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S. J. Elston; E. A. Coleman

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The influence of spontaneous polarization on symmetry recovery addressing schemes for ferroelectric liquid crystal devices

by S. J. ELSTON* and E. A. COLEMAN
Department of Engineering Science, University of Oxford, Parks Road, Oxford OX1 3PJ, UK

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Symmetric addressing is investigated in both low and high spontaneous polarization ferroelectric liquid crystal devices. For devices containing low polarization materials the approach is shown to prevent image ghosting. High polarization materials however show a locking effect at a particular grey level. This extends over a range of pulse amplitudes and frequencies, and is explained as an ionic effect. It may limit the exploitation of symmetric schemes to low polarization materials.

1. Introduction

Although ferroelectric liquid crystals (FLCs) have been under investigation for around twenty years [1, 2] their commercial exploitation is still very limited. In particular the use of these materials in the 'next generation' of displays, predicted in the early 80s, has not materialized. Their bistability and relatively fast switching [3] are potential advantages when compared with the commonly used nematic materials; there are however also a number of problems. These include the difficulty of obtaining large areas of high quality alignment, the complexity of the internal smectic layer structure and limited shock resistance. A further problem is the difficulty of achieving grey scale in display devices using FLCs, a direct consequence of their bistability.

A number of solutions to the grey scale problem have been proposed, including sub-pixellation [4], temporal dither [5] and partial switching [6]. The simplest to implement, in principle at least, is the latter of these. This approach exploits the domain switching process which takes place in FLC device structures. Applying a pulse of sufficient amplitude to start the switching process (form domains), but insufficient to cause total switching, will leave the device in a multi-domain partially switched state. As the domains are typically a few tens of microns across they will not be individually resolved by a viewer, and the result is an apparent grey state. Varying the proportion of black and white domains (by varying the pulse amplitude) results in a controlled grey level.

There are a number of difficulties limiting the exploitation of this approach. One which has recently received attention is the influence of ions on the partially switched states [7, 8]. When the FLC device is in one switched state ions drift in the field of the spontaneous polarization; this has a significant effect on subsequent switching, and is particularly important for partially switched states. The result is a memory effect in a device, or pixel, which leads to image ghosting/smear in display applications.

2. Symmetry

It was recently proposed that this problem could be overcome by the use of a symmetric addressing scheme in FLC displays [9]. The idea was that the device should be alternately switched between opposite states, *so that there is no net polarization across the device, and therefore no ionic build up*. This can be extended to the case of partially switched states. It is then necessary to use either stroboscopic illumination (to illuminate only one half of the cycles), or a second device with its switching set to invert the optical effect of alternate cycles [9]. This was demonstrated for a test device containing a low spontaneous polarization FLC material, showing a range of controlled grey levels.

In such a scheme we may need to switch a device faster than conventionally necessary; this will be especially important if using stroboscopic illumination and observing alternate cycles. High speed switching can be achieved by using a material with a high spontaneous polarization, but such materials are normally particularly prone to ionic effects. When using a symmetric addressing scheme however, we would expect such effects to be minimized; with alternate cycles being in alternate states there should be no significant ionic build-up.

Here we will illustrate directly how symmetry recovery

*Author for correspondence.

removes ghosting in a low spontaneous polarization FLC material. We will then show results for a high spontaneous polarization material, and discuss the implications of these.

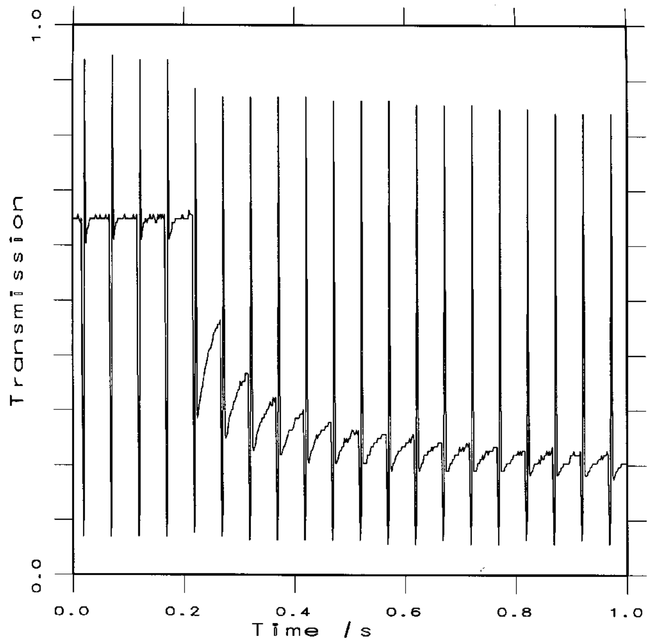
3. Experiments

Our experimental arrangement probes the transmission (at 690 nm) through devices placed between crossed polarizers and oriented so that one of the extreme switched states shows extinction. Devices are driven from a computer controlled arbitrary waveform generator, and the optical response is logged on an 8-bit digitizing oscilloscope. The devices are 2 micron thick, polyimide aligned.

