Optical Engineering

OpticalEngineering.SPIEDigitalLibrary.org

Driving technology for improving motion quality of active-matrix organic light-emitting diode display

Jongbin Kim
Minkoo Kim
Jong-Man Kim
Seung-Ryeol Kim
Seung-Woo Lee

SPIE.

Optical Engineering 53(9), 093105 (September 2014)

Driving technology for improving motion quality of active-matrix organic light-emitting diode display

Jongbin Kim, Minkoo Kim, Jong-Man Kim, Seung-Ryeol Kim, and Seung-Woo Lee*
Kyung Hee University, Department of Information Display and Advanced Display Research Center, 1 Hoegi-dong, Dongdaemun-gu, Seoul 130-701, Republic of Korea

Abstract. This paper reports transient response characteristics of active-matrix organic light emitting diode (AMOLED) displays for mobile applications. This work reports that the rising responses look like saw-tooth waveform and are not always faster than those of liquid crystal displays. Thus, a driving technology is proposed to improve the rising transient responses of AMOLED based on the overdrive (OD) technology. We modified the OD technology by combining it with a dithering method because the conventional OD method cannot successfully enhance all the rising responses. Our method can improve all the transitions of AMOLED without modifying the conventional gamma architecture of drivers. A new artifact is found when OD is applied to certain transitions. We propose an optimum OD selection method to mitigate the artifact. The implementation results show the proposed technology can successfully improve motion quality of scrolling texts as well as moving pictures in AMOLED displays. [DOI: 10.1117/1.OE.53.9.093105]

Keywords: active matrix organic light emitting diode; motion quality; overdrive; dithering.

Paper 140412 received Mar. 12, 2014; revised manuscript received Aug. 13, 2014; accepted for publication Aug. 19, 2014; published online Sep. 18, 2014.

1 Introduction

For many years, active-matrix organic light-emitting diode (AMOLED) displays have been hot issues. People pay attention to the AMOLED display as a future display which is flexible, transparent, or ultrathin.[1–3] Now, the AMOLED displays are about to come to the forefront of flat-panel displays, especially in the mobile display market since AMOLED displays have many advantages, such as a wider color gamut, lower power, and faster response time than liquid crystal displays (LCDs). Despite the advantages of AMOLED, there are still many limitations, such as the life time of devices, material cost, manufacturing issues, and nonuniform luminance due to characteristic variations of TFT and OLED.[2–4] In addition, the response characteristics of AMOLED displays are not always faster than LCDs. Yoon et al.[5] reported that slow rising responses are caused by back-plane circuitry and the driving scheme.[5] They proposed a source-follower type pixel circuit to improve the response characteristics of the AMOLED display.

In order to improve the response characteristics of the LCDs, the overdrive (OD) technology is commonly used.[6–11] In this paper, we improve the response characteristics of AMOLED based on the OD technology. We present an optimized OD technology combined with a dithering algorithm[12] for the AMOLED displays without modifying the conventional gamma architecture of the drivers. In addition, we verify that the proposed method can improve the response characteristics of AMOLED for all transitions.

*Address all correspondence to: Seung-Woo Lee, E-mail: seungwoolee@khu.ac.kr

2 Transient Response Improvement of AMOLED

2.1 *Transitions of AMOLED*

We measured and compared the rising responses of mobile OLED and LCD displays. For our experiments, we used commercially available smart phones that adopt AMOLED and active-matrix liquid crystal display (AMLCD).

Figure 1 shows the transient responses of the AMLCD and the AMOLED. In Fig. 1, rectangles and triangles represent the rising transitions of AMLCD and AMOLED displays, respectively. The rising transition from mid-gray level (from gray level 128 to 192, for example) of the AMOLED is faster than that of the AMLCD as shown in Fig. 1(a). The luminance of the transition to white level rises in a short time, but does not reach the white luminance level as shown in Fig. 1(b). During the rest of the frame time, the luminance slowly drops. Thus, the rising response of the AMOLED display looks like a saw-tooth waveform. It is hard to say that the rising transition from black to white (from 0 to 255) is faster than AMLCD, as shown in Fig. 1(b). This means that the motion blur artifact on smart phones can be easily observed when we scroll web pages that contain many black texts on a white background. Thus, the transient responses of AMOLED displays need to be improved to provide users with better image quality.

In order to improve the response characteristics, we adopt the OD technology. Figure 2 shows the rising transitions from the black level when the conventional OD technology is applied. In the case of the 8-bit grayscale used in this experiment, the OD values range from 0 to 255. In order to determine appropriate OD values, we adjusted the OD values so that the luminance peaks can reach respective target levels within one frame. As a result, the peaks reached the respective target levels within one frame for the transitions from black to 64, 96, and 128 as shown in Fig. 2 (solid lines).

