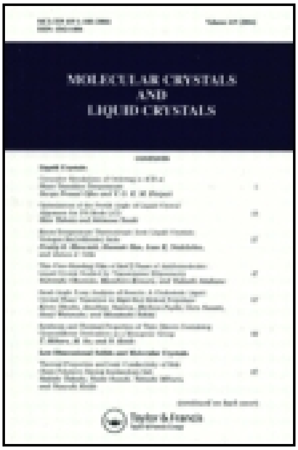

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MODELLING OF THE ELECTRICAL CHARACTERISTICS OF A MATRIX ADDRESSED SSFLCD DEVICE

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Abstract The electrical characteristics of a Surface Stabilised Ferroelectric Liquid Crystal Devices (SSFLCD) differ from that of conventional liquid crystal devices (LCDs.) in that the current response to an applied voltage includes a polarisation term in addition to the capacitative charging and resistive loss parts of a conventional LCD.

The electrical characteristics of the SSFLCD are modelled, and the implications for TV applications deduced from the model are discussed.

INTRODUCTION

When considering using the SSFLCD for large area matrix addressed displays, it is important not only to assess the distortion effects due to the resistance and capacitance of the matrix, but also to consider the contribution of the polarisation reversal current to the waveform distortion as well. It is also important to quantify the extra power consumption due to polarisation reversal, which is thought by many to put an upper limit on the practical value of the spontaneous polarisation.

We present theoretical and experimental results describing waveform distortion in an SSFLCD matrix, and we use the theoretical model described to relate the voltage, current and power requirements of such a display to the LC. material properties.

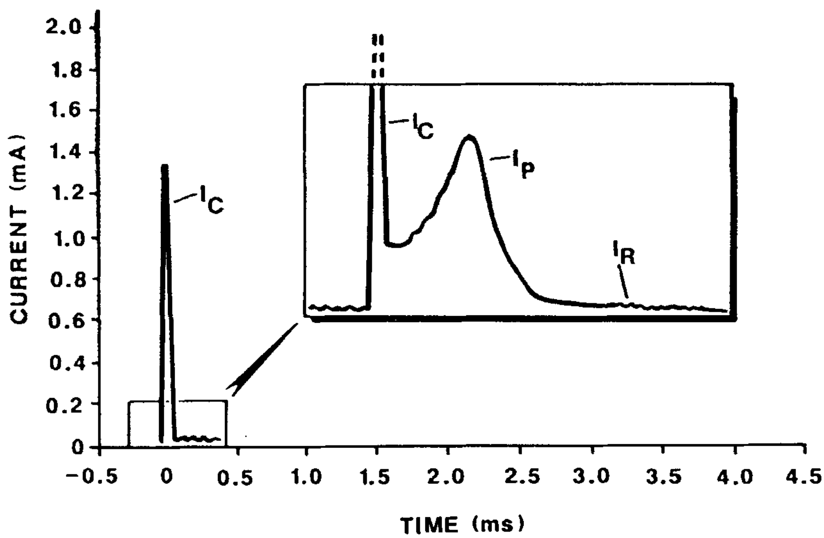
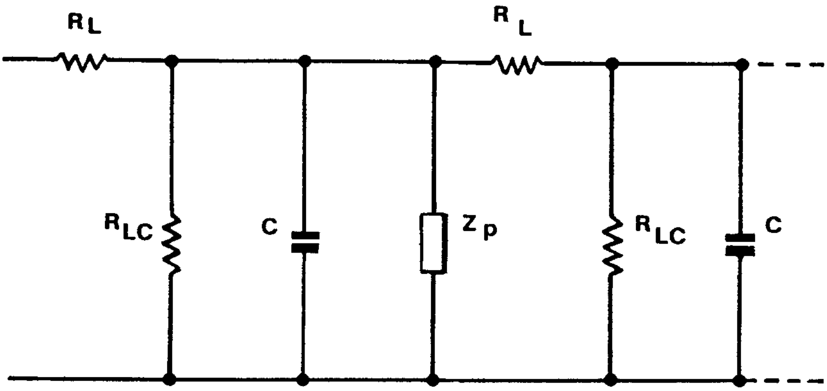


FIG 1 CURRENT FLOW IN AN SSFLCD

THEORY

The three main contributions to current flow in an SSFLCD are shown in figure 1. They are :that due to the charging up of the capacitance of the device, I_r; that flowing as a result of the finite resistance of the LC material, I_r; and that due to the re-orientation of the LC molecules, I_p.



