Hybrid Scan Display

Delivering multiple 3D images to multiple viewers

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Overview

A company called Realfiction, based in Denmark, has developed a new type of 3D display. It is similar in concept to a parallax barrier display in its ability to deliver glasses-free 3D images, but the components have been upgraded significantly. Specifically, the LCD display has been upgraded to a microLED display and the parallax barrier film has been upgraded to a new fast ferro-electric LCD (FLCD) modulator. This acts like a dynamic parallax barrier. The system also adds eye tracking to deliver images for up to 5 viewers. Alternative future versions not discussed in this white paper also enable multi-view displays with fixed or dynamic viewing zones of completely different content, such as dual-view displays for cars, for example.

Besides a standard 2D viewing mode, two additional modes of operation are possible with the same hardware. In Mode 1, a single stereoscopic 3D image can be presented simultaneously to multiple viewers within the viewing sweet spot. These viewers can move independently with the eye tracking used to ensure left and right eye images are delivered correctly to the viewer's eyes. Outside of the sweet spot, viewers will see a perfectly normal 2D image.

In Mode 2 operation, each of up to 5 viewers can receive different stereoscopic images. This could be 5 different movies for the five people, or individual 3D to multiple viewers that allows a look-around capability for each viewer. For example, imagine 5 people viewing an artifact in a museum, each moving independently around the object with the display delivering correct stereoscopic images to each person as they move about, delivering a "look around" capability. This is a much more demanding mode to support, but the new hardware configuration seems capable of meeting this design goal.

So far, Realfiction has demonstrated both Mode 1 and Mode 2 operation in a small 1.4" proof-of-concept display. In development is a 15" second generation Proof-of-Concept device capable of also demonstrating both modes.

3D Market Need & Status

3D can be a truly magical experience. You can be a diver, wonderfully immersed in an underwater world of tropical fish, or you can accompany an astronaut on a space journey as if you were almost weightless yourself. Giant Screen Cinema has shown such a potential of 3D to awe its audiences. But the flip side is that the current technical limitations cause distractions, that in the longer run seem to outweigh the wow factor. Maybe this is the reason why 3D cinema has a history of coming back in waves, as new generations want to experience the wow factor. But we need to solve the technical issues if we want 3D to stick around and become a feature of home entertainment displays in the future.

These current technical limitations include the following topics that are addressed below in this paper:

- Required viewing sweet spot
- Improved horizontal parallax
- Vergence and accommodation conflict

- Vergence and motion-parallax conflict
- Miniaturization effect
- Limitation of discreet perspective views
- Moire-like interference
- Immersiveness from large display sizes
- Insufficient frame rate

Required viewing sweet spot
Consumers and professionals want a 3D display that provides natural 3D images without glasses. Some applications are for single viewers, but many applications desire to support multiple viewers with good 3D images. So far, glasses-free 3D displays have always had a viewing "sweet spot"; a zone that has a certain horizontal and vertical viewing range as well as an ideal depth range from the display. Outside the sweet spot the 3D image can fall apart. Clearly, a technology that eliminates the sweet spot is desirable.

Improved horizontal parallax
Auto-stereoscopic displays are glasses-free displays that can provide a few different stereoscopic views in the horizontal direction (horizontal parallax). Super-multi-view displays are auto-stereoscopic displays that overlap multiple views to provide a more seamless viewing experience (improved horizontal parallax). This can provide a decent look around capability with fairly-high fidelity. Such displays may or may not use eye tracking. Applications like TV, gaming, automotive, surgery, conference rooms and digital signage all desire the ability to support multiple users with high fidelity 3D images.

Vergence and accommodation conflict
It is also desirable for 3D displays to minimize any eye strain and nausea. This is often caused by the conflict between vergence (how your eye tow in or out when focusing on an object) and accommodation (where your eyes focus). In stereoscopic or auto-stereoscopic displays, the image is always in focus at the display surface, while the stereo image pairs may place the virtual object in front of or behind the screen surface. This is not a natural condition, and it is the cause of the vergence-accommodation conflict. Addressing this conflict is important in any 3D display design, especially in personal displays for close viewing, where the disparity between focus and vergence is pronounced for typical content like, for example, a 3D movie. For larger displays observed at greater distances, it is still important to keep this conflict in mind when designing content and limit the duration of "in your face" type effects.

Vergence and motion-parallax conflict
Another factor which may cause discomfort is the conflict between vergence and motion-parallax. For example, when watching a 3D movie in a cinema and sitting still, you can have a realistic feeling of depth. However, when you move your head the view perspective does not reflect the head position change. This is due to a lack of look-around capability. It gives an uncomfortable feeling that an object or a whole scenery is somehow strangely "strapped to your head" and always turns towards you, which can make you feel quite seasick if you don't sit still.

Miniaturization effect
A cause of distraction is also the so-called "miniaturization effect", which is the artifact that people

and objects look smaller than in real life, giving a feeling that your favorite actors are characters in a puppet theater. The problem is especially pronounced when content is shown on screens smaller than the content was originally rendered for (like watching a movie rendered for theatrical on a TV screen). When watching 2D, like a painting or a photo, we are so used to a person being much smaller than in real life that we are not offended by it. But in 3D, when we have depth and when objects appear solid in front of us, our brain automatically correlates the extension of objects on our retinas to physical sizes of the objects. Miniaturization can be avoided when you know the display size and the viewing distance for each viewer in the audience by adjusting stereo parameters such as camera distance and left/right eye image horizontal offset (parallax). But if viewers are not located at the same distance from the display, it requires delivery of an individual 3D image to each viewer.

Limitation of discreet perspective views

Another common cause of reduced image fidelity in super-multi-view displays is a limited number of discreet perspective views. Even with 100 individual perspective views you will notice distinctive “jumps” in perspective when moving you head around. One way to mitigate this is to have overlapping, blended perspective views, but this results in smearing of pixels and blurring of the image, especially for objects appearing at large depth in front of the display. Another way to mitigate perspective “jumps” is to track the position of the viewer and render the views in real time, either by a ray tracing system like a game engine or by AI-enhanced interpolation of perspective views. This requires delivery of a dedicated 3D perspective image to each viewer.

Moire-like interference

Many autostereoscopic displays today use slanted lenticular arrays. These have the limitation that moire-like interference effects between the color mask and the slanted lenticular array reduces clarity of fine details such as small text. This has been mitigated by some manufacturers by a clever electrically controlled lenticular array. This can be switched off to act like a clear window, allowing the display to operate in full-quality 2D when using a text editor or spread sheet, for example. However, it does not change the fact that in 3D mode, the clarity of fine details is reduced, which effectively excludes many professional use cases of lenticular-based 3D displays.

