P-8: A New Hybrid Analog-Digital Driving Method to Improve AMOLED Lifetime

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Abstract

We propose a new hybrid pixel driving method that combines conventional digital driving with analog compensation for the declining electrical performance that occurs as OLEDs age. Image uniformity, and thus display lifetime, is improved by directly measuring the variation in OLED voltage at each pixel for a given OLED current level and then controlling the voltage drop across its driving TFT of an individual pixel.

1. Introduction

A number of methods of digital driving have been proposed to achieve uniform images in active matrix organic light-emitting displays (AMOLEDs) [1, 2]. Digital driving methods that use multiple sub-frames achieve better image uniformity than analog driving methods and consume less power per pixel [3]: even though each pixel is addressed several times during the display of each frame time, the power saved in the pixel circuit typically exceeds the extra power required by the peripheral circuit. Moreover, a digital pixel circuit typically contains fewer thin-film transistors (TFTs), allowing a higher aperture ratio than analog driving methods, especially for bottom-emission type AMOLEDs. However, a serious drawback of digital driving is that image uniformity is compromised over time by a current-voltage (I-V) shift in the organic light-emitting diodes (OLEDs). This is because the driving TFT operates as a switch in its linear regime to deliver a positive supply voltage (V_{DD}).

To overcome the consequence of this OLED I-V shift, the negative supply voltage ($V_{cathode}$) or the positive supply voltage (V_{DD}) of each pixel can be adjusted, to redefine the operating point of the pixel circuit and restore the brightness of the image [4]. However, adjusting $V_{cathode}$ or V_{DD} for the whole pixel array has a limited ability to improve display uniformity and lifetime, because the extent of the OLED I-V shift varies from pixel to pixel.

We propose a new hybrid digital approach that combines compensation of the entire pixel array with analog adjustment of individual pixel currents by controlling the voltage drop across the driving TFT of each pixel.

2. OLED Compensation

Coarse compensation for the I-V shift across the entire pixel array is achieved by changing V_{DD} or $V_{cathode}$ to compensate for the I-V shift of the most degraded pixel OLED (Fig. 1(a)). Individual pixel current levels are then adjusted to compensate for the pixel-to-pixel variation in voltage for a given OLED current (I_{ON}) by changing the source-gate voltage (V_{SG}) of the driving TFT (Fig. 1(b)).

To determine the required change in V_{SG}, the I-V shift of each OLED is monitored by measuring its forward voltage for a given current. This measurement has previously been proposed [5] to keep track of changes in OLED characteristics, but in the content of an analog driving method.

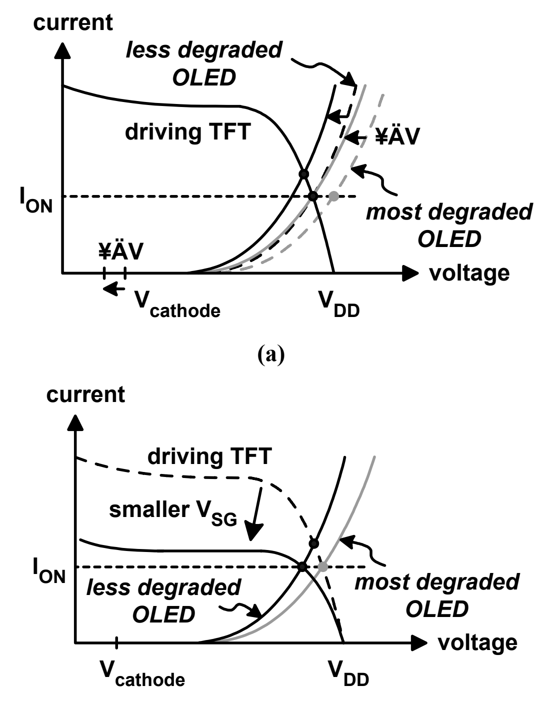

Figure 1. Load-line interpretation of the new hybrid driving method: (a) display-wide adjustment of a supply voltage, such as $V_{cathode}$; and (b) individual control of the source-gate voltage (V_{SG}) of the driving TFT of each pixel.

