

52.2: Invited Paper: Color Sequential LCD Based on OCB with an LED Backlight

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Abstract

We have fabricated a 13.3" XGA (1024 by 768) TFT color sequential liquid crystal display using Optically Compensated Birefringency (OCB), illuminated by an LED backlight. We fabricated the color sequential display using mostly feasible process technology, and examined the performance and potential of a color field sequential scheme. The display was connected to a laptop computer and examined for flicker perception.

1. Introduction

1.1 Color sequential LCD

Color representation in a conventional color liquid crystal display (LCD) is done with a combination of liquid crystal cells, micro color filters on each pixel, and a white backlight. On the other hand, a color sequential LCD reproduces each color component in a time sequence using synchronously pulsed colored backlights and a liquid crystal cell without micro color filters.

The color sequential liquid crystal display is expected to have three times higher optical efficiency than a conventional LCD with color filters, because each color filter absorbs about two-thirds of the original light source.

The number of pixels for the color sequential display is one third of that for a conventional display. As a result, a color sequential LCD is expected to have a higher aperture ratio than a color filter type display with the same resolution, or to have a potential to make the LCD with three times higher resolution using the same technology [1]. A reflective color sequential display is also proposed with the expectation of producing a higher resolution display [2].

This technique can also improve the production yield by reducing the number of pixels.

1.2 Requirements for the driver timing

Instead of having one third of the number of pixels, each pixel of the color sequential LCD should be driven three times as fast as a conventional LCD assuming the same frame rate. Unfortunately, the sequential color field scheme requires even shorter response time for the LCD panel and the backlight than in a conventional LCD because the sequential pictures have larger variation among sub-frames for different colors even when the panel is displaying a still picture.

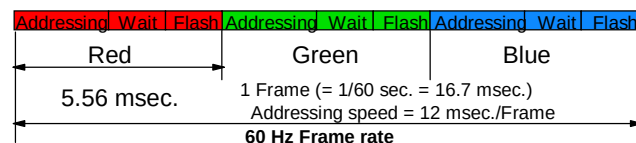


Figure 1

Assuming 60 Hz is an adequate frame rate, the sub-frame frequency is 180 Hz, and each sub-frame only has a total of 5.56 ms for addressing, to wait for the LC response, and for the backlight flash, as shown in Figure 1.

Recently many articles have been presented describing color sequential LCDs using rapid response LCs. To reduce the addressing and wait period, fast response polymer-stabilized (40 μ s) or surface-stabilized (100 μ s) ferroelectric liquid crystal displays were used with a drive scheme that combines the addressing and erasing (dark state) [3][4]. By using ferroelectric liquid crystal and Si wafer electronics, a UXGA (1920 by 1200) reflective micro display was demonstrated with a refresh rate of 2.16 KHz [5].

It was shown to be effective to divide the panel using a striped organic-LED backlight that is synchronized with the addressing circuitry of the OCB panel. [6]. Optimization of bend cells for the color sequential display was demonstrated with a response time of 0.5 ms and 1.9 ms for white to black and black to 90% white respectively, showing the potential for color sequential displays [7]. We have chosen OCB as a cell structure since it is possible to assemble using similar process technology as conventional TN.

1.3 Requirements for the backlight

A fluorescent lamp is normally difficult to use for pulsed operations because the mercury vapor pressure drops during the blanking duration, and the light output decreases as a result. The fluorescence decay times of the red and green phosphors used in a conventional fluorescent tube are not fast enough for color sequential displays [8].

We used an LED backlight for our color sequential LC display, because LEDs satisfy the fast response time requirement for the color field sequential operation. In addition, the emission spectra of LEDs are suitable for a display with very high color purity. [9]

We fabricated the color sequential display using conventional technology as much as possible, and examined the performance and potential of the color field sequential scheme. We also examined the human visual perception of flicker.

2. Experiments

2.1 LCD panel

We used an OCB liquid crystal panel incorporated with a TFT-LCD with a 13.3" XGA (1024 by 768) format. As the top substrate we used a conventional TFT active matrix with each pixel consisting of three RGB sub pixels. The bottom substrate used was the same as the original color filter substrate but no color filter layers were attached.

The thickness of the liquid crystal layer was 7 μ m and the tilt angle was about 5 degrees. In this work, we used a biaxial film which is basically a negative birefringence film having a small retardation in the plane of the film surface. The cell structure is shown in Figure 2. The pi-cell appears dark if biased at 8V and bright at 3V.

