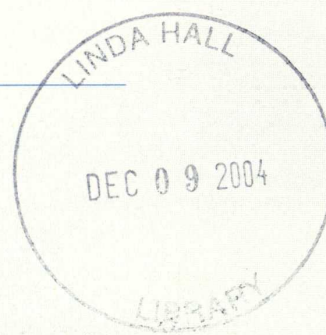


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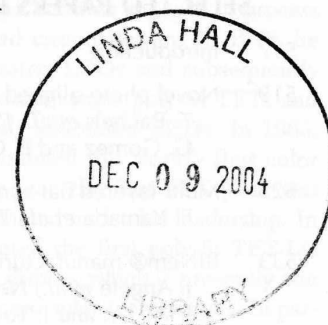
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An integrated poly-Si TFT current data driver with a data-line pre-charge function

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Abstract — We have developed an integrated poly-Si TFT current data driver with a data-line pre-charge function for active-matrix organic light-emitting diode (AMOLED) displays. The current data driver is capable of outputting highly accurate ($\pm 0.8\%$) current determined by 6-bit digital input data. A novel current-programming approach employing a data-line pre-charge function helps achieve accurate current programming at low brightness. A 1.9-in. 120 × 136-pixel AMOLED display using these circuits was demonstrated.

Keywords — OLED, current data driver, current program, pre-charge.

1 Introduction

Poly-Si thin-film-transistor (TFT) OLED displays hold great promise for use in mobile phones, PDAs, PCs, and TVs, offering wide viewing angles, fast response, low power consumption, and panel thinness.

To obtain uniform images on poly-Si TFT AMOLED displays, it is necessary to ensure uniformity in the brightness of each pixel. This brightness is dependent on the current in the OLED that is driven by each pixel circuit, and an important issue for poly-Si TFT OLED displays has been the pixel-driving technology needed to achieve uniformity in OLED currents. The main difficulty is non-uniformity in the current-voltage characteristics of the poly-Si TFTs that form part of the pixel circuit. A number of pixel-driving schemes have been proposed to overcome this disadvantage.¹⁻⁷ Among them, those that employ a current-programming approach,^{4,5} which works to compensate for variations in both V_t and mobility in poly-Si TFTs, are effective in achieving good uniformity. Unfortunately, however, this approach suffers from a serious drawback. Specifically, the lowness of its current for a dark gray scale means that (1) programming time will be relatively long and (2) a highly accurate current data driver will be required. While such driving accuracy might be externally supplied, as with, for example, drivers composed of crystal-Si MOSFETs that offer high uniformity in current-voltage characteristics, the use of such drivers would increase programming time further because of the increase in high parasitic capacitance induced by the connection between the data drivers and the display panel. What is needed, then, is to integrate high-accuracy current data drivers into the AMOLED display substrate itself.

Further, there is also high parasitic capacitance in the data-line capacitors, and the need at low current levels to charge these data-line capacitors would also increase pro-

gramming time. To deal with this we need a data-line pre-charge function.

In this paper, we propose for AMOLED displays an integrated poly-Si TFT 6-bit current data driver and a novel current-programming approach that employs a data-line pre-charge function. The proposed design reduces current-programming times at low brightness and achieves accurate current programming. We also demonstrate a 1.9-in. poly-Si TFT OLED display which employs these circuits.

2 Current data driver

2.1 Driver configuration

Figure 1 is a block diagram of the poly-Si TFT 6-bit current data driver, which contains 60-bit shift-register 1, 6-bit data registers, 6-bit data latches, 60-bit shift register 2, 60 6-bit digital-to-current converters (DCCs), a standard current source circuit, pre-charge circuits, and 1-to-2 selectors. These last five components form the design's "current signal block."

