A Novel AMOLED Pixel Circuit to Alleviate Effects of Leakage Current using Additional Compensation Leakage Current Path

Yi-Jui Chen[1], Fang-Yi Lin[1], Jui-Hung Chang[1], Po-Chun Lai[2], and Chih-Lung Lin[1]

E-mail: cllin@ee.ncku.edu.tw
[1]Department of Electrical Engineering, National Cheng Kung University, No.1, University Road, Tainan 701-01, Taiwan R.O.C.
[2]AU Optronics Corp., Hsinchu Science Park, Hsinchu 300-78, Taiwan, R.O.C.
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ABSTRACT

This work proposes a new AMOLED pixel circuit compensating for the threshold voltage (V_{TH}) of driving TFTs and V_{DD} I-R drop. Moreover, the effect of large leakage currents for LTPS TFTs is alleviated. Simulation results show that the relative current error rates are below 4.72% as V_{TH} varies by ±0.5 V.

1 Introduction

Active-matrix organic light-emitting diode (AMOLED) displays with low-temperature polycrystalline silicon thin-film transistors (LTPS-TFTs) have received high attention due to the wide viewing angle, fast response, high contrast ratio, high brightness, and thinness [1], [2]. Owing to the advantages such as high current driving capability and small layout area, LTPS TFTs are appropriate for small/medium size displays. [3]. However, due to the process variation, LTPS TFTs have a threshold voltage (V_{TH}) variation issue that will cause non-uniform driving currents generated by LTPS TFTs [4], [5]. To solve the V_{TH} variations of the driving TFT, several compensation circuits have been proposed [6] – [8]. Dawson et al. [6] proposed a 4T2C pixel circuit which compensates for the V_{TH} variations by using a diode-connected method. However, an unexpected current flowing through the OLED during the compensation period results in the flicker phenomenon, decreasing the contrast ratio of AMOLED displays. Hence, Wu et al. [7] presented a compensation pixel circuit that turn off the OLED by applying a low voltage to the anode of an OLED device. Therefore, no unexpected current flows through the OLED, preventing the image flicker phenomenon. Nevertheless, the direct current that flows from the V_{DD} to the V_{SS} during the precharging period results in large power consumption. For small and medium-sized wearable AMOLED displays, the power consumption is necessary to be reduced to extend the lifetime owing to their small battery capacity. The low frame rate design is an effective method to reduce power consumption. As the frame rate decreases, the charging and discharging frequency of source driver ICs decreases, and also the emission time is prolonged [9], [10]. Because of the long emission time, the voltage stored at the gate node of the driving TFT may be distorted by the leakage current of the LTPS TFTs, resulting in unstable OLED current [11], [12]. Neither of the abovementioned circuits solves the problem of large leakage current, so they cannot maintain a stable OLED current at a low frame rate, leading to poor image quality.

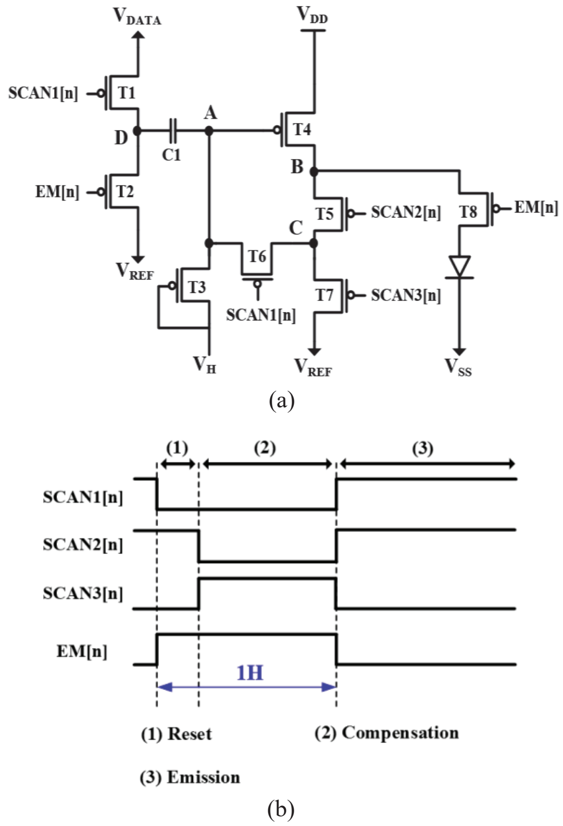


Fig. 1. (a) Schematic and (b) timing diagram of proposed pixel circuit.

