An External Compensation Technique for Burn-in Degradation in 30-inch Flexible AMOLED Displays

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Keywords: OLED display, burn-in, image sticking, external compensation.

ABSTRACT

In ultra-high-definition AMOLED displays, external compensation improves burn-in by varying the current through the driving TFT. However, sensing the current through the driving TFT for all pixels is time-consuming because of the increased number of scanning lines. Hence, in this study, we propose an external compensation technique that provides rapid feedback.

1 Introduction

Active-matrix organic light-emitting diode (AMOLED) displays have progressed toward large-size and ultra-high-definition, mainly for television use [1, 2], because of their wide viewing angles, high contrast and fast response time. For large AMOLED displays, oxide thin-film transistor (TFT) backplanes are widely used as driving TFTs to control the pixel current through the OLED device, whose luminance almost in proportion to the current density. Hence, the current must be precisely controlled, and variations in driving TFTs during operation can deteriorate the image quality of displays.

To compensate for the instability of driving TFTs, several approaches have been proposed [3-6]. Among them, in-pixel compensation circuits are unsuitable for large displays because they require more transistors and the manufacturing process is complicated. External compensation circuits are one appropriate method for large ultra-high-definition displays because they are comparatively simple pixel circuits and contain a limited number of transistors.

In an external compensation circuit, because variations in driving TFTs occur during operation, it is necessary to estimate and compensate for them as soon as possible. To estimate the variations, the current through the driving TFT must be sensed in a blanking period while images are reproduced on the display. However, since the current in only one horizontal line can be sensed in a frame period, it is time-consuming to estimate the characteristics of the driving TFTs for all pixels in ultra-high-definition displays. Therefore, in this paper, we propose an external compensation technique to shorten the time required for feedback by reducing the sensing time and interpolating from the surrounding current data.

2 External compensation technique

The external compensation system is shown in Fig. 1. In the display period, the switch, Tr1, is opened and a data voltage is stored in the capacitor, C, of the pixel, and the current corresponding to the data voltage flows

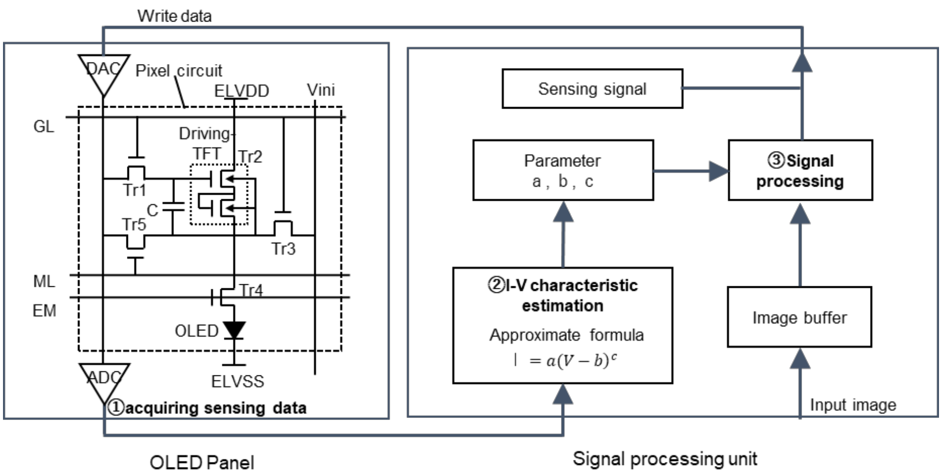


Fig. 1 An example of an external compensation scheme

through the driving TFT. Then, the OLED emits light based on the current. In the sensing period, the switch, Tr5, is opened and the current through the driving TFT flows to the ADC and is acquired as a digital value. By repeating this process, current values corresponding to specific data voltages, are acquired for each pixel. Using these data voltages and current values, the I-V characteristic of the driving TFT in each pixel is estimated using the following formula:

$$I = a(V - b)^c \quad (1)$$

As a result, the I-V characteristic of each pixel can be parameterized by three parameters: a, b, and c, which are stored in the memory of the signal processing unit. In the signal processing unit, by comparing the initial I-V characteristic with the new I-V characteristic of each pixel, a signal level is converted such that the current value flowing through the driving TFT becomes constant.

