Received 1 January 2020; revised 3 March 2020; accepted 4 March 2020. Date of publication 18 March 2020; date of current version 1 April 2020.
The review of this paper was arranged by Editor A. Nathan.

Digital Object Identifier 10.1109/JEDS.2020.2981725

Decreased Motion Blur in Large-Size, Organic, Light-Emitting Device Panels Due to Integrated Gate Driver Circuits With a Moving-Picture Response-Time-Reduction Method

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This work was supported by the Basic Science Research Program through the National Research Foundation of Korea funded by the Ministry of Education, Science and Technology under Grant 2019R1A2B5B03069968.

ABSTRACT The motion blur of a large-size, organic, light-emitting device (OLED) panel could be reduced by decreasing the moving-picture response time (MPRT). The MPRT of an OLED display panel with a fast response was significantly affected by the frame frequency and the compensation driving method, and the MPRTs of large-size OLED display panels could be significantly decreased by using an integrated gate driver circuit with a MPRT reduction method. The MPRT was decreased due to the ability to turn the emitting pixels off in advance, which was possible due to the provision of black data. The integrated gate drivers were designed so that a normal display, black data insertion, and operation in the compensation mode could be achieved. The MPRT of a 65-inch ultra-high-definition (UHD) OLED panel was decreased to 3.4 ms by using an integrated gate driver circuit. The MPRT reduction method proposed in this study can reduce the MPRT time to below 6.8 ms according to the black data insertion duty. This MPRT time of 6.8 ms can be further reduced to 3.4 ms in 50% black data duty, showing a 50% MPRT improvement. Thus, the motion blur of such large-size OLED display panels can be significantly reduced by decreasing the value of the MPRT.

INDEX TERMS Motion blur, large-size organic light-emitting device, moving picture response time, integrated gate driver.

I. INTRODUCTION

Recently, display technologies have been rapidly developing due to advances in materials and electronic technologies. Among the several displays, organic light-emitting devices (OLEDs) have positioned themselves as next-generation display panels in the high-end TV market, having replaced liquid crystal displays (LCDs) [1]–[3]. Because of the self-emission characteristics of OLEDs, they can realize perfect black images with high brightness, but without light leakage. Simultaneously, OLEDs achieve wider viewing angle and uniform luminance by using precise compensation [4], [5]. Despite these overwhelming advantages, the high price of OLEDs has slowed their transition to the OLEDs, for which integrated gate drivers have been developed to achieve reduced cost. On the other hand, the picture quality of OLEDS must be enhanced to make them more competitive in the market place. Even though significant improvements in the response times of LCDs have been achieved, the response times of OLEDs are still too slow [6], [7].

Oxide thin-film transistors (TFTs) have been used as backplanes for OLED displays and are different from the amorphous-silicon (a-Si) TFTs commonly used for LCDs [8]–[12]. Because the mobilities of oxide TFTs are 8 to 10 times higher than those of a-Si TFTs, the integrated circuits in OLEDs tend to be smaller. On the other

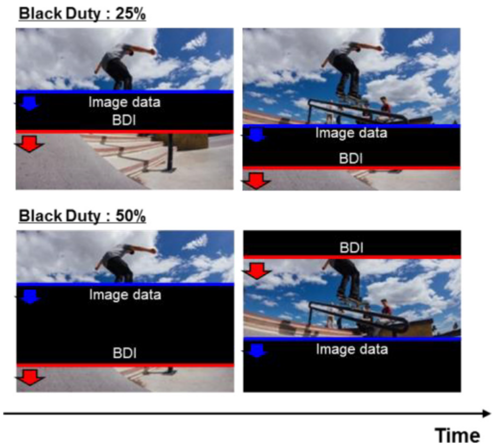

FIGURE 1. Driving concept of the organic light-emitting devices for MPRT reduction.

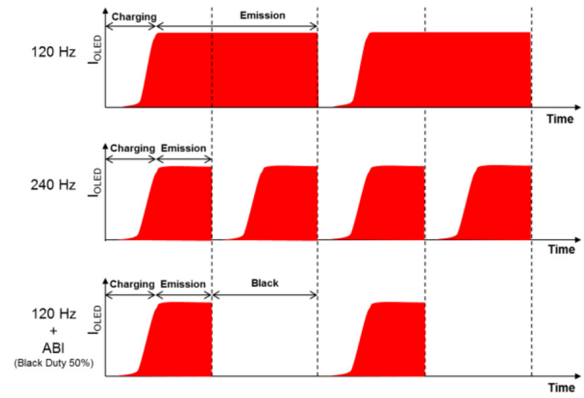

FIGURE 2. Driving waveforms of the organic light-emitting devices with adaptive black data insertion for MPRT reduction.

