Analysis of Response Time Characteristics between LCD TV and OLED TV

Hee Eun Lee[1], JaeHong Kim[1], Seungwon Yoo[1], Jang Jin Yoo[1]

lhe_1008@lgdisplay.com

[1] LG Display, 30 Magokjungang 10-ro, Gangseo-gu, Seoul, 07796, Korea

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ABSTRACT

Response time of TV has also become an important specification as gaming market grows. In this paper, response time of latest LCD and OLED TV was analyzed based on measurement method of international standards. As display technologies develop rapidly, further study of measurement method of response time will be needed.

1 Introduction

The response time of a display describes how quickly the display could switch from an image to next image. Generally, the response time is measured as white to black transition time or gray-to-gray transition time. The response time is often referred to as the time from 10% to 90% of the relative display luminance levels [1, 2].

The response time for display could be measured by the time-varying relative luminance output of the display with a high speed LMD (Light-Measurement Devices). For measurement of response time, the time varying (transitional) test pattern is applied to the display. The speed of transition of test pattern should be slow enough to ensure that the output relative luminance shows the steady-state. The test pattern is generally used as full pattern size, but if luminance of display is changed by luminance loading, the test pattern can be changed that has maximum luminance [1, 2]. Especially, the response time of LCDs is not easy to analyze because most of LCDs have modulation that is induced by the pulse-width modulation (PWM) circuit used for dimming of backlight. In this case, the modulation should be considered as part of the display luminance output, and the applying of moving-window-average filter is one of method to analyze [1, 3].

Nowadays, with the rapid development of the game market, the demand for higher display performance of fast response time is increasing [4]. The demand is same aspect for not only gaming monitors also TVs for game console. This paper introduces the comparison of the response time for the latest LCD TV and OLED TV, then analysis the phenomenon.

2 Measurement

2.1 Set-up

For comparison of response time between LCD TV and OLED TV, the latest TV samples were used, one is 65" 4K LCD TV that is applied PWM driving and the other is 65" 4K OLED TV. The TV set-up was default condition in game mode.

The response time was measured using two kinds of test patterns. One of test pattern is 100% window size of white-to-black transitional pattern, and the other is 10% window size of white-to-black transitional pattern which shows maximum luminance for LCD TV. The test pattern was designed using ffmpeg (version 4.4, www.gyan.dev) and consisted of repetitions of white and black. The frame rate of test pattern was 120Hz that is same as frame rate of TV, then one cycle consisted as total 5 seconds as slowly as enough that TV shows steady-state luminance.

For measurement, luminance colorimeter (RD-80S, Topcon, 2 degree aperture size) and oscilloscope (MSO9404A, Agilent) were used. The test condition was configured perpendicular to display at 50cm measuring distance in darkroom. The number of captured data was 100k samples/second that is enough to measure fast response time, and the high resolution mode was applied to reduce noise on oscilloscope set-up.

2.2 Analysis

The response time was analyzed by Matlab (R2019b), to find 10% and 90% levels of relative luminance and to calculate moving-window-average for PWM driving of LCD TV.

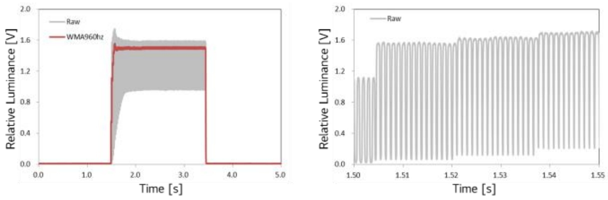
In order to determine 10% and 90% signal levels of relative luminance outputs, the steady-state luminance value was calculated based on the mode value of the signal to avoid effects of noise.

For analysis of LCD TV, moving-window-average filter was applied to consider modulation by PWM driving [1, 3]. The frequency of moving-window-average was set under the same conditions as the PWM driving frequency, which is 960 Hz for game mode. For calculating response time of LCDs, the correction factor was also applied. On the other hand, for analysis of OLED TV, it was not required to calculate moving-window-average filter because it shows no ripple on rising and falling waveforms.

3 Results

3.1 Response time of LCD TV

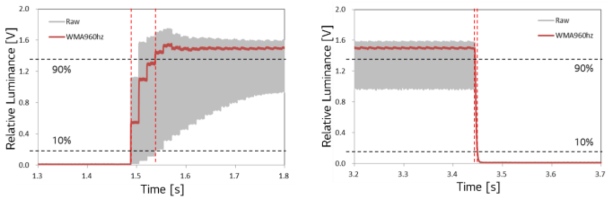
The measured waveform of LCD TV at 100% window size test pattern is shown in Fig. 1(a). The gray area represents the raw data of measured data, which contain ripples as shown in enlarged part of graph on the right of Fig. 1(b). The ripple is caused by PWM driving of LCD backlight. To analyze ripple, the moving-average-filter is required and the red line on Fig. 1(a) represents the filtered waveform as frequency of 960 Hz, same as PWM frequency.



(a) Whole of waveform (b) Enlarged part of waveform

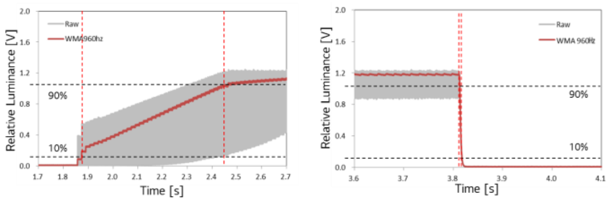
Fig. 1 Waveform of LCD TV and the ripple

Fig. 2 shows the part of rise time and fall time of measured waveform of LCD TV at 100% window size. Fig. 2(a) and Fig. 2(b) show the rise time and fall time, respectively. The measured waveform of LCD TV at 10% window size test pattern is shown in Fig. 3.



