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(54) LIQUID CRYSTAL DISPLAY AND CONTROL

(71) We, BBC, BROWN, BOVERI & COMPANY LIMITED, a Company organised under the Laws of Switzerland, of CH-5401, Baden, Switzerland, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:-

The present invention concerns a liquid crystal display, particularly for installation in electronic instruments, comprising a nematic, twisted liquid crystal cell with electrodes built up of individual segments and attached to cell walls, these electrodes being adapted to be connected to a control circuit.

When operating twisted nematic liquid crystal cells it is apparent that the contrast of the display elements is strongly dependent on the viewing angle.

When such displays are driven by multiplex decoders (Dynamic Matrix Addressing; see IEEE Trans., Electron Devices ED-21, 1974, p. 146-155), the following limiting relationship is found for the effective voltages at the display elements:

$$V_{on}/V_{off} = [(N_x^{1/2} + 1)/(N_x^{1/2} - 1)]^{1/2}$$

where V_{on} = Effective voltage at the electrode elements selected,
V_{off} = Effective voltage at the electrode elements not selected,
N_x = Number of addressing lines selected sequentially per control period.

The relationship above shows that increasing the number of addressing lines selected sequentially per control period must result in a decrease of the effective voltage at the electrode elements selected.

Experimental determination of the optical properties of twisted nematic liquid crystal cells in multiplex operation, as well as the above relationship, have led to the general belief that liquid crystal cells are not very well suited to multiplex operation.

It is the task of the invention to take steps generally to improve the optical properties of the liquid crystal displays, and in particular, to make a rational multiplex operation of twisted, nematic liquid crystals possible.

The aforementioned task is solved, according to the invention, in that the light rays used for the transmission of information in a liquid crystal display as first mentioned herein leave the cell in planes orthogonal to the planes of the cell walls and form an angle not equal to 90° with the planes of the cell walls, the orthogonal planes being aligned with the direction of the unexcited nematic molecules located at half the thickness of the liquid crystal layer. (The "unexcited" nematic molecules are molecules not affected by an applied electric field).

The invention is based on the realization that the viewing angle resulting in maximum contrast between display element and background increasingly deviates from a viewing angle normal to the cell walls with an increase of the number of the address lines selected per control period. This results in the following conclusion: The multiplex capability of the nematic liquid crystal displays is improved considerably by a smaller viewing angle, according to the invention, than has been customary up till now.

In the following, embodiments of the invention are described by means of drawings, showing in:

Figure 1 a twisted liquid crystal cell shown schematically with viewing angle α drawn in,

Figure 2 the angle-dependence characteristic of twisted, nematic liquid crystal displays viewed in two planes at right angles to each other,

Figure 3 the curve of the voltage-contrast characteristic of a twisted, nematic crystal cell with various viewing angles α,

Figure 4 a liquid crystal cell operated in transmission mode, with collector lens and plane of projection,

Figure 5 a first reflection-operated liquid crystal display, mounted at an angle in an electronic computer, or calculator,

Figure 6 a second reflection-operated liquid crystal display with an additional prism for light deflection, mounted conventionally in a computer, or calculator,

Figure 7 a third liquid crystal display, analogous to Figure 6, but with a Fresnel prism,

Figure 8 a fourth liquid crystal display, optionally transmission- or reflection-operated, with prism for light deflection, mounted in a recessed position in the electronic computer, or calculator,

Figure 9 basic representation of a multiplex-driven liquid crystal display.

According to Figure 1, 1 marks a cell which has a nematic liquid crystal layer between a first cell wall plane 1*a* and a second cell wall plane 1*b*. In the boundary layer of the cell wall planes 1*a*, 1*b* the molecules or groups of molecules of the liquid crystals are oriented in the way drawn in schematically, resulting in a twist of appr. 90°. The molecules located at half the thickness of the liquid crystal layer correspondingly show a twist angle of appr. 45° with respect to the edges of the cell wall planes 1*a*, 1*b*. A plane E stands vertically on the cell wall plane 1*a*, at the same twist angle of appr. 45°, and serves to define the viewing angle α. An angle formed between an observer 20 and the cell wall plane 1*a* is called the viewing angle, α, angle being in the plane E and its apex being at least approximately in the centre of the cell wall plane 1*a*.

The leg of the viewing angle α leading to the observer 20 is marked L and symbolizes a light ray L used to transmit information.

