Display Technologies and their Applications in E Books

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Abstract: ***Since the back four decades the researchers of liquid crystal displays have focused primarily on matching the image quality of cathode-ray tubes used in television sets and computer monitors. That goal has been met. Now display developers are turning their attention to a new goal-electronic display media that begin to match the essential qualities of paper. The success of portable electronic devices for reading digital books and periodicals will depend on the development of displays that are light-weight, durable, energy-efficient and readable under a broad range of lighting conditions. About a thousand e-books can be stored on one CD which equivalent to several shelves of printed books.***

Keywords: Energy efficient, liquid crystal displays, e books, Emissive Displays, Reflective Displays

1. Introduction

Portable devices for reading electronic versions of books, periodicals and other documents could have been in the hands of the general public several years ago if there had been a suitable commercially available flat panel display to support it. The other essential parts needed for construction of portable reading devices, such as memory storage, smart electronics with adequate power management, and even batteries with sufficient energy density, have been available since the early 1990s. It is the display technology that has slowed the development of the so-called e-books and tablets. Flat panel displays that we see today on laptop computers and handheld devices require too much power and still do not provide the readability we expect from printed books and periodicals. Inks and paper have been developed over many centuries to provide a reading surface that is easy on the eyes, and can be read under a broad range of lighting conditions from low-level room light to bright sunlight at the beach. The concept of using reflective displays to reduce power consumption came in the course of display development for the laptop computer. In the laptop, batteries consume a large percentage of the device's weight and the short time between recharges is a significant inconvenience. We are on the verge of achieving a suitable display for an electronic book.

This paper reviews the current display technology, the issues confronting them for the e-book application, and describes where the display technology is headed to meet these needs. One technology, the cholesteric liquid crystal display (Ch-LCD) [1] technology, is close to meeting the low-power requirements and viewing quality of ink on paper.

2. Weight Limits & Battery Size

An important parameter of the e-book is its necessary weight limitation. It cannot be heavier than we normally expect a book to be. It is important to note that it is this weight limitation that determines the maximum weight of the battery and, hence, the electrical energy available to operate the book. Frequent charging of the battery or frequent battery replacement is not a viable solution from the consumer's point of view. It is a simple exercise to determine the battery size. If one takes a number of books from the shelf and weighs them, one finds that a preponderance of their weight is between 1.5 and 2.5 pounds, depending upon the number of pages, page size and whether the book has a paper or hard back cover. For the purposes of this discussion, let us take the weight of the book to be 2.0 pounds. Such a book can be comfortably held while reading. To estimate the battery size, we need to determine the weight of the other components of the e-book. A book currently under development at Kent Displays, Inc., has a display size of 6.3 inches on the diagonal for the active part of the display. This is about the size of the printed portion of a page for a paperback novel.

Table 1: Approximate weights for the various components of an e book the size of a typical paperback novel. The weight of the battery is selected to limit the total weight of the device to 2.0 pounds.

Component	*Weight*
Display Module	0.5lbs.
Controller Board & Electronics	0.5 lbs.
Package	0.7 lbs.
Battery (5.4 Wh)	0.3 lbs.
Total	2.0 lbs.

As indicated in table 1, the weight of the various components, less the battery, totals 1.7 pounds. This fixes the weight of the battery at 0.3 pounds to meet the 2.0 pound weight limitation. The size of the battery establishes the energy that can be stored. A well-developed battery technology in use today is the nickel-metal hydride battery. A battery size of 0.3 pounds can store up to 5.4 watt hours (WH) in a battery of this type. With a lithium-ion battery under development today, we could at most double this output.

3. Various Display Technologies and their Energy Consumption

The various flat-panel display technologies can be classified according to their energy consumption: emissive types where the displays emit light to be seen by the viewer; refreshed type reflective displays that use reflected light, but require a constant supply of power to maintain the image on the screen; and the bistable memory type reflective displays that do not consume any power until an image is changed on the screen. These three display technologies are reviewed in terms of the lifetime of the battery it takes to run them.

