A high image quality organic light-emitting diode display with motion blur reduction for ultrahigh resolution and premium TVs

Hong Jae Shin, SID Member | Soo Hong Choi | Jae Yi Choi | Jae Kyu Park | Sung Joong Kim | Seong Ho Yun | Jeong Rim Seo | Sung Joon Bae | Han Seop Kim | Chang Ho Oh

1TV Development Group, LG Display, Paju-si, South Korea
2TV Business Unit, LG Display, Paju-si, South Korea

Correspondence
Hong Jae Shin, TV Development Group, LG Display, 1007, Deogeun-ri, Wollong-myeon, Paju-si, Gyeonggi-do 413-811, South Korea.
Email: hongjae.shin@lgdisplay.com

Abstract
In this paper, we present a high image quality organic light-emitting diode (OLED) display with motion blur reduction technology. Our latest work includes driving method that reduces motion blur using an adaptive black data insertion, brightness compensation technology, the simple structure pixel with low capacitance coupling for horizontal noise, and the multifunction integrated gate driver. The moving picture response time (MPRT) value of the OLED display panel with a fast response time was significantly affected by the frame frequency and the compensation driving method. The MPRT value of the large-size OLED display panels was significantly decreased by using the integrated gate driver circuit with an MPRT reduction method. The decrease in the MPRT value originated from the turning of the emitting pixels off in advance resulting from providing black data. The integrated gate drivers were designed to achieve the normal display, the black data insertion, and the compensation mode. The MPRT value of the 65-in. ultrahigh-definition (UHD) OLED panels was decreased to 3.4 ms by using an integrated gate driver circuit. The motion blur of large-size OLED display panels was significantly reduced due to a decrease in the MPRT value.

KEYWORDS
high image quality, integrated gate driver, large size-organic light-emitting device, motion blur, moving picture response time

1 | INTRODUCTION

Recently, organic light-emitting diodes (OLEDs) are positioned as a next-generation display panel, replacing liquid crystal displays (LCDs) in the high-end TV market.1–3 The self-emission characteristics of the OLEDs can realize perfect black without light leakage and high brightness. Simultaneously, achieve a wider viewing angle and uniform luminance using precise compensation.4,5 On the other hand, it is one thing to emphasize the advantages of the OLEDs more clearly by improving the picture quality of the OLEDs. In case of the response
time, many improvements have been performed in the LCD, and it is necessary that OLED has to be differentiated from LCD.\textsuperscript{6,7} The oxide TFTs have been used as OLED display backplanes, which are different from a-Si TFTs commonly used for LCDs.\textsuperscript{8–10} Because the oxide TFTs have a mobility of 8 to 10 times higher than a-Si TFTs, the integrated circuits in OLEDs tend to be smaller. On the other hand, being depletion-mode transistors, they often have a negative initial threshold voltage ($V_{th}$), which results in leakage current and even in malfunction if not well designed.\textsuperscript{11–13}

Moving picture response time (MPRT) has been used to quantify the visual perception of moving images for display applications.\textsuperscript{14–16} To measure basic MPRT, first, we take a blurred width of moving image (BEW) by using pursuit CCD camera. Second, BEW is divided by the velocity of the moving image which is the distance moved during one frame (N-BEW). Third, N-BEW multiplies by frame rate (N-BET). Finally, all of N-BET in many conditions of the moving image is averaged, which is called MPRT. If MPRT value is shorter, it means sharper moving image is shown. Therefore, MPRT characteristics are directly related to the quality of moving images in display applications.\textsuperscript{17,18}

