14-1: Passive Matrix Addressing of Electrophoretic Image Display

T. Bert, G. Van Steenberge, H. De Smet, F. Bruyneel, J. Doutreloigne
ELIS-TFCG/IMEC, Ghent University & IMEC vzw, Gent, Belgium
E. Schroten, A.A.J. Ketelaars
Papyron BV, Groningen, The Netherlands
G. Hadziioannou
Ecole Européenne de Chimie Polymères et Matériaux, Strasbourg, France

Abstract
This paper presents a novel technique for passive matrix addressing of electrophoretic displays. The addressing scheme is successfully applied in a working demonstrator with 5x7 pixels. To our knowledge, this is the first time a working electrophoretic display with passive matrix addressing is presented.

1. Introduction

There is an increasing interest in bi-stable, reflective displays technologies such as Electrophoretic Image Display (EPID). Low power consumption, high contrast in outdoor environment and the potential combination with flexible substrates make EPID especially suited for large area applications such as signs and billboards for advertising purposes.

The electrophoretic image displays that are being marketed to date, are addressed using direct drive, which means that every pixel is directly connected to a dedicated output of the driving electronics. However, as a result of the rapidly increasing pixel count and pixel density, it becomes mandatory to multiplex the driving signals somehow. In liquid crystal display technologies, this is normally done using active or passive matrix addressing. Active matrix addressing implies that an electronic switch (usually a Thin-Film Transistor or TFT) is incorporated at every pixel location. This is not needed for passive matrix addressing, which relies on the intrinsic switching capability of the display medium due to a voltage threshold in its electro-optical response curve. Due to its complexity, the active matrix technology has always been more expensive than the much simpler passive matrix technology.

The use of active matrix addressing in flexible large area applications however, is still in an early development phase, and far from obvious, although several research groups are working in this direction [1,2,3].

On the other hand, the backplane of passive matrix addressed electrophoretic display can be as simple as a PET substrate with a simple ITO pattern.

Passive matrix addressing of electrophoretic displays would therefore be a very attractive alternative, leading to a reduction in development time, production complexity and manufacturing cost.

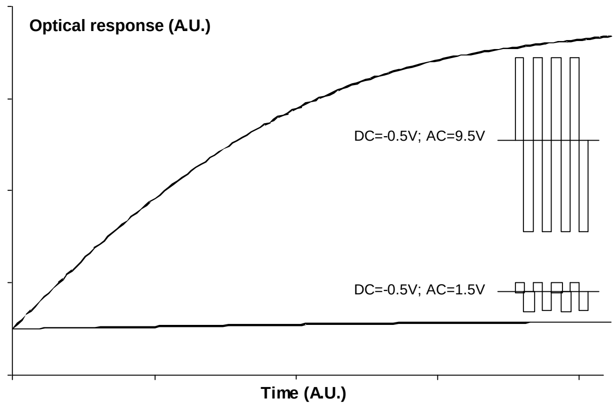


Figure 1 Optical response as function of time for two different addressing waveforms with the same DC component

2. Problem definition and prior art

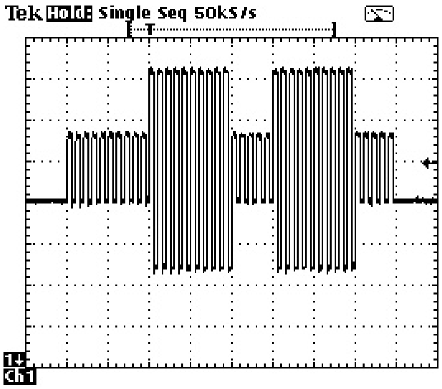
It is generally believed that, due to the lack of a threshold voltage, passive matrix addressing is not compatible with electrophoretic image displays.

In the past, matrix addressing of electrophoretic displays was indeed only demonstrated using a complicated triode design in the display [4]. Unfortunately, this approach adds to the cost and even sacrifices the possibility of creating a flexible display.

