Scanning Backlight System For High Frame Rate LCD with IGZO-TFT Technology

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ABSTRACT

The demand for high frame rate displays with low latency continues to increase for recent rapid expansion of the gaming market. We developed a high frame rate LC panel with IGZO-TFT that can achieve high moving picture quality in combination with a scanning backlight.

1 Introduction

1.1 IGZO Evolution

IGZO material was introduced by Kimizuka et al. in 1985 [1]. And ever since the application of a-IGZO to TFT was reported by Hosono's group in 2004 [2], many groups worldwide have reported on studies and developments of IGZO. We were the first in the world to mass-produce IGZO-LCDs and have done so since 2012. As shown in Fig. 1, at the G8 factory, the initial TFT process of the first generation (IGZO1) was an ES type TFT in 2012. Then, the display resolution also evolved from 300ppi to 400ppi, evolved to a CE-type TFT, and even more so to a fifth generation (IGZO5). With each generation, we have reduced capacitance (ES-type → CE-type), increased mobility and improved reliability [3-5]. The IGZO display has been advanced in technology development with GIP (Gate driver In Panel). Currently, we are producing the 5th generation (IGZO5) and developing a 7th generation (IGZO7). The IGZO5 that is currently in production achieves a mobility of 15 cm2/Vs, satisfies the TFT static characteristics and long-term reliability, and is especially optimized for GIP [6].

Fig. 1 IGZO evolution

Additionally, the display resolution has advanced in recent years from 100 ppi to 400 ppi or more due to the display market demand for high resolution. Moreover, narrow border demands from the display market are not limited to specific products. Narrow borders have been applied to a wide range of products from small displays like smartphones to PCs like 2-in-1 PCs and tablets. For example, a PC display with a 2mm or less border is required for about a 15-inch display. Thus, the IGZO display has advanced to narrow borders with GIP. In particular, at the G8 mother factory, our IGZO-TFT is optimized for GIP circuitry for small to medium size displays (about 5 to 30-inch displays). It has been developed and produced so that the long-term reliability and high performance of the GIP are exhibited from low frame rates to high frame rates, and from low temperatures to high temperatures (including vehicle standard conditions) [6].

1.2 Scanning Backlight System

The high frame rate LCD with IGZO-TFT as mentioned above can achieve low latency suitable for gaming applications and improve moving picture quality. In addition, impulse-type backlight driving, such as flashing backlight driving and scanning backlight driving, is well known as a driving method that further improves moving picture quality. These technologies have been proposed for various applications that require high moving picture quality [7-9].

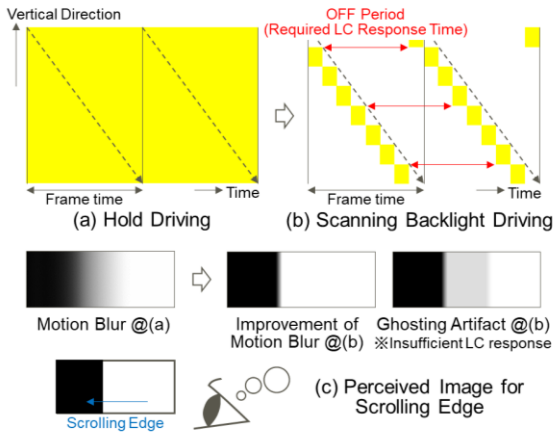


Fig. 2 Improvement of Moving Picture Quality

Figures 2(a) and (b) show examples of a relationship between writing data to the panel (dotted line) and lighting backlight (yellow filled) in “Hold Driving” and “Scanning Backlight Driving”. Fig. 2(c) shows the perceived scrolling edge in each driving. “Hold Driving” has a problem called “Motion Blur”, when we perceive a scrolling edge. “Scanning Backlight Driving” can improve the “Motion Blur”. However, when the LC response time is insufficient, the moving picture quality degradation called “Ghosting Artifact” is perceived. A high frame rate panel for gaming PC applications especially has a shorter frame time. Therefore, “Scanning Backlight Driving” requires much faster response LC panels to achieve high moving picture quality.