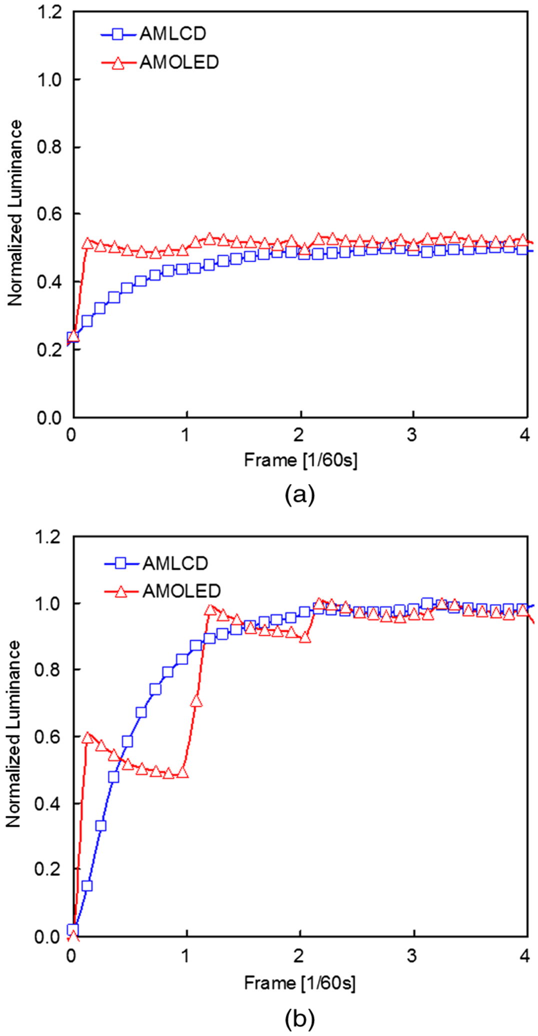

Fig. 1 Comparison of rising transitions (a) from gray level 128 to 192 gray and (b) from black to white level of commercial active-matrix organic light emitting diode (AMOLED) products. Luminance levels were normalized by the luminance of the white level.

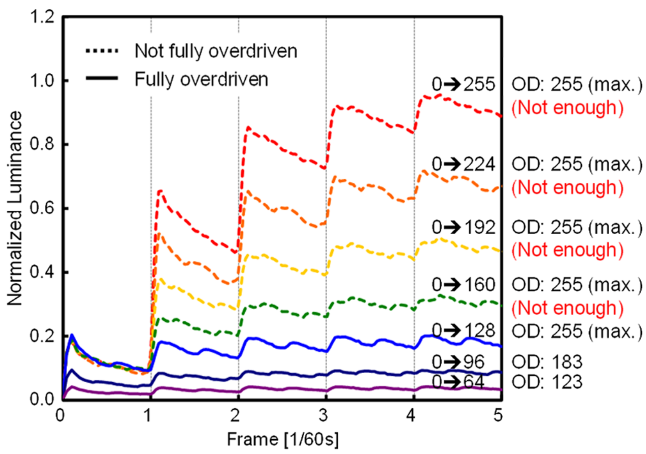

Fig. 2 Rising responses of AMOLED display when the conventional overdrive (OD) is applied.

However, at the transitions from black to 160, 192, 224, and white, the rising transitions of AMOLED cannot be fully overdriven even with 255, which is the highest level (dotted lines). During the first frame, their peaks reached 20% of white luminance even though their target levels are approximately 35%, 50%, 75%, and 100%, respectively. These results indicate that the digital OD value, 255, is not sufficient. The higher the data voltage gets, the higher the luminance is. Therefore, an OD voltage higher than the white voltage is necessary. This means the conventional OD cannot be applied to AMOLED displays. In order to overcome the limitation of the conventional OD application, we propose a new OD technology combined with a dithering technology in the next section.