Immersiveness from large display sizes

To have a truly magic, immersive and still comfortable 3D experience, a large display is important to avoid the feeling of either looking out through a small window or into an aquarium. A large display can be located so the display edges are outside the central part of your vision. This is important, not only for immersion, but also to avoid frame-violations, i.e. objects stereoscopically appearing in front of the display, but being cropped by the display frame. This creates conflicting depth cues for the brain, which not only reduces the depth experience, but also causes discomfort. While a large display can mitigate this, consumer willingness to pay for a large display would most likely depend on the ability to watch it with a group of friends or your family, hence requires multi-viewer technology.

Insufficient frame rate

The frame rate of the display is the time needed to provide new images to the left and right eyes. It is generally accepted that a frame rate of 60 Hz is needed as a minimum to minimize motion artifacts and flicker. That means the display must be refreshed at a minimum of 120 Hz per stereoscopic 3D image pair in order to meet the 60 Hz frame rate requirement. Some 3D displays do not meet this requirement, and others meet the requirement but are limited to single viewer use.

Perspective and summary of limitations
Many companies today market their 3D displays as "holographic". In fact, most are not true holographic displays. They are mostly super-multi-view type displays. True, large holographic displays with moving images in full natural color will address the needs discussed above, but they remain in a development stage. On the other hand, a term like "3D TV" has become associated with products suffering from all or most of the limitations discussed above plus reduced resolution, crosstalk, flicker and a need for glasses, so this is not a good name for a new type of display either. There is a need for a new category name for a new and improved super-multi-view 3D display.

Today, no 3D displays, even glasses-free ones, address all the needs discussed above. Realfiction's Hybrid Scan Display addresses most, but not all these market needs. There is still a viewing sweet spot with some clever ways to mitigate, but not solve, the vergence-accommodation issue. The big innovation is the ability to support multiple users simultaneously with the same or separate stereoscopic images. Such a capability helps to mitigate the conflict between vergence and motion-parallax and the miniaturization effect. Content is rendered by a Unity game engine thus helping to reduce any perspective jumps. And the technology is not lenticular based, so there is no loss of resolution in changing from 2D to 3D. All these factors address the main issues with the acceptance of 3D displays and will enable many professional and consumer use cases for larger displays.

Display Architecture

As mentioned previously, the Hybrid Scan Display is similar in concept to a parallax barrier display, but with upgraded elements. The base display is a microLED array. This was chosen to enable very fast refresh rates and response time along with the ability to offer a wide range of luminance values. This is a major upgrade compared to an LCD display.

The second key element is the FLCD modulator. FLCDs have been around a long time and have been commercialized at the microdisplay size level. They have been prone to mechanical vibration and require an inverse image cycle for DC balancing, thus reducing their efficiency significantly. A new Electrically Suppressed Helix FLCD display developed by the Hong Kong University of Science and Technology has solved the mechanical stability concern. To address the DC balance issue, Realfiction can scan the device with DC balanced patterns, eliminating the need for a blanking interval taking up 50% of the duty cycle, as is traditionally used for FLCD.

Eye tracking is also employed along with an FPGA, LED drivers and custom software.

A proof-of-concept display has been developed and shown publicly by the company. Figure 1 shows a photograph of one of the first laboratory experiments while Table 1 gives the specifications for the first generation PoC. In development is a second proof-of-concept display that is 15 inches diagonally. This is being developed to demonstrate the scalability of the technology. Specifications are shown in Table 2.

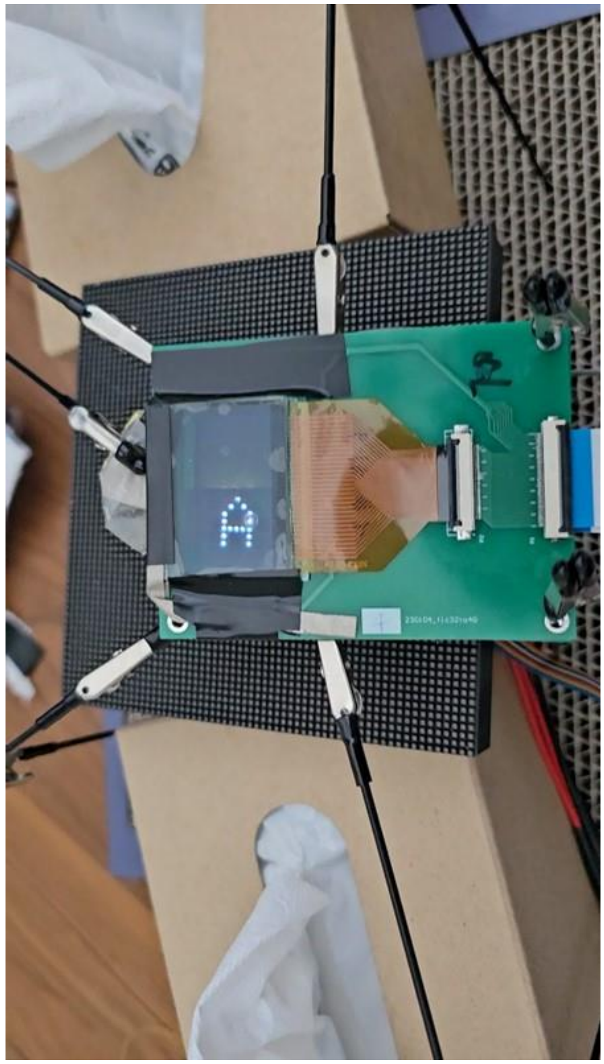

Figure 1: Proof-of-Concept Hybrid Scan Display

1.4" Proof-of Concept Display		
microLED component	Luminance	~ 1000 nits
	Resolution	32 x 24
	Size	1.8"
	Pitch	0.5mm
	Frame rate	60 or 120 Hz
	Refresh rate	120 or 240 Hz
	Multiplexing ratio	32
	Drive matrix	passive
	speed of response	< 10 microseconds
Ferro-electric LCD modulator	Size	1.4"
	Drive matrix	direct drive
	Frame rate	60 or 120 Hz
	Refresh rate	120 or 240 Hz
	Vertical slit width	0.5mm
	Number of barrier slits	32
	Distance from microLED display	30mm
	speed of response	50 microseconds
Controller	Custom drivers	16 data lines
		32 scan lines
	Eye tracking hardware and software	
	Central FPGA module controllers and LED driver chips	
	Specially developed algorithms for different operation modes	