Each 6-bit data register receives 6-bit digital gray-scale data when scanning signals are output from 60-bit shift register 1, and it outputs this data to each 6-bit data latch. The 6-bit data latches send 6-bit digital data to the 6-bit DCCs. The 6-bit DCCs carry out two different operations. One is to memorize values of the six standard currents (I_s , $I_s \times 2$, $I_s \times 4$, $I_s \times 8$, $I_s \times 16$, $I_s \times 32$) generated by the integrated standard current source circuit in the driver. The other is to output the gray-scale currents (I_s , $I_s \times 2$, ..., $I_s \times 62$, or $I_s \times 63$) determined by the digital data from the 6-bit data latch. Each 6-bit DCC is composed of 6 1-bit DCCs connected in parallel. Each 6-bit DCC sends an analog current signal to the pre-charge circuit. A 1-to-2 selector outputs the signals to each of two outputs of the driver, one after the other. This is accomplished over a single horizontal period. 60-bit shift register 2 outputs scanning signals to

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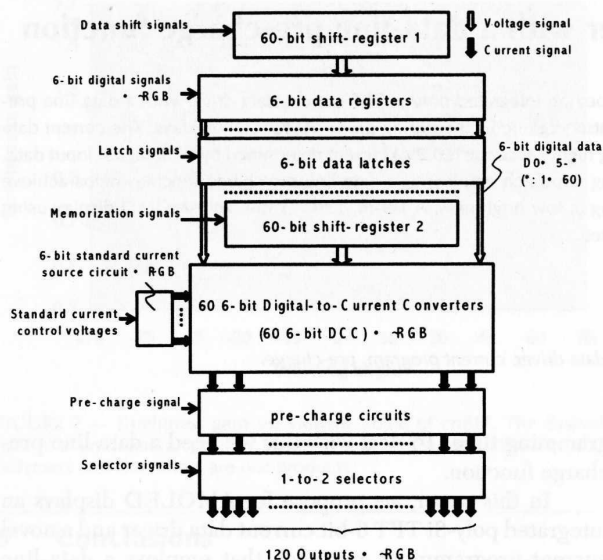


FIGURE 1 — Block diagram of current data driver, which contains shift register 1, 6-bit data registers, 6-bit data latches, shift-register 2, 6-bit digital-to-current converters (DCCs), a standard current source circuit, pre-charge circuits, and 1-to-2 selectors.

6-bit DCCs. The output timing of the scanning signals is synchronous with the 6-bit DCC's operation of memorizing the values of current supplied by the standard current source circuit.

2.2 1-bit digital-to-current converter

The current-copier-type 1-bit DCCs of which the 6-bit DCC is composed are able to output a highly accurate cur-

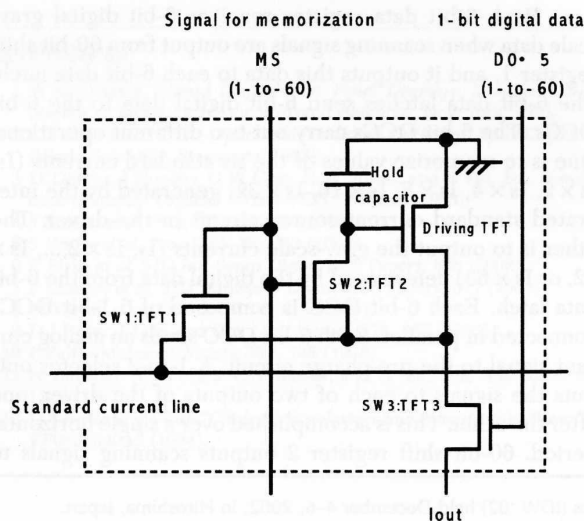


FIGURE 2 — Basic 1-bit current-copier-type DCC, composed of a current-copier circuit and a switching TFT (SW3) controlled by 1-bit digital data signals sent from a 6-bit data latch.

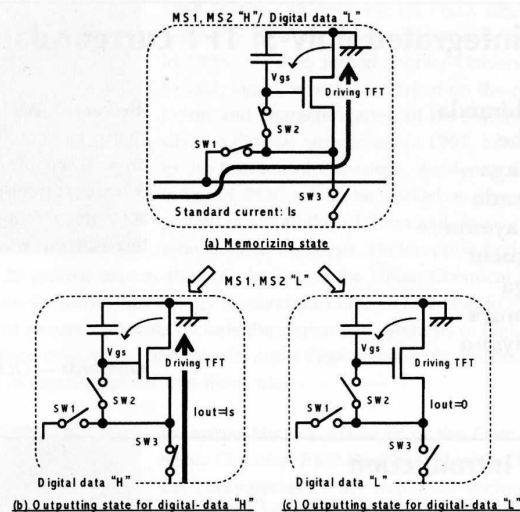


FIGURE 3 — Operation states of the current-copier-type 1-bit digital-to-current converter: the memorizing state, the outputting state for 1-bit data "H," and the outputting state for 1-bit data "L."

rent. In this section, in order to clarify what makes this accuracy possible, we give a detailed explanation of the 1-bit DCC's design and operations.

