Polarizer-free Reflective LCD Combined with Ultra Low-power Driving Technology

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Lower-power-consumption displays are increasingly in demand, as power demands from conventional display technologies still limit their usage. Liquid crystal technologies can answer this need through the use of reflective displays, low frame-rate drive, and the addition of pixel-based memory.

Abstract

Sharp has developed a new reflective LCD without polarizers, the characteristics of which provide excellent visibility (reflectance = 50%, CR = 10:1). Moreover, this display features an extremely low power consumption of 10 microwatts by the use of low frequency drive (less than 1 Hz); and it accomplishes this without flicker and image retention. These characteristics were realized through the combination of a pixel memory circuit and a new Polymer Network Liquid Crystal (PNLC) material.

Introduction

Displays and their associated technology have become an important part of everyday life, but development is not standing still. Lower-power-consumption displays are increasingly in demand, as power demands from conventional display technologies still limit their usage. Liquid crystal technologies can answer this need through the use of reflective displays, low frame-rate drive, and the addition of pixel-based memory. This is already being accomplished to some degree with the electrophoretic display[*1] or the cholesteric liquid crystal display[*2], but those displays typically require relatively high drive voltages and exhibit a slow response. With these drawbacks in mind, a combination of Reflective Liquid Crystal Display (RLCD[*3]) technology, combined with a low frame-rate drive scheme[*4] and pixel-based memory circuits[*5,6], becomes a promising development.

Since the power consumption of an LCD module generally depends on its drive frequency, the lower the frame rate becomes, the less power consumed by the module. Adding pixel-based memory allows the module to memorize images at the pixel level with the data drivers suspended.

A reflective display (RLCD) using a Polymer Network Liquid Crystal (PNLC)[*7] display system controls the transmission or scattering of incoming light rays without the use of polarizers. Its main features are its high light utilization efficiency, (due to the polarizer-free system) and a wide viewing cone. The PNLC module allows for a very low-energy, paper-like display.

Polymer Network Liquid Crystal displays have some inherent challenges because they utilize Thin-film Transistor (TFT) structure. These are the high drive voltages, slow response, and low-holding-voltage-ratio. Advances in material technologies have allowed for improvement of these properties[*8]. Sharp's objective was to develop an ultra-low-power Reflective LCD with excellent optical capabilities by using a combination of PNLC and single-bit pixel memory.

Principle

Sharp's newly developed Memory LCD is composed of the PNLC layer formed between a transparent electrode and mirror-like reflective pixel electrodes, with embedded one-bit pixel memory circuits underneath the reflective mirror electrodes in the pixel area.

Pixel Memory Technology

A block diagram of Sharp's Memory LCD is shown in Figure 1. The display interface is very simple, because only five inputs are required (including power supply). The glass substrate has these items integrated monolithically:

- Timing generator
- 3-line serial interface
- Common electrode driver
- Polar inversion circuit
- Scan driver
- Data driver
- Pixel memory circuits

When a still image is being displayed, that image data is stored in the 1-bit memory in each pixel. With the data stored in each pixel, there is no need for any refresh signals, only a power supply. Also, since all circuits are CMOS, only a single 5 V supply is required. This combination results in overall ultra-low-power consumption.

