Emission Gate Driver Generating Reliable and Adjustable Scan Signals for Micro-LED Displays

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Abstract
This work proposes an emission gate driver to generate adjustable scan signals. The reliability of emission scan signals can be enhanced by increasing the driving capability of TFTs and the stabilization period. Therefore, the proposed gate driver is feasible for micro-LED displays.

1 Introduction

Nowadays, active-matrix (AM) micro light-emitting diode (micro-LED) displays have been developed for advanced consumer electronics, such as smartwatches, augmented reality headsets, and automotive devices [1]. Micro-LED displays possess extreme resolution and luminance to provide high-quality images [2]. However, considering the power consumption of displays, micro-LEDs avoid being driven at maximum power all the time. Therefore, emission gate drivers producing adjustable emission scan signals are exploited for pixel circuits, which assist in the emission control of micro-LEDs [3]-[6]. The luminance of micro-LED displays can be modulated to save power according to ambient light.

An emission gate driver is required to drive many pixels of one row based on horizontal resolution, resulting in long rising and falling times due to heavy output loadings [7], [8]. Low-temperature polycrystalline silicon thin film transistors (LTPS TFTs) with increased aspect ratios, exhibiting outstanding current driving, are adopted to shorten the rising and falling times [9], [10]. Furthermore, the reliability of emission scan signals is also significant. An et al. proposed a gate driver that integrates all scan signals for a typical pixel circuit [11]. In the part of the emission scan, the gate driver can modulate the width of the emission pulse by changing the operating frequency and inputting multiple pulses. The large size of the pull-down TFT is designed to discharge the output rapidly. However, incomplete discharge to the low voltage (VGL) still occurs because the gate voltage is not low enough to fully turn on the pull-down TFT, influencing the driving of the pixels. Additionally, Chang et al. presented an emission gate driver to produce tunable emission pulses [12]. The gate driver can decrease the gate voltage of pull-down TFT to a lower voltage than VGL by the capacitive coupling effect, ensuring the output is pulled down to VGL. Nevertheless, in the pull-up period, the output is pulled up to VGH during 50% of the time and floating during the other 50%, which is unstable and susceptible to signal disturbances.

This work develops a novel emission gate driver based on LTPS TFTs, which modulates the pulse widths of scan signals...
by different phases of start pulses. To enhance the robustness of emission scan signals, the voltage at the gate node of the pull-down TFT is lowered, and the period of the pull-up TFT in the floating state is reduced. Therefore, the gate driver can steadily output the required $V_{GL}$ and $V_{GH}$ to control the pixels of micro-LED displays.

2 Circuit Operation and Driving Scheme

Figs. 1(a) and 1(b) present the circuit schematic and timing diagram of the proposed emission gate driver, comprising one pull-down TFT (T1), one pull-up TFT (T3), five switch TFTs, and two capacitors and employing two opposite clock signals of 7.5% duty ratio. CK1 and CK2 are utilized by gate drivers for odd rows of pixels, while CK3 and CK4 are for even rows of pixels. ST is an adjustable start pulse in the first stage to determine the pulse widths of all emission scan signals ($EM_{[N]}$, $EM_{[N-1]}$, and $EM_{[N+1]}$), the last and next stage of emission scan signals, control this stage. The operational details of the gate driver are described in the following.

2.1 First Period

CK1 and ST are $V_{GL}$ to turn on T2, T5, and T7. Nodes $A_{[N]}$ and $P_{[N]}$ are charged to $V_{GH}$. When $P_{[N]}$ is at $V_{GH}$, T3 and T4 are turned off. Subsequently, $Q_{[N]}$ goes to $V_{GL} + |V_{TH2}|$, making $EM_{[N]}$ discharged to $V_{GL} + |V_{TH2}| + |V_{TH1}|$ through T1.

2.2 Second Period

CK1 becomes $V_{GH}$ to turn off T2 and T7, while CK2 becomes $V_{GL}$ to turn on T4. Node $A_{[N]}$ is discharged to $V_{GL} + |V_{TH1}|$, $Q_{[N]}$ is coupled to $2V_{GL} + |V_{TH2}| + |V_{TH1}|$ − $V_{GH}$ by C1 to strengthen the driving capability of T1, and $EM_{[N]}$ is pulled down to $V_{GL}$ through T1.