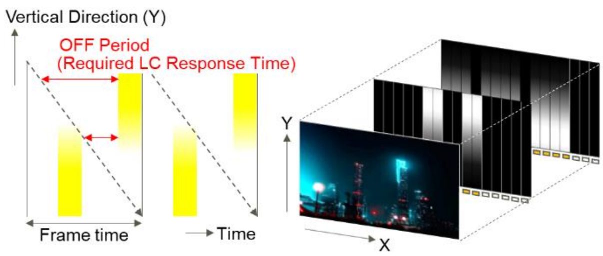
1.2.1 8-Segment Driving (Back-lit Type Backlight)

“Off Period” in Fig. 2(b) shows the interval between writing data to the LC panel and lighting the scanning backlight in an LCD of “Scanning Backlight Driving”. To increase “Off Period” is one of the ways to achieve high moving picture quality. In order to increase “Off Period”, the scanning backlight should have many segmented areas from top to bottom of the screen. Because an LC panel combined with the scanning backlight has a huge number of scanning lines.

Our developed back-lit type mini-LED backlight capable of 2D dimming has many segmented areas [10]. Moreover, we developed a scanning backlight system combining the mini-LED backlight and 360Hz panel with IGZO-TFT for gaming PC applications [11]. Our developed prototype with “8-Segment Scanning Backlight Driving” achieved significantly higher moving picture quality compared to “Hold Driving”.

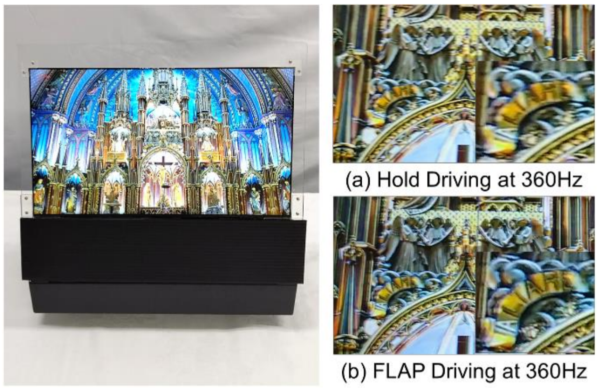
1.2.2 FLAP Driving (Edge-lit Type Backlight)

In order to meet the demand for thinner modules, we developed a backlight system capable of 2D dimming with three LGPs (Light Guide Plates) [12]. Moreover, we customized the configuration with two LGPs to meet the laptops’ requirement. We call our developed scanning backlight driving method “FLAP Driving” [11]. Fig. 3 shows an example of driving method and backlight configuration on “FLAP Driving”. The prototype reduced the thickness of the LCD module and achieved a narrower border on three sides, because of LEDs on one bottom edge.



(a) Driving Method (Example) (b) Backlight Configuration

Fig. 3 FLAP Driving



(a) Hold Driving at 360Hz

(b) FLAP Driving at 360Hz

Fig. 4 Previous Prototype of FLAP Driving

Figure 4 shows the previous prototype and the actual appearance of the scrolling image: (a) a “Hold Driving” shooting image, (b) a “FLAP Driving” shooting image. In order to reproduce the viewing conditions of a moving picture as pursued by eye movements, these images were captured while panning the camera. These images show that “FLAP Driving” has better moving picture quality compared to “Hold Driving” although it has only two segments for scanning backlight driving.

2 Evaluation Method

We evaluate the moving picture quality with EBET (Extended Blurred Edge Time) as recommended by IEC [13]. For example, EBET is equal to one frame time in “Hold Driving”, if response time of an LC panel is 0ms. Moreover, EBET of “Hold Driving” is constant regardless of the direction to write data (LC panel scanning direction in Fig. 5), because the backlight is always turned on.

