International Journal of Engineering & Technology
CENTRE OF PROFESSIONAL RESEARCH PUBLICATIONS
ISSN 2049-3444

International Journal of Engineering and Technology Volume 3 No. 4, April, 2013

An Improved Driving Scheme in an Electrophoretic Display

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ABSTRACT

Driving scheme in an electrophoretic display often consists of a series of driving waveforms for various image transitions. A driving waveform for a specific image transition is important as it determines the quality of the new image in shortest time duration. In the mean time, the resulted residual DC should be minimized and preferably becomes zero after one or more image transitions on a specific pixel. In traditional driving waveforms, a white gray scale is used as a reference before writing a new image. However, the driving time is too long when a dark gray needs to be written. In this paper, a new driving waveform design principle is proposed, in which both black and white states are used as the references for obtaining light grayscales and dark grayscales respectively. In this way, the shortest route is selected for updating gray images, the shortest image update time will be guaranteed when entire display screen is updated. A set of new driving waveforms is designed according to this principle in which DC balance is also considered. A number of commercially available E Ink EPD modules are tested. Experimental results show that the proposed driving waveforms have a shorter driving time than traditional waveforms.

Keywords: *Electrophoretic displays (EPD), driving scheme, waveform, reference gray scale, DC balance.*

1. INTRODUCTION

Electronic paper is an important display medium and the electrophoretic principle is an important technology for providing electronic paper displays. Firstly, it is bi-stable and can retain display content. Secondly, electrophoresis material is easy to control and the duration of applied voltage can be controlled to determine the display gray scale. A lot of studies about the driving schemes for the EPD have been done in previous works [1-3], which results have been successfully applied in commercial E-Ink based EPD modules.

The driving waveform is an important part of the electrophoretic display system as the driving schemes will determine the image quality, update time and flicker effects. In an electrophoretic display, the electrophoresis of particles with charge occur electrophoresis under the applied voltage, but the response of electrophoretic particles to the duration of applied voltage is nonlinear [4-5]. So, an appropriate voltage sequence must be chosen in order to driving electrophoretic particles to achieve grayscale display correctly. The voltage timing which is applied to the electrode on the substrate is often referred to a driving waveform. A typical driving waveform contains four stages: erase the original image, reset to black state, clear to white state and write the new image [6]. At the end of the third stage, a white reference gray scale whose reflectance value is consistency should be formed. However, the driving time is too long and it has a bad effect on visual comfort.

Some researches have recently been done for reducing the driving time. For example, Zhenxing wang et al [7] used four kinds of screen update mode to update the display according to the different images that need to update on the EPD, and it could improve the update speed. However, these methods just change the screen refresh modes and it could not reduce the duration of the driving waveform. Guofu Zhou et al [8] proposed a driving principle based on the closest rail reset to reduce the driving time, but this method did not consider the DC-balancing aspects. Wenchung Kao et al [9] studied the property of the suspension viscosity, characterize the response latency of the device, and propose a new driving waveform which could reduce driving time effectively. However, the driving time could still be shortened. In this paper, a new driving scheme, in which two reference gray scales are chosen to reduce the driving time. In the new driving waveform, the black gray scale and the white gray scale are used as the reference gray scales, and the original gray scale is written to one of the reference gray scale according to the new gray scale. Experimental results show that the proposed driving waveform could work very well on the real E-ink commercial EPD. In addition, the length of the total waveform or image update time could be reduced by more than 10 percent.

2. MICROENCAPSULATED EPD DISPLAY SYSTEM

The EPD has been proposed and studied since the early 1970s, however, there were a number of problems:

Firstly, uneven distribution of charged particles, as well as the lack of a stable threshold voltage. The introduction of microcapsules for electrophoretic display technology was an important breakthrough: (1) As particles were isolated in a finite volume capsule, particle diffusion and aggregation is restricted to resolve the long-standing instability problem. (2) It can achieve gray level by controlling the voltage applied to the pixel electrode. In general, the electrophoretic display material includes electrophoretic particles, electrophoretic suspension, background staining material and a kind of charge control agent. The structure of TFT-EPD is shown in Figure1.

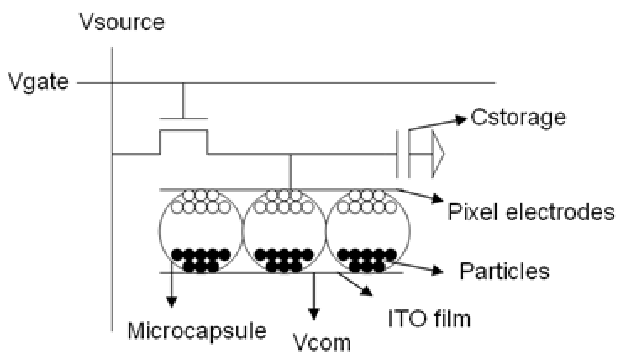


Figure1. The structure of a TFT-EPD.