Figure 1 shows the MPRT characteristics classified by display type and driving conditions. Traditional cathode ray tube (CRT) displays do not have the sample-hold characteristics. Due to the sample-hold characteristics of LCDs and OLEDs, fast moving scenes displayed on those display panels are often seen blurred. Degradation of the motion image quality due to motion blurs on the hold-type displays, such as LCDs and OLED displays, is a well-known issue and has been researched for a long time.\textsuperscript{19} Although the response time of the OLED device itself is several tens of nanoseconds, OLED displays suffer from motion blur because of the hold-type-display characteristics that are a result of their active-matrix driving. The driving methods of a higher frame rate and a shorter temporal aperture are known to be effective in improving motion image quality.\textsuperscript{20,21} However, a higher frame rate requires complex signal processing and a higher driving technology. Realizing ultrahigh-definition (UHD) displays at a frame rate of over 240 Hz then becomes difficult. The ability of a person to sense the moving speed of an object is about 5.7 ms, so when watching a fast moving image such as sports, motion blur is perceived and OLED TV technologies by reducing MPRT is required. Thus, it is necessary to have less than 5.7 ms that a person can recognize the motion blur in the fast moving images.

In this paper, we present a new OLED display using adaptive black data insertion (ABI) driving method in which motion blur is not recognized in a fast moving image at 120-Hz frame driving, and MPRT characteristic is similar to 240-Hz frame driving. This technology was applied to real product development to improve the image quality and the price competitiveness of OLED display panels.

\section*{2 | PROPOSED OLED DISPLAY WITH MOTION BLUR REDUCTION}

\subsection*{2.1 | Proposed OLED display panel and circuit}

The proposed OLED display panel and driving circuit for the UHD OLED TVs is shown in Figure 2. The proposed pixel circuit, which consists of three TFTs, one capacitor,
a current source for the OLEDs, scanners, sensors, and a sensing line, compensates for variations in the threshold voltage and the mobility of the carriers in the TFTs. The $T_{\text{DR}}$ is used as a current source, the $T_{\text{SC}}$ acts as a switch for inputting the image data, and the $T_{\text{SE}}$ electrically connects the $T_{\text{DR}}$ to the external circuit during sensing operations. The sensing line contains one pixel consisting of red, white, green, and blue subpixels. The initial high luminance uniformity of the OLEDs can be maintained by continuously compensating for variations in the luminance with respect to its initial values. It is possible because the proposed circuit can sense the mobility of the carriers and the threshold voltage in real time. This method also corrects the threshold voltage shift and the mobility shift by using real-time sensing and compensation to continuously maintain initial high luminance uniformity.

**2.2 MPRT enhancement driving method**

Figure 3 shows the concept of the proposed panel driving method uses ABI to reduce the motion blur in fast moving images. First, video data are written first, the black data are used after holding duty, and the video data, which have been used before, are erased with the black data. Then, another video data come out of the next frame again, and this process is repeated. When the gap between video data and black data are longer, holding duty becomes longer, resulting in a decrease in the MPRT improvement effect, the MPRT improvement effect increases with decreasing holding duty.

Figure 4 shows a driving waveform, which explains sending the black data. When $N$ lines are simultaneously applied to black data, the frame frequency becomes less than 240 Hz. $N$ is set within a range that satisfies the
circuit operation frequency and pixel charging characteristics at 120 Hz frame frequency. The fabricated 65-in. UHD OLED display panel is designed to select eight lines at the same time, and the one pixel charging time is 3.0 $\mu$s.

OLED display is required to sense and compensate the threshold voltage of the pixel TFT for sustaining uniform luminance. The setting of the sensing timing makes it difficult to implement the ABI technology. Therefore, it becomes more complicated for sensing timings to avoid overlapping timings for video data and black data. The sensing pixels of the line typically operate in 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 to no crash with another gate signal such as video scanning clock signal and black data clock signal. Because the sensing timing should be performed within serious limitations, the sensing method in the pixel is different from the conventional one to achieving sufficient sensing performance. The black data insertion with a duty of 50% is equivalent to a holding time of 240 Hz, which is expected to contain a similar effect in the improvement of the motion blur.

