High-PPI Fast-Switch Display Development for Oculus Quest 2 VR Headsets

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Abstract

Recently, Meta rolled out Oculus Quest 2 all-in-one VR systems which have brought more virtual reality entertainment and experiences for users to discover. A 5.46" 773 PPI (pixel per inch), 1920 RGB x 3664, fast-switch LCD with low-persistence backlight is used to get visual fidelity of around 21 PPD (pixel per degree) without any blur or ghost artifact. In this paper, we will present the overview of Quest 2 display architecture, performances and some of the design challenges which we have addressed.

Author Keywords

virtual reality, VR headset, fast-switch LCD, pixel per inch, pixel per degree, MIPI, low temperature polysilicon, in-plane switch

1. Introduction

When a virtual reality (VR) system is developed, lots of factors should be considered, such as motion-to-photon latency, visual acuity (PPD), field of view (FOV), visual artifacts, power dissipation, weight, thermal requirements, ergonomic comfort, ease of use, and intuitive user interfaces [1]. The visual acuity is the ability to read an image at a certain distance and it's determined by display pixel density (PPI; pixel per inch) and viewing optics parameters, such as focal length and MTF (modulation transfer function). The field of view is limited by display resolution, computing capability and lens architecture. Many kinds of visual artifacts might be noticed in VR headsets because the image presented on the display is magnified by the lens. These artifacts include chromatic aberration, distortions, pupil swim, motion blur, ghosts or tailing effects, and static or motion screen door effect (SDE) which is defined as any visible repeating structure pattern on a pitch larger than a sub-pixel in any direction. Some of them can be completely or partially calibrated on the computing side and by careful lens design and fabrication, but to suppress the others, such as blur, ghosts, and SDE, the VR display should be elaborately tailored. Meanwhile, weight, outline dimension, and power consumption in the display module has a significant impact on the overall VR product design [2].

In 2020, Meta released Oculus Quest 2, the next generation of all-in-one VR (virtual reality) [3-4]. Quest 2 pushes the state of VR forward with a redesigned all-in-one form factor, new Touch controllers, and our highest-resolution display ever as depicted in Figure 1. The new display features 1832 x 1920 pixels per eye and with 50% more pixels than the original Quest, everything from multiplayer games and productivity apps to 360° videos looks better than ever. With Quest 2's increased graphics processing power, this new display is capable of supporting 90 Hz and furthermore, we provide 120Hz operation as an experimental feature [5].

Meta is moving forward to the metaverse [6] through extensive research and development of innovative concepts although there are challenges ahead, and the Quest 2 is only a small step to get there (a lot more yet to come). In this paper, we introduce a fast-switch LCD (liquid crystal display) specifically designed for VR applications, describe the architecture of the Quest 2 display, and present its specifications and performances.

Figure 1. Oculus Quest 2 VR.

2. Fast-Switch LCD for VR Applications

Various display technologies, including LCDs [7], OLEDs (organic light emitting diodes) [8], and micro displays [9], such as μOLEDs (micro OLEDs) and μLED (micro light emitting diodes) displays, have been introduced in the VR systems. In the Oculus Quest 2, the LCD technology has been selected considering the mass production maturity, affordable price, and possibility of pixel density increase.

In order to suppress visual artifacts, such as motion blur, ghosts and trailing effects, fast-switch (FS) LCDs have been developed. The FS LCD has three important features as follows:

1) Fast panel scan-out
2) Fast LC (liquid crystal) response time
3) Low-persistence backlight illumination

After all of the gate lines are scanned-out as fast as possible, we wait until the LC settles down and then the backlight is illuminated for a short time as shown in Figure 2.

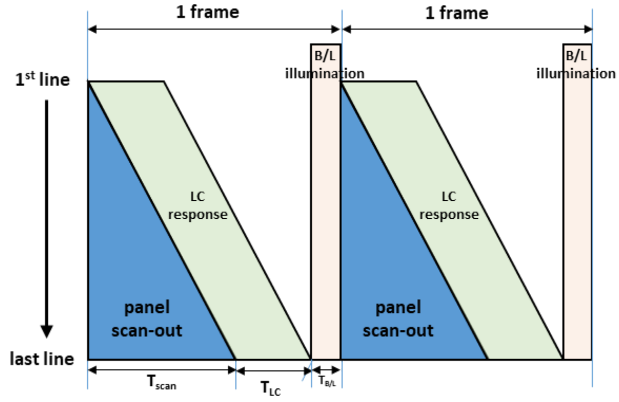

Figure 2. Typical timing diagram of the FS LCDs for VR applications.