The charge control agent can prevent charges from condensation and can prevent particle deposition at the capsule wall. It provides good electrophoretic properties for electrophoretic particles. The charge control agent could make the charged particle zeta potential reaching the level which could make a particle whose radius is about 1 μm containing 50-100 charges. The corresponding electrophoretic mobility typically reaches $10^{-5} - 10^{-4} cm^2 / Vs$, The response time can be expressed with the following formula (1).

$$T = \frac{6\pi d^2 \eta}{V \zeta \varepsilon} \tag{1}$$

In equation (1), T is the response time, d is the distance between the pixel electrode and common electrode, V is the voltage applied on the pixel electrode, ζ is the particle zeta potential, ε is the dielectric constant of suspension liquid. The microcapsule contains white and black particles, and black particles move to pixel electrodes and white move to common electrodes when the pixel electrode is positive, and then, the display presents black gray. Conversely, the display presents white gray when the pixel electrode is negative. Since the white particle and black particle can move toward a fixed direction on the effects of voltage, a range of gray scale could be gotten by changing the duration of voltage applied to the pixel electrode. A clear structure of EPD can be obtained with the help of high power microscope. In Figure 2, left part of the EPD is white and the pixel electrode is provided with negative voltage, and the white particle moves to the common electrode. The other part of the EPD is black and the positive voltage has been provided for the pixel electrode, so white particles move toward the pixel electrode and the black particle move toward the common electrode.

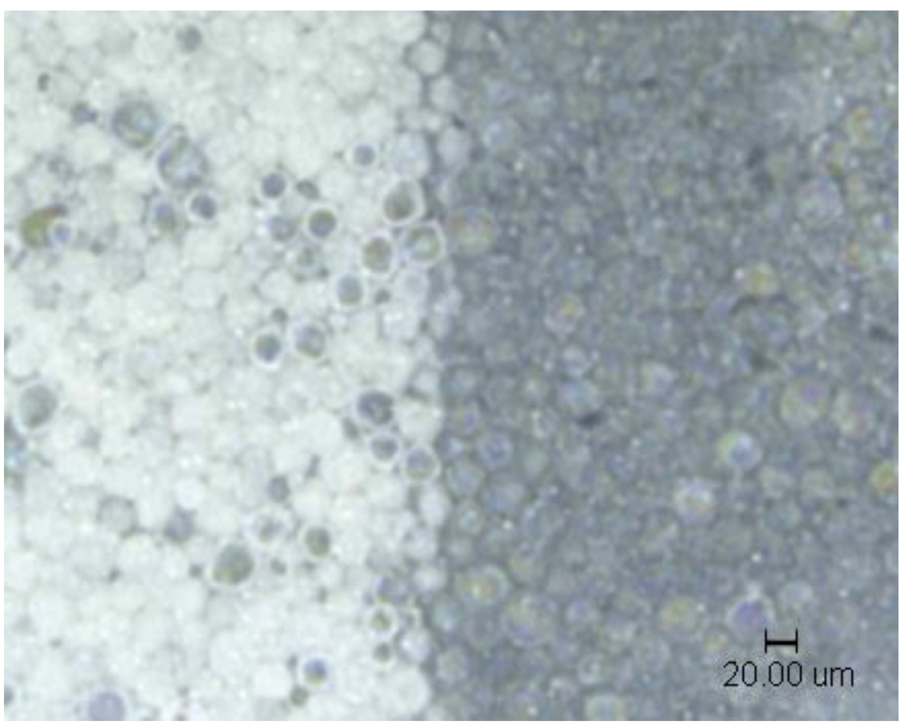
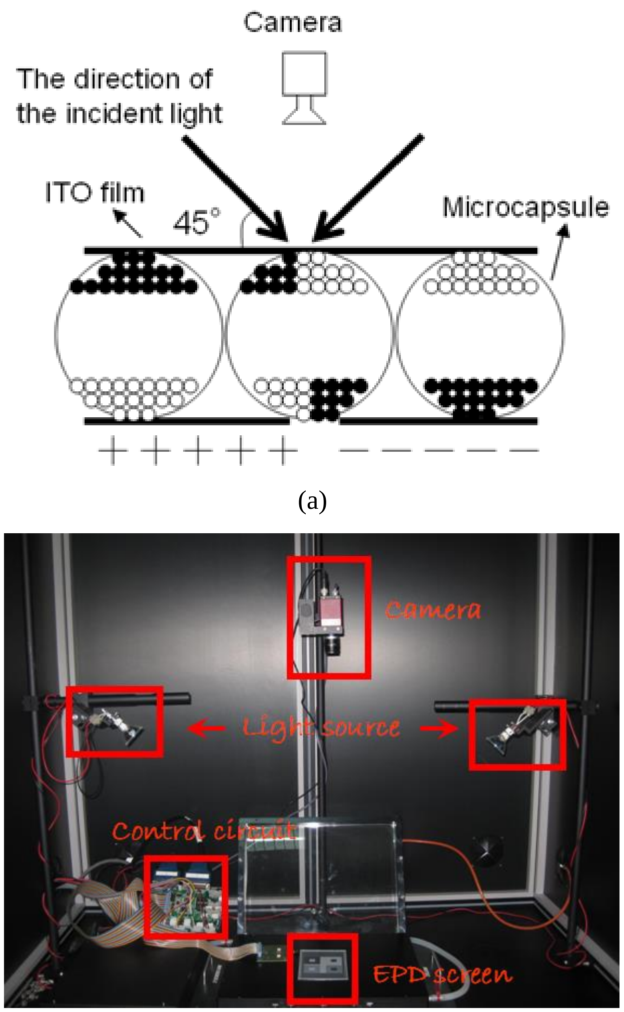