In this work, we present a compensation pixel circuit that adopts p-type LTPS TFTs for low-frame-rate AMOLED displays. The proposed circuit can compensate for the V_{TH} variation of the driving TFT and the V_{DD} I-R drop that is caused by the parasitic resistance on the power supply line. Additionally, a leakage compensation scheme is employed in the proposed circuit to alleviate the distortion of the OLED current during emission time. From the simulation, the relative current error rates are less than 4.72% with the V_{TH} variations of the driving TFTs are ±0.5 V. Compared to the conventional 4T2C pixel circuit, the proposed circuit significantly ameliorates the leakage current under long emission time and reduces the voltage distortion at the gate node of driving TFT, verifying that the circuit can maintain a stable OLED current.

Therefore, the proposed circuit is appropriate for low-frame-rate AMOLED displays.

2 Circuit Operation and Driving Mechanism

Fig. 1(a) is the proposed AMOLED pixel circuit, and Fig. 1(b) shows the timing diagram of its control signals. This circuit consists of eight TFTs and one capacitor. T4 is the driving TFT, and other TFTs (T1-T3, T5-T8) are the switching TFTs. The circuit operation is divided into the following three stages:

(1) Reset period: SCAN1[n] is low to turn on T1 and T6, and SCAN3[n] is also low to turn on T7. SCAN2[n] and EM[n] are high to turn off T2, T5, and T8. The voltage of nodes A and C are reset to V_{REF}, and node D is charged to V_{DATA}. In the proposed circuit, the current flowing through the OLED is blocked by turning off TFT T8 to suppress flicker phenomenon. Also, T3 is used to achieve leakage compensation, and the gate and source nodes of T3 are connected to V_H to keep T3 turned off at all stages.

(2) Compensation and data input period: SCAN2[n] goes low to turn on T5, and SCAN1[n] remains low to turn on T1 and T6. SCAN3[n] goes high to turn off T7. Hence, T4 becomes diode-connected, and nodes A and C are charged to V_{DD} - $|V_{TH\_T4}|$, where V_{TH_T4} is the threshold voltage of T4. Additionally, T1 remains turned on to maintain node D at V_{DATA}, and T8 remains turned off to keep OLED turned off.

(3) Emission period: SCAN1[n] and SCAN2[n] become high to turn off T1, T5, and T6. SCAN3[n] and EM[n] become low to turn on T2, T7, and T8. Node D is charged from V_{DATA} to V_{REF}. Owing to the capacitive coupling effect of C1, the voltage of node A (VA) is coupled as follows:

$$V_A = V_{DD} - |V_{TH\_T4}| + V_{REF} - V_{DATA} \tag{1}$$

where T4 is operated at the saturation region and starts to generate OLED current. Accordingly, the OLED current can be calculated as the following equation:

$$\begin{aligned} I_{OLED} &= \frac{1}{2}k\left(V_{SG} - |V_{TH\_T4}|\right)^2 \\ &= \frac{1}{2}k\left[V_{DD} - \left(V_{DD} - |V_{TH\_T4}| + V_{REF} - V_{DATA}\right) - |V_{TH\_T4}|\right]^2 \\ &= \frac{1}{2}k(V_{DATA} - V_{REF})^2 \end{aligned} \tag{2}$$

where k is $\mu \cdot C_{OX} \cdot W/L$ of T4. As shown in Eq. (2), the V_{TH} of T4 and the power supply voltage, V_{DD}, are eliminated. Therefore, a highly uniform OLED current can be generated by the proposed pixel circuit even if the V_{TH} of TFTs varies or the deviation in V_{DD} occur. Although the OLED current is not affected by the threshold voltage variation and the V_{DD} I-R drop, the large leakage current of LTPS TFTs is still a problem. Due to a low-frame-rate operation applied to the proposed circuit, the emission time is greatly prolonged. The leakage current of the LTPS TFTs will cause the gate voltage of the driving TFT to be distorted at this long emission time, thereby affecting the stability of the OLED current. In order to alleviate the effect of leakage current on the OLED current during the emission time, a compensation structure is designed in the proposed circuit. The voltage at node A will be decreased by the leakage path formed by T6 and T7. To compensate for the leakage current, T3 is added to provide the compensating leakage current. Because V_H is higher than V_A, T3 forms a compensation leakage current path. The voltage variation of node A is reduced by balancing leakage currents at node A, enhancing the stability of the OLED current under the emission period. Consequently, the proposed circuit is feasible for low-frame-rate displays.