The optical response of the pi-cell with the color field sequential driver was examined as shown in Figure 3 by using a He-Ne laser as a light source.

An exceptionally fast response time is associated with this specific alignment control structure, where the molecular alignment turns by 180 degrees across the cell.

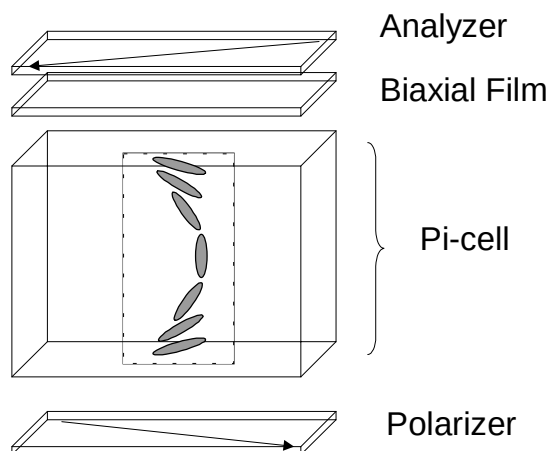


Figure 2

If a field is applied, molecules pointing 45 degrees with respect to the field experience the maximum torque so that the turn on time is significantly reduced (1 ms or less). When the bias is released, the tilted deformation generates a large reverse torque, because at the middle of the cell the alignment remains vertical, bisecting two sub cells with half a cell gap, and thus the turnoff time is also very short (4 ms). The turnoff time can be made even shorter by using a backflow effect [10].

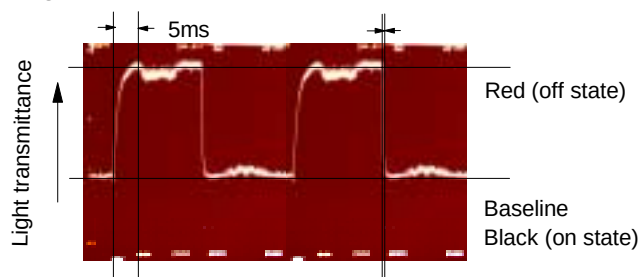


Figure 3

2.2 Backlight

Figure 4 shows the chromaticity diagrams of the LEDs used for the backlight and a cold cathode fluorescent (CCFL) tube as a reference. The color gamut of the LEDs is much wider than that of CCFL. The structure of the LED backlight is shown in Figure 5. The light source of the backlight is assembled as an array of 12 x (RGB) x 28 LEDs and light scattering films were placed between the array and LCD panel. An expected brightness of this panel was five times that of the CCFL backlight [9]. The power consumption of the LED backlight was approximately one half of the fluorescent tube for this panel size.

In addition to the full screen color sequential illumination, one half or one third of the screen could be illuminated synchronized with the LCD screen-driving signal.

The brightness of the backlight was more than 1600 cd/m² while operating at 22% duty cycle.