Figure 2. Microcapsule electrophoresis display screen

3. THE TEST EQUIPMENT FOR EPD EXPERIMENTS

In order to test various performance of an EPD, an equipment is used to measure the reflectivity of the EPD as shown in Figure 3. In this equipment, a camera is used to record the reflectivity and two spot lights are used to provide light for the measurement. Then, the control circuit is used to provide driving waveforms to EPD screen and control EPD display timing. The geometric angle between incident light and the EPD screen is 45^{o}, and this supplies a good optical environment for the measurement. The brightness information of the display can be recorded by the camera when the driving waveform is changed. In the experiment process, some commercially available six-inch microcapsulized E-Ink EPD panels are used for testing.



(a)

(b)

Figure 3. Experimental equipment for measuring the EPD reflectivity upon the application of a driving waveform. (a) The schematic diagram of equipment. (b) The real test environment

In the experimental equipment, the camera could take 57 photos per second, and the reflectance transformation process can be recorded clearly. In order to ensure the consistency of experimental data, the light source must be stable. The test is carried out in an airtight container to avoid the external optical disturbance.

4. DRIVING WAVEFORM DESIGN AND EXPLAINATION

Generally speaking, a driving waveform should erase the previous image effectively and write new image within shortest time. The rule of DC balance must be obeyed in the same time. Otherwise, the residual DC may damage the display when the DC is unbalanced for a long while. In the traditional driving waveforms, four stages are needed to form a driving waveform: erase the previous image, reset to black state, clear to white state and write the new image. The second stage and the third stage could form a square wave whose duty cycle is 50% and the duration of positive and negative voltage is equal. Hence, the two stages will not lead to residue DC. The first stage must be designed according to the previous gray scale. For example, the negative voltage duration of the first stage in the driving waveform, which could drive the EPD to show the new gray scale, must equal the duration of the fourth stage positive voltage in the driving waveform which can drive the EPD to show the previous gray scale. In Figure 4, the unit of time is 1/50=20 ms as if the frame rate is typically 50 frames/s, so the waveform duration in each of these stages must be an integer multiple of 20ms, and the DC balance could be reached if equation (2) is established. In (2), $t_w^{'}$ is the positive voltage duration of fourth stage in the driving waveform which could drive the EPD to show the previous gray scale, and t_e is the negative voltage duration of the first stage in the driving waveform which could drive the EPD to show the new gray scale. The voltage state in each slot can be set as 15 V, 0 V, or -15 V.

$$t_e = t_w^{'} \qquad (2)$$

In Figure 4, the duration of t_e and t_w must be changed when a different gray scale is required to display, and a unified white reference gray scale must be formed at the end of the third stage. However, the four-stage driving waveform may need a long driving time. So, a shorter driving waveform, which has three stages, has been proposed for reducing driving time. An example of the driving waveform is shown in Fig.5.