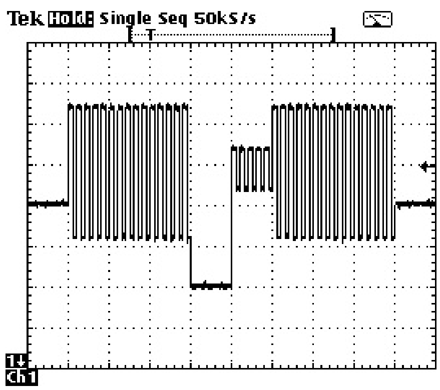
Although a threshold voltage is indeed not observed in the electrophoretic electro-optical effect, the switching characteristic is certainly not a linear function of the applied voltage. Because the distribution of the electric field depends on the position and movement of the charged pigments, the non-linearity increases even more.

Furthermore, the dynamics of an electrophoretic pixel is quite peculiar and is characterized by a prominent memory effect.

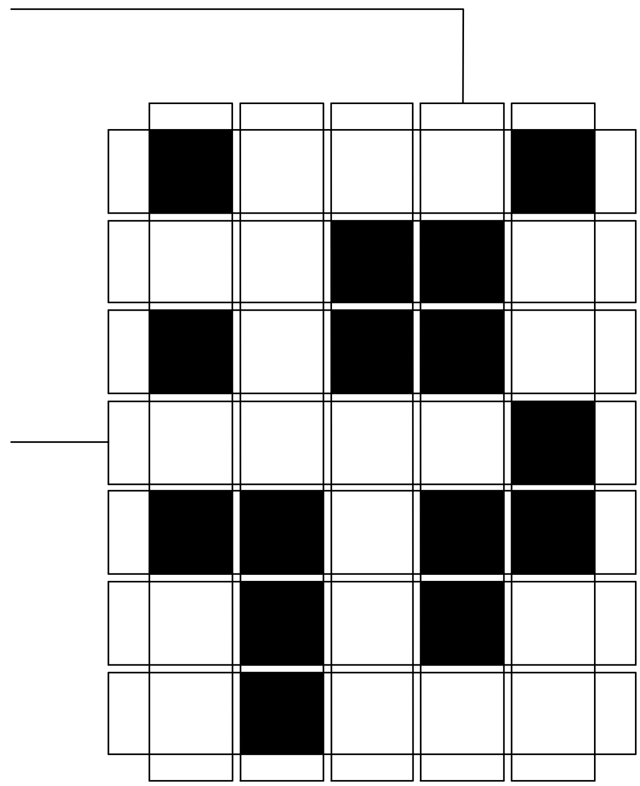
This paper describes how we have succeeded in employing the non-linearity and the typical dynamic behaviour of the electrophoretic effect to design a passive matrix addressing scheme.

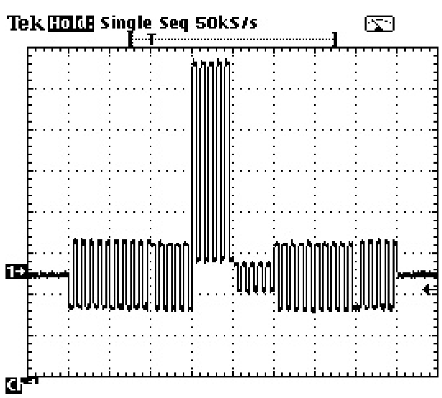


column 4 signal

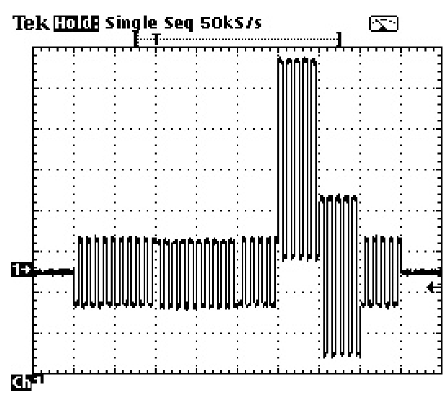


row 4 signal





voltage across pixel (4,4) (white)



voltage across pixel (6,4) (black)

Figure 2 Passive matrix driving scheme: row and column signals and resulting voltage across a pixel that switches to white and a pixel that switches to black

3. Experimental data gathering

Using a test set-up that monitors the reflectivity of the display, we investigated the switching behaviour of electrophoretic cells. These cells show a strong memory effect, that complicates the driving schemes.

