Uniformity Improvement with Time-division Driving for Low-level Luminescence of AMOLED Displays

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ABSTRACT

This study proposes a time-division driving method for uniformity improvement of AMOLED displays at low-level luminescence. This method produces two subframes including a short-term subframe with intense emission in a frame period. The reduction of luminous variation was demonstrated using an AMOLED display.

1 INTRODUCTION

Active-matrix organic light-emitting diode (AMOLED) displays have progressed toward large sizes and high resolutions, mainly for television use [1, 2]. However, non-uniform luminescence, induced by initial unevenness and temporal degradation of AMOLEDs, is an inevitable problem and deteriorates the image quality of the displays. For large-sized AMOLED displays, an oxide thin-film transistor (TFT) backplane is widely used to flow the pixel current. Since the drain current responds exponentially to the gate voltage in the subthreshold condition of oxide TFTs, a small variation in the gate voltage or potential of a power supply node is greatly amplified to a large variation of luminance [3].

Several approaches have been reported to compensate for the characteristic variation of oxide TFTs [4–6]. Among them, an in-pixel compensation scheme is unsuitable for large-sized displays because of the complicated pixel structure. An external compensation scheme, being the one of eligible methods for large-sized displays, is insufficient to compensate for luminous variations at low-level luminescence. The characteristics of oxide TFTs deviate notably at low-level luminescence due to their steep subthreshold. For the external compensation, since accuracy depends on whether to quantize for large or small fluctuations, luminous deviations exist residually. For high-resolution displays supplying a minute current to each pixel, accurate compensation is more severe. Therefore, a novel compensation scheme is necessary to improve the uniformity at low-level luminescence without increasing the signal processing cost.

Amplitude modulation is a technique to flow a specified current into each subpixel. However, this technique has the disadvantage that the small amplitude wave is intensely influenced by noise and unevenness. For this issue, some driving techniques are reportedly presented as pulse-width modulation and pulse-density modulation [7–9]. Nevertheless, there are still no actual uses due to the complicated pixel circuit.

To address these problems, this study proposes the time-division driving method which enhances spatial uniformity at low-level luminescence with typical circuit structures.

2 TIME-DIVISION DRIVING METHOD

2.1 Driving scheme

The proposed method generates two subframes, including a short-term subframe for low-level luminescence and a long-term subframe for high-level luminescence. Figure 1 illustrates driving waveforms during a frame period for low-level and high-level luminescence. The horizontal and vertical axes represent time and instantaneous intensity of light emission, respectively. As shown in figure 1 (a), the short-term subframe is only employed for low-level luminescence. The short-term subframe increases the instantaneous intensity of light emission compared with a conventional emission shown by the dashed line in figure 1 (a), spatially stabilizing the luminous distribution. For high-level luminescence in figure 1 (b), two subframes are used to reproduce the high-level luminescence with a tolerable emission.

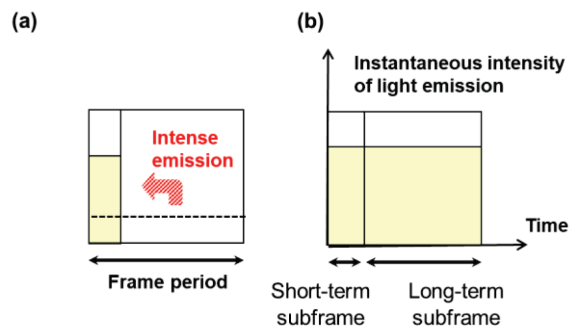

Fig. 1 Driving waveforms during a frame period for low-level (a) and high-level (b) luminescence.

Figure 2 illustrates signal waveforms on scan lines and on a data line. The periodic scan signal sequentially turns on switching TFTs. At the same time, the data are written into the storage capacitors of the subpixels. During the frame period, two scans are alternately conducted so that the subframes can be divided by a fixed duty ratio. As shown in figure 2, Line 1 is scanned for the long-term subframe after Line k is scanned for the short-term subframe. On the data line, the image signals are arranged with double speed of frame frequency, so that double scanning can be implemented on the conventional backplane with an acceptable scan-time.

