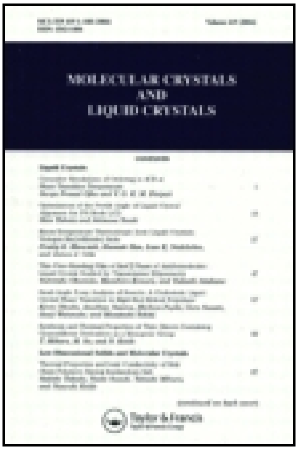

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POLAR AND DIELECTRIC MULTIPLEXED ADDRESSING OF A NEMATIC BISTABLE DISPLAY

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Any planar liquid crystal cell, asymmetric with respect to the middle plane parallel to the boundary plates, presents an electro-optical response dependent both on the amplitude of the external electric field and on its polarity. Pixels of commercial passive liquid crystal matrix correspond to symmetric cells and hence their electronic multiplexing schemes are not suitable to address matrices composed of asymmetric pixels. All known bistable nematic cells present a kind of asymmetry, and new multiplexing schemes have to be developed. Here we show how the polar and the dielectric couplings in bistable nematic cells can be used to perform novel effective waveforms.

Keywords: liquid crystal; nematic; bistability; multiplexing; display

INTRODUCTION

An important experimental effort has been in progress for the past twelve years with the aim to obtain bistable electro-optical devices based on nematic liquid crystals (NLC). These novel devices could join the advantages of passive and active matrix liquid crystal displays, allowing fast optical response time as the order of one millisecond, very short electronic addressing time on the order of a few microseconds, and intrinsic textural bistability, hence practically infinite multiplexability [1].

At present, at least three different approaches have been developed in the world [2–4]. All these systems are based on the usual planar cell geometry; cells are made by two parallel planar glass plates, containing the

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liquid crystal material. Different from the case of commercial passive liquid crystal display, surface treatments on the two containing boundary plates are not the same. Therefore bistable cells are asymmetric with respect to the middle plane parallel to the boundary plates. We recall that in all traditional nematic liquid crystal devices the electro-optical response depends only on the amplitude of E, due to the dielectric coupling proportional to $\boldsymbol{E}^2$. In the case of asymmetric cells, the electro-optical response is sensitive also to the sign of the external electric field $\boldsymbol{E}$ due to polar effects [5].

In our experiments, as usual, $\boldsymbol{E}$ is perpendicular to the conductive glass plates and cells are filled with a nematic with positive dielectric anisotropy $\varepsilon_a = \varepsilon_{//} - \varepsilon_{\perp} > 0$. Due to the additional polar coupling, the addressing schemes of novel multiplexed bistable nematic devices are expected to be different from the standard ones used for current displays (passive STN and active TFT displays) [6,7]. In this work, we present an analysis of this problem and experimental results that demonstrate the multiplexing capability of our bistable samples based on electrically controlled creation and annihilation of surface defects, which is an example of Surface Bistable Nematic Display (SBiND)[2].

In principles, in any liquid crystal display (LCD) each pixel could be addressed by unique drive circuits (Direct Driving). As the number of pixels increases, direct driving becomes impractical due to the huge number of drive circuits and external interconnections. The system complexity can be reduced by using time multiplexing schemes like the time division multiplexing (TDM) [7]. In this case, pixels are organized in a matrix of rows and columns and they are addressed sequentially, for instance, row by row.

A nematic LCD always requires an AC drive voltage with virtually no DC component. In fact DC operation may cause electrochemical reactions inside the display and/or cell polarization due to ion accumulation on boundary pates, with consequent reduction of display performance and lifetime. The typical multiplexing scheme is based on time division, with the number of time divisions equal to the number of the display rows. In traditional displays, the DC component is eliminated by reversing the polarity of both row and column, signals during alternate frames [7]. This signal inversion has no effect on the rms value of the pixel waveform. In practice, as the applied multiplexing signals must have a zero DC component, our row and column waveforms must have a zero time average.