2.2 *New OD Technology for AMOLED*

The basic concept of the proposed driving scheme is as follows: voltages corresponding to data levels 0 to 192 generate 256 luminance levels and voltages corresponding to 192 to 255 are only used for OD. It is not possible to create higher analog voltages than that of the white level based on the conventional digital-to-analog conversion concept. But OD voltages higher than the white level become possible if we consider an arbitrary digital gray level, for example 192, as a digital white code. If the digital code 192 is converted to the analog white voltage in drivers, we can create OD voltages higher than the white level. Digital codes from 192 to 255 are used for OD levels and those from 0 to 192 are assigned for black to white data. A new DAC scheme is proposed as shown in Fig. 3. Figure 3(a) shows the conventional DAC method of the AMOLED display used for our experiment. In Fig. 3(a), the white voltage was 3.4 V. We set the data voltage of the gray level 192 to 3.4 V as shown in Fig. 3(b). Thus, the digital code 192 corresponds to the white voltage. Then, we need to adjust the analog voltages of digital codes from 0 to 192 so that they properly fit the luminance of all levels from black to white of the AMOLED display. We have only 193 digital codes, but we need to generate 256 distinguishable luminance levels. To achieve 256 luminance levels with 193 digital codes, we exploit and modify the dithering technology,[12] and propose a new OD technology for AMOLED. Even though the voltage range for the DAC increases as shown in Fig. 3(b), the actual supply level of driver ICs does not increase. Conventional driver ICs have voltage headroom beyond the DAC range for other purposes. For example, the headroom voltages are reserved to enhance readability under sunlight. Thus, our proposed technology does not increase power consumption because our method can use or share the voltage levels that already exist.

Figure 4 shows a conceptual illustration of the proposed dithering algorithm for AMOLED. The key idea of our approach is to use following relation: $256 \times 3/4 = 192$. Therefore, the algorithm consists of two steps: a data expansion (multiplied by 3) and a bit reduction (divided by 4). For example, the input 8-bit data, 255, is expanded to 10 bit, 765, after multiplying 255 and 3 as shown in Fig. 4. If 765 is divided by 4, then the quotient and remainder are $(191)_{8\,\mathrm{bit}}$ and $(1)_{2\,\mathrm{bit}}$, respectively. The 2-bit remainder provides a dithering pattern depending on the frame sequence. Figure 5 shows how quotient data is spatially and temporally displayed. There is another example when the input 8-bit data is 5 in

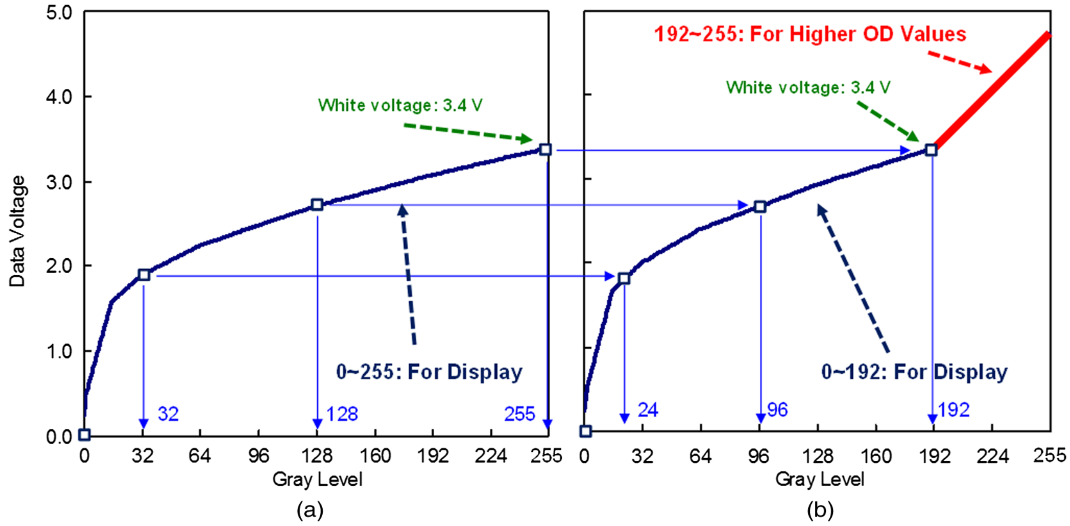

Fig. 3 A new digital-to-analog conversion (DAC) scheme to create OD voltages higher than the white level. (a) Conventional DAC scheme and (b) proposed DAC method.

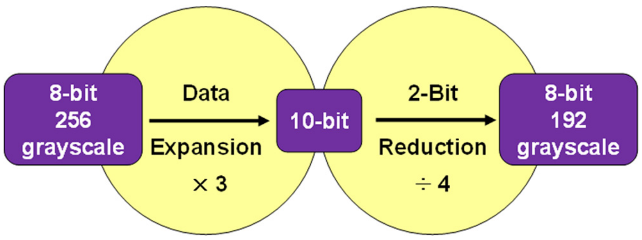

Fig. 4 Conceptual illustration of the proposed dithering algorithm to achieve 256 distinguishable luminance levels by using 193 digital codes.

Fig. 5. In this way, we can generate 256 distinguishable luminance levels with 193 digital codes.

