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The invention relates to ferroelectric liquid crystal
5 displays.

Ferroelectric liquid crystal displays, more particularly of
the DHF (deformed helix ferroelectric) type, are an attractive
alternative to conventional TN (twisted nematic) or STN (super-
10 twisted nematic) displays, particularly when large angles of
view, grey tints or short switching times are required, e.g. when
operating at low temperatures.

The operation of ferroelectric liquid crystal displays is
15 described e.g. in EP-A-309 774. If operated in "symmetrical"
mode, they have the disadvantage of a large switching angle of
 $\pm 45^\circ$, necessary for maximum transmission. Mixtures with a
large switching angle are difficult to produce and generally
slower than mixtures with a small switching angle. They also
20 tend to wind up the helix before the maximum switching angle is
reached. Hitherto there have been no LC materials with an
optimum switching angle, i.e. optimum lightness in symmetrical
mode. On the other hand, if they are operated in "asymmetrical"
mode, one disadvantage is that no use can be made of the
25 alternating polarity of the individual images. If, for example, the
displays have to remain dark for a long period, a negative voltage
must be applied during all this time. This results in space
charges in the liquid crystal and at the boundary surfaces. The
space charges alter the electro-optical characteristic, which can
30 result in ghost images and similar, very disturbing effects, which
may make the display useless.

The object of the invention is to provide a ferroelectric
liquid crystal display which does not have the disadvantages of
35 previously known displays of this kind.

According to the invention this is achieved by two liquid
crystal cells disposed one behind the other between two



polarizers, one cell having line electrodes and the other having pixel electrodes, and by means for actuating the pixel electrodes with image information in synchronism with the line electrodes, the orientation and refractive index of the liquid crystal cells
5 being so chosen that transmission is not substantially altered when the control voltages are reversed, and the two displays being so actuated that the switching angle never exceeds $\pm 22.5^\circ$ and the polarity of the voltages is periodically so inverted that on average there is no DC voltage across the cells.

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Preferred exemplified embodiments of the invention will now be described with reference to the accompanying drawings, in which:

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Fig. 1 is a sectional diagram through a conventional DHF cell;

Fig. 2 is a perspective diagram of a DHF cell according to the invention;

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Fig. 3 shows the orientation and double refraction properties of the cell arrangement shown in Fig.2, and

Fig. 4 shows the orientation and double refraction
25 properties of an alternative arrangement.

As Fig. 1 shows, a conventional DHF cell comprises two glass plates 12 fitted with transparent electrodes 10 and orientation layers 11 and about $2\text{ }\mu\text{m}$ apart. A liquid crystal layer
30 13 is disposed in between. The liquid crystal has a ferroelectric "Sc*" phase with a helical structure. The axis 14 of the helix is parallel to the plates and the pitch is shorter than the wavelength of visible light. If no voltage is applied, the helix is not deformed and the average refractive index points towards the axis of the
35 helix. If a voltage is applied between the two electrodes, the average refractive index (i.e. the long or major axis of the refractive index ellipsoid) rotates in the plane of the glass plates, in one direction for positive and in the opposite direction



for negative voltages. If the voltage is progressively increased, the angle becomes saturated at a maximum switching angle $q_{\max}$ which is characteristic for the ferroelectric liquid crystal. At saturation, the helix is wound up. If the voltage is lowered, the helix re-forms. This process, however, may take some time, so that winding up of the helix is usually avoided in DHF cells. This means, however, that the maximum usable angle of rotation must be chosen less than $q_{\max}$.

If a DHF cell is placed between crossed polarizers, the light transmission alters as a result of the rotation of the refractive index. It can be shown that a rotation of 45° is necessary for switching from maximum lightness to darkness. In the dark state, the optical axis is parallel to one of the polarizers, whereas in the light state it is rotated 45° therefrom. As already explained, a DHF display can be operated in two different modes which differ with respect to the angle $q(0)$ between the optical major axis and one of the polarizers at an applied voltage of 0 V as follows:

In the symmetrical mode, an applied voltage of $U = 0$ V corresponds to the angle $q = 0$, i.e. darkness. At both positive and negative voltages U , transmission increases and reaches a maximum when $q = \pm 45^\circ$. The same transmission is therefore obtained for positive and negative voltages of equal value. This enables the same image to be recorded alternately with positive and with negative voltage, so that on average no DC voltage component occurs at the cell and consequently no ghost images appear.

In the asymmetrical mode, $U = 0$ V corresponds to an angle of rotation of 22.5° , i.e. 50% transmission. A voltage of one polarity (e.g. positive) increases q and consequently increases transmission, whereas the opposite polarity decreases both quantities. For complete switching from light to dark, the range of modulation for q need be only $\pm 22.5^\circ$.



The invention combines the advantages of both operating modes without the aforementioned disadvantages. the most important advantage of the invention is that ferroelectric liquid displays can be actuated in "asymmetrical" mode without ghost
 5 images forming and, in the case of DHF cells, without large switching angles, which have hitherto been impracticable.

Fig. 2 shows an embodiment of the invention in which two DHF liquid crystal cells 210, 211 immediately following one
 10 another are disposed between crossed polarizers 21, 28. The liquid crystal cell 210 consists in a known manner of a liquid crystal layer 23 between two substrates, one with line electrodes 22 and the other with surface electrodes 24. This liquid crystal cell is switched one line at a time, at constant
 15 amplitude. The liquid crystal cell 211 comprises a liquid crystal layer 26 between two substrates comprising pixel electrodes 25, 27 and actuated with the image information in synchronism with cell 210. Fig. 2 omits orientation layers, electric connections to the LCDs or any active matrix of components of the liquid crystal
 20 cell 211.

