12.4: *Distinguished Student Paper:* Passive-Matrix-Driven Field-Sequential-Color LCD

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Abstract

A new fast liquid crystal display mode is demonstrated. This liquid crystal mode is based on a stressed splay twist deformation and can be driven in passive matrix or active matrix manners. This new display mode can be used to achieve full color display effect, in conjunction with a pulsed red-green-blue backlight unit.

1. Introduction

Passive matrix color LCDs, such as CSTN LCD or CTN LCD, are common. They have a few benefits, such as low cost, simple structure and driving mechanism. However, there are several drawbacks: Firstly, owning to the time averaging multiplexing driving method, such as Alt and Pleshko Method or MLA, video rate display is not possible for passive matrix display. Secondly, since 80% of BLU brightness is absorbed by the red-green-blue color filters, the overall power efficiency, typically 10% is very low. Finally, due to color leakage of color filter, the color saturation for STN is usually poor.

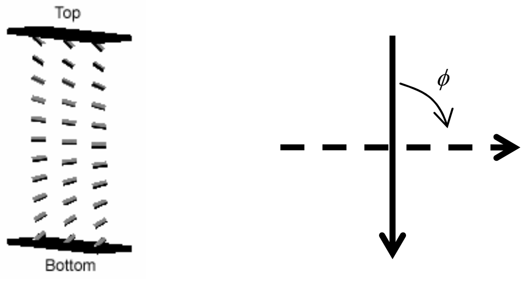
In order to solve the mentioned problems, Field Sequential Color (FSC) display is introduced. Actually there are several LC mode which can be applied in FSC displays. The most promising candidate is the bend cell or π-cell which was first proposed by P. J. Bos [1]. However, such bend mode is not stable under zero voltage bias. It is because the elastic energy of splay mode is always less than the bend mode under the same boundary conditions. With the high pretilt angles [2,3], typically (45^{o} to 65^{o}) which depends on the splay and bend elastic constants, the bend mode can be stabilized at zero voltage bias. Such kind of stabilized bend mode is named No-Bias Bend mode [4]. However, neither π-cell nor NBB is applicable to passive matrix display device. It is because, in passive-matrix liquid-crystal displays, multiplexing is achieved by using the intrinsic non-linear characteristic of the liquid crystal mode. Owning to zero threshold voltage, the cross talk is not able to be minimized. Therefore, only direct drive (active-matrix-driven) is possible for them.

Another candidate for fast switching LCD is the vertically aligned nematic LCDs. Their response time can be reduced by decreasing the effective cell gap, such as 1.5μm, and by using low rotational viscosity liquid crystal. Fast switching time of 2ms has been claimed. Vertical alignment can provide excellent contrast (>1000:1). Extremely high contrast is the crucial factor of performance of field sequential LCD. High contrast ratio will induce good color saturation and purity for color mixing. Or else, the color leakage will affect the color reproduction. But such small cell gaps are not a favorable for manufacturing. Furthermore, it is well know that the optical anisotropy of the negative liquid crystal is low, therefore, it is difficult to obtain enough birefringence for high transmission efficiency.

In this paper, a stressed splay twist (SST) LCD structure is proposed. By using a modified Alt and Pleshko passive matrix driving method, a 16x16 passive matrix SST prototype is demonstrated. In conjunction with a pulsed red-green-blue BLU, full color image is produced.

2. Experiments and Results

Fast optical switch time is the most important requirement for field sequential color LCD. However, for passive-matrix-driven FSC LCD, such property is not sufficient. The liquid crystal mode should also be able to have sufficiently high cross-talk rejection property. Secondly, optical respond of the electrical pulse should be non-linear, so that the scanning time can be compensated.



1a 1b

Figure 1. (a) SST Mode 3D configuration, (b) the rubbing direction and the twist direction, dash line is bottom, solid arrow is top alignment layer. ϕ is the twist angle from bottom to top.

Figure 1a shows the 3D SST mode LC configuration. The main difference between TN mode and SST mode Figure 1b is the alignment direction. SST performed a reversed twist angle at $-\pi/2$, while TN has a natural twist angle at $\pi/2$. The optical setup of the SST mode display is shown as Figure 2. The polarizer and analyzer are placed as 0^{o} with the input director of the LC cell. 3μm spacer is applied to the display. The liquid crystal is MDA-05-3933 with $\Delta n=0.17$. Since the pretilt angle α is 2^{o}. The optical performance of SST is similar to TN mode, it exhibits normally dark state [5].