Table 1: Specifications for the 1.4" Proof-of-Concept Hybrid Scan Display

15.5" Proof-of Concept Display		
microLED component	Luminance	~ 5000 nits
	Resolution	320 x 240
	Size	15"
	Pitch	0.5mm
	Frame rate	60 or 120 Hz
	Refresh rate	120 or 240 Hz
	Multiplexing ratio	32
	Drive matrix	passive
	speed of response	< 10 microseconds
Ferro-electric LCD modulator	Size	15"
	Drive matrix	direct drive
	Frame rate	60 or 120 Hz
	Refresh rate	120 or 240 Hz
	Vertical slit width	0.5mm
	Number of barrier slits	32
	Distance from microLED display	30mm
	speed of response	50 microseconds
Controller	Custom drivers	240 data lines
		320 scan lines
	Eye tracking hardware and software	
	Central FPGA module controllers and LED driver chips	
	Specially developed algorithms for different operation modes	

Table 2: Specifications for the 15" Proof-of-Concept Hybrid Scan Display

Operational Modes

Mode 1 Operation

Figure 2 shows the flow chart of the operation of the display in Mode 1.

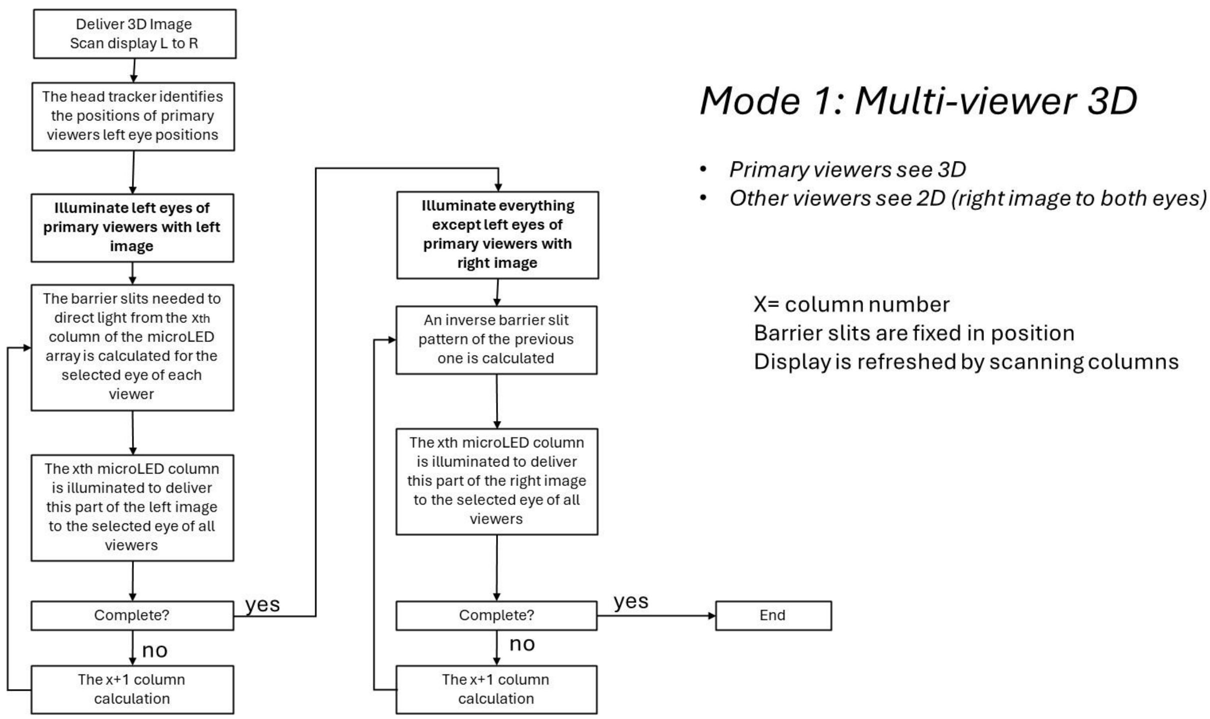

Figure 2: Flow Chart for Scanning in Mode 1

Figure 3 shows an illustration of the left side of the flow chart in Figure 2. As can be seen, several microLED columns and FLCD slits are on to deliver parts of the left eye view to all left eyes of the viewers within the sweet spot. The size of the sweet spot, defined by the maximum viewing angle and maximum viewing distance, depends on a number of factors such as number of slits per module, slit width, scanning speed and distance between FLCD and microLED display etc. The microLED array can be refreshed at either a 120 or 240 Hz rate to deliver images to the left and right eyes. Meanwhile, the FLCD modulator is updated with a new pattern of slits as each microLED column is illuminated. One full column scan of the microLED array is needed to deliver the left eye image. The same is needed to deliver the right eye image. The viewer-perceived frame rate (receiving left and right eye images) is 60 or 120Hz.

Figure 4 shows an illustration of the right side of the flow chart in Figure 2. Here, the inverse of the slit pattern used in the first time slot is employed with right eye images presented on the microLED. This blocks the right eye image from reaching the left eye of viewers while flooding the rest of the viewing area with the right eye image. This allows users outside of the sweet spot to see an image (the right eye). The inverted pattern on the FLCD also has the benefit of maintaining DC balance.

Figure 5 shows an animation of Mode 1 operation.

