Novel Compensation Pixel Circuit with Simultaneous Emission Driving Scheme for High-Resolution AMOLED Displays

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ABSTRACT

This proposed work using simultaneous emission (SE) driving scheme to compensate for the V_{TH} variations of LTPS TFTs for high-resolution AMOLED displays. Simulated results demonstrate that the relative current error rates are all below 3.5% when V_{TH} of driving TFT varies by ±0.5 V.

1 INTRODUCTION

Active-matrix organic light-emitting diode (AMOLED) displays have become the trend of screen technology because of the characteristic of self-emission, high contrast ratio, wide viewing angle, and fast response time [1], [2]. Low-temperature polycrystalline silicon (LTPS) backplanes have been frequently employed in AMOLED displays owing to the advantages of high current driving ability and stable electrical characteristics. [3], [4]. In spite of these benefits, LTPS thin-film transistors (TFTs) have different threshold voltage (V_{TH}) values from one another on panels, resulting in non-uniform luminance problems and poor image quality [5]. Moreover, for pursuing better visual experience, pixel circuits with high speed programming are greatly needed. Several approaches for compensating TFTs have been proposed in accordance with high-resolution panels. Lin *et al.* [6] presented a 4-TFT circuit with parallel driving schemes for the compensation of V_{TH} shift and luminance drops. Fan *et al.* [7] proposed a 5-TFT circuit with simultaneously emission (SE) driving schemes for detecting V_{TH} variations of driving TFTs and current-resistance (I-R) drop problems. Although these abovementioned circuits successfully compensate V_{TH} variations in high-resolution panels, the flicker problem induced by flowing current into the OLED in transient period causes image quality a lower contrast ratio [8]. Furthermore, almost all of the compensation circuits for high-frame-rate or high-resolution panels have complex structure including numbers of TFTs and signal lines, compared with two-TFT and one-capacitor (2T1C) structure of the conventional pixel circuit. Without simple structure, the circuits cannot be realized in the small layout area. In addition, complicated structure brings more instable factors and lower aperture ratio. Chen *et al.* [9] proposed a three-TFT pixel circuit using one control signal with mirror compensation. The circuit is quite simple but unfortunately it is unsuitable for high-resolution panels because of finite time for compensation. Another way to realize simple pixel structure for detecting V_{TH} variations in high-resolution panels is by using external compensation circuits [10]. However, it will be massive mathematical operation and high costs in the external circuit system.

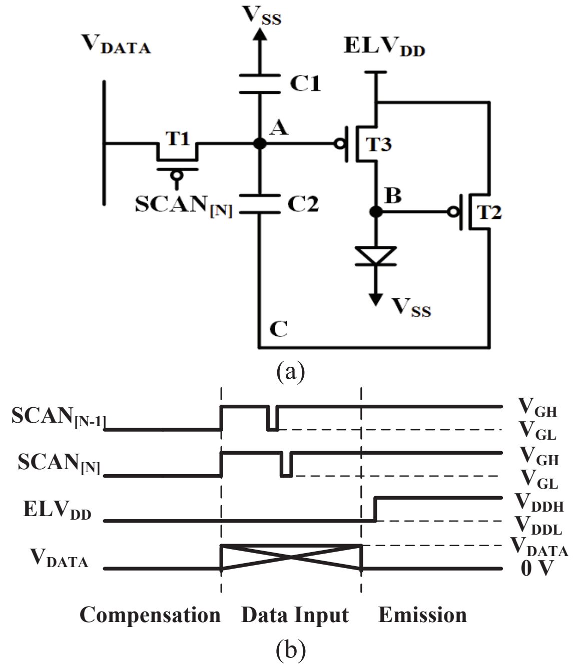


Fig. 1. Proposed pixel circuit. (a) Schematic diagram. (b) Timing diagram.

In this work, a concise 3T2C pixel circuit is proposed, adopting SE driving schemes in order to suit for high-resolution panels. With the design of matching structure, our proposed circuit can compensate V_{TH} variations of driving TFT and only one control signal is needed. By using source follower structure to discharge anode voltage of the OLED to ELV_{DD} for V_{TH} detection, all OLEDs in panels are turned off during the non-emission period. Therefore, flicker phenomenon is completely eliminated. Based on the simulated results, the current error rates are below 3.5% for the whole range of date voltage when V_{TH} of driving TFT varies from -0.5 V to 0.5 V. Accordingly, the proposed pixel circuit proves its effectiveness.

