5.2: Field-Sequential-Color LCDs Based on Transient Modes

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Abstract

A new configuration called stressed splay twist (SST) mode is proposed. Such device has much stronger transient effect than conventional TN mode. By using this dynamic approach, the true steady state-to-steady state response time of the liquid crystal can be ignored. The transient response time is used, in conjunction with the pulsed light source. A QVGA FSC displays prototype using SST mode is demonstrated.

1. Introduction

Many applications require optically fast switching liquid crystal displays. One significant application is the elimination of motion blur in LCD television. The other is the use of field sequential color (FSC) to achieve full color display without the use of color filters. There are several fast switching LCD configurations, and one is the bend cell or pi-cell. It fulfills the most essential requirement of short switching time and good viewing angle [1]. However, this bend mode is not stable under zero voltage bias, because the elastic energy of splay is always less than the bend configuration M. Xu et al. [2] and F. S. Yeung et al [3]-[4] suggested some kinds of stabilized bend mode named “No-Bias Bend” mode using high pretilt angles. However, further research effect is required for uniform high pretilt angles over large area. Another candidate for fast switching LCD is the vertically aligned nematic LCD. Their response time can be reduced by decreasing the cell gap, such as to <2μm, 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. For all LCD modes, the response time can be decreased by reducing the effective cell gap.

In all previous studies of fast LCD, it is required that the LCD can go from one state to another within a short time. Suppose the LC alignment is in a certain steady state configuration at voltage V1 and another steady state configuration at voltage V2, it is then required that the LC molecules change their configuration from one to another rapidly when the voltage is changed from V1 to V2. However, this is a stringent requirement that is not necessary if the backlight is a pulsed light source such as a light emitting diode (LED). Here, we note that in most LCD applications nowadays, the frame rates are very fast. For example, in a 120 frame per second display, the frame time T_f is only 8ms. For the case of field sequential color displays, the frame times are even shorter. Thus it is an overkill to require the LC molecules to change their alignment within such a short time and stay in that configuration. One can simply use the transient response in such applications, especially working in conjunction with a pulsed backlight unit.

In our approach, the dynamic behavior of LCD is made used of. Instead of requiring fast switching, which can be difficult, our approaches make use of the fast transient response of the LCD. The transient characteristic of different mode of liquid crystal display is carefully studied. It is found that a so-called stressed splay twisted configuration can produce fast transients that can be used for fast dynamic switching.

2. Stressed Splay Twist Mode and Its Transient Effect

One particular transient effect is the optical bounce [5]. The optical bounce is usually a nuisance that has to be eliminated in LCD. Here it is emphasized and enhanced. Note that optical bounce is only one of the many possible transient effects. All of these effects are useful in our approach for producing a fast LCD. Effectively, in the present approach, the transient effect of SST mode is used to produce fast LC optical response. Since the sub-frame time of the field sequential display is typically very short, the transient response is as good as the steady state response. The grayscale is obtained by averaging transmittance of the sub-frame. By using this dynamic approach, the true steady state-to-steady state response time of the liquid crystal can be ignored. The transient response time is used, in conjunction with the pulsed light source. It is found that the transient can provide good transmittance and sufficient brightness for the display. The brightness of the transient can be as high as 90%. And the transient can be completed with in 1.8ms. In particular, the cell gap can be as large as 5μm. Such configuration can be applied to drive the field sequential display using passive matrix which has been reported last year [6].

Figure 1a shows the 3D SST mode LC configuration. The top and bottom are ITO glass substrates. The main difference

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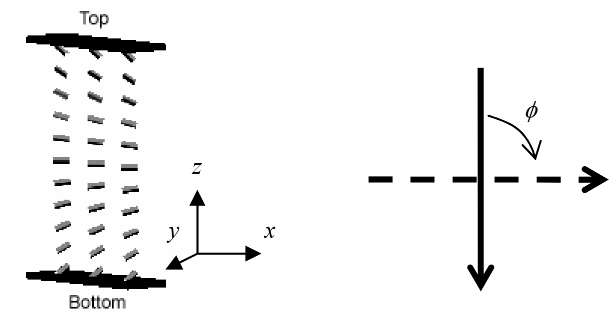
between TN mode and SST mode Figure 1b is the alignment direction. SST performed a reversed twist angle at ϕ=-π/2, while TN has a natural twist angle at ϕ=π/2. Since their configuration is very similar to each other, the optical appearance at static state is actually the same.