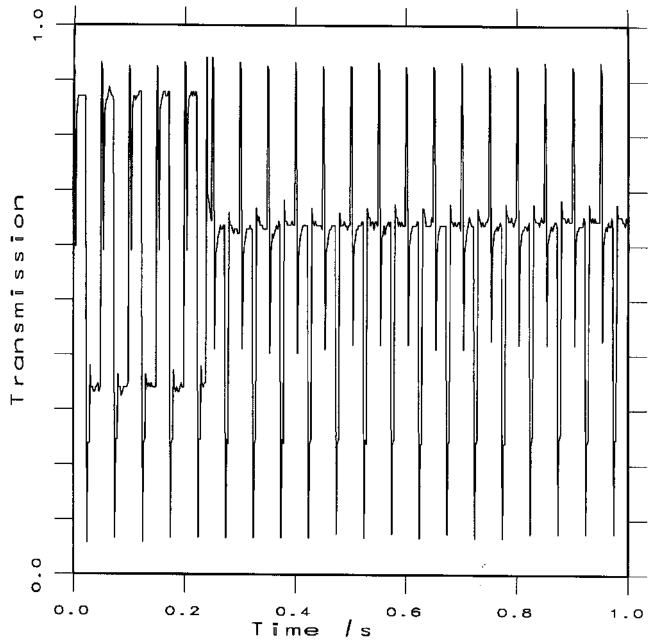
Figure 1 (*a*) shows the response of a low polarization device (ZLI3655-000, $\mathbf{P}_S = 7\,\mathrm{nC\,cm}^{-2}$) to a change in driving pulse amplitude for a non-symmetric scheme. This scheme consists of a 100 microseconds reset pulse into the dark state, followed 5 milliseconds later by a 100 microsecond switching pulse of opposite polarity and controllable amplitude; the sequence is repeated every 50 milliseconds. We clearly see that it takes many cycles for the device to settle to a new partially switched state after the switching pulse amplitude is changed; this would be observed as serious ghosting/smear in a display.

Figure 1 (*b*) shows the response to a change in pulse height for a symmetrized version of the above scheme. This has the same reset and switching pulse described above, but additionally has a reset pulse of opposite polarity 25 milliseconds after the start of the sequence, and a corresponding opposite polarity switching pulse at 30 milliseconds. In this scheme both switching pulse amplitudes are changed simultaneously. The alternating switched states in the cycle can be seen in figure 1 (*b*), and it is also clear that the new equilibrium is reached very rapidly after the pulse amplitude is changed. This shows very clearly the power of the symmetry recovery technique in avoiding the effects of ionic memory, and corresponding image ghosting effects. In principle this can be combined with a second device, or stroboscopic illumination, in order to form a useful display system [9].

Before showing the influence of a higher spontaneous polarization on the symmetry recovery approach it is useful to illustrate results in a different form. We extract from the optical response the transmission state immediately before the reset pulses in each direction. For very small switching pulse amplitudes, this will obviously be the previous reset state, and for large switching pulse amplitudes the fully switched states will be observed. As the switching pulse amplitudes are varied, each of the states will cross over to become the other. This is illustrated in figure 2, which shows the evolution of the



(*a*)



(*b*)

Figure 1. (*a*) The response to a change in pulse height for a non-symmetric scheme (low spontaneous polarization material); note that it takes many cycles to reach a new equilibrium grey state. (*b*) The response to a change in pulse height for a symmetric scheme with the same device, showing that equilibrium is reached almost immediately.