Figure 2 shows the basic circuit of a 1-bit DCC. It is composed of a current-copier circuit and a switching TFT (SW3) controlled by 1-bit digital data signals sent from a 6-bit data latch. The current-copier circuit is composed of a driving TFT, two memorizing-switches TFT (SW1, SW2) controlled by a signal [MS (1-to-60)] sent from 60-bit shift register 2, and a hold capacitor.

Figure 3 shows the three operation states of the 1-bit DCC: the memorizing state, the outputting state for 1-bit data "H," and the outputting state for 1-bit data "L." In the memorizing state, SW1 and SW2 are ON, SW3 is OFF, and the hold capacitor and the gate capacitor of the driving TFT have been charged in order to send a standard current (I_s , $I_s \times 2$, $I_s \times 4$, $I_s \times 8$, $I_s \times 16$, or $I_s \times 32$) into the driving TFT (in Fig. 3, this current is " I_s "). In the outputting states, SW1 and SW2 are OFF, SW3 is ON or OFF, and the driving TFT outputs " I_s " or zero so that the hold capacitor and the driving TFT's gate capacitor can retain their charge so as to send " I_s ." Note that of the four TFTs in this 1-bit DCC, three are switches; the fourth is the "driving TFT" used for memorizing and outputting.

2.3 Experiments

We have experimentally fabricated the 6-bit DCC described above. Its measured output characteristics are shown in Fig. 4. Here, the output current value of the driver increases as the value of the gray scale increases, which indicates 6-bit monotony for the current output. Figure 5 shows deviations among the MSB (63 gray-scale) output currents for four outputs in each frame, as measured for five

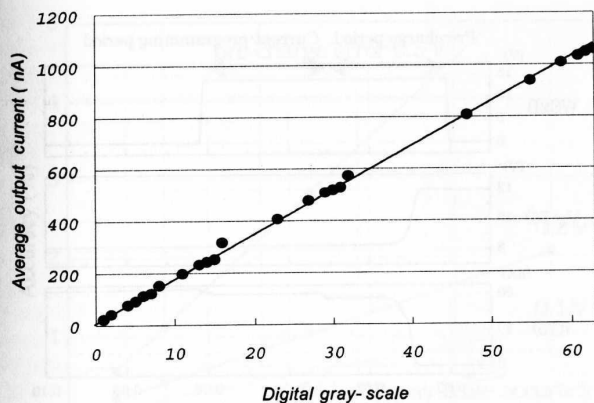


FIGURE 4 — Current driver output characteristics.

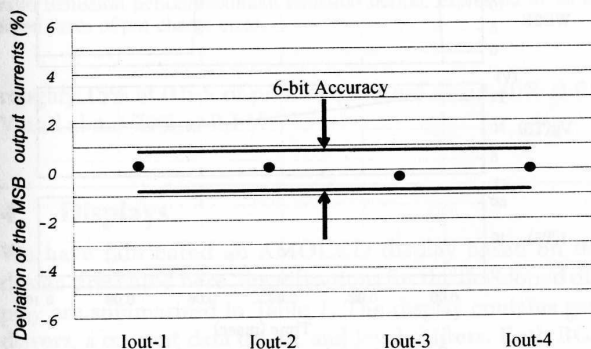


FIGURE 5 — Deviation among four output currents for four outputs in each frame, as measured for five samples.

samples. As may be seen, at MSB, where the output current is the highest, the current driver satisfies 6-bit accuracy ($\pm 0.8\%$) requirements.