In our bistable matrix, we can't simply reverse the polarity of the driving waveform, because we could change the response of the pixel due to the linear dependence on E of SBiND. This behavior is similar, but not identical, to ferroelectric chiral smectic liquid crystal displays [8]. The similarity stays on the polar properties, but nematics are real anisotropic liquids and their behavior is strongly influenced by surface effects (local anchoring strength, flow), whereas ferroelectric liquid crystal displays are made by a monodimensional crystal, and surfaces are mainly necessary to stabilize the particular texture where the intrinsic helix is untwisted.

EXPERIMENTAL OBSERVATIONS

The cell which we are investigating presents two main stable textures in the absence of an external electric field: the *H* state, a stable uniform hybrid texture, and the *T* state, characterized by a variable density of stable nematic surface defects [2].

Cells are made by two parallel transparent glasses which contain the nematic liquid crystal 5CB (Pentyl Cyano Biphenyl) that has a strong positive dielectric anisotropy at room temperature $\tilde{\varepsilon}_a$ 14. The electrodes are thin transparent indium-tinoxide (ITO) films deposed on the boundary glasses. One plate is coated with ortho-decyl-dimethyl-[3-trimethoxy silil)-propyl] ammonium chloride (DMOAP) to obtain homeotropic alignment, while the other one is treated with an oblique SiO evaporation under vacuum to produce weak planar anchoring [9]. The cell thickness is 1.6 μm measured before filling the cell with an interferometric method.

The experimental set-up is described in Figure 1. The sample is connected to two waveform generators which give, respectively, positive and negative DC pulses or AC signals of controlled shape, length, and amplitude. These signals are synchronized by a third waveform generator that acts as a clock. The amplitude of electric pulses is controlled by an 1 mhz external amplifier with a variable amplification factor up to 100 : 1. The

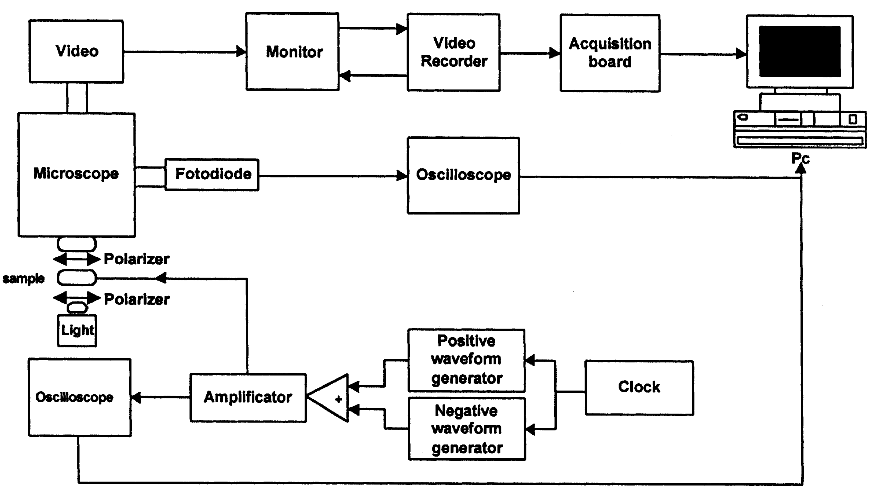

FIGURE 1 Experimental set-up.

common ground is connected to the SiO-coated plate. Samples are observed between crossed polarizers using an optical microscope. The optical axis of the cell, when in the hybrid configuration, is aligned along one of the polarizers. In this geometry the H state doesn't transmit light. On the contrary, the T state acts as a depolarizer and allows the light transmission [2]. The image captured by the polarizing microscope can be stored on a videotape or digitally acquired by a PC. A photomultiplicator is coupled with the microscope to measure, when required, the transmitted light intensity vs. time.