In order to apply black data without increasing the frame frequency, N lines were selected at the same time, and black data were applied at the same time. Non-sequential driving of the gate line causes a horizontal line defect. The reason is the difference in coupling capacitance between the gate line to which BDI is applied and the gate line to which image data are applied. To solve this problem, a design that reduces coupling between pixels and horizontal luminance compensation technology is applied.

2.3 Multifunction integrated gate driver in panel

The proposed integrated gate driver is implemented on the oxide TFT substrate and performs functions such as image display, compensation operation, and black data insertion function. Figure 5 shows the schematic diagram of the gate driver circuit. A block for Q-node charging to sense and compensate the OLED pixel in the previous version of the gate driver, which is installed in addition to the Q-node charging. However, an additional Q-node reset function is installed in this work. In this part, the sensing is completed in the previous circuit, and the whole frame is automatically reset in the next frame. However, because the reset function is omitted due to the black data insertion function in this circuit, a block for resetting of the Q-node is necessary.

Figure 6 shows the timing diagram of the proposed integrated gate driver, which is divided into the display data writing period and the black data insertion period. The display data writing period can be explained with

**FIGURE 4** Driving waveform of the adaptive black data insertion to reduce the motion blur in fast moving images

**FIGURE 5** Simplified schematic of the proposed integrated gate driver for multifunction operation
four steps. First, a start pulse (VST) comes to shift register and the input TFT (T1) charges the gate node of the pull-up TFT. The rising transition of the clock that enters drain node of pull-up TFT increases Q-node by bootstrapping and a gate pulse (G[n]) is generated at the same time (T2). As clock signal changes to low level, G[n] is discharged by pull-down TFT, and Q-node returns and keeps the previous level of T1 until the reset pulse (RST) comes (T3). Finally, Q-node is completely discharged by a high level of reset pulse (T4). The proposed method of MPRT enhancement is necessary to make additional gate pulse for insertion of black data. The operation of the black data insertion period (T5–T8) is almost similar to display data writing period driving (T1–T4) except that N stage gate pulses are generated simultaneously (T6), whereas another has only one gate pulse at a time. In other words, black data are inserted while these lines are turned on together.

Figure 7 shows the simulation results of the integrated gate driver as functions of the times. The integrated gate drivers generate the normal scanning, black data insertion, and compensation operation waveforms which are good enough to drive OLED panel.

3 | RESULTS AND DISCUSSION

Figure 8 shows a 65-in. UHD OLED display panel fabricated to verify enhancement of the motion blur in large-size organic light-emitting device panels by using integrated gate driver circuits with a MPRT reduction method. Figure 9 shows the measurement result of the integrated gate driver output. The falling time of the circuit is approximately 1.2 μs, which is fast enough to drive UHD OLED displays with enhanced MPRT at 120-Hz frame frequency. Because the gate on-time of the fabricated UHD OLED displays is 3.0 μs, its falling time should be 1/2 to charge and discharge within this time. The gate driver has the dual pull down configuration that slows down the degradation rate 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.23 The reliability characteristics of the whole circuit are determined by the $V_{th}$ shift amount of TFTs on the QB-nodes, such as the pull-down TFT, which have the dominant turn-on duty.24 Therefore, the dual pull down technology comprising two sets of pull down TFTs is applied to delay the degradation speed.
and increase the lifetime. The lifetime of the integrated gate driver is a very important issue and should ensure the product reliability. Therefore, it is very important to predict the lifetime of the circuit by reliability evaluation in panel development.

Figure 10A shows the test result of moving image displayed by conventional driving method in fabricated OLED displays. In the conventional driving method, a serious burred edge of the ball was observed due to the intrinsic hold type driving. Figure 10B shows the moving image displayed by the driving method with MPRT reduction technology proposed in this paper. The proposed method provides a sharp edge of the object, and the results showed a better performance in motion blur than that of the conventional driving method.