Table I
DESIGNED PARAMETERS OF PROPOSED PIXEL CIRCUIT

Parameter	Value	Parameter	Value
(W/L) T1-T3, T5-T8 (µm/µm)	3/3	(W/L) T4 (µm/µm)	3/22
SCAN1, SCAN2 (V)	-4 – 5	V_{REF} (V)	-1.5
SCAN3, EM (V)	-4 – 5	C1 (pF)	0.4
V_{DD} (V)	3.3	V_{DATA} (V)	-1.53 – -0.81
V_{SS} (V)	-3.3	1 H (µs)	46

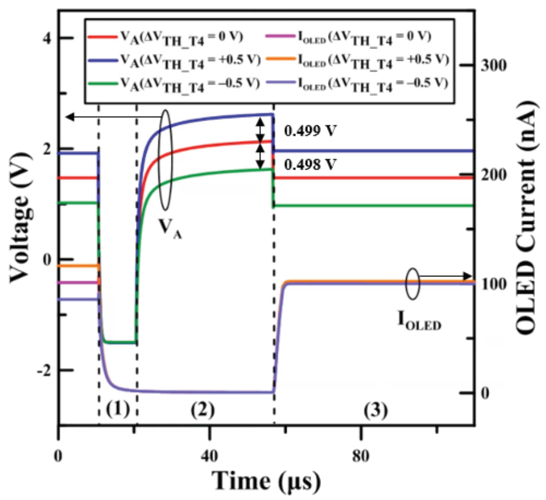
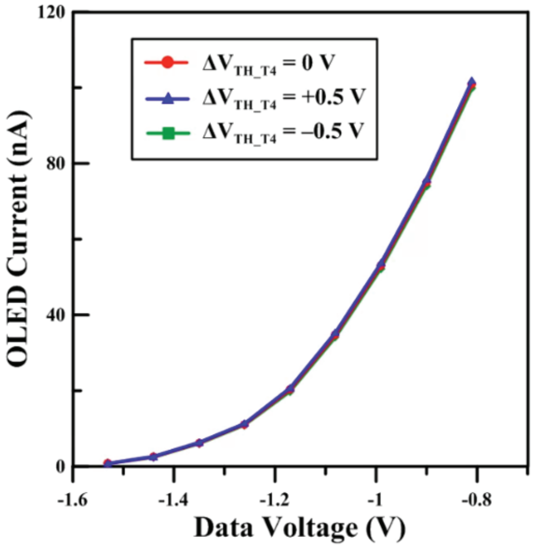


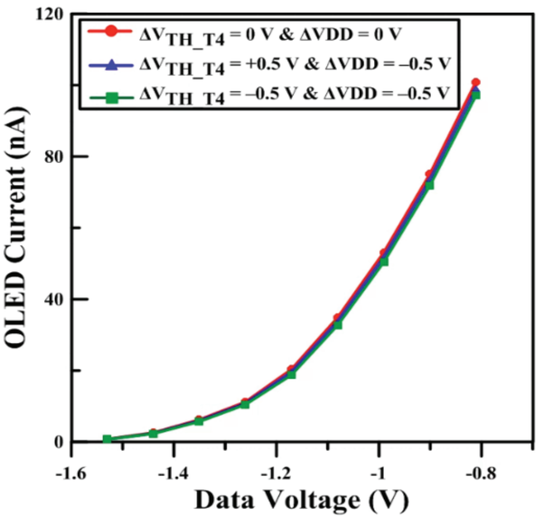
Fig. 2. Transient waveforms of node A and OLED currents as V_{TH} varies by ±0.5 V.

3 Results and Discussions

To verify the proposed AMOLED pixel circuit for use in a 1.41-inch 320×360 display at the frame rate of 15 Hz, the proposed circuit is simulated by using an HSPICE simulator. Fig. 2 plots the simulated transient waveforms of node A and OLED currents with the V_{TH} variations of driving TFTs are ±0.5 V. The differences of the voltages at node A at the end of the compensation and data input period are +0.499 V and −0.498 V, which approximates the V_{TH} variation of ±0.5 V, confirming the compensation capability of the proposed circuit. Fig. 3(a) presents OLED currents versus the data voltages when the V_{TH} variations of the driving TFTs are ±0.5 V, and



(a)



(b)

Fig. 3. Simulated OLED currents versus data voltages when (a) V_{TH} variations of driving TFTs are ±0.5 V, and (b) V_{TH} variations of driving TFTs are ±0.5 V and V_{DD} drops 0.5 V.

