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An intra-panel interface using three transmission lines for flat panel displays

Youngkwon Jo[1a)], Hoyoung Park[1], Suki Kim[1], and Kwang-Hyun Baek[2]

[1] *School of Electrical Engineering, Korea University, Anam, Seongbuk-gu, Seoul, 136–701, Korea*

[2] *School of Electrical Engineering, Chung-Ang University, 221 Heukseok, Dongjak-gu, Seoul, 155–756, Korea*

a) *banid@korea.ac.kr*

Abstract: In this paper, a new signaling scheme is proposed for intra-panel interface using three transmission lines for flat panel displays. The interface utilizes multi-level current signaling with delta-y configured resistor network. It increases the number of symbols and differentiates the symbols with pseudo differential signaling. The interface utilizes input buffer with low input impedance to reduce driving current. Therefore, the interface has lower frequency with low driving current when it has same data rate as conventional intra-panel interface. As a result, electromagnetic interference can be lowered. The interface is fabricated using a 0.18 um CMOS technology, and its measured bit error rate was 3.9×10^{-11}.

Keywords: intra-panel interface, flat panel display interface, pseudo differential signaling, multi-level current signaling

Classification: Integrated circuits

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1 Introduction

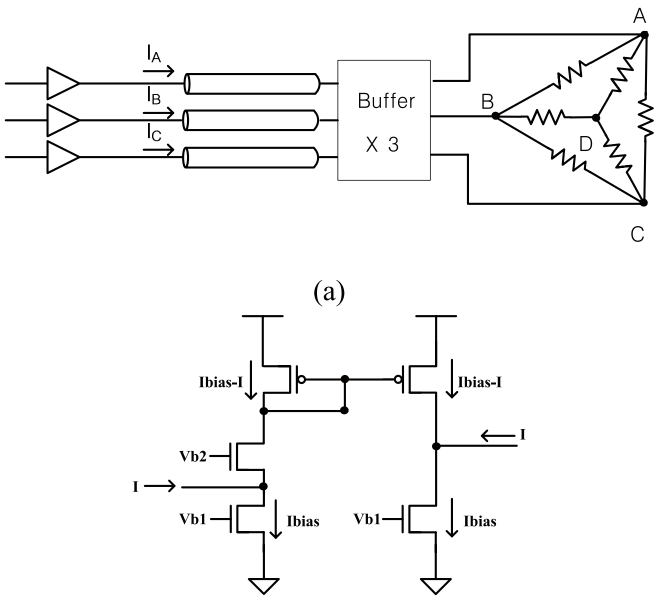
As multimedia systems (e.g., digital cameras, Blu-ray players and console game players) transit to higher definition and quality images, higher resolution and deeper color displays are required. These displays require more data to be displayed for a given frame. Data from a multimedia system are transmitted to the source driver through the graphic controller and the timing controller of the flat panel display. Intra-panel interface (IPI) is defined as the interface from the timing controller to source driver. As the amount of data increases, the data rate in the IPI needs to increase proportionally while the electro-magnetic interference (EMI) in IPI also increases. Data rate increases by the square of pixels per edge while EMI increases by the fourth power of pixels per edge [1].

To lower EMI, the proposed IPI utilizes multi-level current signaling which has 12 symbols and transmits RGB data with one symbol. It also utilizes input buffer to lower driving current. These help to lower EMI.

2 The proposed Intra-panel Interface

Fig. 1 (a) shows simplified structure of the proposed interface. First, the principle of the delta-y configured resistor network is presented. If all the resistors have the same resistance and the sum of currents I_A, I_B and I_C is 0, nodal equation of node D is $I_{AD} + I_{BD} + I_{CD} = 0$. Then the floating node D sustains any fixed value. At that time, the differential voltages between each node of A, B and C are proportional to current difference between each transmission line. And the differential voltage between D and each of the nodes A, B, and C is proportional to the current of each transmission line. Eq. (1) represents this feature.

$$\begin{aligned} V_{AB} &= \frac{1}{4}R(I_A - I_B), V_{BC} = \frac{1}{4}R(I_B - I_C), V_{CA} = \frac{1}{4}R(I_C - I_A) \\ V_{AD} &= \frac{1}{4}RI_A, V_{BD} = \frac{1}{4}RI_B, V_{CD} = \frac{1}{4}RI_C \end{aligned} \tag{1}$$



(b)

Fig. 1. (a) Simplified structure of the proposed interface (b) Input buffer.

