltages on static lines, creating noise on static lines. This coupling mechanism can be described by mutual capacitance and mutual inductance and a qualitative analysis of crosstalk is established. For simplicity, taking two coupled transmission lines which are close to each other as an example, as is shown in Fig. 1. High-speed digital signal is added to the dynamic line (signal line 1), the other three ends are terminated. In this case noise will appear at both ends of the static line (signal line 2), moreover the near-end noise and far-end noise have different manifestations. The LC equivalent circuit of the coupling line is used to qualitatively analyze the crosstalk situation in Fig. 1, that is, to qualitatively analyze the near-end crosstalk and far-end crosstalk of the static line. Since the analysis is qualitative, we can use one section LC equivalent circuit for the analysis. Figure 2 shows the one section LC equivalent circuit in which C_0 and L_0 depicts the capacitance and inductance per unit length of the transmission line while the C_m

and L_m depicts the mutual capacitance and mutual inductance per unit length of the transmission line. These two quantities describes the coupling between the transmission lines.

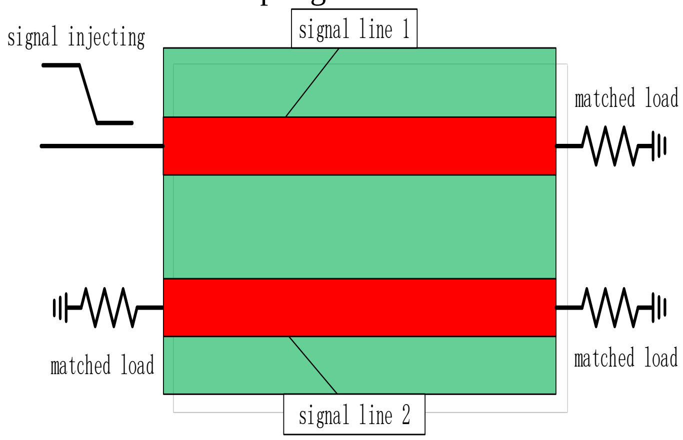

Fig. 1 Two coupled transmission lines which are close to each other

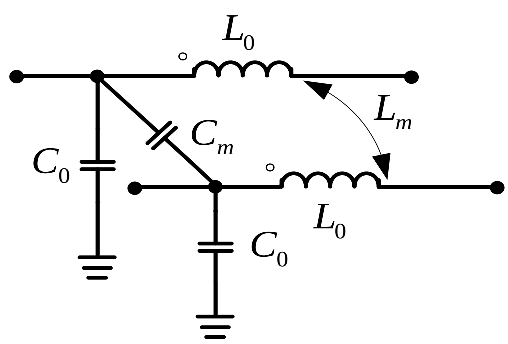

Fig. 2 One section LC equivalent circuit of coupled transmission line

The noise of generated on the signal line 2 (static line) in Figure 1 can be expressed as:

Capacitive coupling: $I_{2C}= C_m\ dV_1/dt$ (1)

Inductive coupling: $V_{2L}= L_m\ dI_1/dt$ (2)

Generally, the digital signal is a step signal with a certain rising time. Supposing that the signal front on signal line 1 increases linearly from zero to V_1 or I_1 within the rising time, the dV_1/dt in Eq. (1) and dI_1/dt in Eq. (2) can be approximated as V_1/RT or I_1/RT, so the noise can be expressed as follows:

Capacitive coupling: $I_{2C}= C_m\ V_1/RT$ (3)

Inductive coupling: $V_{2L}= L_m\ I_1/RT$ (4)

The voltage changes in the dynamic line will lead a noise current on the unit length of the static line through the mutual capacitance and the noise current is $I_C=C_mV_1/RT$. The current changes in the dynamic line will lead a noise voltage on the unit length of the static line through the mutual inductance and the noise voltage is $V_L=L_mI_1/RT$. When the signal is transmitted along the dynamic line, the backward coupled noise continues to flow back to the near end at a constant speed along the static line. The dynamic signal leaves a trailing and steady backward noise on the static line. After the signal travels a certain length, the end of the noise will reach a stable value. At the time of $t=TD$, the dynamic signal reaches the far-end load of signal line 1, however the coupled current will continue to flow backward along the static line to the near end and with the extra time of TD, it will reach the near end, so the near-end noise on the static line lasts for a fraction of time of $2TD$. As the signal travels along the dynamic line, the forward noise propagates forward along the static line at the same speed as the dynamic line signal. At every point along the static line there is noise superimposed on the existing noise and the forward coupling noise and dynamic signals arrive at the far end at the same time of *t=TD*. The far-end noise is a pulse and the duration time equals the rise time of signal, which is *RT*.