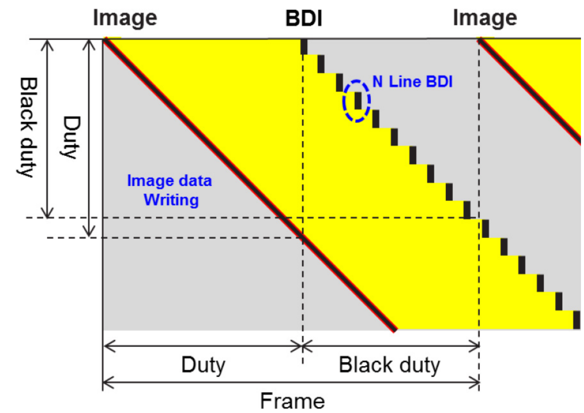

FIGURE 3. (a) Duty and (b) writing scheme of the video and the black data.

hand, being depletion-mode transistors, oxide TFTs often have a negative initial threshold voltage (Vth), which results in a sizable leakage current and, if not well designed, in malfunctions [13]–[17]. Image quality enhancement in motion picture technology involves integrated gate drivers in which black data insertion technology has been inserted. LCD technologies, such as black data or frame insertion, back-light local dimming, and high-frequency driving, have been applied to improve the moving-picture response time (MPRT) [18]–[20]. This paper presents a novel technological design for a fast MPRT OLED panel with a new integrated gate driver to improve the image quality and the price competitiveness of OLED display panels. Experiments we performed show that the motion in an OLED display can be reduced by using our design approach, which consists of a MPRT reduction driving method with an integrated gate driver circuit.

II. MPRT REDUCTION TECHNOLOGY

A. MPRT REDUCTION DRIVING METHOD

Figure 1 shows the proposed sequential screen motion of adaptive black data insertion (ABI). First, after the video data have been written, black data are used after the holding duty, and the video data are erased by the black data. Then, other video data come from the next frame again, and this process is repeated. When the gap between the video data and the black data is longer, the black duty becomes longer, resulting in a decrease in the value of the MPRT, the value of the MPRT increasing with decreasing black duty. Figure 2 shows 120- and 240-Hz conventional driving waveforms and the ABI driving waveform. Black data insertion with a duty of 50% is equivalent to a holding time of 240 Hz, which is expected to have an effect of reducing motion blur [21]–[23].

Figure 3 shows a picture explaining the sending of black data. When black data are inserted, the frame frequency is 240 Hz because the signals with the same number of the gate line outputs as the image data are sequentially inserted. However, the frame frequency becomes 120 Hz $*$ (1 + 1/N) when N number of black data are simultaneously outputted. When N lines are simultaneously inserted into the black data, the frame frequency becomes less than 240 Hz.

OLED displays are required to sense and compensate for the threshold voltage of the pixel TFT if uniform luminance is to be sustained. The setting of the sensing timing makes the implementation of ABI technology difficult, and avoiding overlaps of the sensing timings with the timings for video data and black data is very complicated. The sensing pixels of the line typically operate during a porch time between the frame and the frame right after scanning the last line of the display. Even though the video data have been written on the last line, the black data are still being written in the middle of the screen. Therefore, the sensing timing should be established so as not to interfere with the other gate signals, such as the video scanning clock signal and the black data clock signal. Because the sensing timing is subject to serious limitations, the sensing method in the pixel is different from the conventional sensing method used to achieve sufficient sensing performance. Although the sensing operation in the general drive mode takes place in the long porch interval of 300 us, the sensing operation with the ABI method proposed in this study, in which black data are inserted into the porch interval within the short time between gate signals to prevent interference with those gate signals, is different from the conventional method.