TABLE I

PARAMETERS OF PROPOSED PIXEL CIRCUIT

Parameter	Value	Parameter	Value
SCAN1 (V)	-15 ~ 15	$(W/L)_{T1}$ (μm/μm)	3/3
ELV_{DD} (V)	0 ~ 12	$(W/L)_{T2,\,T3}$ (μm/μm)	3/22
V_{SS} (V)	4.5	$(W/L)_{TOLED}$ (μm/μm)	7/25
V_{DATA} (V)	5.55 ~ 6.45	C1 (pF)	0.15
C_{OLED} (pF)	0.1	C2 (pF)	0.15

2 CIRCUIT SCHEMATIC AND OPERATION

Fig. 1 depicts the diagram of the proposed pixel circuit and its corresponding timing chart. This circuit is composed of three p-type LTPS TFTs (T1-T3) and two capacitors (C1 and C2). T1 is used to connect data line and node A so that the pixel can receive specific data voltage (V_{DATA}) from source integrated circuits (ICs). T2 is assumed to be the same electrical characteristics with driving TFT (T3) so that the circuit can generate exactly $2V_{TH}$ to accomplish compensation. T3 is a driving TFT in order to drive the OLED, and the source-gate voltage of the T3 will determine the value of currents flowing through the OLED in the emission period. SCAN[N] is a control signal for the [N]th row. The operation of the proposed circuit can be separated into three periods as the following.

(1). Compensation period:

SCAN[N] goes low to turn on T1. Node A is discharged to 0 V. Meanwhile, ELV_{DD} goes to 0 V (V_{DDL}) as well. Thus, node B which originally stores emission voltage of the OLED from the previous frame starts discharging through T3 to ELV_{DD}. Furthermore, T2 becomes another source follower structure with the gate voltage of V_B and the drain voltage of V_{DDL} (0 V). Therefore, node C is discharged through T2 to ELV_{DD}. At the end of this period, V_B and V_C becomes,

$$V_B = \left|V_{TH\_T3}\right| \tag{1}$$

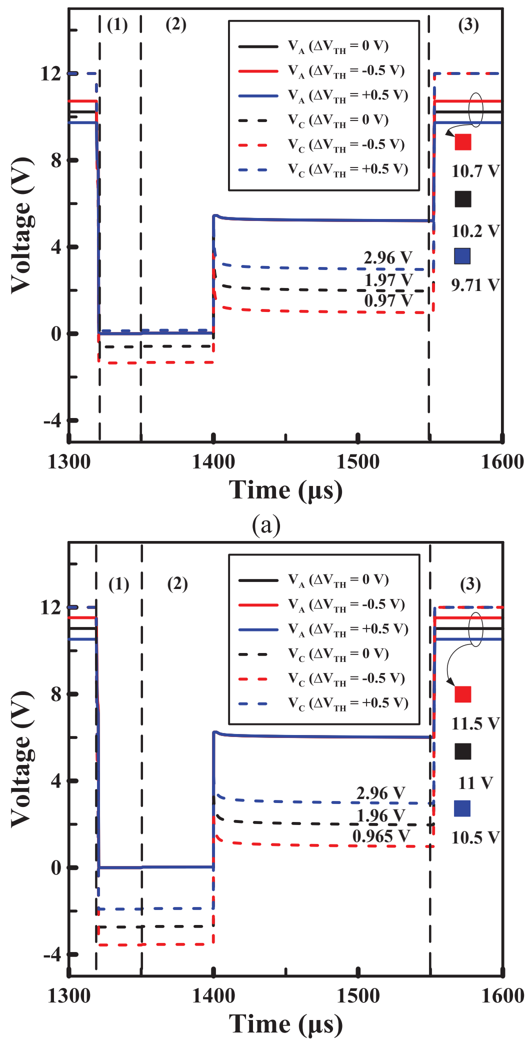
$$V_C = \left|V_{TH\_T2}\right| + \left|V_{TH\_T3}\right| \tag{2}$$