To understand how to multiplex our bistable pixel, it is useful to trace the electric response of the samples (see Figure 2). We apply positive or negtative DC pulses of variable length t_p and amplitude V. We fix t_p and we measure the threshold for the $H \rightarrow T$ transition (writing curve): we measure the negative pulse amplitude that is necessary to bring the cell in the maximum density of surface defects. After that we measure, at the same t_p, the positive voltage necessary for the $T \rightarrow H$ transition (erasing curve). These measures are repeated for different t_p.

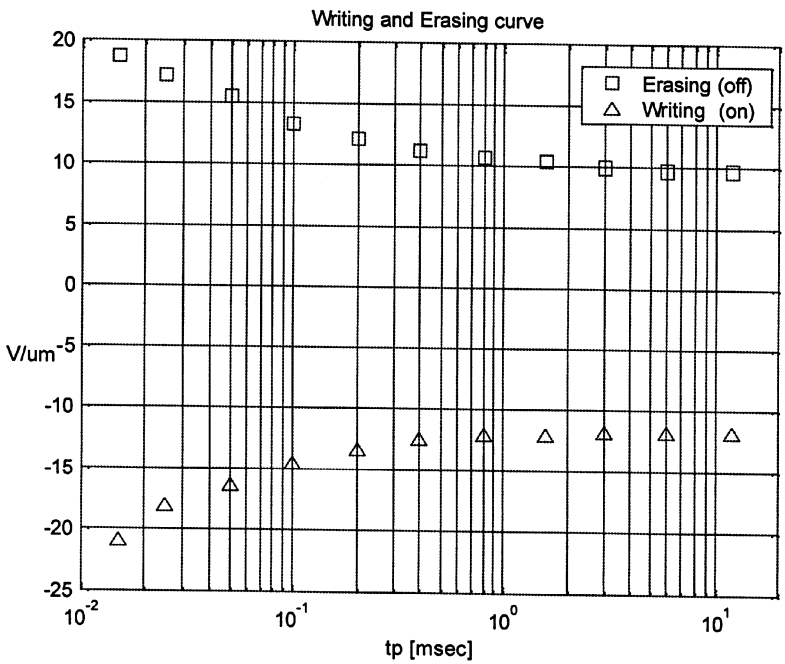

FIGURE 2 Electric response of the SBiND pixel. The writing curve ($H \rightarrow T$ transition) is obtained by means of negative DC pulses ($-V$, t_p). To measure the erasing curve ($T \rightarrow H$ transition), we use positive DC pulses (V, t_p).

This optical response of our display is different from the transmission curve of actual passive matrix displays. In fact, in our case, we do not have a curve that is a function of the rms voltage of the external field, but instead there are two different curves, the erasing and the writing ones, that are the function of the duration, the amplitude, and the polarity of the applied electric pulses. The understanding of these two curves is essential to multiplex our display.

POLAR AND DIELECTRIC MULTIPLEXING SCHEMES

In our addressing scheme we first choose the length of a single electric pulse, which addresses a row, and after we change the pulse amplitude to achieve the thresholds required to turn on or off the pixel of the display.

We tested two general different independent row waveforms that multiplex the SBiND pixel (see Figure 3):

1. The first row waveform is composed of 4 single pulses of equal length t_p and amplitudes $\pm V_R$.
2. The second row waveform is in similar to the first one, but it is composed of only 2 rectangular electric pulses of the same length t_p, and amplitudes $\pm V_R$.

