REDUCTION OF EMI FROM HIGH-SPEED TRANSMISSION LINE WITH NARROW RETURN TRACE USING QUASI-DIFFERENTIAL SIGNALING

Akihiro Namba*, **Makoto Nishihara***, **Tetsushi Watanabe****
Yoshitaka Toyota*, **Osami Wada***, **Ryuji Koga***

* Faculty of Engineering, Okayama University
** Industrial Technology Center of Okayama Prefecture
E-mail: {namba, nisihara, toyota, wada, koga}@dev.cne.okayama-u.ac.jp, watanabe@okakogi.go.jp

Abstract: Authors have introduced a quasi-differential signaling system, which is the method to realize low EMI (electromagnetic interference) transmission by matching the degree of imbalance of a line, a driver and a load. In this paper, authors present the measurement result of a common-mode current flowing on a transmission line, which has a narrow return trace. As a result, we confirm the effectiveness of EMI reduction using the quasi-differential signaling for the system with narrow return trace.

Key words: Quasi-Differential Signaling, Narrow Return Trace, EMI, Common-Mode, Degree of Imbalance.

1 Introduction

Electromagnetic interference (EMI) is a serious problem for high-speed circuit designers. A high-speed signal trace on a printed circuit board (PCB) needs a return path, and normally a ground plane or sometimes a power plane is used for the return path that should be wide enough to suppress EMI. However, in practice, it is difficult to place such a wide and complete ground plane on a high-density PCB. Thus EMI from a high-speed transmission line becomes large because of the common-mode excitation[1–3].

Authors introduced a quasi-differential signaling (QDS) that is the method to reduce EMI[4]. The QDS system has a signal trace with a narrow return trace, and the transmission line is driven by an asymmetric driver and terminated by an asymmetric load. A transmission line has its own degree of imbalance, which can be expressed by a current division factor. If the degrees of imbalance of the driver and the load are equal to the current division factor of the line, common-mode is not generated[3, 5]. The QDS is the method to reduce EMI by matching the degree of imbalance of a line, a driver and a load.

The differential signaling is often used to realize a high-speed transmission with low EMI. When the differential signaling is used for a multiple signaling, a return line is needed for each of channels. On the other hand, the QDS needs only one return line for all channels, that is the same as the single-ended signaling, and the return line does not require an infinite plane.

In this paper, authors show two types of measurement results of a common-mode current flowing on a test PCB that has a narrow return trace. One is the result for the single-ended signaling, and another is the result for the QDS. This paper shows that the QDS can reduce common-mode current.

2 Principle of Quasi-Differential Signaling System

2.1 Overview

The Equivalent circuit of a QDS system is shown in Fig. 1. The transmission line is asymmetric consisting of Line 1 and Line 2. The source impedances Z_{S1} and Z_{S2}, the load impedances Z_{L1} and Z_{L2}, the voltage sources E_1 and E_2 are not symmetrical either. The impedances Z_{L1} and Z_{L2} are the normal-mode terminations of the transmission line. The impedance Z_{CT} is a center-tap impedance, and Z_{SG} is the impedance between the sources and the ground.

The QDS system is divided into three parts, a drive part, a transmission line part, and a load part; and the degree of imbalance of each part is considered. The degree of imbalance is expressed using the current division factor[3, 6]. If one of the current division factors differs from others, the common-mode current is generated and it is proportional to the difference of the current division factor. Then the common-mode current generates radiated emission. The QDS is a method to realize a low EMI transmission line by matching the degrees of imbalance of a line, a driver and a load.