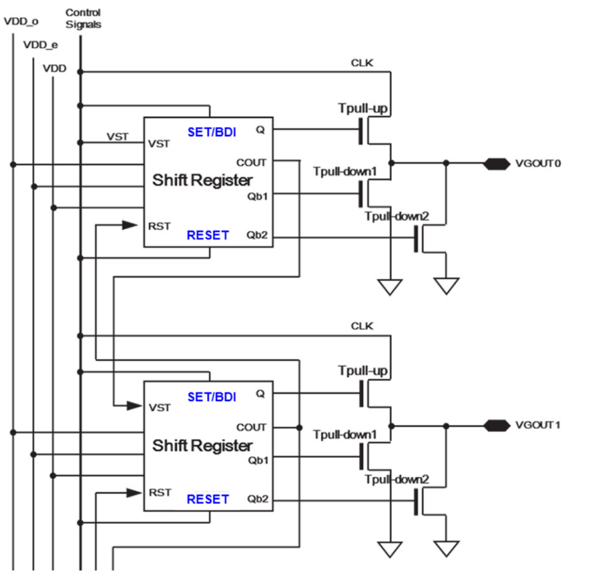

FIGURE 4. Simplified schematic diagram of the proposed integrated gate driver for adaptive black data insertion.

B. INTEGRATED GATE DRIVER FOR BLACK DATA INSERTION

A schematic diagram of the novel developed gate driver for black data insertion is shown in Figure 4. The dual pull-down structure is controlled by each of the two Qb-nodes. Only one of the two pull-down TFTs is used to suppress the Vth shift by reducing the duty ratio to 50%. The gate driver proposed in this paper has SET, BDI and RESET terminals to implement black data insertion to improve MPRT characteristics. During BDI operation, a signal is applied to this terminal, and a gate line to which black data are applied is selected. A block for Q-node charging, in addition to Q-node charging, to sense and compensate for the OLED pixel in the gate driver, as published in the literature [24], is installed. However, the reset function of the additional Q-node should be installed so that the sensing is completed in the circuit, and the whole frame is automatically reset in the next frame. Because the reset function is omitted in this circuit due to the black data insertion function, an additional RESET signal is required for Q-node discharging. Because the additional RESET signal is a functional signal added after black data have been inserted, there is no side effect for Q-node discharging.

Because oxide TFTs are depletion-mode TFTs with negative V_{th} values, leakage currents might cause malfunctions, especially in the sensing mode, for which the pulse width is much larger than it is in the display mode [27]. The channel length, mobility, center and maximum values of the V_{th}, and maximum distribution of for the manufactured a-IGZO TFT are 5.5 μm, 9.5 cm^2/v.s., 0.05 V, and 0.57 V, respectively. The manufactured TFT showed excellent uniformity, but negative Vth when the distribution characteristics were considered. By applying a bias voltage to the source higher than that applied to the gate when the TFT is off, circuit errors can be prevented because the leakage current of the TFT is eliminated when V_{gs} ($V_g - V_s$) is lower than the negative V_{th} of the TFT.

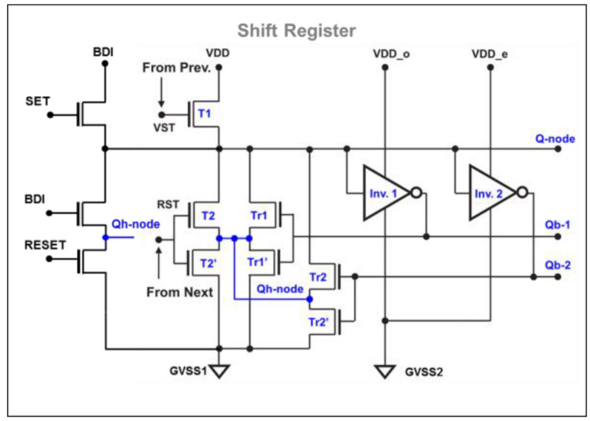

FIGURE 5. Schematic diagram of the shifter register for a black data insertion function.

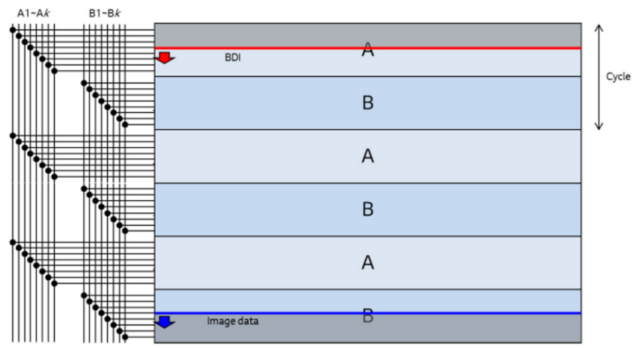

FIGURE 6. Control signal sets for the video data and the black data.