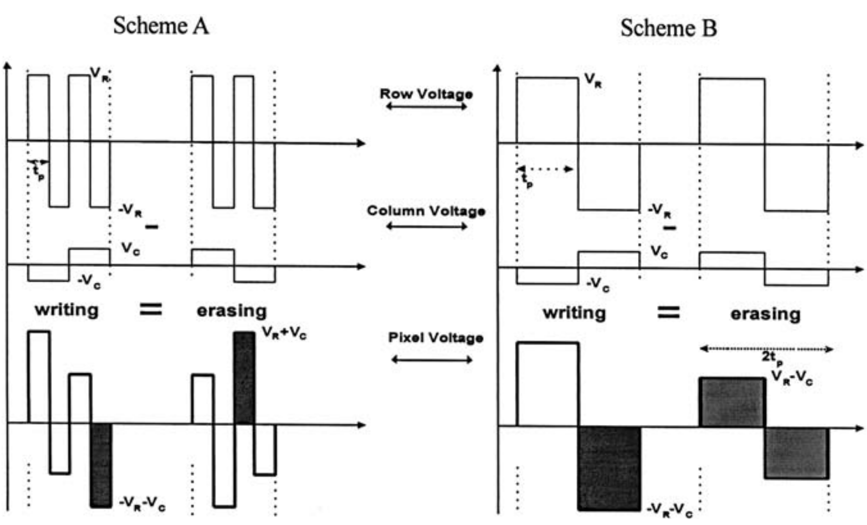

FIGURE 3 Two different schemes to multiplex SBiND displays. In scheme A the erasing and writing process is a polar effect; in scheme B the erasing process is a dielectric effect.

The column waveform, which has a total length equal to the row waveform length, in both cases is made by two consecutive rectangular pulses of the same length and amplitudes $\pm V_C$ to avoid any DC component.

To multiplex the SBiND pixel, we first choose the duration of the single pulse of the row signal t_p, and then its amplitude V_R. For the scheme A, the absolute value of the amplitude of the row signal must be smaller than the absolute values of writing and erasing thresholds (Figure 4). Instead, in the scheme B, the absolute value of the amplitude of the row signal must be greater than the erasing threshold at $2t_p$ and it is independent of the absolute value of writing or erasing thresholds at t_p (Figure 5).

The two schemes have the same behavior for the writing process. This is always a polar effect. The amplitude of the writing column signal is chosen to obtain the last rectangular pulse of length t_p of the composed pixel signal with an amplitude greater than the writing threshold. In both cases, the preceding rectangular pulses, which compose the pixel signal, have only a temporary effect and they don't influence the final cell switching.

The two schemes have different behaviors for the erasing process. The scheme A works on polar properties of the cell [5,10]. In this case, the

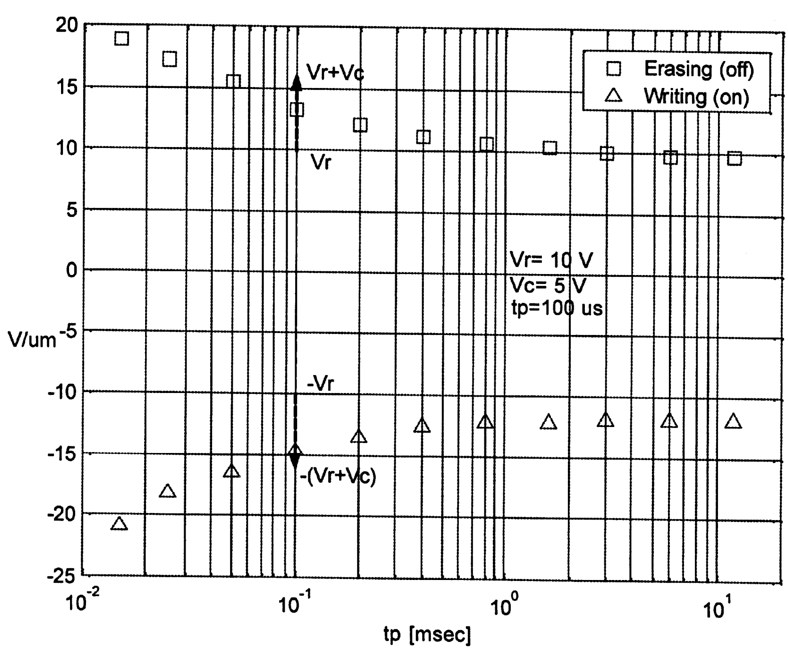

FIGURE 4 Method to multiplex a SBiND matrix by scheme A.