2.2 Common-Mode Voltage and Current Division Factor

We will discuss the normal-mode and the common-mode currents of a transmission line. As

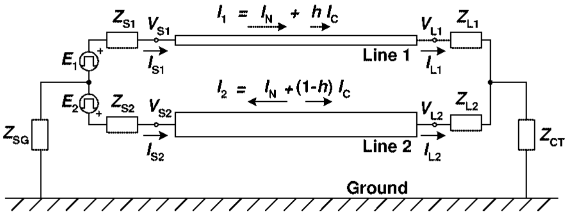


Fig.1 Equivalent circuit of a quasi-differential signaling system.

shown in Fig. 1, the current on the signal line I_1 and the current on the return line I_2 are expressed as the following equations using the normal-mode current I_{N} and the common-mode current I_{C}:

$$
\begin{aligned}
I_1 &= I_{\mathrm{N}} + hI_{\mathrm{C}}, &(1)\\
I_2 &= -I_{\mathrm{N}} + (1-h)I_{\mathrm{C}}, &(2)
\end{aligned}
$$

where h is called as a current division factor ($0 \leq h \leq 1$)[3, 6]. The value of the parameter h changes with the transverse structure of the transmission line. The value of h of the balanced line is 0.5, and the value of h of the ideal microstrip line having an ideal infinite ground plane is zero.

Figure 2 shows the voltage diagrams of a transmission line. The current division factor of the transmission line is expressed as h, and the factors of the driver and the load are expressed as h_{S} and h_{L}, respectively. The common-mode voltage at the output of the driver is V_{Cdriver}, and is equal to $h_{\mathrm{S}}V_{\mathrm{SN}} + V_{\mathrm{S2}}$; and the common-mode voltage at the input of the load is V_{Cload}, and is equal to $h_{\mathrm{L}}V_{\mathrm{LN}} + V_{\mathrm{L2}}$. The common-mode voltages of the input and the output of the line are V_{SC} ($= hV_{\mathrm{SN}} + V_{\mathrm{S2}}$) and V_{LC} ($= hV_{\mathrm{LN}} + V_{\mathrm{L2}}$), respectively. If $h_{\mathrm{S}} \neq h$, then ΔV_{SC} is generated at the input of the line, and if $h_{\mathrm{L}} \neq h$, ΔV_{LC} is generated at the output of the line. ΔV_{SC} and ΔV_{LC} are expressed by the following equations:

$$\Delta V_{\mathrm{SC}} = (h - h_{\mathrm{S}})V_{\mathrm{SN}} = \Delta h_{\mathrm{S}} V_{\mathrm{SN}}, \qquad (3)$$

$$\Delta V_{\mathrm{LC}} = (h - h_{\mathrm{L}})V_{\mathrm{LN}} = \Delta h_{\mathrm{L}} V_{\mathrm{LN}}, \qquad (4)$$

where Δh_{S} and Δh_{L} are the difference of the current division factor between a line and a driver or a load. These differences ΔV_{SC} and ΔV_{LC} generate the common-mode current which radiates the EMI. If ΔV_{SC} and ΔV_{LC} are zero, the common-mode current is not generated.

2.3 Current Division Factor

2.3.1 Current division factor of a transmission line

The current division factor of the transmission line h is determined by the cross-sectional structure of the transmission line. In general, the current division factor can be calculated by a numerical calculation as an electrostatic problem.

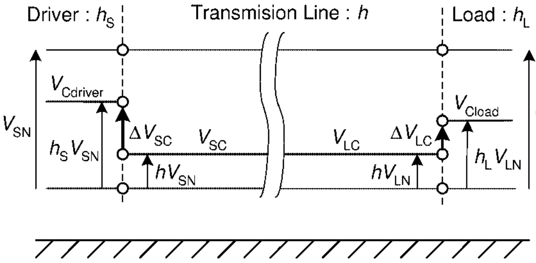


Fig.2 Voltage diagram of a transmission line at the connecting point.

In this investigation, the current division factor h is calculated using the boundary element method (BEM)[5].

