A Novel Complementary Mirror Type Analog Buffer for LTPS TFT-LCD Data Drivers

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Abstract: Instead of traditional operational amplifies (OP-AMPs) and threshold voltage compensation type analog buffers, this work presents a novel complementary current mirror (CCM) type analog buffer for integrated data drivers of low-temperature polycrystalline silicon thin-film transistor (LTPS-TFT) displays. The proposed CCM analog buffer makes use of a p-type and an n-type current-mirror-type buffer to achieve large voltage swing. The proposed buffer does not need capacitors and external control signals, so it features compact size and good linearity.

Key words: analog buffer; complementary current mirror; data driver; LTPS; TFT-LCD

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应用于低温多晶硅薄膜晶体管液晶显示器之新型互补电流镜式模拟缓冲放大器

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摘 要：取代传统运算放大器和临界电压补偿型模拟缓冲器，提出了一种新型的互补式电流镜模拟缓冲器，可以利用在低温多晶硅薄膜晶体管液晶显示器驱动电路上。使用N型电流镜和P型电流镜来交互使用以达到较大的电压输出范围，并且使用一开关控制电路实时控制切换，所以可以提出的电压缓冲器不需要电容或时脉讯号就可以运作，这样可以节省很多布局时所需要的面积，且依然维持良好的线性趋势。

关键词：模拟缓冲器；互补式电流镜；资料驱动电路；低温多晶硅；薄膜晶体管液晶显示器

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Low temperature poly-Si thin-film transistors liquid-crystal displays (LTPS-TFT-LCDs) with integrated driving circuits on glass substrate have been developed[1-10]. LTPS-TFT LCDs may eliminate driver ICs and reduce the cost and enhance its reliability. Driving circuits of TFT-LCDs generally include data receivers, shift registers, data registers, digital-analog-converters (DACs), and output buffers[1-3]. Due to heavy RC loads in data lines and pixel electrodes on a panel, output buffers amplify analog voltages from DACs and charge for data lines and pixel electrodes.

Because the operation-amplifier-type (OP-AMPs) analog buffer, usually used in CMOS circuits, needs lots of transistor, it causes large chip area and large variation of electrical characteristics of buffers due to threshold-voltage mismatch of LTPS-TFTs. Therefore, source-follower-type buffer is better choice for LTPS-TFT-LCDs[5-10].

General source-follower-type analog buffers for LTPS-TFTs have two types of architects, one is threshold-voltage-compensation type (VTC type)[5-9], the other is current-driving-type (CD type)[10]. The threshold-voltage-compensation-type buffer raises the input voltage by a threshold-voltage of the driving TFT, and passes the voltage from the gate through the source of the TFT. It just cancels the threshold-voltage of the LTPS-TFT. Therefore, the output voltage

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equals to the input voltage. The current-driving-type buffer converters the input voltage to a drain-to-source current, by storing a corresponding gate-to-source voltage in a capacitor. Then the drain-to-source current of the driving TFT generates a gate-to-source voltage, which equals to the input voltage.

1 Three Types of Buffer Circuit

1.1 Push-Pull Analog Buffer

Figure 1 shows the push-pull analog buffer for LTPS-TFT integrated data drivers and its timing diagram of the control signals[8]. This buffer compensates the threshold voltage of the TFT and belongs to the VTC type source follower. A capacitor is used to store the threshold-voltage. During period(1), switches 1 and 2 are closed and switches 3 and 4 are opened. The capacitor stores the threshold-voltage of either the P-TFT or the N-TFT. During period 2, switches 3 and 4 are closed and switches 1 and 2 are opened. The input analog signal (Vin) passes through the capacitor and increases the previously stored threshold-voltage. The gate voltage of the driving TFT becomes the voltage of 'Vin+Vth', and the output voltage becomes the voltage of 'V_{gate}-V_{th}'. Therefore, the output voltage will equal to the input one. However, this buffer has a dead-band in the middle of the voltage swing, because it is a class B structure.