Figure 11 shows the MPRT characteristics of the 65-in. UHD OLED displays. The panel is normally functioning with scanning operation and sensing operation, and the motion blur on the screen decreases when the ABI function is turned on. The MPRT reduction method proposed in this study has the feature of reducing the MPRT value to below 6.8 ms according to the black data insertion duty. For 50% black data duty, the MPRT value of 6.8 ms can be reduced to 3.4 ms, showing a 50% MPRT improvement. Therefore, the MPRT characteristics of the OLED displays were successfully enhanced, which can implement a better picture quality on the advantages of the previous version of the integrated gate driver, such as cost reduction, narrow bezel, and flexible display, which might significantly contribute to the popularization of the OLED displays.

Table 1 shows the device performances of the 65-in. high MPRT OLED display fabricated utilizing the proposed integrated gate driver. The fabricated 65-in. UHD OLED panel achieves 6.5-mm bezel, normal display, and compensation operation works properly. When the BDI function is turned on, it is confirmed that the motion blur is surely reduced. The differentiated image quality of the OLED displays, such as black expressiveness, color rewrite, and fast pixel response, can be
clearly enhanced in comparison containing the panel with the integrated gate driver of the previous version.

4 | CONCLUSION

The high image quality OLED displays fabricated utilizing the integrated gate driver circuits by using the MPRT reduction method for the large-size TVs were achieved. The motion blur of the large-size OLED display panels was significantly reduced by using the integrated gate driver circuit with the MPRT reduction method. The decrease in the MPRT originated from the turning of the emitting pixels off in advance resulting from providing black data. The integrated gate drivers were designed to achieve the normal display, the black data insertion, and the compensation mode. With these results, the MPRT value of the 65-in. UHD OLED panels was decreased to 3.4 ms by using an integrated gate driver circuit for high-image quality OLED TVs.

ORCID
Hong Jae Shin  https://orcid.org/0000-0003-1080-4101

REFERENCES
1. Shin HJ, Park KM, Takasugi SJ, et al. A high-image-quality OLED display for large-size and premium TVs. SID Symposium Digest. 2017;48(1):1134–1137.
2. Shin HJ, Takasugi SJ, Park KM, et al. Novel OLED display technologies for large-size UHD OLED TVs. SID Symposium Digest. 2015;46(1):53–56.
3. Jackson WB, Marshall JM, Moyer MD. Role of hydrogen in the formation of metastable defects in hydrogenated amorphous silicon. Phys Rev, B vol. 1989;39:1164.
4. Luan X, Liu J, Pei Q, Bazan GC, Li H. Gate-tunable electron injection based organic light-emitting diodes for low-cost and low-voltage active matrix displays. ACS Appl Mater Interfaces. 2017;9(20):16750–16755.
5. Seol HC, Ra JH, Hong SK, Kwon OK. An AMOLED panel test system using universal data driver ICs for various pixel structures. IEEE Trans Electron Devices. 2017;64(1):189–194.
6. Lin CL, Chen PS, Deng MY, Wu CE, Chiu WC, Lin YS. UHD AMOLED driving scheme of compensation pixel and gate driver circuits achieving high-speed operation. J Electron Dev Soc. 2018;6(1):26–33.
7. Liao LY, Chen CW, Huang YP. Local blinking HDR LCD systems for fast MPRT with high brightness LCDs. IEEE J Display Technol. 2010;6(5):178–183.
8. Chang GW, Chang TC, Jhu JC, et al. Temperature-dependent instability of bias stress in InGaZnO thin-film transistors. IEEE Trans Electron Devices. 2014;61(6):2119–2124.
9. Lebrun H, Szydlo N, Bidal E. Threshold-voltage drift of amorphous silicon TFTs in integrated drivers for active matrix LCDs. J Soc Inf Disp. 2003;11(3):539–542.
10. Mativenga M, Choi MH, Choi JW, Jang J. Transparent flexible circuits based on amorphous-indium-gallium-zinc-oxide thin-

