IEEE Open Journal on
Immersive Displays

test_extraction@gmail.com

Received 17 October 2023; revised 21 December 2023; accepted 3 January 2024. Date of publication 28 February 2024;
date of current version 14 March 2024. The review of this paper was arranged by Associate Editor Arokia Nathan.

Digital Object Identifier 10.1109/OJID.2024.3370888

Display and Optics Architecture for Meta's AR/VR Development

LINGHUI RAO[1], NAAMAH ARGAMAN[2], JIM ZHUANG[1], AJIT NINAN[2], CHEONHONG KIM[2], DAOZHI WANG[2], AND SHIZHE SHEN[2]

(Invited Paper)

[1]Meta, Redmond, WA USA
[2]Meta, Sunnyvale, CA USA

ABSTRACT We believe in the future of connection in the metaverse. The addition of immersive technologies such as augmented reality (AR) and virtual reality (VR) is the next step in this progression. In this paper, we will provide an overview of Meta's progress in display and optics development for AR and VR. The overview will cover different architectures that may lead to wide adoption of AR and VR devices in the near future as well as solutions that will mature over time. We will also discuss different components maturity and utilizing human perception for building systems made for human vision.

INDEX TERMS Augmented reality, display, optics, virtual reality.

I. INTRODUCTION

The metaverse is the next evolution in social connection and the successor to the mobile internet, which helps people connect and get closer together [1]. Meta is moving forward to the metaverse through extensive research and development of innovative concepts. The addition of immersive technologies such as augmented reality (AR) and virtual reality (VR) is the next step in this progression.

To support the most optimized visual experience for Meta AR/VR applications, we have designed the architecture of Meta's Display and Optics system and developed the visual performance evaluation matrixes. In this paper, we will introduce the design concepts, challenges, and discuss the human perception study for maximized visual performance.

II. INFINITE DISPLAY SYSTEM FOR VR ARCHITECTURE

Meta's Infinite Display features high resolution fast-switch display panels with an advanced lens system. Various display technologies, including LCDs [2], OLEDs (organic light emitting diodes) [3], and micro displays [4], such as μOLEDs (micro-OLEDs) and μLED (micro light emitting diodes) displays, have been introduced in the VR systems. The OLEDs on glass or flexible substrate give wide color gamut and high contrast, but its pixel density is very limited. The micro displays provide the highest pixel density thanks to silicon wafer backplane technology while they cost significantly more than the other display types. Meanwhile, the LCD can achieve fairly high pixel density at affordable price. From Oculus Rift to Oculus Go, Quest, Rift S, Quest 2 and Quest Pro, Meta has advanced in VR display and optical architecture design and manufacturing to enable the immersive user experience. In this section, we are going to focus on the review on the most recent Quest 2 and Quest Pro products.

For both Quest 2 and Quest Pro products, the LCD technology has been selected considering the mass production maturity, affordable price, and possibility of pixel density increase. The innovative pancake lens works by folding the light inside the optical system, and reduces the optical stack thickness by 40%, compared with Quest 2. Fig. 1 below shows the unique display and optics system designed to be harmonized with the product design and to bring a hyper-realistic visual experience for Quest Pro. Overall, we were able to increase the system resolution for Meta Quest Pro (22 Pixels Per Degree) by 10% compared to Meta Quest 2 (20 Pixels Per Degree). Plus, Quest Pro achieved 25% of the full-field visual sharpness improvement in the center view, 50% of the peripheral region improvement, and larger color gamut than Quest 2. The Infinite Display system also allows consumers to adjust the lens distance from eyes with a new eye relief dial to optimize fit, face tracking and viewing experience.

