SESSION V: Optoelectronic Technology and Applications

WPM 5.2: Liquid Crystal Matrix Displays

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RECENTLY, A NEW ELECTROOPTIC EFFECT—dynamic scattering in nematic liquid crystals was described[1]. This paper will discuss the application of this effect to reflective matrix displays capable of producing moving halftone images in real time.

Figure 1a shows the basic liquid crystal element. It consists of a 1/2-mil layer of nematic liquid crystal material between electroded glass plates. The material has the rheological properties of a liquid, but behaves optically like an ordered crystal. In nematic materials the rod-like molecules are in parallel alignment. In this state the material is transparent and the viewer sees the dark background, while the incident light is reflected to whence it came. The molecules are polar, but the polar axis is angularly displaced from the molecular axis. The equivalent circuit of a liquid crystal cell consists of a capacitor and resistor in parallel. The relative dielectric constant and resistivity of the material are about 3 and 10^{10} ohm-cm, respectively.

Figure 1 shows the behavior of a display element when an electric field is applied. Figure 1a shows the relaxed state prior to applying a voltage. In Figure 1b the voltage has just been applied. The dipoles rotate into alignment and the molecules briefly scatter light. Continued application of the voltage causes ions to be launched into the material. While in transit they create a wake and the molecules in the wake are aligned as shown in Figure 1c. The boundary between field-aligned and wake-aligned molecules forward-scatters light resulting in increased brightness in the viewer's direction. In Figure 1d the voltage is removed and ionic flow ceases. Scattering boundaries remain until order gradually returns and the element is again in the relaxed state.

Figure 2a depicts graphically the described events. The slow increase in brightness is caused by an inherent delay in the initiation of ion flow. The decay time of brightness is strongly dependent upon temperature. Scattering can be quenched by applying a voltage pulse shortly after removal of the excitation voltage as shown in Figure 2b[1a]. If large in amplitude but limited in duration, this pulse reorients the molecules without launching new ions.

The brightness and contrast of the display element are dependent on the angles of viewing and illumination. The relationship is plotted in Figure 3 for one combination of angles. The curves for other angles are similar.

For use in a matrix display an element must possess a threshold, and preferably storage. The slow decay of brightness of the liquid crystal can provide storage, but the threshold must be provided externally; e.g. by diodes as shown in Figure 4a. Only diodes selected by coincident row and column signals can conduct. Addressing may be element- or line-at-a-time[2,3], but at conventional TV speeds the latter is generally preferred. The preprocessed information is contained as amplitude modulation of the column signals C, and the constant amplitude sequential row selection pulses R have a width of 60 μs. When the forward resistance of the diode and the source impedances of the addressing signals are low, then the equivalent addressing signal of Figure 4b can fully charge the display cell in 60 μs. Neglecting diode leakage, the cell voltage decays with a time constant of 3-4 ms, which is the relaxation time of the liquid crystal. Since the cell does not respond promptly, the peak in the brightness response occurs at a point where the cell voltage has decayed significantly as shown in Figure 4d. Some disadvantages of this addressing scheme are the following: large addressing voltages are required; brightness response is critically dependent on the resistivity of the liquid crystal; average contrast is low.

Figure 5 shows a better addressing scheme. A capacitor is placed in parallel with the liquid crystal cell to increase the time constant of the circuit. Now the applied voltage is stored across the liquid crystal for the entire field period. The addressing voltage required to achieve saturated brightness from the liquid crystal is thus substantially reduced, and the average brightness also increases considerably. However, a second diode D_2 is needed in this circuit to discharge the stored voltage at the end of the field period. This reset operation also occurs line-at-a-time just before the row is updated with new information.

The system of Figure 5 can be improved by introducing the low impedance generators designated *FT* for applying fast turn-off pulses. Since the capacitor C is much larger than the capacitance of the liquid crystal cell, most of the voltage pulse from *FT* appears across the liquid crystal cell. Also, node *X* stays close to *E* and diodes D_1 and D_2 remain reverse biased. This system permits smear-free moving images to be obtained with liquid crystal displays.