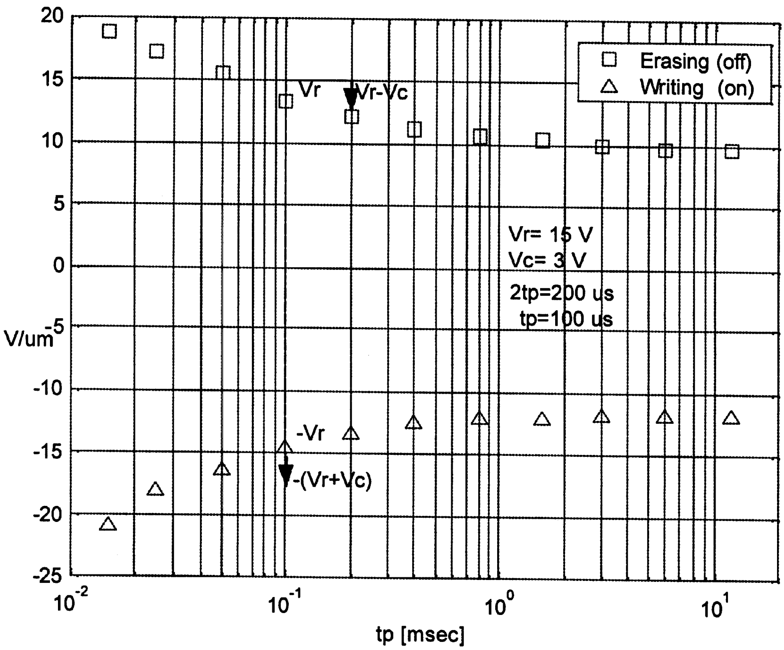

FIGURE 5 Method to multiplex a SBiND matrix by scheme B.

amplitude of the writing column signal is chosen so that the last rectangular pulse, which composes the pixel signal, doesn't reach the writing or erasing threshold and the last but one rectangular pulse has an amplitude larger than the erasing threshold and it is responsible for the cell switching. The preceding rectangular pulses, which compose the pixel signal, have only a temporary effect and they don't influence the final cell switching. Scheme B uses the dielectric molecular property.

To evidence the dielectric coupling, we made another type of measurement, submitting our sample to zero average burst signals of high frequency. Now t_p is the duration of the burst. In this case, we observe the erasing behavior (Figure 6), but it is impossible to write the pixel.

DISCUSSION AND CONCLUSIONS

We can now show how to multiplex asymmetric cells by using the scheme A or the scheme B. In the case of the scheme A, we obtain the Polar Amplitude Duration Method (PADM); by using the scheme B, we have the Dielectric Amplitude Duration Method (DADM).