3. Pixel Circuit and Its Operation Steps

A pixel circuit for this method of compensation is shown in Fig. 2(a). Its operation consists of three steps: (1) applying reverse bias to the pixel OLEDs; (2) OLED voltage measurement for the desired I_{ON} at each pixel; and (3) image display with the data voltages (V_{SG}) determined from the OLED voltage data. Exemplary supply voltage levels and the corresponding data signal for each step are illustrated in Fig. 2(b). V_{SH} and V_{SL} are respectively the positive and negative supply voltages of a scan driver.

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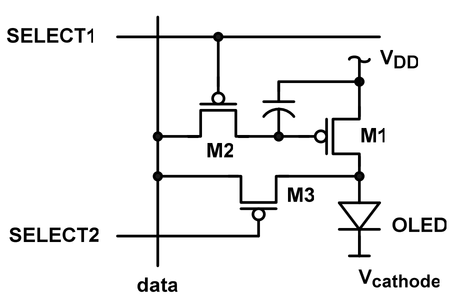
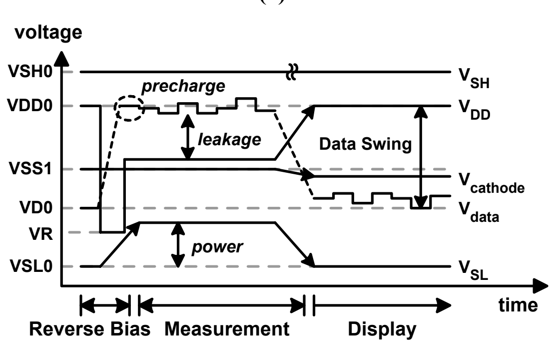
Reverse bias suppresses the I-V shift by reducing V_{DD} and keeping the driving TFT on with the gate voltage bootstrapped, while all the SELECT2 signals stay high (VSH0). At the beginning of the reverse bias step, all the rows of pixels are scanned with SELECT1 signals and all the driving TFTs (M1) are sequentially turned on with a data voltage of VD0. Then, all the switching TFTs (M2 and M3) in the pixels are turned off and V_{DD} is reduced to VR. Because the current through M2 and M3 is negligible, the charge stored in the storage capacitor is unaffected and the gate voltage of the driving TFT is bootstrapped when V_{DD} is reduced.

The OLED voltage is measured by keeping V_{DD} low, turning M2 and M3 on, and forcing I_{ON} through the OLED. When the reverse bias step is finished, all the data lines are precharged to increase the speed of measurement. During the measurement step, each data line is driven by a current source of I_{ON}, and all the rows of pixels are scanned with SELECT1 and SELECT2 signals at the same time. When M2 and M3 are on, M1 is diode-connected and turned off. The anode voltage of an OLED at I_{ON} is measured through M3 and a corresponding data line. In this step, V_{DD} can be set at a higher level than VR to reduce the leakage current through M1 and V_{SL} may be shifted high to reduce the power consumed by the scan operation.



(a)



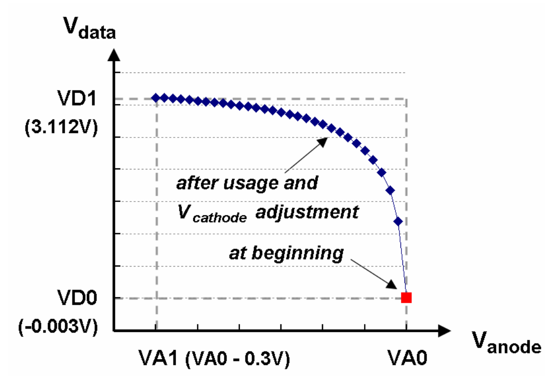
(b)

Figure 2. (a) Schematic description of the proposed pixel circuit and (b) illustration of supply voltages and a data signal.

