Active Matrix Electrophoretic E-Book Display

Guofu Zhou[1] *and Mark Johnson*
Philips Research, High Tech Campus, Building 34, Eindhoven 5656 AE, The Netherlands
Karl Amundson and Robert W Zehner
E Ink Corporation, 733 Concord Avenue, Cambridge, MA 02138 USA
Alex Henzen and Jan van de Kamer
IRex Technologies BV, High Tech Campus, Building 46, Eindhoven 5656 AE, The Netherlands

Abstract

A high-resolution microencapsulated electrophoretic display has been jointly developed by E Ink and Philips. This was successfully commercialized in 2004,when incorporated as the screen of Sony's Librié e-reader. The display system is also being used in Sony new generation e-reader, to be introduced to the market in 2006. This display system including display drivers/controllers and driving schemes are reviewed in this paper and the 8.1" display from iRex Technologies is also discussed.

1. Introduction

Electronic content in the form of text, illustrations and images is increasingly available. While it is already feasible to read all our documents from our computer screens, we still prefer to read from paper prints. As a consequence, an increased amount of paper prints are generated, which increases inconvenience to consumers and paper use – worsening the environment. Reading on an electronic device such as a Laptop PC, PDA, mobile phone or e-reader has been an alternative for many years but people don't read from these devices for hours. These screens are usually based on liquid crystal displays containing backlights and double glass plate. Without a backlight the displays are just too dark and the reading experience just doesn't feel right. Reflective LCDs have recently been used as the display screen of e-readers, but the reading performance deviates largely from that of real paper prints. What we need is an e-book with a display, which looks and even feels like paper. E-book displays with a performance identical to conventional paper in terms of brightness and contrast are a holy grail of the display industry and enable a new usage model of "immersion reading" (i.e. reading a display for hours as you do with a book). An e-book display needs to fulfill the following requirements*:*

- Readability, resulting from a combination of high resolution, high reflectivity, and insensitivity to viewing angle and lighting conditions;
- Portability and comfortable hand-held reading (as opposed to reading from a fixed screen), resulting from a thin and light form and flexibility.
- Ultra-low power consumption, where no power is required to maintain the image once written.

An ideal electronic paper display will combine all of these features.

Electrophoretic displays are a very good candidate in this respect. In an E Ink microencapsulated electrophoretic display, charged particles move in a fluid when a voltage is applied to the electrodes (see figure 1)[1-3]. Here, positively charged white particles and negatively charged black particles move in a clear fluid. The particles are contained within small capsules to keep everything stable. The viewer therefore looks either at a white surface that reflects in all directions (like paper) or to a black surface which is as dark as black ink. In this manner, it is possible to generate high-resolution pictures and text which looks just like a piece of paper. The world's first paper-like electrophoretic display jointly developed by E Ink and Philips has been introduced into the market since April 2004, as the display screen of the Sony Librié e-reader as illustrated in Figure 2, which looks like true paper.

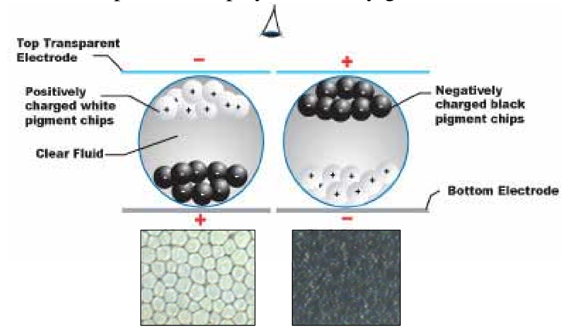

Figure 1: Electronic ink basic principle

2. The Display Module

In comparison to TFT LCDs, some of the key characteristics of electronic ink that have significant impact on the required driving electronics are:

- Electronic ink responds to both voltage and pulse length.
- An impulse is required only when the image needs to be changed.
- Higher voltages, typically ± 15 volts, are required.

[1] Email address: guofu.zhou@philips.com

- ➢ The image stability of electronic ink requires the drive signal to represent the difference between the previous and desired new state, necessitating "differential driving" methods.

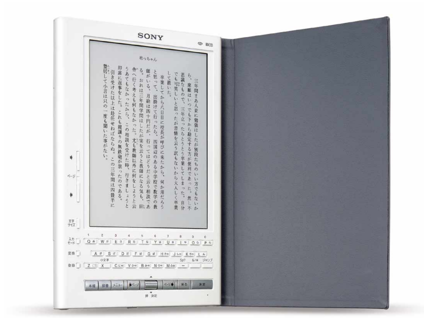

Figure 2: Sony Librié -reader with 160ppi E Ink - Philips EPD screen

Given these characteristics, several basic properties of the display electronics had to be re-thought :

- ➢ The higher voltage demands a redesign of the TFT-structure with two TFT's placed in series, as well as a newly designed source-driver architecture.
- ➢ Image stability necessitates the drive signal to be determined from the difference between the desired state and the previous state - this is referred to as "differential driving".
- ➢ Differential driving requires the presence of a positive and a negative voltage, as well as 0 V. For this reason, dedicated source drivers have been developed.