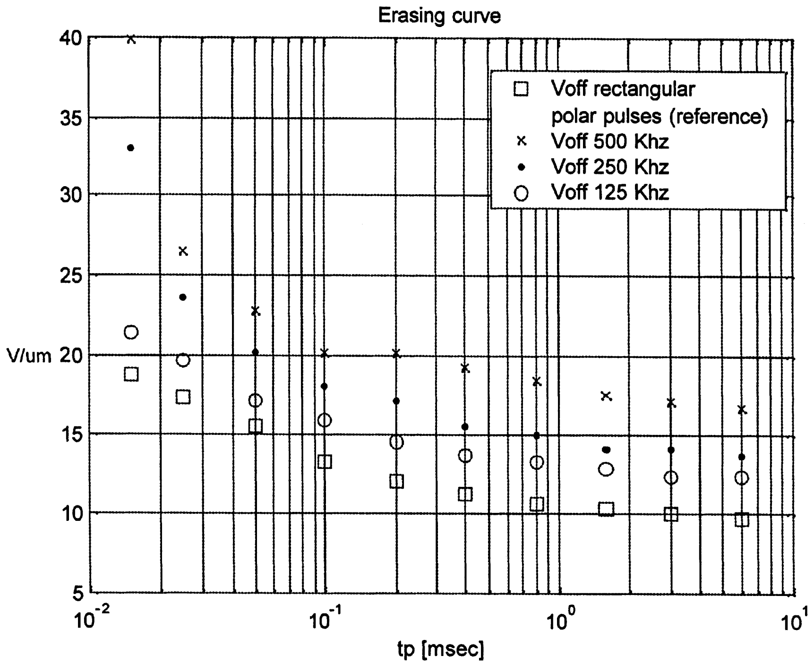

FIGURE 6 Erasing curves of the SBiND pixel. The lowest one is obtained stimulating the sample by a positive pulse *Voff* of duration t_p, the others are obtained stimulating the sample by zero average burst signals of high frequencies.

Figure 7 represents the PADM for a two-row ($N_R = 2$) and two-column ($N_C = 2$) matrix, the DADM is illustrated in Figure 8. For clarity, we present only a 2×2 matrix, although more columns or rows can be included without altering the principle. As these devices are intrinsically bistable, the maximum number of addressed rows is limited only by the time T necessary to draw a frame and by the time $\Delta t_{\min}$ necessary to address the single row: $\mathrm{N}_{R,\max} = T\Delta t_{\min}$.

In the PADM scheme, the matrix rows, normally held at zero potential, are sequentially selected with a waveform composed of 4 rectabgular electric pulses of equal length t_pR and amplitudes $\pm V_R$. The row waveform doesn't transport any information to the pixels of the display. After the last row of the display has been selected, a new frame can be displayed and the process is repeated. As $\Delta t = T/N_R$ the length of each active rectangular pulse of the row waveform is $t_{pR} = \Delta t/4$. In this method, the information to be presented in the display is carred by the column signals. The column signal consists of two rectangular pulses of amplitudes $\pm V_C$ and length $t_{pC} = 2^* t_{pR}$. When the pixel in the position (x, y) of the display matrix is

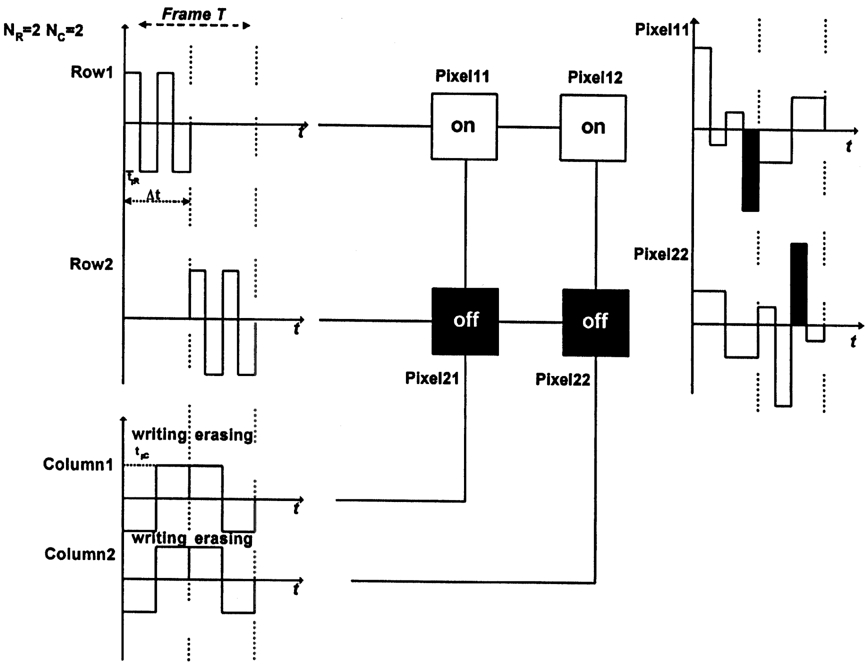

FIGURE 7 PADM (Polar Amplitude Duration Method).

