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Liquid Crystal Matrix Displays Using Additional Solid Layers for Suppression of Parasite Currents†

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Abstract—Because of their light-scattering behavior under the influence of an electric field, liquid-crystal layers are suitable as active layers in flat picture screens. In screens built up as conducting-line-matrixes the cross-talk arising from parasite currents has to be suppressed. Besides that a display unit with a large-volume picture needs the ability to store the information, since liquid crystals have a long rise-time.

It is shown that cross-talk is suppressed by combining a ferro-electric ceramic layer with the liquid-crystal layer in a liquid-crystal matrix using the non-linear properties of the ceramic, and that the necessary storage is obtained by the ceramic's ability to store polarization states.

Further on it is shown by examples, that liquid crystal screens based on this double layer can be practical in a wide range.

Introduction

Experiments described in the literature demonstrated, that by using liquid crystals, it is possible to display optical information with a versatility similar to that of the cathode ray tube. In these experiments liquid crystal displays operated at the full television rate. Essentially, this was done by scanning a liquid crystal film with an electron beam which impressed a locally variable electric field into the liquid crystal film.[1,2] Many recent efforts of realizing a universal display, of which the application of liquid crystals is only one example intend to avoid the disadvantages of the electron-beam-addressing (power-requirements, high voltage, large volume, limited display-area, vacuum-tube) and to use primarily matrix addressing for generation of the locally variable electric field. It is desired to

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construct in this way a flat solid state display, which can be operated by integrated circuits and which can be produced with a large area. On this basis, liquid crystal displays are also conceivable in principle.

Problems of the Liquid Crystal Matrix Display

If a voltage V is applied across one X- and one Y-conductor strip of the crossed-conductor-matrix shown in Fig. 1, the display element

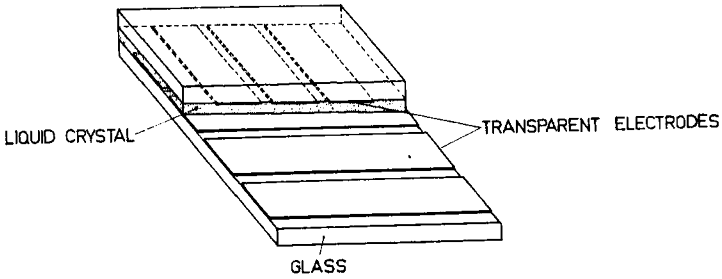

Figure 1. Liquid crystal layer between crossed-conductor-matrix.

at the intersection of the electrode couple will receive the full voltage V, while at many other display-elements voltages equal to or less than $V/2$ will appear by a shunt effect. If the active layer between the electrodes consists of the nematic liquid crystal only, definite switching of a single display element into the dynamic scattering mode is not possible in this matrix. Generally, besides the excitation of the intersection element by the activated $X-Y$-conductor couple, the neighbouring elements of these conductors are, though weaker, also in the dynamic scattering mode. This is demonstrated in Fig. 2. For good visible and fast excitation of dynamic scattering with all presently known nematic liquid crystals, field strengths that amount to a multiple of the threshold field strength for dynamic scattering are necessary.

A first main problem existing with such a matrix is, therefore, to provide a sufficiently high electrical threshold. Another main problem stems from the relatively long rise times of the nematic LC's: If for example a display corresponding approximately to a TV frame with half a million elements is to be addressed 24 times per second, for excitation of dynamic scattering it is necessary that

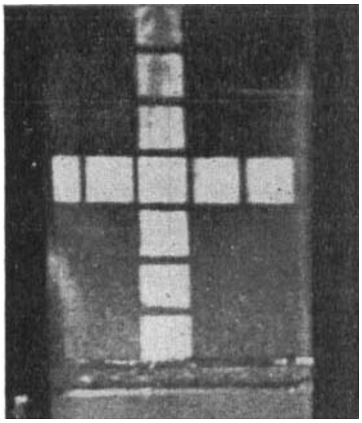

Figure 2. Demonstration of the cross-talk arising from parasitic currents in the screen of Fig. 1.

the addressing pulses are applied longer than corresponds to the scanning time per element. This means: The elements must be able to store the electric signals that contain the brightness information.

Solutions

Both problems can be solved by combining a ferro-electric ceramic layer with a liquid crystal layer. In the following, proposals which have been tested on models are made in this direction. First a version A of a liquid crystal matrix display is discussed, where only the threshold problem is solved. This version is relatively simple in its technology and is practicable first for fast dynamic displays, which only need up to several thousand raster elements and secondly for displays having an arbitrary number of raster elements and only slow changes. In the second case the storage effect of nematic/cholesteric liquid-crystal-mixtures is utilized. In version B, the problem of storing the electrical pulses containing the brightness pattern is also solved.