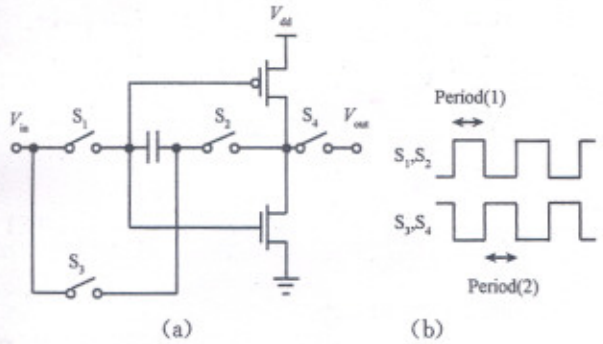


Fig. 1 (a) Push-pull analog buffer for integrated LTPS-TFT-LCD data drivers. (b) Timing diagram of control signals

1.2 Threshold-Voltage-Compensation Type Buffer

Figure 2 shows the threshold-voltage-compensation-type analog buffer and its timing diagram of the control signals[9]. It consists of two transistors, a capacitor, and four switches.

During period (1), switches 1 and 2 are closed and switches 3 and 4 are opened. The threshold-voltage of the driving TFT is stored in a capacitor.

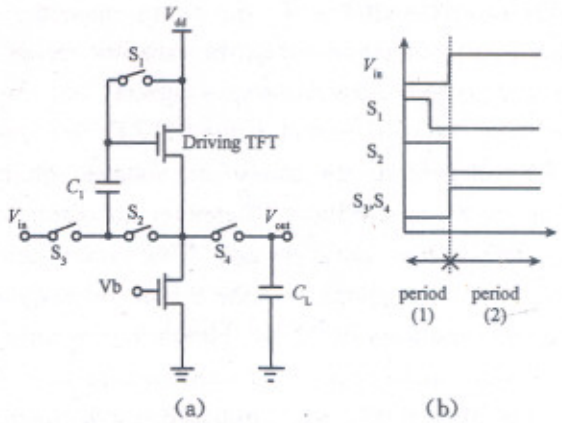


Fig. 2 (a) Threshold-voltage-compensation type analog buffer. (b) Timing diagram of control signals

During next period, switches 3 and 4 are closed, and switches 1 and 2 are opened. The gate voltage of the driving TFT becomes the voltage of 'V_{in}+V_{th}', and the output voltage becomes the voltage of 'V_{gate}-V_{th}'. So, the output voltage follows the input voltage. However, the threshold-voltage-compensation-type buffer needs a capacitor, a fixed bias voltage and additional two clock signals to control the switches.

1.3 Current-Driving Type Analog Buffer

Figure 3 exhibits the current-driving type analog buffer[10]. It comprises an N-TFT and a P-TFT, a capacitor, and four switches. During the sampling period, switches 1 and 3 are closed and switches 2 and 4 are opened. The N-TFT generates a drain-source current controlled by the input voltage. The drain-source current of the P-TFT will equal to that of the N-TFT and thus P-TFT generates a corresponding source-gate voltage. The induced source-gate voltage will store in a capacitor. During driving period, switches 2 and 4 are

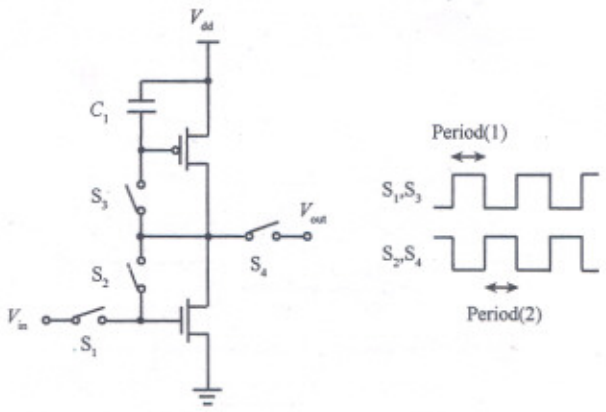


Fig. 3 (a) Current-driving type analog buffer. (b) Timing diagram of control signals