On the other hand, scanning backlight driving tends to have different EBET for the direction to write data, when the number of segments is smaller. Fig. 3 shows that the “Off Period” tends to be different for the direction to write data in “FLAP Driving”. In order to evaluate these differences of EBET caused by same factors including the number of segments, we have proposed moving picture quality evaluations at multiple evaluation positions [9,11,13]. Fig.5 shows five evaluation positions on a screen in this paper.

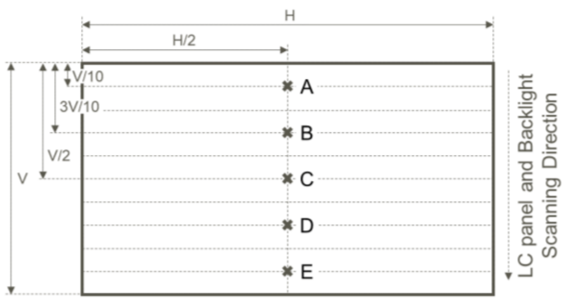


Fig. 5 Evaluation Positions on a Screen

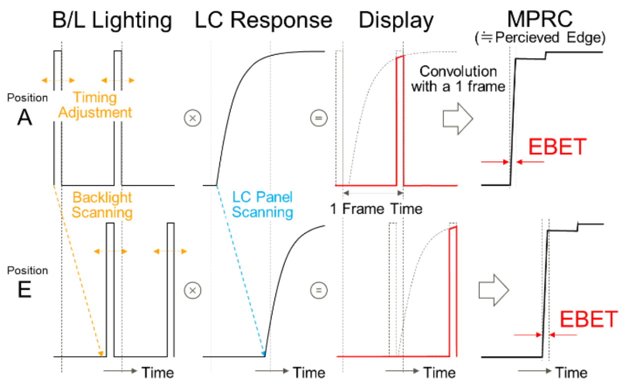


Fig. 6 "Indirect Method" to calculate EBET (Example)

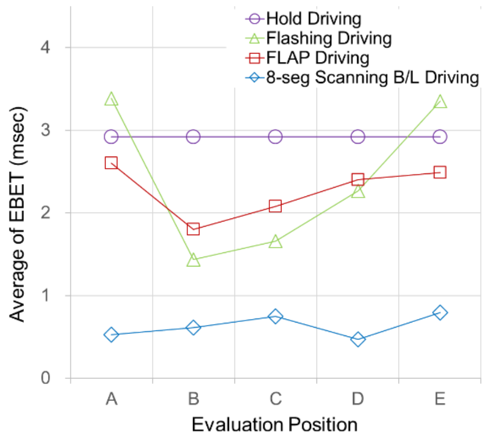


Fig. 7 Average of EBET

Figure 6 shows an overview of the method for calculating EBET and MPRC (Moving Picture Response Curve). EBET is calculated from BET (Blurred Edge Time), which is calculated from the transition points at 10% and 90% of MPRC (EBET = BET / 0.8). EBET is equivalent to the blur width of a perceived scrolling edge, because MPRC indicates perceived edge normalized by scrolling speed. Fig. 6 shows "Indirect Method", which calculates MPRC with backlight lighting waveform and LC response curve [13,14]. Our developed simulation system based on "Indirect method" can calculate EBET of an LCD. The calculation needs LCD's parameters such as frame rate, response time of an LC panel, lighting duty of a backlight, and light intensity including light leakage from adjacent areas in a scanning backlight. Thus, our system has the advantage that EBET can be predicted before making a prototype.

We compared simulated and measured results to estimate the accuracy of our simulation system. As a result, the average error ratio of the simulated EBET against the measured EBET was suppressed to 2.1% (for 72 patterns of gray level transitions).

3 Results

In order to achieve high moving picture quality in these scanning backlight systems, a faster response LC panel is required. We developed a new LC panel that has faster response than that of the previous prototype (Fig.4). In this paper, we evaluate the moving picture quality of our scanning backlight systems combined with our new panel. We simulated EBET and obtained optimal backlight lighting timing for each driving. These backlight lighting timings were adjusted to minimize the difference between all evaluated positions. The temperature condition of the panel surface was set at 30 ± 1 °C, and the frame rate was 360 Hz at all evaluation conditions.

