LETTER

Development of a Novel Current Controlled Organic Light Emitting Diode (OLED) Display Driver IC

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SUMMARY In this letter, we propose new driving methods for designing a driver independent of the current property of Organic Light Emitting Diodes (OLED) displays. The proposed methods are the Look-Up Table (LUT) and the Pulse Width Modulation (PWM). The LUT is used to handle the amount of the current for driving the OLED display panel and the PWM is applied to represent the gray scale on the OLED display panel. In particular, the proposed methods are used for the manufacturing of 1.8″ 128 × 128 dot passive matrix OLED display panel. The designed circuit was fabricated using 0.6 μm, 2-poly, 3-metal CMOS process and applied to the Personal Communication System (PCS) phone successfully.

key words: *OLED, driver IC, current driver, PWM, LUT*

1. Introduction

The increasing demand for portable applications has caused a significant growth of display devices that are small, thin, and easy to operate. In such a situation, there is increasing interest in the potential application of organic light-emitting diodes (OLEDs) [1]. It is well known that OLED is one of the pioneer next generation flat panel display application with good contrast, low operation voltage, short response time, wider view angle, and lower manufacturing cost [2]. Researches and developments have been focused on optimizing materials and device structures [3]. A generalized driver with good performance is needed for these display device studies [4].

In this works, new driving methods such as PWM and LUT method have been studied and a highly integrated CMOS current driver IC for OLED has been successfully developed and applied to a display for personal communication system phone.

The rest of the paper is organized as follows: Sect. 2 explains driving methods with PWM signals and usage of look up table. In Sect. 3, we explain the digital and analog circuits in detail and show the layout of the OLED driver IC. Section 4 explains the properties and performance of the driver IC, and shows the result of our practical implementation. Finally, a conclusion is drawn in Sect. 5.

2. Driving Methods for OLED

Now we will describe the driving waveforms and how can we achieve the 64 gray scales with 4 bit per pixel data. And we propose the current control methods using LUT.

2.1 Pulse Width Modulation for Segment Driver

There exist many methods to achieve gray scale on display devices. In this section, we will explain the Pulse Width Modulation (PWM) method for OLED display.

Figure 1 shows the driving PWM signals. Vertical axis represents the column of pixels selected by common driver. On the other hand, horizontal axis represents time passage. Each shadowed part is the display period.

A line period is divided into 63 sub-periods (T) in order to express 64 gray levels. The width of the driving segment signal represents contrast of the selected OLED pixel. Then controlling the segment signal width, it is possible to express 64 gray levels. For example, seg [0] represents $7/64(7T)$ gray level of the first pixel and seg [n] represents $60/64(60T)$ gray level of the nth pixel on the selected line. Gray scale expressions are achieved by the way of these PWM signals.

2.2 Look-Up Table for Current Control

Conventional display devices output the value of the image data to the actual current level, using the data in the storage. Thus, the current level of the driver de-

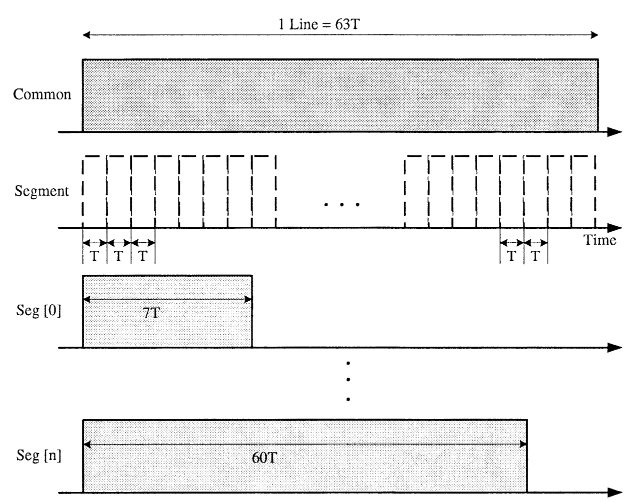

Fig. 1 PWM signals for segment driver.

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pends on the property of the particular display panel. To overcome the problem, we propose the LUT for implementation of a driver IC independent of the current property of OLED display panel.