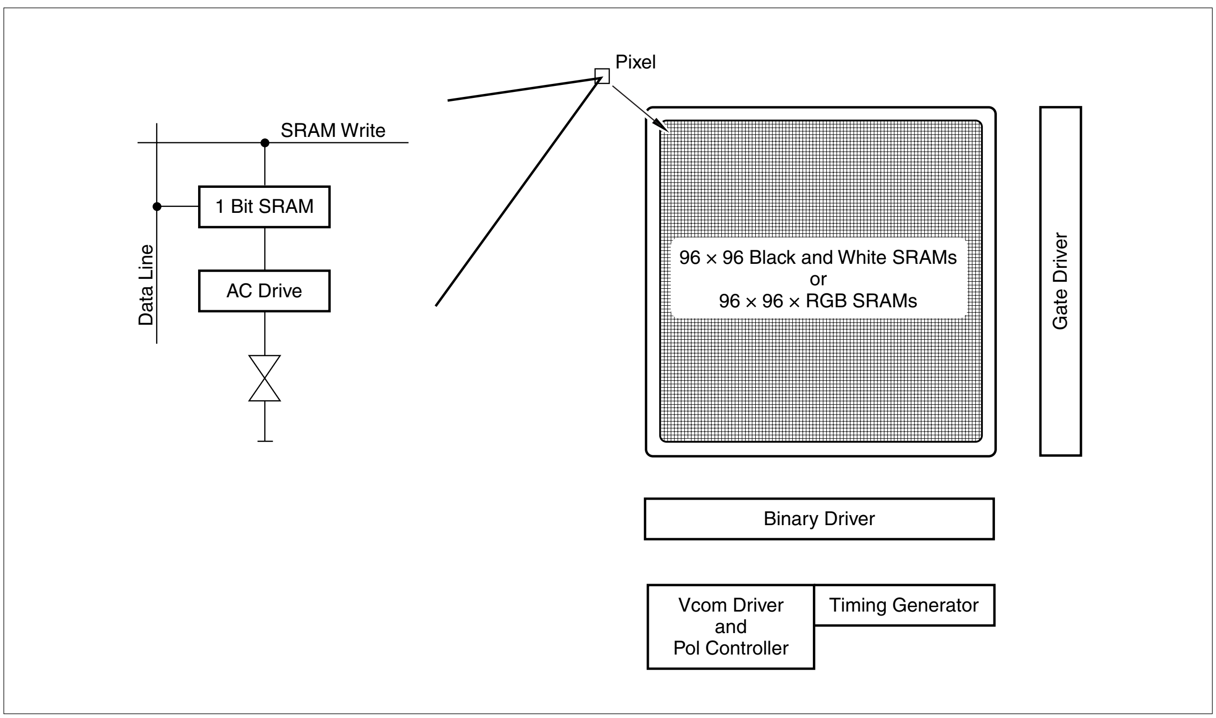


Figure 1. System block diagram of the 1.35-inch prototype display.

Polymer Network Liquid Crystal Technology

PNLCs are manufactured by irradiating a mixture of monomers, liquid crystals, and a photo-initiator under ultraviolet light. This results in a layer possessing a micro-separated structure of liquid crystals and polymer networks.

Sharp's system has no polarizers, so images are displayed by switching the PNLC layer between the light-scattering state and the transparent state. When in the scattering state, the Polymer Networked Liquid Crystals break up any specular reflection. The observer sees a diffusely lit panel and recognizes this image as a bright (or white) state (see Figure 2(a)), at all viewing angles. When switched to the transparent state, the PNLCs reveal the reflective mirror electrodes under the pixel area. The observer then sees no diffuse light other than any specular reflections, and recognizes the image as dark or black. See Figure 2(b).

Sharp's Memory LCD exhibits a normally-white display. So for a white-state, 0 V is applied to any PNLC cell, and to switch it to a black-state, a certain voltage is applied to any PNLC cell. The driving voltage, whether 0 V or the switched voltage, is held on the pixel electrodes by the data stored in each pixel's memory. This drive scheme can operate at low frame rates without problems due to the less-than-100%-hold-voltage ratio. This low frame-rate operation using individual pixel-memories can reduce power consumption drastically, due to the low frequency for the data-driver.