3 Novel current-programming approach with data-line pre-charge function

As previously noted, the 6-bit DCCs are able to output current accurately, with 6-bit resolution. The problem of long current-programming time remains, however, and in this section we explain our novel current-programming approach, which employs a data-line pre-charge function in order to reduce current-programming times and to achieve accurate current-programming at low gray-scale levels. This approach has become possible because the current data driver has been integrated into the display substrate itself.

3.1 Circuit design

Figure 6 is a diagram of both the pixel circuit and the integrated current data driver containing a pre-charge circuit. The pre-charge circuit is composed of one TFT (T1) and a voltage-follower amplifier. TFTs (T2 ~ T4) are switching TFTs. The current source indicated in the diagram represents a 6-bit DCC which generates an analog current on the basis of 6-bit digital data that has been input to it, as was previously noted in Section 2. The output of the data driver is connected to a data line *via* a selector, which is used to select an appropriate data line for connection.

The pixel circuit contains five TFTs: one driving TFT (T5) and four switching TFTs (T6 ~ T9). The gate length and width of the driving TFT (T5) are designed to be the same as those of the driving TFT in the pre-charge circuit. The switching TFTs are controlled by signals that are output by an integrated gate driver to three pixel circuit inputs [Write scan1 (WS1), Write scan 2A/B (WS2A/B), and Erase scan (ES)]. In order to control the emission period, the switching TFT (T8) is used to cut off the current to the OLED, and the switching TFT (T9) is used to initialize the OLED.

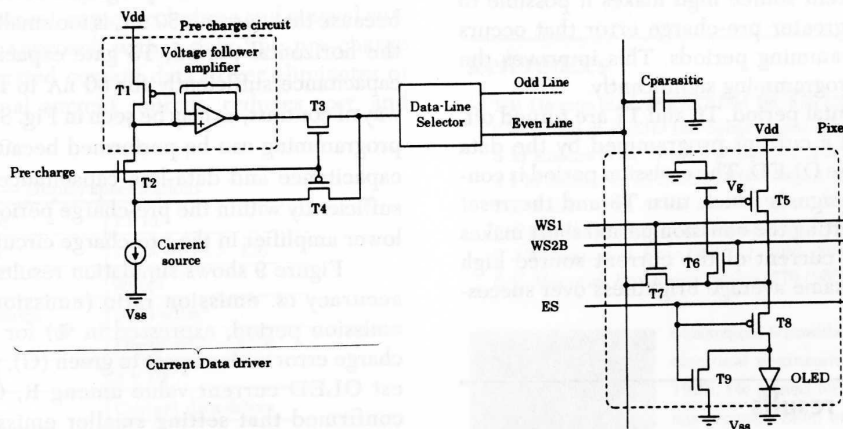


FIGURE 6 — The schematic diagram of both the pixel circuit and the current data driver with the pre-charge circuit.

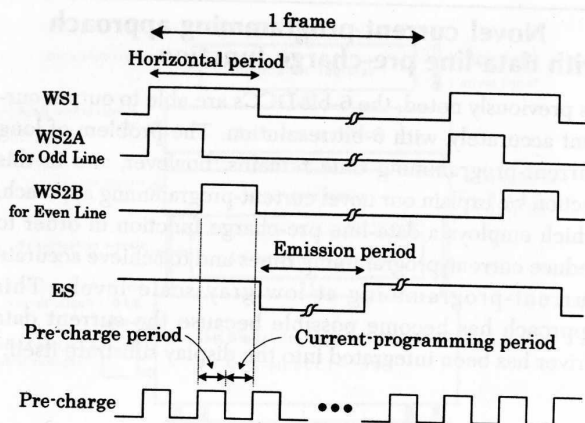


FIGURE 7 — Timing chart illustrating current data driver and pixel circuit operations. The signals Write scan1 (WS1), Write scan 2A/B (WS2A/B), and Erase scan (ES) are output by an integrated gate driver.

3.2 Circuit operations

Figure 7 is a timing chart which illustrates how the current data driver and pixel circuit work.