According to the invention the liquid crystal cells 210 and 211 are so constructed and actuated as to avoid interfering DC voltage components. This is done by changing the polarity of the
 25 applied voltages from image to image. One important feature of the invention is that light transmission (the grey scale value) is the same in both these phases.

Fig. 3 diagrammatically shows the orientation and double
 30 refraction properties of the two liquid crystal cells 210 and 211 for three grey stages - i.e. light on line 35, grey on line 36 and dark on line 37, in columns 31 and 32 for phase 1 and in columns 33 and 34 for the oppositely actuated phase 2. The polarizer 21 (Fig. 2) is polarized at right angles, i.e. parallel to the major axis,
 35 in column 31, whereas the analyser 24 is crossed relative thereto.



The double refraction of the two liquid crystal cells is identical and approximately equal to half the wavelength, i.e. $\Delta n \cdot d = \gamma/2$ with $\Delta n = n_a - n_o$, where $n_{a,o}$ denotes the extraordinary and the ordinary refractive index of the DHF structure, d = cell thickness and γ = wavelength (≈ 550 nm). The shaded sectors in Fig. 3 show the range of rotation of the optical major axis in electro-optical use; negative voltages (e.g. column 31) rotate the major axis to the left whereas positive voltages (e.g. column 33) rotate it to the right. At an applied voltage of 0 V, the optical major axis is rotated 22.5° clockwise from the vertical in the case of the first liquid crystal cell 210 (columns 31 and 33), and 67.5° anticlockwise in the case of the second liquid crystal cell 211 (columns 32 and 34). In all, the two cells, i.e., e.g. the two directions of rubbing of the orientation layers, are rotated 90° from one another.

Fig. 3 shows directly that transmission in the two phases is identical. In line 35, phase 1, the linear polarized light is not influenced by the first liquid crystal cell 210 (column 31), since it is polarized parallel to the optical axis. The second liquid crystal cell 211 (column 32) acts as a $\gamma/2$ plate, i.e. it rotates the direction of polarization through 90° , so that light can pass through the analyser 24 without attenuation. In phase 2, the first liquid crystal cell 210 (column 33) acts as a $\gamma/2$ plate and the second liquid crystal cell 211 (column 34) does not influence polarization. In both phases, therefore, light is transmitted without attenuation. In the other extreme case of minimum transmission (line 37) the double refractions of the two liquid crystal cells balance out, both in phase 1 (columns 31 and 32) and in phase 2 (columns 33 and 34), i.e. transmission between crossed polarizers is at a minimum.

In the general case, i.e. grey (line 36), a voltage U_2 with $|U_2| \leq |U_1|$ is applied to the second liquid crystal cell 211. In phase 1 the light arriving at the second liquid crystal cell 211 is polarized at right angles, whereas the first liquid crystal cell 210, as before, has no effect on polarization. The optical axis of the second liquid crystal cell 211 is rotated relative to the



analyser through an angle $\alpha < 45^\circ$ controlled by the voltage U_2 . This results in transmission proportional to $\sin^2(2\alpha)$. In phase 2, the first liquid crystal cell 210 rotates the polarization through 90° (column 33), which is then horizontal on arrival at the second liquid crystal cell 211. Since in this case the voltage $-U_2$ is applied in phase 2 (column 34), the optical axis is rotated by $45^\circ - \alpha$ relative to the analyser, and consequently transmission is proportional to $\cos^2[2(45^\circ - \alpha)]$. "Cos" because the incident light is polarized parallel to the analyser. This however is proportional to $\sin^2(2\alpha)$, i.e. is identical with phase 1.

Since α can take any value between zero and 45° depending on the signal voltage U_2 , the transmission $\sin^2(2\alpha)$ takes any value between 0 and 1.

Exact positioning of the crossed polarizers or of the two liquid crystal cells is not critical. As Fig.3 shows, transmission for the dark state (line 37) is at a minimum for any direction of the crossed polarizers, since the double refractions cancel out exactly. In the light state (line 35) the colour may depend slightly on the position of the polarizer. Exact positioning can therefore be used for optimising the colour.

Fig.4 shows another possible reciprocal arrangement of the two cells and polarizers. In contrast to Fig.3, the cells are rotated through only 45° from one another. As a result, in phase 1 in the dark state (line 47, columns 41 and 42) the phase shifts are added instead of compensating one another as in Fig.3. If however the polarizers are oriented parallel and at right angles to the resulting major axis, transmission is at a minimum.

As will be evident to a person skilled in the art, other configurations having a similar effect are possible, more particularly when using thicker birefringent cells with $\Delta n \cdot d = \gamma$ or $\Delta n \cdot d = 3\gamma/2$.

Application of the invention is not restricted to DHF cells, although they are particularly preferred. Periodic changing of



polarization is advantageous also in the case of SSF liquid crystal displays, as a means of avoiding ghost images and switching delays in these displays also.





Claims

1. A ferroelectric liquid crystal display comprising two liquid crystal cells disposed one behind the other between two
5 polarizers, one cell having line electrodes and the other having pixel electrodes, and by means for actuating the pixel electrodes with image information in synchronism with the line electrodes, the orientation and refractive index of the liquid crystal cells being so chosen that transmission is not substantially altered
10 when the control voltages are reversed, and the two displays being so actuated that the switching angle never exceeds $\pm 22.5^\circ$ and the polarity of the voltages is periodically so inverted that on average there is no DC voltage across the cells.
- 15 2. A liquid crystal display according to claim 1, wherein the two liquid crystal cells are DHF displays.