In our works, we have 4 two-port RAMs for image data storage. Each RAM contains full 128×128 range data in 4 bit (16 level) per pixel format. From these 4 bit data, we can get the 64 level values using LUT which maps 16 gray levels to 64 gray levels. The advantage of this scheme is that the amount of the current itself associated with each level can be set to an arbitrary value. As shown in Fig. 2, the data processed by the LUT is mapped to the specified value and is delivered to the resultant output stage. It makes fine tuning possible in the case of applying the driver to the panels with different property. The data of 64 gray scales produce PWM signal and then display the desired image at the panel.

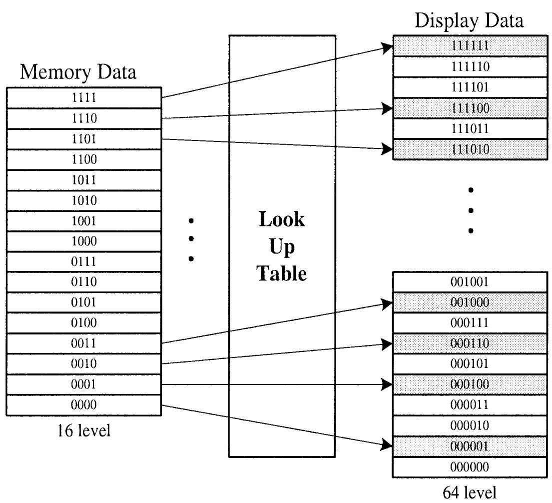

Fig. 2 Look Up Table (LUT) for current control.

3. Circuit Design for OLED Driver

3.1 Digital Control Circuit for OLED Driver

In this section, we will describe the overview of the OLED driver IC. The full circuit configuration of the OLED display driver IC is presented in Fig. 3. This driver consists of two units: controlling circuit and driving circuit.

Instructions and data for display are fetched from a microcontroller unit (MCU). The display instructions are subsequently decoded into the internal register block and the display data are stored into memory. MCU interface unit supports Intel 80x systems and Motorola 68 systems with 8/16 bits general bus width. This MCU interface unit transfers control signals and image data to the internal register unit.

Internal register unit consists of 22×16 bit register. This unit has parameters for the OLED driver IC. Analog parameters control the power save mode and contrast control. Registers for digital function parts set the flag and the required values. And status register has the current status of the driver IC.

The internal graphic memory block contains 4 two-port random access memories. It contains full graphic image and accessed via MCU interface unit.

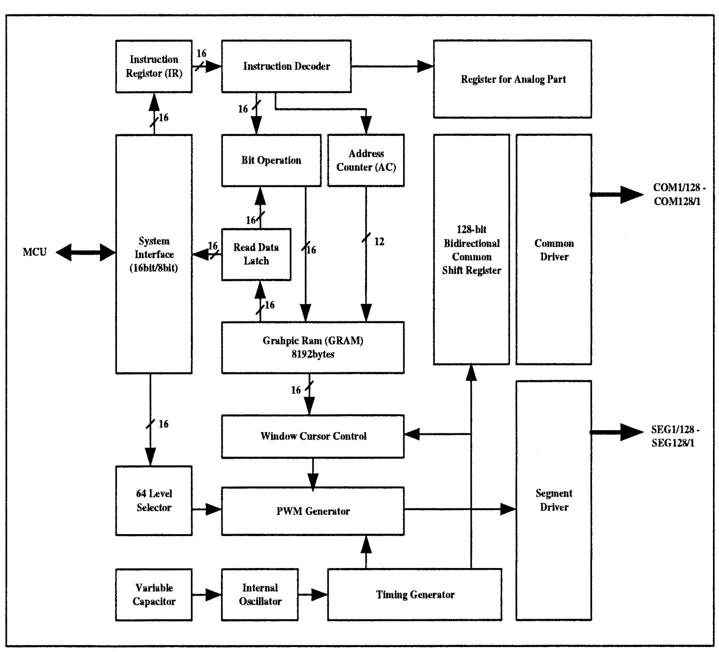

Fig. 3 Block diagram of drivers and control circuits for OLED display panel.

Bit operation unit performs AND, OR XOR operations and bit rotation operation. With this function block, system engineers can implement the background images and animation easily.

Window cursor control unit has many functions related to graphic display. First it accesses graphic ram unit and get the data of next line and performs the digital functions. It contains vertical scroll, partial display, partial vertical scroll, and cursor control.