Version A

For an alternating voltage, a ferro-electric layer represents a capacity which varies with the amplitude of the applied voltage.

This can be seen from the familiar hysteresis loops, of which two specific cases are shown in Fig. 3: The large loop is traversed for an amplitude V, the small one for $V/2$.† The slopes of the broken lines are, as known, proportional to the effective dielectric constant, that is, to the capacity of the ferro-electric layer. If the ferro-electric ceramic possesses a sufficiently square hysteresis loop, below the saturation region the capacity increases very strongly with the amplitude of the applied voltage.

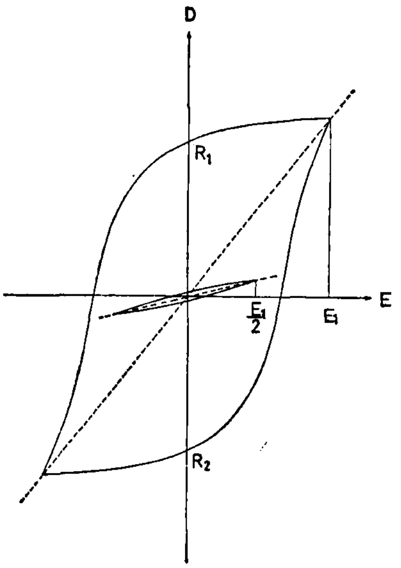

Figure 3. Hysteresis loops of a ferro-electric ceramic at a field strength of E_1 or $E_1/2$.

A double layer, consisting of a ferro-electric ceramic and a liquid crystal layer therefore represents for alternating voltage pulses, the series connection of a non-linear and a linear capacity. By suitably dimensioning the capacities of both layers, the voltage across the liquid crystal layer can be made to increase much stronger than linear with the total voltage applied across the double layer, as is

† If one polarizes the ferro-electric ceramic to the remanence state R_1 and if one then applies the $V/2$ amplitude then the small hysteresis loop in Fig. 3 is essentially displaced only parallel to the D-axis by the appropriate difference of remanence polarization.

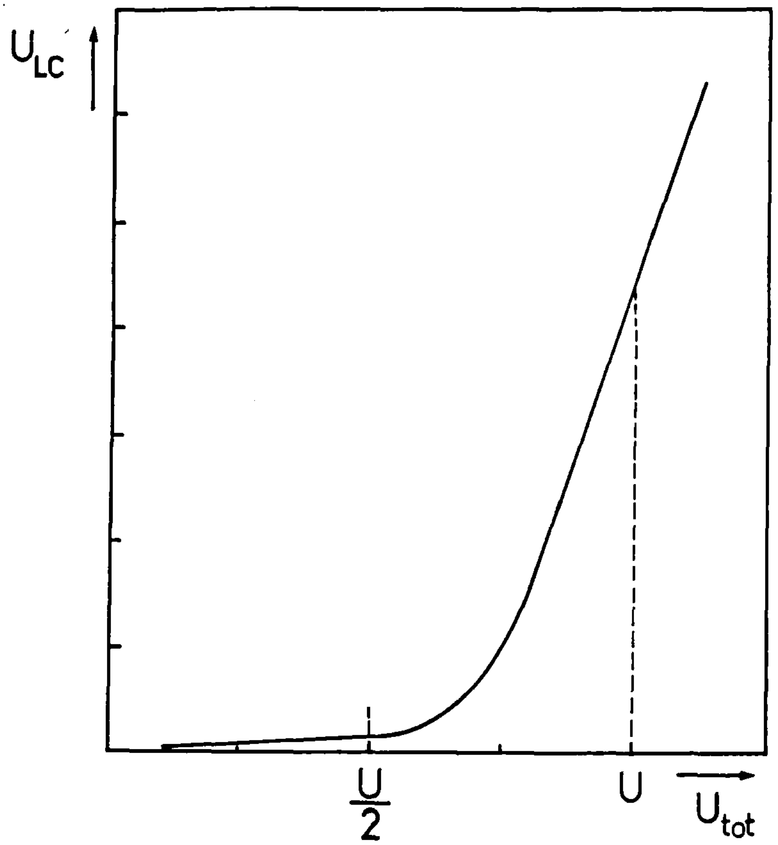

Figure 4. Voltage amplitude U_{LC} across the liquid crystal layer as a function of the total voltage (U_{tot}) across the double layer.

shown in Fig. 4. By this method the necessary electrical threshold voltage of the display elements in a liquid-crystal-matrix can be obtained. (This is demonstrated in Fig. 5, which shows that a single display element can be excited by matrix addressing using this method.) The double layer is provided on one side with the X-, and on the other side with the Y-conductors. Because of the great differences in the dielectric constants of the ferro-electric ceramic and the liquid crystal, it is necessary among other things to match the capacity by using different breadths of the X- and Y-conductor strips. This can be realized for example in a setup shown in Fig. 6a and Fig. 6b.

