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A 128 × 128 ELECTRO-OPTICAL INTERFACE FOR REAL TIME DATA PROCESSING (*)

G. LABRUNIE, J. ROBERT and J. BOREL
C. E. N. G.-L. E. T. I., BP 85, Centre de Tri, 38041 Grenoble Cedex, France

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Résumé. — Les cristaux liquides nématiques peuvent être adressés électriquement lorsqu'ils sont montés en couches minces. Nous présentons dans cette communication un composeur de données optiques à cristaux liquides à adressage matriciel, mettant en œuvre l'effet électro-optique de modulation d'indice, ou *effet de champ*, obtenu dans une structure homéotrope soumise à un champ électrique alternatif. Il s'agit d'un dispositif d'affichage de 128 × 128 points capable de présenter simultanément 1,6 × 10^4 informations optiques digitales, l'ensemble étant inscrit en quelques millisecondes.

Abstract. — Nematic liquid crystals can be electrically addressed when sandwiched in thin layers. We present in this paper a liquid crystal optical data composer which is X-Y addressed using the electro-optical effect of index modulation, a *field effect*, realised for an a. c. electric field on an homeotropic structure. It is a 128 × 128 dots display capable of presenting at the same time 1.6 × 10^4 digital optical data, with overall writing times of a few milliseconds.

1. **Introduction.** — The main physical and electro-optical properties of nematic liquid crystals are well known to be related to their structural, optical and dielectric anisotropies. Hence, only a few words will be said about the classical thin cell of nematic liquid crystal and its dynamic behavior under a. c. electric field [1].

A liquid crystal cell consists of two optically flattened glass plates, separated by a mylar sheet spacer or a vacuum deposited insulating wall. Reactively sputtered indium oxide coated on the two glass plates, cleaned and rubbed, gives an homeotropic structure to a thin nematic film, i. e. a homogeneous orientation of the molecules perpendicular to the plates. In the absence of an external electric field, molecules of negative dielectric anisotropy ε_a are aligned perpendicular to the plates (Fig. 1). The optic axis of the uniaxial medium is

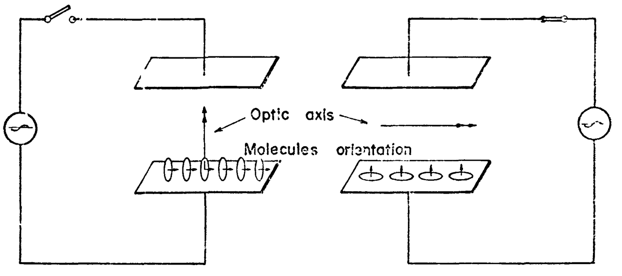

FIG. 1. — Field effect mode for a nematic liquid crystal with a negative dielectric anisotropy.

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also perpendicular to the plates. If an electric field is applied to the cell, molecules tend to align parallel to the plates due to their negative dielectric anisotropy. This is also true for the optic axis, and the transparency of the cell placed between crossed polarizers is changed. Intermediate values of the molecules tilting and of the cell's transparency are obtained by controlling the field strength. When the electric field is switched off, the homeotropic structure is restored with a time constant depending on the cell thickness and on the physical constants of the liquid crystal.

This electro-optical field effect is used in the following experiment.

We use a well known nematic liquid crystal which is M. B. B. A. (p-methoxy benzilidène-p-n-butyl aniline). The homeotropic liquid crystal cell is placed between crossed polarizers and we examine the transmitted monochromatic light when an a. c. pulse is applied to the cell. Figure 2 gives an idea of what can be observed.

A 300 V pulse is applied to a 7.5 μm thick cell. On the left, we can see that a pulse width of 20 μs gives a rise time for the electro-optical effect of about 20 μs and a delay time in the same range. If we increase the time scale, we can see on the right of the figure that the storage and decay times can be in the range of 10 to 20 ms.

This is the basic effect used in our composer : the storage effect within the medium allows us to address the other dots of the display. Theoretically, we have a possible number of addressed dots during the storage time equal to 20 ms/20 μs = 10^3.