R_L ≡ RESISTANCE OF MATRIX LINES

R_{LC} ≡ RESISTANCE OF LIQUID CRYSTAL

C = CAPACITANCE OF LIQUID CRYSTAL

Z_p ≡ EQUIVALENT IMPEDANCE DUE TO POLARISATION REVERSAL

FIG 2 EQUIVALENT CIRCUIT

In order to model the voltage and current flow in a matrix of FLCD, we begin by drawing an equivalent circuit for a linear array of FLCD elements, as shown in figure 2. Where : R_L is the resistance of the transparent electrodes making up the array; R_{LC}, is the resistance, and C is the capacitance of the SSFLCD element and Z_p, is the equivalent circuit element describing the current flow I_r.

Since there is no real circuit element corresponding to Z_p, it is necessary to deduce a mathematical expression relating the current flow through Z_p, to the voltage applied across it, in order to build a complete model of the array.

If we consider the polarisation reversal giving rise to Ip as simply being a stack of dipoles rotating around to point in the opposite direction, then the observed current will be proportional to the velocity of the charge in a direction normal to the electrodes:

$$I = \sin\theta \cdot \frac{d\theta}{dt} \qquad (1)$$

Where θ, is the angle the dipole makes with the normal to the electrodes.

We can regard the dynamics of this molecular re-orientation classically, by assuming Eq. (2), describing the torques acting on the molecules, is obeyed.

$$E.P.\sin\theta + \Delta\epsilon^2\cos\theta + \eta\cdot\frac{d\theta}{dt} = I_m\frac{d^2\theta}{dt^2} \qquad (2)$$

Where E = applied electric field; P = permanent dipole moment; $\Delta\epsilon$-Dielectric anisotropy; η= a viscosity coefficient; I_m Moment of inertia of a molecule.

If we make the simplification that the system is overdamped, that is the viscous resistance to motion is much greater than the inertial component of the system. This means that the rate of change of the re-orientation, d θ/dt, of the system will be in phase with the the applied torque. We can roughly say, assuming that the P_s coupling dominates that:

$$\frac{d\theta}{dt} \propto \sin\theta \tag{3}$$

By choosing $\theta = k.V(t-t_o)$, where k and t_o are empirically determined constants, and V the applied voltage, and only defining θ over the range $0 < \theta < \pi$, and by using the condition that the total charge flowed $=P_s.A$, where A = area of the electrode then:

$$I = \frac{2.Ps.A.V_{(x,t)}.k}{\pi} \sin^2\left(V_{(x,t)}.k(t-t_o)\right) \tag{4}$$

Figure 3a shows the theoretical fit to the experimental data by using the two fitting parameters k and t_o and figure 3b shows the theoretical fit with the same fitting parameters