2.3.2 Current division factor of a driver

The voltage sources E_1 and E_2 shown in Fig. 1 are expressed by the following equation:

$$
\begin{aligned}
E_1 &= E_{\mathrm{C}} + (1-\alpha)E_{\mathrm{N}}, &(5)\\
E_2 &= E_{\mathrm{C}} - \alpha E_{\mathrm{N}}, &(6)
\end{aligned}
$$

where, E_{C} and E_{N} are the common-mode and the normal-mode voltage sources, respectively, and α is the voltage division factor of the normal-mode voltage source. The normal-mode source impedance of the driver is defined as Z_{SN} ($= Z_{\mathrm{S1}} + Z_{\mathrm{S2}}$) and the normal-mode characteristic impedance of the transmission line is defined as $Z_{0\mathrm{N}}$. If we assume a driver connected to a transmission line that has infinite length, then a current division factor of a driver h_{S} is expressed as follows[4]:

$$h_{\mathrm{S}} = \frac{\alpha(Z_{\mathrm{SN}} + Z_{0\mathrm{N}}) - Z_{\mathrm{S2}}}{Z_{0\mathrm{N}}}. \qquad (7)$$

Consequently, h_{S} is determined by the source impedances Z_{S1}, Z_{S2}, the normal-mode characteristic impedance $Z_{0\mathrm{N}}$, and voltage division factor of the normal-mode voltage source α.

2.3.3 Current division factor of a load

A current division factor of a load h_{L} is expressed as follows[4]:

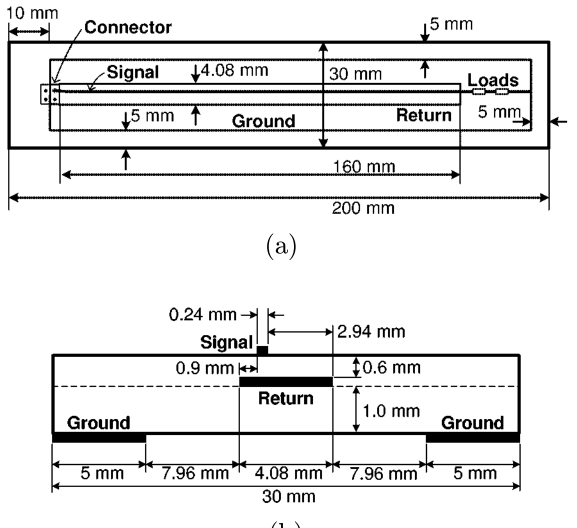
$$h_{\mathrm{L}} = \frac{Z_{\mathrm{L2}}}{Z_{\mathrm{L1}} + Z_{\mathrm{L2}}}. \qquad (8)$$

The factor h_{L} is determined by the load impedances Z_{L1} and Z_{L2}.

3 Experiment

3.1 Test PCB

In order to evaluate the common-mode current of a signaling system with narrow return trace,



(a)

(b)

Fig.3 The test PCB; (a) top view, (b) cross-sectional view.

a test PCB shown in Fig. 3 was prepared. Figure 3(a) illustrates the top view of the PCB, and Fig. 3(b) illustrates the cross-sectional view of the PCB. The width of the return trace on the PCB is only 4.08 mm. The single-ended signaling (SES) and the quasi-differential signaling (QDS) can be implemented by changing the value of the loads on the PCB.

The dimensions of the test PCB are $200\times30\times1.8$ mm^3. The PCB consists of the three layers; the signal layer, the return layer and the ground layer. The insulator material of the PCB is glass epoxy (FR-4), and the relative permittivity is 4.3. The topside of the PCB has a signal trace. The width of the signal trace is 0.24 mm and the length is 160 mm. The inner layer has a return trace whose width is 4.08 mm. The signal trace is located at 0.9 mm from the edge of the return trace, and the cross-section of the transmission line is asymmetric. The backside has a reference ground located at the edge of the PCB. The thickness between the signal and the return layer is 0.6 mm, and the thickness between the return and the ground layer is 1.0 mm as shown in Fig. 3(b).

A connector is located at the one end of the trace. Two loads (Z_{L1}, Z_{L2}) are located at another end of the trace. The loads Z_{L1} and Z_{L2} are terminations of the normal-mode circuit.

