STATIC SCATTERING IN FILLED NEMATIC: NEW LIQUID CRYSTAL DISPLAY TECHNIQUE

Indexing terms: Liquid crystals, Display systems, Scattering, Optical properties of substances

A new bistable liquid crystal display is described that uses a nematic phase in which solid particles are dispersed. The display effects rely on direct static light scattering so that no polarisers are required. A two-frequency addressing scheme provides, in principle, a method for electrical control.

Introduction: Almost all liquid crystal displays produced commercially use polarised light which is modulated by nematic layers.[1] Displays based on light scattering hold promise for higher yields of light. However, dynamic scattering displays[2] could not compete in terms of power consumption and reliability. A promising advance was made by dispersion of small droplets of nematics in polymers which are light scattering in the rest state, but can be made transparent through the application of a permanent electric field.[3,4] We introduce a display that enables switching between a stable scattering and a stable transparent state by electrical pulses.

Scattering 'on' state: The display effect described is due to the static light scattering of a nematic liquid crystal in which solid particles are dispersed. The properties of these particles are: their low primary diameter below 30 nm, high specific surface of 50 to 300 m^2/g and low bulk density permitting stable dispersions with a high ratio of the volume of the nematic phase, typically 99 to 97%. The particles can be dispersed in any conventional nematic liquid crystal. The resulting filled nematic is put between two glass plates with ITO electrodes spaced at typically 14 μm in a conventional display configuration. To allow for the application of an external voltage the glass plates have ITO electrodes. In this situation the nematic layer scatters light strongly. This defines the on state of what is potentially a bistable liquid crystal display. The scattering is believed to be caused by strong variation of the local orientation of the nematic director.[5] Probably many small domains with different orientations occur due to the large area of limiting internal surfaces of the dispersed particles. An obvious material requirement for strong scattering is a large value of the birefringence Δn of the nematic liquid crystal.

It should be noted that the present scattering effect differs essentially from that in an encapsulated nematic.[3,4] The nature of the solid frame work does not require any matching of the optical properties of the dispersed particles and the nematic phase.

Electric-field effect: switching from on to off state: As the nematic material, we have chosen ZLI 1132 from E. Merck consisting of *p*-substituted benzonitriles having a positive dielectric anisotropy $\Delta\varepsilon \simeq 10$ and a Δn of 0·14 at room temperature. For this phase, solid particles of pyrogenic silanised silica (R812 from Degussa[6]) proved to be advantageous. If we apply an AC voltage of 400 Hz the absorption decreases as a function of the voltage as shown in Fig. 1. At relatively high voltages of 150 V the display becomes almost completely transparent. After switching off the voltage, the scattering adjusts at a low level which is influenced to a minor degree by the frequency used. This defines the off state of the bistable display, and shows the feasibility of switching from on to off.

We found that in the transparent state with a voltage applied, the nematic director is almost perfectly homeotropically oriented over the full display. After switching off the voltage a less perfect homeotropical orientation with distinct patterns can be observed. Such a stable situation after switching off the voltage is only possible if the boundary conditions are weak at the internal interfaces which define the small nematic domains. Hence, not surprisingly, we find a dependence of the display effect on the prior treatment of the solid particles, which still has to be further investigated. Related to this is a certain influence of the boundary conditions of the external glass plates.

Problem of switching from off to on: Having switched to the transparent off state it is not immediately obvious how the scattering on state can again be reached. We shall briefly mention some methods that have been tried but not fully explored yet.

(*a*) The display can easily be brought back to the original scattering state by a small mechanical shear. However, the resulting bistable display (switched on by a mechanical shear and switched off by an electric voltage) obviously has some crucial disadvantages.

(*b*) Some preliminary experiments show that the scattering on state can alternatively be obtained by applying ultrasound to the display. Though the mechanism is not clear to us, it certainly seems to warrant further investigation. This method would be especially interesting if the ultrasound could be applied locally. It was found that by an external ultrasound source of 800 kHz a pattern with sharp boundaries could be written into the display.