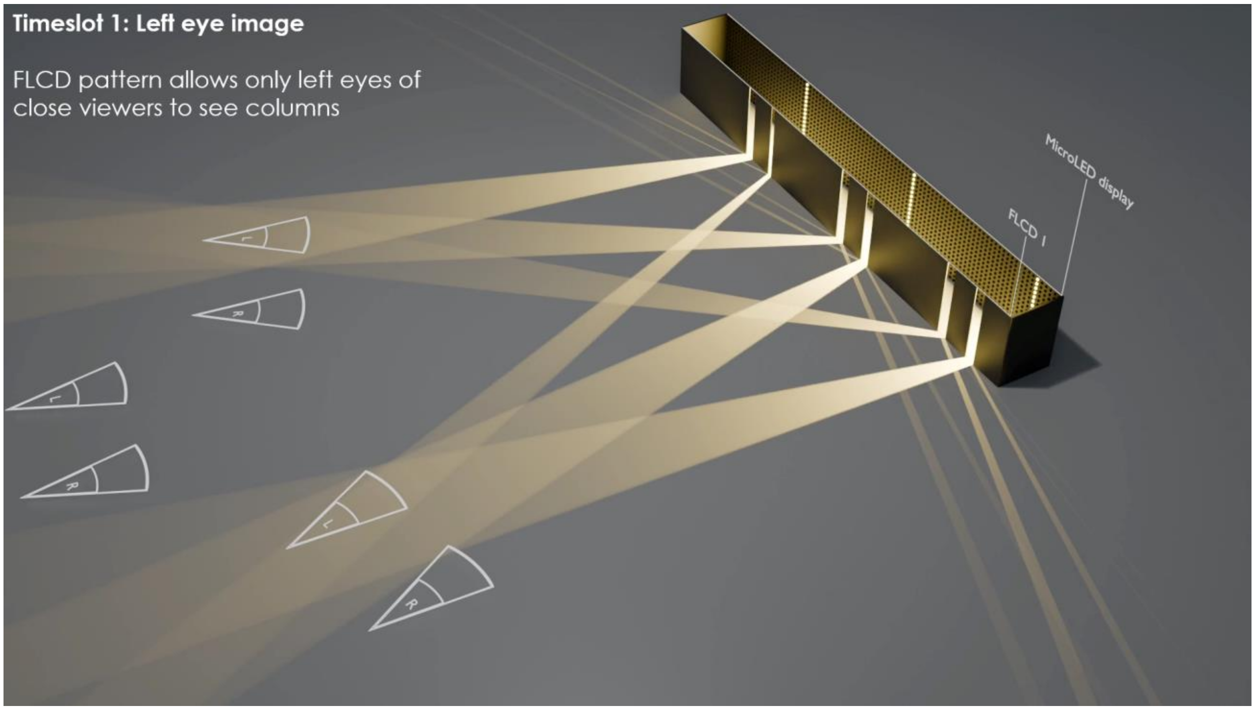

Figure 3: First Time Slot - Mode 1

Figure 4: Second Time Slot - Mode 1

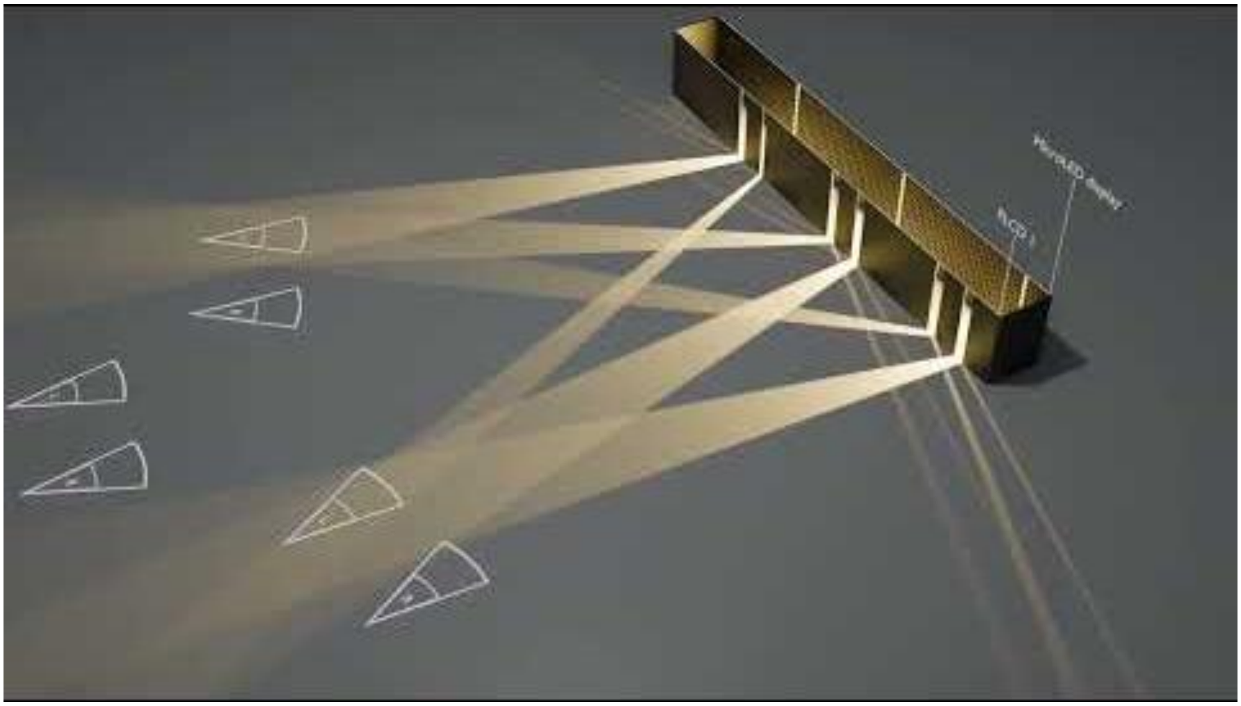

Figure 5: Animation of Mode 1 Operation

Mode 2 Operation

Figure 6 provides a flow chart of the operation of Mode 2. In this mode, up to 5 different viewers can be supported with five independent stereoscopic views. To create these views, Realfiction uses software built on top of the Unity render engine to generate the images at each eye position. The engine does not need to know if an eye is a left eye or right eye – only its position in the space in front of the display. It then renders only the column information needed for that eye and slit before incrementing to render the column information for the next eye position.

In this mode, the FLCD is scanned sequentially at 60 or 120 Hz and the LED matrix is updated with a new pattern of columns for each slit. One scan creates a full set of 10 images (for 5 viewers), because at least 10 columns are illuminated with different pixel patterns for each slit being open and are focused onto the eyes by the slit. One or more columns may be illuminated with the same pixel values corresponding to one of the 10 images, to create either a narrow or wide divergence of the beam, to accommodate for different viewer distances given a certain precision of the eye tracker. Each pixel is formed as combination of the scan patterns of the FLCD and the microLED display and the pixels' illuminated area is horizontally delimited by a slit and vertically by an LED, resulting in the term "hybrid scan." The combined hybrid scan system now delivers a total of 600 - 1200 frames per second. As a result, each viewer-perceived frame rate is now 60 – 120 for up to five different viewers,

This is a much more complicated and demanding mode compared to Mode 1 with the timing and luminance issues described more thoroughly in the Luminance - Refresh Rate Challenge section.

Figure 7 shows an animation of Mode 2 operation.

