# A Novel Data Driver for Passive Matrix Organic Light-emitting Devices with High Gray Scale Images utilizing a High Uniform Current

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## Abstract

*A novel data driver for passive matrix organic light-emitting devices (PM-OLEDs) with high gray scale images was designed. The proposed circuit consisted of a main current bias circuit as well as sample & hold circuits in each channel of the data driver to compensate a current offset. These results indicate that a data driver designed by using the current offset compensation technique holds promise for potential applications in PM-OLED displays with high gray scale images.*

## 1. Introduction

Organic light emitting devices (OLEDs) have been particularly attractive because of current interest in potential applications in flat panel displays [1, 2]. OLEDs have received much attention due to their promising application advantages, such as low cost, a high brightness, a wide viewing angle, a fast response time, a low operating voltage, and a very thin thickness [3, 4]. In particular, since the PM-OLED displays contain the significant merits of both a simple fabrication process and a low cost, they are very useful for small size handheld applications, such as mobile phones and personal digital assistants. Since the OLEDs are operated by the current, the luminance of the OLEDs is proportional to the magnitude of the current applied to each pixel [5, 6]. A pixel current in the PM-OLED displays is supplied from the data driver. Since the process variations resulting from the oxidation degradation, mobility and threshold voltage variation in the fabrication devices occur, the voltage drop of the power supply line in the data driver circuit induces the data driver output current to non-uniformity. These inherent problems deteriorate the uniform brightness and the accurate gray scale display in the OLED panel, which is very important for the expansion of the display gray scale. Therefore, a design of the novel data driver with an uniform output current, which is independent of the process offset and the voltage drop of the power supply line, is necessary for reducing the non-uniformity of the output current.

This paper reports a design for a novel PM-OLED data driver, which can improve the uniformity of the output current.

## 2. A current offset compensation method of the data driver

Figure 1 shows a proposed current-variation compensation method for the data driver. The proposed data driver circuit consists of a main current bias circuit and sample & hold circuits in each channel of the data driver to compensate for deviation in the current. During the scan time, the main current bias and the output circuits are connected by using the channel select switch, and the main current bias circuit programs the output current to each output circuit of the data driver sequentially. The M'th channel output circuit connected to the main current bias circuit has the HP PMOS for the bias operation (HPb[M]), a capacitor between the gate and the source ($C_{GS}$[M]), and a sample & a hold under the gate bias voltage of the HP PMOS for the output (HPo[M]), the sample & the hold circuit being connected with the PM-OLED panel.

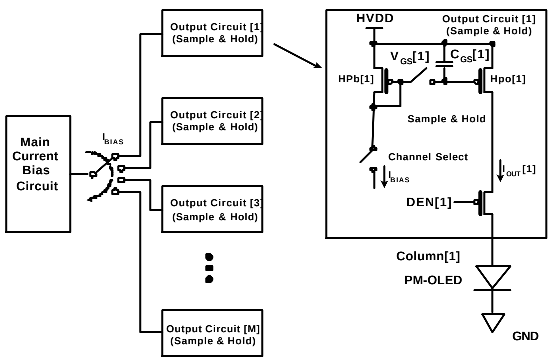


Figure 1. A proposed current offset compensation method for the data driver.

When a gate bias voltage is applied to all of the channels during a scan time, the data enable signals are activated due to their own gray scales. The output current and the offset compensating operation of the proposed circuit are related by

$$I_{OUT}[M] = (\mu_p \pm ?\mu_p)(C_{ox} \pm ?C_{ox}) \times \frac{W_p \pm ?W_p}{L_p \pm ?L_p}\left(V_{GS}[M] - |V_{THP} \pm \Delta V_{THP}|\right)^2 \quad (1)$$