(*c*) To investigate further the electric switching possibilities, we considered a nematic material with a negative dielectric anisotropy, $\Delta\varepsilon \simeq -5$. Starting from the scattering on state the application of voltages up to 100 V leads to even a small *increase* of the scattering. Previously we assumed weak boundary conditions at the internal interfaces leading on application of a voltage to a nematic with $\Delta\varepsilon > 0$ to uniform homeotropic orientations within the domains. Similarly we may assume planar nematic domains for the present case of $\Delta\varepsilon < 0$. However, now the director patterns of the various nematic domains will not at all be uniform, but will be random in the planes perpendicular to the electric field. This leads again to light scattering. Clearly the result is a potential possibility for reaching the scattering state without mechanical shearing.

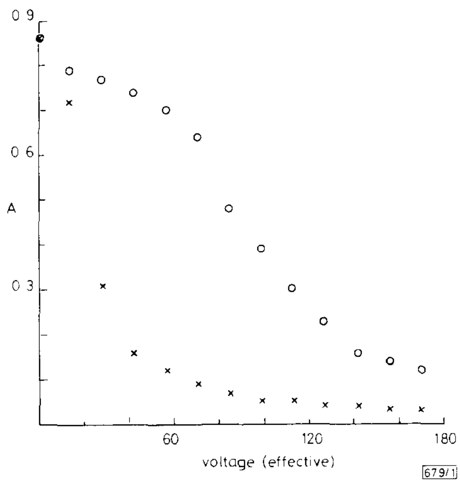

Fig. 1 *Absorption A of ZLI 1132 filled with 2·8 vol.% of Aerosil R812 against effective voltage (400 Hz) measured in 14 μm layer*

× voltage on
○ after voltage switched off
Absorption defined as intensity of light beam having aperture of 4° in front of and behind cell

Two-frequency addressing scheme: Evidently the possibilities mentioned to switch the display electrically on or off can be applied together in the case of a nematic material that combines both $\Delta\varepsilon > 0$ and $\Delta\varepsilon < 0$. This situation can be found in nematics that have a low-frequency relaxation of the dipole moment parallel to the long molecular axis.[7] As an example we take the material ZLI 2461 that has the following dielectric properties at room temperature:[8]

$\Delta\varepsilon \simeq +2{\cdot}0$ at 400 Hz

$\Delta\varepsilon \simeq -1{\cdot}9$ at 20 kHz

Its frequency of dielectric isotropy is 2·3 kHz at 20°C. After the introduction of the particles, application of a voltage at 400 Hz and 20 kHz, respectively, leads to an off and on state in the desired manner. Under the conditions mentioned above the switching time to obtain the on state was 18 ms (3 ms delay, 15 ms rise) and back to the off state 8 ms (3 delay, 5 ms decay). Dielectric measurements of the on and off states agree approximately with the frequency dependent values given for ZLI 2461, confirming the assumptions of (almost) homeotropic and random planar orientations. Although the effect should be optimised in terms of material parameters[9] such as Δn and $\Delta\varepsilon$, the principle of a bistable, electrically controlled, scattering, nematic liquid crystal display has been demonstrated.

Above the frequency of dielectric isotropy, as usual,[5] dynamic scattering can be observed (at $\sim$4 kHz). This can also be used to produce scattering that can be maintained, however, in a weakend form after the field has been switched off.

Conclusions: In conclusion we have shown the possibility of a bistable liquid crystal display using a filled nematic material as described. The display effect relies on direct static light scattering; hence no polarisers are required and the brightness is in principle excellent. This should make the effect potentially attractive for large-area displays such as billboards and overhead projectors. The two-frequency addressing scheme provides in principle a method for electrical control.

It should be emphasised that many aspects still have to be investigated, including the physics of the display effects. No attempts have been made yet to optimise the material parameters of the nematic liquid crystal. The effects of prior treatment of the boundaries (both of the filling material and the external glass plates) also still have to be investigated systematically.

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ANALYSIS OF EFFECTS OF QUANTISATION IN MULTILAYER NEURAL NETWORKS USING STATISTICAL MODEL

Indexing terms: Neural networks, Modelling

A statistical quantisation model is used to analyse the effects of quantisation when digital techniques are used to implement a real-valued feedforward multilayer neural network. A measurement of the degradation of performance of the network is derived following some assumptions. The newly defined 'effective nonlinearity coefficient' plays an important role in the study.