Mode 2: Individual 3D to Multiple Viewers

- *Primary viewers see multiple 3D images based on eye position*
- *Enables a "look-around" capability*
- *Designed to support 5 viewers*

n = slit number
m = viewer eye number
m <= 5
Display is refreshed by scanning microLED array

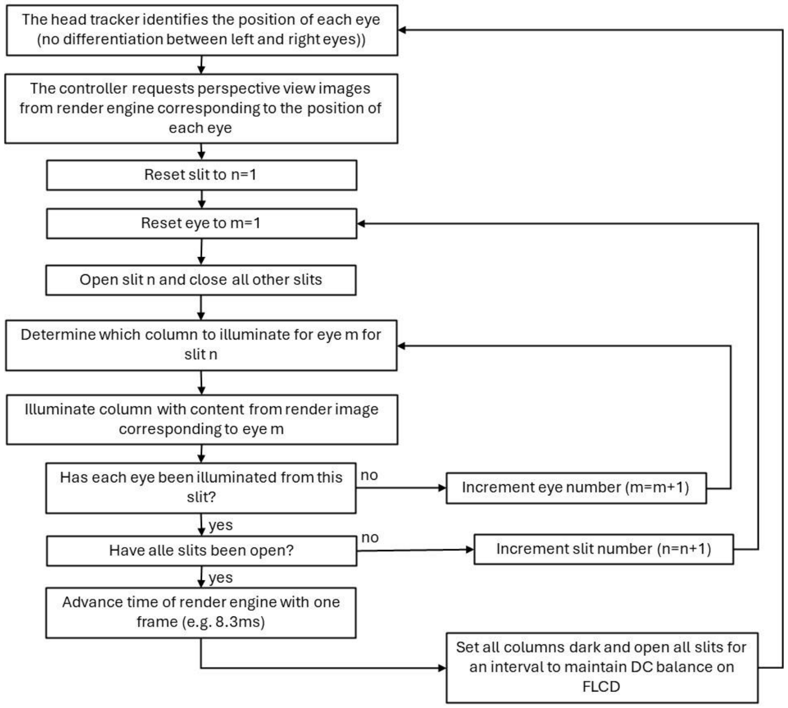

Figure 6: Mode 2 Flow Chart

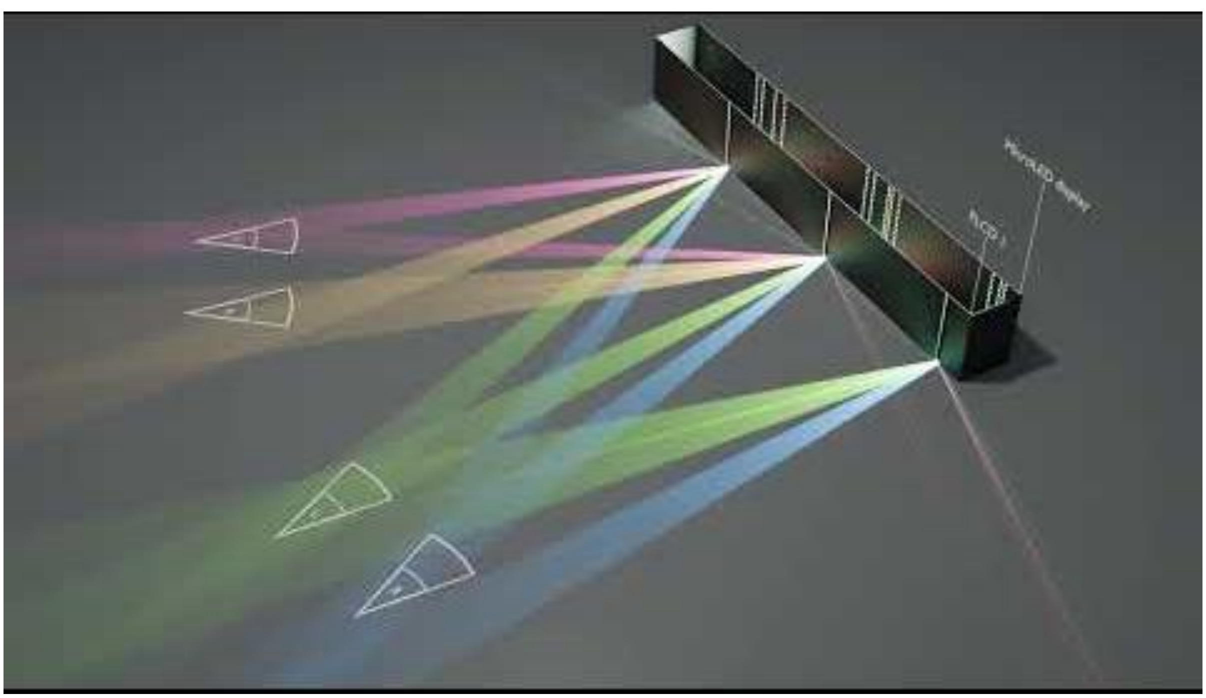

Figure 7: Animation of Mode 2 Operation

Mitigating Concerns

Error Rays

In general, the microLED display will be composed of a series of tiles or modules. Each module can be driven independently per the above flow charts. As a result, multiple columns could be on at the same time. And, since the FLCD modulator is physically separated from the microLED array by a short distance, it is possible for light from one column to leak into an adjacent slit. These are unwanted or error rays as they can also find viewer's eyes, decreasing 3D contrast and image fidelity. Figure 8 shows them circled in black. When an error ray finds a viewer's eye, a "view crash" occurs.

There are two ways to mitigate this artifact. One is to detect view crashes using data from the eye tracking system and correspondingly alter the scan sequence of one or more LED matrices. For example, reverse overall scanning from right to left or reverse scanning of two neighboring columns.

The second and preferred method is to add a second FLCD modulator that is parallel to the first one but offset in the direction of the microLED display by about 1.5mm. In practice two light modulators on 0.7 mm glass substrates may be laminated together to create an offset of approximately 1.5mm between the LC layers.

The second light modulator has apertures wider than or horizontally offset from the first but is controlled in a similar manner to the first. Because it is offset from the first, this will result in a different pattern of open and closed slits than in the first light modulator. The two combined patterns will block many of the error rays. Figure 9 shows the result. Additionally, this may reduce crosstalk between left and right eye images caused by light leakage in the first light modulator, including both leakage in gaps between barrier slits and transmission through closed slits.