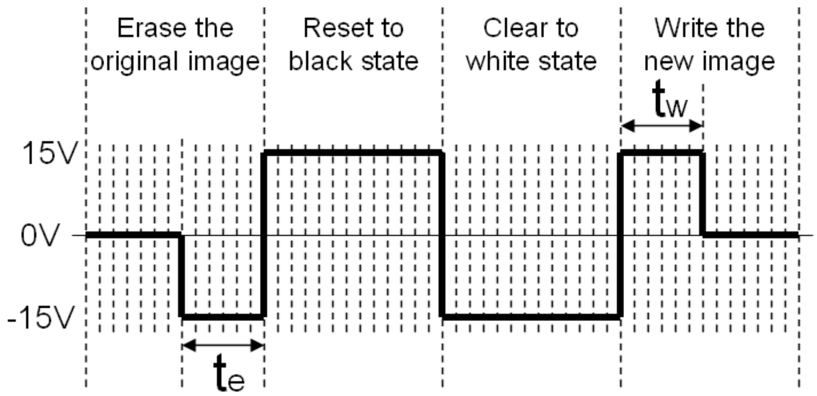


Figure 4. An example of a traditional driving waveform according to literature [6]

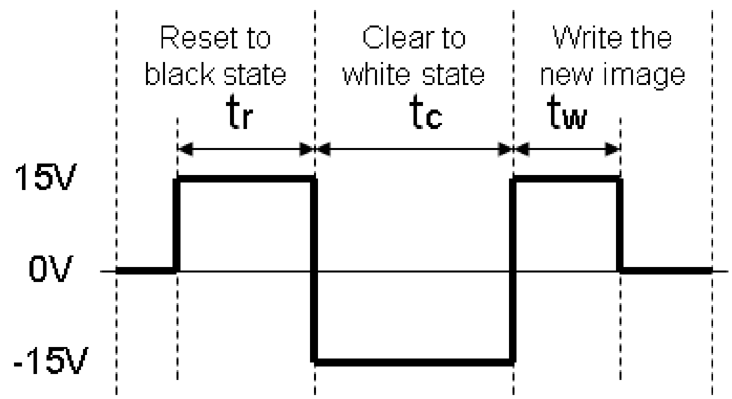
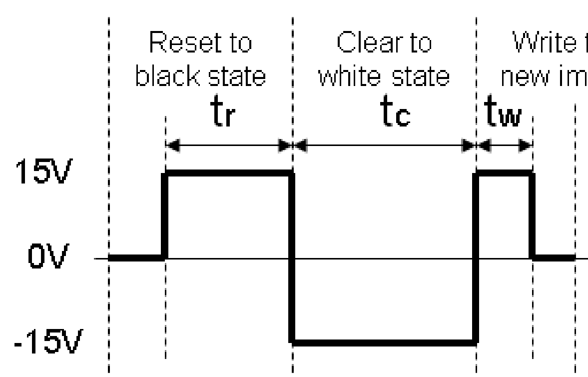


Figure 5. An example of the driving waveform with reduced driving time according to literature [9]

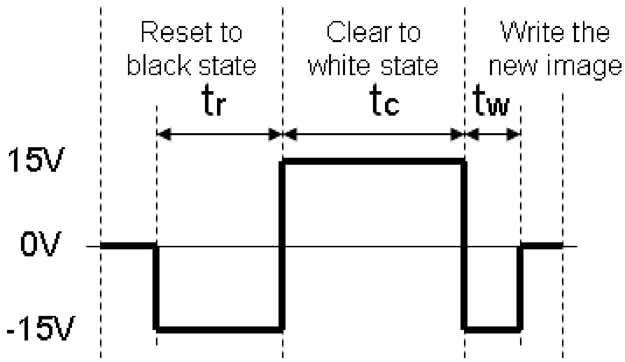
In Figure 5, the driving waveform complies with the rule of DC balance. For realizing DC balance, the relationship among t_r , t_c and t_w is shown in (3).

$$t'_w + t_r = t_c \tag{3}$$

Where t'_w is the positive voltage duration of fourth stage in the driving waveform which could drive the EPD to show the original gray scale. In a driving circuit, the time of the positive voltage is the same as that of the negative voltage, so the driving waveform could reach DC balance. However, there are some disadvantages in this method. In the end of the second stage, a white reference gray scale is formed and the EPD needs to change from the white gray scale to form other gray scales. So, a longer driving time is needed if dark gray or black state is required to display. In order to improve the speed of updating images, the reference gray scale should be closer to the final gray scale. Therefore, we propose that the white state and the black state are used as the reference gray scale. The selection of reference gray scale should depend on the final gray scale. For example, the black gray scale should be taken as the reference gray scale if the final gray scale is the black gray or dark gray. And the white gray scale should be taken as the reference gray scale if the final gray scale is white gray or light gray. An example of the proposed driving waveform which takes the white state as the reference gray scale for obtaining light gray (a) and an example of the proposed driving waveform which takes the black state as the reference gray scale for obtaining dark gray (b) are shown in Figure 6.