Introduction: One of the first problems in the hardware implementation of real-valued artificial neural networks is to determine how many bits are necessary to represent physical states, parameters and variables, to ensure certain performance. We use the statistical model of quantisation to study the effects of quantisation in feedforward multilayer neural networks. The idea is that a quantised signal can be represented by the original signal plus a quantisation error (noise), $e(n)$, which is assumed to be white noise, uniformly distributed in $[-\Delta, \Delta]$ (Δ is the quantisation width) and independent of the signal.[1] In the following, $E\{z\}$ represents the expectation of z, σ_z^2 denotes the variance of z, and σ_Δ^2 is the variance of the quantisation error which equals $\Delta^2/12$.

Effects of quantisation:

(1) *First hidden layer:* In the following, x_k^0 is the input signal from input node k, w_{ik}^0 is the weight connecting node k in the input layer and node i in the first hidden layer, y_i^0 is the input of node i and x_i^1 is the output

$$y_i^0 = \sum_{k=0}^{K_1-1} w_{ik}^0 x_k^0 \quad (1)$$

$$x_i^1 = f(y_i^0) \quad (2)$$

$f(\,)$ is the nonlinear transfer function of a node and the bias is treated as an input.

Assuming x_k^0 and w_{ik}^0 are quantised by N bits (one bit for sign), Δ_0 is the quantisation width and the quantised value falls in $[-\Delta_0(2^{N-1}-1), \Delta_0(2^{N-1}-1)]$ which can be approximated to $[-\Delta_0 2^{N-1}, \Delta_0 2^{N-1}]$ when N is large enough; therefore

$$y_i^0 = \sum_{k=0}^{K_1-1} (w_{ik}^0 + \Delta w_{ik}^0)(x_k^0 + \Delta x_k^0)$$

$$\simeq \sum_{k=0}^{K_1-1} w_{ik}^0 x_k^0 + \Delta y_i^0 \quad (3)$$

$$\Delta y_i^0 \overset{\text{def}}{=} \sum_{k=0}^{K_1-1} w_{ik}^0 \Delta x_k^0 + \sum_{k=0}^{K_1-1} x_k^0 \Delta w_{ik}^0 \quad (4)$$

Δx_k^0 and Δw_{ik}^0 are quantisation noises and are independent of each other, and of w_{ik}^0 and x_k^0. The corresponding variance is

$$\sigma_{\Delta_0}^2 = \Delta_0^2/12 \quad (5)$$

Assuming x_k^0 and w_{ik}^0 are uniformly distributed in $[-\Delta_0 2^{N-1}, \Delta_0 2^{N-1}]$ and independent of each other we have

$$\sigma_{\Delta y_i 0}^2 = \left(\sum_{k=0}^{K_1-1} E\{(x_k^0)^2\} + \sum_{k=0}^{K_1-1} E\{(w_{ik}^0)^2\}\right)\sigma_{\Delta_0}^2$$

$$= \zeta_0 K_1 \Delta_0^4 2^{2N} \quad (6)$$

$$\zeta_0 = 1/72 \quad (7)$$

To relate quantisation widths of different layers, we have to make some assumptions on the distribution of y_i^0.

$$\sigma_{y_i 0}^2 = \sum_{k=0}^{K_1-1} E\{(x_k^0)^2 (w_{ik}^0)^2\} = (K_1 \Delta_0^4 2^{4N})/144 \quad (8)$$

where noise is omitted. We define

$$\max|y_i^0| = \sqrt{(3\sigma_{y_i 0}^2)} = \eta_0 \sqrt{(K_1)} \Delta_0^2 2^{2N} \quad (9)$$

$$\eta_0 = 1/[4\sqrt{(3)}] \quad (10)$$

The distribution of y_i^0 is assumed to be uniform in $[-\max|y_i^0|, \max|y_i^0|]$. This distribution gives the same variance (power) of $\sigma_{y_i 0}^2$.