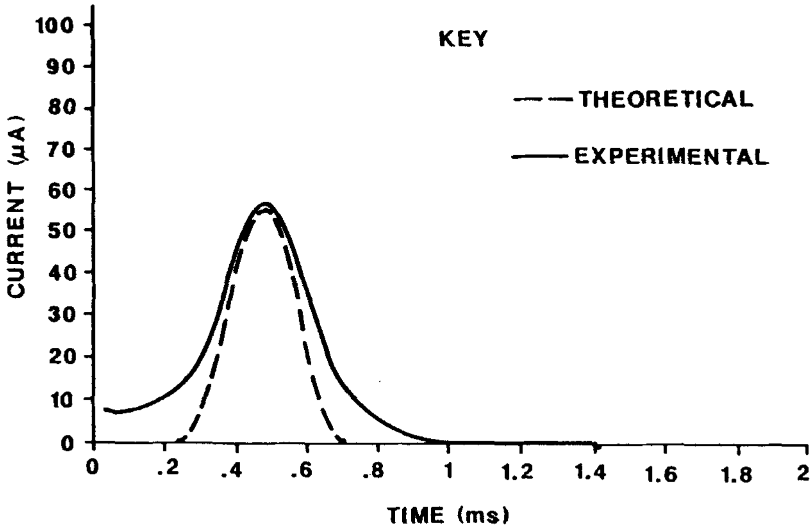


FIG 3a

THEORETICAL AND EXPERIMENTAL DATA FOR POLARISATION REVERSAL CURRENT (a) WITH 50V PULSE (b) WITH 20V PULSE

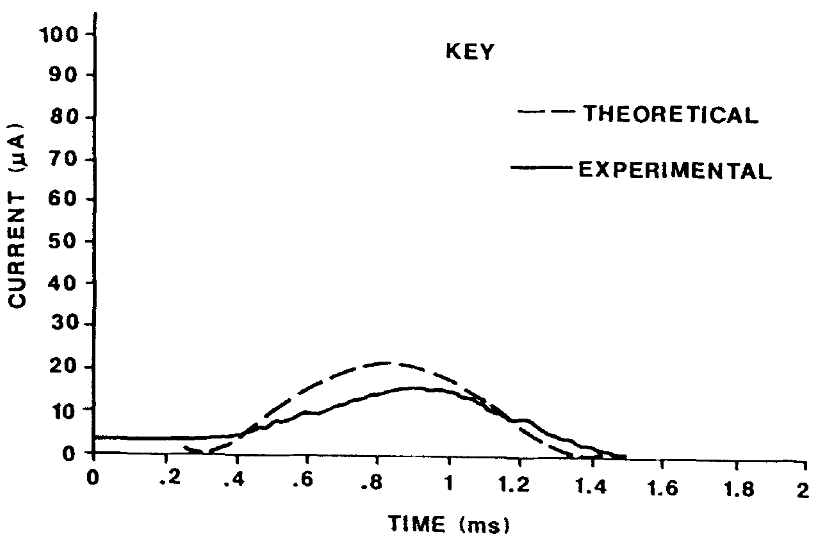


FIG 3b

but at at a lower applied voltage. The important part of the theory is that the voltage dependence of the current flow should be adequately described, which figures 3a and 3b clearly show.

We can extend the Telegraph Equation, which describes the voltage as a function of time and position down an RC transmission line, to describe the transmission shown in figure 2, which represents a line in the SSFLCD matrix, by using Eq. (4):

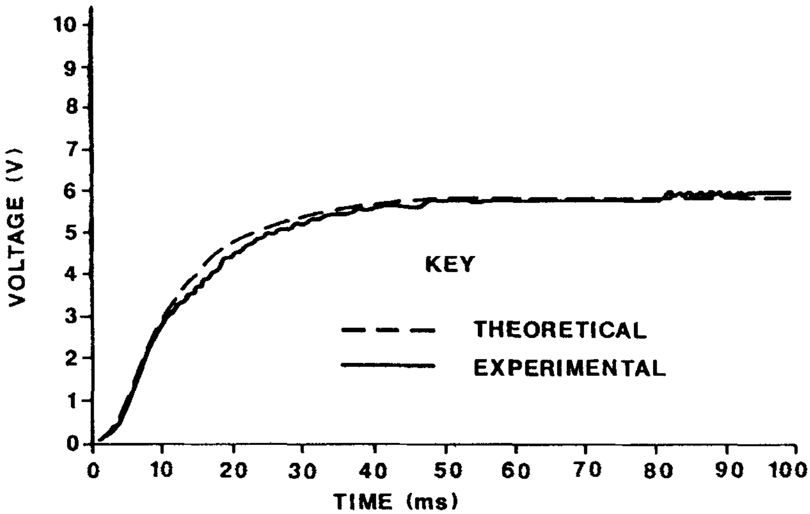
$$\frac{1}{R_L}\cdot\frac{\delta V_{(x,t)}}{\delta t}=C.\frac{\delta V_{(x,t)}}{\delta t}+\frac{1}{R_{LC}}\cdot V_{(x,t)}+$$