Figure 6 shows the overall data flow of the proposed driving scheme. There are two blocks: dithering and OD blocks. The input digital data ranging from 0 to 255 enter the dithering block. The output range of the dithering block becomes 0 to 192 as shown in Fig. 6. Depending on the change between previous and current frame data, current data may be overdriven or bypassed. Thus, the output range of the OD block is from 0 to 255. Therefore, we can completely OD all the transition of AMOLED without changing the conventional architecture of the data voltages.

Figure 7 shows an example of an OD look-up table for the proposed method. Here, PF means previous frame data and CF is current frame data. In the case of the transition from 0 to 160 in Fig. 7(a), the OD value is 246, which is higher than 191. The OD voltage is 4.54 V which is higher than 3.4 V, representing the conventional white voltage as shown in Fig. 7(b).

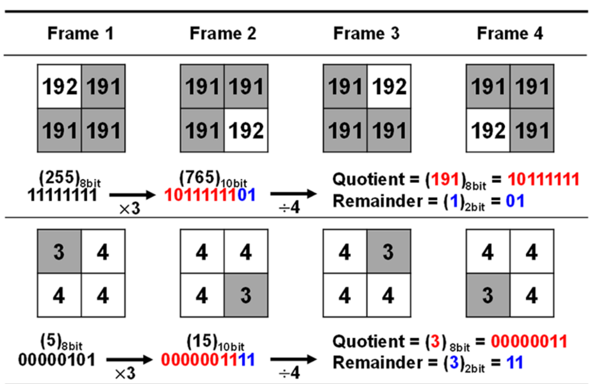

Fig. 5 Examples of the proposed dithering algorithm.

3 Experimental Results and Discussion

We implemented the proposed OD technology by using a commercial field programmable gate array (FPGA) board to drive the AMOLED panel. As shown in Fig. 8, the image data from a graphics card in a personal computer is transferred to the FPGA board through a digital visual interface cable. The FPGA board performs the dithering and OD corresponding to Fig. 5 with the transferred image data. Then, it transmits the image data to the AMOLED panel through the general purpose input output connector.

Figure 9 shows the rising transitions from the black level before and after applying the proposed OD technology. We can see the luminance peaks successfully reach the target levels. For quantitative comparison, we performed motion picture response time (MPRT) simulation considering the smooth pursuit and integration of the brightness of human eyes.[13,14] The MPRT simulation results also show the

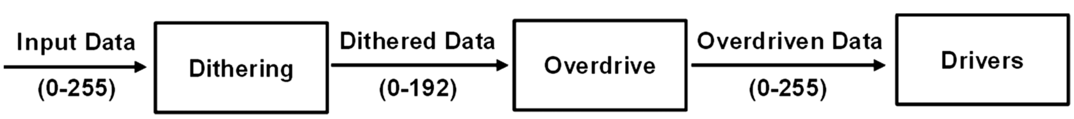

Fig. 6 Schematic diagram of the proposed driving technology for improving motion quality of AMOLED.

PF \ CF	0	32	64	96	128	160	192
0	0	57	109	154	205	246	255
32		32	70	106	147	184	221
64			64	99	138	174	210
96				96	133	168	204
128					128	163	199
160						160	195
192							192

(a)

PF \ CF	0	32	64	96	128	160	192
0	0.24	2.17	2.64	3.04	3.66	4.54	4.73
32		1.90	2.30	2.61	2.98	3.30	4.00
64			2.24	2.55	2.90	3.21	3.77
96				2.53	2.85	3.16	3.64
128					2.81	3.12	3.54
160						3.09	3.45
192							3.39

(b)

Fig. 7 An example of overdrive look-up table for the proposed scheme. (a) Digital domain and (b) voltage domain.