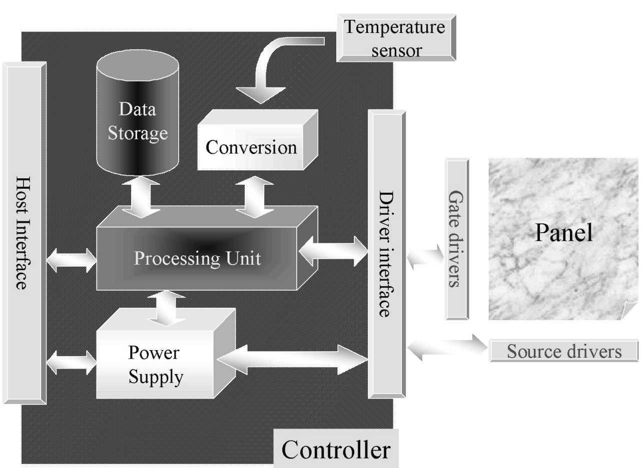

Figure 3: system electronics

Because of the differential drive required for proper addressing of electronic ink an entirely new display controller system is required to translate image data into voltages to be delivered to the panel.

To meet these demands, the firmware in the controller must translate the incoming pixel values into differential image information, and then determine the duration and amplitude of the voltage pulses necessary to effect the transition to the desired state from the previous display state (figure 3)[3,4].

3. Display Characteristics

Based upon the above details, a module incorporating a high-resolution display with a real paper-like look has been realized (Fig. 2). The characteristics of the display are described in the following table.

Table1: Characteristics of the Philips/E Ink active matrix electrophoretic display in the Librié product

Diagonal	6"
Columns x Rows	800 x 600 (SVGA)
Resolution	160ppi
No. grey levels	4
Reflectance	36% (typical)
Contrast Ratio	9:1 (typical)
Viewing Angle	180^o

4. Driving methods and greyscale performance

The driving schemes used in this product were summarized in [6-9]. The principle of using a single reset pulse towards closest rail turned out to be very powerful in achieving accurate greyscale and minimal flicker/flashing and reduced image retention. Figure 4 illustrates a rail-stabilized driving principle based on reset to the closest rail. In this approach, the reset state is determined by the next image content regardless of the previous image and the graytones are always achieved via the closest rail. To achieve a light gray (LG) graytone between white and the middle gray (MG), the white state is selected as the reset state because it is the closest to the light gray. In contrast, to achieve a dark gray (DG) graytone between black and the middle gray (MG), the black state is selected as the reset state as it is the closest to the dark gray. In this way (figure 4), in an image update, the monochrome version of the new image is first obtained first, followed by the addition of the gray tones from their respectively closest rail states. A reasonably accurate graytone is achieved with minimized optical flicker and shortened update time.

Using an additional reset period and the introduction of a series of ac pulses prior to the driving waveforms further increases the greyscale accuracy [9]. Figure 5 shows a histogram for over 1000 pseudo-random transitions of the display between full screen images with four grey levels (white, black, and two intermediate grey states), addressed in one continuous sequence. The resulting grey states are not only evenly spaced across the optical range of the display, but also the maximum error within any state is less than +/- 1.5 L*. (L* is a unit of light ness as defined in the CIELAB standard, and can be calculated from reflectivity as $L^* = 116 (R/R_0)^{1/3} - 16$, where R and R_0 are the reflectivity of the