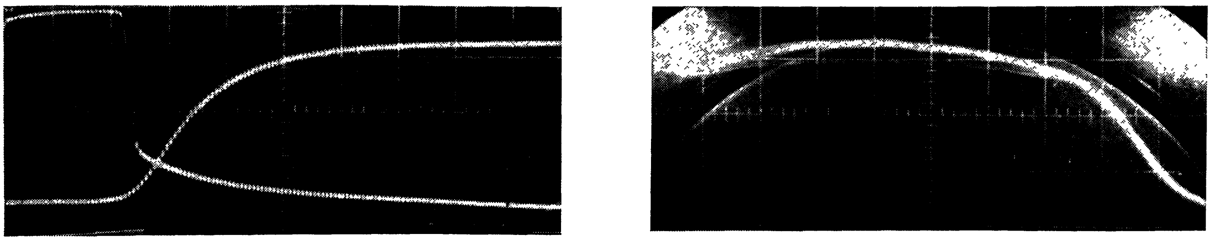

FIG. 2. — Transmitted light through an addressed dot ($V = 300$ V r. m. s., $L = 7.5$ µm) for one pulse : Left : addressing pulse and rise time (scale : 10 µs/div.) — Right : storage and decay time (scale : 2 ms/div.)

In a matrix addressing display, other limitations appear due to the fact that parasitic pulses are applied to a given dot during the storage time. Elsewhere, we generally apply voltage pulses of null mean value in order to avoid ion migration within the cell, and remain in the field effect mode. Ion migration causes a very fast degradation of the liquid crystal, thus limiting drastically the cell lifetime.

2. **Conception of the display.** — Figure 3 gives a schematic view of the display. It is made of two optically flat glass plates coated with indium oxide etched into stripes 280 µm wide and 20 µm spaced. The thickness of the cell is adjusted by a mylar spacer in the range $L = 5$ to 10 µm. At rest, owing to the indium oxide surface properties, we obtain a homeotropic cell : no transmitted light between crossed polarizers. Now we use the storage properties of the liquid crystal to address the whole dots of the display by means of X-Y addressing. Each word Y_1, Y_2, ... is sequentially addressed, and data are fed into bits X_1, X_2, ... simultaneously. Figure 4 gives a more detailed view of the addressing signals.

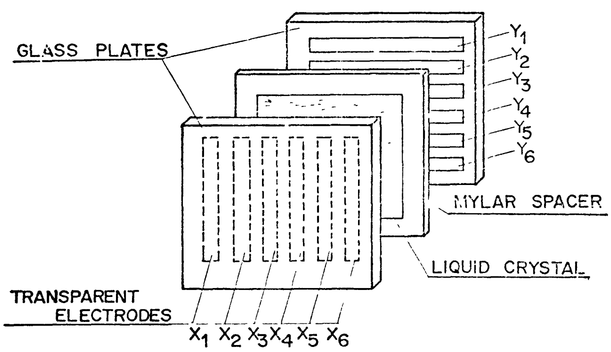

FIG. 3. — Schematic of the electro-optical display.

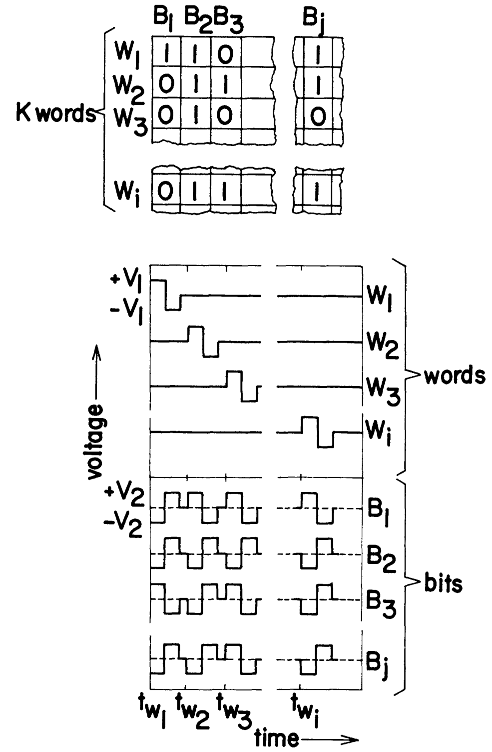

FIG. 4. — Addressing pulses in the time selection mode.

Suppose that we want to address a k words display using bits signals B_1, B_2, ...

A *one* will correspond to applying a $(V_1 + V_2)$ signal, and a *zero* to applying a $(V_1 - V_2)$ signal. In fact we apply either a. c. signals V_1 and V_2 in phase for $(V_1 - V_2)$ or with a phase shift of π for $(V_1 + V_2)$. A fast rise time is obtained by using a much higher voltage than the threshold voltage. The pulse widths are adjusted in order to induce the desired value of the birefringence in a sort of *time selection.* The display is driven sequentially and the whole page must be written in a time shorter than the natural storage time of the liquid crystal.