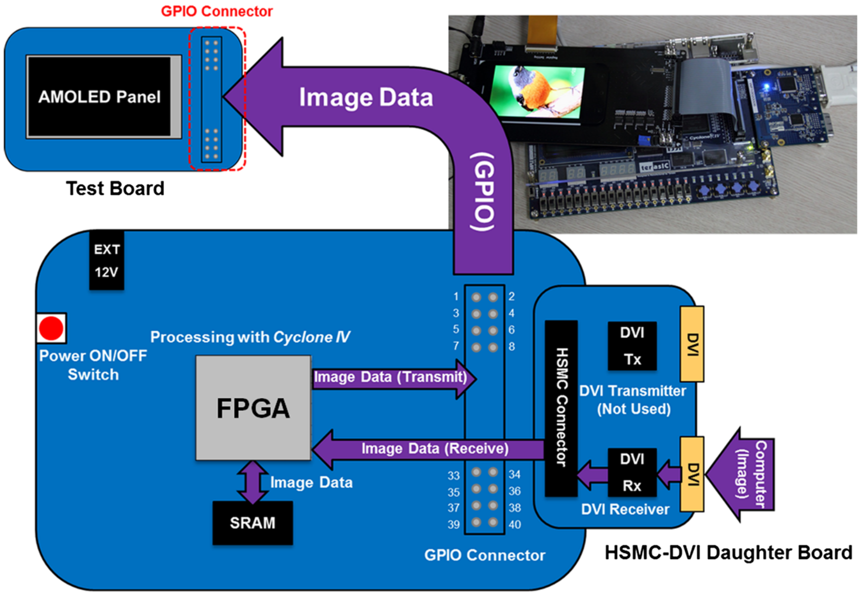

Fig. 8 Schematic of hardware implementation.

response times and are improved by the proposed technology. As a result, we expected the motion quality of the AMOLED display would be better. As shown in Fig. 10, however, we observed the overshoot artifact near edges of black characters scrolling down on an AMOLED display when the proposed OD technology is applied.

The artifact from the OD technology should be removed to prevent users from perceiving it. After investigation, we found that the optimum OD values are different depending on the history of the data transition. The transitions are largely divided into two categories such as static and dynamic transitions.[8] The static transition has a data change after a long and stable state. However, the start level of the dynamic transition includes only a few frames. For example, fast scrolling text patterns as shown in Fig. 10 correspond to the dynamic transition.

Figure 11 shows the measured responses of the static (black→white) and dynamic transitions (white→black→white). Here, OD_static means the OD value optimized for the static transition. When we applied OD_static to the static transition, the luminance reached the target level within 1 frame, which is the same the case in Fig. 9(b). However, the dynamic transition applied by the OD_static showed a luminance overshoot as shown in Fig. 11. It can be recognized as an overshoot artifact by human eyes as shown in Fig. 10.

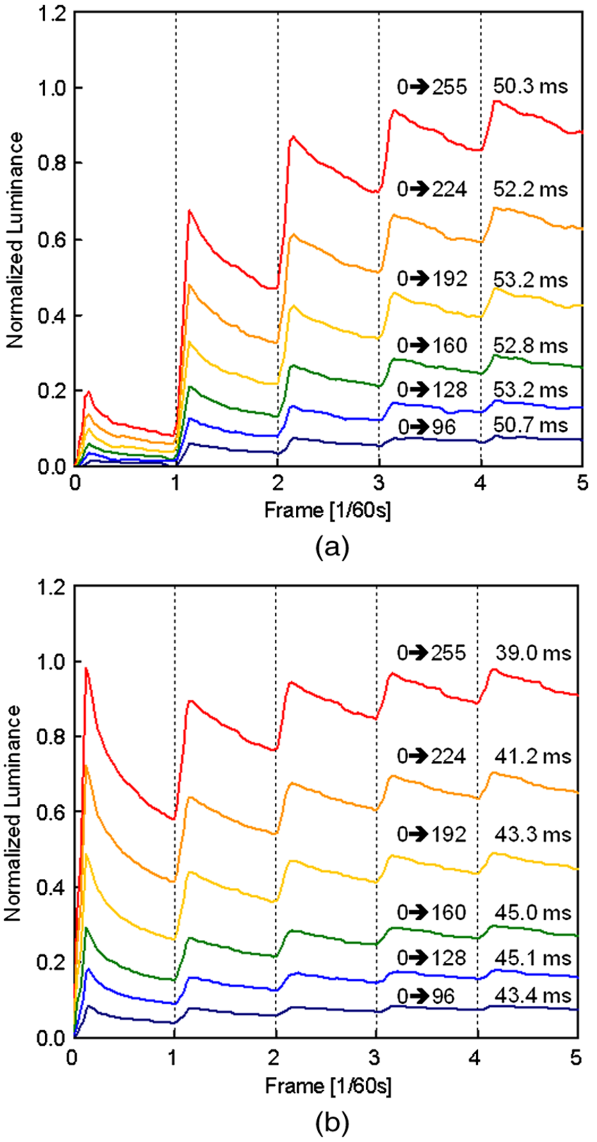

Fig. 9 The rising transitions from black level (a) without and (b) with the OD technology. The motion picture response time of each transition is added for comparison.

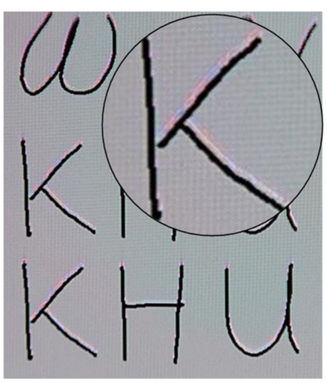

Fig. 10 Images of scrolling text patterns taken when the OD technology is applied.