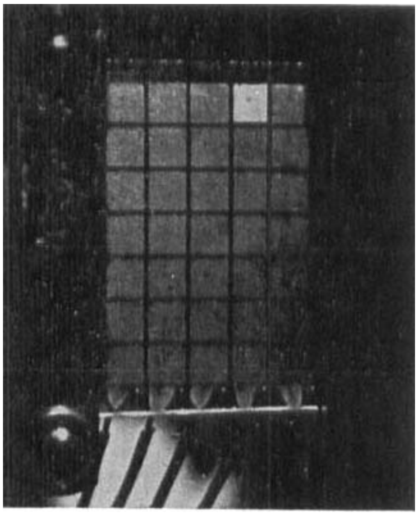

Figure 5. Laboratory model of a liquid crystal matrix display (version A). One display element (ca. 0.1 in × 0.1 in) is excited.

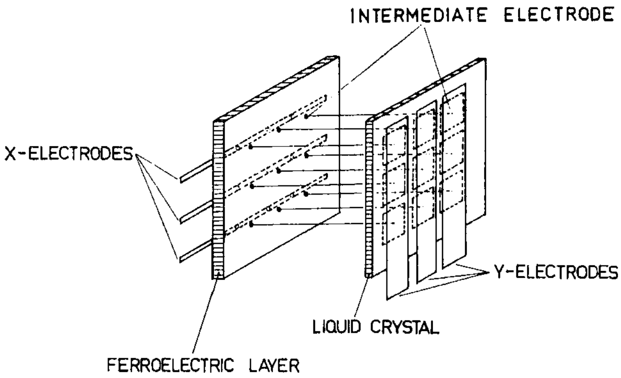

Figure 6a. Principle of a matrix display of version A.

The ferro-electric ceramic elements of the matrix display must be polarized by the addressing pulses alternately in positive and negative field directions. This can be done in practice for example by writing one frame with positive pulses and then applying across all elements at the same time one negative pulse, which is so short, that the liquid crystal will not be excited, but all ceramic elements will be polarized

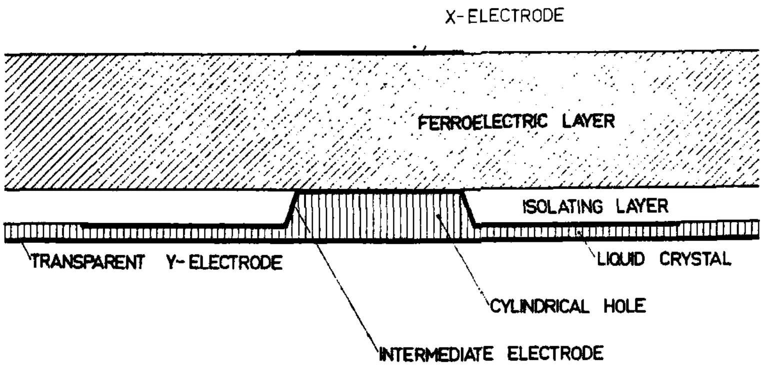

Figure 6b. Integrated setup of the matrix display in Fig. 6a realized in the laboratory model. Transverse section of one display element.

inversely.† Then again, the next frame is written with positive pulses, etc. The degree of brightness of the display elements is controlled by the amplitude of the write-pulses.

Since the resistivity of the ferro-electric ceramic is substantially greater than that of the liquid crystal, the ferro-electric layer can also be provided with a bias voltage.

Version B

In this version the video signals are stored as polarization states in the ferro-electric ceramic whereby for example, on a display consisting of 1 million elements, 24 frames per second can be displayed in spite of the long rise-times of the liquid-crystals. The principle is explained with the aid of Fig. 7a. One side of the ferro-electric layer carries the X-, the other the Y-conductors. At each intersection of an X- and Y-conductor, on the side of the Y-conductors, a very small electrode spot (called readout-electrode) is isolated from the corresponding Y-conductor but is capacitively coupled to the Y-conductor by the ferro-electric ceramic between them. Opposite to these readout electrodes, correspondingly larger electrode spots are on the backface of the liquid crystal layer. On the frontface of the

† The polarization charges brought onto the liquid crystal capacitors by the reset pulse are shorted out by simple electronic measures during the switching off of the reset pulse.

liquid crystal is a uniform transparent front electrode. In Fig. 7b it is shown how these two electrode rasters are connected.