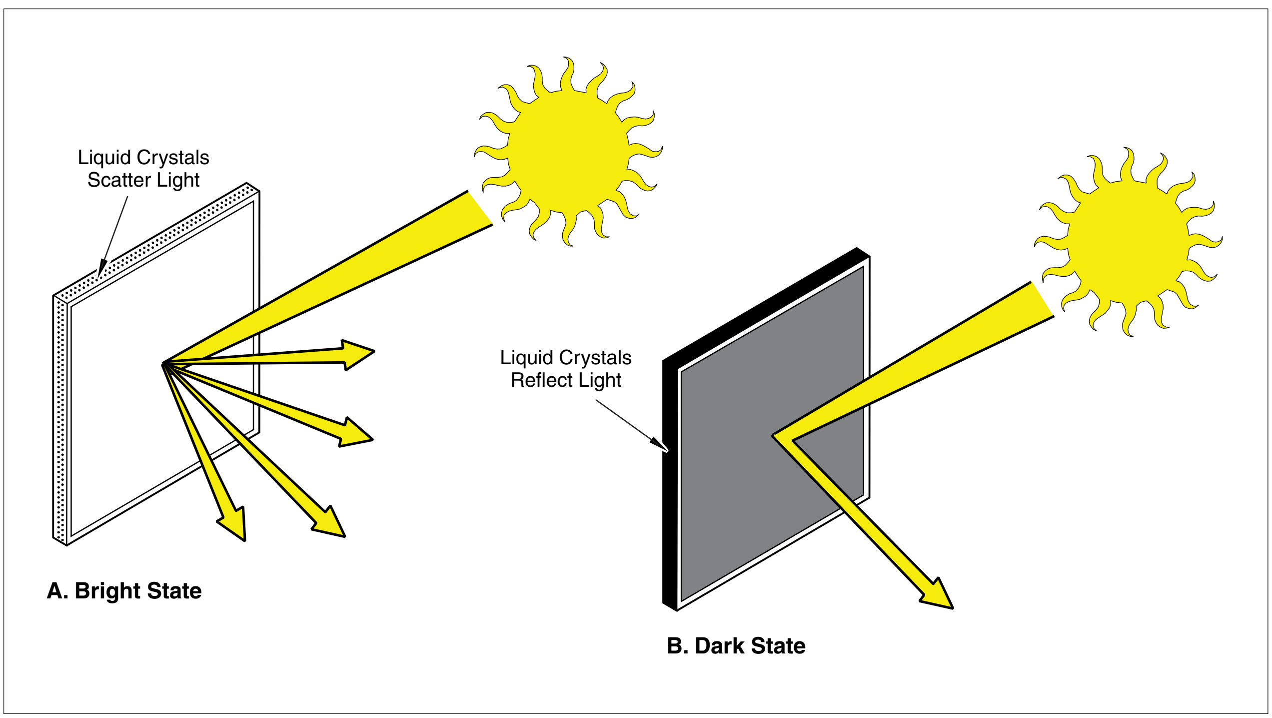


Figure 2. Principle of operation.

Results

Power Consumption

Generally, the power consumption of any LCD is related to the drive frequency and the displayed image. The relationship of frame rate to power consumption for Sharp's 1.35-inch prototype display is shown in Figure 3. Note how power consumption drastically decreases with frame rate. When displaying a clock pattern at 1 Hz, power consumption for the monochrome panel is 10 µW and for the color panel, 25 µW. When displaying a black pattern (all cells ON) over the entire display area at 1 Hz, power consumption for the monochrome panel becomes 15 µW and for the color panel, 30 µW. These ultra-low-power-consumption panels are made possible by well-controlled process technology which reduces the TFT leakage currents.

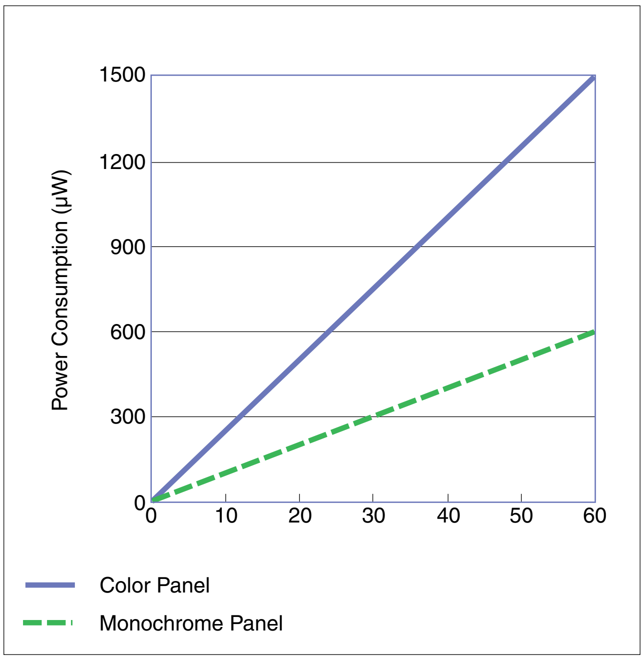


Figure 3. Frame rate dependent power consumption for the 1.35-inch prototype display.

Flicker and Image Retention

The human eye is very sensitive to flicker at frequencies below 30 Hz. Therefore, the most important issue when dealing with LCD drive frequencies below 30 Hz is to de-emphasize any flicker. Moreover, image retention becomes another big problem at low driving frequencies, due to the movement of impurity ions in the liquid crystal matrix. The challenges to achievement of an ultra-low-power-consumption PNLC display then become flicker reduction and inhibiting any image retention.