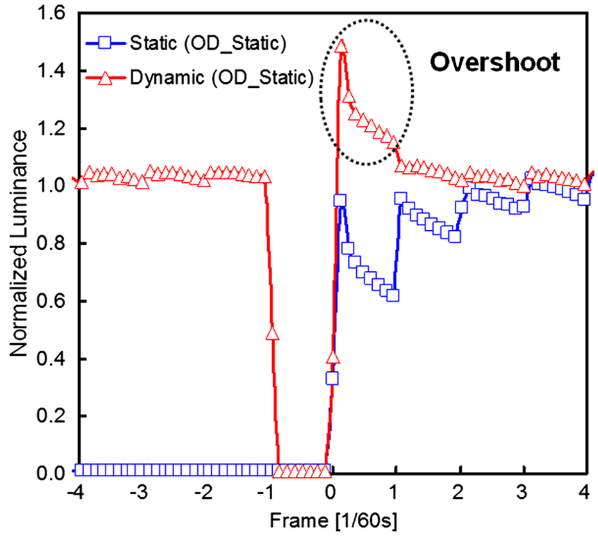

Fig. 11 Static and dynamic transitions of AMOLED display when the OD technology is applied.

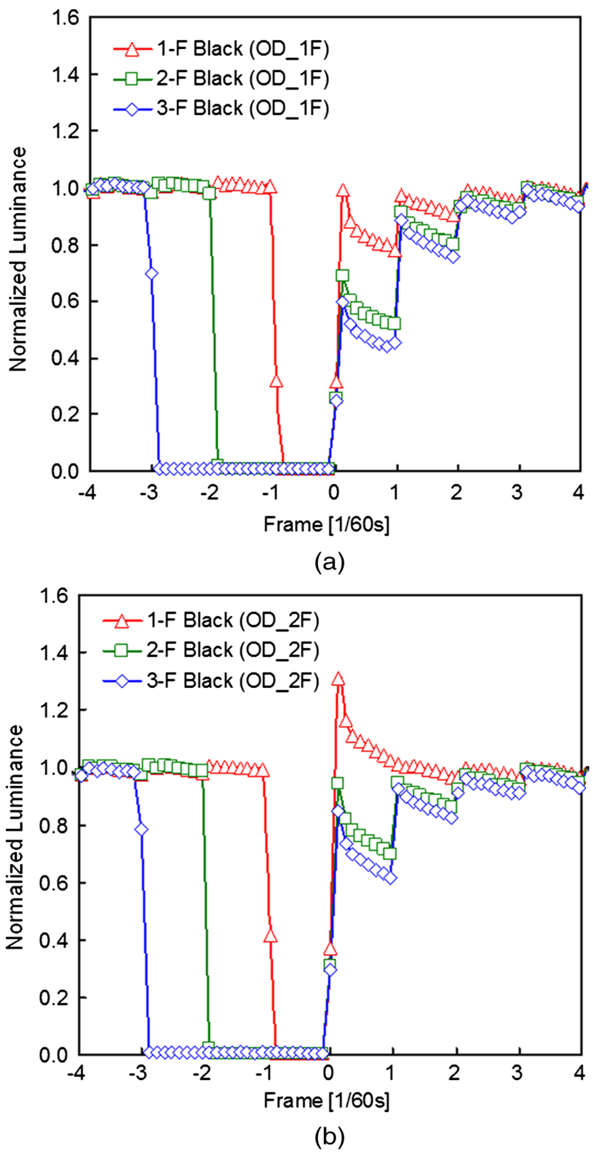

Fig. 12 Measured responses of transitions with black levels for one, two, and three frames when (a) OD_1F is applied and (b) OD_2F is applied.

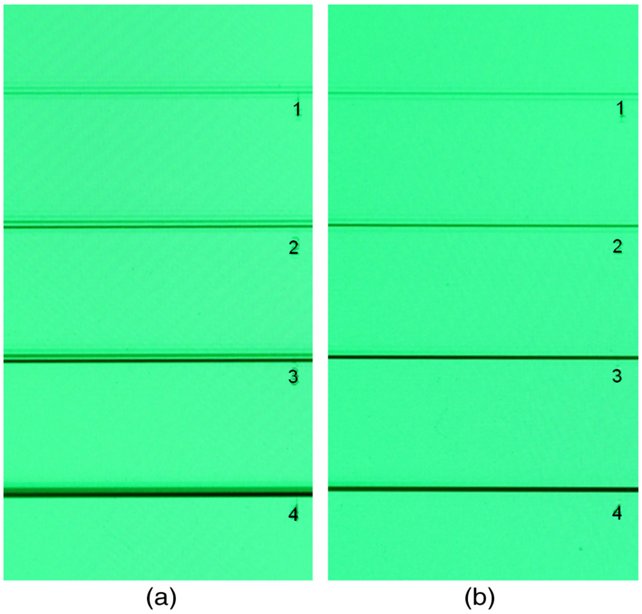

Fig. 13 Images of scrolling line patterns taken at (a) original AMOLED and (b) OD_1F-applied AMOLED.