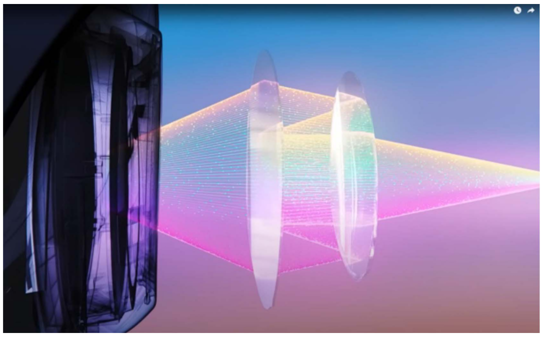

FIGURE 1. **Infinite display system architecture for quest pro.**

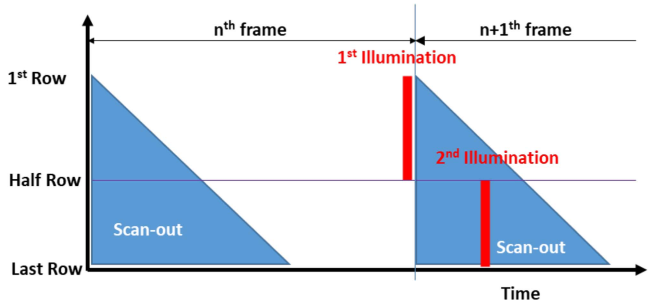

FIGURE 2. **Typical timing diagram of the quest 2 LCDs with the split backlight.**

TABLE 1 **Specifications of Meta Quest Pro and Quest 2 Displays**

Specifications	Quest 2	Quest Pro
Display Type	Fast-Switch (FS) LCD	
Resolution	1920 RGB x 3664 773 PPI	1920 RGB x 3664 1058 PPI
Active area size	5.46" (3.43" per eye)	2.48" per eye
Sub-pixel format	RGB stripe	
B/L illumination	Global	Local dimming
Color gamut	sRGB	DCI-P3

A. VR DISPLAY DESIGN

To lead the VR innovations for fitness, gaming and work, we introduced high resolution, high efficiency and fast-switch panel designs for Meta VR products. Meta Quest 2 has a single Fast-Switch LC display panel design for both eyes [5]. Meta Quest Pro is equipped with two individual fast-switch liquid crystal display panels. The LCD panels are 1800 $\times$ 1920 pixels per eye. For Quest pro, the display resolution density is 1058 PPI, which is 37% higher compared to Quest 2. In addition, the local dimming backlight technology was introduced to Quest Pro to enhance the display color gamut, contrast and improve power consumption [6].

In order to suppress visual artifacts, such as screen door effects, mura, motion blur, ghosts and trailing effects, and to enhance power efficiency, fast-switch (FS) LCDs have been developed with below considerations.

1) HIGH EFFICIENCY AND HIGH RESOLUTION FAST-SWITCHING PIXEL DESIGN

The Meta VR display team has driven the display technology to over 1000 PPI to reduce artifacts, such as screen door effect (SDE), and improve text readability. SDE describes a mesh-like appearance on a screen or projected image [7]. SDE could be observed along the gate and data lines, which is related to the display fill factor design. For the Infinite Display system, special display panel and pixel design were implemented to improve the aperture ratio uniformity. With the increased resolution, development in panel process optimization is also implemented to ensure robust manufacturing operation.

A fast response display is needed to improve the system latency, which impacts the user experience on VR devices [8]. The LC response time was engineered with LC material tuning, cell design/process control, and also panel driving optimization.

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

Power consumption is important for battery life and system thermal management. Higher PPI display intrinsically has more challenges for power efficiency. Meanwhile, compared to the Fresnel lens system, the demand of Quest Pro display brightness was ~4–5 times higher due to the pancake lens system. We have taken all the system requirements into consideration in architecting the backlight design, panel pixel design, and overall optical stack innovation to maximize the optical transmittance improvement.

2) BACKLIGHT DESIGN OPTIMIZATION

Low persistence illumination: 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, low-persistence illumination has been adopted by controlling the duty ratio in the backlight timing. Fig. 2 below 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