Elsewhere, we must take into account in our display the fact that parasitic pulses of value V_2 are applied during the whole writing time on the dots. But it can be seen that in our addressing sequence, these parasitic pulses, and the resulting cumulative effect on the whole display, are independent of what is written.

If a complete theoretical analysis of the effect is carried out, we find that in our case (if the induced birefringence $\Delta n \ll n_e - n_0$ and if the applied voltage $V_1 - V_2 \gg V_{th}$, which is practically always the case), the induced birefringence is given by the following formula

$$\Delta n(t, V) = \Delta n_{00} \exp A V^2 t$$

(t is the time).

Or else, for :

Address « 1 » :

$$\Delta n_1 = \Delta n_{00} \exp A.[(V_1 + V_2)^2 + (k - 1) V_2^2].\tau$$

Address « 0 » :

$$\Delta n_0 = \Delta n_{00} \exp A.[(V_1 - V_2)^2 + (k - 1) V_2^2].\tau$$

where :

— A is a function of the liquid crystal physical constants,

— Δn_{00} is the birefringence induced by thermal fluctuations

$$\left(\Delta n_{00} = \Delta n_{\max} \cdot \frac{L^2}{\pi^2 . K_{33}} \cdot k_B T \simeq 10^{-4}\right)$$

— τ is the pulse width.

Applying these results to our mode of selection, for a k words display, the values Δn_1 and Δn_0 are obtained for a selected *one* and a selected *zero*. The related transmissions through address « 1 » and address « 0 » dots are respectively :

$$T_1 = \sin^2\left(\pi \frac{\Delta n_1 . L}{\lambda}\right)$$

and

$$T_0 = \sin^2\left(\pi \frac{\Delta n_0 . L}{\lambda}\right)$$

between crossed polarizers (Fig. 5). The contrast ratio, defined as the ratio of the transmitted light through a *one* to the transmitted light through a *zero*, is also easily derived.

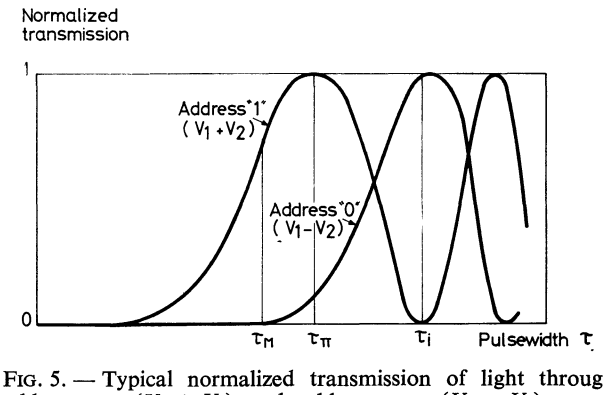

FIG. 5. — Typical normalized transmission of light through address *one* ($V_1 + V_2$) and address *zero* ($V_1 - V_2$) versus pulsewidth τ for $k = 128$ (see text).

As far as the contrast ratio is concerned, several modes of operation can be used :

— The first one is obvious : the pulsewidth is adjusted at a value τ_{Π} corresponding to the first maximum of transmitted light through a *one* (Fig. 5).

In that case, $\Delta n_1 = \lambda/2\,L$, and the contrast can be written in the following way :

$$C = \sin^{-2}\left(\frac{\Pi}{2} \cdot \frac{\Delta n_0}{\Delta n_1}\right).$$

As mentioned in a previous paper [2], this corresponds, for $k = 128$, to a contrast ratio of about 5/1, which has been checked experimentally.

— The second one, theoretically predicted by deriving the general expression of the contrast ratio versus pulsewidth τ, corresponds to the maximum contrast ratio, reached for $\tau = \tau_M$ (see Fig. 5). Calculations as well as experiments, as we will see, give contrast ratios greater than 50/1 in that case. Values ranging between 200 and 500/1 have been frequently measured.

— Other modes of operation can be used by varying τ, such as the contrast inversion given by $\tau = \tau_i$ (Fig. 5).

A last remark should be made concerning the contrast ratio. It does not depend on the addressing recurrence frequency for a fixed image (provided that it does not exceed about 100 Hz), as the electrical conditions of operation (generally the pulsewidths) are adjusted for this recurrence frequency. On the other hand, addressing a moving image at recurrence frequencies higher than about 10 Hz gives rise to trails in the image.