Figure 2 at the top shows cell 1 in plan view (viewed from above). Plane E of Figure 1 cuts cell 1 in the intersection line S_1, and a plane, at right angles thereto, in the intersection line S_2. Viewing angle α lies in plane E, viewing angle β in the plane at right angles thereto mentioned. The intensity I of the light ray used for the transmission of information, with respect to angle α or β and at an effective voltage of 3V and 1.4V between the electrode pairs selected in each case, can be read from the diagrams shown below.

Whereas intensity I shows no symmetry with either effective voltage as a function of the viewing angle α, intensity I as a function of angle β behaves symmetrically with respect to the normal to the cell wall plane 1*a*.

The response properties of liquid crystals to electrical fields are known (Proc. IEEE 60, 1972, p. 1002-1003) and here do not require further explanation. Figure 3 shows the curves of voltage/contrast characteristics of a nematic liquid crystal cell with the viewing angle α=60°, α = 75°, α = 90°, although this last value is not within the ambit of the invention. The cell measured containing a liquid crystal layer 10 um thick, consisting of a cyano Schiff's base (see Proc. IEEE 60, 1972, pages 1002-1003).

Figure 4 shows a transmission-operated cell 1 inclined with respect to an axis of projection P and serving as a display of alpha-numeric characters on a plane of projection 10. A collector lens 30 with principal planes *h*,*h'* serves to magnify the projection image of the numbers "43" selected in the example. The projection axis P also contains a light source 11 functioning as a projection lamp. The two smaller vertex angles formed between a cell wall plane and the axis of projection P are preferably 85° at the most.

The electrodes mounted on the cell wall planes 1*a*, 1*b* are transparent and are distorted in a direction corresponding to the inclination of cell 1 with respect to the axis of projection P. As Figure 4 shows, in detail A of the figure "43" selected, this distortion is compensated in the magnified projection image standing at right angles to the axis of projection P.

For reasons of optical geometry the extended centre line m_z of the cell and the extended centre line *h*, lying between the principal planes *h*, *h'*, intersect on the extended plane of projection 10 in a point of intersection Z.

The plane of projection 10 could also be inclined with respect to the axis of projection P, instead of lens 30 being inclined with respect to the axis of projection P.

In the experimental arrangement described above (The distance, light source 11 to plane of projection 10 is 400 mm), the following measuring results characteristic of the invention were obtained in multiplex operation:

	$CR_1 = 20$	$CR_1 = 25$	$CR_1 = 30$
$\alpha=90°$	$N_x = 9$	$N_x = 6$	$N_x = 2$
$\alpha=75°$	$= 18$	12	7
$\alpha=60°$	$= 34$	23	15

with α = viewing angle
CR_1 = Contrast ratio between electrode elements selected and background
N_χ = number of sequentially selected address lines per control period T

The above measuring results show how the multiplex capability of a twisted nematic liquid crystal cell is increased by the use of a smaller viewing angle α. The resulting differential magnification and consequent distortion are compensated by distorted electrode elements, and do not become apparent.

A reflection-operated liquid crystal display, Figure 5 is built into the instrument housing 5 of an electronic computer or calculator. Cell 1 comprises eight digits and is controlled by a multiplexed control circuit 6. Maximum contrast of the electrode elements controlled is obtained in a viewing angle α of appr. 80°. Cell 1, therefore, is inclined by appr. 20° with respect to the plane of the base of the instrument housing 5. This inclination of cell 1, adapted to the preferred position of an observer, bearing in mind the reduced viewing angle, provides all the advantages of multiplex operation.

The customary illumination incident from above results in increased brightness of the display with the use of a ribbed, or greatly roughened reflector surface 3. Preferably the depth of roughening is at least 5 microns.

In the display of Figure 6 cell 1 is mounted parallel to the plane of the base of the instrument housing 5. The reduction in viewing angle α obtained in multiplex operation is corrected as necessary for good legibility of the display through deflecting the light ray L in prism 4.

In the arrangement according to Figure 6 the viewing angle α with a display in multiplex operation ($N_x = 8$) could be increased from 62° to 78° with the aid of a plexiglass prism mounted on cell 1. (The word "Plexiglass" is a registered Trade Mark).