In Sharp's system, no problems occur due to the less-than-100%-hold-voltage ratio. However, when using a low frame rate (in this case, 1 Hz), impurity ions find it easy to migrate and thus form a double electric layer. The formed double electric layer causes a reduction in the applied voltage to the Polymer Networked Liquid Crystals; thus it becomes a cause of flicker and/or image retention by suppressing the relaxation of the liquid crystals with each mode switch from the dark state (voltage ON) to the bright state (voltage OFF). To reduce this flicker and to inhibit image retention, Sharp has refined the PNLC material and improved the methods by which the PNLC is fabricated.

To be of best use, Sharp's PNLC material must saturate sufficiently at the driving voltage and the impurities should be reduced as much as possible. By modifying the monomer and Liquid Crystal materials in the PNLC, the saturation voltage could be decreased without reducing the reflectance. The amount of the flicker and the relaxation time of any image retention also decreased as the amount of the PNLC photo initiator decreased (see Table).

Initiator Concentration	**Low**	**Middle**	**High**
Flicker Value (a.u.)	1.3	15.7	20.7
Relaxation Time (s.)	0.09	0.18	6.26

This means that the photo-initiator acts as an impurity in the PNLC even after the UV-cure step. However, reducing the photo-initiator causes a reduction of reflectance and weakens the reaction of the polymer networks in the PNLC. Therefore, the preparation of the material becomes very important and process sophistication increases; especially for PNLC materials operating at low frame rates.

The fabrication conditions that form the PNLC layer (especially UV-cure temperature and intensity) also determine the PNLC properties. The reflectance decreased with a reduction in UV-cure temperature and the UV intensity. The PNLC saturation voltage increased with an increased UV-cure temperature and intensity; while the flicker value decreased with increasing UV intensity. Sharp has succeeded in eliminating flicker and image retention at low frame rates, by optimizing the PNLC layer fabrication conditions (Figure 4).

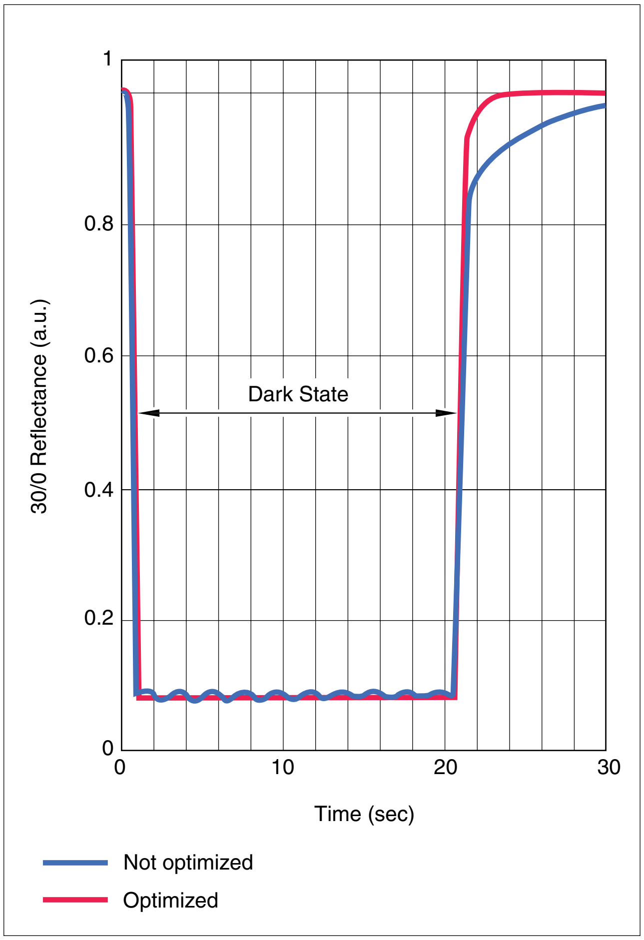
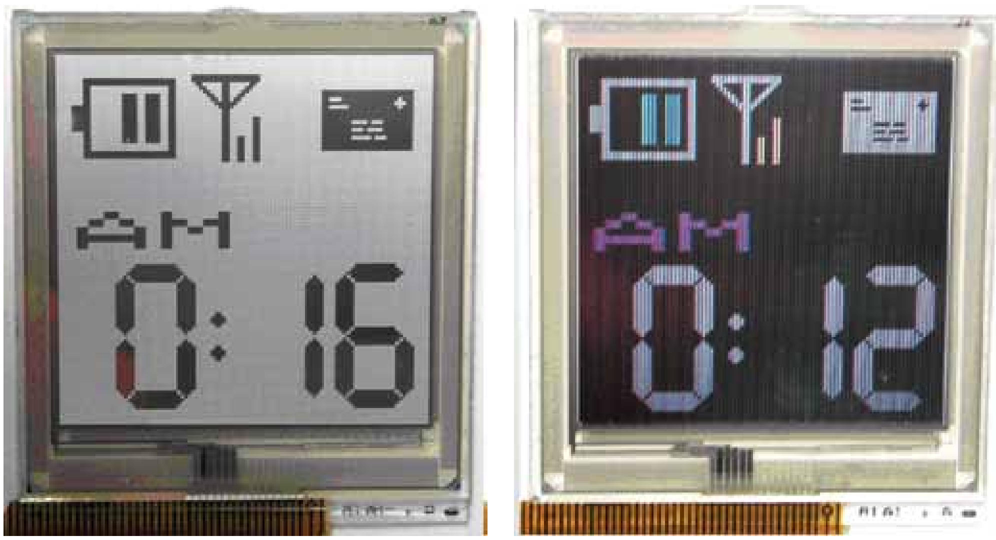