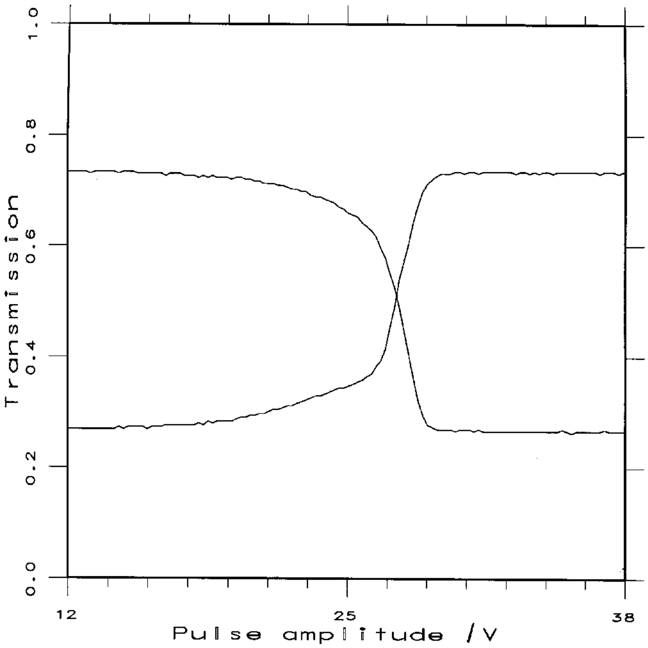


Figure 2. The 'state' curves for a low spontaneous polarization material, showing the response to varying pulse height in a symmetric scheme. The two curves are extracted from alternate halves of the symmetric cycle.

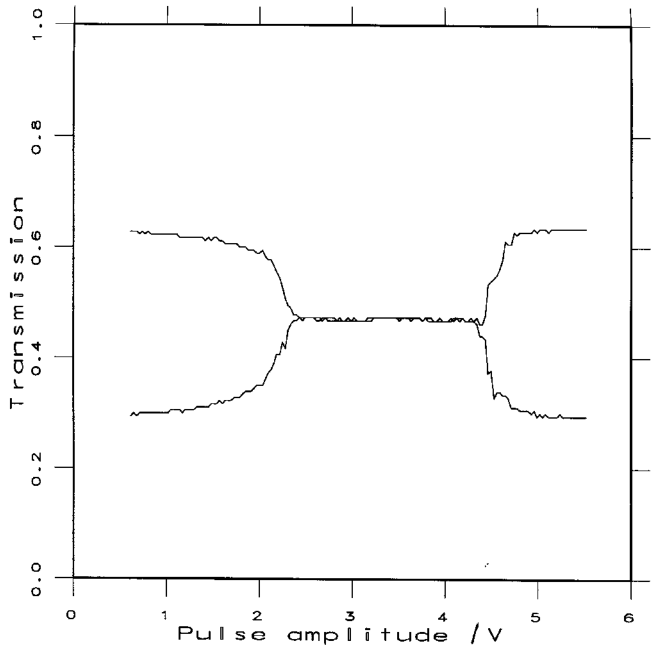


Figure 3. The 'state' curves for a high spontaneous polarization material; note the locking over a range of pulse heights.

states for steadily increasing pulse amplitudes. Outside of the illustrated region, the pulse amplitude variation has no effect. It can be seen that the behaviour in alternate cycles is highly symmetric, and that a controlled grey scale could be achieved by extracting one of the curves (through stroboscopic illumination, etc.). If similar effects can be obtained in high spontaneous polarization materials then a high speed symmetric scheme may be available.

To test the high spontaneous polarization case we use a similar cell filled with ZLI3655-100, which has a polarization of $23\,\mathrm{nC\,cm^{-2}}$ at room temperature. We retain the same symmetric timing sequence used above, but now, because of the higher spontaneous polarization, the reset pulse amplitudes and the switching pulse amplitudes are reduced to a suitable level. The states obtained for varying switching pulse amplitude are shown in figure 3; it is clear that these are somewhat different from those seen in figure 2. In particular we observe a severe 'locking' effect for a range of pulse amplitudes, resulting in what are effectively three stable states. This effect can be further illustrated by taking stroboscopic polarized microscopy images of the switched states. These are shown in figure 4, where the first pair of images show the states with small switching pulse amplitudes, the second pair show the states with switching amplitudes in the 'locked' regime, and the third pair show the states with larger switching pulse amplitudes (and are in effect the complement of the first pair).