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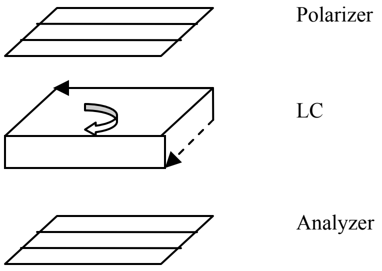

Figure 2. Optical setup of the SST mode LCDs. The direction of twist is shown as block arrow; Polarizer is 0° with input LC director; dotted arrow is bottom rubbing direction and solid arrow is top rubbing direction; Analyzer is 90° with output LC director

In order to obtain FSC display, the traditional time averaging multiplexing driving method, such as 3:1, Alt and Pleshko [6,7] or active addressing method [8,9] is not applicable. Instead of that, single pulse pixel addressing should be considered. The idea can be illuminated using Figure 3.

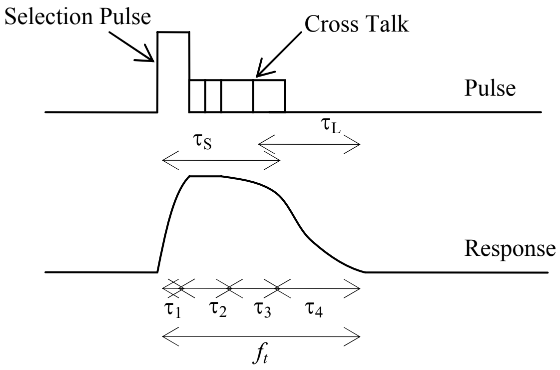

Figure 3. Pulse response of the SST mode.

$$\tau_{total} = \tau_1 + \tau_2 + \tau_3 + \tau_4 \le f_t \tag{1}$$

It is found that the optical response behavior can be characterized into 4 period of time. τ_1 is LC addressing time using the single selection pulse; τ_2 is saturation time of the LC corresponding to sufficiently high selection pulse. Sometimes, it may not be found, it is because the V_{ON} may not be high enough owning to high multiplexing ratio. τ_3 is the relaxation time of LC under cross talk. In other words, it is the grey to grey switching response. τ_4 is the relaxation time at zero bias voltage. According to Gibb's free energy, if there is not external work, such as electric field, applied. The LC system will relax at the shortest time. By optimizing these 4 parameters, FSC can be obtained. The total response time (1) must be completed within the frame time f_t, such as 5.5ms.

From Figure 3, it can be found that the total scan time is τ_S which is composed with τ_1, τ_2 and τ_3. Instead of time average addressing method, a single pulse drive is applied. Therefore τ_1 is actually required larger or equal to the rising time of the liquid crystal under "ON" Voltage V_{ON}, such as 1.58V. In order to improve the contrast of the PM FSC display, the cross talk must be minimized. Therefore, V_{OFF} is set beyond the threshold voltage of LC, such as 1.43V. Such restriction causes the number of the scanning line, N and transmission is not able to optimize according to Alt and Pleshko method.

Furthermore, owning to single pulse addressing, the number of scan line N, is limited by (2) the ratio of τ_S to τ_1 rather than the steepness *P* of the TVC curve.

$$N = \min\left(\frac{\tau_S}{\tau_1}, \left(\frac{(1+P)^2+1}{(1+P)^2-1}\right)^2\right) \tag{2}$$

where $$P = \frac{\Delta}{V_{th}}$$

The dependence of the rise time τ_1 has been studied for decades. There are several parameters which govern the dynamic behaviors of liquid crystal under electric field, such as STB constant, viscosity, cell gap, and initial LC configuration. Detailed description can be found in the literature [10,11]. The basic idea [12,13] and lengthy equations [14,15] will not be repeated here. Figure 4 shows the TVC of the displays. The driving method is pulse drive with duration τ_1=200μm and frame time f_t=5.5ms. The BLU is lighted up during τ_L. The transmission level is obtained by photodiode and integration meter.

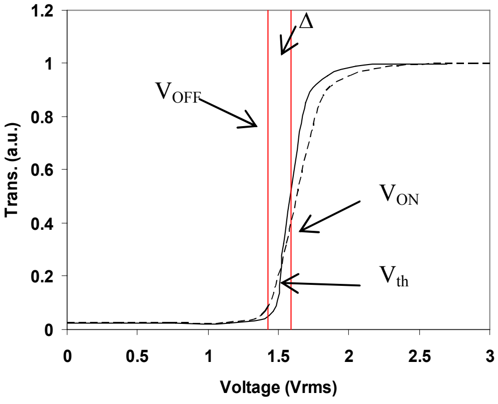

Figure 4. The TVC of the SST mode display. Solid line is SST Mode; Dot line is Normal TN Mode

It can be found that SST mode has higher steepness of TVC than TN mode since SST mode have higher stress energy then TN. Steeper TVC improves the multiplexing selection ratio and the display contrast as well.