We also investigated overdriven responses depending on how dynamically a transition occurs. Figure 12 shows the measured responses of transitions with black level for one, two, or three frames. Here, we applied two OD values: OD_1F and OD_2F. OD_1F and OD_2F are the optimum OD values for transitions with black levels during one and two frames, respectively. For example, OD_2F is the optimum OD value extracted from the transition with black level insertion during two frames. As shown in Fig. 12(a), when OD_1F was applied to dynamic transitions with one-frame black, the luminance level reached the target level within one frame (red solid line with triangles). When OD_2F was applied, the dynamic transition with one-frame black showed an overshoot, as shown in Fig. 12(b), which means the overshoot artifact can be perceived for the dynamic transition with one-frame black as shown in Fig. 10. If we apply OD_2F to all the other transitions, the overshoot artifact is observed even though the overall motion quality is improved, which results in poor image quality. The best way to solve the problem is to apply optimum OD value such as OD_1F or OD_2F depending on the transitions in the AMOLED displays. The history of data transitions needs to be recorded, which requires more frame memory. In addition, we need to find out OD values depending on the history of data transition, which is a time consuming job. Therefore, in order to improve the motion quality and simultaneously mitigate overshoot artifacts, we recommend OD_1F as the most appropriate OD value for all kinds of rising transitions.

Figure 13 shows the images of scrolling line patterns taken with the original AMOLED and the OD_1F-applied AMOLED. The test images include black lines which have various widths. They have patterns similar to text patterns. The images were scrolled down with a constant speed of 4 pixels per frame. We can see the motion blur artifact in Fig. 13(a). Figure 13(b) shows the image of the OD_1F-applied AMOLED. The lines became clearer than those on AMOLED without OD application. Figure 14 shows the images of scrolling text patterns taken with the original AMOLED and the OD_1F-applied AMOLED. The motion blur and the overshoot artifact were remarkably reduced. We find that our proposed OD technology can improve the motion quality of the AMOLED displays when they display moving pictures as well as scrolling texts.

4 Conclusion

This paper has reported a severe response problem of the AMOLED displays. We, however, have proposed a new OD technology customized to the AMOLED displays. Since the conventional OD method cannot successfully improve all the responses, we modified the OD technology by combining it with a dithering algorithm. In addition, the proposed OD technology is easy to implement for the AMOLED displays without modifying the conventional gamma architecture of drivers. We have succeeded in implementing our technology and verified that motion artifacts were properly removed. We expect that AMOLED displays with our proposed technology would provide high motion quality to mobile device users.

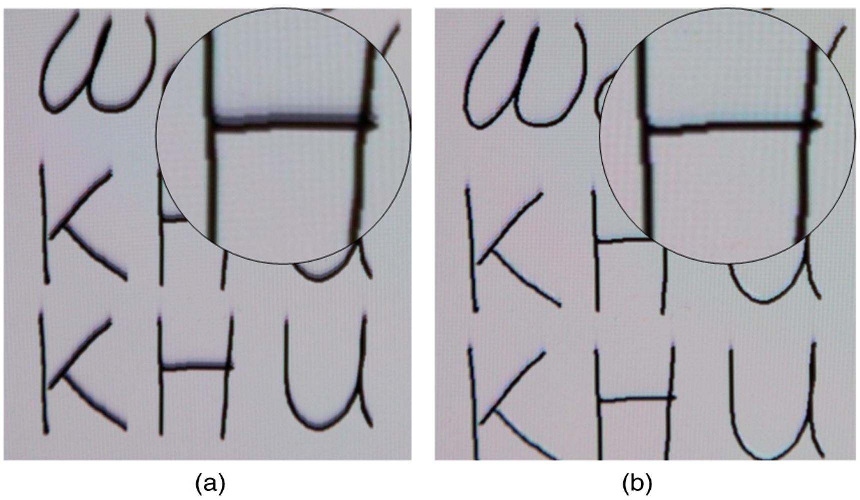

Fig. 14 Images of scrolling text patterns taken at (a) original AMOLED and (b) OD_1F-applied AMOLED.