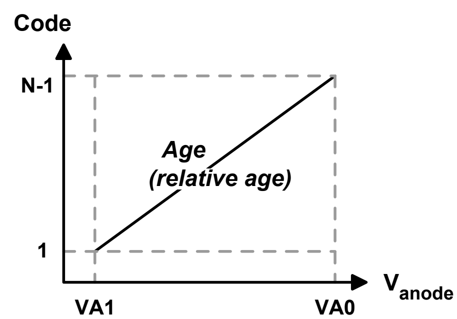
The image is displayed by using multiple subframes, just as it would be with a conventional circuit, because M3 is off during the display period [2]. However, $V_{cathode}$ and the data voltage (V_{data}) are calibrated from the measured changes in pixel OLED voltage, as depicted in Fig. 2(b). Fig. 3(a) shows an example of the calibration curves for the data voltage used to turn on a pixel OLED. It is assumed that the change in the OLED voltage will not vary by more than 0.3V.

4. Calibration Method

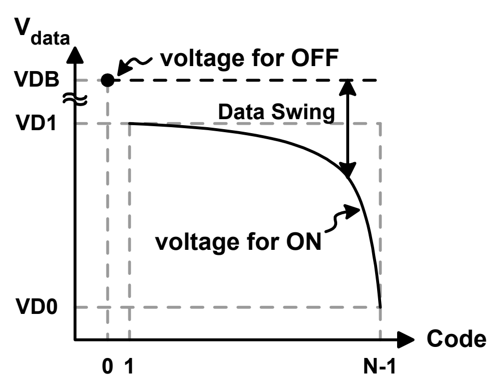
The calibration curve can be obtained using A/D and D/A converters with the transfer characteristics shown in Figs. 3(b) and 3(c) respectively.



(a)



(b)



(c)

Figure 3. Example of (a) a calibration curve; and transfer characteristics of (b) A/D and (c) D/A converters for the proposed pixel circuit.

During the measurement step, the anode voltages (V_{anode}) of the pixel OLEDs are measured, digitized and stored in an age memory. Relative anode voltages are then determined with respect to the maximum anode voltage, which is set at N-1. The digital value obtained from this calculation can be regarded as an age code, and these codes are stored in the age memory. During the display step, an age code is used to generate an input code to the D/A converter. In each subframe period, the 1 bit of video data provided for each pixel is ANDed with each bit of the age code corresponding to that pixel at the input to a data driver, which consists of D/A converters with the transfer characteristic shown in Fig. 3(c). The D/A converters can be implemented as an R-string type with several reference voltages. The output for the code 0 turns off the OLED.

After $V_{cathode}$ has been adjusted to compensate for the I-V shift of the most degraded pixel OLED, V_{data} for the highest measured anode voltage (VA0) is the same as the initial value of VD0. When the display is new, there is little variation in V_{anode} and an uncompensated digital driving method would show excellent image uniformity, and VD0 can be used for all the pixels. After some changes in values of V_{anode} have been detected, the value of V_{data} diverges from VD0. As the measured values of V_{anode} change further, the root-mean-square (RMS) value of voltage swings at the data lines decrease, and so does the power consumption of the data driver: this may compensate to some extent for the power required for $V_{cathode}$ adjustment.

5. Simulation Results

To assess the extent of the compensation for OLED I-V shift, OLED currents in the green and blue pixels were investigated. Green pixels use less current than red or blue ones but make the main contribution to luminance. Blue pixels take the largest current and degrade fastest. The OLED I-V shift was assumed to be parallel in all the simulations.

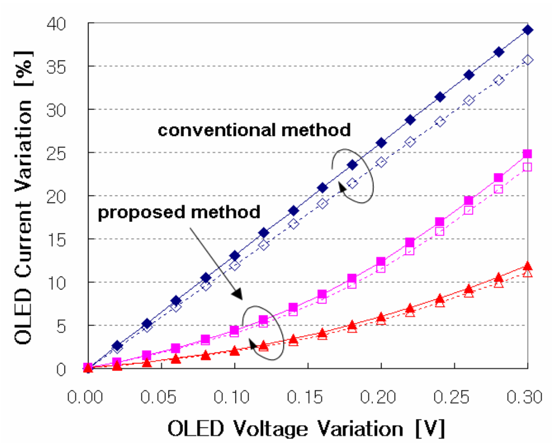


Figure 4. Variations in the OLED current for green (solid lines) and blue (dotted lines) pixels resulting from variation in the threshold voltage at the driving TFT: resulting from the conventional digital driving method (diamonds), and the proposed method for ±50mV (triangles) and ±100mV (squares) variations in the threshold voltage.