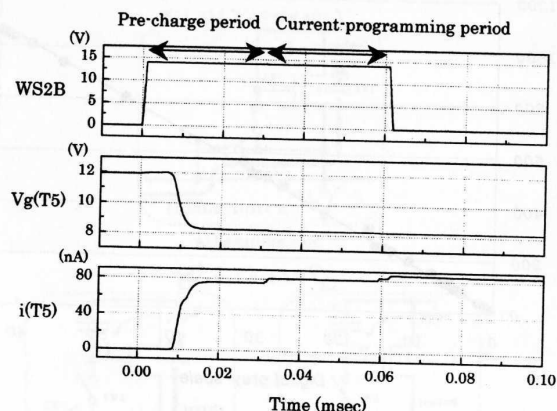
A single horizontal period contains both the pre-charge and current-programming periods. In the pre-charge period, T2 and T3 are turned on, T4 is turned off, and current from the current source flows into T1. A voltage-follower amplifier outputs the gate voltage of T1 into the gate electrode of T5, with T6 and T7 turned on. This pre-charge function rapidly pre-charges the voltage in the gate electrode of T5 so that a current roughly equivalent to the value of the current source flows through T5.

In the subsequent current-programming period, T4 is turned on, T2 and T3 are turned off, the pre-charge circuit is disconnected, and the current from the current source is directly supplied to the pixel circuit. While a pre-charge error may be generated if there exist variations in characteristics between T1 and T5, or if there is an offset voltage in the voltage-follower amplifier, this error can be compensated for during current-programming periods. Setting the current from the current source high makes it possible to compensate for the greater pre-charge error that occurs during current-programming periods. This improves the accuracy of current programming significantly.

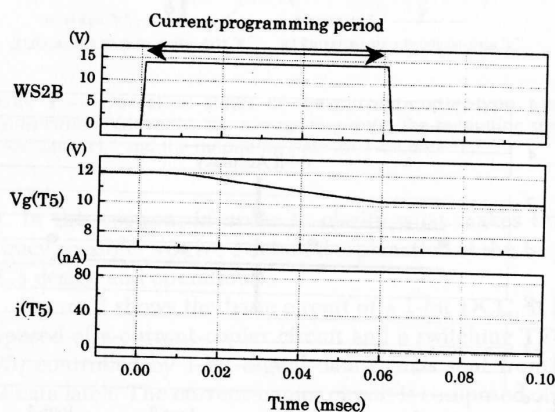
After the horizontal period, T6 and T7 are turned off, T8 is turned on, and a current programmed by the data driver is supplied to the OLED. The emission period is controlled by erase-scan signals which turn T8 and the reset TFT T9 on and off. Setting the emission period short makes it possible to set the current of the current source high enough to obtain the same average brightness over successive frame periods.

3.3 Simulation results

Figures 8(a) and 8(b) show, respectively, simulation results for transient response in cases both with and without pre-



(a) Pixel-driving with pre-charge



(b) Pixel-driving without pre-charge

FIGURE 8 — Simulation results for transient response in cases both with (a) and without (b) pre-charge. Both (a) and (b) show response for levels from the current source of from 0 to 80 nA.

charge. Both show response for levels from the current source of from 0 to 80 nA. As may be seen in Fig. 8(b), without pre-charge, the value of the current from the current source cannot be programmed into the pixel circuit because that current, 80 nA, is too small to discharge, within the horizontal period, T5 gate capacitance and data-line capacitance sufficiently for 80 nA to flow through T5. By way of contrast, as may be seen in Fig. 8(a), with pre-charge, programming can be performed because both the T5 gate capacitance and data-line capacitance can be discharged sufficiently within the pre-charge period by the voltage-follower amplifier in the pre-charge circuit.

Figure 9 shows simulation results for OLED current accuracy vs. emission ratio (emission period/maximum emission period, expressed in %) for three cases of pre-charge error with respect to green (G), which has the smallest OLED current value among R, G, and B. We have confirmed that setting smaller emission periods makes higher accuracy possible. We have also found that a 64-level gray scale can be achieved by setting the emission ratio to