Fig. 3(b) shows OLED currents at different data voltages when V_{TH} varies by ±0.5 V and V_{DD} drops 0.5 V. As shown in Figs. 3(a) and 3(b), neither the V_{TH} variation nor the V_{DD} I-R drop affects the uniformity of the OLED current generated by the pixel circuit. Fig. 4 plots the relative current error rates of the proposed pixel circuit for the TFT V_{TH} variations are ±0.5 V. The relative current error rates are all below 4.72%, confirming that the proposed circuit can generate high uniformity display images. To verify the feasibility of the leakage current compensation mechanism, the variations in the OLED current of the proposed pixel circuit and the conventional 4T2C pixel circuit under the 66.67 ms emission period are compared in Fig. 5. At low, medium, and high gray levels, the increases of the

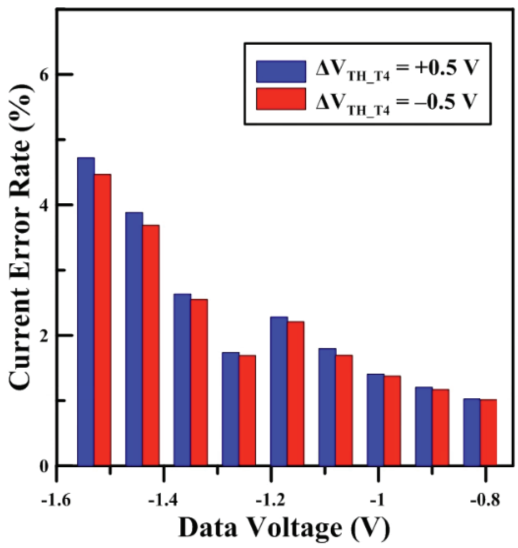


Fig. 4. Relative error rates of OLED currents with V_{TH} variations of ±0.5 V.

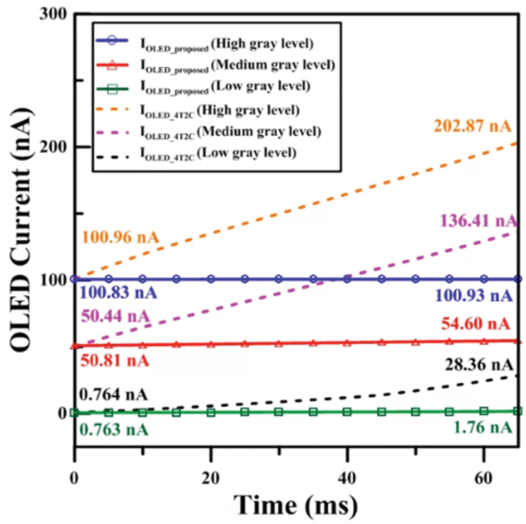


Fig. 5. Variations of OLED currents of proposed pixel circuits and conventional 4T2C pixel circuits during emission time.

OLED currents of the conventional 4T2C circuit are 27.6 nA, 85.97 nA, and 101.91 nA, respectively, under long emission time. In contrast, the OLED current variation of the proposed circuit is only 1 nA, 3.79 nA, and 0.1 nA at low, medium and high gray levels, respectively. The proposed leakage compensation mechanism can successfully compensate for the distortion of the OLED current results from the leakage current. Consequently, the stable images can be obtained in low-frame-rate displays.

4 Conclusions

A new p-type LTPS pixel circuit used in low-frame-rate AMOLED displays is proposed. By using the diode-connected compensation method, the threshold voltage variations and the

V_{DD} I-R drops are successfully compensated. The OLED current distortion caused by the leakage current under the long emission period is alleviated by using the designed compensation mechanism. From the simulation, the relative current error rates of the OLED currents are less than 4.72% with the V_{TH} variations of the driving TFTs are ±0.5 V. Furthermore, the variations in the OLED current during the emission period were reduced to 1 nA, 3.79 nA, and 0.1 nA at low, medium, and high gray levels, respectively. Consequently, the simulation results verify that the proposed pixel circuit is appropriate for the low-frame-rate AMOLED displays.

Acknowledgments

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