2.2 Signal processing scheme

For implementing double scans on a frame period, image to subframe data conversions are needed to control the two subframes separately. Figure 3 shows examples of the signal conversion functions for short-term and long-term subframes. Image signals are converted into two signals based on the look-up table, which keeps emission volume constant. In these examples, the conversion is divided below and above the threshold level of 0.5. For high-level luminescence, since instantaneous brightness is consistant on both subframes, signal levels are determined by the conventional regulation, which is illustrated by the dashed lines in figure 3. Otherwise, as shown in figure 3, signal levels are amplified for short-term subframes (a) and reduced for long-term subframes (b).

The amplification for short-term subframes depends on a duty ratio of short-term subframes. Figure 3 (a) is the function for the duty ratio of 25 %. Since the short-term subframe period is one-fourth of a frame period, four times emission intensity is necessary to keep emission volume constant. As considered from the correlation between a signal level and an emission intensity, the signal levels below the threshold level are set to an approximately twofold of the conventional function.

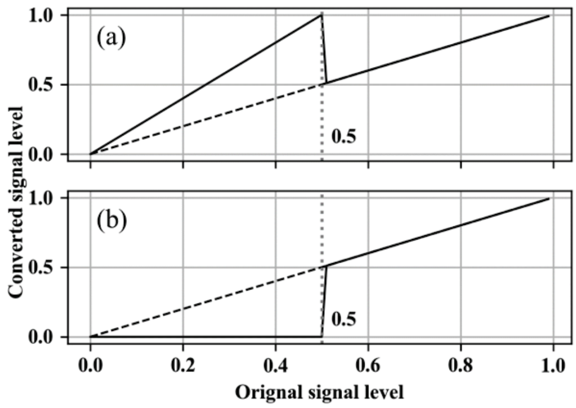

Fig. 3 Examples of the look-up table for short-term (a) and long-term subframes (b) in the case with a duty ratio of 25 %

3 EXPERIMENTS

To validate the short-term subframes of the proposed method, luminous distributions were spatially measured with an OLED display. In these experiments, the short-term subframes were replicated by inserting black images in a gray image frame. Figure 4 shows the driving waveforms employed on the measured OLED display. The conventional waveform is indicated as the duty ratio of 100 % in figure 4 (a). Meanwhile, figures 4 (b) and (c) are waveforms of the proposed method simulated with black insertion frames. For low-level luminescence with short-term subframes, the predetermined width of

