Driving Method with Variable Integration Time for Ambient Light Sensing Circuit

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Abstract
We proposed driving method with variable integration time for ambient light sensing. One operation period of the proposed driving method consists of several sub-integration periods with variable integration time which can enlarge dynamic range of ambient light sensing circuit. Temperature dependent characteristic of p-intrinsic-metal (p-i-m) diode can be compensated using the proposed driving method

1. Introduction

An ambient light sensing function in the mobile displays, which can contribute to low power consumption and improved visibility by detecting ambient light intensity and controlling the brightness of the display panel accordingly, can be implemented using low temperature polycrystalline silicon (LTPS) thin film transistor (TFT) technology [1-5]. If an ambient light sensing function is implemented using a photo sensor chip or discrete photo detecting element in the display module that allows light to be guided to the chip, there are problems associated with the increase in the volume of the display and difficulties in the manufacturing of the display module that allows light to be guided to the chip. Therefore, an ambient light sensing circuit using LTPS TFTs can both decrease the display module volume and lower the manufacturing cost.

Ambient light sensing circuits, which consist of LTPS TFTs and photo diode such as p-intrinsic-n (p-i-n) diode or p-intrinsic-metal (p-i-m) diode, have an integration capacitor for converting the photo leakage current of the photo diode into analog voltage because the photo leakage current of the photo diode is too small to readout directly. Therefore, the dynamic range and resolution of output signal depend on size of the integration capacitor in the most ambient light sensing circuits. In case of an ambient light sensing circuit with small integration capacitor, it has good resolution under low ambient light intensity but cannot perform sensing operation under high ambient light intensity due to saturation effect of the small integration capacitor. In case of an ambient light sensing circuit with large integration capacitor, it can perform sensing operation under high ambient light intensity but has poor resolution under low ambient light intensity. Moreover, it is very difficult to sense ambient light intensity at high temperature condition because thermal leakage current of the photo diode drastically increases according to temperature on the glass. Therefore, in case of an ambient light sensing circuit with small integration capacitor, it may be also difficult to sense low ambient light intensity at high temperature condition.

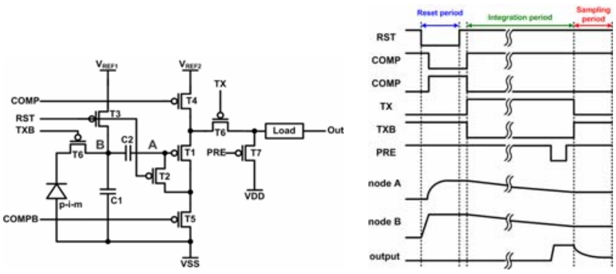
To solve these problems, the adaptive sensitivity control method and temperature compensation method using reflector have been proposed [3, 5]. They have reasonably wide dynamic range and good temperature compensation. However, the adaptive sensitivity control method can not compensate temperature problem and the temperature compensation method using reflector can not sense low ambient light intensity at high temperature condition.

In this paper, we proposed the driving method with variable integration time for wide dynamic range and temperature compensation. The proposed method is verified by measurement of the source follower type ambient light sensing circuit using LTPS TFTs and p-i-m diode.

2. Proposed driving method

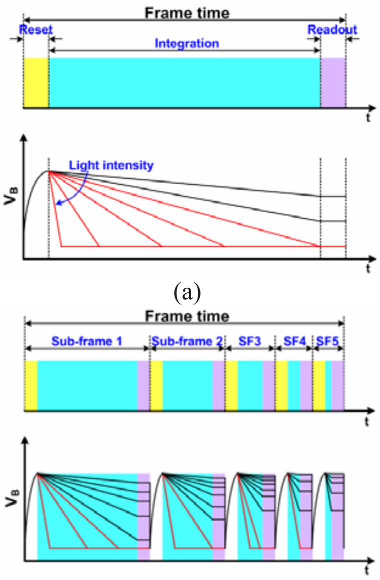
Figures 1 (a) and (b) show the source follower type ambient light sensing circuit and timing diagram [4]. The source follower type ambient light sensing circuit consists of p-type TFTs and p-i-m diode for low manufacturing cost. The timing diagram shown in figure 1 (b) is a driving sequence for sensing operation. The driving sequence consists of reset, integration, and sampling period.

Figures 2 (a) and (b) show operation principles of previously reported and the proposed driving methods. In previously reported driving method shown in figure 2 (a), it is difficult to sense high ambient light intensity because integration time and size of p-i-m diode and C1 are fixed. When ambient light intensity becomes higher than sensible intensity of an ambient light sensor, an ambient light sensor outputs saturated signal. Therefore, the dynamic range of an ambient light sensing circuit with previously driving method is restricted by fixed integration time and size of p-i-m diode and C1.



(a) (b)

Fig. 1. (a) Schematic diagram of source follower type ambient light sensing circuit and (b) timing diagram.