FIGURE 11 MPRT characteristics of (A) the conventional OLED driving and (B) the proposed OLED driving method to reduce the motion blur in fast moving images

TABLE 1 Device performance of the fabricated OLED display with a gate driver integrated panel

| Item                | Content | Unit   |
|---------------------|---------|--------|
| Panel size          | 65      | in.    |
| Resolution          | 3840 × 2160 | -     |
| Frame rate          | 120     | Hz     |
| Brightness          | 150/500 | cd/m²  |
| MPRT ABI on         | <3.5    | ms     |
| MPRT ABI off        | <6.8    | ms     |
| Gray to gray        | <0.001  | ms     |
| TFT backplane       | Coplanar type IGZO | - |
| Panel structure     | 1 gate – 1 data | - |
film transistors. IEEE Electron Device Lett. 2011;32(2):170–172.
11. Zhang LR, Huang CY, Li GM, et al. A low-power high-stability flexible scan driver integrated by IZO TFTs. IEEE Trans Electron Devices. 2016;63(4):1779–1782.
12. Kim B, Cho HN, Choi WS, et al. A novel depletion-mode a-IGZO TFT shift register with a node-shared structure. IEEE Electron Device Lett. 2012;33(7):1003–1005.
13. Wu WJ, Song XF, Zhang LR, et al. A highly stable bidie gate driver integrated by IZO TFTs. IEEE Trans Electron Devices. 2014;61(9):3335–3338.
14. Har-Noy S, Nguyen TQ. LCD motion blur reduction: a signal processing approach. IEEE Trans Image Process. 2008;17(2):117–125.
15. Chan SH, Wu TX, Nguyen TQ. Comparison of two frame rate conversion schemes for reducing LCD motion blurs. IEEE Signal Process Lett. 2010;17(9):783–786.
16. Chan SH, Nguyen TQ. LCD motion blur: modeling, analysis, and algorithm. IEEE Trans Image Process. 2011;20(8):2352–2365.
17. Nam HN, Lee SW. Low-power liquid crystal display television panel with reduced motion blur. IEEE Trans Consumer Electron. 2010;56(2):307–311.
18. Oka K, Enami Y. Moving picture response time (MPRT) measurement system. SID Symposium Digest. 2004;35(1):1266–1269.
19. Igarashi Y, Yamamoto T, Tanaka Y, et al. Summary of moving picture response time (MPRT) and futures. SID Symposium Digest. 2004;35(1):1262–1265.
20. Kuroki Y, Nishi T, Kobayashi S, Oyaizu H, Yoshimura S. A psychophysical study of improvements in motion-image quality by using high frame rates. J Soc Inf Disp. 2007;15(1):61–68.
21. Usui T, Takano Y, Yamamoto T. A study on a driving method of OLED displays for better motion image quality with adaptive temporal aperture control. J Soc Inf Disp. 2017;25(8):472–479.
22. Shin HJ, Takasugi SJ, Park KM, et al. Technological progress of panel design and compensation methods for large-size UHD OLED TVs. SID Symposium Digest. 2014;45(1):720–723.
23. Shin HJ, Takasugi SJ, Choi WS, et al. A novel OLED display panel with high-reliability integrated gate driver circuit using IGZO TFTs for large-sized UHD TVs. SID Symposium Digest. 2018;49(1):358–361.
24. Jang YH, Yoon SY, Kim B, et al. a-Si TFT integrated gate driver with AC driven single pull-down structure. SID Symposium Digest. 2006;37(1):208–211.
25. Shin HJ, Park BH, Son MY, et al. A novel high reliable integrated gate driver with bi-scanning structure using a-Si TFT for large size FHD TFT-LCD TVs. SID Symposium Digest. 2010;41(1):35–38.