where $\mu_P$ and $?\mu_p$ are the mobility and the mobility variation of the device, $C_{ox}$ and $?C_{ox}$ are the capacitance and the capacitance variation of the gate reactive to the channel due to the oxide degradation, $W_p$ and $?W_p$ are the channel width and the channel width variation, $L_p$ and $?L_p$ are the channel length and the channel length variation, $V_{THP}$ and $?V_{THP}$ are the threshold voltage and the threshold voltage variation, respectively, and $V_{GS}[M]$ is the bias voltage between the gate and the source of the devices. Hereafter, the variations of the $?\mu_p$, $?C_{ox}$, $?W_p$, $?L_p$, and $?V_{THP}$ are denoted by the device mismatch. When the output circuit of the data driver is connected with the main current bias circuit by using the selective switch, the current in HPb[M] flows into the main current bias circuit, and the $V_{GS}[M]$ is determined by the bias current ($I_{BIAS}$). The current programming bias method, taking into account $?W_p$, $?L_p$, and the variations in the capacitance, the mobility, and the threshold voltage, provides the gate of HPb[M] with a different $V_{GS}[M]$ in each channel to compensate for the variations caused in the current by variations in the simulation parameters. Since the current of HPo[M] is the same as that of HPb[M], the $V_{GS}[M]$ of HPo[M] is equal to that of HPb[M]. Therefore, since there is practically no current variation in any channel, the currents of all the output channels remain constant.

## 3. A design of the proposed data driver circuit in the OLED displays

Figure 2 shows an 128 x 128 color PM-OLED driving system designed by using the proposed high gray-scale data diver. It is composed of a scan driver, a data driver, an OLED controller, and a direct current-direct current converter. The controller transmits vertically a synchronizing signal to the scan driver, and it sends horizontally a synchronizing signal to both the scan driver and the data driver. The external data are transmitted to the data driver through the controller in the digital signal driver. The variation in the output current of the 384-channel data driver is compensated for by using the proposed high gray-scale data driver, as shown in Fig. 2. The 384-channel data driver consists of a data controller, a shift register, a data sampling latch, a gray scale converter, a level shifter, and a current output circuit. The logic supply voltage and the maximum driving output supply voltage of the PM-OLEDs used in this design are 2.8 and 18 V, respectively.

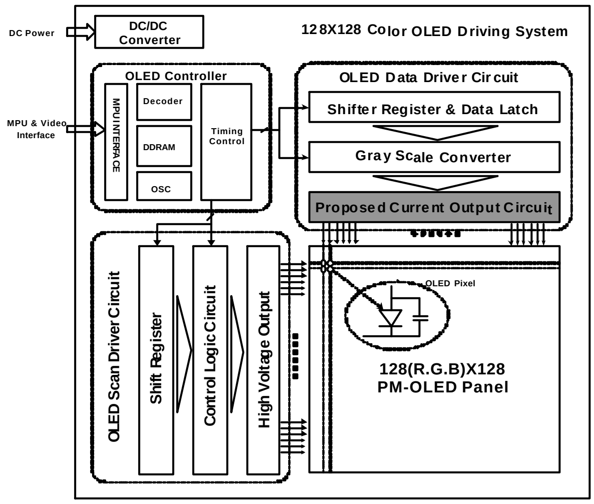


Figure 2. An 128 x 128 color PM-OLED driving system designed by using the proposed high gray-scale data diver.

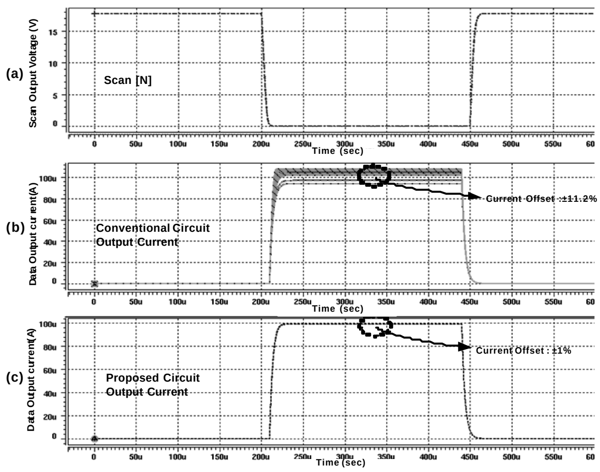


Figure 3. (a) Output waveforms of the M' th scan driver output, (b) data output current of the conventional data driver circuit, and (c) data output current of the proposed data driver circuit as functions of the driving time.