We focused on the response to periodic square waves with different amplitudes, frequencies and DC components. We found that the reaction speed of the cell to a modest DC component can dramatically be increased by the addition of a sufficiently strong AC component. This behaviour is illustrated in Figure 1.

We also found that a signal with a moderate AC component but without a DC component does not significantly influence the reflectivity of the cell.

The observed behaviour is consistent with the assumption that the DC component provides the driving force for the pigments to migrate from one side to the other, while the AC component provides the energy to overcome the forces that act on the particles at the electrode.

4. Passive matrix addressing scheme

Figure 2 shows a passive matrix addressing scheme that is based on these findings. The addressing consists of 3 consecutive phases: preparation, selection and rest. The image is written from top to bottom, which means that first, all rows except the first one, are in the "resting" phase and the first row is in the "preparation" phase. After one row time, the second row enters the preparation phase and the first row is in the "selection" phase. To the column electrodes, signals are applied that correspond with the desired state (black or white) of the pixels in the selected (first) row. After another row time, the third row enters the preparation phase, the second row enters the selection phase and the first row is again in the resting phase. This process continues until all rows have been written in.

We will now discuss the different phases in some more detail:

4.1 Preparation phase

During the preparation phase, a complete row of pixels is switched to the reflective state by applying the combination of a high positive DC voltage and an AC voltage. This is accomplished by biasing the corresponding row electrode with a sufficiently high negative DC voltage. Although the exact waveform seen by a pixel in the preparation row depends on the signal on the corresponding column, the end result is always the same: the pixel turns to white.

4.2 Selection phase

During the subsequent selection phase, the same row of pixels experiences a small negative DC component, combined with an AC component that depends on the column driver output. If this AC component is weak, the pixel stays reflective; if the AC component is strong, the pixel switches to black, corresponding with the behaviour shown in Figure 1. This is accomplished in practice by applying a small AC signal with a modest positive DC bias to the selected row and AC signals with either a low or a high amplitude to the columns.

4.3 Resting phase

During the resting phase, the pixels experience a modest AC signal without DC component, which leaves them unchanged.

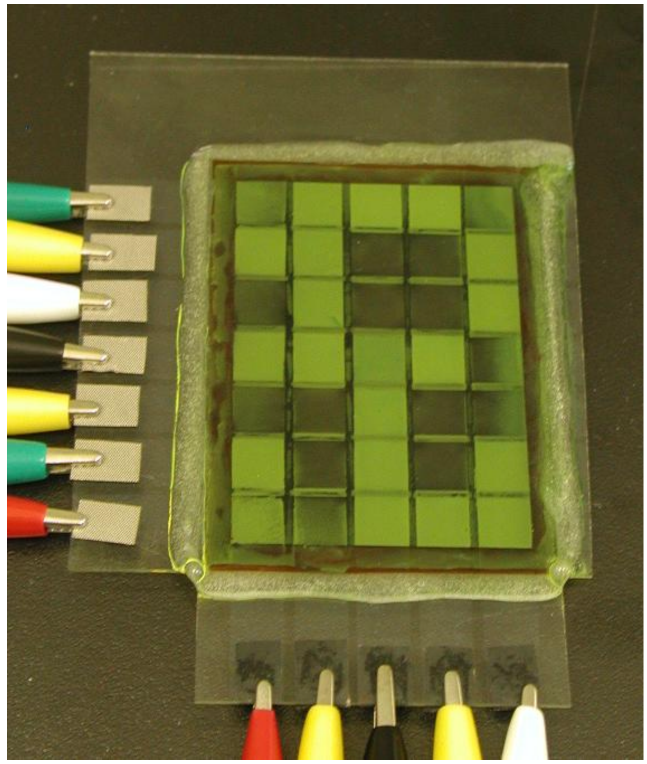


Figure 3 Photograph of a 5x7 matrix display, demonstrating the passive matrix driving of an electrophoretic display