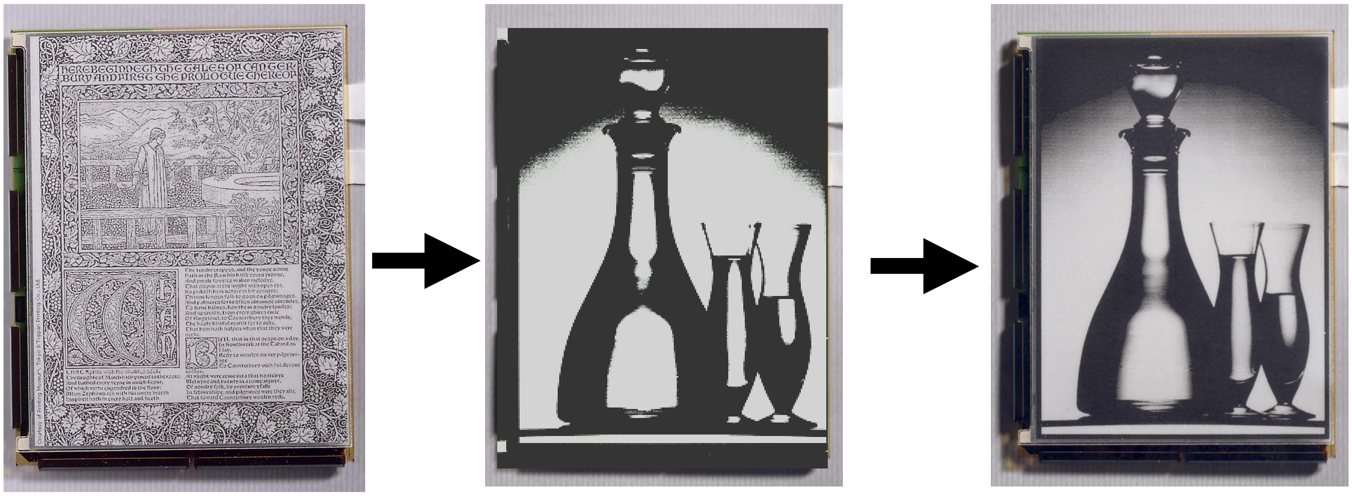

Figure 4: Image update using reset to closest rail approach: Previous image (left hand side) is switched to a reset state formed by a 1 bit representation of the following image (middle) before being driven to final image (right hand side)

sample and a 100% reflective standard, respectively.)

5. New Development

Recently, it was reported that Sony would be introducing next generation e-reader based on the above display [10]. To further emulate the characteristics of conventional paper, the writing

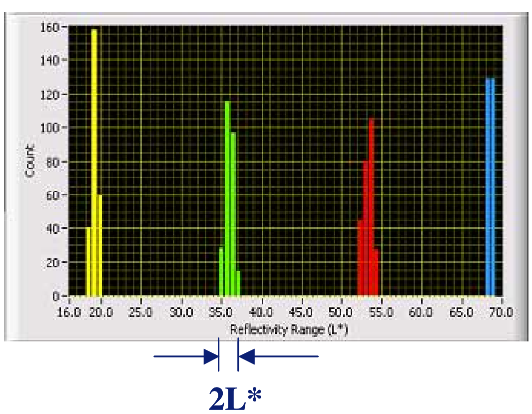

Figure 5: Histogram of over 1000 pseudo-random transitions of an AM display between full screen images with four gray levels.

functionality on such e-paper display is also essential, which has recently been successfully demonstrated by Henzen et. al. as schematically shown in Figure 6 [11]. An electromagnetic input panel is integrated behind the imaging layer on the display panel, which touch sensor is provided by Wacom components, employing electromagnetic signals to detect position and status of a special, passive stylus, using the principle of electromagnetic resonance. The panel's electronic circuit delivers information about stylus position, pressure and even inclination, as well as the position of up to four switches incorporated in the stylus.

To be able to obtain immediate feedback to a user's action, special image update strategies were developed to increase the turnaround time of display update and new display controller logic was created. In stylus mode, drawing or erasing can be triggered by inverting the polarity of the applied drive voltage.

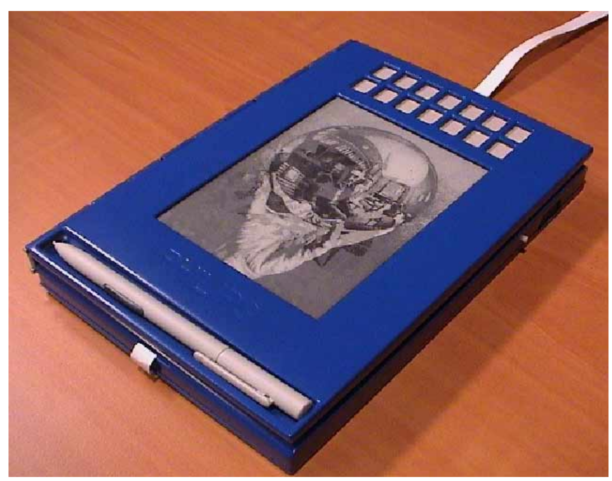

Figure 6: Input panel module prototype

More recently, iRex Technologies developed an 8.1" display with this touch/pen input functionality, which is integrated in their iLiad e-reader as shown in Figure 7. The characteristics of the display are summarized in Table 2. The iLiad product is ready for launch in the market in April 2006 [12].

Table2: Characteristics of the iRex active matrix electrophoretic display with touch input (iLiad reader)

Diagonal	8.1”
Columns x Rows	1024 x 768 (XGA)
Resolution	160ppi
No. grey levels	16
Pen input/scribbling	Yes
Viewing Angle	180^o

6.References

Figure 7: iLiad e-reader of iRex Technologies

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