In multiplex operation the electrode elements not selected also show some contrast with respect to the background. With a correspondingly small viewing angle α these electrode elements can have an interfering effect on an observer through light rays L'. These light rays L' are reflected totally in prism 4 and are thus eliminated for the observer.

The display in Figure 7 also uses a prism 4 which here, however, is a Fresnel prism, with the advantage of low installation height.

The display in Figure 8 is mounted in a recessed position and at an incline in the housing 5. The light rays L used for the transmission of information are deflected by total reflection at the hypotenuse face of prism 4. The inherently interfering light rays L' leave the prism 4 and are absorbed in an absorber 41. A milk glass cover 12 is joined flush with the upper surfaces of the instrument housing 5 and the prism 4 and admits the light necessary for reflection- operation to cell 1.

The arrangement in Figure 8 can be modified by substituting a mirror, inclined correspondingly, for the prism 4. It is disadvantageous, however, that the interfering light rays L' are also deflected.

The displays in Figures 6, 7 and 8 use the customary reflectors 3 set into liquid crystal cells. All the displays in Figures 5-8 can also be operated by replacing the reflector 3 with a light source, e.g., incandescent bulb, fluoroscent tube, etc., or with a semitransparent reflector in transmission.

Figure 9 shows the simplified operation of the liquid crystal display with a control circuit 6 for multiplex operation. The cell 1 has a number of electrode elements determined by the type of display. The electrodes on the cell wall plane 1*a* are marked 2*a* and those on the cell wall plane 1*b* are marked 2*b*. The electrodes 2*a*,2*b* are assembled in the form of a matrix in rows and columns and are selected sequentially by a control circuit 6 during the control period T. In the example of Figure 9, T is the time elapsed from the selection of the first row to the selection of the last row. With a coincidence in time of the selection signal on the rows with the signal on the columns the corresponding pair of electrode elements then switches the liquid crystal layer lying between them into its transparent state, i.e., an image is formed. The number of sequentially selected address lines, corresponding in Figure 9 to the number of the rows shown, is marked N_x and constitutes a criterion for selecting the magnitude of the viewing angle α. Thus the pulse duration is obtained from T/N_x.

The invention can also be applied to individually controlled, twisted nematic liquid crystal cells. The use of such cells, according to the invention, makes possible the operation with reduced voltages and currents, thus considerably increasing the operational life particularly of battery-fed displays. For instance, this would make it possible to supply the display according to the invention built into a wrist watch to be supplied without voltage transformation from a single battery.

WHAT WE CLAIM IS:-

1. A liquid crystal display comprising a nematic, twisted liquid crystal cell with electrodes built up of individual segments and attached to cell walls, said electrodes adapted to be connected to a control circuit, and wherein, in use, the light rays used for the transmission of information leave the cell in planes orthogonal to the planes of the cell walls and form an angle not equal to 90° with the planes of the first cell walls, the orthogonal planes being aligned with the direction of the unexcited nematic molecules located at half the thickness of the liquid crystal layer.

2. A liquid crystal display according to claim 1, further comprising a light source; the light rays emitted by the light source during operation in transmission mode forming an axis of projection at an angle oblique to the normal to the cell wall.

3. A liquid crystal display according to claim 2, wherein the two smaller vertex angles formed between a cell wall plane and the axis of projection are 85° at the most.

4. A liquid crystal display according to claim 2 or 3, further comprising a lens the principal planes of which assume an angle not equal to 90° to the axis of projection.

5. A liquid crystal display according to any preceding claim wherein the plane of projection assumes an angle of not equal to the axis of projection.

6. A liquid crystal display according to claim 2 further comprising a lens the principal planes of which form an angle of 90° to a projection axis, and the plane of projection and the cell wall plane each form an inclined angle with the axis of projection.

7. A liquid crystal display according to any preceding claim wherein the electrodes attached to the cell wall planes are distorted in one direction in such a manner that an undistorted projection image is formed on the plane of projection.

8. A liquid crystal display according to any preceding claim mounted in an instrument housing, and wherein the cell wall plane forms an oblique angle with the plane of the base of an instrument housing.

9. A liquid crystal display according to claim 8, further comprising a reflector, said reflector being profiled or roughened, the depth of the roughening being at least 5 microns.

10. A liquid crystal display according to any of claims 1 to 7 mounted in an instrument housing characterized in that the cell is arranged parallel to the plane of the base of an instrument housing and that there is a prism on the observer's side.