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Because all the resistors have the same resistance, common mode noise of three transmission lines is induced on the floating node D like virtual circuits between node D and each of the nodes A, B and C. Therefore, the differential voltage between D and each of the nodes A, B, and C can reject common mode noise. That is, the direction and the difference of all the currents can be detected without common mode noise. And it does not need any reference voltage to differentiate current. To achieve these, the proposed interface needs to satisfy three requirements.

1) The total current of three transmission lines must be 0. If it is not 0, the voltage of node D will be changed depending on the total current.

2) The current of each transmission line must not be same. If the current of each transmission line is same, voltage difference between each node cannot be obtained.

3) The current of each transmission line must not be 0. If it is 0, the voltage difference of node D and each node of A, B and C cannot be obtained.

The current of each transmission line is designed to be either one of these choices, $\pm 100\,\mathrm{uA}$, $\pm 200\,\mathrm{uA}$ or $\pm 300\,\mathrm{uA}$. There are three cases to select a line for 300 uA and two cases for 300 uA current direction. For each case, there are two combinations of 200 uA and 100 uA. Therefore, the number of symbols are 12 ($= 3 \times 2 \times 2$). The efficiency per symbol of the proposed IPI is $\log_2 12$ (3.58) bits/symbol, and its efficiency per line is 1.2 bits/line.

Fig. 1 (b) shows schematic of input buffer. Input buffer receives current from transmission line and drive currents into following delta-y resistors. Because the input buffer has 50 ohm input resistance, the resistance value of following delta-y resistors can be increased to increase voltage swing.

If the delta-y configuration is directly connected to transmission lines, the resistance value is 200 ohm to match characteristic impedance of transmission line. In this design, the differential voltage swing between each node A, B and C is set to 100 mV, and the current needed to swing 100 mV is 2 mA. Therefore, the total current of the proposed IPI is 6 mA. Three times more current is needed for the proposed IPI compared with the conventional IPI.

To lower its driving current, an input buffer with 50 ohm input resistance is used. Transmission lines have very low noise (differential noise) in themselves, and external noise sources such as EMI induces common mode noise on balanced differential transmission lines [2]. Compared with common mode noise due to external noise source, differential noise is very low. And loss at the transmission lines is generally low (about 0.32 dB/m in our design) [3]. Therefore, although SNR is degraded, signals can be detected if common mode noise is rejected. Additionally, induced noise voltage due to external noise source is divided according to output resistance of current driver (CR) and buffer's input resistance [4]. Because CR's output resistance is much larger than buffer's input resistance, most of induced voltage is applied to

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CR. Therefore, noise current is not increased much although induced voltage is large. Thus current level can be reduced.

Because input buffer is matched to the transmission line, all of the current flows into input buffer. The current which flowed into the input buffer is mirrored to PMOS located on the right side of the input buffer. That is, the current from transmission line flows into output of the input buffer.