The variation in the OLED current caused by the I-V shift and the changes in the threshold voltage (V_{th}) of the driving TFT is shown in Fig. 4. The transfer characteristic of the D/A converters can be adjusted to match the average characteristic of the driving TFTs in each display panel after fabrication. Therefore, the variability in the characteristic of the driving TFT was considered only in the scope of a panel and the changes in V_{th} were assumed to be less than ±100mV. The changes in mobility were also assumed to be less than ±10% for the same reason. Fig. 5 shows the variation in OLED current caused by the OLED I-V shift and the changes in the mobility of the driving TFTs.

The pixel circuit in Fig. 2(a) with the switching TFTs (M2 and M3) of $4\mu m/4\mu m$ and the storage capacitor of 0.1pF was used for the simulations. The driving TFT (M1) was sized to $8\mu m/4\mu m$ for green OLEDs and to $16\mu m/4\mu m$ for blue OLEDs. In addition, a 2” QVGA display was assumed.

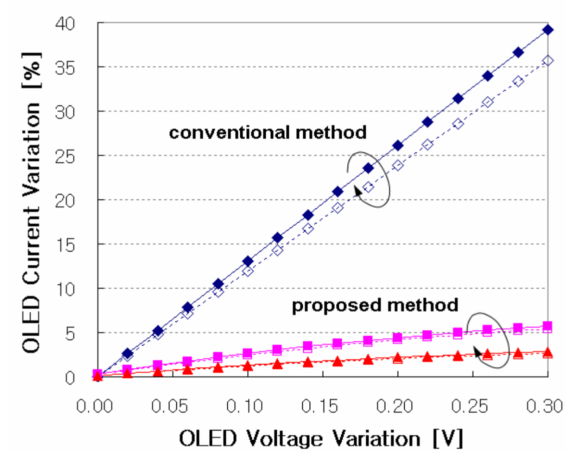


Figure 5. Variation in the OLED current for green (solid lines) and blue (dotted lines) pixels resulting from variation in the mobility at the driving TFT: resulting from the conventional digital driving method (diamonds), and the proposed method for ±5% (triangles) and ±10% (squares) variations in the mobility.

Figure 4 shows that the OLED current variations in the green and blue OLEDs for an OLED voltage variation of 0.3V have been substantially reduced from 39% and 36% for the conventional digital driving method to 12% and 11% for the proposed hybrid driving method, respectively, in the presence of ±50mV variation in the V_{th} of the driving TFT. For ±100mV, the OLED current variations were 25% and 23%, respectively for the green and blue OLEDs, which are much lower than those for the conventional digital driving method. The OLED current variations for the conventional digital driving method remained almost constant even with the variation of TFT characteristics, as expected.

The improvement in the OLED current uniformity is much clearer in Fig. 5, which shows that the OLED current variations in the green and blue OLEDs for an OLED voltage variation of 0.3V have been reduced to 3% for the proposed hybrid driving method, in the presence of ±5% variation in the mobility of the driving TFT. For ±10%, the OLED current variations were about 6% and 5%, respectively for the green and blue OLEDs.

There are two sources of compensation error which limit the improvement in the OLED current uniformity. One is the adjustment error of the supply voltage ($V_{cathode}$) and the other is the calibration error of the data voltage (V_{SG}). However, the $V_{cathode}$ adjustment error makes very small impact on the OLED current uniformity, as shown in Fig. 6. For ±50mV error of $V_{cathode}$ control, the OLED current variation changed by about ±5% of its original value over the most range of the OLED voltage variation from 0 to 0.3V. On the other hand, the calibration error of V_{SG} can be reflected in the simulation as the V_{th} variation of the same magnitude and kept less than 10mV which is small enough.