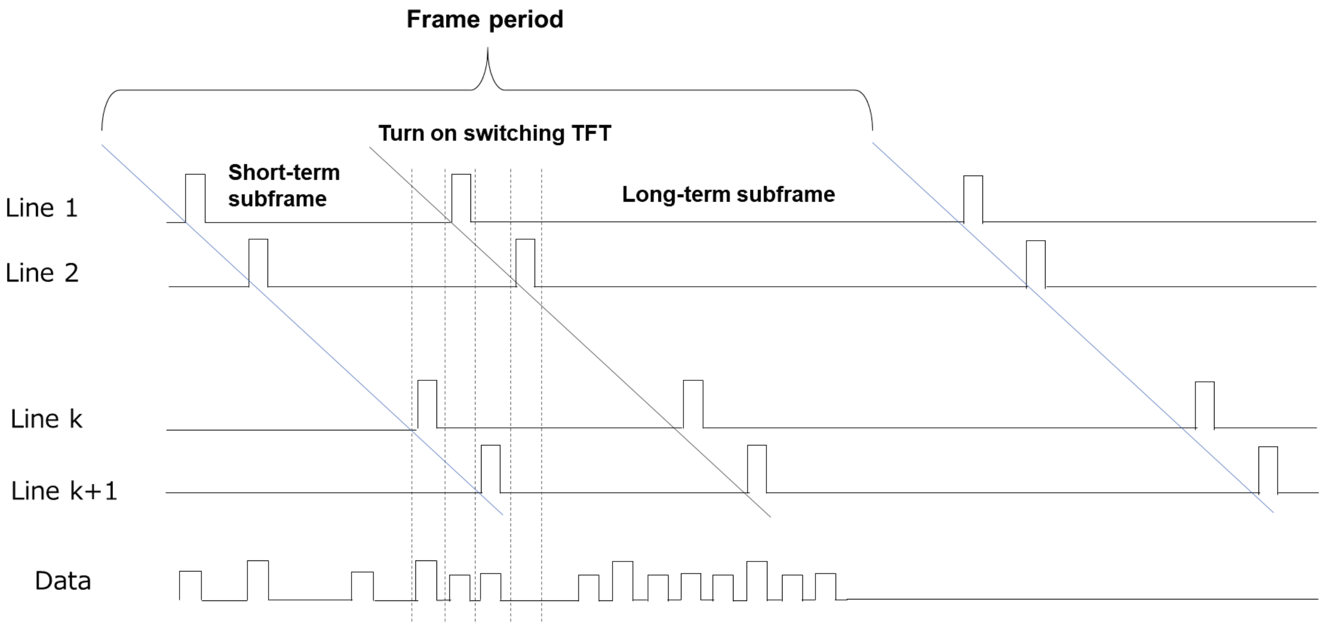

Fig. 2 Data writing sequence for two subframes

subframes can be regarded as the duty ratios of 50% (b) and 25% (c) in figure 4. The gray images were refreshed at 30 Hz. The intensity of the luminescence was modified by operating the image levels. The amplitude of waveforms was adjusted so that the emission volume was consistent between the frame periods.

In the experiments with each duty ratio, a signal generator prepared the images on an OLED display. Subsequently, luminous distributions were measured by using a two-dimensional colorimeter. From the measured data, average luminance and the deviation at each subpixel were calculated. The deviation from average luminance was evaluated as luminous deviation (LD) through

$$\mathrm{LD} = \frac{L_{ij} - L_{ave}}{L_{ave}} \tag{1}$$

$$L_{ave} = \frac{1}{mn}\sum_{i=1}^{m}\sum_{j=1}^{n} L_{ij} \tag{2}$$

where L_{ij} is luminance at the [*i*, *j*]th pixel, and the (m, n) term represents the number of horizontal and vertical pixels, respectively. The luminance levels were averaged on a display screen.

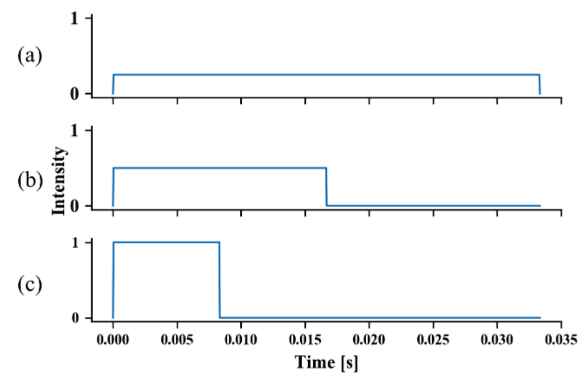

Fig. 4 Driving waveforms with duty ratios of 100% (a), 50% (b), and 25% (c) in experiments with black insertion frames

4 RESULTS AND DISCUSSION

Figure 5 shows histograms of LD measured in the experiments with duty ratios of 100% and 25% as blue and orange lines, respectively. Average luminance was equivalent in those measurements. The results indicate that the luminescence was distributed more uniformly with a duty ratio of 25% than for 100%.