11. A liquid crystal display according to claim 10 wherein the prism is a Fresnel prism.

12. A liquid crystal display according to any of claims 1 to 7 further comprising a prism which deflects the light rays used for the transmission of information by total reflection and wherein interfering light rays reach an absorber arranged at the prism.

13. A liquid crystal display according to any of claims 1 to 7, further comprising a prism prism which deflects interfering light rays at one surface by total reflection and wherein the light rays used for transmission of information are passed out with little or no such deflection at the same surface.

14. A liquid crystal display according to claim 1, wherein the light rays used for the transmission of information are deflected at a mirror placed at an inclination to those rays.

15. Use of a liquid crystal display according to claim 1 in multiplex operation, a control circuit being designed in such a way that there are at least four address lines selected sequentially per control period.

16. A liquid crystal display substantially as hereinbefore described with reference to and as shown in the accompanying drawings.

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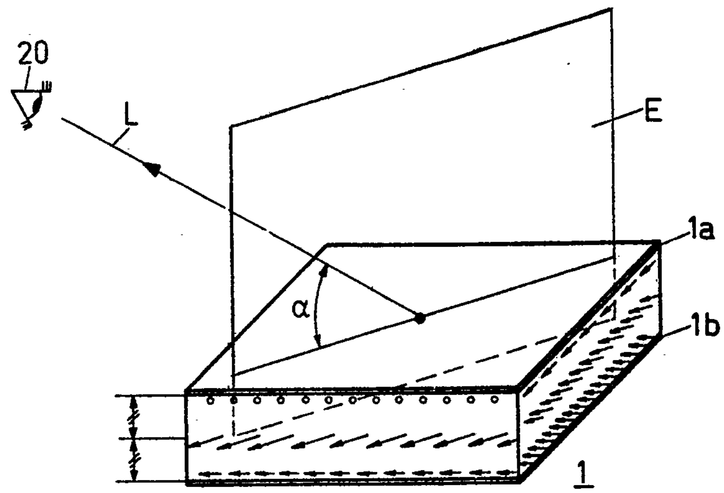

