An Analysis of GamingDisplay Based on Relationship between Response Time and Refresh Rate for Moving Picture Quality

Jin-Sang Lee, Tae-Kyung Lee, Yeong-Moon Kim, Jang-Hyun Cho, Eun-Woo Roh, Seung-Won Jung, Du-Hwan Oh and Han-Seop Kim

altary@lgdisplay.com
LG Display Large Display Development Group, 245 LG-ro, Wollong-myeon, Paju-si, Gyeonggi-do 10845, Korea
Keywords: OLED, Moving Picture Quality, Refresh Rate, Response Time, GtG, MPRT

ABSTRACT

In this paper, we studied the correlations among the three key factors: refresh rate, GtG, and response time of major gaming display models and based on this result, we analyzed how OLED can attribute to the high performance monitor panel considering the correlation between MPRT and response time.

1 Introduction

Recently, rapid growth of game industry is emerging as a hot topic in display industry. It constantly demands hardware advances in displays due to high-end console games driven by new PlayStation and XBOX models and also, game genres such as MOBA (Multiplayer Online Battle Arena) and FPS (First Personal Shooting Game) in PC game industry rising in popularity. In response to this trend, display performance has improved from 120Hz to 180Hz, 240Hz and recently up to 360Hz for gamers' needs based on the prevalence of high-performance graphics chipsets and commercialization of high-speed interface standards as DP1.4 / HDMI 2.1 (w/DSC), etc. [1]

There are two main requirements for displays to be specialized in gaming: clear image and fast reactivity. Characteristics that meet this requirement are high refresh rates, low response times, and low input latency. Among them, refresh rate and response time are the characteristics required to reduce image blur, and it can be calculated from the value of MPRT. As mentioned above, refresh rate has been commercialized up to 360 Hz, and it is expected that 480 Hz or higher will be released in the near future. In the case of response time, it heavily depends on the display technology. LCD, for example, has slower response time because the liquid crystal material (fluid) has viscosity. LCD works as power is applied to the liquid crystal fluid which is pressed between electrodes of two pieces of glass substrates. With power, the molecules are forced to change order and rearrange, but the process takes time physically because of the high viscosity nature of LCD. IPS and VA are typical types of LCDs used in gaming displays, and both technologies generally apply boosting the OD (Over Drive) circuits when switching gradations to improve the response speed of liquid crystals. In addition, there is a BDI/BFI technology to improve the hold type characteristics, however it causes luminance degradation and flicker. So the BDI/BFI is not high often used in an actual gaming environment. In particular, since the length of the frame cannot be calculated in advance in a VRR environment, there are restrictions on BDI/BFI driving technology. [2][3]

On the other hand, OLED converts current directly into light energy, so it has nothing to deter the response time compared to LCD.

In this paper, we analyzed the four types of LCD and OLED response time based on waveform and the effect of the response time shape for each condition on MPRT. Through this, the performance of each display type was predicted in the ultra-high refresh rate gaming display to be developed in the near future.

2 MPRT Characteristic

MPRT is an evaluation method that represents motion blur as a concept of time and is affected by refresh rate and response time (additionally, BDI/BFI). At this time, the MPRT is measured by taking a video shot of a scrolling image with a camera and the BEW (Blurred edge width) is measured. MPRT is an evaluation method that represents motion blur as a concept of time and is affected by refresh rate and response speed BLU scanning.

$$MPRT = \frac{BEW}{Pixel\ Speed \times Frame\ Rate}$$

BEW is a factor influenced by response speed, and MPRT can be expressed as shown in Figure 1 as a characteristic according to frequency and response speed.

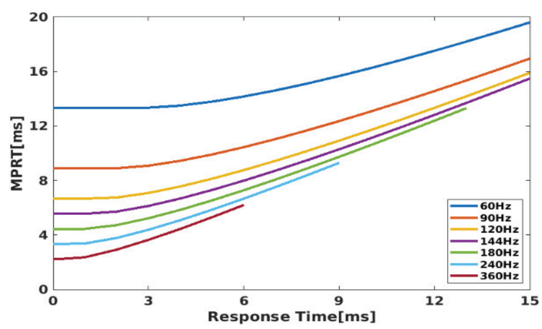

Fig. 1 MPRT according to Response Time

Figure1 shows that fast response time is important when developing a high refresh rate for high performance.