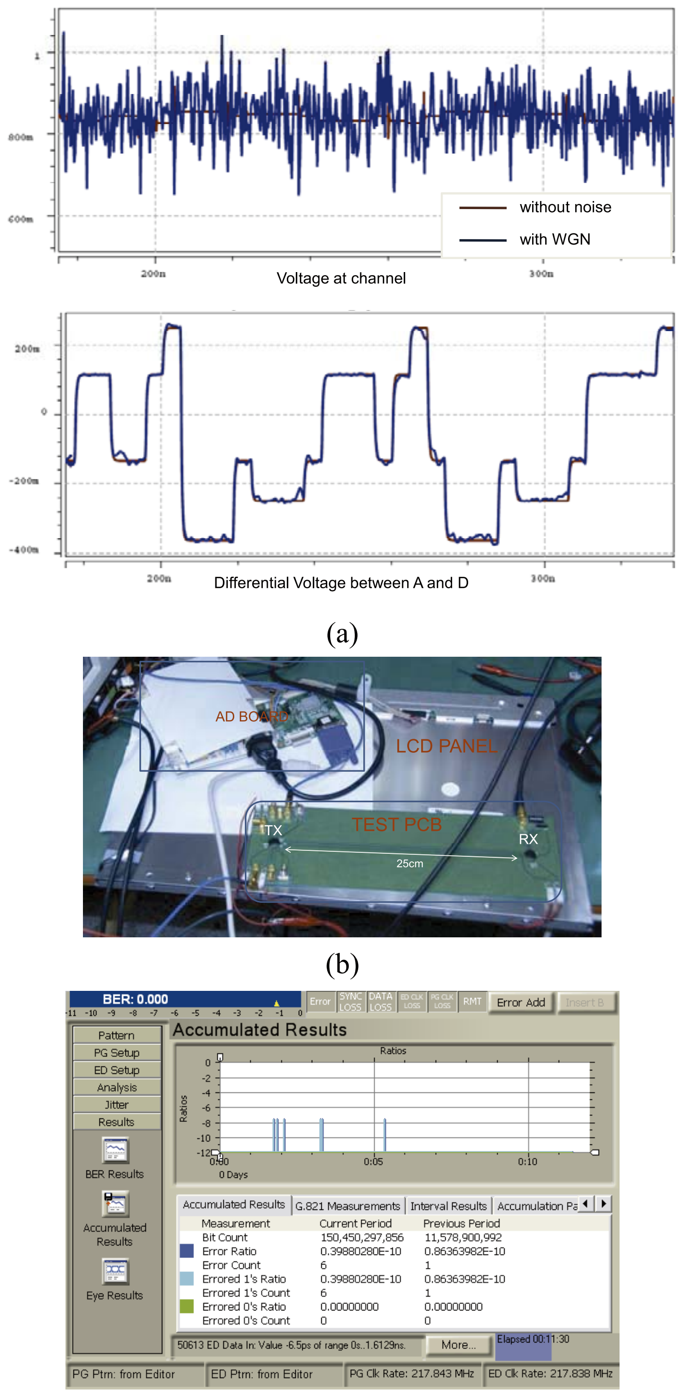

Fig. 2. (a) Simulation results without noise (red line), with WGN (blue line) (b) Test setting (c) BER result.

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Using this input buffer and delta-y resistors, sufficient voltage swing can be obtained with 15% of the driving current of the conventional point to point differential signaling (PPDS) [5].

To support 720 channel, 12 bit color depth, 60 Hz refresh rate and 1080 vertical lines, the interface requires a minimum data rate of 560 Mbps. The proposed IPI is designed to supports 654 Mbps considering 16% data overhead using a 0.18 CMOS process. The simulation is performed under the condition that channel models of flexible printed circuit and printed circuit board have no noise and white Gaussian noise (WGN), respectively. The upper waveforms of Fig. 2 (a) show voltages of channel without noise and channel added common mode noise, respectively. Without noise, the channel swings about 30 mV. The bottom waveforms show differential voltages between node A and node D of Fig. 1 (a). This shows that common mode noise is rejected effectively.

To verify the performance of the proposed IPI, the interface is tested on a 25 cm long PCB which is same length as a 30 inch flat panel display and measurement was performed above real LCD panel turned on to test in the environment similar to real environment (see Fig. 2 (b)). Because one symbol contains 3.58 bits of data, it transmits the RGB data with one symbol. Therefore, bit error test is performed with 217 MHz (=data rate/3). Fig. 2 (c) shows that the measured BER is 3.9×10^{-11}.

3 EMI Calculation

In this section, electromagnetic emission is calculated for the three transmission lines. We will determine the radiated fields of the three transmission lines at a point that is perpendicular to the line conductors and in the plane containing them assuming that the line conductor is an electric pole [4]. This model needs an important and simple assumption that the measurement point is in the far field of lines. Maximum field occurs in the plane of the wires and on a line perpendicular to the wires when more current flows on the outer path such as in the case of $I_1 = 300\,\text{uA}$, $I_2 = -100\,\text{uA}$ and $I_3 = -200\,\text{uA}$.

