Development of the 2D-UV^{2}AⅡ LCD Mode for Field Sequential Color see-through

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Abstract

We have developed the 2D-UV^{2}AⅡ LCD mode with see-through performance combined with field sequential color (FSC) technology. The prototype FSC-LCDs have clear, blur-free see-through performance and the following overwhelmingly superior display performance: a liquid crystal mode efficiency (transmittance) of over 97%, color gamut of 93.5% of NTSC with FSC drive, contrast of over 16,000, and excellent viewing angle characteristics.

1 Introduction

In recent years, the development of the FSC method has been promoted as one of the drive methods of the liquid crystal display device for displaying a color image. In the general FSC method, the display period (1 frame period) of one screen is divided into three subframes, and the light sources of the backlight light, red (R), green (G), and blue (B), are used. Then, the LEDs are switched by time division (see Fig. 1a). In synchronization with this, an image signal of a color corresponding to the color of the light of each LED is sequentially given to the liquid crystal display panel to control the transmission state, and additive color mixing is performed on the retina of the observer's eye as shown in Fig. 1b.

(a) (b)

Fig. 1 (a) Display image of RGB LED switching, (b) Color display image

The FSC method enables color display without forming multiple sub-pixels in a single pixel, eliminating the need for color filters, simplifying the structure and enabling higher resolution. In addition, since light from the LEDs is used directly, there is no need to form a color filter in each pixel, which has a low light transmittance of 30% or less. The light utilization efficiency of each LED is improved.

In addition, with a see-through display, the background, i.e., the rear side of the display panel, is transparent, allowing information displayed on the display panel to be superimposed on the background as shown in Fig. 2. By applying this to the display technology of stereoscopic images using the DFD (Depth-Fused 3-D) optical illusion phenomenon [1], various expressions are possible depending on the idea.

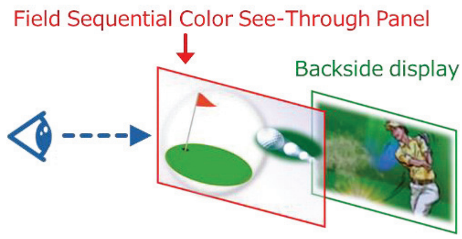


Fig. 2 Application image

Furthermore, see-through LCDs using PDLC, which cannot display black, have also been proposed [2][3]. However, in order to maximize the expressive power of the displayed image, we focused our development efforts on LCDs that can display black using polarizers. After studying the feasibility of FSC see-through performance in VA, FFS / IPS, and TN LCD display systems, we selected the VA mode, which enables mass production of large direct-view panels. We had chosen VA mode because it could be mass-produced with large direct-view panels. By using UV^{2}AⅡ technology, even 8K (7680 x 4320 pixels) high resolution large-screen panels have been manufactured [4], and we can leverage our production experience and infrastructure knowledge. First, we made a prototype with the size of a medium-sized panel and evaluated the optical characteristics. As a result, it became clear that the following issues must be overcome in order to achieve both transparency and high-speed response that can ensure a sufficient color gamut in FSC drive.

2 Experiments

2.1 Blurring of transparent images

For stereoscopic display like the DFD, the background must be clearly visible without blurring of the transparent image. In order to suppress the blurring of transparent images It was estimated that the following issues need to be solved.

1. splitting of light rays due to periodic changes in the azimuthal axis of liquid crystal orientation (due to the azimuthal angle of the refractive index)
2. spreading of light rays due to lensing effects caused by the in-plane distribution of the refractive index of the liquid crystal.

To solve these, it was necessary to make the orientation axis and refractive index uniform. However, a single domain of LC alignment was not suitable due to viewing angle issues, and prevention of degradation of viewing angle characteristics was the next necessary condition. The results of evaluating the blurring of transmitted images due to differences in orientation division in Table 1 showed that the blurring of transmitted images could be eliminated by making the orientation axes of the liquid crystal parallel. It is supposed that the refractive index distribution in the panel was made uniform and the refraction of the light passing through the panel was aligned in one direction.