3 Experience

The high performance display characteristics were analyzed by selecting four monitors that are evaluated well in the market. Company A's OLED display is a product released as a TV and has been set to game mode to evaluate performance. Three LCD monitors were selected as representative products of gaming display with various refresh rates. These four displays have been selected to represent different refresh rates of 120Hz, 180Hz, 240Hz, and 360Hz, and the main specifications of each product are as shown in Table 1.

TABLE. 1 Monitors' Specification

	A	B	C	D
Panel	OLED	IPS LCD	VA LCD	IPS LCD
Size	48	34	32	25
Resolution	UHD	WQHD	QHD	FHD
FPS	120Hz	180Hz	240Hz	360Hz

In order to measure on/off response time, GtG, and MPRT, it was measured by the method specified in IDMS. Response time was defined as an average value of rising time and falling time, and GtG and MPRT were measured under the condition of 9 by 9 and a representative value was defined as an average value. [4]

Three types of LCD monitors were analyzed according to OD conditions, and backlight unit dimming was set under conditions that did not operate. Each of the three types of LCD monitors has three OD setting options, and while switching each option, we analyzed the maximum value that can guarantee a fast response time without making inverse ghosting. To determine whether moving picture quality is affected or not, we looked for motion blur and inverse ghosting through color MPRT evaluation.

As a representative example, we will explain based on monitor B. The OD of monitor B has three setting options, and the GtG and MPRT values according to the condition are shown in Table 2, and the representative waveform is shown in Figure 2. In OD setting1, the GtG waveform was stretches as shown in Figure 2(a) under the condition that OD algorithm was turned off, and GtG was 5.785ms and MPRT 9.606ms was relatively slow. In OD setting3, GtG waveform shows a rapid rise as shown in Figure 2(c), GtG was 2.159ms and MPRT was 5.885ms, the fastest among OD conditions. However, when the moving picture quality is checked with scrolling color patch, inverse ghosting image occurs as shown in Figure 4. This phenomenon is also observed in the MPRT waveform, as shown in Figure 3(c). We found that applying the OD algorithm excessively to reduce GtG and MPRT causes inverse ghosting and affects the video quality.

TABLE. 2 Result based on OD setting conditions in Monitor B

120Hz	Setting 1	Setting2	Setting 2
Response Time	5.31	3.29	3.21
GtG	5.785	3.581	2.159
MPRT	9.606	7.279	5.885

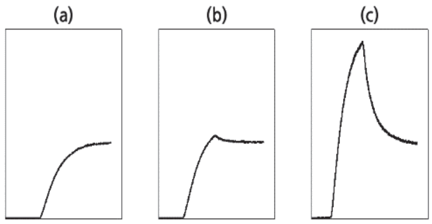

Fig. 2 GtG Waveforms
(a) Setting1, (b) Setting2, (c) Setting3

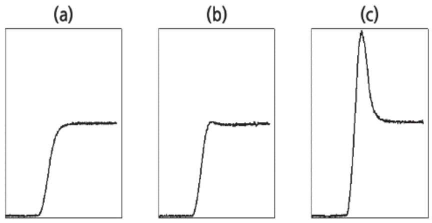

Fig. 3 MPRT Waveforms
(a) Setting1, (b) Setting2, (c) Setting3

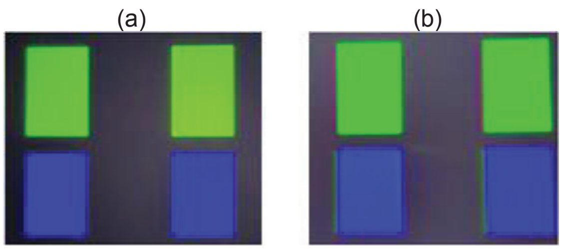

Fig. 4 Moving Picture Quality of Monitor B
(a)Still Image (b) Inverse Ghosting at Moving Image