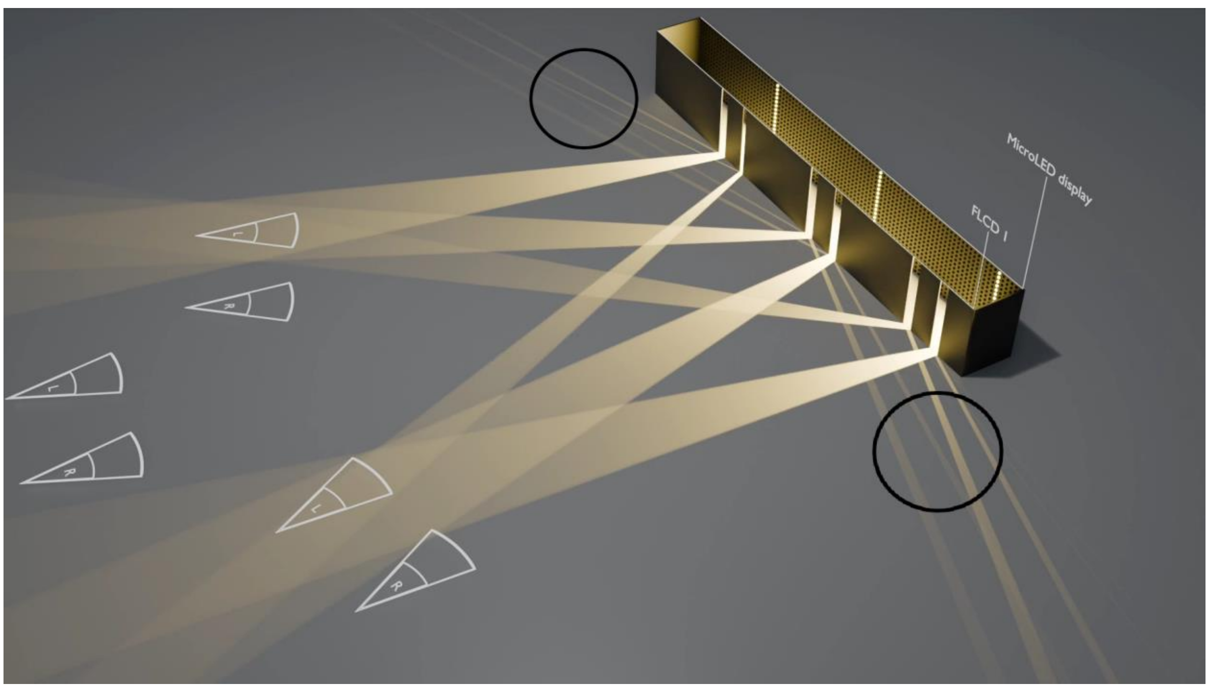

Figure 8: Error Rays

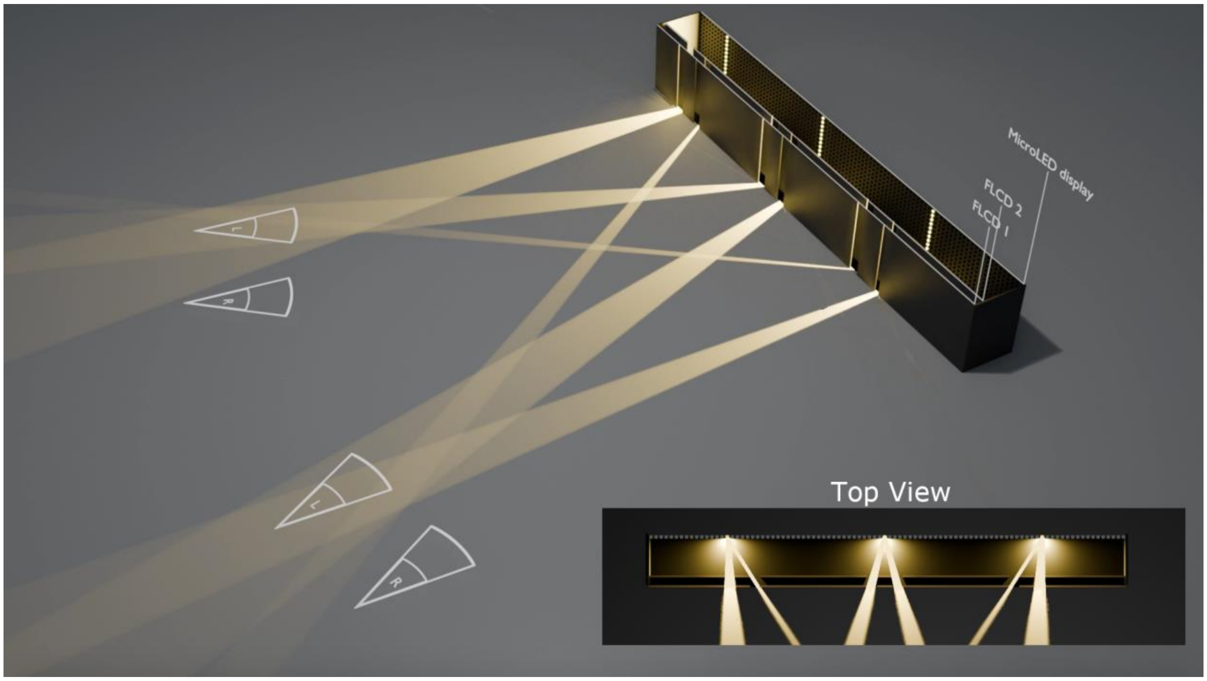

Figure 9: Mitigating Error Rays with a Second FLCD Modulator

Diffractive Effects

It is well known that passing light through narrow slits will cause a diffraction of the light. The slits create a pattern of vertical bright and dark fringes. The two slit diffraction pattern is different from the single slit pattern. If the slits in the Hybrid Scan Display are narrow enough to cause diffractive effects, it is possible that unwanted side lobes could reach the eyes of viewers.

For the two-slit situation, the diffracted light from each slit will interfere. But this interference depends on the coherence length, Lc of the light. The coherence length of the light source is the distance over which the light wave maintains a predictable phase relationship. The coherence length Lc is given by:

$$Lc=\lambda^2/BW$$

Where λ is the central wavelength of the emitted light (eg. 550nm) and BW is the spectral bandwidth of the LED (eg. 30nm). This gives a typical coherence length for a LED of 10 um.

One must also consider the Coherence time (τc). This is the time over which the light wave maintains a fixed phase relationship and is given by:

$$\tau c = Lc/c$$

where Lc is the coherence length and c is the speed of light. With Lc= 10um, we get $\tau c = 0.033$ picoseconds.