Normal-mode characteristic impedances of the transmission line are measured with differential TDR* (54754A, Hewlett Packard). Measured normal-mode characteristic impedance of the line is 95 Ω.

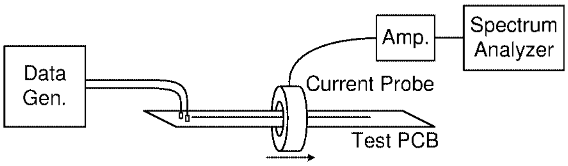


Fig.4 Measurement setup of the common-mode current.

Table 1 The values of the loads and the voltage setups to implement the SES and the QDS.

	SES	QDS
Z_{S1}	50 Ω	50 Ω
Z_{S2}	0 Ω	50 Ω
Z_{L1}	91 Ω	82 Ω
Z_{L2}	0 Ω	10 Ω
$\lvert E_1\rvert$	4.95 V$_{\mathrm{PP}}$	4.56 V$_{\mathrm{PP}}$
$\lvert E_2\rvert$	0 V$_{\mathrm{PP}}$	2.04 V$_{\mathrm{PP}}$

The current division factor h of the transmission line is 0.11, which is calculated by BEM[5].

3.2 Measurement Method of Common-Mode Current

The common-mode current of the single-ended signaling (SES) and the quasi-differential signaling (QDS) with narrow return trace are measured. Figure 4 shows the measurement setup of the common-mode current. A data generator (81200, Hewlett Packard) excites the transmission line, and a current probe (94111-1, ETS) detects the common-mode current spectrum of the test PCB. The output voltage of the current probe is amplified, and is measured by the spectrum analyzer (MS2601B, Anritsu). The current probe is moved along the transmission line, and the maximum current is measured.

In order to implement the SES and the QDS, the values of the loads and the output voltage of the data generator are changed. Table 1 shows the values of the loads and the voltage setups of the data generator. In order to match the degree of imbalance of the driver h_{S} and the load h_{L} with the imbalance of the transmission line h, the values of the loads $Z_{\mathrm{L1}}, Z_{\mathrm{L2}}$ and the voltages E_1, E_2 are decided by Eq. (7) and (8). Here, the loads are matched to the normal-mode characteristic impedance Z_{0N}; $Z_{\mathrm{L1}}+Z_{\mathrm{L2}} = Z_{\mathrm{0N}}$. Frequency of the signal is 10 MHz (period is 100 ns), duty cycle is 50 %, rise and fall times are 0.5 ns.

3.3 Measurement Results

Measurement results of the common-mode current spectra are shown in Fig. 5. The dashed line

---

*TDR : Time Domain Reflectometry

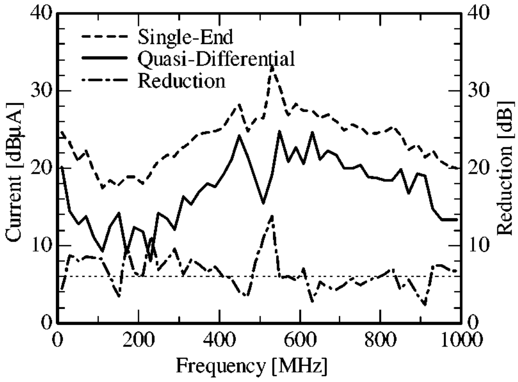


Fig.5 Spectra of common-mode current.

shows the measurement result for the SES, and the solid line shows the result for the QDS. The alternate long and short dash line shows the difference between the results of the SES and the QDS. Figure 5 shows that the amount of reduction by using the QDS is 6 dB.