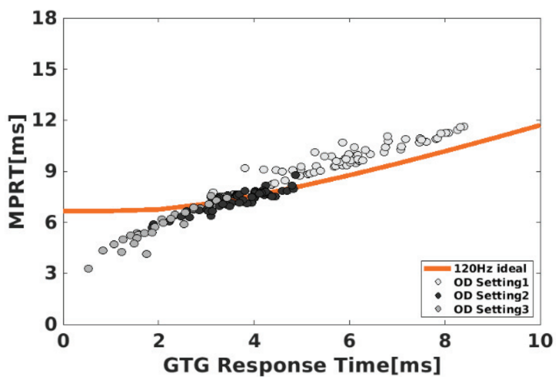

Fig. 5 Relationship between MPRT and GtG according to OD options of Monitor B

As shown in Figure 5, the relationship between GtG and MPRT is analyzed according to OD conditions. OD setting 1 has slower GtG compared to the other two options. Therefore, we observed longer motion blur in this condition. And it is located above the ideal value in the MPRT measurement result in Fig. 5. OD setting3 has a faster GtG than the other two conditions, and the MPRT is located below the ideal value line, however inverse ghosting images are easily observed in moving picture. Therefore, we chose Setting2 (without inverse ghosting image) as the representative OD setting condition, and the GtG and MPRT values at this time were analyzed as representative values. Monitor C and D were also analyzed based on the same judgment criteria. But it should be noted that Monitor C applied OD under three conditions, resulting in heavy inverse ghosting image under all conditions.

4 Result

The MPRT was measured in refresh rate band represented by each monitor, and the results are shown in table 3. Figure 6 shows the result of comparing the measured MPRT and GtG with the ideal value. The GtG value and MPRT value of each display are matched and expressed as a graph, and the solid line represents the ideal value of MPRT. Comparing each point with a solid line, it can be seen that the measured value is similar to the ideal value. In order to analyze the accuracy, the suitability was confirmed by quantifying it with mean square error (MSE).

Monitor A is an OLED display and it showed fast response time close to zero with a response time of 0.043ms. The three LCD Monitors were measured in response time from 3.02ms to 4.065ms, with monitor C being the fastest at 3.02ms on average, and monitor D

TABLE. 3 Response Time, GTG, MPRT Result

		A	B	C	D
Refresh Rate [Hz]		120	180	240	360
Response Time		0.043	3.290	3.020	4.065
60Hz	GtG	0.043	4.086	2.229	4.978
[ms]	MPRT	13.34	14.08	13.01	14.23
	(MSE)	0.053	0.279	0.551	0.161
120Hz	GtG	0.044	3.581	1.836	4.552
[ms]	MPRT	6.415	7.279	6.658	8.217
	(MSE)	0.136	0.207	0.224	0.076
240Hz	GtG			1.507	3.709
[ms]	MPRT			3.543	5.104
	(MSE)			0.115	0.335
360Hz	GtG				2.832
[ms]	MPRT				3.961
	(MSE)				0.283

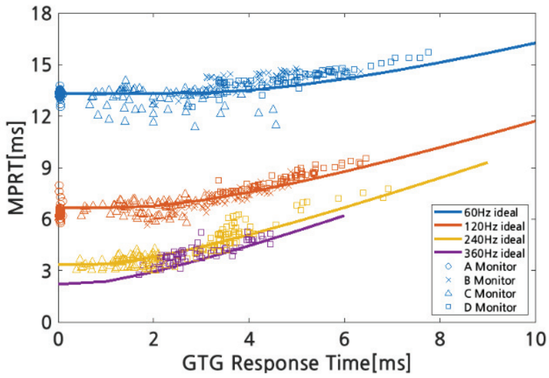

Fig. 6 Relationship between MPRT and GTG Response Time

being the slowest at 4.065ms on average. The three LCD monitors showed an average response speed of 3.458ms. Based on this analysis, the liquid crystal response time of these three LCD monitors was defined as an average of 3.458ms.

Monitor A, which is OLED, when set to 60Hz and 120Hz, GTG was 0.043ms and 0.044ms, and there was no relative difference. However, three types of LCD monitors tended to have faster GtG as the refresh rate increased. This is estimated as the effect by setting the OD algorithm. When analyzed based on the 120Hz result, the MPRT of monitor A was 6.415ms, monitor B was 7.279ms, monitor C was 6.658ms, and monitor D was 8.217ms. Monitor A, which has the fastest GtG, was also the fastest in MPRT. This trend was also observed at 60Hz.