This result suggests that if the time separation between the opening of two slits is a few picoseconds or more (which it will be), the light waves from the two slits will be incoherent with respect to each other, and no interference pattern will be observed by the observer. You would see only the sum of the individual diffraction patterns from each slit, single-slit diffractions having much smaller amplitude than interfering multi-slit diffraction.

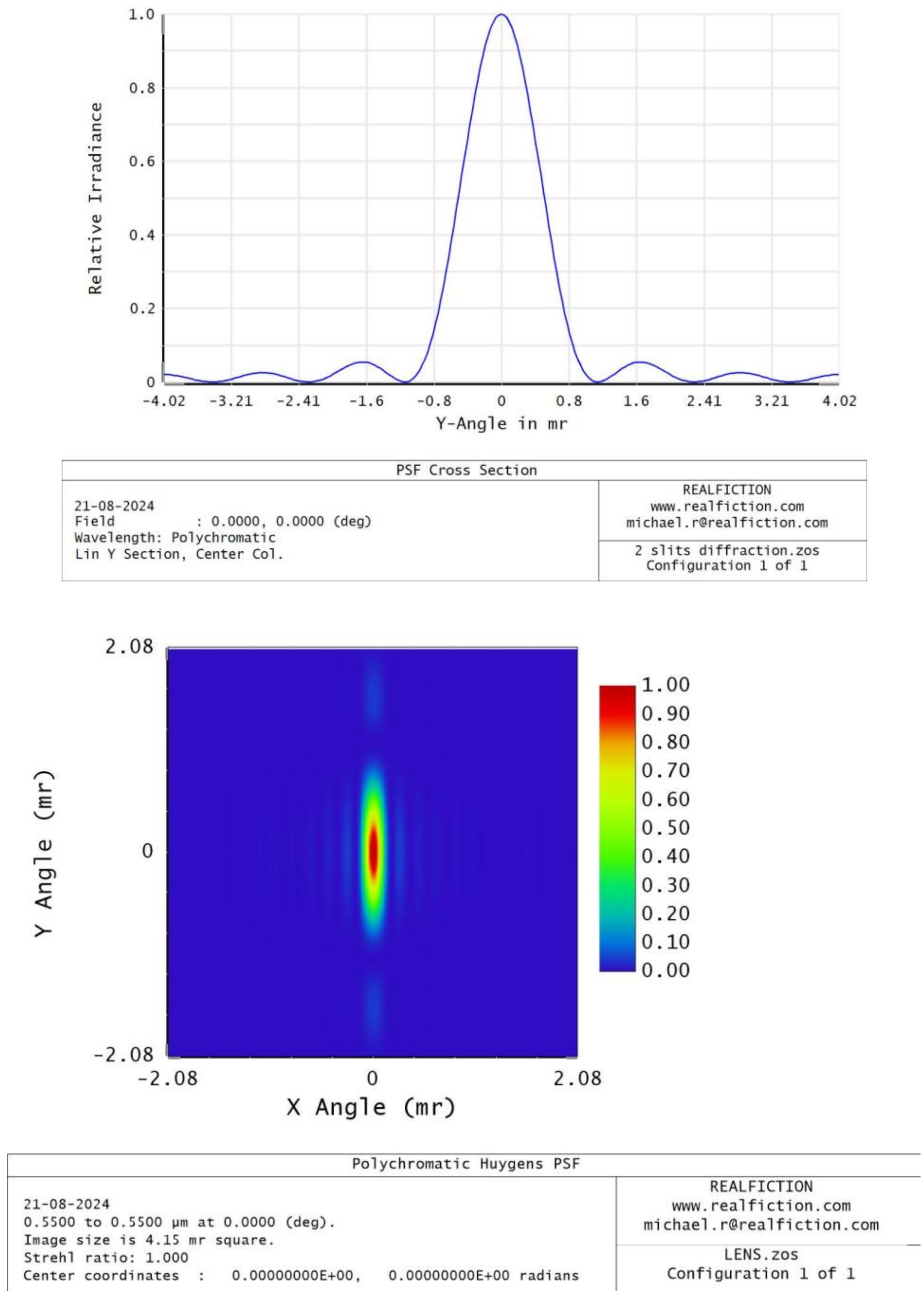

Figure 10: Irradiance Pattern for a 0.5mm x 3mm slit

Now one must consider how these diffraction patterns will be observed by a viewer in the sweet spot. Figure 10 shows the irradiance pattern for a single 0.5mm x 3mm sized slit. The central lobe is no more than two milliradian wide, so quite narrow. Any side lobes will be so dim as to have no effect if they were delivered to the wrong eye.

Moire

Moire is the interference pattern that results with two overlapping structures where the pitch of each does not match when observed from a given point of view. In the Hybrid Scan Display, the pixel gaps in the microLED array form one pattern while the black matrix in the FLCD create a second pattern.

One solution is to match the two pitches of these elements, but this would only work for a very restricted eye box, because there is a distance between the light modulator and the microLED display.

Another option is to keep a low ratio between the horizontal extension of black matrix structures on the FLCD and the horizontal extension of the active light emitting areas of the LEDs, thus minimizing moire amplitude. A third option is to use a pseudo-random matrix pattern and reduce the spacing between slit electrodes to such a degree that the fringe field effect will cause slits to "bleed" together and close the gaps between slits, in other words take advantage of the normally unwanted pixel crosstalk caused by fringe field effects.

If the black matrix is used on the FLCD modulator, one can also apply a batwing type diffuser over the microLED array. This diffuser closes gaps between microLED pixels and ensures a uniform illumination horizontally across each pixel, hence eliminates moire patterns. A diffuser placed over a microLED display would normally reduce ambient contrast significantly, but with the FLCD in front of it, this can be mitigated by proper polarization control, much like the situation of an LCD panel in front of a miniLED backlight with diffuser.

Flicker and strobing

The display modules need to be scanned at a refresh rate, which the FLCD light modulator can keep up with. This will be smaller than the sometimes very high refresh rates seen on LED wall modules. The high refresh rates used in LED walls are designed to combat flicker and strobing, i.e. the disturbing effects of series of small dot patterns left by Pulse Width Modulated (PWM) "dot shaped" LEDs on the retina of gaze-tracking or saccadic rotating eyeballs. Placing a batwing diffuser over the microLED array closing the pixel gaps can mitigate flicker and strobing at refresh frequencies as low as 90Hz, effectively the same way a 120Hz CRT tube does not present flicker because the electron-beam induced dots on the phosphor bleeds more or less together.

