Switching power supply circuit with voltage-drop compensation for AMOLED displays

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Abstract: A power supply circuit that compensates for the voltage drop in the large-sized AMOLED display panel is presented. The voltage drop, which degrades luminance uniformity, is directly detected, and the detected value is then fed back to the controller circuit to adaptively adjust the power supply voltage in order to minimize the voltage drop. The validity of the proposed technique was verified by experimental results; the two-fold improvement was achieved in terms of the measured voltage drop. As a result, the measured luminance uniformity was also significantly enhanced.

Keywords: OLED display, switch-mode power supply (SMPS), voltage drop, DC-DC converter, feedback circuit, supply power distribution

Classification: Energy harvesting devices, circuits and modules

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1 Introduction

In recent years, the AMOLED technology has attracted considerable attention as a very desirable display. However, as large-sized and high-resolution AMOLED displays such as Full-HD (1920 x 1080) and Ultra-HD (3840 x 2160) have come into wider use for TV applications, the voltage (IR drop) by pixel currents of the supply voltage to the OLED on the panel becomes a critical issue [1, 2]. Due to the finite conductance of fabricated metal lines, the pixel currents flowing through the parasitic resistances on the power supply lines cause voltage drops, which can limit the uniform gray-level operation and deteriorate long-range uniformity.

Recent papers have reported a variety of attempts to effectively compensate for voltage drop. However, the compensation pixel circuits [2, 3, 4, 5, 6] are generally somewhat more complicated than the conventional pixel circuits composed of two transistors and one capacitor (2T-1C), resulting in the reduction of aperture ratio. Moreover, the external compensation techniques [7, 8, 9] require highly complex hardware, which could lead to higher costs. Furthermore, their compensation techniques are difficult to be adopted in digitally driven OLED panels [10].

In this paper, a new power supply circuit with voltage-drop compensation for large-sized high-resolution AMOLED displays is proposed. Compared with the previous approaches, the voltage-drop compensation is performed in a proposed step-down DC-DC converter circuit with an additional feedback loop which adaptively adjusts the output supply voltage by sensing the average value of total voltage drops on the panel. Since revision of the pixel circuit is not required, a high aperture ratio (2T-1C pixel) can be maintained, and the proposed scheme is also highly compatible even with the digital-driven panels.

2 Supply voltage distributions

An equivalent power supply circuit model of an AMOLED panel with a 2T-1C pixel structure is illustrated in Fig. 1. As shown in Fig. 1, the OLED is driven by the pixel current $I_{EL}$ generated by the potential difference between the gate and the source $V_{GS}$ of the driving thin-film transistor (TFT), given by $|V_{Data} - V_{DD}|$. However, the driving current that passes through the supply power causes a voltage drop due to the parasitic resistance $R_P$ of the power line. Therefore, the $V_{GS}$ in each driving TFT varies from pixel to pixel along the supplied voltage $V_{DD,M}$, generating various $I_{EL}$. This phenomenon causes non-uniform luminance from the top to the bottom of the panel. The power supply voltage $V_{DD}$ (source of each driving TFT) of the pixel can be modeled as:

$$V_{DD,M} = ELV_{DD} - \sum_{m=1}^{n} \left( R_P \sum_{k=m}^{N} I_{EL,k} \right).$$  (1)
where \( N \) and \( n \) are the total number of vertical pixel rows and the vertical pixel position, respectively. Thus, the error current \( \Delta I_{EL,nM} \) of the \( n \)-th row pixel owing to the voltage drop can be approximated as:

\[
\Delta I_{EL,nM} = I_{EL,Ideal} - I_{EL,nM} \approx \frac{1}{2} \mu C_{ox} \left( \frac{W}{L} \right)_{DTFT} \left[ \sum_{n=1}^{N} R_P \cdot \frac{1}{2} \sum_{k=m}^{n} I_{EL,kM} \right]^2,
\]

where \( \mu \), \( C_{ox} \), and \( (W/L)_{DTFT} \) are the mobility, oxide capacitance, and aspect ratio of driving TFT, respectively. Note that electrical variations of DTFTs such as threshold voltage \( V_{th} \) and mobility \( \mu \) shifts are not considered in Eq. (2).

Fig. 2 shows the simulation data of the supply-voltage \( V_{DD} \) distributions for a 55-inch Full-HD (1920 × 1080) 2T-1C AMOLED panel. In this simulation, it was assumed that \( R_P = 9.26 \Omega \) (total resistance on single power line = 10 k\( \Omega \)), typical \( I_{EL,Ideal} = 100 \) nA, typical \( ELV_{DD} = 6 \) V, \( \mu C_{ox}(W/L)_{DTFT} = 200 \mu A/V^2 \), and \( V_{th,TFT} = 5 \) V. In the single-bank (left of Fig. 2), \( ELV_{DD} \) is supplied only from the top side of the panel. The middle of Fig. 2 shows the result of the dual-bank structure in which \( ELV_{DD} \) is supplied to both sides of the panel. The center-supplied \( ELV_{DD} \) structure (right of Fig. 2) provides the supply-voltage \( ELV_{DD} \) to the center of the panel.