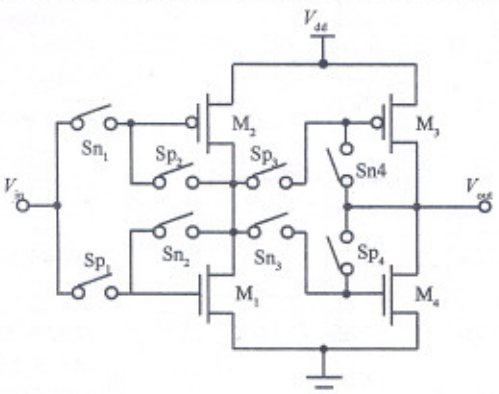
closed, and switches 1 and 3 are opened. The source-gate voltage stored in the capacitor makes the P-TFT generate the drain-source current. So, the N-TFT has the same current as the P-TFT. And the N-TFT will generate the gate-source voltage, which equals to the input voltage. Therefore, the output voltage follows the input voltage. This current-driving type buffer can compensate the threshold-voltage and mobility mismatch of TFTs. However, the capacitor and extra control signals will consume large area.

In this work, the proposed complementary current mirror type (CCM type) analog buffer does not need any capacitor, bias voltages and clock signals, so the circuit area can be keep small. By using n-type and/or p-type current-mirror, the input voltage is duplicated to the output node.

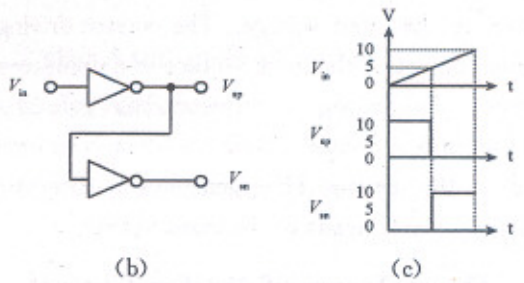
2 Proposed Buffer Circuit

2.1 Proposed Complementary Current Mirror Type Analog Buffer

Figure 4 shows the schematic and timing diagrams of the proposed CCM-type analog buffer. It consists of two P-TFT, two N-TFT, eight switches, and an internal control-signal-generating circuit. The internal control-signal-generating circuit will generate two control signals according to the input signal, as shown in Fig. 4(c). The generated control signals 'Vsp' controls switches Sp_1, Sp_2, Sp_3, and Sp_4, and 'Vsn' controls switches Sn_1, Sn_2, Sn_3 and, Sn_4. When the input voltage is smaller than 5 V, Sp_1, Sp_2, Sp_3, and Sp_4 are closed and Sn_1, Sn_2, Sn_3, and Sn_4 are opened. The CCM type buffer becomes a P-TFT current-mirror buffer, as shown in Fig. 5 (a). On the contrary, when the input voltage is larger then 5 V, Sp_1, Sp_2, Sp_3, and Sp_4 are opened and Sn_1, Sn_2, Sn_3, and Sn_4 are closed.



(a) Proposed complementary current mirror type analog buffer



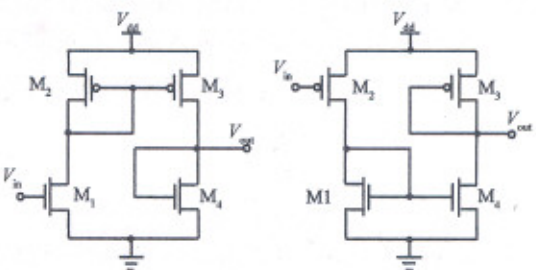
(b) (c)

(b) Internal control-signal-generating circuit.
(c) Timing diagram of the input and control signals

Fig. 4

The proposed buffer acts as an N-TFT current-mirror buffer, as shown in Fig. 5 (b). As the input voltage is applied, the input-TFT will generate the drain-source current. Then, the current mirror copies the current to another side. Hence, the output-TFT current equals to the input-TFT one. Based on equation (1), if two TFTs have the same mobility (μ), capacitor of gate dielectric (C_{ox}), and threshold-voltage (V_{th}), and because channel width (W), channel length (L), and drain-source current (I_{ds}) are the same values, the gate-source voltages of the two TFTs will be the same. Therefore, the output voltage will equal to the input voltage.

$$I_{DS} = \frac{1}{2}\mu C_{OX}\frac{W}{L}(V_{GS} - V_{TH})^2 \qquad (1)$$



(a) (b)