Vergence-Accommodation Conflict

One way to mitigate the vergence-accommodation conflict is to locate the display at a viewing distance which matches the average object distance in typical content as best as possible. For content such as 3D movies and multiplayer games for example, this normally means an observation distance of several meters, hence requires a large display. The eye tracking solution in the Hybrid Scan Display is also capable of determining the gaze angle of each viewer. This allows for the customization of the stereo image pair for each user, by for example, delivering content matched to the viewer's interpupillary distance. To help minimize vergence-accommodation conflicts, the content can be rendered to slightly blur the content outside of the viewer's gaze angle. This is essentially foveated rendering and should help to reduce vergence-accommodation issues.

Luminance - Refresh Rate Challenge

In Mode 2, the display is being designed to support five viewers with 5 independent stereoscopic images. To maintain the same frame rate as Mode 1 for 5 viewers, the frame rate would need to be five times faster. This would require some extreme response times in the range of 10 microseconds of both microLED display and FLCD.

To maintain the same luminance as in Mode 1, the peak luminance of the microLEDs must be five times as high as the image must be presented in one-fifth the time. This type of operation will also increase power consumption by around five times as well.

For smaller numbers of viewers, the power increase will be less. Still, the fact remains, that in situations with 5 viewers, the display needs to deliver 10 different images, and this will require much more power than delivering a single image. Realfiction believes that in situations where 5 viewers are gathered to see 3D, this is an acceptable trade off. Like the introduction of color masks in LCDs, four- or five doubling the power need, did not hold back color TV.

Depending on the frame rate and number of viewers desired, some trade-offs may be required. For example, some bit depth in the gray scale may be sacrificed but mitigated with spatial and temporal dithering.

While microLEDs can be designed for response times below 10 microseconds, the FLCD response time is limited to around 50 microseconds. As a result, a new scanning operation was developed for Mode 2 to solve this problem. In Mode 1, the light modulator and the microLED is scanned from right to left at the 240Hz rate. In Mode 2, only the light modulator is scanned from right to left. For each FCLD scanline, the microLED illuminates 10 different non-sequential LED columns. Which columns depend on eye positions. It does so one slit at a time, one scan per frame. The black matrix in the modulator closes gaps between slits and creates slit openings narrower than the slit pitch. In essence, the slits may be regarded, rather than barrier slits, as focusing aperture slits. In other words, when open, a slit focuses light similarly to a cylindrical lens in a way similar to how a pinhole camera works.

Crosstalk

All stereoscopic displays exhibit some level of crosstalk, i.e. one eye sees a faint overlay of the image intended for the other eye, sometimes also referred to as a “ghost image”. So-called “ghost busting” algorithms (yes, that is the term used in the cinema industry) can digitally pre-process images and mitigate this to some extent, but it is still important to keep the native crosstalk low, preferably at 1 or a few percent. A lot of factors contribute to crosstalk. For time-multiplexed LCD displays, pixel response time is a major contributor. The very short response times of LEDs and the FLCD in the Hybrid Scan Display mitigates this.

In displays using refractive optics like lenticular-based 3D displays, lens aberrations and mechanical lens precision can be a major factor. The Hybrid Scan Display eliminates this factor by eliminating refractive optics altogether. In the Hybrid Scan Display the low contrast of the FLCD light modulator could be a source of crosstalk. Adding a second layer of FLCD light modulator can mitigate this, as this will not only double, but increase contrast to the second power. Internal reflections between the LED chips and the FLCD glass substrate could be another source of crosstalk. This can be mitigated by laminating a ¼ wave retarder film to the backside of the polarizer, which is already part of the FLCD. This can “trap” reflections by circular polarization, a method also used in standard OLED displays to reduce ambient reflections.

Power consumption

In a normal 2D mode of operation, the Hybrid Scan Display is expected to consume significantly less power than a regular LCD display. In Mode 1 of operation (3D to multiple viewers), the power consumption is expected to be slightly lower than that of a regular LCD display. In Mode 2 of operation (individual 3D to multiple viewers), the Hybrid Scan Display is expected to consume more power than a regular LCD display, with the level depending on the number of viewers.

Summary

Realfiction has invented and patent applied a new method for creating individual 3D to multiple viewers on flatscreen displays. The 15” Proof of Concept device now in development will use a microLED display along with a newly-developed Ferro-electric LCD modulator. It is designed to support five viewers and deliver five totally independent stereoscopic images to these viewers – a capability no other display can deliver at this time. Such a display offers benefits for 2D viewing (power consumption) while opening up new use cases like dual-view displays, simultaneous 2D/3D displays and even multiple simultaneous 3D viewing options.

Below is a summary of the concerns with stereoscopic 3D displays and how the Hybrid Scan Display addresses them.

3D Viewing Concerns	Hybrid Scan Display
Required viewing sweet spot	Does have viewing sweet spot but image can be adjusted for each viewer in a sweet spot. Viewers outside the sweet spot see 2D (in Mode 1)
Improved horizontal parallax	Uses eye tracking without a resolution-limiting lenticular array to maintain image fidelity
Vergence and accommodation conflict	Unity render engine can create images with hig central fovea fidelity and slight blurring outside this area to reduce effects of VAC. Depth range should also be limited in the content creation process.
Vergence and motion-parallax conflict	Eye tracking and re-rendering of the image eliminates this effect
Miniaturization effect	A large display helps to mitigate this effect, but the Hybrid Scan Display can also render content for each viewer based on position in the sweet spot to address this effect as well.
Limitation of discreet perspective views	There is no lenticular array so the microLED/FLCD combination retains full resolution for each rendered view.
Moire-like interference	Several methods are employed in the Hybrid Scan Display to reduce this effect.
Immersiveness from large display sizes	The 15-inch PoC display in development now is designed to illustrate the scalability of the technology so large displays can be made in the future.
Frame rate	The Hybrid Scan Display has a frame rate of 60 Hz in Mode 2 with a referesh rate that varies with the number of users (1200 Hz for 5 users). In Mode 1, the frame rate can be either 60Hz or 120Hz.
Cross Talk	Using microLEDs and FLCDs as the display components eliminates the slow time response of LCDs, a major crosstalk contributor. Clever management of reflections with retarder films also helps reduce crosstalk.

Table 3: Summary of 3D Viewing Concerns and How the Hybrid Scan Display Addresses these Concerns