2-1. Fast Panel Scan-Out

In contrast to conventional LCDs which may utilize the entire frame time for data scan-out, the FS LCDs require much faster scan where the gate lines should be updated as fast as possible in order to obtain enough time for the LC material to settle down before the backlight is turned on. When the LC settling time is not sufficient, users could notice visual artifacts, such as ghosts and tailing effects in swift motion.

We customized a DDIC (display driver integrated circuit) to minimize the horizontal line time and the optimum value has been chosen considering panel loading and MIPI (mobile industry processor interface) data rate.

2-2. Fast LC Response Time

A fast response time in LC switching is an important ingredient to the FS LCDs. There have been various fast response LC technologies, such as OCB (optically compensated band), blue phase, and ferroelectric LC [10]. However, these LC modes have several drawbacks, such as high voltage requirements and limitations in analog driving. The LC response time is impacted by several factors, including LC layer thickness (cellgap), viscosity, temperature and surface treatment, as well as the driving electrode architecture [11]. An IPS (in-plane switching) LC mode has been tailored to get both fast switching and high efficiency.

2-3. Low-Persistence Backlight Illumination [12]

Motion blur is a significantly noticeable spatiotemporal artifact which occurs when an image is presented with a finite display frame rate and eyes move across the image. It also reduces visual acuity due to the blurred image. This artifact becomes even more apparent and users will notice it all over the place in VR applications because the display images are world-locked instead of being head-locked.

In order to minimize the motion blur artifact, the frame rate has been increased (e.g. 72Hz max. in Oculus Go, 80Hz in Rift S and 120Hz max. in Quest 2) and low-persistence illumination has been adopted by controlling the duty ratio in the backlight timing.

3. Quest 2 Display Architecture

Figure 3 below illustrates the panel configuration of the Oculus Quest 2 FS LCDs where a single display panel is used for both eyes. There is a dead space, where pixels are inactive, between the two separate active areas to save power consumption and to reduce the scan-out time. 4 corner cuts in the display module outline are employed for compact product design as well as 4 corner chamfers in each active area to cut out the outside of the viewing area.

The panel is scanned out continuously on the long side (portrait mode), which enables a single DDIC implementation. The frame rate is controlled by adjusting the blanking time (vertical back/front porches) while keeping the panel scan-out time the same.

A split backlight architecture which has LED (light emitting diode) bars on the left and right side makes the backlight illumination control more flexible, which enables 120Hz frame rate [5]. The dead space between 2 eyes has a function of preventing light from leaking to the opposite active area.

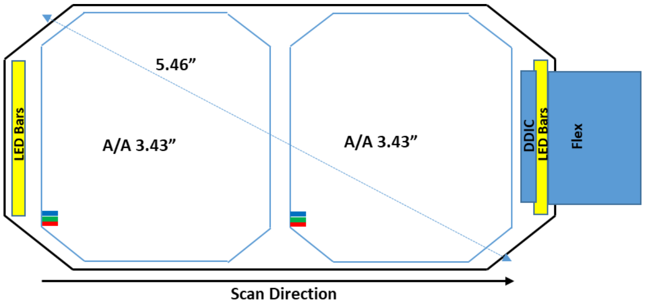

Figure 3. Configuration of Oculus Quest 2 displays.

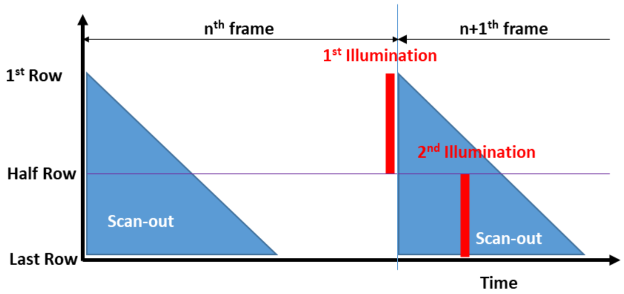

Figure 4. Typical timing diagram of the Quest 2 LCDs with the split backlight.

Figure 4 above shows the typical timing diagram of the Quest 2 FS LCD with the split backlight. The left LED bars are illuminated after the LC completely settles down in the left half active area. Meanwhile the right LED bars may extend into the next frame but the illumination should be finished before the right half active area scan gets started. The illumination timing has been optimized for each frame rate to get the best visual performance, such as no ghosts and minimized stereoscopic disparity.