This can be easily overcome by erasing the overall interface before each address. The best way to achieve this, in our opinion, is to take advantage of the well-kown relaxation effect of the dielectric constant $\varepsilon_{\parallel}$ which takes place for frequencies f_R as low as $f_R = 2.5$ kHz [3] for certain nematic liquid crystals mixtures. We have experimentally checked this phenomenon for several mixtures synthetized in our laboratory or commercially available, and we are about to use it in our displays.

In this way, one can expect to display moving images at addressing recurrence frequencies even greater than 100 Hz without trails, and with operating electrical conditions and contrast ratios independent of the recurrence frequency.

3. **Experimental results.** — Experimental results were first obtained for a 32 × 32 data composer [2]. We have recently built a more complex display of 1.6×10^{-4} dots. Table I gives the main features of this 128 × 128 display.

TABLE I

Features of the nematic liquid crystal 128 × 128 optical data composer

NEMATIC LIQUID CRYSTAL 128 x 128 OPTICAL DATA COMPOSER

Liquid Crystal	M.B B A (p Methoxybenzilidene p.n. Butylaniline)	
	$n_o = 1.545$; $n_e = 1.756$ ($\lambda = 6328$ Å)	at room temperature
	$n_o = 1.56$; $n_e = 1.81$ ($\lambda = 5145$ Å)	
	$\varepsilon_a = \varepsilon_{\parallel} - \varepsilon_{\perp} = -0.57$	
Device	Cell thickness = 8 μm	
	Data block size = 38.5 x 38.5 mm²	
	Addressing voltages: on words V_1 = 120 V r.m.s.; on bits . V_2 = 10 V r.m.s.	
	One line addressing pulsewidth = 20 μs	
	Data composition time = 2.5 ms	
	Natural storage time = 5 ms	
	Read-out contrast ratio = 50 to 100/1	
	Optical efficiency in ON state = 86 %	
	Data transfert rate for these conditions = 4×10^5 bits/s	
	Maximum data transfert rate > 10^6 bits / s	

It can be noticed that :

— Data composition times of 2.5 ms are achieved.

— Contrast ratios are greater than 50/1.

— Data transfert rates higher than 1 Mbits/s are achieved, and this value can be overcome if erasing techniques are applied, which is not the case in our display up to the present.

— Optical efficiency of 86 % in the ON state, and without any AR coating, is reached. That means that the liquid crystal diffusion is very low : in fact, it can't be measured experimentally.

Figure 6 gives a schematic of the operating electronics. It allows us to obtain by means of a TV camera, a TV image which is electronically sampled on 128 × 128 digital data. This image can be stored in a memory and displayed alternately on a TV monitor and on the N. L. C. interface. Alternatively, the electronics can be operated in real time simultaneously on the TV monitor and on the interface at a rate of 25 frames per second.

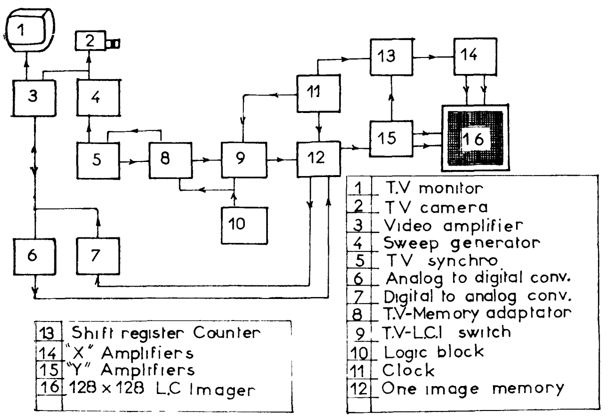

FIG. 6. — Schematic of the operating electronics.

Figure 7 shows an example of a TV frame sampled on 128 × 128 digits. On the left is the image on the TV screen and on the right, the corresponding image on the display. The slight difference in the sizes of the two images is due to the fact that the TV frame is sampled into dots which are rectangular, whereas those of the nematic liquid crystal display are square.

4. **Conclusion.** — In conclusion let us note that the use of liquid crystal displays can find many applications in the field of real time data processing in coherent optics.

They can be used as :

— Page composers for holographic optical memories.

— Spatial filters addressed by a computer for the different kinds of image processing on a coherent optical bench.

— An interface for displaying two dimensional functions on coherent optical sets for real-time processing. This application needs analog data composers, which are now under study in our laboratory.

And finally, it can be used as a filter operating mathematical operations in coherent optics, such as derivation, convolution, and other similar computations.

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FIG. 7. — Black and white 128 × 128 dots image :
Left : image on a TV monitor. — Right : image on the interface.

References

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