1a 1b

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

The dynamics of the SST mode can be described by Ericksen-Leslie Nematohydrodynamics Theory [7-10] and reads

$$\sigma_{ji,j} = \frac{\partial}{\partial z}\begin{pmatrix} -p\delta_{ij} - n_{k,i}\partial_{n_{k,j}}F + \alpha_1 n_k n_p A_{kp} n_i n_j + \alpha_2 n_j N_i \\ +\alpha_3 n_i N_j + \alpha_4 A_{ij} + \alpha_5 n_j n_k A_{ki} + \alpha_6 n_i n_k A_{kj} \end{pmatrix} \quad (1)$$

Where p is the hydrostatic pressure, F is the elastic free energy density, α_i are viscosity coefficients, n_i is LC directors, v_i are the velocity of n_i

$$A_{ij} = 1/2\left(v_{i,j} + v_{j,i}\right), \qquad (2)$$
$$N_i = n_i + 1/2\left(v_{i,j} - v_{j,i}\right)n_j$$

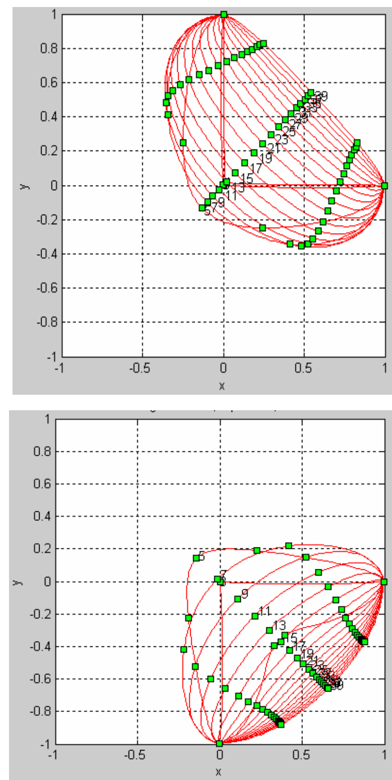
$$\xi_1 = -\gamma_1 \frac{n_x n_y}{n_z}\dot{n}_x - \left(\gamma_1 \frac{n_y^{\,2}}{n_z} + \gamma_1 n_z\right)\dot{n}_y + \alpha_3 n_x n_y \frac{\partial v_x}{\partial z} + \left(\alpha_3 n_y^{\,2} - \alpha_2 n_z^{\,2}\right)\frac{\partial v_y}{\partial z} \quad (3)$$
$$\xi_2 = -\left(\gamma_1 \frac{n_x^{\,2}}{n_z} + \gamma_1 n_z\right)\dot{n}_x - \gamma_1 \frac{n_x n_y}{n_z}\dot{n}_y + \left(\alpha_3 n_x^{\,2} - \alpha_2 n_z^{\,2}\right)\frac{\partial v_x}{\partial z} + \alpha_3 n_y n_x \frac{\partial v_y}{\partial z}$$

Where

$$\xi_1 = n_y\left(\frac{\partial F}{\partial n_z} + \frac{\partial}{\partial z}\frac{\partial F}{\partial n_{z,z}}\right) - n_z\left(\frac{\partial F}{\partial n_y} + \frac{\partial}{\partial z}\frac{\partial F}{\partial n_{y,z}}\right) + \frac{\Delta\varepsilon}{4\pi}E^2 n_z n_y \quad (4)$$
$$\xi_2 = n_x\left(\frac{\partial F}{\partial n_z} + \frac{\partial}{\partial z}\frac{\partial F}{\partial n_{z,z}}\right) - n_z\left(\frac{\partial F}{\partial n_x} + \frac{\partial}{\partial z}\frac{\partial F}{\partial n_{x,z}}\right) + \frac{\Delta\varepsilon}{4\pi}E^2 n_z n_x$$

γ_1 is the rotational viscosity. $\Delta\varepsilon$ is dielectric anisotropy of liquid crystal and E is Electric field.

By solving equations (1), (3), we can obtain the dynamics of the liquid crystal director in side the bulk system. The backflow effect of SST and a TN-90 configuration are presented as the liquid crystal director projection plot on XY plane. The time sequence of the director configuration is labeled in ascending order.