(a) Rise time : 50 ms (b) Fall time : 5 ms

Fig. 2 Waveform of LCD TV at 100% window size



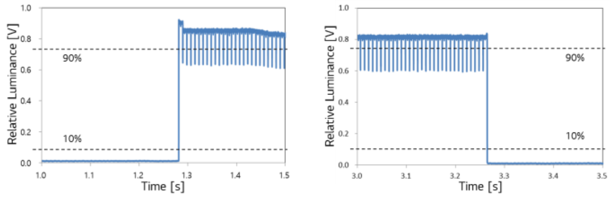
(a) Rise time : 590 ms (b) Fall time : 5 ms

Fig. 3 Waveform of LCD TV at 10% window size

As a result of the response time of LCD TV, two significant characteristics were found. One is that the rise time is comparatively slower than fall time, and the other is that there may be a difference of more than 10 times in the rise time depending on the pattern size. There were no other variables except the pattern size during the measurement process.

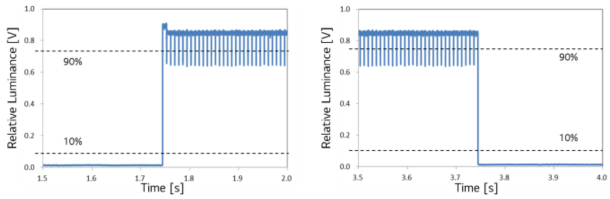
3.2 Response time of OLED TV

The measured waveform of OLED TV is relatively simple compared to LCD TV. Fig. 4 and Fig. 5 represent waveform of OLED TV at each 100% and 10% window size test pattern. Unlike LCD TV, it was not needed to calculate the moving-average-filter because waveform of OLED TV does not show ripple during rise and fall time. For OLED TV, there is no significant difference between 100% and 10% test patterns. Also, the rise time and the fall time seem to have similar values.



(a) Rise time : 0.1 ms (b) Fall time : 0.1 ms

Fig. 4 Waveform of OLED TV at 100% window size



(a) Rise time : 0.1 ms (b) Fall time : 0.1 ms

Fig. 5 Waveform of OLED TV at 10% window size

4 Discussion

4.1 Local dimming and response time of LCD

Unlike OLED TV in which each pixel emits light, LCD TV emits light through backlight, and local dimming algorithm is applied to control backlight according to input image to improve image quality [5-8]. If full white test pattern is input, all of LEDs in backlight will emit light. However, if 10% white test pattern is input, then 10% area is detected by local dimming and only the LEDs in the area emit. With the development of the local dimming, the image quality of LCD TV has been improved, but the local dimming shows some visual artifacts such as clipping, non-uniformity, halo, backlight flicker, and so on [5-7]. Especially, to avoid the backlight flicker artifact, some of low-pass temporal filters are generally adopted for LCD [5-10]. But as the trade-off, the temporal filter could lead backlight delay because the image changing when fast video is input may be faster than the filtered backlight [5-9]. The difference of response time of LCD TV between test pattern sizes could be evoked by local dimming.

4.2 Horizontal line time and response time of OLED

Response time of OLED is significantly faster than that of LCD TV because the response characteristics of materials are fast. However, it has a characteristic that could be affected by the measurement environments because of fast response time [11].

In this paper, the response time was basically measured with 2 degree aperture of LMD at 50 cm of test distance. However if the aperture size of LMD, test distance, or panel size is changed, the response time could be also changed because of the horizontal line time of display, that is required time to electrically address the horizontal data line of display [1, 2]. This phenomenon could be appeared more clearly in OLED TV than LCD TV, because OLED has as fast response time as the horizontal line time. If the driving frequency of OLED 4K TV is 120 Hz, then the horizontal line time is about 4 us (8300us for 2160 lines). When measuring the response time, the horizontal line time corresponding to the number of addressed lines in the measurement filed should be added [12].

To confirm the horizontal line time and response time of OLED TV, one more test condition was measured as 35 cm. Each of rise and fall time of OLED TV measured at 50 cm was 0.1 ms, but when measured at 35 cm, it was measured as 0.08ms. The difference of response time could not be regarded as measurement deviation, because it was obtained results through repeated measurements. The number of measured lines could be calculated as measurement field size, considering the aperture size of LMD and test distance. It is calculated about 50 lines for 50 cm, then about 40 lines for 35 cm with the test environment. The difference of two tests seems to be caused by the number of measured lines, about 10 lines.

Refer to international standards, it is recommended to control the size, and shape of test pattern or LMD measurement field to reduce the influence of horizontal line time on response time [1, 2]. However, this recommendation has limitations in measuring the response time of OLED TV that is too fast.

5 Conclusions

In this paper, the response time of the latest LCD TV and OLED TV was measured in full white pattern and 10% white pattern and each characteristic was analyzed. For LCD TVs, it was confirmed that the test pattern size affects the rise time and the local dimming was expected to be one cause. For OLED TVs, there was no difference in test pattern size, but the response time has influence by horizontal line time. Further study will be needed such as diverse pattern size, position, color, LCD TV's PWM driving analysis method and so on. In addition, the measurement method for response time on international standard need to be improved, as display technologies such as local dimming of LCD TV and OLED TV has developed significantly as well.

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