Figure 4. Optical response of the 1.35-inch prototype display at 1 Hz.

Performance

A photograph of the display operating at a 1 Hz frame rate is shown in Figure 5. The integrated reflectance values (d/8) are over 50%, with a contrast ratio of 10:1 for the monochrome display, and 20% reflectance; with a contrast ratio of 5:1 for the color display. The displays do not exhibit flicker or image retention at high temperature (+70°C) and low temperature (-30°C) over 500 hours even with 1 Hz frame rate. These tests have been carried further without defect: from -30°C to +80°C; and under sunlight for over 500 hours.



A. Monochrome Display

B. 8-bit Color Display

Figure 5. Display Example of 1.35-inch prototype.

The table below compares Sharp's newly developed displays to other typical commercially available displays. The integrated reflectance is roughly twice that of a conventional Reflective Liquid Crystal Display (RLCD) which contains a polarizer; and is 25% higher than that of the electrophoretic display. In comparing typical usage profiles, the power consumption of Sharp's display is reduced to approximately 1/60 of a conventional RLCD with a polarizer, and to approximately 1/3 of the electrophoretic display; even though power consumption depends on image content[*9]. Sharp's display has other merits with its moving-image display capability and wide operating temperature range. It is difficult to display moving images on an electrophoretic display and its upper operating temperature is limited to +50°C.

Sharp's display therefore has all the desirable features as a mobile display: good visibility, low power consumption, moving-image display capability and adaptability to various environments.

Display Mode	New RLCD		Conventional RLCD	Electrophoretic
	Monochrome	Color	Color	Monochrome
Number of Pixels	96 × 96	96 × 3 × 96	96 × 3 × 96	96 × 96
Integrated Reflectance	50%	20%	11%	40%
Chromaticity (x, y)	(0.310, 0.333)	(0.310, 0.335)	(0.308, 0.341)	(0.305, 0.326)
Contrast Ratio	10:1	5:1	15:1	7:1
Drive Voltage	5 V	5 V	< 5 V	15 V
Power Consumption	10 µW @ 1 Hz	25 µW @ 1 Hz	2 mW	30 µW @ 1/15 Hz
Operating Temperature	-20°C to +70°C	-20°C to +70°C	-20°C to +70°C	0°C to +50°C
Storage Temperature	-30°C to +80°C	-30°C to +80°C	-30°C to +80°C	-25°C to +70°C
Response Time	100 ms	100 ms	50 ms	260 ms

Conclusion

In this paper, Sharp has demonstrated the development of an extremely-low-power display with good visibility. This reflective display has been developed through the combination of individual cell pixel memory circuits and a new PNLC material. Sharp has also reduced the amount of flicker and image retention at low frame rates by refinement of the materials and the fabrication methods.

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