4. Specifications and Performances

Table 1 below summarizes the specifications of Oculus Quest 2 displays. The conventional LTPS (low temperature polysilicon) backplane has been customized to get the fast data scan-out. By tailoring the IPS LC mode, we could achieve the maximum GTG (gray to gray) response time of 3.5msec (typ.) compared to around 20msec in conventional IPS LCDs.

Table 1. Specifications of Oculus Quest 2 displays.

Items	Specifications	Remarks
Display type	Fast-Switch (FS) LTPS LCD	
Resolution	1920 RGB x 3664	773 PPI
Pixel size	(10.95µm x 3) x 32.85µm	
Active area size	5.46”	3.43” per eye
Sub-pixel format	RGB stripe	
Module outline dimensions	66.3mm x 135.98mm	4 chamfers with 12.24mm x 12.24mm
Module weight	24.3g (typ.)	
Brightness	100 nits (typ.)	User brightness control
Panel orientation	Portrait	DDIC on short side
Frame rate	60Hz ~ 120Hz	120Hz: experimental feature
B/L illumination	Global	Split backlights
Color	sRGB	8 bits per color
Interface	MIPI D-PHY 1.1 2 ports	
Power consumption	<950mW	

Active area for each eye has a diagonal size of 3.43” and a nominal diagonal size is 5.46”. The resolution per eye is 1920 RGB x 1832 (773 PPI) and it gives around 21 PPD paired with our viewing optics. The color gamut of sRGB is reproduced in 8 bit depth per color channel. As shown in Figure 5, the Quest 2 optical system provides smooth and crisp visual experiences to users.

As mentioned in Section 1, a repeating structure pattern on a pitch larger than a sub-pixel in any direction (e.g. horizontal, vertical, and diagonal) could cause visible screen door effects. The most apparent SDE is the one along the gate and data lines, which is caused by the gate black matrix (BM) width, but at 773 PPI of the Quest 2 display, there is a hard limit to suppress it. Careful post spacer (PS) arrangement and resultant fill factor non-uniformity among the same color sub-pixels play an important role in avoiding several other kinds of SDEs, such as a diagonal SDE and an alternating row or column SDE. A single domain LC cell is preferred rather than having an asymmetrical pixel structure in alternating lines.

The default frame rate in the Quest 2 is 90Hz and a DFR (dynamic frame rate) feature between 60Hz and 90Hz has been implemented. As an experimental feature, 120Hz is also provided to developers thanks to the split backlight. As an interface between the DDIC and SoC (silicon on chip), MIPI D-PHY 2 ports are used and the power of <950mW is consumed at 90Hz.

Figure 5. Visual fidelity of the Quest 2 LCD through viewing optics.

5. Conclusions and Remarks

In summary, high resolution (773 PPI) displays have been developed for Oculus Quest 2 VR headsets by using a novel display architecture and VR-optimized design. A 5.46” 773 PPI, 1920 RGB x 3664, fast-switch LCD with low-persistence split backlight is used to get visual fidelity of around 21 PPD @90Hz or higher frame rate without any blur or ghost artifact.

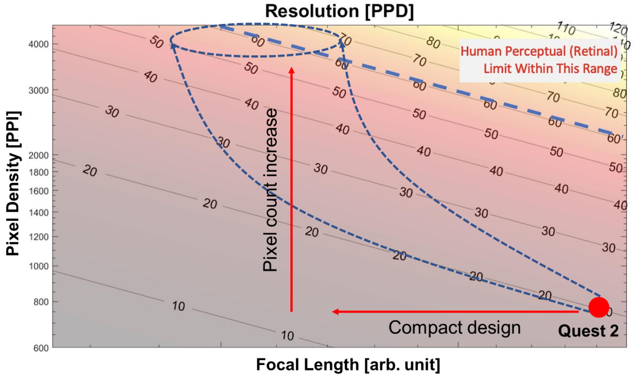

Figure 6. The evolution of the VR optical system at Meta.

The Quest 2 is just the beginning of the journey to Metaverse. Meta is conducting extensive research and development of innovative concepts to get there, which include but not limited to high-PPI micro displays, foveation, and high-fidelity viewing optics. Figure 6 depicts the evolution of the VR optical system at Meta. We are aggressively increasing the pixel counts to pass the human perceptual limit (60 PPD). For compact product design and resultant ergonomic comfort, the focal length in the lens design is decreased, which makes the display pixel density (PPI) even higher.

6. References

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