Figure 7 shows the results of the simulated EBET at each driving. The horizontal axis gives the screen positions (Fig.5) and the vertical axis gives the average of simulated EBET (for 72 patterns of gray level transition).

The results show that "8-Segment Scanning Backlight Driving" (blue line) has the highest moving picture quality and has significant improvement compared to "Hold Driving" (purple line). Moreover, the EBET of "FLAP Driving" (Red line) is better than that of "Hold Driving" in all evaluated positions.

On the other hand, "Flashing Driving" (green line) is a driving method in which the entire screen lights simultaneously with an impulse lighting. The EBET of "Flashing Driving" is worse than that of "Hold Driving" at Position A and E, because "Off Period" is insufficient at these positions. These results indicate that "FLAP Driving" has advantageous moving picture quality against "Flashing Driving" with no segmented areas.

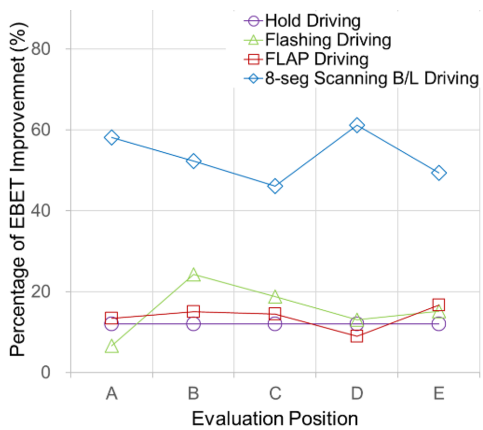


Fig. 8 Improvement Rate of EBET

Figure 8 shows the EBET improvement rate of the new LC panel compared to the previous panel combined with our prototype. These results indicate that each driving method improved the EBET by more than about 10%, because of the LC response improvement. In particular, "8-Segment Scanning Backlight Driving" improved more than three times compared to the others in this evaluation.

4 Discussion

We focus on the number of segments and discuss the features of each driving. “8-Segment Scanning Backlight Driving” has the highest moving picture quality and the largest improvement rate of EBET by new LC panel compared to the others. This is caused by the large number of segmented areas, which makes “Off Period” longer. As a result, they are more receptive to the improvement effects of LC response. Moreover, the moving picture quality of “FLAP Driving” has improved compared to “Hold Driving”. However, the EBET of “FLAP Driving” is worse than that of “8-Segment Scanning Backlight Driving”, because of the small number of segmented areas. On the other hand, the most important feature of “FLAP Driving” is that it can achieve moving picture quality improvement, a thinner shape, and a narrower border on three sides simultaneously. We achieved the feature by customizing the number of LGPs to make it thinner. In addition, edge-lit type backlight generally costs less than back-lit type backlight, because of the number of LEDs.

Each driving should be selected according to users’ demand for each element, because each driving differs in features of elements such as thickness, frame width, cost, and moving picture quality. For example, “FLAP Driving” is suitable for users who request a balance of all the above elements. “8-Segment Scanning Backlight Driving” is more suitable for higher moving picture quality and elements such as HDR, which are not discussed in this paper.

The demand of high frame rate LC panels for gaming applications is expected to continue. Therefore, faster response of LC panels will continue to be an important technical element. Moreover, scanning backlight driving is one of the important technical elements to improve moving picture quality. In order to evaluate these scanning backlight systems, we proposed the EBET evaluation method for each screen position. We have also created new advantage in “FLAP Driving” that can achieve moving picture quality improvement, a thinner shape, and a narrower border on three sides simultaneously. This advantage can be achieved by our faster response LC. Thus, a faster response LC is needed in the scanning backlight system.

5 Conclusions

We developed a faster response LC panel with IGZO-TFT technology. Our high frame rate LC panel can not only achieve low latency, but also be optimally combined with scanning backlight driving to improve moving picture quality. Our technologies can provide more suitable solutions for various requirements of gaming applications.

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