We now explain the feedback time, which is the update interval of the I-V characteristics for all pixels. Most of the feedback time consists of sensing time to obtain the current values through the driving TFT of all pixels. In a frame, the current values for only a horizontal line can be determined in one measurement. Hence, when there are 2,160 scanning lines, nine measurement points, and four-times averaging to remove noise, it takes about 22 minutes for sensing, as follows:

$$22\ min. \fallingdotseq 77{,}760 \text{ frames} = 2{,}160 \text{ lines} \times 9 \text{ points} \times 4 \text{ times}. \quad (2)$$

In the above example, nine current values for nine data voltages are measured per pixel. If the I-V characteristics for each individual pixel can be estimated by a measurement point, the sensing time can be shortened to 3 minutes, as follows:

$$3 \text{ min.} \fallingdotseq 8{,}640 \text{ frames} = 2{,}160 \text{ lines} \times 1 \text{ points} \times 4 \text{ times}. \quad (3)$$

Hence, to shorten the sensing time, we propose a novel technique for external compensation that estimates the I-V characteristics by reducing the measurement points for each individual pixel.

3 Compensation algorithm

In this section, we describe our proposed compensation algorithm, which consists of three techniques: interpolation from the measurement results for surrounding pixels, selection of measurement points, and estimation of the L-V characteristics from the voltage shift.

Fig. 2(a) shows an example of estimating the I-V characteristics from nine measurement points. Here, (1) to (9) indicate the voltages for measuring the current. In the conventional method, the I-V characteristics are estimated by using a plurality of measurement points at a specific pixel, whereas in our proposed method, the measurement voltage is assigned to each pixel, one-by-one, as shown in Fig. 2(b). When estimating the I-V characteristics of the central pixel (5) in Fig. 2(b), nine measurement results for the surrounding pixels are used to estimate the I-V characteristics. By interpolating from the surrounding pixels in this way, it is possible to estimate the characteristics with a measurement point for each individual pixel, and the sensing time can be reduced. In

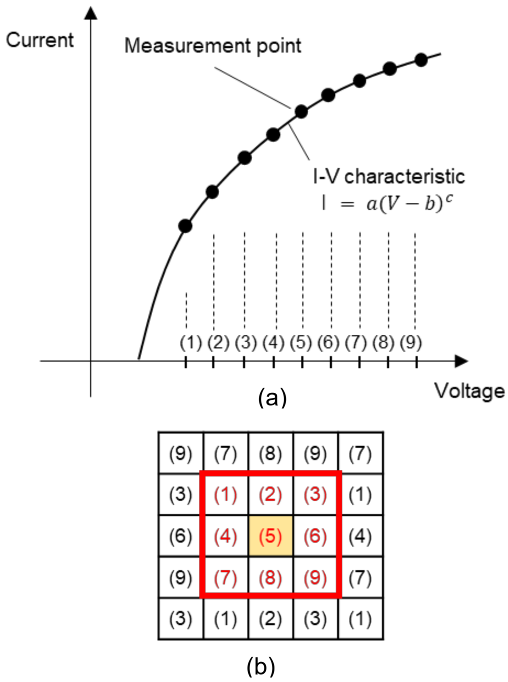


Fig. 2 Interpolation from measurement results for surrounding pixels.

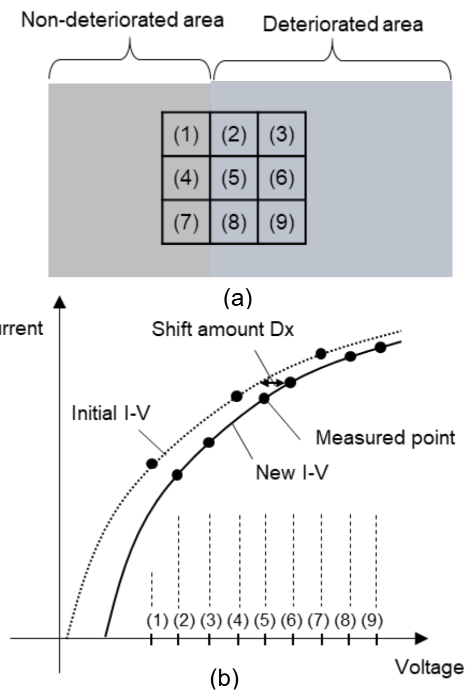


Fig. 3 A technique to select measurement points used for the estimation.

general, since neighboring pixels emit light at a similar luminance, it is thought that their state of deterioration will also be the same. Hence, it is considered that the estimation can be performed with high accuracy, even when interpolated.

