22.1: Bistable Bend-Splay LCD

X. J. Yu and H. S. Kwok
Center for Display Research and Department of Electrical and Electronic Engineering
Hong Kong University of Science and Technology
Clear Water Bay, Kowloon, Hong Kong

Abstract
A bistable liquid crystal display based on the bend and splay configurations has been demonstrated. This display can remain indefinitely either in the splay deformation or in the bend deformation mode. It has the advantages of wide viewing angles, good contrast ratios, faster selection and low operating voltages.

1. Introduction
Liquid crystal displays that are truly bistable under zero voltage bias are desirable for many practical applications. Several bistable display technologies have been actively pursued, including cholesteric, nematic, and ferroelectric liquid crystal displays. Each technology has its own merits and unique applications.

The bistable cholesteric display device is switched between aligned helical state (planar texture) and unaligned helical state (focal-conic texture). Another class of bistable liquid crystal display is based on ferroelectric liquid crystals. The bistable states are both homogeneous alignment states with different orientations. Yet another class of bistable liquid crystal display is based on the twisted nematic effect in a liquid crystal display. It relies on the interplay between the elasticity of the liquid crystal and the surface anchoring conditions. Such bistable twisted nematic displays switch between ϕ and $\phi+2\pi$ [1,2] or $\phi+\pi$ [3] twist states where ϕ can be several fixed values, both negative and positive.

In this paper, we demonstrate a bistable liquid crystal display based on the bend and splay configurations (BBS). For certain pretilt angles on the surface of the liquid crystal cell, the bend and the splay configurations will have same elastic energy, which leads to a bistable display. This display can be switched by the application of horizontal and vertical electric fields. This type of bistable liquid crystal display may have more advantages than the other types of bistable displays described above. It may have better viewing angles, better contrast ratios, faster selection and lower operating voltages than the other bistable displays based on the twisted nematic effect.

2. Theory and Experiments
LCD will show bend and splay bistability when bend- and splay-deformations have the same elastic energy. As is known well, the elastic energy per unit wall area of no twist LC is given by the equation,

$$E=\frac{1}{2}\int_{\theta(0)}^{\theta(d)}(K_{11}\cos^2\theta+K_{33}\sin^2\theta)\dot{\theta}^2\,dz \qquad (1)$$

where K_{11} and K_{33} are the splay and bend elastic constants, respectively. θ is the tilt angle.

Under the condition that $\theta(z)$ is nearly linear distribution (It is true for most LC materials.), if the splay and bend cells have the same elastic energy, then the following equation can be derived:

$$(K_{33}-K_{11})\sin 2\alpha+(\pi-4\alpha)(K_{33}+K_{11})=0 \qquad (2)$$

where α is the pretilt angle.

By solving this equation, the condition for the pretilt angle such that the splay and bend deformation energies are the same can be obtained. For example, for MBBA, $K_{33}/K_{11}=1.3$. Hence α is about 47^o. In general it can be shown that α is always between 45^o and 58^o for all values of K_{33}/K_{11}. Under the condition that equation (2) is satisfied, bistability can be obtained. Actually bistability can be achieved even if the deformation energies for the bend and splay cells are slightly different. There is actually another possible configuration for this boundary condition. It is a π-twist cell. It can be proved that this π-twist state has a much higher total elastic energy than both bend and splay state and can be ignored [4].

The large pretilt angle that is required for bend-splay bistability can be obtained by one of several ways. It has been reported that both photoalignment [5,6] and normal polyimide rubbing [7,8] can be used to produce pretilt angles from 0 to 90^o. Another method to make strong anchoring at large pretilt angles is by SiO_x evaporation. In the present experimental demonstration of the bistable bend-splay display, both SiO_x evaporation and polyimide rubbing methods were used. For the demonstration using SiO_x as the alignment layers, the glass plates with ITO electrodes are treated by oblique SiO_x evaporation with evaporation angle of 85^o, and thickness of 60~150nm these being known to give the oblique anchoring of the liquid crystal molecules [9-11]. Under this condition the pretilt angle is around 45^o as measured by the traditional crystal rotation method. The experimental data in this section are based on such SiO_x alignment layers. We have also been successful in using photoalignment to obtain 45^o pretilt and making the BBS cell.