Acknowledgments

This work was supported by LG Display, the IT R&D program of MKE/KEIT (Grant No. 10041416, The core technology development of light and space adaptable new mode display for energy saving on 7 inch and 2 W), and a grant from Kyung Hee University in 2010 (KHU-20100851).

References

1. S. E. Burns et al., "Flexible active-matrix displays," in *Society for Information Display (SID) Symp. Digest*, Vol. 36, pp. 19–21, John Wiley & Sons (2005).
2. J. Y. Park, "Progress of AMOLED technology," *Proc. SPIE* **5632**, 17–24 (2005).
3. M. H. Lee et al., "Development of 31-Inch Full-HD AMOLED TV using LTPS-TFT and RGB FMM," in *Society for Information Display (SID) Symp. Digest*, Vol. 40, p. 802, John Wiley & Sons (2009).
4. X. Guo and S. R. P. Silva, "Investigation on the current nonuniformity in current-mode TFT active-matrix display pixel circuitry," *IEEE Trans. Electron Devices* **52**(11), 2379–2385 (2005).
5. J. S. Yoon et al., "New pixel structure with high G-to-G response time for large size and high resolution OLED TVs," in *Society for Information Display (SID) Symp. Digest*, Vol. 44, pp. 1010–1013, John Wiley & Sons (2013).
6. R. I. McCartney, "A liquid crystal display response time compensation feature integrated into an LCD panel timing controller," in *Society for Information Display (SID) Symp. Digest*, Vol. 34, pp. 1350–1353, John Wiley & Sons (2003).
7. H. Nakamura and K. Sekiya, "Overdrive method for reducing response times of liquid crystal displays," in *Society for Information Display (SID) Symp. Digest*, Vol. 32, pp. 1256–1259, John Wiley & Sons (2001).
8. S.-W. Lee et al., "Motion artifact elimination technology for liquid-crystal-display monitors: advanced dynamic capacitance compensation method," *J. Soc. Inf. Disp.* **14**(4), 387–394 (2006).
9. Y. Cho et al., "New overdrive technology for liquid-crystal displays with a simple architecture," *Opt. Eng.* **49**(3), 034001 (2010).
10. J.-M. Kim et al., "Liquid crystal displays with temperature-independent characteristics," *Opt. Eng.* **51**(7), 077402 (2012).
11. J. Kim et al., "User-friendly minimization technology of three-dimensional crosstalk in three-dimensional liquid crystal display televisions with active shutter glasses," *Opt. Eng.* **51**(10), 107401 (2012).
12. S.-W. Lee and H. Nam, "A new dithering algorithm for higher image quality of liquid crystal displays," *IEEE Trans. Consumer Electron.* **55**(4), 2134–2138 (2009).
13. Y. Igarashi et al., "Summary of moving picture response time (MPRT) and futures," in *Society for Information Display (SID) Symp. Digest*, Vol. 35, pp. 1262–1265, John Wiley & Sons (2004).
14. D. Sasaki, M. Imai, and H. Hayama, "Motion picture simulation for designing high-picture-quality hold-type displays," in *Society for Information Display (SID) Symp. Digest*, Vol. 33, pp. 926–929, John Wiley & Sons (2002).

Jongbin Kim received his BS and MS degrees in physics and information display at Kyung Hee University, Republic of Korea, in 2010 and 2012, respectively. He is currently working toward his PhD degree in the Department of Information Display at Kyung Hee University. His research interests include driving methods and circuits for LCD and OLED displays and driving technology for color motion performance of LCDs.

Minkoo Kim received his BS and MS degrees in the Department of Information Display at Kyung Hee University, Republic of Korea, in 2011 and 2013, respectively. He is currently working toward his PhD degree in the same department at Kyung Hee University. His research interests include driving methods and circuits for various types of displays including LCD, OLED, and so on.

Jong-Man Kim received his BS and MS degrees in physics and information display at Kyung Hee University, Republic of Korea, in 2010 and 2012, respectively. He is currently working toward his PhD in the Department of Information Display at Kyung Hee University. His research interests include driving methods and circuits for LCD and e-paper displays and driving technology for color motion performance of LCDs.

Seung-Ryeol Kim received his BS and MS degrees in physics and information display at Kyung Hee University, Republic of Korea, in 2011 and 2013, respectively. He is currently working toward his PhD degree in the Department of Information Display at Kyung Hee University. His research interests include driving methods and circuits for low-power display.

Seung-Woo Lee received his MS and PhD degrees from KAIST in electrical engineering in 1995 and 2000, respectively. He joined Samsung in 2000, where his work has focused on the development of key driving technologies for active-matrix liquid-crystal displays. He is currently an associate professor in the Department of Information Display at Kyung Hee University. He has been active with SID as a senior member. He became an IEEE senior member in 2010.