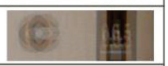
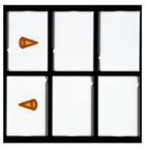
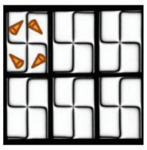
Distance	2D-UV²A Ⅱ		UV²A	
10cm	1.5 Landolt ring		0.5 Landolt ring	
50cm				
200cm				—
Polarizer axes & Liquid crystal orientation pixel photo				

Table 1 LC orientation and transmitted image

2.2 Improved transmittance (LC mode efficiency)

As a comparative verification between the current state of transmittance and color gamut and the TN mode, a single domain VA mode without orientation division (no dark lines) was prototyped using a conventional liquid crystal material, and the transmittance and color gamut were compared. As a result, it was confirmed that the transmittance (mode efficiency) exceeded the target TN without a dark line, and we decided to aim for a dark lineless.

		1D-VA			TN		
White brightness		292.05cd/m²			289.20cd/m²		
Black brightness		0.02734cd/m²			0.19512cd/m²		
Contrast ratio		10,682			1,482		
Saturation		Y	x	y	Y	x	y
	W	292.1	0.338	0.361	289.2	0.34	0.357
	R	80.1	0.586	0.293	44.3	0.661	0.331
	G	197.4	0.272	0.628	107.4	0.226	0.665
	B	50.1	0.164	0.149	9.6	0.15	0.045
	NTSC ratio	59.1%			93.1%		

Table 2 Transmittance and color gamut

1D-VA was superior to TN panel in monochromatic brightness. On the other hand, the color gamut was 59% of NTSC as shown in Table 2, which was much lower than 93% of TN mode. Therefore, we proceeded with development so that 90% of NTSC could be achieved in VA mode.

2.3 Color mixing

The cause of the deterioration of the color gamut was found to be color mixing due to poor liquid crystal response performance and "fall response" (see Fig. 3 and Table 3)

As a result of the simulation experiment in Fig. 4 and Table 4, the target value of fall response time was set to 2.55 msec as the response performance required to achieve 90% of NTSC ratio. As a result of the optical designing for LCD including the liquid crystal material and the alignment film material, it was expected that the target "falling response" of 2.55 msec would be achieved.

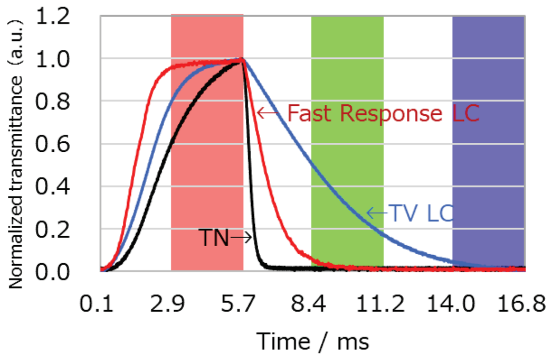


Fig. 3 Response waveform and color mixing.

	TV LC (VA)	TN
R brightness (ref)	100%	100%
B Mixing	33%	0%
G Mixing	3%	0%

Table 3 Color mixing rate when set to R

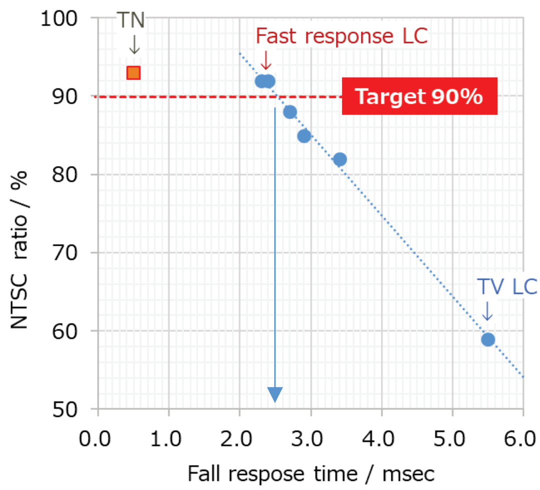


Fig. 4 Fall response time and NTSC ratio

	NTSC ratio	Fall response time
TV LC	59%	5.5msec
Target	90%	2.55msec
TN	93%	2.25msec

Table 4 Target value of response performance

2.4 Fast response LC material

However, although a thinner cell thickness is effective for the fast response, it leads to a decrease in production yield and cannot be produced efficiently. Further, the fast response performance and the reliability of the LC material are in a trade-off relationship, and moreover, it is necessary to design the optical condition while balancing the pre-tilt generation performance and the reliability of the photo alignment material. Therefore, by optimally designing a fast response liquid crystal material we were able to overcome these trade-off relationships and photo alignment materials.