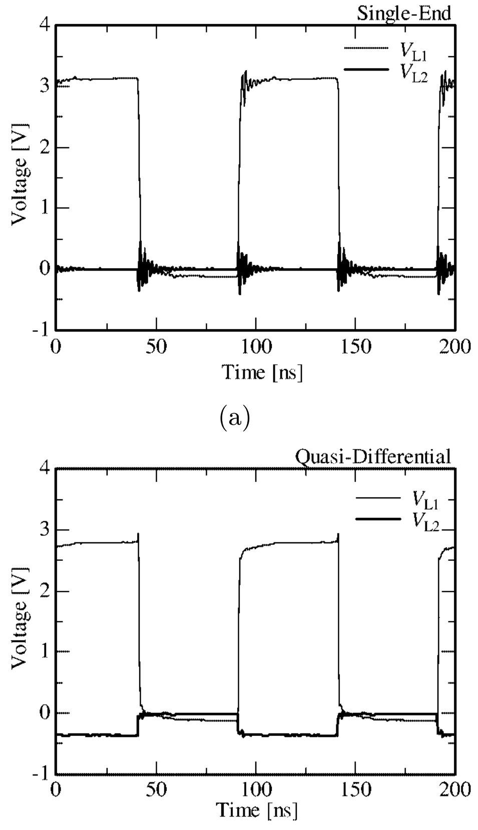
Theoretically the amount of reduction is infinite in dB since the common-mode current that is proportional to Δh_{S} or Δh_{L}; however, the measurement result of the reduction is about 6 dB. It is due to that the size of the reference ground is not large enough. It is the future work that the reference ground will be extended to stabilize the reference voltage.

The voltage waveforms at the loads $V_{\mathrm{L1}}(\mathrm{t})$, $V_{\mathrm{L2}}(\mathrm{t})$ are illustrated in Fig. 6. Figure 6(a) shows the waveforms of the SES, and Fig. 6(b) shows the waveforms of the QDS. The thin line shows the voltage between the signal and the reference ground, and the thick line shows the voltage between the return and the reference ground. The waveforms of the SES shown in Fig. 6(a) have large ringing. The oscillation frequency of the ringing is 530 MHz, and the measurement result of the common-mode current for SES shown in Fig. 5 has a peak at 530 MHz. On the other hand, the waveforms of the QDS shown in Fig. 6(b) have no ringing.

Consequently, the quasi-differential signaling can reduce EMI from a signaling system with narrow return trace.

4 Conclusions

This paper has presented the effectiveness of EMI reduction using the quasi-differential signaling system. The common-mode current of the test PCB, which has narrow return trace, was measured. The result has shown that the common-mode current can reduce by using the quasi-differential signaling system compared with the single-ended signaling system. Furthermore, the quasi-differential signaling system can suppress a ringing of a voltage.



(a)

(b)

Fig.6 Voltage waveform at the loads; (a) single-ended signaling, (b) quasi-differential signaling.

References

[1] D. M. Hockanson, *et. al.*, “Investigation of fundamental EMI source mechanisms driving common-mode radiation from printed circuit boards with attached cables,” IEEE Trans. on Electromagn. Compat., Vol.38 No.4, pp.557–566, Nov. 1996.

[2] N. Oka, *et. al.*, “Influence of ground plane width on reduction of radiated emission from printed circuit boards,” IEICE Trans. Commun., vol.J82-B, no.8, pp.1586–1595, Aug. 1999, (in Japanese).

[3] T. Watanabe, *et. al.*, “Common-mode-current generation caused by difference of unbalance of transmission lines on a printed circuit board with narrow ground pattern,” IEICE Trans. Commun., vol.E83-B, no.3, pp.593–599, March, 2000.

[4] A. Namba, *et. al.*, “Quasi-Differential Signaling for Low EMI,” Proc. of 2003 ICEP, pp.288–293, April 2003.

[5] T. Watanabe, *et. al.*, “Estimation of common-mode EMI caused by a signal line in the vicinity of ground edge on a PCB,” 2002 IEEE Int. Symp. on Electromagn. Conpat., pp.113–118, Aug., 2002.

[6] H. Uchida, “Fundamentals of coupled lines and multiwire antennas,” pp.37–89, Sasaki printing and publishing, Sendai, 1967.