Now it is also important to consider the cycle/frame time dependence of this locking effect, as it is high speed (short frame time) switching which will be of most interest. We may expect that at higher frame frequencies the locking effect would not occur for the high spontaneous polarization material, and that at lower frame frequencies a locking effect would also be observed in the low spontaneous polarization material. Figure 5 shows a contour plot of the difference between states for the low polarization device with frame times ranging from 25 milliseconds (twice the speed of that shown in figure 2) to 1·25 seconds (25 times slower than in figure 2). The pulse widths are scaled to the frame time (i.e. range from 50 microseconds to 2·5 milliseconds), and the amplitudes are scaled to keep the crossover regime on the graph. It can be noted in figure 5 that at no frame time is there a plateau in the crossover regime. Thus, with the symmetrized addressing scheme, increasing switching pulse amplitude results in a smooth cross over between states with no locked region (over a wide range of frame times).

Figure 6 shows a similar contour plot for the high polarization device, with frame times ranging from 2·5 milliseconds (20 times the speed of that in figure 3) to 125 milliseconds (2·5 times longer than that shown in figure 3). Again the pulse widths are scaled to the frame

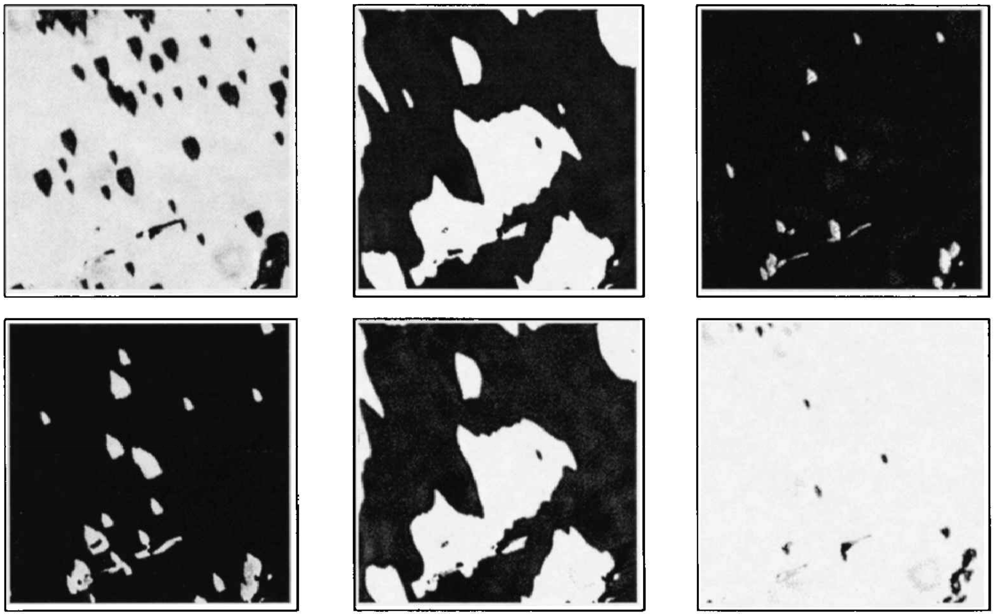


Figure 4. Stroboscopic microscopy images of the domains in the three characteristic regimes of the state curves for the high polarization material. In the first and last pairs of images the switching is alternating between symmetric states, but in the central pair (corresponding to the locked regime) little or no switching is taking place.

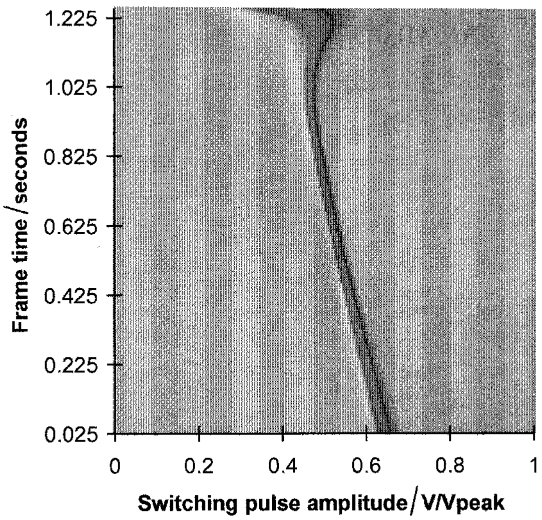


Figure 5. Shaded contour plot of the difference between states for a low spontaneous polarization material over a frame time range of 25 milliseconds to 1·25 seconds. The switching pulse amplitude is varied from zero to a peak value of $V_{peak} \approx 20f^{0.333}$ where f is the frame frequency in Hz. The light grey regions on the left and right of the plot represent the switching regimes; the multi-shaded band shows a smooth transition between them and indicates that no locking effect is present.