In the initial state, let all ceramic elements be in the upper remanence point R_1 of the hysteresis loop (Fig. 3). By applying

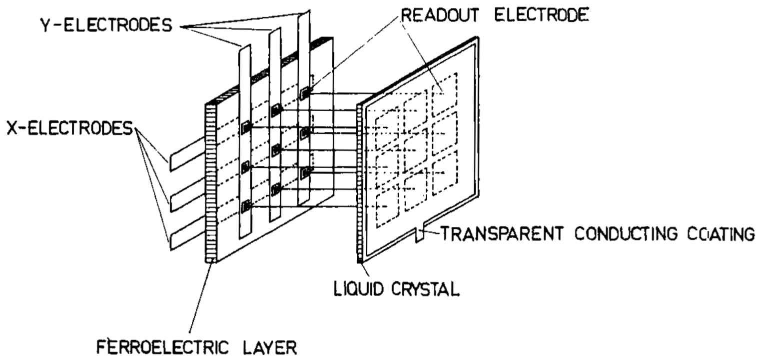

Figure 7a. Principle of a matrix display of version B for high speed displays.

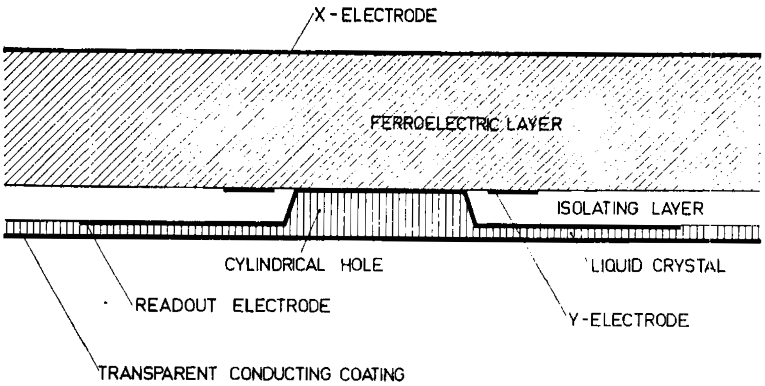

Figure 7b. Integrated setup of the matrix display in Fig. 7a. Transverse section of one display element.

negative direct voltage pulses across the conductor matrix (X- and Y-conductors), the individual elements are polarized inversely, for example, into the lower remanence state R_2. The polarization process takes about 1 μsec. The image information is thus first converted into a polarization pattern stored in the ferro-electric ceramic. Now, this polarization pattern can be converted at the same moment into a visible image on the liquid crystal film by applying a single positive pulse (a readout pulse) of about 1 msec across all X-conductors together, and the uniform front electrode. This readout pulse causes all ferro-electric elements to return to the initial state R_1. During this flipping back of the ferro-electric domains, polarization charges corresponding to the magnitude of the preceding polarization will flow to the respective liquid crystal capacitor elements, thus exciting the liquid crystal. After that, the next frame can be written into the ceramic, etc.

Remarks about the Ceramic and the Liquid Crystals

In our experiments, ceramic materials consisting of lead zirconate/ lead titanate mixtures proved to be very suitable. They have relatively square hysteresis loops and can be prepared in large thin plates. The thickness of the ceramic layer was of the order of 100μ, that of the liquid crystal about 10μ. With a thickness of about 50μ these mixtures have a sufficient transparency, so that a matrix which also operates in transmitted light can be realized.

The addressing voltage pulses had an amplitude of about 100 V. The rise-times of the nematic liquid crystals used were several msec and the decay times were of the order of 100 msec.

In order that the liquid crystal capacitor elements, charged by polarization of the ceramic, do not discharge substantially within the rise-time of the liquid crystal, the liquid crystal should have high resistivity. With liquid crystals having a resistivity of about $10^{10}\,\Omega$-cm, very satisfactory results were achieved. The liquid crystals used were supplied by the firms Hoechst, Merck and LCI. Though the concept ferroelectric plus liquid crystal layer is similar to the well-known concept ferroelectric plus electroluminescent layer, especially the very low power requirements of the liquid crystals, and their specific rise and decay times, make possible the described solutions which we think to be practicable for a liquid crystal matrix display.

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