,where V_{TH_T2} and V_{TH_T3} are the threshold voltage of TFT T2 and TFT T3. As mentioned earlier, T2 and T3 are assumed to be the same electrical characteristic. Then, V_C can be further expressed as,

$$V_C = 2\cdot\left|V_{TH\_T3}\right| \tag{3}$$

(2). Data Input period：

When SCAN[N] changes from high to low voltage (V_{GL}), T1 is turned on and node A is charged to V_{DATA}. Meanwhile, node C is coupled to $2|V_{TH\_T3}| + V_{DATA}$ and



(b)

Fig. 2. Transient waveforms of nodes A and C of proposed 3T2C pixel circuit with V_{TH} variations in condition of (a) high gray level and (b) low gray level.

starts discharging current through T2 to ELV_{DD}. At the end of this period, V_C becomes,

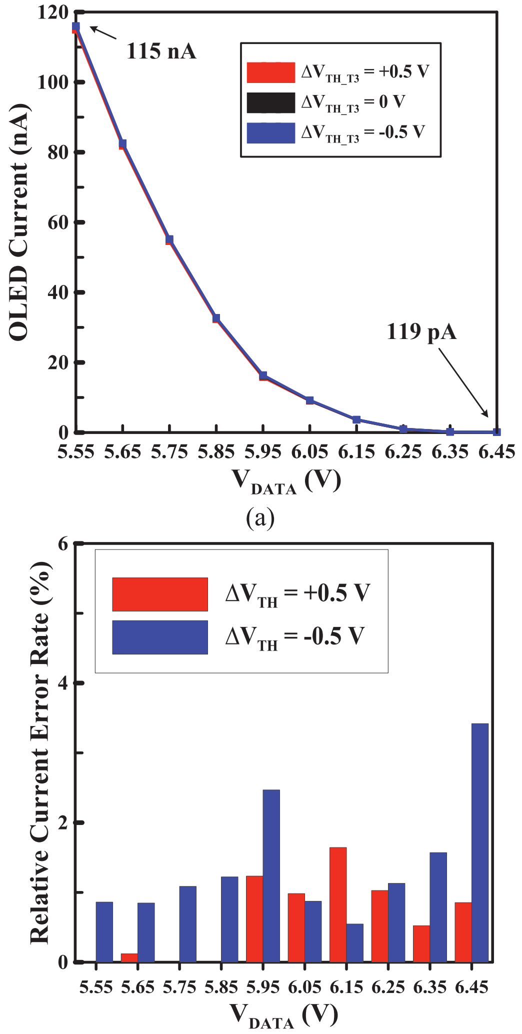
$$V_C = 2\cdot\left|V_{TH\_T3}\right| \tag{4}$$

Since C1 and C2 are designed to be an identical capacitance and V_C changes from $2|V_{TH\_T3}| + V_{DATA}$ to $2|V_{TH\_T3}|$, V_A becomes,

$$V_A = \left(\frac{C1}{C1+C2}\right)\cdot V_{DATA} = \frac{1}{2}V_{DATA} \tag{5}$$

(3). Emission period：

SCAN[N] is at V_{GH} and T1 is turned off. Because node B is at low level voltage, T2 is already turned on. When ELV_{DD} turns to V_{DDH}, node C is set to V_{DDH} immediately. Therefore, V_A is coupled to,



(a)

(b)

Fig. 3. (a) OLED currents versus data voltages (b) Relative current error rates of proposed 3T2C pixel circuit with V_{TH} variations of ±0.5 V.

$$V_A = \frac{1}{2}V_{DDH} + \frac{1}{2}V_{DATA} - |V_{TH\_T3}| \tag{6}$$

Consequently, T3 is in the saturation region and the current can be expressed as,

$$\begin{aligned} I_{OLED} &= \frac{1}{2}\mu_{T3}C_{OX}(\frac{W}{L})_{T3}\left(V_{SG} - |V_{TH\_T3}|\right)^2 \\ &= \frac{1}{2}\mu_{T3}C_{OX}(\frac{W}{L})_{T3}\left(V_{DDH} - \left(\frac{1}{2}V_{DDH} + \frac{1}{2}V_{DATA} - |V_{TH\_T3}|\right) - |V_{TH\_T3}|\right)^2 \\ &= \frac{1}{2}\mu_{T3}C_{OX}(\frac{W}{L})_{T3}\left(\frac{1}{2}V_{DDH} - \frac{1}{2}V_{DATA}\right)^2 \end{aligned} \tag{7}$$

According to the equation (7), the item $|V_{TH\_T3}|$ has been eliminated, which means the V_{TH} of driving TFT does not affect the value of I_{OLED}. Therefore, the uniformity of current for good image quality of display devices is ensured.