To compare the LD for various average luminance levels, root mean square (RMS) values are calculated. Here, the RMS values of the LD are evaluated as

$$\mathrm{RMS} = \sqrt{\frac{1}{mn}\sum_{i=1}^{m}\sum_{j=1}^{n}\left(\frac{L_{ij} - L_{ave}}{L_{ave}}\right)^2} \tag{3}$$

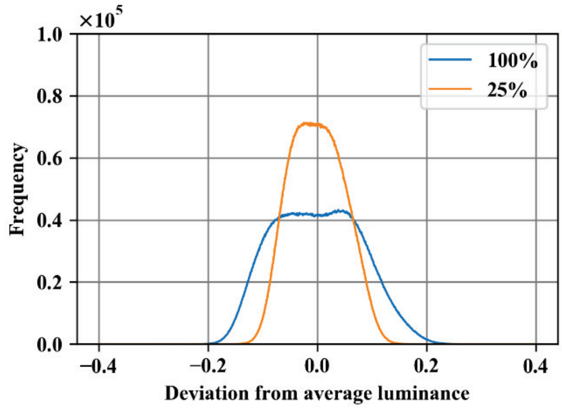

Fig. 5 Histogram of deviation from average luminance in experiments with duty ratios of 25% and 100%

Figure 6 shows the RMS values of LD with average luminance below 5 cd/m^2. The vertical and horizontal axes represent RMS values and the average luminance, respectively. In this graph, the plotted lines indicate distributions with duty ratios of 100%, 50%, 25%, and 25% estimated distribution from the duty ratio of 100%. As a result, the deviations clearly increase toward low luminance. Furthermore, the deviations decrease in experiments with a duty ratio of 25% as compared with 50% and 100%. The measured distributions of 25% deviated more than the distribution estimated from the 100% duty ratio distribution.

The RMS suggests the magnitude of luminous variations. Specifically, luminous uniformity deteriorates at low-level luminescence below the average luminance of 5 cd/m^2. Meanwhile, the luminous uniformity of the 25% duty ratio, replicating short subframes of the proposed method, is evidently enhanced at low-level luminescence.

On the supposition that the RMS depends on the intensity of light emission, the corresponding RMS values can be derived from the relationship between the average luminance and the intensity of light emission. In figure 6, the red line indicates that the distribution of the 25% duty ratio is estimated from the distribution of the 100% duty ratio. As compared with the experimental results shown by the green line, a difference is observed in the distributions of the RMS values. This result can be attributed to the inaccuracy of the actual signal levels and the intensity of light emission.

These results demonstrate that luminous uniformity can be improved by using short-term subframes at low-level luminescence. Additionally, by combining the proposed method with external compensation techniques, more enhancement of luminous uniformity is expected.

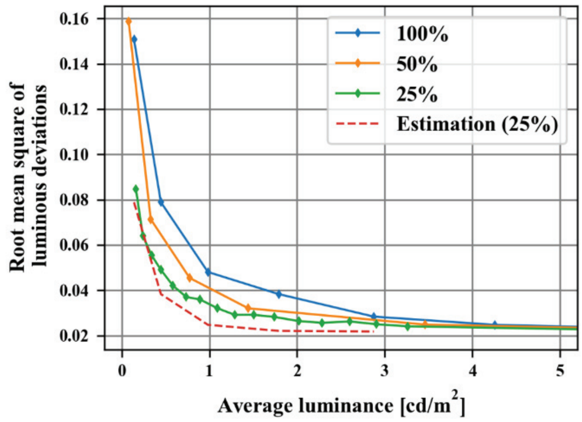

Fig. 6 Comparison among luminous deviations of experiments with duty ratios of 100%, 50%, 25%, and 25% estimated values

5 CONCLUSIONS

This study explains the improvement of luminous uniformity at low-level luminescence of AMOLED displays with the time-division driving method. In experiments replicating the short-term subframes, luminous distributions were spatially measured and compared with a conventional emission. The experimental results show that low-level luminescence is distributed more uniformly with the short-term emission than with the conventional emission. These results suggest that the proposed method provides more uniform low-level luminescence.

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