On the other hand, in our proposed method, when a deteriorated area and a non-deteriorated area are included in the surrounding area, as shown in Fig. 3(a), the error of the estimation is considered to be large. Therefore, we propose a technique to select the measurement points used for the estimation from nine surrounding pixels so that compensation can be performed accurately, even near the boundary between deteriorated and non-deteriorated areas. As shown in Fig. 3(b), the voltage-shift, Δx, which is the distance between a measured point and the initial I-V curve at the same current value, is calculated for each measured point. Then, the I-V characteristics are estimated from only the surrounding pixels that are close to the voltage-shift amount of the central pixel. The I-V characteristics also change to some extent in the gain direction. However, since the threshold shift is considered to be a major cause of burn-in, it is thought that it can be determined by the voltage shift.

There is also a problem in that the accuracy of the estimated I-V characteristics at a low-current level are small. In fact, the correlation between the actual L-V characteristics and the I-V characteristics, estimated by the sensing data, is small at low-current (luminance) levels, although the correlation is large at high-current (luminance) levels. Therefore, since it is necessary to predict the I-V characteristics at low current levels, we propose a method that uses the initial L-V characteristics to predict them. As shown in Fig. 4, first, we calculated the voltage shift between the initial and the new I-V curve at specific points, for example, at a, b, c, and d. Then, by adding those voltage-shift amounts to the initial L-V curve, the relationships between the voltage and the

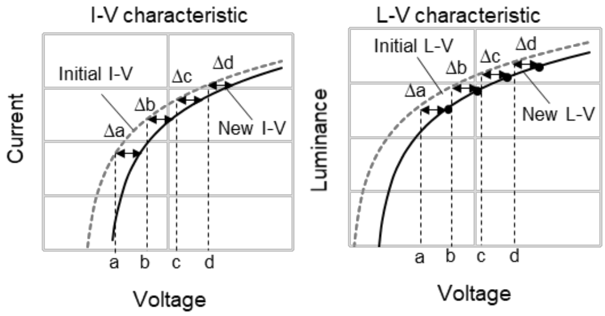


Fig. 4 Estimation of new L-V characteristics.

luminance after characteristic fluctuation can be obtained. Hence, the new L-V characteristics are estimated from those relationships. In an OLED display, the current and the luminance are almost proportional, and the correlation between the L-V characteristics and the I-V characteristics is high. Therefore, it is considered possible to apply the voltage shift of the I-V curve to that of the L-V curve.

4 Experiments

We evaluated the effectiveness of the proposed method using a 30-inch flexible OLED panel [7]. The specifications of the flexible panel are shown in Table 1. The degradation test pattern, shown on the left-hand side of Fig. 5, was displayed on the OLED panel for hundreds of hours. A photograph of the OLED panel after the occurrence of burn-in is shown in the center of Fig. 5. Although a white image was displayed, it was observed that some regions of the screen became dark or colored. A photograph of the compensation result using the proposed algorithm is shown in the image on

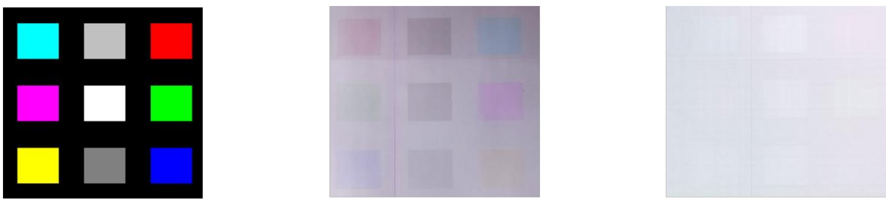


Fig. 5 Results of compensation technique. (left: degradation test pattern, center: burn-in image without compensation, right: burn-in image with compensation)