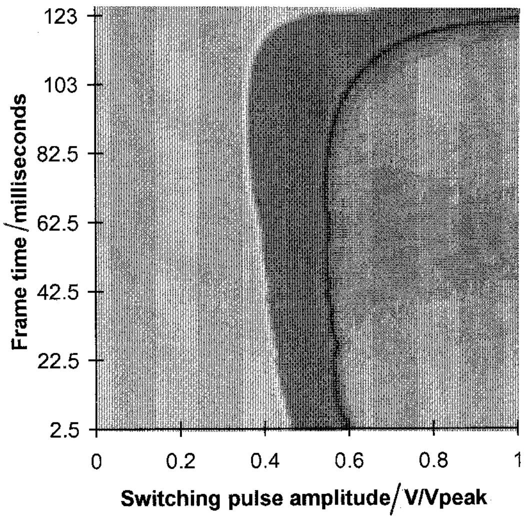


Figure 6. Shaded contour plot of the difference between states for a high spontaneous polarization material over a frame time range of 2·5 to 125 milliseconds. The switching pulse amplitude is varied from zero to a peak value of $V_{peak} \approx 0{\cdot}216f$ where f is the frame frequency in Hz. The light grey regions on the left and right of the plot represent the switching regimes. Additionally there is a broad band between these (of darker grey on the plot) which represents a locked regime.

times (i.e. range from 5 to 250 microseconds), and the amplitudes are scaled accordingly. Now however there is a plateau (i.e. a locked regime) which extends over a significant switching pulse amplitude range (at all frame times investigated). Thus it appears that even with short frame times of 2·5 milliseconds, corresponding to a frame frequency of 400 Hz, a serious locking effect is observed in high spontaneous polarization materials. High speed symmetric addressing does not appear to avoid the difficulties of ionic memory in such materials.

4. Discussion

We have noted some of the problems which ions cause in FLC devices and shown that symmetry recovery is a useful technique for low spontaneous polarization materials. This appears however to break down for partially switched states in the case of high polarization materials. The reasons can be understood if we consider what happens during switching of partially switched states around the 50% level. If a device is switched at the 50% black/50% white level using a symmetric scheme and a reset is applied followed by a 50% switching pulse, then we expect the device to remain at the 50/50 level. This is true whether it is a black reset followed by a partial switch towards the white, or a white reset followed by a partial switch towards the black. If such a process is observed using stroboscopic polarized microscopy, then we see that not only does the device remain 50/50 switched, but also that the same regions remain black and white for either sequence (see figure 4). This has been noted before for devices containing low polarization materials if they have been left in a partially switched state for many seconds [8]. While for low polarization materials the effect is minimized through symmetric addressing, it remains for high polarization materials. This is very clear in the second pair of images in figure 4, which are virtually identical.

When switching takes place in FLC devices, the domains are seeded through defects which are not necessarily symmetric. Thus regions which seed easily when switching from black to white may not seed when switching from white to black. The result is that a region which has seeded when switching from the black reset state towards a partially switched state (and is therefore in a white state) may not seed when switching from the corresponding white reset state towards a partially switched state (and therefore it remains in a white state). In such a region the ions will drift in the field of the net polarization even if the addressing is symmetric. For high polarization materials this will be a significant effect, and makes the region subsequently difficult to change. So in a high polarization device, regions can switch alternately between black and white states, but can also become locked in one of these states. We therefore see three regimes as the switching pulse amplitudes are increased. One where there are just the alternating reset states, one where the device has locked into a partially fixed switched state, and one where we see alternating switched states. The observation of these three regimes is a consequence of the interaction between ionic memory effects and the attempt to implement symmetric addressing in the high polarization device.

While it may be hoped that this effect would diminish if the frame rate is increased, we observe that it remains, at least for the device used, at frame rates of up to 400 Hz. This is however not surprising since an area in which ions have drifted in order to stabilize a particular state is expected to remain in that state, and whether the device frame rate is of low or high frequency is of little consequence, as the area is not switching (other than during the short reset periods). It has been noted that the symmetry effects and consequent lack of image sticking in high spontaneous polarization antiferroelectric liquid crystal devices leads to hope that a similar effect may be possible in ferroelectric materials [10]. It appears however from the above results that this is not so.

In summary, we see that although the symmetry recovery scheme works well with low spontaneous polarization FLC materials, this may not be the case for high polarization materials, even at reasonably high frame rates. This is because ions cause regions of the device to 'lock' into a fixed state.

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