64-gray level select unit is the early mentioned LUT block. In this unit, we added 6 bit adder to implement the bright control.

PWM generator consists of six 128 bit shift registers, one 6 bit counter and 128 comparators. The comparator output is the segment drive signal.

Timing controller makes required clocks from the internal or external oscillator.

Analog driving circuits composed of 128 common drivers and 128 segment drivers, the latter get the signal form the PWM generator unit as we mentioned. Detail description of Analog part will be continued in our next sections.

3.2 Segment and Common Drivers

The recombination of electrons and holes injected from anode and cathode makes OLED pixels radiate. Furthermore, such operation is made possible by the segment and common drivers related to the row and column lines of OLED panels as shown in Fig. 4. In this paper, we adopted the passive matrix driving method suitable for the mono displays having simpler architecture than that of the active matrix driving method. The pixel chosen by such a method is given the constant current by the associated segment driver in Fig. 5. The brightness of a pixel depends on a PWM signal and the selection of a display line is determined by the common driver in Fig. 6.

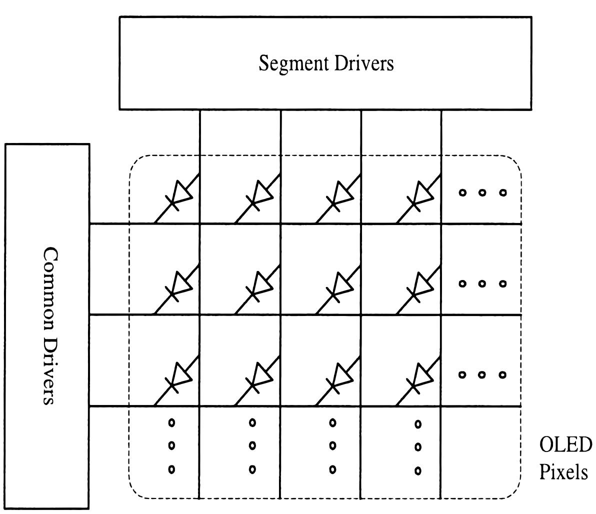

Fig. 4 A block diagram of passive matrix OLED.

The segment block contains 128 segment drivers and each segment driver is made up of a current source, a switch, and a current sink. V_{bias} is a voltage which is generated by the bias circuit of Fig. 7. The current supplied to the OLED element is controlled by applying V_{bias} to the gate of the current source M_1. M_2 is a PMOS transistor used as a switch and V_{sels} is the control voltage applied to the gate of M_2 through the level shifter. The operation of the segment driver is determined by M_2. The current in M_2, I_{out}, flows toward the OLED element when M_2 is ON. At the same time, MOS transistor M_3 has to be turned off to prevent I_{out} from sinking into the ground. This is achieved by using the delay circuit. The delay circuit is used to prevent that the switching operation between M_2 and M_3 is overlapped. If the segment driver is not chosen, M_2 is OFF and M_3 is ON, taking the seg to the ground level. Thus, the injection of I_{out} into the OLED element is stopped. M_3, which acts as a current sink, helps the voltage of the seg to keep the lowest potential.

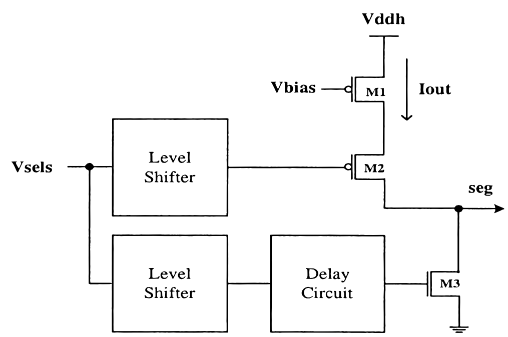

Fig. 5 Block diagram of OLED segment driver.

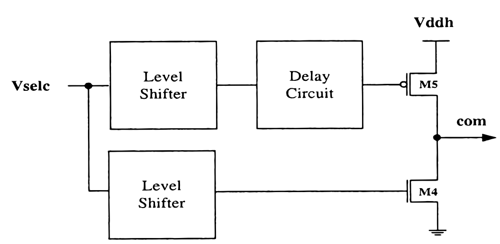

Fig. 6 Block diagram of OLED common driver.