MOS transistors can also be used to address liquid crystal display matrix elements. Row selection pulses are applied to the gate terminals, column signals to the drain terminals, and the liquid crystal cells in parallel with storage capacitors are connected to the source terminals. The transistors function as switches which are closed while a row pulse is present. Since the channel of the MOS transistor conducts in both directions, separate reset signal busses are not required. Fast turn-off pulses may be applied in the manner described above.

All of the foregoing addressing schemes have been used with 2 × 18 liquid crystal display matrices employing discrete components to implement the circuitry. These displays are addressed at TV speeds to produce moving halftone images. Worst-case disturb pulses are also applied to simulate the environment of a real 525 line matrix. Figure 6 is a photograph of one of these displays.

Acknowledgments

The authors are indebted to G. H. Heilmeier for numerous valuable insights into the behavior of liquid crystals, and to L. A. Zanoni and E. L. Kaschak for construction of the displays.

[1a]The possibility of achieving fast turn-off was first pointed out by G. H. Heilmeier.

[1]Heilmeier, G. H., Zanoni, L. A., and Barton, L. A., "Dynamic Scattering: A New Electrooptic Effect in Certain Classes of Nematic Liquid Crystals", *Proc. IEEE*, p. 1162-1171; July, 1968.

[2]Lechner, B. J., "A Ferroelectric Transcharger Controlled Electroluminescent Matrix Display", *ISSCC Digest of Technical Papers*, p. 86-87; Feb., 1965.

[3]Lechner, B. J., Samusenko, A. G., Taylor, G. W., and Tults, J., "Ferroelectric Controlled Electroluminescent Displays", *Proceedings National Aerospace Electronics Conference*; May, 1966.

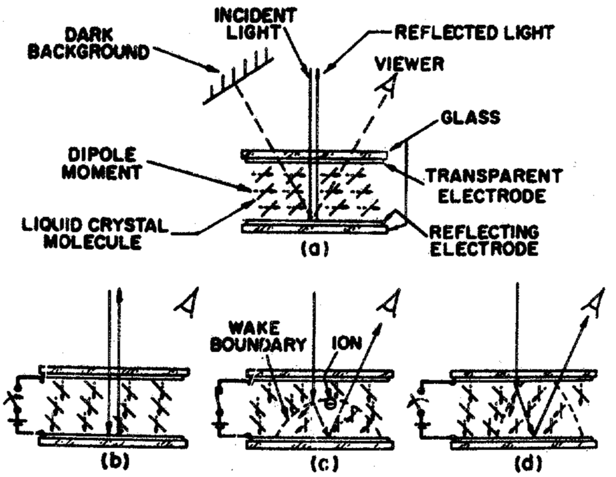

FIGURE 1—**Cross section of the basic liquid crystal cell and its response to an applied electric field.**