M

$$\frac{2Ps.A.V_{(x,t)}.k}{\pi}\mathrm{Sin}^2\left(V_{(x,t)}.k\left(t-t_o\right)\right) \qquad (5)$$

Eq. (5) can be solved without the 'V' in the Sin ($kV(t-t_O)$) term, using Half Range Fourier analysis, and then iteratively substituting the result of this into the full Eq. (5) to obtain the full solution.

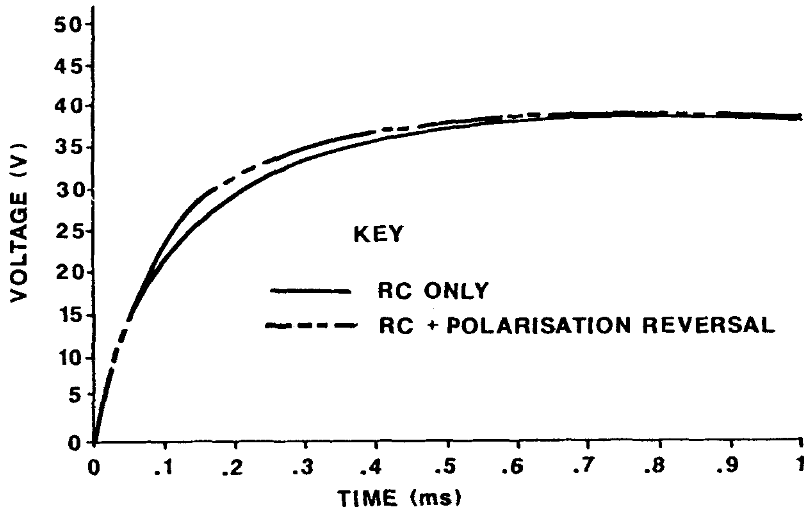
Although Eqn. (5) only applies to a linear array of SSFLCD elements we can model the voltage at any point in a two dimensional matrix using the superposition principle, and performing the calculation twice.



DIELECTRIC CONSTANT = 5
SHEET RESISTIVITY = 200 Ω/□
LC RESISTIVITY = 7×10^{11} Ω m
PIXEL SIZE = 0.9 x 0.9mm
DISPLAY THICKNESS = 1.0um
SOURCE RESISTANCE = 600 Ω
NO. OF PIXELS = 64 x 64
MEASURED AT PIXEL 64,64

FIG 4 COMPARISON OF THEORETICAL AND MEASURED RISE TIMES AT A VOLTAGE BELOW THRESHOLD FOR SWITCHING

RESULTS



DIELECTRIC CONSTANT	= 5
SHEET RESISTIVITY	= 200 Ω/□
LC RESISTIVITY	= 7×10^{11} Ω m
PIXEL SIZE	= 0.9 x 0.9mm
DISPLAY THICKNESS	= 1.0µm
SOURCE RESISTANCE	= 600 Ω
NO. OF PIXELS	= 500 x 700
MEASURED AT PIXEL	500,700
SPONTANEOUS POLARISATION	= 100nC/cm^2

FIG 5 RISE TIMES IN AN A4 SIZE DISPLAY WITH RISE TIME COMPARABLE TO SWITCHING SPEED OF POLARISATION REVERSAL

The experimental matrix we used was 64 ,64 and 1um thick with each of the pixels .9 mm square. Initially we used an applied voltage below the threshold for switching, and compared the experimental and theoretical results at the 64th row and column. (See figure 4.) As the applied voltage was below threshold, the calculations were made using Eq. (5) without the last term (which is zero below threshold as there is no polarisation reversal).