(b)

Fig. 2. (a) Operation principles of previously reported driving method and (b) proposed driving method (m=5).

In the proposed driving method shown in figure 2 (b), one frame period consists of 'm' sub-frame periods. The driving sequence of one sub-frame period is same as that of figure 1 (b). Each sub-frame has different integration time and the integration time of 'm'th sub-frame is same as half that of 'm-1'th sub-frame. If we let the integration time of 1st sub-frame to T_1, the integration time of 'm'th sub-frame is derived as

$$T_m = T_1 \cdot 2^{-(m-1)}. \quad (1)$$

So, analog output signal of the ambient light sensing circuit with the proposed driving method does not saturate under high ambient light intensity as shown in figure 2 (b). Therefore, it can be easily implemented the ambient light sensing circuit with wide dynamic range using the proposed driving method due to multi-frame operation with variable integration time.

Each output signal of all sub-frames is merged into one digital signal through simple signal processing flow. Figures 3 shows output signal processing flow. Each analog output signal of all sub-frames is converted into n-bit digital signal by n-bit analog-to-digital converter (ADC). Each converted digital signal of all sub-frame operations is multiplied by 2^{m-1} and it can be expressed as

$$\begin{aligned}\Delta V_m \times 2^{m-1} &= \frac{I_{PHOTO} \cdot T_m}{C_1} \times 2^{m-1} \\ &= \frac{I_{PHOTO} \cdot T_1 \cdot 2^{-(m-1)}}{C_1} \times 2^{m-1} = \Delta V_1,\end{aligned} \quad (2)$$

where C1 is the capacitance of integration capacitor in figure 1 (a), and ΔV_m and I_{PHOTO} are the analog voltage signal of 'm'th sub-frame operation and the photo leakage current of the p-i-m diode, respectively. Finally, the interpolator block outputs (n+m-1)-bit data which is interpolated by each multiplied sub-frame data.

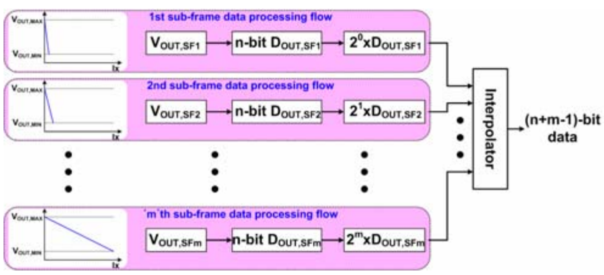


Fig. 3. Signal processing flow for (n+m-1)-bit data which is interpolated by each multiplied sub-frame

data.

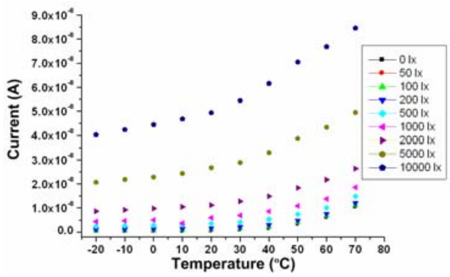
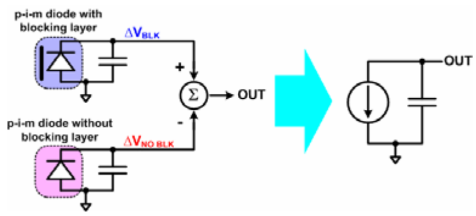
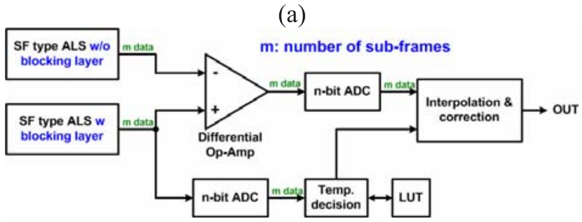


Fig. 4. Measured leakage current of p-i-m diode in reverse bias according to temperature and illuminance.



(a)



(b)

Fig. 5. (a) Conceptual operation principles of temperature compensation and (b) system block diagram for temperature compensation.

3. Temperature compensation method

The photo leakage current of the p-i-m diode is determined by incident light intensity in reverse bias condition. It is possible to sense ambient light intensity for sensing the photo leakage current of the p-i-m diode because the photo leakage current is a dominant leakage source of the p-i-m diode at low temperature. However, the thermal leakage current of the p-i-m diode increases drastically when temperature on the glass substrate increases. So, the thermal leakage current can be larger than the photo leakage current and the ambient light sensing circuit can not operate normally. Figure 4 shows measured leakage current of the p-i-m diode in reverse bias according to temperature and illuminance, and we can verify that the thermal leakage current increases with respect to temperature.