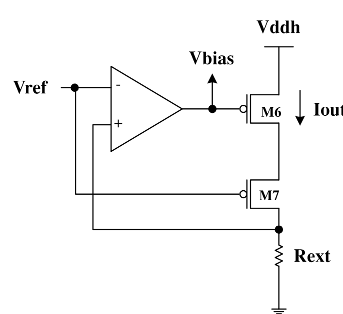

Fig. 7 Block diagram of bias circuit.

The gate of M_2 is connected to the output of the level shifter. The level shifter converts the voltage level of the V_{sels} to that of the V_{ddh}. V_{ddh}, which is the output voltage of the DC-DC converter, becomes very higher than the supply voltage used at the typical CMOS process. The level shifter serves the function of a voltage translation.

The common block also contains 128 common drivers and each common driver consists of a current source and a current sink, M_4 and M_5. M_4, which is an NMOS transistor, acts as the switch and I_{bias} goes through M_4.

When M_4 is ON, I_{out} supplied from the segment driver is taken to the ground via the OLED element. If M_4 is OFF and M_5 is ON, then the com is set at V_{ddh}, There is no current flowing into the OLED element regardless of the voltage of the seg. Using the level shifter, the V_{selc} is converted to the V_{ddh} to turn on M_4. The delay circuit is also adopted to keep the signal from being overlapped between M_4 and M_5.

The bias stage consists of an operational amplifier, two PMOS transistor, and, a registor. It is used to bias each segment driver. We find that the registor, R_{ext}, of the bias circuit of Fig. 7 is given by

$$R_{ext} = \frac{V_{ref}}{I_{out}} \tag{1}$$

I_{out} is the current that allows the OLED element to emit light and V_{ref} is the reference voltage of the operational amplifier.

3.3 DC-DC Converter

Figure 8 shows the simplified block of the DC-DC converter embedded in the driver IC. It consists of a reference circuit, a feedback resistor, a control circuit based on Pulse Frequency Modulation (PFM) and an oscillator. Using the output voltage of the converter that varies from 8 V to 12 V enables the operation of the segment and column drivers to be made on the 3.3 V supply voltage. The integrated DC-DC converter with two external passive components (L, C) was designed and fabricated on a 0.6 μm CMOS process.

The architecture of the adopted converter is very similar to that of the booster. The operation for boosting the output voltage V_{out} of the converter is done by the ON/OFF behavior of the switch transistor M_1. To easily understand the principle of the converter, it is assumed that the switch M_1 turns off and that the V_{out} is equal to the V_{dd}. During the charging period, if the M_1 turns on, the current in the inductor (L_{ext}) increases and PMOS transistor M_2 prevents the capacitor (C_{ext}) from discharging to ground. The behavior of the active rectifier M_2 is similar to that of the diode. V_{out} is fed back to the positive input of the comparator through the voltage divider that consists of resistors (R_1, R_2). The negative input of the comparator is connected to V_{ref}. When the negative input of the comparator falls below V_{ref}, the square-wave oscillator affects the switch operation of M_1 to increase V_{out}. Storing energy in the L_{ext} and transferring it to the C_{ext} results from the rapid switching operation of M_1. When the positive input of the comparator is higher than V_{ref}, the M_1 is OFF and keeps the V_{out} from increasing. This is the principle of PFM. With this method, the inductive charge pumping boosts V_{out} up to the desired level and keeps it at that point.

3.4 Physical Implementation

Driver IC utilized here are fabricated under Hynix 0.6 μm 16-volt 2-poly 3-metal CMOS process. Figure 9 shows the layout pattern of the full OLED driver IC

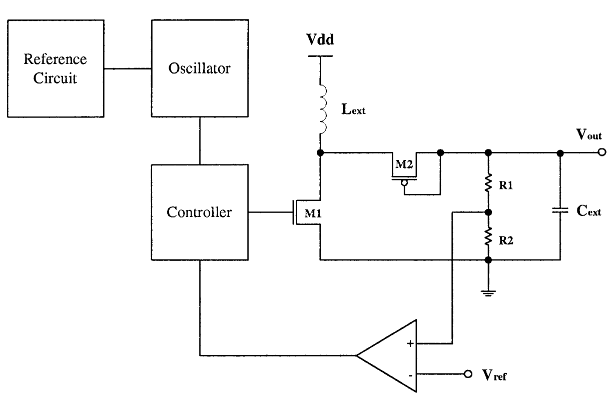

Fig. 8 Block diagram of DC-DC converter.