Fig. 5 (a) P-TFT current mirror buffer. (b) N-TFT current mirror buffer

2.2 Simulation Results

Figure 6 shows the simulation results of the P-TFT and the N-TFT current mirror analog buffers. For the P-TFT current mirror buffer shown in Fig. 5 (a), it is found that when the input voltage is low, the output voltage almost equals to the input voltage. Contrarily, the output voltage does not follow the input voltage when the input voltage is high. This is because when the input voltage is low, the input-TFT operates in the saturation region, and the drain-source current is only depend-

ent on the gate-source voltage. When the input voltage is high, the input-TFT is in the triode region. The drain-source current correlates with both the gate-source voltage and the drain-source voltage. Moreover, the drain-source voltage of M_1 does not equal to that of M_4, so the output voltage does not follow the input voltage. These results can be explained as follows.

(1) For low input voltage (in the saturation region):

$$I_{D1} = \frac{1}{2}\mu_n C_{OX}\frac{W}{L}(V_{GS1} - V_{TH})^2, V_{GS1} = V_{IN} \quad (2)$$

$$I_{D4} = \frac{1}{2}\mu_n C_{OX}\frac{W}{L}(V_{GS4} - V_{TH})^2, V_{GS4} = V_{OUT} \quad (3)$$

$$I_{D1} = I_{D4} \quad (4)$$

$$\frac{1}{2}\mu_n C_{OX}\frac{W}{L}(V_{IN} - V_{TH})^2 = \frac{1}{2}\mu_n C_{OX}\frac{W}{L}(V_{OUT} - V_{TH})^2 \quad (5)$$

$$V_{IN} = V_{OUT} \quad (6)$$

(2) For high input voltage (in the triode region):

$$I_{D_1} = \frac{1}{2}\mu_n C_{OX}\frac{W}{L}[2(V_{GS1} - V_{TH})V_{DS1} - V_{DS1}^2] \quad (7)$$

$$V_{GS1} = V_{IN} \quad (8)$$

$$I_{D_4} = \frac{1}{2}\mu_n C_{OX}\frac{W}{L}(V_{GS4} - V_{TH})^2 \quad (9)$$

$$V_{GS4} = V_{OUT} \quad (10)$$

$$I_{D_1} = I_{D_4} \quad (11)$$

$$\frac{1}{2}\mu_n C_{OX}\frac{W}{L}[2(V_{IN} - V_{TH})V_{DS_1} - V_{DS_1}^2] = \frac{1}{2}\mu_n C_{OX}\frac{W}{L}(V_{OUT} - V_{TH})^2 \quad (12)$$

$$V_{OUT} = \sqrt{2(V_{IN} - V_{TH})V_{DS} - V_{DS}^2} + V_{TH} \quad (13)$$

$$V_{OUT} \neq V_{IN} \quad (14)$$

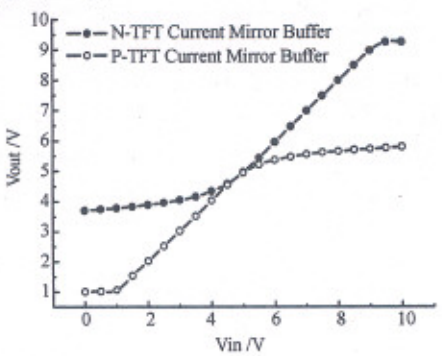


Fig. 6 Simulation results of the P-TFT and the N-TFT current mirror type analog buffers

On the other hand, for the N-TFT current mirror buffers shown in Fig. 5 (b), the output voltage follows the input voltage as the input voltage is high. Otherwise, the output voltage does not follow the input voltage as the input voltage is low. The dc analysis of the N-TFT current mirror buffer is analogous to equations (2)~(14).

In this work, we combine the P-TFT and the N-TFT current mirror buffers to obtain the CCM-type analog buffer as shown in Fig. 4(a). The proposed buffer can switch automatically between the P-TFT and the N-TFT buffers according to the input voltage. Thus, the buffer does not need external clock signals to control the switches. Figure 7 shows the simulation results of the proposed CCM type analog buffer. The solid dot line exhibits the output characteristics. It is found that the buffer has a good linearity from 1 V to 9 V of the input voltages. Figure 7 also shows the offset voltages (V_{out}-V_{in}, blank dot line) of the buffer. The typical offset voltages are below 65.1 mV for the input voltages from 1 V to 9 V.