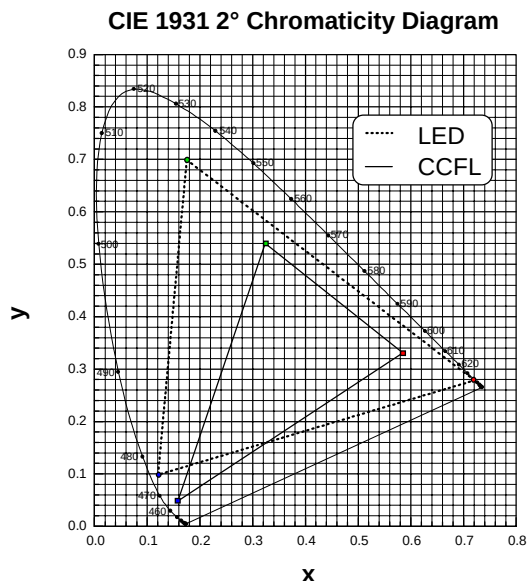


Figure 4

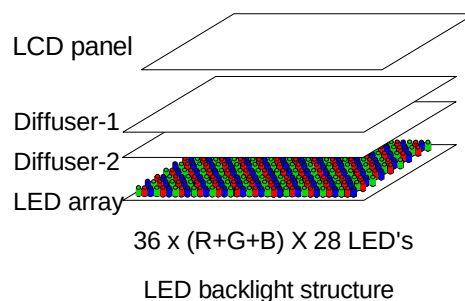


Figure 5

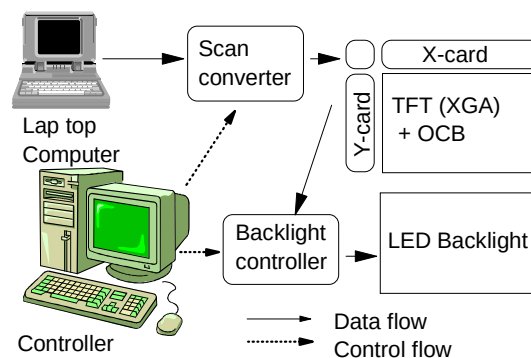


Figure 6

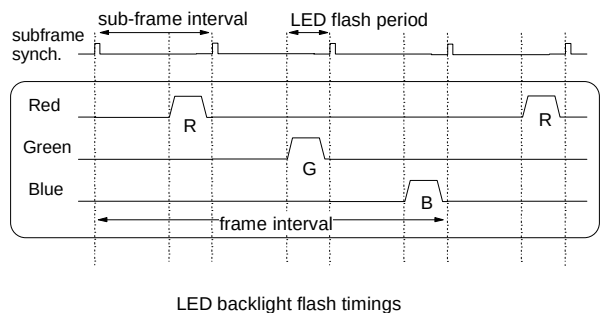


Figure 7

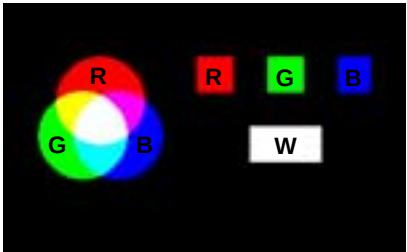
2.3 Driving scheme and electronics

Figure 6 shows the configuration of the LCD drive electronics. The TFT array is driven by a controller with a frame buffer memory to convert the input pixel drive signal flow to color sequential order with an independently adjustable clock frequency. The controller also generates backlight timing signals as is shown in Figure 7. In addition to the full screen scan, one half or one third of the screen could be scanned to speed up the frame frequency.



Figure 8

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color chart

Figure 9

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3. Results

The display was connected to a laptop computer running Windows 95. Figure 8 shows a picture of playing cards on a part of the fabricated color-sequential display. Table 1 summarizes the minimum frame frequencies at which people did not perceive flicker. The brightness of the screen was 85 cd/m² and the duty cycle of the backlight was 10% for this test. People were less sensitive to flicker for the color sequential than RGB simultaneous switching, in other words, switching of white light. Another factor we have to consider for the color sequential display was that people have higher sensitivity to flicker at the edge of their visual field than in the center. The results indicated that a frame frequency of at least 60 to 70 Hz is necessary to avoid flicker with 85 cd/m² and 10% backlight duty cycle.

We also examined the flicker sensitivity for each individual color by observing the left half of the color chart in Figure 9. Table 2 shows frequencies that produced intolerable flashing for each color. Green is the most sensitive to flicker and then blue and red. By gradually reducing the sub-frame frequency from higher frequencies, the flicker in the green area of the color chart becomes obvious first, at around 150 Hz, when people observed the chart at the center of their field of vision. The duty cycle of the LED flashing period was 22% for each color for this experiment.

Table 1

Drive scheme	Frame frequency direct view [Hz]	Frame frequency side view [Hz]
R G B sequential	58 Green	67 Green
R,G,B simultaneously	67 White	73 White

Table 2

	R	G	B
Frequency (Hz)	30	50	35

4. Discussion

We fabricated a color sequential 13.3" XGA TFT LCD using an LED backlight and OCB cell structure. The display was connected to a laptop computer and examined for flicker perception.

We tested the flicker sensitivity and the results indicated that a frame frequency of at least 60 to 70 Hz is necessary to avoid flicker for a display with a luminosity of 85cd/m² and operating at a 10% duty cycle. By showing a color chart and reducing the sub-frame frequency from a higher frequency, the flicker sensitivity was also shown to have a color dependency, with green areas being most sensitive to flicker (at around 150 Hz) when people observed the chart at the center of the field of vision. It was 30 Hz and 35 Hz for red and blue respectively. This color dependency

for flicker sensitivity suggests to us the potential of a better driving scheme for color sequential displays with less flickering.

The color field sequential display is more suitable for smaller size displays using amorphous TFT and OCB, because the addressing circuitry power consumption becomes significant when the drive frequency becomes higher for larger panels. In addition, color separation and flicker sensitivity was lower at the center of the eyesight.

5. References

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