This is accomplished by applying to the "resting" rows an AC signal with the same frequency and phase as the column signals and whose amplitude is the mean value of the low and the high amplitudes of the column signals. Hence the amplitude of the resulting AC waveform experienced by the resting pixels does not depend on the data written to the selected row.

5. Implementation

To prove this principle of passive matrix addressing, we constructed a 5x7 electrophoretic image display with a blue dye and a yellow pigment. The top and bottom electrodes are patterned in rows and columns respectively, each pixel being approximately 1 cm^2 in size.

In order to apply the desired waveforms to the row and column electrodes, we used a driving circuit based on a versatile high-voltage low-power driver IC that was originally developed for cholesteric texture LCD addressing [5].

A photograph of a working passive matrix electrophoretic display is shown in figure 3.

6. Conclusion

This paper presents a novel technique for passive matrix addressing of electrophoretic displays. The lack of a threshold voltage, generally considered necessary for passive matrix addressing, is circumvented by exploiting the unique dynamic behaviour of electrophoretic mixtures under a combination of AC and DC driving forces.

In addition, we present a working device demonstrating the application of the addressing scheme to a display of 5x7 pixels.

To our knowledge, this is the first working electrophoretic image display ever presented that is driven using passive matrix addressing.

The authors are convinced that the availability of passive matrix addressing of electrophoretic displays is an important step forward towards achieving a low cost large area flexible display technology.

7. Complete author addresses

- Tom.Bert@rug.ac.be, Geert.VanSteenberge@rug.ac.be, Herbert.DeSmet@rug.ac.be, Filip.Bruyneel@rug.ac.be, Jan.Doutreloigne@elis.rug.ac.be

  ELIS-TFCG/IMEC
  Sint-Pietersnieuwstraat 4
  B-9000 Gent, Belgium

  http://www.come.to/tfcg

- E.Schroten@Papyron.com, T.Ketelaars@Papyron.com
  Papyron B.V.
  Nijenborgh 4
  9749 AG Groningen, The Netherlands

  http://www.papyron.com

- hadzii@ecpm.u-strasbg.fr

  Ecole Européenne de Chimie Polymères et Matériaux-ECPM
  25 rue Becquerel
  67078 Strasbourg cedex 2, France

  http://www-ecpm.u-strasbg.fr

8. References

[1] T. Kawase, H. Sirringhaus, R.H. Friend, T. Shimoda, “All-Polymer Thin Film Transistors Fabricated by High-Resolution Ink-jet Printing”, in *SID01 Tech. Dig.*, pp. 40-43, 2001.

[2] Y Chen, K. Denis, P. Kazlas, P. Drzaic, “A Comfortable Electronic Ink Display Using a Foil-based a-Si TFT Array”, in *SID01 Tech. Dig.*, pp. 157-159, 2001.

[3] K. Amundson, J. Ewing, P. Kazlas, R. McCarthy, J.D. Albert, R. Zehner, P. Drzaic, J. Rogers, Z. Bao, K. Baldwin, “Flexible, Active-Matrix Display Constructed Using a Microencapsulated Electrophoretic Material and an Organic-Semiconductor-Based Backplane”, in *SID01 Tech. Dig.*, pp. 160-163, 2001.

[4] Electrophoretic Display Panel with Internal Mesh Background Screen, US Patent 5,276,438 January 4, 1994.

[5] J. Doutreloigne, H. De Smet, and A. Van Calster, “A versatile micropower high-voltage flat-panel display driver in a 100V 0.7mm CMOS Intelligent Interface Technology”, IEEE Journal of Solid-State Circuits, vol. 36, no. 12, pp. 2039-2048, 2001.