Figure 5 shows a schematic diagram of the shifter register for a black data insertion function. During BDI operation, signals are applied to the BDI, SET and RESET terminals, and the Q-node charges to output the selected gate line. After the BDI operation, a signal is applied to the RESET terminal to discharge the Q-node. The leakage current can be successfully suppressed by adding the Qh-node. The size of the shift register should be increased as the Oh-node, and a TFT to apply voltage, which is essentially required to prevent malfunction of the circuit due to TFT leakage, has been added. The Q-node is not directly connected to the low-voltage line via any TFT; the node is connected only to the Qh-node, which is automatically connected to the low-voltage line. The Qb-node and the Qh-node always have the same voltages, and the operation of the TFTs between two different nodes at high voltages can be turned off safely even when the Vth value of the TFT is negative.

Figure 6 shows the clock signal (CLK) sets for the video data and the black data. The gate driver should open the Q-node once within one frame to transmit the gate pulse for the black data. In this case, because the CLK pulse sets for transmitting the video data overlap, the CLK pulse sets for the video data and the black data should be separated.

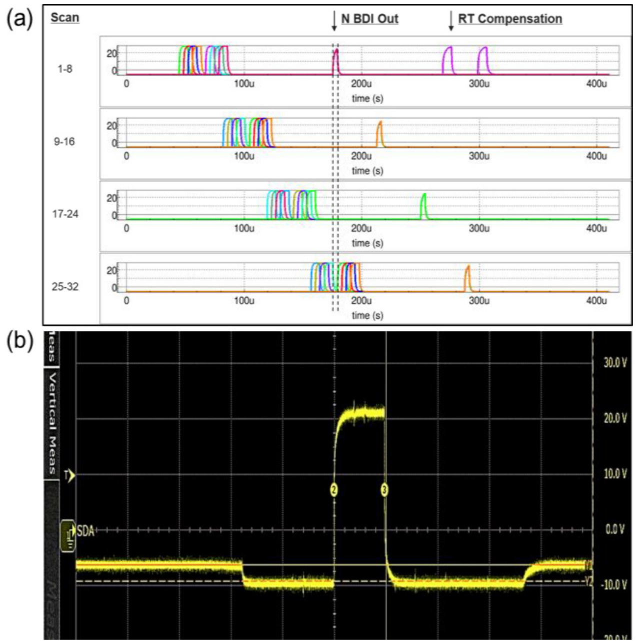

FIGURE 7. **(a) Simulation results as a function of time for the integrated gate driver, and (b) the experimental integrated gate driver output.**

When the video data are transmitted from the CLK A set, the output for the black data should be transmitted through the CLK B set, and conversely.

III. RESULTS AND DISCUSSION

A 65-inch UHD (ultra-high-definition), organic, light-emitting device panel was fabricated to verify that the motion blur in large-size, organic, light-emitting device panels can be reduced by using integrated gate driver circuits with a moving-picture response time reduction method. Figure 7(a) shows the simulation results as functions of time for the integrated gate driver. The normal scanning, black data insertion, and compensation operation waveforms are good enough to drive OLED panels, as shown in Fig. 7(a). Figure 7(b) shows the measurement results for the integrated gate driver. The fall time of the circuit is approximately 1.2 µs, which is fast enough to drive UHD OLED displays with an enhanced (decreased) MPRT at a 120-Hz frame frequency. Because the gate on-time of the UHD OLED displays is 3.0 µs, its fall time should be 1/2 that value for charging and discharging to take place within that time.

The gate driver has a dual pull-down configuration that slows the degradation rates of the positive voltage bias thermal stress (PBTS) and the response to the initial negative threshold voltage (V_{th}) of the oxide device, as shown in the previous circuit [28]. The reliability characteristics of the entire circuit are determined by the amount of the V_{th} shift of the TFTs on the Qb-nodes, such as pull-down TFTs, which have the dominant turn-on duty [29]. Therefore, the dual pull-down technology comprising two sets of pull-down TFTs was applied to delay the degradation speed and increase the lifetime. The lifetime of the integrated gate driver is a very important issue and should be long enough to ensure product reliability [30]. Therefore, conducting a reliability evaluation during panel development to predict the lifetime of the circuit is important.