The fall response has a linear relationship with the response parameters, which are shown in Fig. 4. As a result of evaluating various liquid crystal materials, we were able to achieve the target value of 2.55 msec or less for the fall response by optimizing the response parameters. The prospect of solving the color gamut problem was clear.

2.5 FSC drive and BL RGB switching timing

Furthermore, it was found that it does not reach 255 gray level with a single writing, corresponding to the 180Hz RGB three-color backlight. This is due to the problem of insufficient brightness due to changes in the capacitance of the liquid crystal material in the vertical electric field, and as shown in Fig 5, it was possible to take measures by writing twice at a writing speed equivalent to 480 Hz. Further, the lighting timing of the backlight was adjusted so that the color reproduction range at the center of the panel was maximized as shown in Fig. 6.

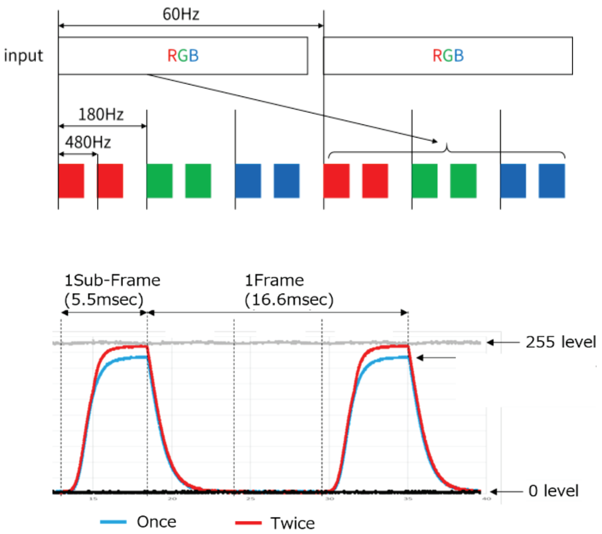


Fig. 5 Input signal timing and LCD response

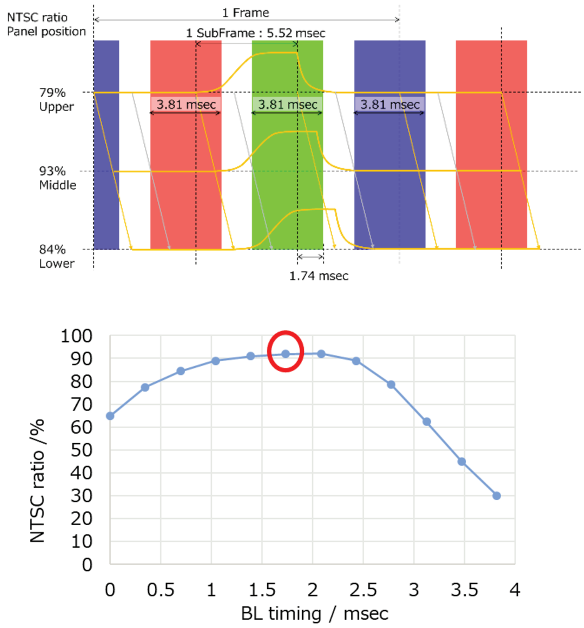


Fig. 6 Example of LED timing at green output

3 Results

To maximize transmittance, dark line-less orientation was achieved as shown in Fig. 7, and high transmittance (high mode efficiency) was achieved as targeted by 2D-UV^{2}AⅡ.

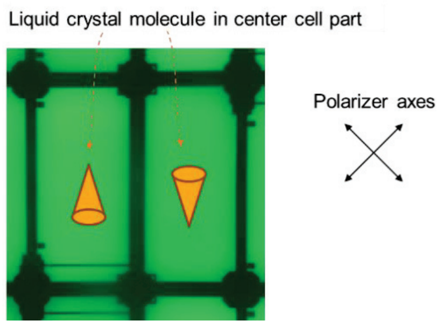


Fig. 7 Picture of liquid crystal orientation at a pixel

In FSC drive, the VA mode, which has a faster rise response, was found to be superior not only in color gamut but also in monochromatic luminance, which is affected by the lack of response of the LCD. The ratio of the total brightness of red, blue, and green to the luminance of white (ideally 100%) reached 94%, 1.7 times that of TN in Fig. 7.