chosen to be on, the column x receives the writing column signal, while the row y is selected. To switch off a pixel, its column electrode receives the erasing column signal during the selection interval of its row. Since the pixel voltage is the difference between the row and column voltages, in the PADM scheme an on-pixel receives a waveform where the last rectangular pulse will have an amplitude greater than the writing threshold. On the contrary, an off-pixel receives a waveform where the last but one rectangular pulse will have an amplitude larger than the erasing threshold and the last rectangular pulse has no effect because its amplitude is too low.

The DADM multiplexing scheme is similar to the PADM but, in this case, the erasing process is a dielectric effect. Now the row signal consists of two opposite rectangular pulses of amplitudes $\pm V_R$ and length t_{pR}. In this case, the length of the active pulse of the row waveform is $t_{pR} = \Delta t/2$. The column signal, as in the PADM case, consists of two rectangular pulses of amplitudes $\pm V_C$ and length $t_{pC} = t_{pR}$. Hence, the pixel voltage of an on-pixel now receives a waveform where the last pulse will have an amplitude greater than the writing threshold during the selection interval. On the contrary, an off-pixel receives a pixel waveform that has an absolute amplitude lower than the erasing threshold at t_{pC} but higher than the erasing threshold at

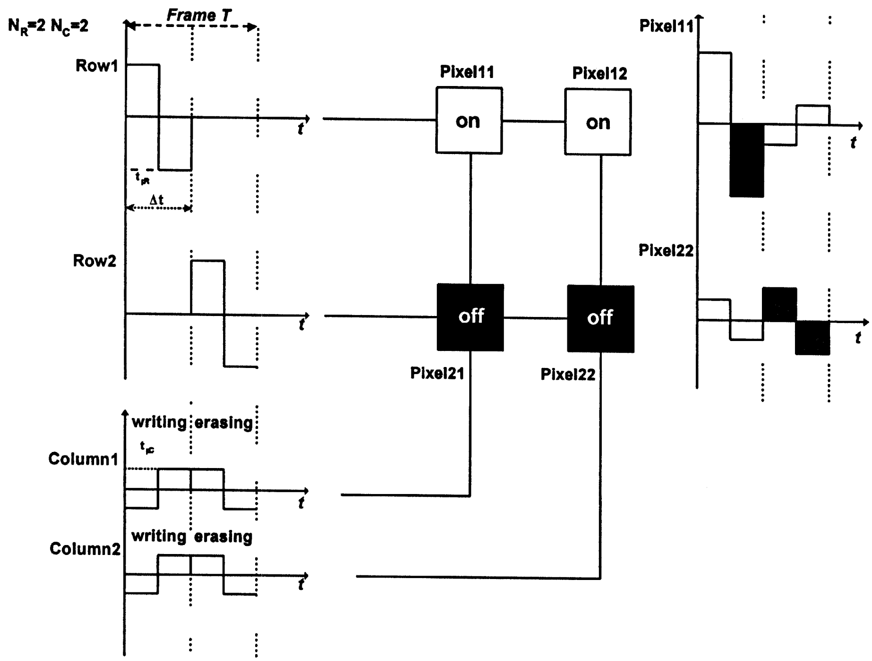

FIGURE 8 DADM (Dielectric Amplitude Duration Method).

$2t_{pC}$. The consequence is that the full-length $2t_{pC}$ of the pixel-composed signal is necessary to switch off the pixel itself.

In conclusion, SBiND devices can be addressed by using their polar and/ or dielectric properties. Multiplexing schemes are more flexible than usual monostable passive twisted nematics, or TFT displays.

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