(a)



(b)

Figure 6. Two examples of the proposed driving waveform whose reference gray scales are selected based on the information of final gray scales.
(a) The white state is taken as the reference gray scale when the final gray scale tends to the light gray scale.
(b) The black state is taken as the reference gray scale when the final gray scale tends to the dark gray scale.

In Figure 6, the relationship among t_r, t_c and t_w is also shown in (3). It has become clear that the new driving waveform according to this paper can easily meet the requirement of the DC balance. However, there is only one white reference gray scale in the driving waveform of Figure 5, and a longer time can be used if a gray scale which tends to be black or dark gray scale in the third stage. In our new driving waveform, a shorter time is required if the black state is used as reference gray scale when the final gray scale tends to be black state. Therefore, the new driving waveform is shorter than the driving waveform as shown in Fig. and is also shorter than the driving waveform in Figure 5.

5. EXPERIMENTAL RESULTS AND CONCLUSION

With the proposed driving waveform, several experiments are performed to verify the driving effect. Firstly, two sets of driving waveforms in Figure 4 and Figure 5, and a set of driving waveform proposed in this paper are designed and downloaded to the lookup table of EPD controller respectively. Then, a camera is introduced to record the driving process. The reflectance of the EPD is shown in Figure 7.

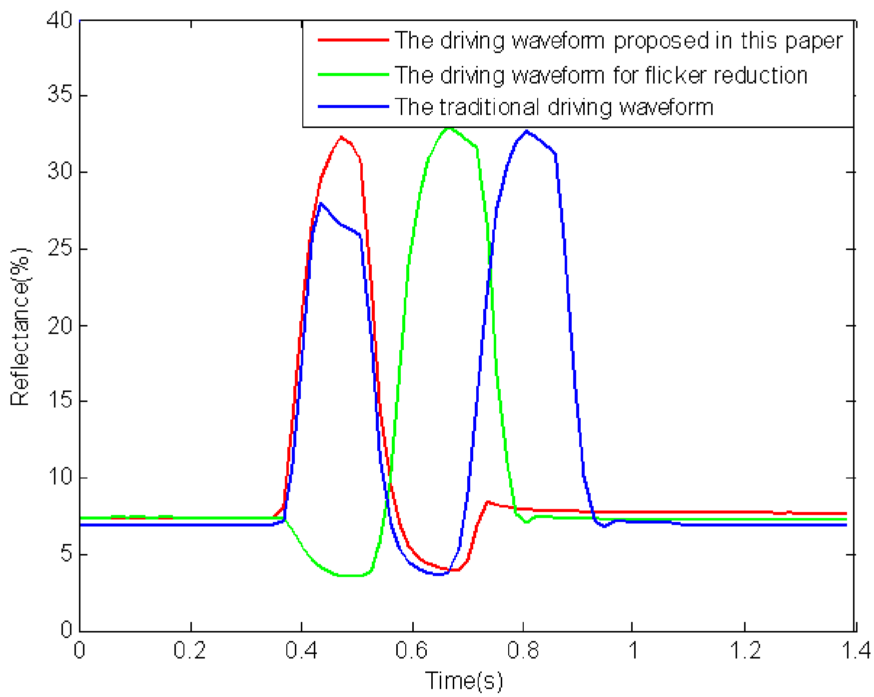


Figure 7. The change process of the EPD reflectance when the EPD is driven by three different driving waveforms.

In Figure 7, the number of flickers produced by the proposed driving waveform is the same as the driving waveform for flicker reduction. However, the traditional driving waveform can produce one more flicker than the proposed driving waveform of this paper. In order to reduce the driving time, the proposed driving waveform in this paper takes both the black state and the white state as the reference gray scale. The last stage of the driving waveform is shortened in half. So, the final gray scale is formed earliest among three driving waveforms when they are at the same time starting point.

The performance of the proposed driving waveform is better than traditional driving waveforms. Firstly, the rule of DC balance is obeyed to prevent static charges from damaging the EPD. Secondly, the driving time is shortened to improve the image update speed. Thirdly, the number of the driving waveform stage is cut to reduce the flicker. In the experiment, the E-ink commercial EPD is used to test the performance of new driving waveforms. So, the design method could provide a good reference for the design of EPD driving waveforms.

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