3. Simulation of near-end crosstalk and far-end crosstalk

Based on theoretical analysis, the ADS (advanced design system) software is used to study the crosstalk problem of high speed digital signal. Fig. 3 presents the simulation circuit of coupled line with match loads at each end. The signal source is the step source of the time domain with rise time of 1ns. Since the electromagnetic wave propagation speed in the vacuum is 300mm/ns and the dielectric constant of PCB (FR4) is about 4, the electromagnetic wave propagation speed in PCB is about 150mm/ns. The rise time (1ns) covers a length 150 mm, 1/10 of which is 15 mm and the length of the coupling line in Fig. 3 is 38 cm which is greater than 1/10 of the length the rise time covers. The coupled line is therefore considered as transmission line. Matching load is connected to both sides of the coupling transmission line. The matching load resistance value is obtained according to the physical parameters of the coupling transmission line and the resistance is parameterized to facilitate to do the fine-tuning. Fig. 4 shows signals of the dynamic line, including the near-end signal V_i and the far-end signal V_o . It can be seen from the figure that the rise time of V_i which is the set value. The far-end signal is reached after 2ns, ie TD=2ns.

The signals on the static line is shown in Fig. 5. It can be seen from the figure that the near-end signal on the static line has a continuous elevation process in the period of 0 ns to 4 ns, which is consistent with the qualitative analysis in the second part, that is, the dynamic signal reaches the far-end load, but the terminal-coupled backward current continues to flow backward along the static line to the near end with an extra time *TD* to reach the near end, so the total near-end crosstalk duration time on the static line lasts for *2TD*. A pulse signal appears at the far-end of the static line after 2ns. As can be seen from Fig. 5, the pulse duration time lasts for 1ns which is equal to the rise time of signal. The observed result is coincided qualitative analysis in the second part, the the far-end noise of the static line is a pulse, and the duration time is the signal rise time.

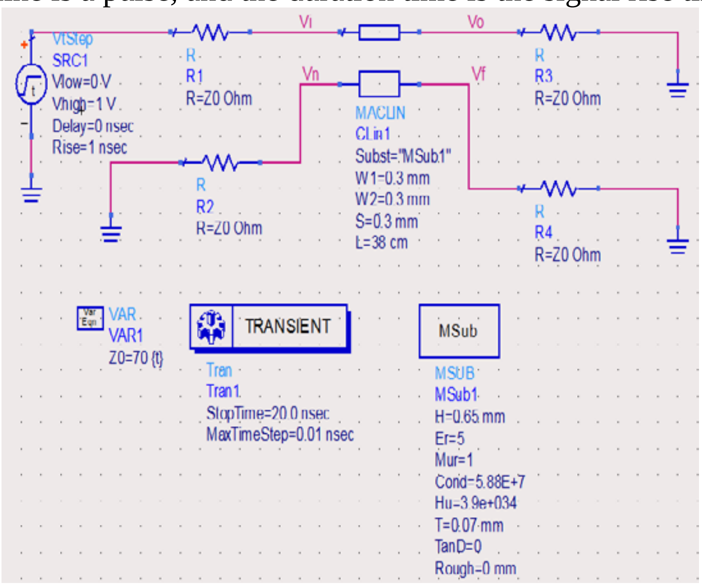

Fig. 3 Coupled transmission line with match load at each end

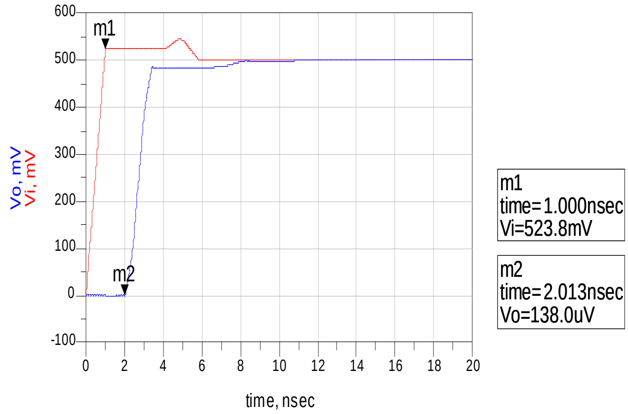

Fig. 4 Far-end and near-end signals of the dynamic line

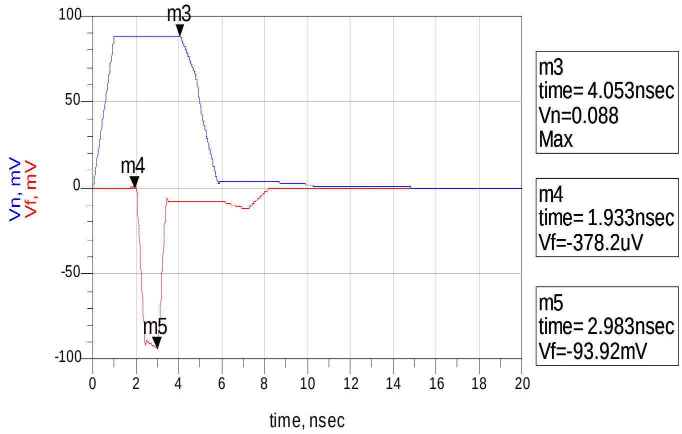

Fig. 5 Far-end and near-end signals of the static line

4. Conclusion

This paper studies the problem of signal integrity in high-speed digital circuits. When the high speed digital signal is transmitted in transmission line, it will interfere with the static line adjacent to it and the crosstalk are near-end crosstalk and far-end crosstalk. The near-end crosstalk duration time is *2TD* while the far-end crosstalk duration time is a pulse with duration time of RT which is the rise time of signal. The simulation results of ADS are in good agreement with the theoretical analysis, which is of reference for engineering design.

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