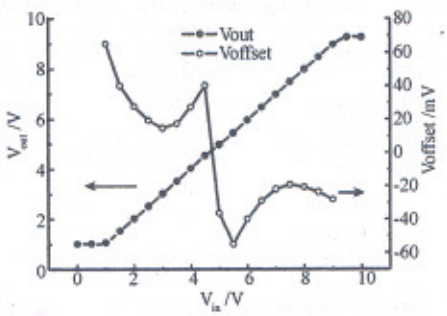


Fig. 7 Simulation results of the proposed CCM type buffer

Figure 8 exhibits the Monte Carlo simulation results of V_{out} vs. V_{in}. The threshold voltages and the carrier mobilities of TFTs are assumed to have a gaussian distribution. The average threshold voltages are 1 V and −1 V for N-TFT and P-TFT, respectively. The average carrier mobility is about 75 cm^2/Vsec for both N-TFT and P-TFT. The Monte Carlo simulation has been executed by 30 times. From Fig. 8, it is found that the buffer has a good dc characteristic except around VDD and GND.

Figure 9 shows the offset voltages obtained by the Monte Carlo simulation. Due to large variation of threshold voltage and carrier mobility of poly-Si TFT, the offset voltages vary from − 89.5 mV to + 61.7 mV.

Table I summarizes the specifications of the proposed CCM type buffer. The load capacitor is 20 pF. The average and maximum offset voltages are 30.9 and 89.5 mV, respectively. The rising and falling times are 4.1 and 4.9 μs, respectively.

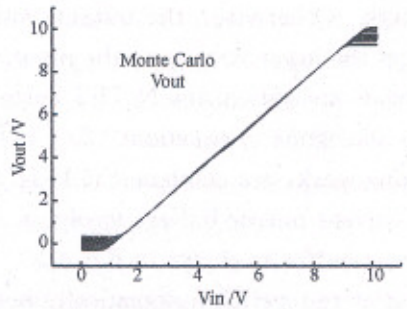


Fig. 8 Monte Carlo simulation results of V_{out} vs. V_{in}

The average power consumption is 136μW.

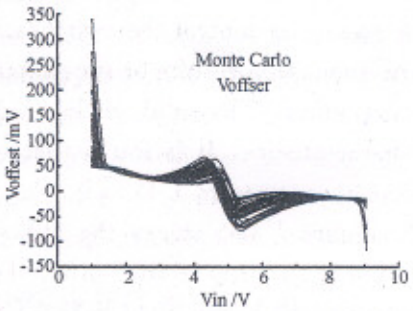


Fig. 9 Monte Carlo simulation results of V_{offset}.

Table I The specifications of the CCM-type buffer.

Parameter		proposed CCM type buffer
Offset Voltage	average	30.9 mV
	maximum	89.5 mV
Rising time (10%—90%)		4.1μS
Falling time (90%—10%)		4.9μS
Average Power Consumption		136μW

3 Conclusions

A new complementary current mirror type analog buffer has been developed for the integrated data driver of poly-Si TFT-LCDs. This proposed buffer does not need any capacitor and external control signals, so it features compact layout area. The presented analog buffer achieves good linearity and low average offset voltage.

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Author's Personal Introduction

Fang-Hsing Wang received the B. S. degree and Ph. D, degree in electronic engiineering from National Chiao-Tung University, Hsinchu, Taiwan in 1991 and 1997, respectively. He was employed by Unipac Optoelectronic Corporation from 1999-2001, where he designed arrays of TFT-LCDs. During 2001-2002, he was an Assistant Professor in Chienkuo Technology University, Chang-Hua, Taiwan. During 2002-2003, he worked for Novatek Corporation to be and IC designer for TFT-LCDs. In 2003, he joined the faculty of National Chung-Hsing University, Taichung, Taiwan, as an Assistant Professor. His research interest include display design and process technology of TFT-LCDs.