Fig. 2. Simulated supply-voltage \( V_{DD} \) distributions for Full-HD AMOLED panel with single-bank \( ELV_{DD} \), dual-bank \( ELV_{DD} \), and center-supplied \( ELV_{DD} \).
3 Switching power supply with voltage-drop compensation

Power $ELV_{DD}$ for driving AMOLED panel is generally supplied from a switch-mode power supply (SMPS) circuitry. The SMPS circuit converts the input power (typical DC level = 12 V) into the desirable output voltage $ELV_{DD}$ ($5$–$7$ V); thus, a step-down buck converting circuit is required. In the voltage-mode control, a resistor divider network placed on the output node is used to feed back a portion ($P_1$) of the output voltage ($ELV_{DD}$) to the inverting terminal of the error-amplifier. This voltage is compared to the internal reference voltage ($V_{REF}$); during steady-state regulation, the error-amplifier output ($V_{CTRL}$) will not go below the voltage required to maintain the feedback voltage equal to $V_{REF}$. Therefore, the output voltage will be $V_{OUT} (= ELV_{DD}) = 1/P_1 \cdot V_{REF}$.

The concept of the proposed voltage-drop compensation is an addition of the supplementary feedback loop in the power supply circuit for the decreased supply voltages ($V_{DD,Nk}$), which are sensed at the bottom of the AMOLED display panel, as depicted in Fig. 3. The presented circuit detects $V_{DD,N1}, V_{DD,N2}, \ldots, V_{DD,NM}$, which are the most dropped voltage of each power supply line at the edge of the panel, and calculates their average value. A portion ($P_2$) of the averaged value is then additionally fed to the error-amplifier of the power supply circuit in order to adjust the output voltage $ELV_{DD}$, adaptively. Therefore, the error-amplifier output $V_{CTRL}$ can be expressed as:

$$V_{CTRL} = V_{REF} - P_1 \cdot ELV_{DD} - P_2 \cdot \frac{1}{M} \sum_{k=1}^{M} V_{DD,Nk}.$$  

(3)

Due to stabilization mechanism of the double-loop negative feedback of Fig. 3, the value of $V_{CTRL}$ reaches close to zero. When a sudden increase of the OLED currents ($I_{EL}$) in the panel occurs by increasing the overall brightness, the non-uniformity of luminance is supposed to be intensified as the IR-drop voltage ($\Delta V_{DD}$) increases, from Eq. (1). In this situation, however, the variation of $V_{DD,Nk}$ appearing at the edge of the panel can be effectively reduced to $[P_1/(P_1 + P_2)] \cdot \Delta V_{DD}$, by virtue of the proposed double-loop feedback operation.
4 Experimental results

To verify the validity, the proposed switching power supply circuitry is designed in conjunction with a synchronous DC-DC buck converter chip and a Full-HD AMOLED panel with a center-driven ELVDD structure, as described in Fig. 4. The step-down converter is controlled by pulse width modulation (PWM) and operates at a fixed switching frequency of 0.65 MHz. The voltage-drops are sensed at the top and bottom of the panel and then averaged by averager circuits ($V_{AVG1}$ and $V_{AVG2}$). The feedback portions ($P_1$ and $P_2$) can be reconfigured by controlling the resistor values $R_1 - R_4$. Table I shows the detailed design parameters for the implementation of the proposed switching power supply circuitry shown in Fig. 4.

![Fig. 4. Configuration of proposed switching power supply circuit for AMOLED display with voltage-drop compensation.](image)

Table I. Implementation of key parameters

| Parameters                      | Value                  |
|---------------------------------|------------------------|
| Input voltage $V_{IN}$          | 12 V                   |
| Output voltage $V_{OUT}$ (= ELVDD) | 6.5 V                 |
| Switching frequency            | 650 kHz                |
| Inductor $L$                    | 3.3 µH                 |
| Load capacitor $C_{LOAD}$       | 50 µF                  |
| Bootstrap capacitor $C_{BST}$   | 0.1 µF                 |
| Band-gap reference (BGR) $V_{REF}$ | 0.765 V            |
| Feedback resistor $R_1$         | 22.1 kΩ                |
| Feedback resistor $R_2$         | 367 kΩ                 |
| Feedback resistor $R_3, R_4$    | 600 kΩ                 |
| Target display panel           | ELVDD-center-supplied digital-driven Full-HD AMOLED |
Fig. 5 shows the measured key waveforms ($V_{DD,Nx}$) when the uniform display with a certain gray-level is driven. The voltage-drop caused by the OLED currents was measured to be $\Delta 515\text{mV}$ in conventional configuration. However, with the proposed technique, it can be clearly observed that the voltage-drop was reduced to $\Delta 260\text{mV}$ (two-fold improvement) since the $ELV_{DD}$ was adaptively adjusted by an additional feedback loop. Fig. 6 shows the measurement result of luminance uniformity. In the case of conventional driving, the luminance varies from pixel to pixel, as shown in Fig. 2. Meanwhile, the luminance with the proposed method is highly uniform regardless of the pixel position owing to the adaptive adjustment.

![Image of key waveforms without and with proposed additional feedback loop]

**Fig. 5.** Measured key waveforms without (left) and with (right) proposed additional feedback loop.

![Image of measured luminance uniformity]

**Fig. 6.** Measured luminance uniformity.

### 5 Conclusion

In this paper, a new power supply circuit with voltage-drop compensation was presented. The voltage-drop is compensated by a proposed step-down converter with an additional feedback loop that adjusts the $ELV_{DD}$ by sensing the averaged value of voltage drops on the panel. According to the experimental results, the luminance uniformity can be significantly improved by using the proposed power supply circuit. In addition, the circuit is compatible with all types of OLED panels. Thus, the proposed technique is highly applicable for high-resolution OLED TVs.