A maximum output current of 100 µA in the complete white gray level generates a luminance of 150 cd/m$^2$.

Figure 3 shows (a) output waveforms of the M'th scan driver output, (b) data output current of the conventional data driver circuit, and (c) data output current of the proposed data driver circuit as functions of the driving time. The output waveforms of the current output circuits were designed utilizing the conventional data driver, as shown in Fig. 3 (a), and the proposed data driver were simulated by using a Monte-Carlo transient simulation method. The device mismatch, the supply voltage variation, and the threshold voltage variation of the HPb for the Monte-Carlo transient simulations were 10%, ± 1V, and 300mV, respectively. When the output voltage of the scan driver was switched from 0V to 18V, the M'th row line was selected, and the data driver supplied the OLED displays with a current according to the gray scale of the display image. The output current variations of the conventional and the proposed output circuits were approximately 11.2% and 1%, respectively, as shown in Figs. 3 (b) and 3 (c).

The design parameters of the data driver with a high gray scale for PM-OLEDs proposed in this study are summarized in the Table I. These results indicate that the current variation obtained by using the proposed data driver was significantly decreased in comparison with that obtaining by utilizing the conventional data driver. When the proposed data driver circuit was used, the non-uniformity of the data output current of the output circuit was below 1%, and the shape of the output circuit waveform was uniform.

## 4. Conclusions

A novel data driver with current offset compensation circuits for the PM-OLEDs was designed by using a hynix high voltage process, the proposed circuit was simulated. The non-uniformity of the output current in the proposed data driver decreased to at least below 1% for all of the devices in a device mismatch of 10% or other worst conditions. These results indicate that a data driver designed by using a current offset compensation technique holds promise for potential applications in PM-OLED displays with high gray scale images utilizing a high uniform current.

Table I. The design parameters of the data driver proposed in this study for high gray-scale PM-OLED.

| Parameter | Value |
|---|---|
| Resolution | 128 (R.G.B) x 128 |
| Display color | 262,144 |
| Data driver (output channel) | 384 (128 x 3) |
| Output current | 100 µA |
| Non-uniformity of the output current | ±1 % |
| Frame frequency | 120 Hz |
| Logic voltage | 2.8 V |
| Driver voltage | 18 V |

## 5. Acknowledgements

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## 6. References

[1] 1. M. A. Baldo, D. F. O'Brien, Y. You, a. Shoustikov, S. Sibley, M. E. Thompson, and S. R. Forrest, Nature **395**, 151 (1998).

[2] 2. R. H. Friend, R. W. Gymer, A. B. Holmes, J. H. Burroughes, R. N. Marks, C. Taliani, D. D. C. Bradley, D. A. Dos Santos, J. L. Bredas, M. Löglund, and W. R. Salaneck, Nature **397**, 121 (1999).

[3] 3. J. R. Sheats, H. Antoniadis, M. Hueschen, W. Leonard, J. Miller, R. Moon, D. Roitman, and A. Stocking, Science **273**, 884 (1996).

[4] 4. V. Bulovic, G. Gu, P. E. Burrows, S. R. Forrest, and M. E. Thompson, Nature **380**, 29 (1996).

[5] 5. G. Gu and S. R. Forrest, IEEE J. Selected Topics in Quantum Electronics 4, 83 (1998).

[6] 6. Y. Kijima, N. Asai, N. Kishii, and S. Ichiro, IEEE Trans. Electron Devices **44**, 1222 (1997)