The basic cell structure of BBS cell is shown in Fig. 1. It is essentially a three-terminal device consisting of the usual top and interdigital bottom electrodes, and the bottom ones are made by etching usual ITO electrodes. The 4μm wide interdigital electrodes were spaced 6 μm apart, resulting in a pitch of 10μm in our experiments. Other dimensions are possible. A cell gap of 3.2μm and LC ZLI5700/7500-000 are used in our experimental demonstrations to get the optimal optical properties.

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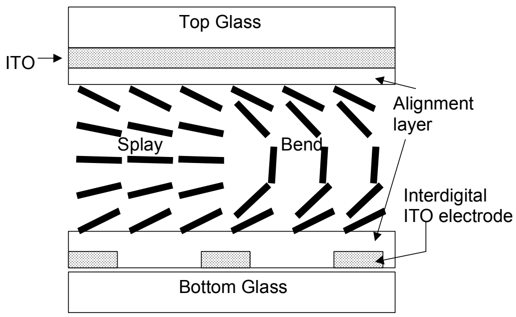

Figure 1. The Basic Cell Structure

3. Results and Discussions

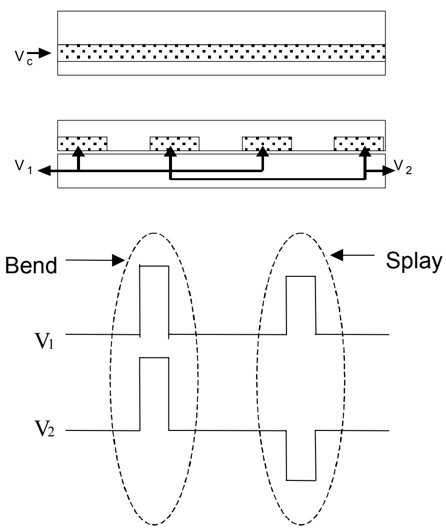

Figure 2. Driving Scheme

The driving method is shown in Fig. 2. The top electrode is biased at a common voltage V_c. Electrical pulses are applied to the interdigital electrodes. The opposing digits are given voltages of V_1 and V_2 respectively. The important point here is that we can control the voltages on the interdigital electrodes such that either a vertical or horizontal electric field is imposed upon the liquid crystal molecules.

In the simplest case, V_c is kept constant at ground. Two electrical pulse trains V_1 and V_2 are applied to the bottom electrodes. When V_1 and V_2 are the same, either positive or negative, the electric field inside the liquid crystal cell is in the vertical direction. The liquid crystal alignment will favor the bend state. When V_1 is opposite in sign to V_2, the electric field inside the liquid crystal cell is horizontal. Thus the splay state is obtained. For a passive matrix driving, V_c will also participate in the driving scheme.

In our first experiments, the rectangular pulses of voltage U ($=|V_1|=|V_2|$) and duration τ are applied. The bend-splay switching results are shown in Fig. 3. Here, U=27V and τ=1ms. It only shows the splay-> bend pulse train. Fig. 4 shows the experimental transmission spectra of the splay and the bend states. It can be seen that the wavelength dispersion for this display is quite small. The dark state is quite dark, giving an experimentally measured *CR* of 45. Fig. 5 shows one of our bistable bens-splay display pictures at different viewing angles. It can be seen that the viewing angle of our bistable display is quit good. Also it is possible to improve the contrast further and the light transmission efficiency by adding a half-wave plate between the polarizers. From theoretical simulations, *CR* of over 200 can be achieved with white light illumination.