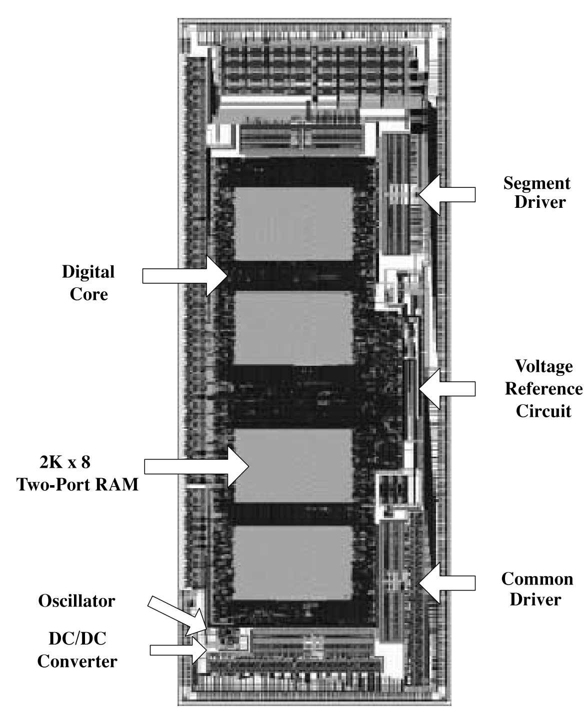

Fig. 9 Layout of the OLED driver IC.

Table 1 The specification of the OLED driver IC.

Display Area	1.8 Inch Diagonal
Pixel Number	128×128
Pixel Pitch	260 μm
Gray Scale	64
Color	Monochrome (Green)
Clock Freq.	10 MHz Internal OSC
Display Freq.	76 Hz
Segment Driver	100 μA at 12 V
Common Driver	12.8 mA at 12 V
Driving Method	Current Driving
Full CMOS Chip Area	$4600 \times 13600\,\mu m^2$
Number of Pins	411 Pins
OSC, DC/DC Converter, Memory	On Chip

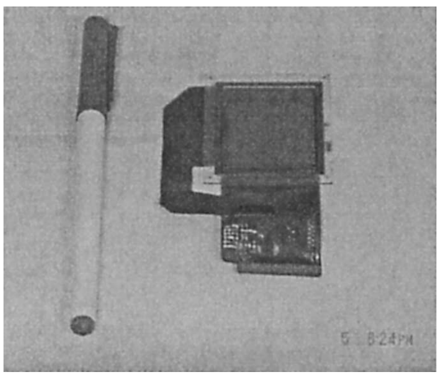

Fig. 10 Photograph of OLED panel and driver IC.

($4600\,\mu$m $\times$ $13600\,\mu$m).

4. Performances

As a result, LUT and PWM method was applicable and 64 gray scale (4 bit) was successfully accomplished. Furthermore, excellent image uniformity and clear image display were achieved. Table 1 summarizes the specification of the OLED displays manufactured in this works.

The developed driver IC was adapted to the 1.8″ passive matrix OLED panel, and implemented display module was used for Personal Communication System (PCS) phone (Fig. 10).

From this result, we showed how these methods are essential in driving OLED display devices. Figure 11 shows the display image of our OLED panel that was driven by the earlier mentioned driver IC. The color of emission is green. Image with good uniformity and high resolution were acquired.

Fig. 11 Display image of PCS phone display panel.

5. Conclusions

In this works, we proposed the new driving methods such as PWM and LUT method for OLED display panel. And highly integrated CMOS current driver IC was presented applicable for organic light emitting diode (OLED) displays. Developed driver IC contains digital display control unit, internal image memory cells, common and segment driver cells, internal oscillator and DC-DC converter.

In conclusion, the best applicable OLED driver IC was developed and implemented to the Personal Communication System (PCS) phone. From this result, we showed how these methods are essential in driving OLED display devices.

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