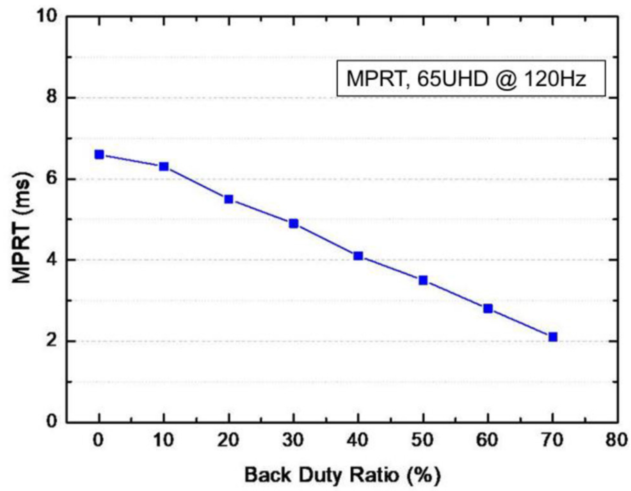

FIGURE 8. **MPRT characteristics of the developed 65-inch OLED display vs. the black duty ratio.**

TABLE 1. **Device characteristics of the 65-inch reduced-MPRT OLED displays fabricated utilizing the proposed integrated gate driver.**

Item		Value	Unit
Panel size		65	inch
Resolution		3840×2160 (WRGB)	-
Frame rate		120	Hz
Brightness		150/500	cd/m^2
MPRT	ABI On	3.4 (50% black duty)	ms
	ABI Off	6.8	ms
GTG		<0.001	ms
TFT Backplane		Coplanar-type IGZO	-
Panel Structure		1G-1D	-

Figure 8 shows the MPRT characteristics of the 65-inch UHD OLED display. The panel normally functions with scanning and sensing operations, and the motion blur on the screen decreases when the adaptive black data insertion function is turned on. Therefore, the MPRT characteristics of the OLED displays were successfully enhanced, which can lead to better picture quality. Motion blur is a phenomenon in displays where a moving image is shown as several still images. The motion blur in a cathode ray tube display with a MPRT of 4 ms cannot be perceived by the human eye. When the ABI is on (based on 50% duty), the MPRT becomes 3.4 ms, which is lower than that of a cathode ray tube display; thus, the motion blur cannot be perceived by the human eye in this case as well. Other advantages compared to the previous version of the integrated gate driver include cost reduction, narrow bezel, and flexible display which might significantly contribute to the popularization of OLED displays.

Table 1 presents the device characteristics for the 65-inch Fast-MPRT OLED display fabricated utilizing the proposed integrated gate driver. The fabricated 65-inch UHD panel achieves a 6.5-mm bezel and a normal screen, and the compensation drive works properly. When the BDI function is turned on, the motion blur is confirmed to have been reduced. The different aspects of the image quality of OLED displays, such as black expressiveness, color rewrite, and fast pixel response, are clearly enhanced in comparison to those aspects of displays containing panels with the previous version of the integrated gate driver.

IV. CONCLUSION

In this research, OLED displays, which had been fabricated for use in TVs with large screens by utilizing integrated gate driver circuits and a MPRT reduction method, exhibited excellent image quality. The motion blur of such large-size OLED display panels was significantly reduced by using an integrated gate driver circuit with a MPRT reduction method. The decrease in the MPRT was due to the emitting pixels having been turned off in advance, based on the provision of black data. The integrated gate drivers were designed to achieve a normal display, black data insertion, and operation in the compensation mode. As a result, by using an integrated gate driver circuit, we were able to reduce the MPRT of 65-inch UHD OLED panels for use in OLED TVs with high image quality to 3.4 ms.

The MPRT reduction method proposed in this study has the feature of reducing the MPRT time to below 6.8 ms according to the black data insertion duty. For 50% black data duty, the MPRT time of 6.8 ms can be reduced to 3.4 ms, showing a 50% MPRT improvement. In this case, the term "Motion Blur-Free" is also used as the motion blur cannot be perceived by the human eye.

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