3.1 Emissive Displays

Considering power consumption alone, emissive-type displays rank the highest, demanding the largest batteries and most frequent recharge intervals. The types of displays we see on laptop computers and many instruments are of the emissive type. These include: backlit LCDs, electroluminescent (EL), and light emitting diodes (LEDs). The Soft book reading device marketed by Soft book Press, Inc., is an example of an e-book that makes use of the backlit LCD. With displays of the e-book size we are considering in this paper, the power consumption to generate the light is, at the very least, 1000 milliwatts (mW). This value can be used for the power to run backlights as well as for the ELs, LEDs, etc. For the power consumed by the e-book, we need to add to this value the power requirement for the control electronics (about 1500 mW). This translates into a battery usage time of only about two hours, which is not considered to be an acceptable time between battery recharges (or replacement) for convenient use of an e-book .The Soft book, which weighs about 2.9 pounds, advertises five hours between recharges for continual use. This recharge interval can be achieved by good power management of the control electronics and a larger battery, thus resulting in a heavier book.

3.2 Refreshed Type Reflective Displays

These displays don't consume as much power as emissive displays, since they make use of reflected ambient light to see the image. Nearly all flat panel displays in today's marketplace (emissive and reflective) are of the refresh type. This display type includes: active matrix twisted nematic (AM-TN) LCDs, super twisted nematic (STN) LCDs [2], optically-controlled birefringence (OCB) LCDs, etc.

The difference between the emissive and the reflective displays [3] of the refresh type is the use of a mirror to collect ambient light replacing the backlight. To avoid an objectionable flicker, these displays need to be refreshed 60 times per second. This translates into a continual power usage of at least 200 mW. This is less than the back light, but still an unacceptable power drain. This is not a significant improvement over the emissive type display. We might improve on power drain by reducing the power of the controller. This can be done using smart electronics that provide efficient power management of the controller.

3.3 Bi stable Memory Type Reflective Displays

This type of display is particularly attractive for the e-book because the display holds the image in memory without any applied power while the reader is viewing the page. Power is applied only when the e-book is paged or updated to display a new image. This is a tremendous energy saving and a dramatic improvement on the operating time of a battery.

Table 2: Energy consumption for an e-book in terms of the operating time between battery recharges for different display technologies. The operating times are listed for a 5.4 Watt-hour battery, a size expected for a two-pound e-book.

Hours between recharges for 3 display technologies			
Average Reading Times Per Page	1 min	2 min	5 min
Backlit LCD of STN or AM-TN Variety	2	2	2
Reflective STN or OCB with Smart Electronics	18	18	18
Reflective Ch-LCD with Bistable Memory	340	680	1700

We could further expect that, because of distractions while reading or studying, graphics, pictures or maps on the page, the average reading time for a page may extend beyond one minute per page. Table 2 compares the e-book battery recharge times for this case. There are only two bistable technologies sufficiently advanced today to be considered for the e-book. These are the Ch-LCD mentioned earlier and the ferroelectric liquid crystal (FLC) [4] display. The FLC technology has been under development for a longer period of time, but has suffered several problems in manufacturing. One manufacturing issue has been that the liquid crystal layer is thinner than in other technologies, which has had the result of giving poor manufacturing yields and of increasing the costs. Problems in implementing gray scale and ruggedness also have been issues, and it has not been successful in replacing STN and TN technologies as earlier expected. There also are problems with brightness when used as a reflective display.

The Ch-LCD, on the other hand, can be manufactured at about the same cost as the STN and is, in some ways, a simpler display to construct, as it has no polarizers, and the tolerances on the cell dimensions are less demanding. Another advantage is that the Ch-LCD can achieve full color operation without color filters. There are two other bistable displays under development today, advertised as paper-like: the rotating-ball technology of Xerox, and the electrophoretic technology of E-Ink. These technologies are in the early stages of development and have many problems to solve, such as the inability to be multiplexed like the STN, FLC or Ch-LCD. This means a high resolution display cannot be made on a simple, low cost, passive matrix. Some other solution, such as an active matrix is required.

4. Display Readability: The Challenge of Ink on Paper

A major challenge for the flat panel display technology is to reproduce the view ability or readability of ink on paper, adjusts to reading outdoors in the sunlight. Since the eye evolved to see with reflected light, a reflected image, like ink on paper, is well-suited for the eye.