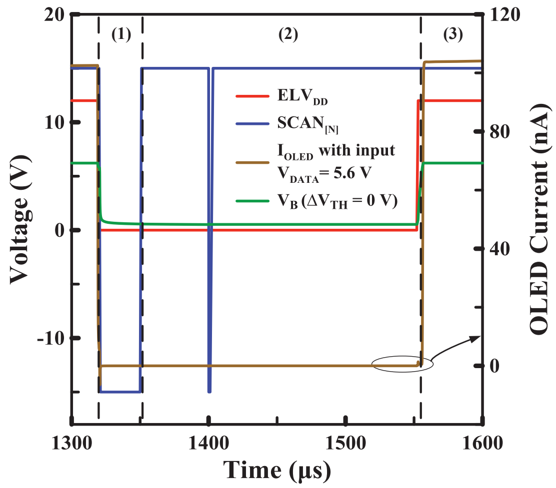


Fig. 4. Simulated waveforms of ELV_{DD}, SCAN[N], V_B and OLED current with V_{DATA} = 5.6 V.

3 RESULTS AND DISCUSSION

To verify the feasibility of the proposed circuit, we used HSPICE software to do simulation and analysis. Table 1 lists all the designed parameters of the proposed pixel circuit in this work. The width and the length of T3 are 3 μm and 22 μm, respectively. The size of T2 which is used for matching the same characteristic of driving TFT is emulated 3 μm of width and 22 μm of length as well. T1 is 3 μm wide and 3 μm long. The OLED is modeled by a p-type diode-connection TFT with an aspect ratio of 7 μm / 25 μm and a 0.1 pF capacitor in parallel connection. Both storage capacitors, C1 and C2, are designed to 0.15 pF. SCAN[N] is from -15 V to 15 V. V_{DATA} ranges between 5.55 V and 6.45 V. V_{DDL} and V_{DDH} of ELV_{DD} are 0 V and 12 V. The constant voltage of V_{SS} is 4.5 V. In order to suit the requirements of 5.15 inch Full HD (1080×1920) panels, SCAN[N] signal is simulated for approximately 2 μs to turn on T1 each row in the data-input period. Fig. 2(a) and Fig. 2(b) plot the transient waveforms of V_A and V_C of the proposed circuit with driving TFT V_{TH} variations when high gray data voltage (V_{DATA} = 5.6 V) and low gray data voltage values (V_{DATA} = 6.3 V) are fed in respectively. The simulation results show that $2V_{TH}$ values which are approximately 0.96 V, 1.96 V and 2.96 V are stored in node C before the emission period. After ELV_{DD} changes to 12 V, the difference of V_{TH} is coupled to node A so that the uniform currents can be generated for driving OLEDs in the emission period. Fig. 3(a) simulates the OLED currents versus data voltages when driving TFT V_{TH} varies ±0.5 V. The results present that OLED currents are almost the same in every data voltage, revealing the non-uniform luminance problem caused by V_{TH} variations is solved. Fig. 3(b) shows the relative current error rates for the whole range of V_{DATA} with ±0.5 V ΔV_{TH} of driving TFT. Since all relative current error rates are under 3.5%, the proposed circuit proves its effective suppression of V_{TH} variations. Fig. 4 illustrates the simulated waveforms of I_{OLED} when input V_{DATA} is 5.6 V. As shown in this figure, V_B which is also the anode voltage of the OLED is less than the constant voltage V_{SS} during the compensation period and data-input period, indicating that there is no current flowing into OLEDs during the non-emission period. Hence the flicker phenomenon is totally eliminated in the proposed 3T2C pixel circuit.

4 CONCLUSION

In this paper, a concise p-type LTPS 3T2C pixel circuit with the SE driving scheme is proposed. By two identical TFTs connected into two source-follower structures, the proposed circuit is able to detect doubled value of threshold voltage ($2V_{TH}$) with only one control signal. Moreover, by utilizing the anode voltage for detecting V_{TH} value, the reverse bias on OLEDs eliminated flicker phenomenon during the non-emission period. Based on the simulated results, the current error rates are within 3.5% for the all range of data voltage. Hence the proposed pixel circuit can realize uniformity luminance and flicker-free for the use in high-resolution applications.

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