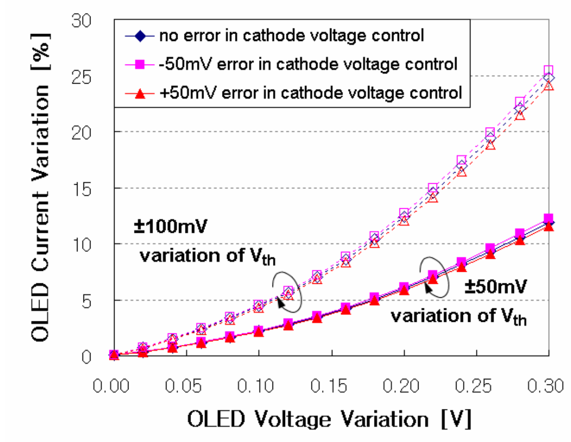


Figure 6. Variation in the OLED current for $V_{cathode}$ control errors of -50mV (squares), 0mV (diamonds), and +50mV (triangles).

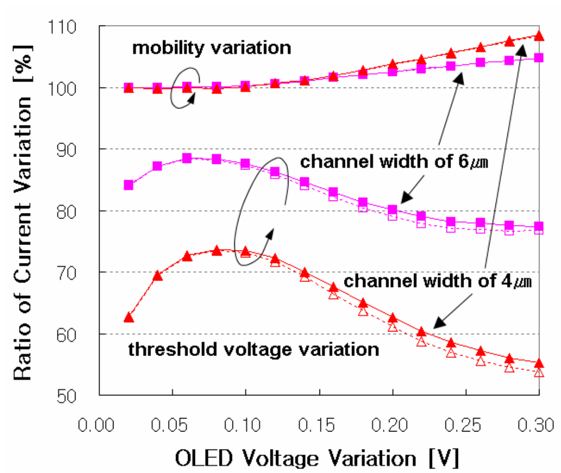


Figure 7. Ratio of green OLED current variation for a driving TFT with reduced channel width to the OLED current variation for the original design (8㎛): channel width of 6㎛ (squares) and 4㎛ (triangles) as a result of ± 50mV (solid lines) and ± 100mV (dotted lines) variations in the threshold voltage of the driving TFT.

To improve the OLED current uniformity further, the channel width of the driving TFT can be reduced. Then the data voltage (V_{data}) applied to turn on the OLEDs should be lowered to maintain the level of immunity to changes in the characteristic of the driving TFT, and this leads to larger voltage swings in the data lines. When the V_{data} calibration was applied, however, the RMS voltage swing at the data lines was less than it was with the conventional digital driving, which suggests that the increase in power consumption in the data driver may not be severe. Fig. 7 shows simulation results for reduced channel widths. The variation in the OLED current in each case is compared with the results for the original channel width of 8㎛. Despite some increase in the variability of the OLED current with changes in mobility, we expect a more uniform OLED current because the effect of changes in the threshold voltage, which causes most of the change in OLED current, was much reduced.

6. Conclusions

We have proposed a new hybrid method of driving OLEDs digitally, which combines a compensation of the entire pixel array with the adjustment of individual pixel currents by analog control of the voltage drop across the driving TFT in each pixel. This method improves the degradation of image uniformity which is caused by the variation of the OLED I-V shift that occurs as a display device is used. This improvement will extend the lifetime of an AMOLED display.

The improvement in OLED current uniformity was verified by simulation. The variation in the OLED current was reduced to about 1/3 of that with the conventional digital driving method when a typical characteristic variation of the driving TFTs in a display panel was assumed. The D/A converters in a data driver can be adjusted for individual panels to be adaptive to the variation of the averaged characteristic of the driving TFTs. An alternative way of compensating for severe I-V shift is to edit the video data. In this case, our hybrid driving method would require less memory than the conventional digital driving method.

7. Acknowledgement

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8. References

[1] M. Mizukami et al., "6-Bit Digital VGA OLED," SID 00 Digest, 36.1, pp.912-915.

[2] A. Tagawa et al., "A novel digital-gray-scale driving method with a multiple addressing sequence for AM-OLED displays", AMD3/OLED5-2, IDW'04, pp.279-282.

[3] D. Fish et al., "A comparison of pixel circuits for active matrix polymer/organic LED displays", SID 02 Digest, 32.1, pp.968-971.

[4] S. Ishizuka, "Active matrix display apparatus", US Patent 6,479,940.

[5] E. Persidis et al., "Active-matrix OLED backplanes based on LTPS for small molecules and polymers", Journal of the SID 15/11, pp.923-929, 2007.