2a 2b

Figure 2. (a) SST Mode directors distribution, (b) TN Mode directors distribution ; square with label represented the position of liquid crystal director at middle of cell *d*/2

The simulation parameter are shown as Table I

Table 1. Simulation Parameters

Cell gap	5µm
Pretilt angle	2°
d/P	0.2
K_{11}	14.9pN
K_{22}	7.2pN
K_{33}	19.4pN
α_1	6.5×10^{-3}
α_2	-79.5×10^{-3}
α_3	-1.2×10^{-3}
α_4	83.2×10^{-3}
α_5	46.3×10^{-3}
α_6	-34.4×10^{-3}

From Figure 2, it can be found that the backflow effect of SST mode is much more rigorous than that of TN under same chiral dopant, cell gap and twist angle. Stronger backflow effect results in much stronger optical bounce. By applying jones matrix, the optical response of the SST and TN mode can be simulated as figure 3. The liquid crystal optical anisotropy is $\Delta n = 0.2$, The polarizer and analyzer is placed 0^o with input and output LC director.

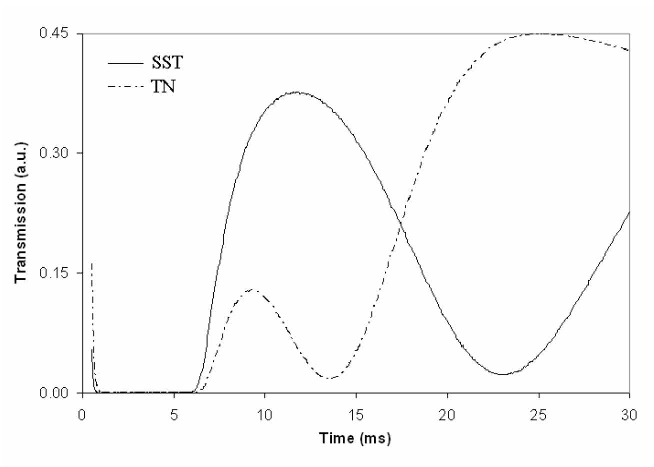


Figure 3. Optical bounce effect of SST Mode (solid line) and Conventional TN Mode (dash line).

3. Experimental Results

A SST mode testing sample with 5µm cell gap is fabricated. The top and bottom ITO glass substrates are coated with conventional polyimide JALS-9203 from JSR. And liquid crystal MLC-6080 from Merck is filled inside the LC bulk. D/P ratio is 0.2. We compare SST optical bounce response with TN mode. The polarizer and analyzer is placed 0^o with input and output LC director.

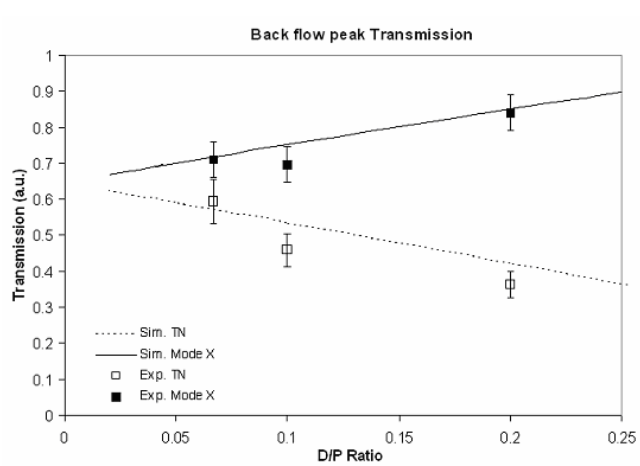


Figure 4. Effects of D/P ratio to SST and TN modes

Figure 4 shows the optical bounce of SST mode is always higher than TN mode. The transmission peak is found about 90% for SST while TN only gets about 30%.

Therefore we come up with a new driving method It is consisted of 2 driving sub-frame within a frame. Firstly we apply a Reset "R" frame, strong optical bounce occurred, the peak of such bouncing can be controlled by Data "D" frame. The experimental results are shown in Figure 5.

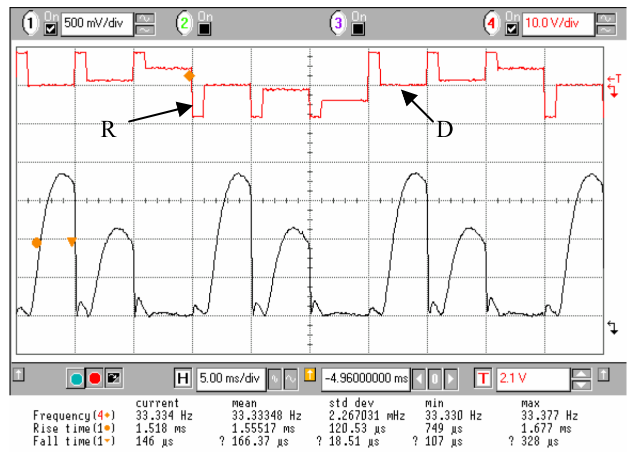


Figure 5. The upper red line is the driving waveform; the lower black line is the optical response.