The ink on the white paper provides the contrast of the image. Inks are highly developed and low cost. The ink on paper is permanent, providing a fixed image that does not flicker and cause eyestrain. As mentioned earlier, the Soft book utilizes a backlit or emissive-type display. As far as a reflective display, there are only a handful of reflective display technologies in the marketplace today that have been implemented in devices similar to an electronic book.

Devices under names such as “notepads,” “PDAs” and “palmtop computers” are for sale today, which implement STN and AM LCDs. These displays are not very bright, having a reflectivity usually less than 20 percent on the brightness scale described earlier. As a result, the background of the display appears gray rather than white. This lack of brightness comes primarily from the fact that these displays require polarized light to display an image. The function of the display is to retard the polarized light, such that it is selectively absorbed in a polarizer. Black and white or monochrome is easily achieved, and color is provided by color filters.

Since color filters can further reduce the brightness, optical birefringence has been used to make color in OCB LCDs. Bistable FLC displays also are of this optical retardation-type. In these retardation-type displays, the polarizer absorbs at least 60 percent of the light. Also, retardation is strongly view-angle dependent. The end result is a severe lack of brightness and very narrow view angles for the retardation-type technologies. The same STN displays, such as used in pagers, employ the use of a “high performance mirror” to increase the brightness. This increased brightness, however, does not come without the sacrifice of view angle, unacceptable for comfortable e-book reading.

High brightness at wide view angles is best achieved by displays that have materials that self-reflect the light. An example is the Ch-LCD technology where the liquid crystal material is designed to reflect pre-selected colors. In their usual form, these displays have a peak reflectivity of 40 percent, twice that of the STN, TN, OCB and FLC retarder types. The reflected colors can be quite brilliant and appear iridescent to yield beautiful full color images over wide viewing angles.

This feature, coupled with their low power capabilities, make Ch-LCDs a preferred technology for the e-book.

Another parameter often used to represent the brightness of a display is the reflected luminance. This parameter takes into account the sensitivity of the human eye. Table 3 shows the measured values of reflected luminance as well as the peak brightness for a newspaper, book, Ch-LCD and STN.

The table shows that neither display technology can match the brightness of paper. The Ch-LCD technology, however, is twice as bright as the STN. It is possible, in principle, to double the brightness of the Ch-LCD; however, that data will not be presented here.

Table 3: Brightness comparison between paper and flat panel displays.

Display medium	*Reflected Reflectance*	*Peak luminance*
Book	82%	86%
Newspaper (newsprint)	61%	67%
CL-CHD	30%	37%
STN	13%	15%

The contrast of the Ch-LCD technology is comparable with the newsprint typically used by newspapers. However, the STN contrast suffers substantially relative to newsprint and the Ch-LCD, primarily because of its strong view angle dependence. The excellent view-angle characteristic of the Ch-LCD is what is responsible for its paper-like appearance.

5. Display Weight and Ruggedness

The weight and ruggedness of a display are determined primarily by the material of the display substrates and bezel. Nearly all displays seen in the marketplace today have glass substrates. Flat glass is low-cost and has no birefringence. A birefringence-free substrate is required for such technologies as the TN, STN, FLC and ECB. Another feature of glass is that it tolerates high processing temperatures. Display technologies, like the active matrix technology, require the substrate to be processed at temperatures approaching 400 degrees Celsius. Glass will sustain these temperatures without being warped or deformed. Glass is also readily available, and thus has been the substrate of choice for displays over the years. Small displays on glass can be made quite rugged with proper mounting of the display in the device. However, on large displays, which are required for e-books, ruggedness can become an issue. Also, glass is heavy. Glass has a density three or four times that of plastic.

An obvious replacement for glass is plastic. However, this has been a long time coming for several reasons. One, nearly all plastics are birefringent, which has the result of destroying the polarized light [5] required for many liquid crystal display technologies. It has been a struggle in plastic technologies to develop low-cost plastics that are suitably free from birefringence. Another problem is the processing temperature. Most plastics need to be processed at temperatures below 150 degrees Celsius. This can be limiting in the fabrication of displays, since many of the layers and coatings on the display need to be processed at temperatures higher than that. An example is the Indium Tin Oxide (ITO) transparent conductive coating required for the display electrodes. For robustness, ITO needs to be baked at temperatures approaching 300 degrees Celsius. ITO, nevertheless, can be used on plastic substrates, but it tends to be soft and easily scratched.