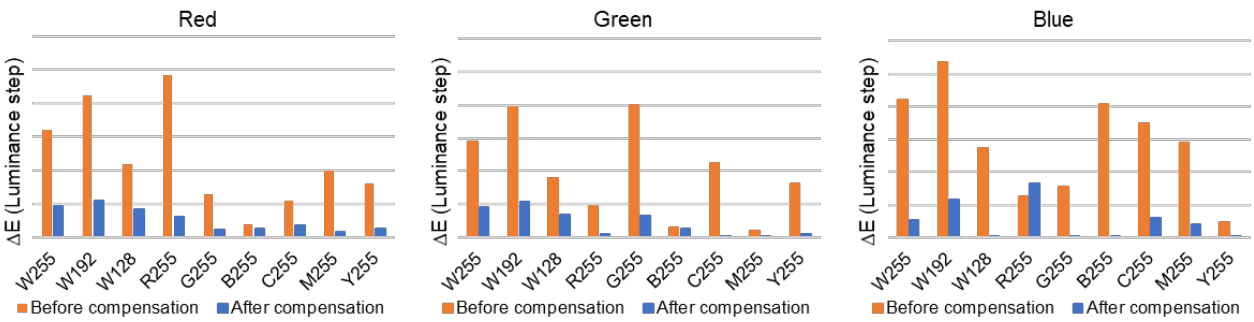


Fig. 6 Luminance step, ΔE, of burn-in compensation in degradation test pattern.

Table 1. Specifications of the OLED panel.

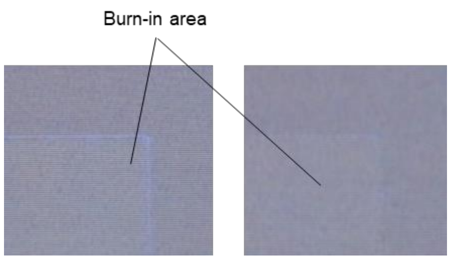
Size(diagonal)	30 inch
Resolution	4K (3840x2160), 147 ppi
Backplane	IGZO-TFT
Display type	Top-emission AMOLED
Total thickness	0.5 mm
Rolling radius	20 mm

the right-hand side of Fig. 5. It was confirmed that burn-in was suppressed when the proposed compensation algorithm was applied. In addition, a single-color-matt pattern of each RGB was displayed and the pictures were taken with a two-dimensional color luminance meter. Then, the difference in luminance between the deteriorated area and the non-deteriorated area was calculated as the luminance step. The measurement results of the luminance steps, ΔE, for each colored region, are shown in Fig. 6. The name of each color and number represents the region displayed in that color and the signal level on the degradation test pattern. The reductions of the luminance steps are shown in Table 2. The proposed method reduced the luminance steps for all color regions down to about 20% of their original values, as did the conventional method, although the sensing time of the proposed method was reduced to one-ninth of their original values.

Table 2. Reductions of luminance steps.

	Conventional (Nine points per pixel)	Proposed (One point per pixel)
R	20.3%	22.9%
G	25.6%	21.6%
B	16.3%	17.0%
All	20.7%	20.5%

On the other hand, when interpolation processing was performed, in some cases, an estimation error became large in the vicinity of the burn-in boundary, and a deterioration in image quality occurred. A bright line around the burn-in area can be faintly observed in Fig. 7 (a). By selecting the measurement points with the proposed algorithm, it is possible to display with suppressed image-quality deterioration, as shown in Fig. 7 (b).



(a) (b)

Fig. 7 Compensation results for proposed

5 Conclusions

In this paper, we proposed an external compensation technique that can compensate while also suppressing the increase in sensing time, which is a problem for high-resolution displays such as large screen displays. Our results showed that the time to provide feedback can be shortened without degradation of the compensation accuracy. In addition, in areas where there was concern about a decrease in accuracy due to interpolation from the measurement results for surrounding pixels, we examined a method for selecting measurement results to be used for predicting I-V characteristics, which showed that deterioration of image quality can be suppressed.

Acknowledgement

We would like to express our gratitude to Sharp Display Technology Corporation for the fabrication of the OLED panel and their advice on the driving scheme for panel sensing.

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