The GTG response time are also measured. Figure 6 shows that all the grey level can be obtained within 1.8ms. The driving voltage is also very low <4V.

Before apply SST mode to FSC displays, we also test the contrast of our device. The contrast ratio can be as high as 300 at 5V data frame driving. Such result is obtained without any compensation film applied, Figure 7.

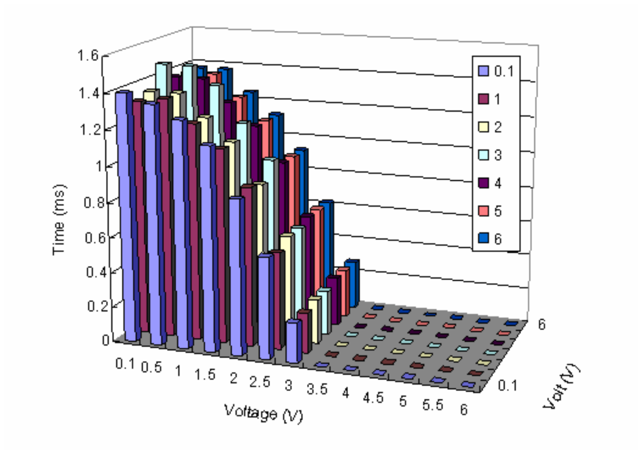


Figure 6. GTG response time of 5µm SST mode

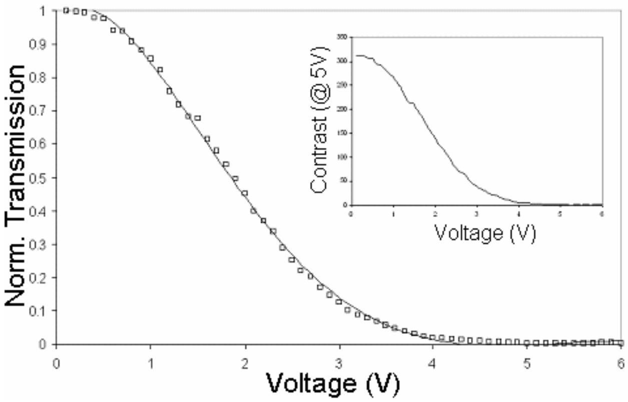


Figure 7. Transmission and contrast versus voltage curve

A prototype of QVGA Field Sequential Color Displays using SST mode is also fabricated successfully. The cell gap is 5μm and Commerical Liquid Crystal MLC-6080 from Merck is applied

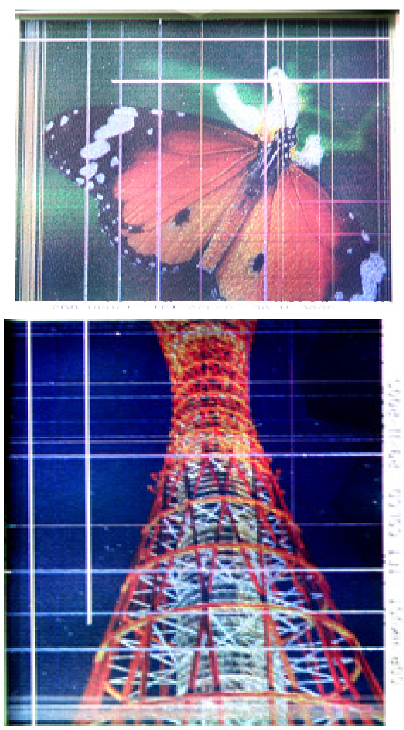


Figure 8. A prototype of QVGA FSC SST Mode Displays

4. Conclusion

It is proven that transient effect can be applied on fast optical response display. A QVGA prototype base on such idea is demonstrated. Since the fabrication process is as simple as TN mode displays, it should be a strong alternative with other fast response liquid crystal device, such as OCB or NBB mode. More than that SST mode can be applied on Passive Matrix Driven FSC Display as well [6].

5. Acknowledgements

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6. References

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