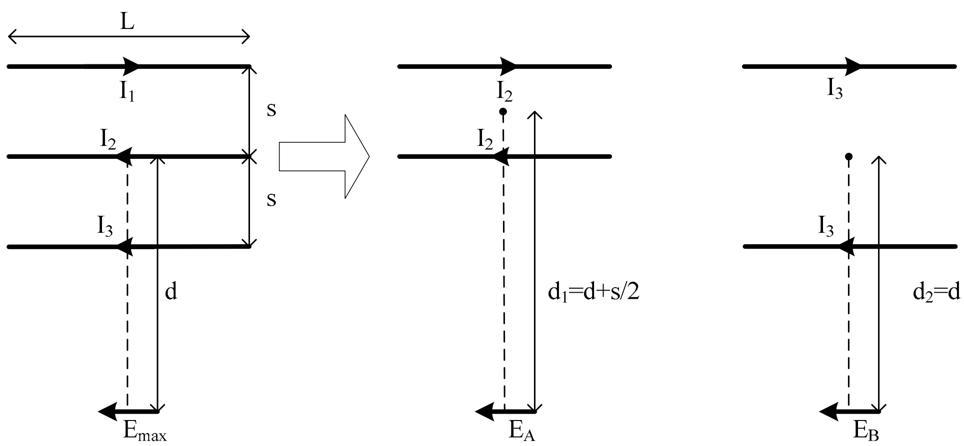

Fig. 3. Radiated field emission of three transmission lines.

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The radiated field which is the superposition of the electric field from the three lines can be determined under the assumption of constant current distributions. The radiated field can be expressed as Eq. (2).

$$\begin{aligned}\overrightarrow{E} &= \overrightarrow{E_1} + \overrightarrow{E_2} + \overrightarrow{E_3} \\ &= j2\pi \times 10^{-7}\frac{f\overrightarrow{I_1}L}{d}e^{-j\beta_0(d+s)} + j2\pi \times 10^{-7}\frac{f\overrightarrow{I_2}L}{d}e^{-j\beta_0 d} \\ &\quad + j2\pi \times 10^{-7}\frac{f\overrightarrow{I_3}L}{d}e^{-j\beta_0(d-s)} \end{aligned} \tag{2}$$

For simple calculation, Eq. (2) can be rearranged into the superposition of two differential pairs as shown in Fig. 3. Because the maximum radiated electric field of current-mode differential pair is shown as Eq. (3) and I_3 is two times of I_2, we can express Eq. (2) as Eq. (4).

$$E_{MAX} = 1.316 \times 10^{-14}\frac{If^2Ls}{d} \tag{3}$$

$$\begin{aligned}E_{MAX} &= 1.316 \times 10^{-14}\frac{If^2Ls}{d} + 1.316 \times 10^{-14}\frac{(2I)f^2L(2s)}{d} \\ &= 5 \times 1.316 \times 10^{-14}\frac{If^2Ls}{d}\end{aligned} \tag{4}$$

According to most EMI regulations, emissions are measured over a conducting plane. Under this condition, the radiation increases by factor of two [6].

$$EMI = 10 \times 1.316 \times 10^{-14}\frac{If^2Ls}{d} \tag{5}$$

Compared Eq. (3) with Eq. (4), the radiated EMI is five times EMI of differential mode. However, the proposed IPI has about one tenth current of the conventional PPDS-based IPI. And frequency is reduced to one third of PPDS and current is reduced to one twentieth. Considering these, the EMI level of the proposed IPI is 1/36 that of the PPDS [5].

4 Conclusions

The proposed intra-panel interface supporting source driver with 720 channel, 12 bit color depth, 1080 vertical lines and 60 Hz fresh rate uses delta-y configured resistor network and multi-level current signaling. The resistor network enabled the increase number of symbols, reject common mode noise efficiently and differentiate symbols without additional reference voltage. The IPI needs only low driving current to utilize the input buffer with low input impedance. The low driving current and increased symbols leads to lower EMI. The performance is verified with a 0.18 um CMOS technology.

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