FIG.1

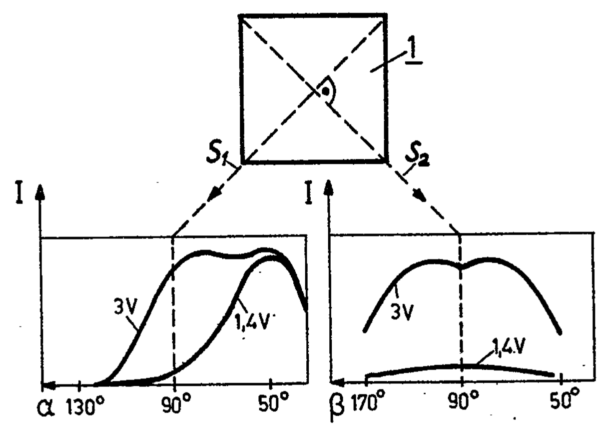

FIG.2

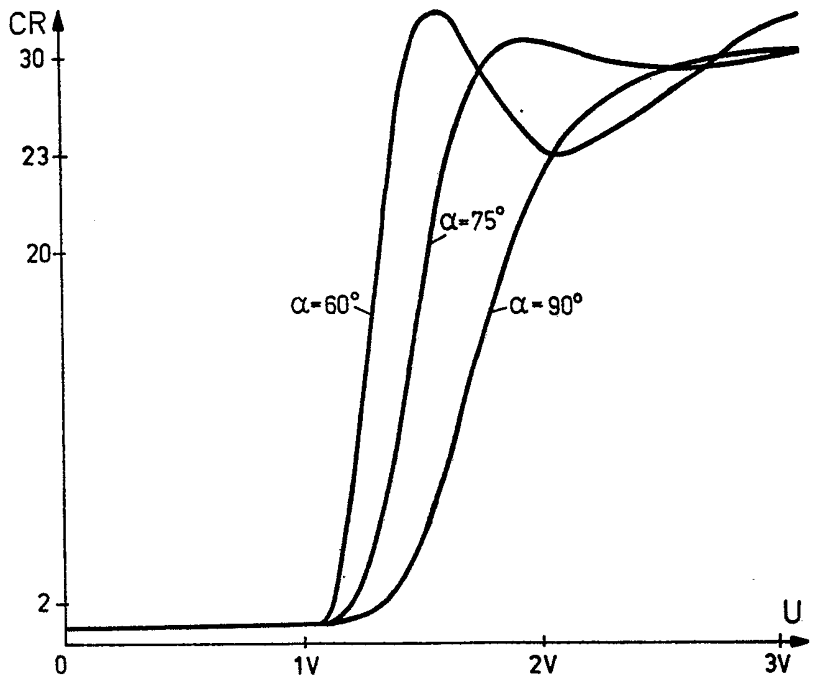

FIG.3

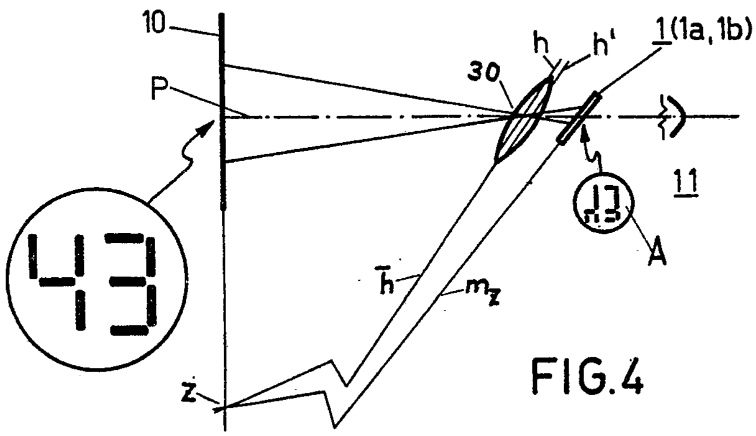

FIG.4

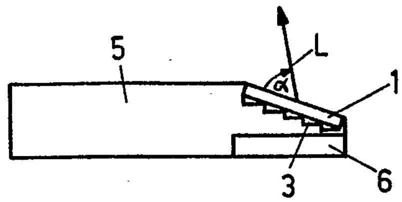

FIG.5

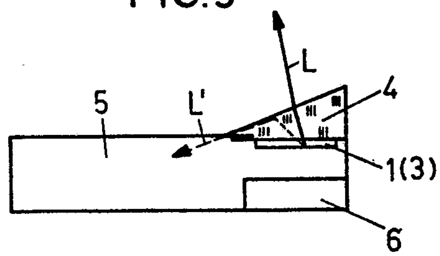

FIG.6

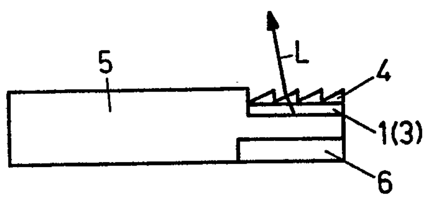

FIG.7

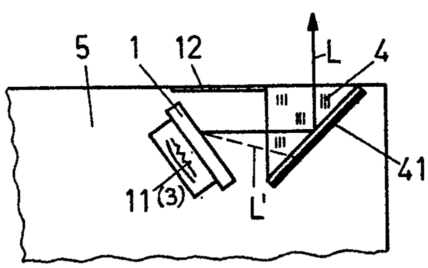

FIG.8

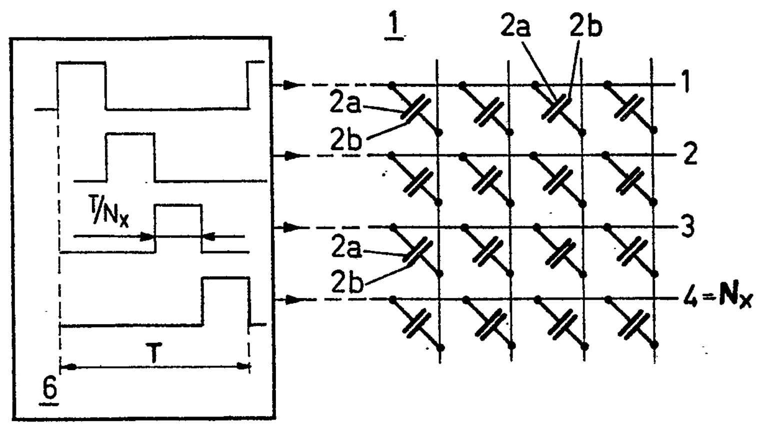

FIG.9