Another issue is that most solvents required in the processing of displays dissolve and/or destroy the plastic material. Fortunately, there have been some plastics, for example Polyethyleneterephthalate (PET), that are resistant to display processing materials.

Large effort has been made at Kent Displays Inc.USA, to develop plastic substrates for Ch-LCDs. This reflective technology is quite amenable to plastic because it does not require polarizers. A full-color e-book display on plastic is under development.

6. CH-LCD Technology for E Books

It is clear from the discussion above that the display technology closest to the needs of the electronic book is the cholesteric display technology. This technology has the highest brightness and contrast for reflected light [6]; it is bistable, reducing the power by orders of magnitude, and is amenable to low-cost plastic substrates. The cost of the cholesteric technology can be comparable to the cost of the STN display technology, which is the lowest-cost, high-resolution display technology on the market today. The view angle of the Ch-LCD technology also is quite wide. Images do not degrade even at 30-degree angles from the normal in the horizontal or vertical direction. Neither the color nor the contrast or brightness is noticeably altered in a 30-degree orientation [7]. This is achieved without any special compensation films as is required with the TN and STN technologies. The display also can be read easily at view angles out to 70 degrees from the normal with a small change in contrast or color. The contrast drops by only 20 percent at 65 degrees. The Ch-LCD technology can be offered at a lower cost with the sacrifice of color. The lowest-cost is a monochrome display with one color on black or one color on white. The reduction in cost results from the display containing a cell with only one cholesteric color.

In certain e-book applications, such as manuals that display maps or instructions, the monochrome display is quite adequate. Kent Displays also produces monochrome products with blue on white, which is often favored by customers for certain applications. Black on white with the Ch-LCD technology requires a double-stack cell configuration [8] with two cholesteric reflective colors that mix to produce white. Black on white is also achieved on the full-color display, which is a triple stack of red, green and blue reflective cholesteric cells. The white state is brighter on the triple stack. At this stage of development, the Ch-LCD technology offers the lowest power consumption with the highest reflective brightness. Low power consumption translates into a lighter weight book with longer recharge intervals. A more robust display is also possible with the Ch-LCD technology, since it is amenable to low cost, plastic substrate materials. Finally, we mention a night vision display from the Ch-LCD technology. This is a display that not only reflects visible light, but also infrared [9]. As such, the display can be read with night vision goggles. This is a unique feature of the Ch-LCD technology and has many applications.

7. Conclusion

E-books serve the needs of people reading text information in digital formats. The discussion has been made in this paper on technology trends, current design issues, and future prospects for e-books. A number of dramatic changes and innovations have affected reading and information dissemination over the ages, with the most recent being the Web and portable information appliances. Trends in technology suggest further improvements to come that will enable even better e-book designs with large volumes of content material made easily accessible and available. Current device designs and e-commerce models suggest directions for the future of reading.

References

[1] P.G.de Gennes, the Physics of Liq. Cryst. , Oxford University Press (1974)

[2] P. Bros & K. Koehler Beran, Mol. Cryst. Liq. Cryst, 133, 329(1984)

[3] D.F.Aliev and A.Kh Zeinally, Zh. Tekh. Fiz. 52, 1669 (1982)

[4] S.T Lager Wall & I. Dahl, Mol. Cryst. Liq. Cryst., 114,151(1984)

[5] G.W. Gray, Mol. Cryst. Liq. Cryst.,, 63,3,(1981)

[6] W.E Haas, 'Liquid Crystal display research: The First Fifteen Years', Mol. Cryst. Liq. Cryst., 94, 1, (1983)

[7] B.Bahadur, 'Liquid Crystal display', Mol. Cryst. Liq Cryst. 109, 1, (1984)

[8] S. Chandrasekhar,'liquid Crystals of disc like Molecules', Adv. Liq. Cryst., 5, 47(1982)

[9] E.P Raynes, Electron Lett. , 9,118(1973)