The grayscale of the display is also adjustable. It can be obtained by adjusting the selection and non-selection ratio of the pixels during scanning time τ_1. A set of experimental data is reported in Figure 5. The scan pulse duration is 200μs. If there is duty of 100% of selection pulse, we can obtain contrast at 27. If there is only 10% of selection pulse combined with 90% of non-selection pulse, the contrast ratio is only 1. Theoretically, there is an infinite number of gray levels.

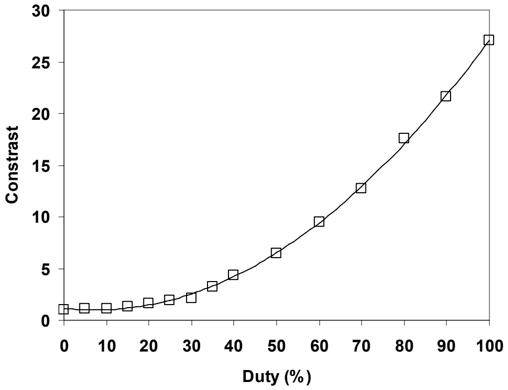

Figure 5. The constrast (grayscale) of the SST mode display using PWM.

Figure 6 shows an actual driving waveform and the optical response of the SST mode passive matrix display. The figure shows that the optical response of the SST mode under our suggested driving scheme fully fulfills the requirement of the FSC display. The pixel fully relaxes within the frame time of 5.5ms. The resultant pixel appearance is shown at right top corner of Figure 6 as well. In order to verify the designed driving scheme and SST mode, a 16x16 passive matrix display is also fabricated successfully. Figure 7 shows a sample picture.

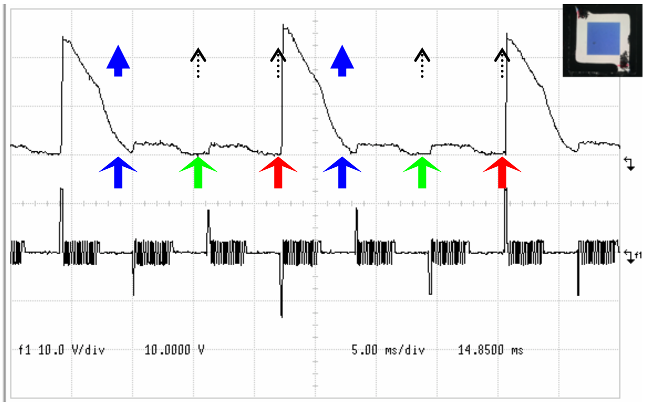

Figure 6. The oscilloscope image shows the optical response of SST mode (top) and the driving waveform (bottom).

The color gamut of the passive matrix SST is summarized at Figure 8. PM-SST has 80% of NTSC. Such performance is comparable with active matrix CF LCD display.

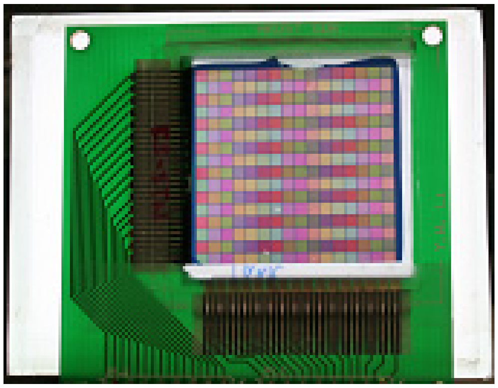

Figure 7. The oscilloscope image shows the optical response of SST mode and the corresponding driving waveform.

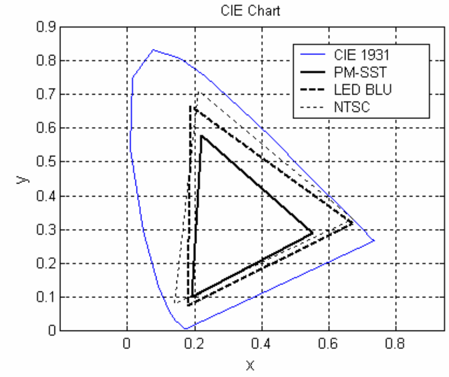

Figure 8. CIE chart of PM-SST with drive duty at 1/32

3. Conclusion

In this paper, a passive matrix driven field sequential color display is demonstrated. There are two main ideas. Firstly a stressed splay twisted mode is introduced. It has higher selection ratio and acceptable fast response time τ_4. The shortest τ_4 is not the best parameters. It is because, the brightness will be reduced. Suitable τ_4, such as equal to τ_S gives the best optical performance. Secondly, a modified Alt and Pleshko driving method is proposed. The aim of this PM method is not to give the maximum number of multiplexing. Instead, the purpose of this method is to provide a solution such that PM display is capable of showing high quality full color video rate display with 80% NTSC.

4. Acknowledgements

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