AUTHOR BIOGRAPHIES

**Hong Jae Shin** is a Research Fellow at LG Display, TV Development Group, Paju, Korea. He received his PhD degree in Electrical and Computer Engineering from Hanyang University, Seoul, Korea, in 2004. He is currently a leader of OLED TV panel design and responsible for large-sized OLED TV panel design. He has developed various design technologies of the OLED display, and especially contributed to world's first mass production of OLED TVs. His research interests include OLED panel design and compensation circuit for the large-sized high resolution OLED TVs, gate driver circuit in panel, driving methods for OLED displays.

**Soo Hong Choi** is a Senior Research Engineer at LG Display, TV Development Group, Paju, Korea. He received his BS and MS degrees in Electrical Engineering from Hongik University, Korea, in 2003 and in 2005. He has developed various design technologies of the OLED display. He is currently involved in developing the integrated gate driver in panel for large size OLED TVs.

**Jae Yi Choi** is a Senior Research Engineer at LG Display, TV Development Group, Paju, Korea. He received his BS and MS degrees in Electrical Engineering from Pusan National University, Pusan, Korea, in 2009 and in 2011. He has developed various design technologies of the OLED display. He is currently involved in developing the integrated gate driver in panel for large size OLED TVs.

**Jae Kyu Park** is a Senior Research Engineer at LG Display Laboratory, Seoul, Korea. He received his BS and MS degrees in Semiconductor Science from Dongguk University, Seoul, Korea, in 2004 and in 2006. He has developed various design technologies of the OLED display. He is currently involved in developing the integrated gate driver in panel for large size OLED TVs.

**Sung Joong Kim** is a Senior Research Engineer at LG Display, TV Development Group, Paju, Korea. He received his BS degrees in Electrical Engineering from Kumoh University, Gumi, Korea, in 2005. He has developed various design technologies of the OLED display. He is currently involved in developing the circuit design for the OLED TVs.
Seong Ho Yun is a Senior Research Engineer at LG Display, TV Development Group, Paju, Korea. He received his BS and MS degrees in Information Display from Kyunghee University, Korea, in 2015 and in 2017. He has developed various design technologies of the OLED display. He is currently involved in developing the integrated gate driver in panel for large size OLED TVs.

Jeong Rim Seo is a Senior Research Engineer at LG Display, TV Development Group, Paju, Korea. He received his BS and MS degrees in Information Display from Kyunghee University, Korea, in 2016 and in 2018. He has developed various design technologies of the OLED display. He is currently involved in developing the integrated gate driver in panel for large size OLED TVs.

Sung Joon Bae is a Division Leader at LG Display, TV Development Group, Paju, Korea. He received his MS degrees in Materials Science and Engineering from KAIST, Daejeon, Korea, in 1995. He is currently the leader of OLED TV panel development. He has developed various design technologies of the OLED display and especially contributed to World-First Mass-Production of OLED TVs.

Han Seop Kim is a Senior Vice-President at LG Display, TV Development Group, Paju, Korea. He received his BS degree in Electrical Engineering from Kyungpook National University, Korea, in 1992. He also received his MS degree in Electrical Engineering from Kyungpook National University, Korea, in 1994. He also received his MS degree in MBA from Korea Advanced Institute of Science and Technology, Korea, in 2011. He is currently the Head of the TV Development Group and responsible for TV development.

Chang Ho Oh is a Executive Vice President at LG Display, TV Business Unit, Paju, Korea. He received his BS degree in Electrical Engineering from Seoul National University, Korea, in 1989. He also received his MS degree in Electrical Engineering from Seoul National University, Korea, in 1991. He also received his PhD degree in Physics of the Electron from Tokyo Institute of Technology, Japan, in 2000. He also received his MS degree in MBA from University of Helsinki, Finland, in 2008. He is currently the Head of TV Business and responsible for TV Business.

How to cite this article: Shin HJ, Choi SH, Choi JY, et al. A high image quality organic light-emitting diode display with motion blur reduction for ultrahigh resolution and premium TVs. J Soc Inf Display. 2020;28:557–565. https://doi.org/10.1002/jsid.919