In detail for each monitor, monitor A had an MSE 0.053, MSE 0.136, which was measured to be an MPRT close to the ideal value, and the average GtG was 0.043ms, 0.044ms and the standard deviation was 0.01. This was because GtG waveforms were measured in a form close to ideal. Monitor B and monitor D set the conditions for which no inverse ghosting image did not occur as the representative OD setting, so the GtG waveform is showing in the form of an S-Curve. That's why GtG and MPRT were relatively slow. Monitor D has been confirmed to have an MPRT of 3.961ms, which is slower than the ideal expectation of 2.2ms, despite the refresh rate of 360 Hz. Because monitor C uses OD strongly, it shows a fast response time with almost the same MPRT as the ideal expectation. When OD algorithms is applied to accelerate MPRT and GtG speeds, but in moving picture quality, they cause inverse ghosting image as shown in Figure 5.

5 Discussion

Through the correlation analysis between response time and MPRT, it was found that fast response time and high refresh rate were important for high-speed display operation. This means that when developing a display with a high refresh rate, the display technology with a fast

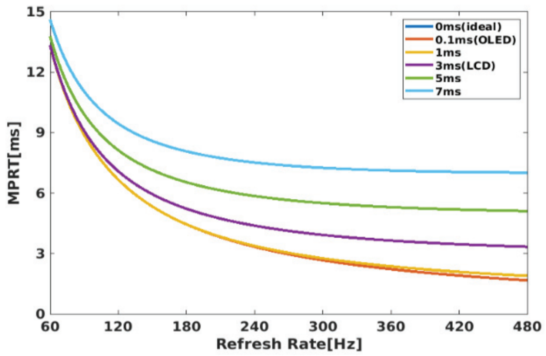

Fig. 7 MPRT according to Refresh Rate

response time has an advantage. Figure 7 rephrases the axis in Figure 1 mentioned above as the relationship between the refresh rate and MPRT.

Figure 7 analyzed the results of 3ms of the average response speed of the LCD and 0.1ms of the OLED response speed obtained through the existing evaluation and the MPRT theoretical values. Based on 120Hz, OLED and LCD are 6.7ms and 7.1ms, which shows 0.4ms difference, showing a 5.9% ratio difference. Based on 240Hz, OLED and LCD show 3.3ms and 4.4ms, respectively which is 0.9ms difference, showing a 27.2% ratio difference. For LCD displays, it should have a 480Hz refresh rate to be as competitive as a 240Hz OLED display to achieve 3.3ms of MPRT equally as shown in table 4.

This means that the maximum refresh rate that can be commercialized as an LCD is limited, and the MPRT performance of ultra-refresh rate products over 240Hz depends on the response time.

TABLE. 4 LCD FPS Corresponding to OLED

MPRT	WOLED	LCD	LCD FPS Corresponding OLED
120Hz	6.7ms	7.1ms	130Hz
144Hz	5.6ms	6.1ms	165Hz
180Hz	4.4ms	5.2ms	234Hz
240Hz	3.3ms	4.4ms	480Hz

6 Conclusions

In this paper, we measured the response time, GtG, and MPRT of the four major gaming displays and analyzed the correlation between response time and MPRT for high performance on the display. It is verified that OLED follows ideal MPRT because its response time is close to zero. And LCD monitors is confirmed the technical difficulty in which inverse ghosting image occurs when implementing fast response time, which causes motion blur when reducing the inverse ghosting image. In order to implement high-speed performance, it is shown that OLED display with a response time of close to 0 is the most ideal technology. It is expected that the difference between MPRT between LCD and OLED will increase as higher refresh rate displays are developed and introduced in the market.

References

[1] LIU Sha, *et al.*, "The Brief Trends Analysis of Gaming Display Device," International Conference on Display Technology, Vol. 52, Issue S2, pp. 913-916 (2021).

[2] Igarashi, Youichi, et al. "43.3: summary of moving picture response time (MPRT) and futures." SID Symposium Digest of Technical Papers. Vol. 35. No. 1. Oxford, UK: Blackwell Publishing Ltd, 2004.

[3] HJ Shin, *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 (2020).

[4] "Information Display Measurements Standards", IDMS(2012)