Moreover, the liquid crystal alignment division pattern was determined with priority given to left-right viewing angle characteristics. As shown in Fig. 8, the 2D-UV^{2}AⅡ mode is symmetrical vertically and horizontally and has no gray level inversion. The above confirms that the characteristics are far superior to those of the TN mode.

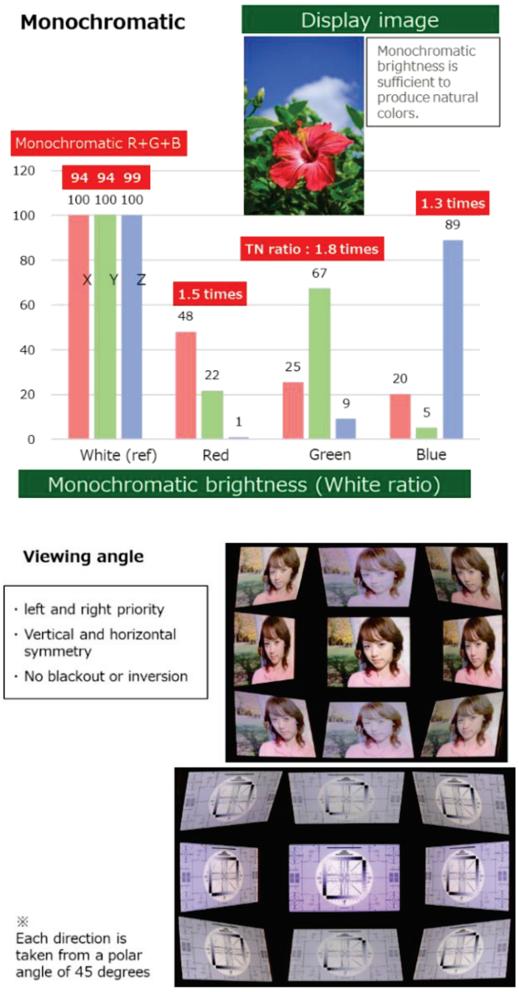


Fig. 8 Display characteristics

4 Conclusion

We are proposing new technology for FSC-driven see-through LCDs that can be produced in middle sizes and are developing for mass production. The newly developed "2D-UV²A Ⅱ " display performance was able to greatly exceed the performance of TN and it can be the best alternative to TN mode for FSC-driven see-through panel applications.

As summarized in the comparison in Table 5, the FSC-LCD panel which we have developed by applying 2D-UV²A Ⅱ shows a high liquid crystal mode efficiency (transmittance) of over 97%, a color gamut of 93.5% NTSC ratio when driven by FSC, a high contrast of 16,000: 1, and excellent viewing angle performance. The result is an attractive display that can be expected to improve expressiveness. Proposing new technologies for our FSC-driven see-through LCDs will create new needs for LCDs with the aim of further increasing product value in the future.

This newly developed the panel is the FSC type see-through LCD which can be manufactured with existing manufacturing equipment. It is characterized by transparency and high transmittance compared to the CF method, the adoption of VA mode reduces black transmittance and increases contrast, excellent viewing angle characteristics. In addition, FSC specific 480Hz drive supported by IGZO5-TFT technology is required, and the LCD has fast response time property for excellent display quality, and BL RGB switching timing are optimized. These developments have increased the degree of freedom in the optical design of LCD panels, dramatically improved display performance, and made it possible to adapt to middle size panels.

From previously proposed methods [5], our FSC-LCD see-through panel technology [6] has evolved and is suitable for future applications such as smart glasses, automobiles, digital signages, showcases and smart appliances. Moreover, we are confident that this display technology will expand new possibilities for expression and performance that are more freely, more enjoyable, more vivid and more powerful.

	2D-UV²A Ⅱ	TN ratio	TN
Mode efficiency (Transmittance)	Target : 96.6% 97.1 %	Better ×1.04	93.5 %
Color gamut NTSC ratio	Target : 90% 93.5 %	Equal ×1.00	93.1 %
Contrast	16,207	Greatly superior ×10.94	1,482
Monochromatic brightness R+G+B/W	94 %	Excellent ×1.68	56 %
Viewing angle characteristics	Vertical, horizontal symmetry No inversion	Greatly superior	Vertical asymmetry With inversion

Table 5 Panel performance comparison table

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