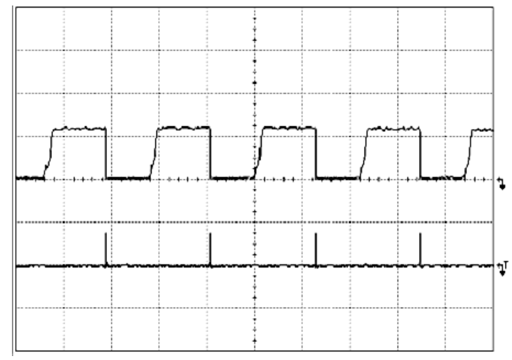

Figure 3. Bend-Splay Switching

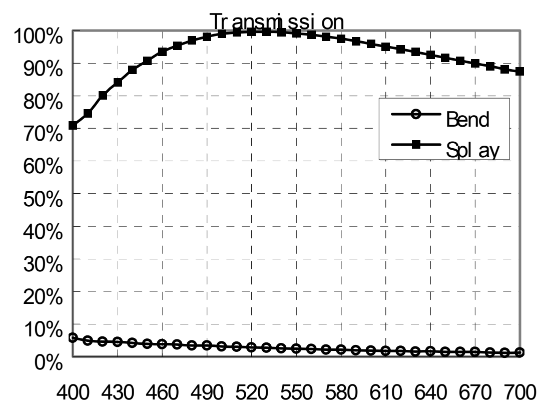

Figure 4. Transmission Spectra of the Splay and the Bend States

Generally, the switching voltage is related to the duration of the switching pulse. For a short pulse, a higher voltage is required. Fig. 6 shows our experimental data. Here we varied the duration of the driving pulses V_1 and V_2, and measured the voltage needed for switching. It can be seen that the smallest duration in our experiments that can achieve bend-splay switching is 50μs. However, over 85V is needed. For a 1ms pulse, the voltage needed is 27V. It can be seen that the voltage needed for switching for this 3.2μm cell is less than 10V for a 10ms pulse. This is well suited for a matrix display using conventional driver electronics.

With the finger electrodes V_1 and V_2, and the common voltage V_c properly designed, a passive matrix can be used to drive our bistable display. An example of the values of V_1, V_2, and V_c is shown in Table for the case of 1ms pulses.

Figure. 5 Viewing Angle of Bistable Bend-Splay Display

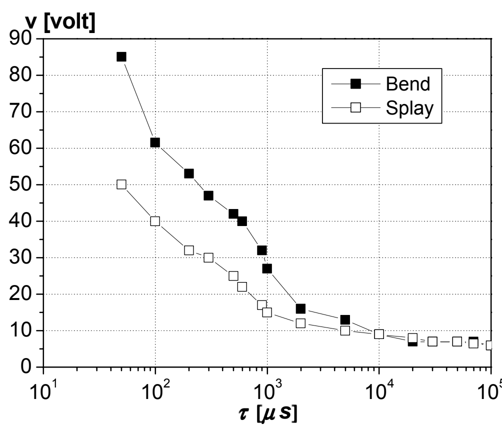

Figure 6. Driving voltages needed as a function of the duration of the driving pulses

Table I. Switching behavior of a passive matrix bistable display

V_1(volt)	V_2(volt)	V_c (volt)	Final state
15	-15	0	Splay
27	27	0	Bend
15	-15	15	No change
27	27	15	No change

The common rows are used as the addressing electrodes. Select voltage is 0 and nonselect voltage is 15V. The data lines are V_1 and V_2. Here a combination of V_1 and V_2 gives the data signal. A combination of 15V and –15V gives the splay state while a combination of 27V and 27V gives the bend state. All of these switching behaviors have been verified experimentally. All the voltages can be offset by a constant voltage without affecting the behavior of the display. For example, 15V can be subtracted from all the voltages to make the select voltage –15V and the nonselect voltage 0. Other voltages are possible as long as switching can be achieved without crosstalk.

4. Conclusions

In this paper, a bistable bend-splay display is demonstrated. Such display may have better viewing angles, better contrast ratios, faster selection and lower operating voltages than the other bistable displays based on the twisted nematic effect. Passive matrix driving schemes for such a display is also disclosed in order to realize a practical device.

5. Acknowledgments

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6. References

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