The leakage current of the p-i-m diode consists of the photo leakage current and the thermal leakage current. So, the thermal leakage current must be eliminated for solving aforementioned problem because the thermal leakage current alters according to temperature on the glass substrate. Therefore, we used another sensing circuit using the p-i-m diode with blocking layer for thermal leakage current elimination and conceptual operation principle of this method shows in figure 5 (a). This method, which is to subtract the output signal of sensing circuit using the p-i-m diode without blocking layer from the output signal of that with blocking layer, can eliminate thermal leakage current as expected because the p-i-m diode with blocking layer has only thermal leakage current as leakage current source. This principle can be expressed as

$$\Delta V_{NO\,BLK} = \frac{(I_{PHOTO} + I_{THERMAL}) \cdot T_{INT}}{C_1},$$
$$\Delta V_{BLK} = \frac{(I_{THERMAL}) \cdot T_{INT}}{C_1}, \quad (3)$$
$$\Delta V_{BLK} - \Delta V_{NO\,BLK} = -\frac{I_{PHOTO} \cdot T_{INT}}{C_1},$$

where T_{INT} is integration time, and ΔV_{NOBLK} and ΔV_{BLK} are analog output signals of sensing circuit using the p-i-m diode without blocking layer and that with blocking layer, respectively.

Figure 5 (b) shows block diagram using two sensing circuits with the proposed driving method with variable integration time for temperature compensation. The proposed driving method is also required for temperature compensation. Because the thermal leakage current of the p-i-m diode rapidly discharges the reverse bias voltage stored in C1 at high temperature, output saturation effect can occur. Therefore, the output signal of sub-frame with short integration time must be used for sensing operation at high ambient light or high temperature condition.

The differential operational amplifier (Op-Amp) performs subtract operation between output signals of two sensing circuits, and subtracted analog signals are converted into digital signal by ADC. The differential Op-Amp can be eliminated using digital subtract operation. Finally, the interpolation and linearity correction block outputs (n+m-1)-bit digital signal through aforementioned multi-frame interpolation using converted digital signal of sub-frames and temperature data. Because the sensing circuit using the p-i-m diode with blocking layer operates as a temperature sensor, the temperature data can be easily obtained without extra temperature sensor.

4. Experimental results

The source follower type ambient light sensing circuit in figure 1 (a) has been fabricated to verify the proposed driving method for wide dynamic range and temperature compensation. The experimental conditions are summarized in table 1. The number of sub-frames is 8 and the integration time of first sub-frame is 4 ms. The output voltage of the ambient light sensing circuit using multi-frame driving method is measured under the condition of ambient light variation from 0 to 20,000 lx and temperature variation from -20 to 70 ºC. The interpolated output signals using the measured output voltage at -20 and 70 ºC are shown in figure 6 (a) and (b). The linearity error of the interpolated output signals under each temperature condition is shown in figure 7. We can confirm that the proposed driving method can compensate temperature problem and the linearity error is under ± 9 % except for low ambient light condition. Moreover, the ambient light sensing circuit with the proposed method exhibits wide dynamic range of 79.7 dB based on experimental results.

5. Conclusions

A newly developed driving method using multi-frame with variable integration time has been proposed for wide dynamic range and temperature compensation. Experimental results show that the proposed method can improve dynamic range and temperature compensation. The dynamic range of the sensing circuit is 79.7 dB and the maximum linearity error is ± 9 % under the condition of temperature variation from -20 to 70 ºC. Therefore, the proposed driving method is suitable for ambient light sensor with wide dynamic range and temperature compensation.

6. Acknowledgements

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TABLE 1. Experimental conditions

Number of sub-frames	8
T_1 (integration time of 1st sub-frame)	4 ms
Ambient light intensity	0~20,000 lx
Temperature	-20~70 ºC

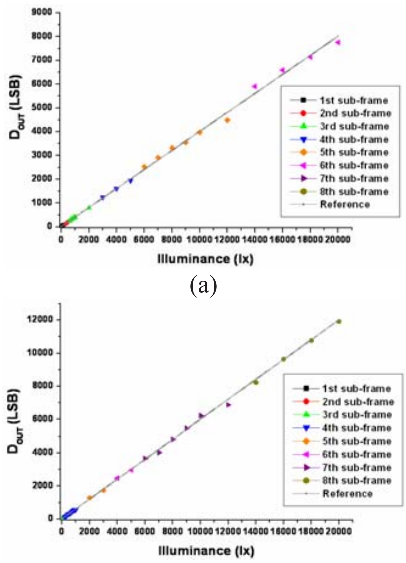

Fig. 6. Interpolated output signal using measured output voltage at (a) -20 ºC and (b) 70 ºC.

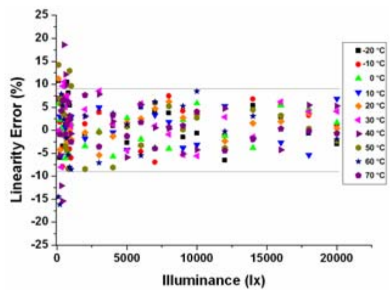

Fig. 7. Measured linearity error of interpolated output signals under each temperature condition.