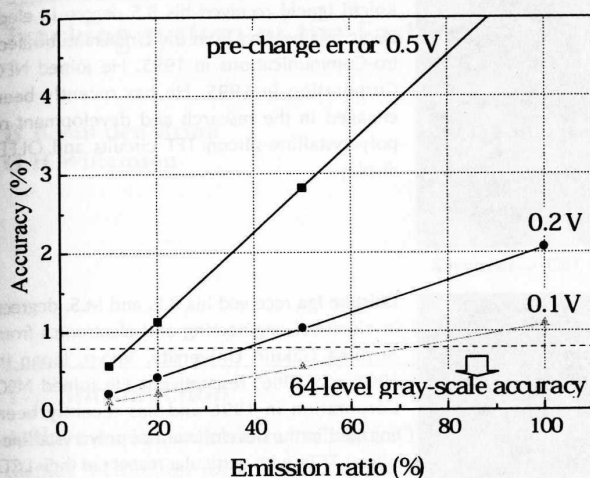


FIGURE 9 — Simulation results for OLED current accuracy vs. emission ratio (emission period/maximum emission period, expressed in %) for three cases of pre-charge error.

roughly 15% at 0.5 V of pre-charge error, about 40% at 0.2 V, and about 70% at 0.1 V.

4 Displays

We have fabricated an AMOLED display based on the design presented here. Specifications for the developed display are summarized in Table 1. The display contains gate drivers, a current data driver, and level shifters. Both RGB digital data signals (6 bits each) and digital control signals are supplied at 3 V from an external controller. Figure 10 shows a sample display image. Here, the emission ratio is about 40%. Good pixel-to-pixel luminance uniformity and gray-scale images have been achieved with this display.

5 Conclusion

We have developed an integrated poly-Si TFT current data driver based on a current-copier technique and a novel current-programming approach with a data-line pre-charge function. The integrated current data driver eliminates of the need for external current sources, reduces cost, and

TABLE 1 — Display specifications.

Display size	1.9 in.
Pixel count	120 × RGB × 136
Pixel pitch	96 ppi
Peak luminance	>150 cd/m ²
Input data	Digital 6 bit × RGB
Input level	3 V I/F
Integrated circuits	Current data driver
	Gate driver
	Level shifter

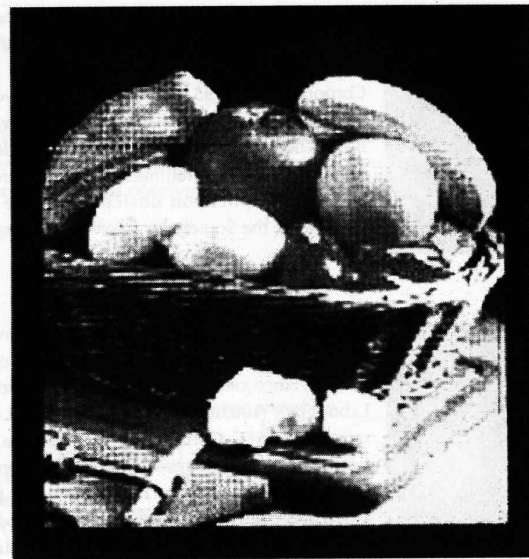


FIGURE 10 — Image on the fabricated AMOLED display.

This figure is reproduced in color on page 592.

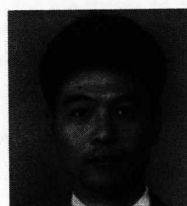
increases reliability in AMOLED display systems, and the novel current-programming approach improves the accuracy of current programming at low brightness. These circuits make it possible to produce AMOLED displays with good gray-scale image quality and good pixel-to-pixel luminance uniformity.

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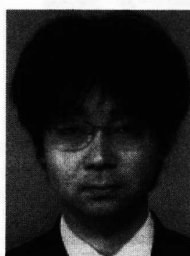
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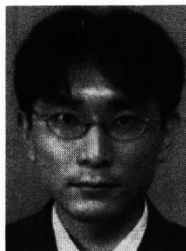


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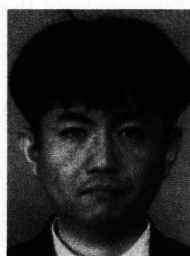


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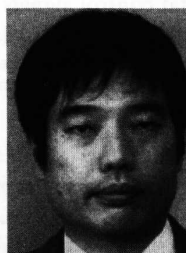


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