2.3 Third Period

CK2 changes from $V_{GL}$ to $V_{GH}$. $P_{[N]}$ is boosted to $2V_{GH} − V_{GL}$ via C2 but is discharged to $V_{GH} + |V_{TH1}|$ instantly because the gate and drain voltages of T5 are $V_{GH}$. In addition, CK1 goes to $V_{GL}$ to turn on T2. $Q_{[N]}$ is charged to $V_{GH}$ to deactivate T1, ceasing the discharge of $EM_{[N]}$.

2.4 Fourth Period

CK1 returns to $V_{GH}$ to turn off T2. CK2 changes from $V_{GH}$ to $V_{GL}$, coupling $P_{[N]}$ to $V_{GL} + |V_{TH1}|$. Therefore, T6 is turned on to maintain $Q_{[N]}$ at $V_{GH}$, and T3 is turned on to pull $EM_{[N]}$ up to $V_{GH}$.

2.5 Fifth Period

CK1 becomes $V_{GL}$ to turn on T2 to hold the voltage of $Q_{[N]}$. CK2 switches to $V_{GH}$, boosting $P_{[N]}$ to $V_{GH} + |V_{TH_T5}|$. As T1 and T3 are turned off simultaneously, $EM_{[N]}$ is at $V_{GH}$ but becomes floating.

The fourth and fifth periods alternate sequentially until the next start pulse is triggered. Since the fifth period is only occupied by 7.5% of the clock period, a stabilizing period of 92.5% can be achieved, effectively reducing the fluctuation in $EM_{[N]}$. Hence, the proposed emission gate driver can generate reliable emission scan signals.

3 Results and Discussions

HSPICE software is employed to verify the function of the proposed emission gate driver. Table I lists the design parameters of LTPS TFTs, capacitors, clock signals, and DC sources used in the gate driver. To investigate the driving

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**Table I**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>(W/L)$_{T1,T2}$ (μm/μm)</td>
<td>162 / (3+3)</td>
</tr>
<tr>
<td>(W/L)$_{T3,T1}$ (μm/μm)</td>
<td>27 / (3+3)</td>
</tr>
<tr>
<td>(W/L)$_{T4,T7}$ (μm/μm)</td>
<td>5 / (3+3)</td>
</tr>
<tr>
<td>ST, CK1-CK4 (V)</td>
<td>-9 - 9</td>
</tr>
</tbody>
</table>

**RC Loadings**

| $R_s$ (kΩ) | 4.22 |
| $C_s$ (pF) | 716 |

Fig. 2 Transient voltage waveforms of clock signals, start pulse, outputs of $N^{th}$ and $N+1^{th}$, and node $Q_{[N]}$.

Fig. 3 Transient voltage waveforms of emission scan signals according to different start pulses.
capability of the gate driver, the output is connected to RC loadings, $R_L$ of 4.22 kΩ and $C_L$ of 716 pF, to simulate driving one row of a 5.23-inch micro-LED display with a resolution of $160 \times 135$ and a frame rate of 120 Hz. Fig. 2 shows the transient voltage waveforms of CK1, CK2, ST, EM$_{[N]}$, EM$_{[N+1]}$, and Q$_{[N]}$ in the proposed gate driver. To further turn on T1, Q$_{[N]}$ is coupled by C1 to -24.5 V, which is noticeably lower than -9 V. EM$_{[N]}$ can be completely pulled down to -9 V. When EM$_{[N]}$ is pulled up to 9 V, a 92.5% voltage stabilization period minimizes voltage fluctuations. Hence, the reliability of the gate driver is verified to implement effective pixel control. Fig. 3 depicts the transient waveforms of emission scan signals when different start pulses are input. As the pulse widths of the start pulses vary, the gate driver can generate the corresponding emission scan signals, modulating the luminance of micro-LEDs. Furthermore, Fig. 4 presents the system diagram of the proposed gate driver for micro-LED displays. To realize the hierarchical transmission, EM$_{[N]}$ is used to transmit to the next stage and feedback to the last stage in addition to driving the pixels of one row. Fig. 5 exhibits the transient output waveforms of ten consecutive gate drivers. Emission scan signals without deviations can be output to pixels row by row. Therefore, the proposed gate drivers can achieve progressive driving in micro-LED displays.

4 Conclusions
This work proposes a gate driver to provide emission scan signals for pixels. By inputting different phases of start pulses, emission scan signals with various pulse widths are generated, realizing the luminance control of micro-LEDs. Furthermore, the simulated results demonstrate the proposed emission gate driver can generate stable emission scan signals consecutively. Therefore, the gate drivers are a promising approach to drive pixel circuits for micro-LED displays.

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