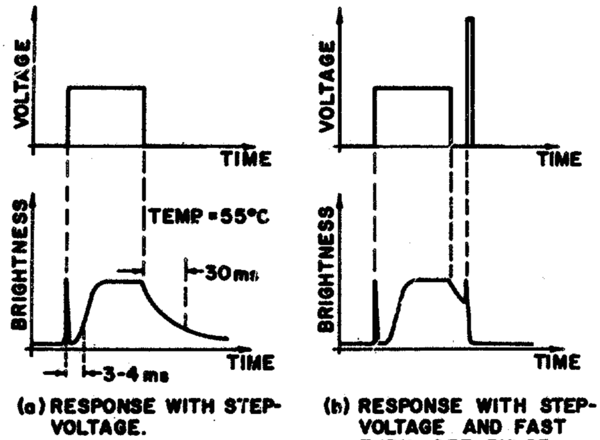

FIGURE 2—**Dynamic brightness response of a liquid crystal cell.**

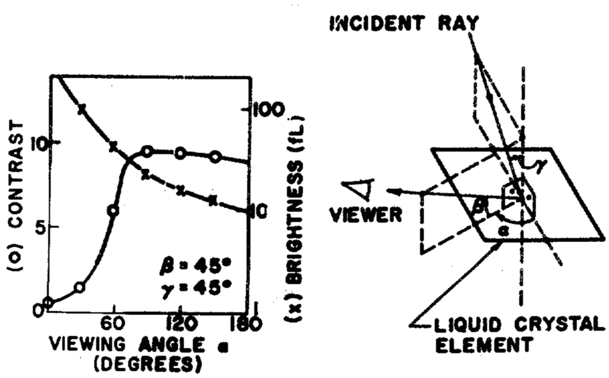

FIGURE 3—**Brightness and contrast of a liquid crystal cell as a function of viewing angle.**

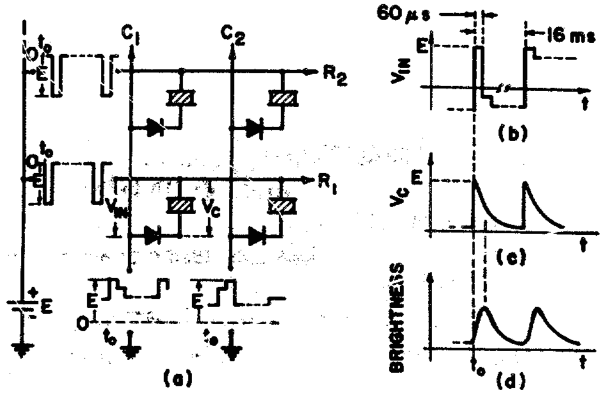

FIGURE 4—**Configuration and operation of a simple liquid crystal display matrix.**

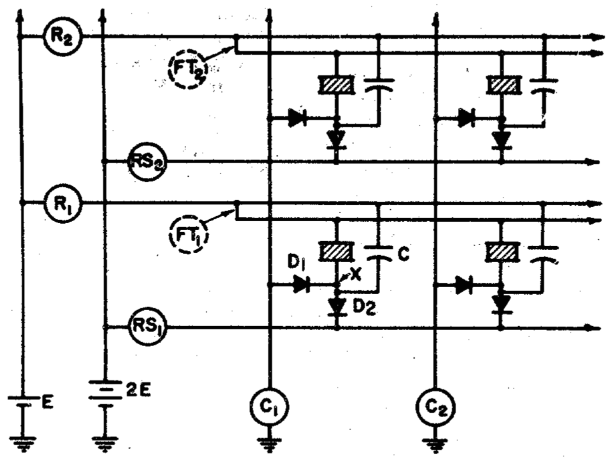

FIGURE 5—**Configuration of an improved liquid crystal display matrix employing storage capacitors and featuring voltage resetting at the end of a field.**

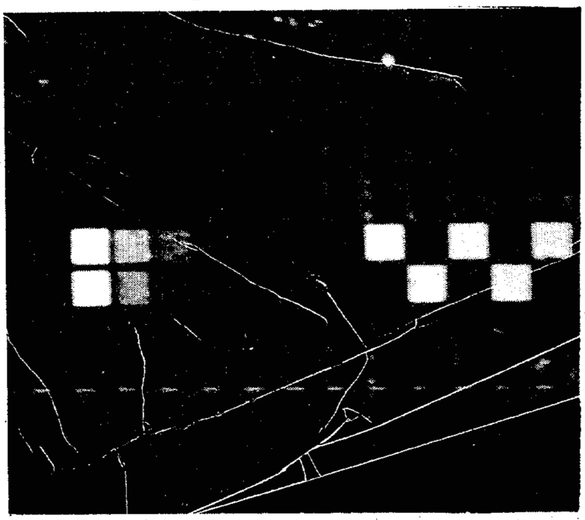

FIGURE 6—**Photograph of a 2 x 18 liquid crystal display matrix showing a halftone image; the dimensions of one cell are 60 x 60 mils.**