Having confirmed the conventional transmission line theory for our matrix, we re-calculated the theoretical results including the polarisation term, using a P_s of 100 nC/cm^2 and compared these results to the case of switching below threshold. We only found a significant difference between the two sets of results when the RC time constant of the display was comparable to the switching time of the LC. (Figure 5.)

The theory in fact predicts that the rise time including the polarisation reversal is faster than the rise time due to RC alone. On closer examination, we see that the initial rise time is slightly slower in the polarisation reversal case, but later on, the polarisation reversal case tails off more slowly, and has the faster rise time.

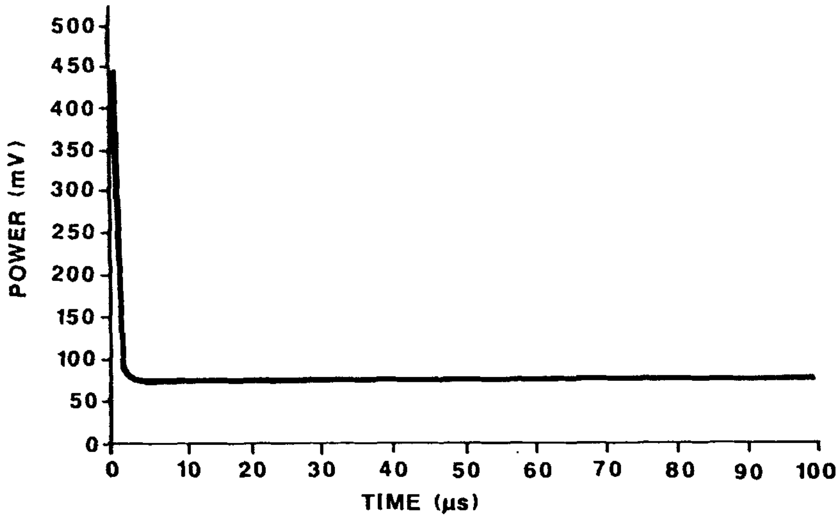
This can be explained by the initial re-orientation of the dipoles taking current out of the circuit, and so slowing the rise time down, and then after the dipoles reach a critical orientation, they continue their rotation under the influence of their own elastic forces, and so put current back into the circuit and hence speed the rise time up.

Although we were not able to verify this limiting case experimentally, we can say that in our experimental device, where the switching speed and the RC time constant were not comparable, that there was no observable difference in the rise time above and below threshold.

DISCUSSION.

We conclude that the limiting factor in producing large area SSFLCDs, in terms of waveform distortion, is the RC time constant of the matrix lines. If this is faster then the switching time of the LC than polarisation reversal effects can be ignored.

There are two important consequences of RC time constant effects relevant to SSFLCDs, these are the attenuation and the rise time of the applied voltage: the attenuation of the voltage in a display could lead to parts of the device responding to crosstalk data pulses, where unwanted switching occurs, while other parts of the display would not switch into the desired states; the effect of slower rise times seems less critical, as our experiments showed little change in response of the LC to pulses with rise times similar to or faster than that of the response time of the LC.



IN THIS LIMITING CASE, POWER AVERAGED OVER A LINE TIME ~ 90W

USING CURRENTLY AVAILABLE MATERIALS ~ 20W

FIG 6 POWER CONSUMPTION OF ONE LINE OF A4 DISPLAY

The power consumption of the device also depends on the RC of the matrix, as well as the resistivity of the LC material. Figure (6) shows these two contributions to the power consumption for the case of an applied voltage step: the peak power occurs as the capacitance first charges up, and then the current decays to the constant level governed by the resistive current flow through the LC material. Both these contributions need to be considered when calculating the net power consumption of devices with different applied pulse widths.

CONCLUSION

By modelling the effect of polarisation reversal current in matrix SSFLCDs, we have shown that its effect on waveform distortion is small for moderately large values of spontaneous polarisation, and that this is also observed experimentally. Although we have not precisely verified the theory, we have shown that this distortion only becomes observable when the rise time due to the RC of the system, becomes comparable to the switching time of the LC.